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REMAINING LIFE MANAGEMENT
OF
EXISTING AC UNDERGROUND LINES

Working Group
B1.09

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WG B1.09

Remaining Life Management of Existing AC underground Lines

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Executive Summary

At the 2004 SC-B1 meeting in Paris it was decided, on the advice of TF B1-15 to initiate a WG B1-09 “Remaining Life of existing underground lines”. A final report was completed by the WG in the beginning of 2008. This summary gives a brief review of the report, in particular the main chapters: Present situation (3), Degradation phenomena (4), Methodology (5), Practical guidelines (6) and Life extension (7).

The subject of Remaining life is a topic that has received attention from many experts over many years, for obvious reasons. The main reason to be interested in Remaining Life is to use the information for a “last minute” Replacement Strategy. Because if the Remaining Life of a component is known, this component can be replaced just before failure. By doing this, power interruptions can be avoided or minimized, investment costs can be spread in a well balanced way and overall costs will be reduced. Unfortunately, this ideal situation cannot be reached easily, as Remaining Life is a very complex phenomenon. And even when it is possible to collect reliable failure data and to understand completely the complicated relevant ageing processes, a decision about replacement is not based solely on technical information. Therefore the WG decided to prepare a guide for Remaining Life Management to be based on a combination of technical, economic and strategic criteria.

Chapter three covers the present situation. In a questionnaire, 15 questions were asked to utilities about their perception of Remaining Life Management. Almost all of replying utilities (43) support the initiative of CIGRE B1 to study the subject of Remaining Life in depth and to try to prepare related practical guidelines. In particular their attention is focussed on getting effective guidance for performing their replacement programs. There is a great need for standardised condition assessment methods and for using the information to make clear maintenance decisions. So far, the age and/or the failure behaviour of a cable system are the only criteria used by the utilities. Many utilities may fear a sudden “failure wave”, without having prepared an appropriate replacement program and without having allocated the necessary resources including budget.

Chapter four gives an overview of degradation phenomena and related diagnostic methods. Degradation is non-reversible change in the functional characteristics of materials and components as a result of in-service operation, and leads ultimately to the situation where the component cannot fulfil its task anymore and will fail. The degradation mechanisms can be classified in thermal, electrical, mechanical and environmental stresses. In reality, the acting ageing mechanisms in practice will most likely be a combination of these mechanisms.

The increasing number of failures due to ageing is demonstrated in figure 1, following the final part of the so called bathtub phenomenon.

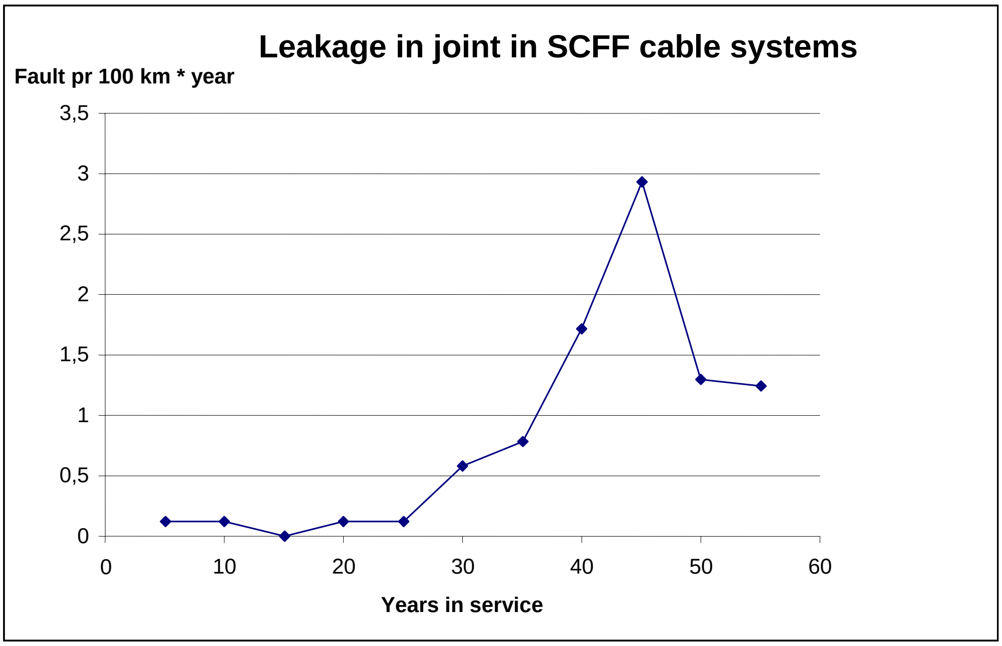


Fig. 1. Failure rates in SCFF cable joints related to years in service

For paper cables, the following main degradation mechanisms are listed:

- Deterioration of mechanical and chemical properties of paper insulation
- Deterioration of impregnated paper insulation due to thermal-mechanical stresses
- Deterioration of impregnated paper insulation due to high electrical stresses
- Degradation of dielectric fluids
- Ageing of metal sheaths.

For extruded cables the following ageing factors can be mentioned:

- Operating temperatures
- Electrical stress
- Contaminations
- Water tree ageing
- Thermal expansion

In chapter 4, a list of typical defects as well as a variety of diagnostic methods, that is available for the major cable types, is described.

Chapter five covers the Remaining Life Methodology in detail

The methodology Remaining Life is a complex phenomenon, which is based on a combination of technical, economical and strategic criteria, as is shown in figure 2.

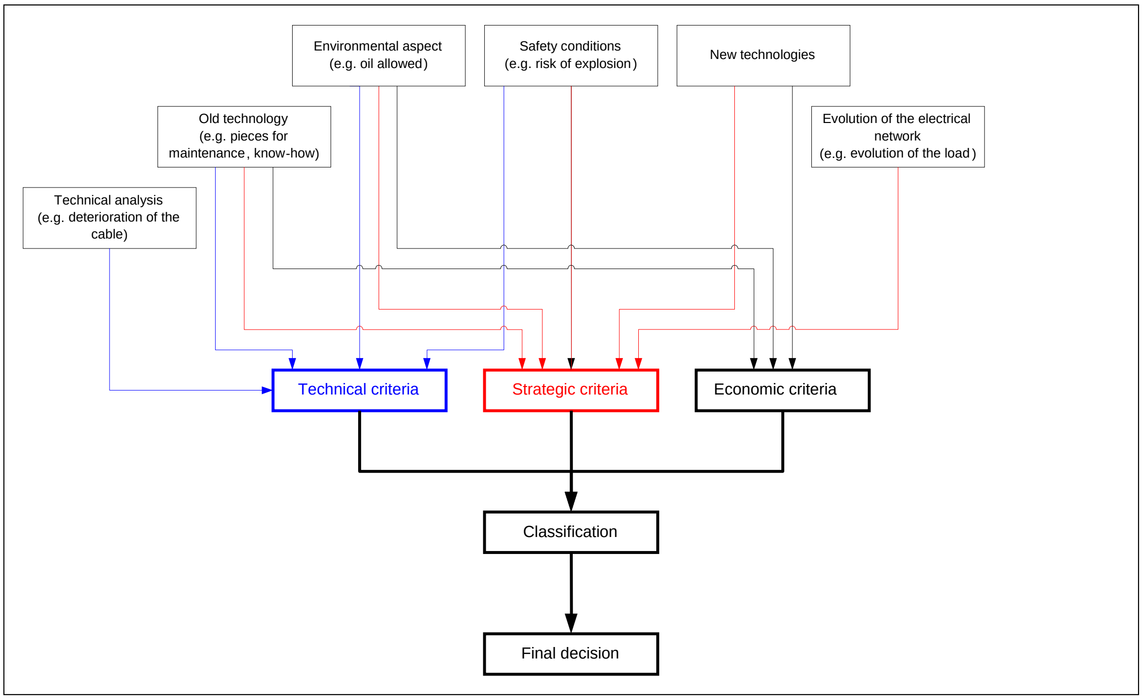


Figure 2 Methodology Summary

The technical criteria are related to an increased measured deterioration and increased number of failures.

The economical criteria are related to the assumption that the replacement of an old cable will be cheaper than its continued operation and maintenance.

The strategic criteria are related to change of external conditions, that may require cable replacement although the technical end of life has not been reached yet.

In **chapter six** the practical guidelines for Remaining Life Management are clarified.

The practical guidelines consist of a number of questions to be answered, in two parts: the simplified approach and the detailed approach. In the simplified approach, the good cables are separated from the questionable ones to be further investigated in the detailed approach. In the simplified approach, 7 questions (2 technical, 3 economical and 2 strategic) are asked. A scoring system enables the utility to prioritise the cables for further treatment according to a certain degree of urgency.

In the detailed approach, 24 questions are raised, of which are 12 technical, 5 economical and 7 strategic. The questions, depending on the importance of the issue, can get different scores. The final score provides an indication if the RL of the cable seems to be satisfactory (green light), the RL of the cable is worrying (red light) or something in between (orange light). Additionally, the scoring system allows the utility to rank the investigated cables, in a similar way as can be done by following the simplified approach. Finally when a cable is in code red or code orange, a life extension program (see chapter 7) can be performed to upgrade respectively from code red to code orange or from code orange to code green.

The working group has set up the initial values, but it is possible for a utility to adjust the system to the knowledge of the individual company.

Chapter seven gives some options for life extension.

Life extension programs are important for two situations:
- If a cable system has reached the expected life time, utilities may still want to operate the cable for another 10-15 years under acceptable conditions
- If a cable system will not reach its expected life, due to accelerated ageing or changes in environmental conditions, utilities want to extend life in order to reach the expected life.

The life extension strategy should not be based on the age of a system, however on the following issues:
- Assessment of insulation ageing
- Assumptions of ageing based on the years in service of the cable system
- Reported field experience
- Reported laboratory results
- Reported data from service providers
- Utility failure statistics
- Use of the just developed practical guidelines for RLM

In this chapter a list of possible actions to accomplish Life Extension are listed for both paper cable systems and extruded cable systems, varying from de-rating to silicon injection.

In **chapter eight** several cases (in total 7) studies, originating from 7 different countries are described.

The purpose of this chapter is to apply the proposed remaining life methodology on a few practical cases and to demonstrate the feasibility of the methodology successfully.

In **chapter nine** a comprehensive bibliography is given.

In **chapter ten** the following main conclusions are given.

- The present practical guidelines are well based on the needs of the utilities, expressed in the circulated questionnaire
  - To be focussed on cable replacement
  - To be practical
  - To be easy to use
- The main part of the report, the guide to use , has been confirmed by the different cases studies, demonstrating the practical feasibility of the guide
- The WG recommends the guide to be evaluated after five year of being used by utilities.

In the appendices information is collected on the Questionnaire (chapter 3), the different type of cables and accessories, a template for failure statistics and the list of members of WG B1-09.

1. Introduction

Introduction

At the 2004 SC-B1 meeting in Paris, it was decided, on the advice of TF B1-15, to initiate a WG B1-09 with the title "Remaining Life of existing underground lines".

The terms of reference for this Working Group were as follows:

- To prepare proper definitions
- To review ageing mechanisms, defects, diagnostic methods for both paper and extruded cables
- To prepare a questionnaire for utilities on present experience in end of life strategies
- To develop a strategy for Remaining Life Management
- To collect case histories
- To prepare guidelines for practical application of a general strategy for Remaining Life Management

The Working Group was asked to consider both paper cables and extruded cables for 50kV and above for land applications only.

The subject of Remaining Life is a complex issue and it has received attention from experts for many years. The reason for this attention is obvious; if we know when a component will be at the end of its life, it can be replaced in a planned way rather than after a failure. So far, recommendations are given in terms of risk of failure; however, the network owner prefers to know about the time schedule. He wants an accurate answer on the question: when is this component going to fail?

All electrical components will reach their end-of-life. Ideally, the component, or in this case, the underground cable, can be replaced in a controlled way before it reaches the end of its life. Remaining Life Management is an approach to asset management that takes into account all relevant aspects related to the end of life considerations. It can, for example, be a broad combination of activities to be applied in the structure of an exchange program. Proper definitions and criteria have to be prepared to apply Remaining Life Management on cables, which are still working properly. In most cases, service ageing will not be the only limiting factor. Other factors, like strategic or economic will determine the replacement as well.

The need to control Remaining Life is, in general, economically driven. However, when comparing "Remaining Life for HV cables" with two complete different issues like the remaining life of "human beings" and "motor cars", it is interesting to note that the philosophies behind these two remaining life issues are different from the philosophy for cables. Remaining Life Management of human beings is almost entirely controlled by the desire that life must be extended as long as possible, irrespective of costs. Exceptions are only

tolerated in case of very severe physical conditions or for human beings at very high age. One could say that for human beings in general, the remaining life management is controlled by technical criteria only.
In case of a motor car the situation is different. A car is seldom changed because the end of technical life has been reached. Very often the remaining life of a car is influenced by non-technical issues such as fashion, lack of innovative improvements with a view to modern conveniences, safety or expected high maintenance costs.

When considering HV cables, the actual Remaining Life Strategy to be applied, lies between the extremes discussed above. On the one hand, the cable life will not be extended at any costs; on the other hand, it will not be exchanged because it does not satisfy the latest fashion anymore. If the truth is in the middle, it can be argued that remaining life management of cables has to satisfy different criteria. These different criteria can be separated into three main categories:

- *Technical* - usually the material properties deteriorate with time (ageing) to a situation where they do not longer satisfy the original requirements, resulting in a failure

- *Strategic* - conditions, for instance environmental conditions, may change resulting in the decision to exchange the cable, although it still satisfies the original technical requirements

- *Economic* - if costs are becoming to high to maintain or to repair the present situation, the component will be exchanged

  These criteria will be considered extensively in the present report, because they are the basis for the Remaining Life Management, to be recommended as practical guidelines for the user.

  In this report, attention is paid to the present practices on remaining life management, based on a world-wide questionnaire to the users. Furthermore, case studies dealing with applications of remaining life management are reported. Finally, a remaining life methodology is discussed resulting in practical guidelines. This methodology is not based on general failure statistics or on a scientific ageing model. Failure statistics are not always available in sufficient quantity and the scientific ageing models currently available do not describe accurately enough the deterioration of related materials. The methodology proposed by this Working Group is based on answers to a variety of relevant technical, strategic and economic questions.

2. Definitions

Introduction

In this section of the report, a list of commonly used terms related to remaining life management is defined.

2.1 Definitions

When applying Remaining Life Management the following terms have to be defined first.

Remaining Life	The *remaining life* of a component at this moment is the difference between the moment when the *end of life* is reached and this moment.
End of Life	*End of life* is reached if the cable system does not meet the requirements any more. Usually it involves a combination of technical, economic and strategic requirements.
Technical End of Life	*Technical end of life* of a cable system is reached when repair does not seem to offer a reliable solution or the cable system does not meet the technical specification.
Economic End of Life	*Economic end of life* of a cable system is reached when it becomes too costly to maintain a cable system in service in comparison to technical alternatives.
Strategic End of Life	*Strategic end of life* of a cable system is reached when the company values are not met any more.
Remaining Life Management	A combination of coherent activities, all related to remaining life issues (condition assessment, diagnostic testing, risk management, maintenance), to be applied in the framework of an exchange program for underground cables.
Critical Link	A *critical link* is one in which there are no alternative feeding arrangements possible

(e.g. a tail-fed supply to an important customer). If something goes wrong with this link, it has critical technical, economical or strategic consequences

Life Extension	*Life extension* is a set of actions taken to prolong the expected life of a cable circuit.
Expected Life	*Expected life* is the expected service time of a new system under normal operating conditions (equals to the remaining life of a new system).

3. Survey of Present Situation: Results of Questionnaire

3.1 Introduction

In order to determine what end-of-life strategies, if any, are used by utilities worldwide, and to make an inventory of the needs of utilities regarding remaining life estimation, a questionnaire was issued in 2005. In this questionnaire, 15 questions were asked regarding the cable network, failure behaviour of cables and accessories, and about maintenance and replacement of cables. The detailed questions can be found in Appendix 1.

3.2 Results

In this chapter, the results of the questionnaire, which are related to the remaining life estimation methodology directly, are discussed. Other results might be very interesting when reviewing cable failure statistics, cable maintenance or cables in general, and are therefore included in Appendix 1.

3.2.1 General

43 utilities answered the (high voltage part of the) questionnaire. The utilities are spread over 4 continents, although especially Asiatic and European utilities provided answers. There are important differences between the answers depending on the continent the utility is based. In the analysis, these differences were noted, but did not lead to a more complex averaging procedure. The answers were averaged by adding the scores of each utility and dividing by the number of answers provided on that specific question.

The 43 utilities have together almost 24,500 circuit km of high voltage cables in operation, which is about 5% of their complete network length. The 37 utilities that completed the medium voltage questions of the questionnaire, had more than 425,000 circuit km of medium voltage cables in operation, consisting of about 26% of their complete medium voltage network length. The averaged answers thus are applicable to a rather large group of power cables and network owners.

Most high voltage cables are XLPE insulated cables (59.9 %) or self-contained fluid filled cables (31.7%). A remaining life estimation methodology for high voltage cables should therefore preferably be applicable to XLPE insulated cables and self-contained fluid filled cables. The other cable types form only a minority group (less than 10%). For the medium voltage, the screened PILC (36%), XLPE (33 %) and belted PILC (22 %) are the most commonly used cable types.

3.2.2 Experienced failure behaviour

At the moment, high voltage paper insulated cables do not seem to fail so much due to ageing. Only 12% of the total number of cable failures in paper insulated high voltage cables are ageing related failures. Most failures are due to third party damage and other exterior failure causes (67%), followed by oil leakage of SCFF cables (12%). Overloading is not considered to be a failure cause at all (0%). For medium voltage cables, these numbers are different. In the medium voltage range, 51% of the paper insulated cable failures are due to third party damage and external failure causes; 29% are due to ageing and 8% due to oil leakages. Failures due to ageing are thus more a concern for medium voltage cables than for high voltage cables, which may be explained by the relative age of the cables: high voltage cables are in general younger than medium voltage cables, although this statement can not be verified by the questionnaire.

Regarding high voltage cables with extruded insulation, only 7% of all failures are due to ageing. Third party damage, water treeing and other causes such as poor installation, manufacturing and construction, rank higher with 65%, 13% and 13% respectively. For medium voltage cables, ageing comes as the second most important failure cause for extruded cables with 17%, behind third party damage (51%) and just before water treeing with 16%.

For high voltage power cables, both paper cables and extruded cables, it can be concluded that ageing is not the most important failure cause at the moment. However for medium voltage cables, after third party damage, ageing is the most important cause of failure.

3.2.3 Number of failures

The number of failures, or the amount of failures per 100 km of network, is still unknown. Work is still in progress within CIGRE WG B1-10: “Update of service experience of underground and submarine cables”. A Technical Brochure will be published, based on the final WG report, probably in 2009.

3.2.4 Cable maintenance and diagnostics

Regarding cable maintenance, most utilities use a combined strategy of time based and condition based maintenance or a combined strategy of time based, condition based and corrective maintenance. It is interesting that 21% (31% for medium voltage) of all utilities perform corrective maintenance only. As far as condition based maintenance is concerned, DC and AC diagnostic tests, tan delta tests, laboratory tests on both aged cable samples and faulted cables and desk studies determining the cable loading and cable ageing and cable condition roughly are performed in more than one-third of all utilities to assess the condition of the power cable under consideration.

It can be concluded that utilities use very different means to assess the condition of power cables and that there is no method or technology which is used commonly by all utilities.

3.2.5 Cable replacement

51% of the utilities have a replacement program to replace their high voltage power cables. From those utilities, 20% stated that the actual moment of replacement depends on a condition assessment, while 70% considered the age as a clear criterion for replacement. This age is typically 40 years for XLPE and typically about 50 years for paper insulated cables (expect gas pressure cables), but range between 15 and 80 years amongst different utilities.

When a power cable is actually replaced, this is quite often based on technical criteria, often on economical criteria, sometimes on strategic criteria. The decision to replace was never based on environmental criteria.

66% of the utilities used a combination of technical and economical criteria to replace cables, by defining a maximum number of failures per year in a single cable route. This number is asked for and the typical answer here is 3 to 4 faults per year in a link, although the numbers differ very much from utility to utility.

It may be concluded that 50% of all utilities do not have a plan to replace high voltage cables while another 40% of all utilities use age as the only criterion to plan reinvestments in the network. There is a wide spread in this age on which reinvestments in cable networks are planned. The actual replacement of a power cable is based mostly on a technical – economical – strategic basis. A simple method, used by 66% of the utilities, is to define the number of faults that a single power cable link may experience in a year, above which the cable is replaced.

3.2.6 Expected failure behaviour

In the future it is expected that paper insulated cables will show a number of failures either low and constant with time, or rising linearly with time based on experiences so far. Only 14% of all utilities expect that the failure rate of paper-insulated cables is going to rise exponentially. The utilities that do expect this refer to the ever-increasing loading and to increasing amounts of sheath problems with paper insulated cables.

Regarding extruded insulated cables, utilities are more pessimistic. For this cable type, the majority of the utilities expect a number of failures linearly rising with time or growing exponentially with time. Water treeing and a lack of knowledge of the true behaviour are reasons stated why the number of failures is expected to rise.

To conclude, the number of expected failures in paper-insulated cables is either low, constant or linearly rising with time while for extruded insulated cables the number of expected failures is linearly to exponentially rising with time.

3.2.7 Need for more knowledge and need for a remaining life estimation methodology

Almost all utilities (>90%) feel that there is a need for more knowledge to assess the technical condition of cables better and a need to better understand degradation processes. More than 75% of all utilities feel that there is a need to better assess the economical, environmental and strategic issues regarding cable replacement better. Nearly all utilities feel that there is a need for a remaining life estimation procedure for power cables. One (brave) no-voting utility stated that there is no threat of large scale cable failures due to ageing and that therefore the value of remaining life estimations is rather low and consequently, that it should not cost too much money in order to economically justify usage of the estimation procedure.

For 86% (70% for medium voltage) of all utilities, it is very important to have a remaining life estimation methodology for power cables. From the gathered tips regarding such methodology, the following is noted:

- It should be practically applicable
- it will be used for determining reinvestments in the cable network
- it must be simplified (referring to all difficult degradation models in literature),
- it should come as a PC program or a tool to operate on a cable-database,
- it should work also with little available information.

Other topics mentioned are a method to improve diagnostic tests, to directly measure the remaining life of a power cable in the field, providing a table with standard lifetimes, and to accumulate failure data.

From this, it can be concluded that more knowledge is needed to assess the technical condition of cables in the field, to better understand degradation processes, to better assess the economical, environmental and strategic issues regarding cable replacement. A remaining lifetime estimation methodology is very important for utilities as it is used to plan reinvestments in the cable network. This methodology should be: a software tool, easy to use, simple, able to work with little data and above all, practically usable.

3.3 Conclusions

From the questionnaire, the following can be concluded:

1. The questionnaire brings together experience from 43 utilities over 4 continents, overlooking 24,500 circuit kilometre high voltage cables and 425,000 circuit kilometre medium voltage cables.
2. The networks of the 43 utilities comprise 5% respectively 26% underground power cables in the high voltage and medium voltage areas.
3. Ageing of high voltage power cables is not an important failure cause at this moment, neither for XLPE nor for SCFF cables. This is different from the medium voltage network: Ageing of medium voltage power cables is the most important cause of failure after third party damage.
4. For reliable failure data, reference is made to the work of WG B1-10 Update of service experience of underground and submarine cable. A report will be completed in 2008.
5. It may be concluded that utilities use very different means to asses the condition of power cables and that there is no method or technology which is used commonly by all utilities.
6. 50% of all utilities do not have a plan to replace high voltage cables while another 40% of all utilities use age as the only criterion to plan reinvestments in the network. The actual replacement of a power cable is based mostly on a technical – economical – strategic basis. A simple method used by, two-third of the utilities, is to define a defined number of faults a single power cable link may experience in a year, before it is replaced.
7. The number of <u>expected</u> failures in paper-insulated cables is either low, constant or linearly rising with time while for extruded insulated cables the number of expected failures is linearly to exponentially rising with time.
8. More knowledge is needed to assess the technical condition of cables in the field, to better understand degradation processes, to better assess the economical, environmental and strategic issues regarding cable replacement.
9. A remaining lifetime estimation methodology is <u>very important</u> for utilities as it is used to plan reinvestments in the cable network. This methodology should be: a software tool, easy to use, simple, able to work with little data and above all, practically usable.

The above summarized conclusions have been used to give guidance to the remaining life estimation methodology as introduced in chapter 5.

4. Survey of Ageing Phenomena and Related Diagnostic Methods

4.1 Introduction

Ageing refers to non-reversible changes in the functional characteristics of materials and components as a result of in-service operation.

Estimating the actual life of power cables operating under normal or emergency conditions is a complex task. There are many factors that affect the cable-operating conditions and consequently the cable life.

In the present survey we only give examples of the main identified ageing mechanisms. For further detailed information the reader is referred to the report CIGRE B1 04 “Maintenance of high voltage cables”.

4.2 Ageing Mechanisms

The stresses acting on high voltage power cables may be classified as follows:

Thermal: due to the operating current under normal and emergency conditions. The maximum operating temperature depends on insulator materials and operating conditions.

Electrical: due to operating voltage under normal and emergency conditions and due to impulse voltages following lightning and switching.

Environmental: due to environmental conditions acting on the external sheaths of the cable (polymer degradation, metal corrosion).

Mechanical: due to laying operations (bending), service conditions (load cycling or externally induced cyclic movements for submarine cables), or accidental damage.

The action of these factors on power cables causes a degradation phenomenon that can result in reduced cable life or failure under service conditions.

The degradation of a component leads to a situation where the component cannot fulfil its task and a fault occurs. The aging of components can be related to the fault rate of the system.
The evolution of the fault rates is normally expected to follow the so called “bath tub curve”. In the beginning of life, the few failures that occur are often due to manufacturing failure or bad assembly. After

these early failures comes a long period where faults are rare. When approaching the end of life of a component, the number of faults begins to rise due to faults in vulnerable areas. The frequency will be rising until it is decided to replace the component.
The following figure shows an example of a failure frequency following the final part of a bath tub curve.

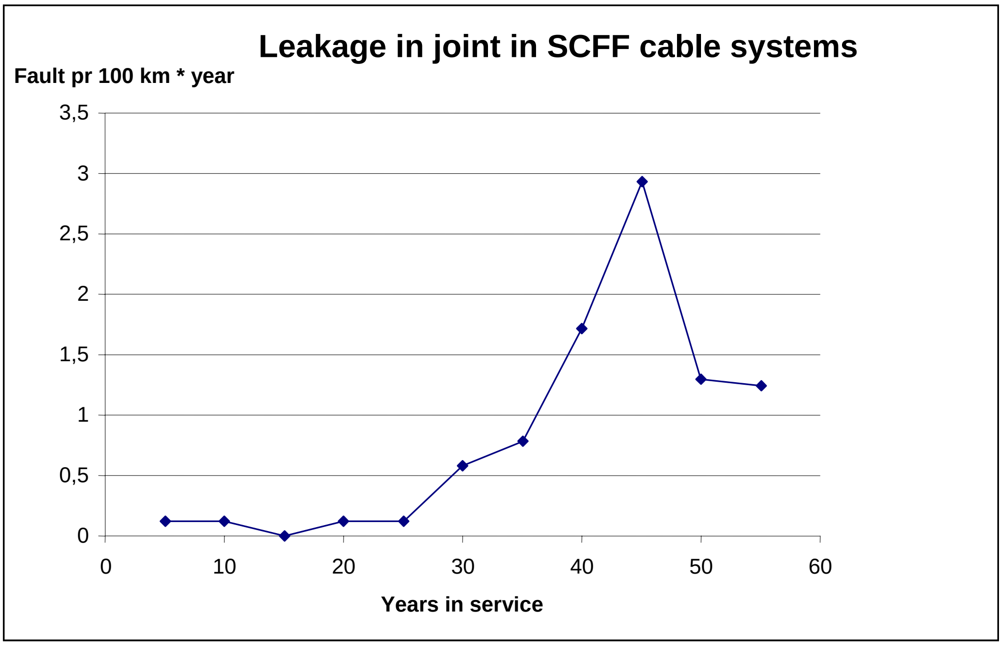


Figure 4.1 – Failure rates in SCFF cable joints related to years in service

As described in this report, the remaining life of the cable system is to be decided not only by the failure frequency (technical criteria) but strategic and economic criteria also have to be taken into consideration.

4.1.1 Paper Cables

The long-term behaviour of oil-filled cables can be compared to that of transformer insulation due to the similarities in the materials used. Many laboratory studies of the degradation phenomena have been based on the same investigations: the determination of gases dissolved in oil. However, contrary to transformers, there are no diagnostics of ageing from dissolved gas analysis for oil-filled cables. In transformer, the gas concentration measured in oil samples can be considered representative of the overall insulation since there is a rapid blending of the gases in such big volumes of oil. In oil-filled cables, the samples are taken at terminations and the concentration of gases is driven by a diffusion process which is characterised by very long time constants.

The severity of ageing cannot be assessed, as in transformers, from the absolute or relative concentration of gases.

Deterioration of paper oil dielectric due to thermal or electrical ageing (partial discharges) can result in failures. A water-free, well impregnated insulation is not reported to degrade under the application of an electrical stress alone. Common causes of electrical degradation are the presence of water oxidising agents or of gas bubbles and elevated temperatures. These conditions may occur in cable operation. Of particular importance is overloading of the cables and, therefore, heating of the cable. Elevated temperature will promote the degradation of the insulating materials and reduce the remaining service life of the cable. However, it is not clear to what degree overheating can reduce the life of a certain type of cable.

Depending on operating practice, emergency overloads may last limited periods of time for a specific number of hours per year. While it is recognised that such operations could have an effect on the cable life, the conditions are chosen to ensure that only limited ageing is likely to occur. Unfortunately, there is no simple answer to the question on what controls the life of a cable. There are many factors that can affect the cable temperature and, implicitly, the cable life. Precise data regarding the installation and operation conditions is seldom available. Consequently, for cases where cables have been designed on the basis of continuous loading at a maximum allowable conductor temperature, the manufacturers admit very little or no overload capacity. In addition, high voltage cable manufacturers do not specify any expected period of cable life. The often quoted period of 40 years is based on the fact that this is approximately the present experience of operated oil-filled cables.

Some factors which accelerate the decomposition of cable dielectric materials are as follows:

(i) Deterioration of mechanical and chemical properties of paper insulation

The main component of paper is cellulose fibre. Ageing of cellulose is related to chemical changes in the material structure. Changes occur in the physical, mechanical and electrical properties with increasing temperature.

(ii) Deterioration of impregnated paper insulation due to thermal-mechanical stresses

Thermal mechanical bending damage can occur by the cable being bent to a relatively sharp bend radius or flex point. During load cycling, the cable tends to bend repeatedly at the same location. Over time, if the cables are not constrained, the repeated bending can cause the cable papers to shift. This can cause local tearing and creasing of the paper tapes. A cable which has been subjected to this type of damage is characterised by a softening of the cable. The insulation structure is weakened and electrical failure can result.

(iii) Deterioration of impregnated paper insulation due to high electrical stresses

Electrical failure of impregnated paper cables is typically a localised event. It can occur, for example, at a hot spot, a mechanically damaged area, or at a sheath defect. If the cable dielectric fluid is not continuously maintained at or above the proper pressure within the cable, degradation of the insulation fluid and paper can occur due to high electrical stresses within the gaseous voids between or within the cellulose paper tapes. This can result in localised partial discharge conditions that could eventually result in electrical failure.

(iv) Degradation of dielectric fluids

The thermal degradation of the dielectric fluid is not as significant as the degradation of the paper in sealed air-free cable systems. Contaminants in the cable system such as water, metallic salts, particles, or oxygen can have noticeable effects on dissipation factor, breakdown strength, acidity and colour, but electrical or chemical tests of the dielectric fluid alone are unlikely to provide sufficient information of value in determining cable system end of life.

(v) Ageing of metal sheaths

As for extruded cables, selection of inferior materials, sheath design, cable manufacturing processes or installations could lead to accelerated mechanical ageing of the sheath and sheath failure. Sheath failure will result in a dielectric fluid leak, and of liquid supply and pressure become insufficient, ionisation will occur, leading eventually to electrical failure. The main causes of mechanical sheath ageing are fatigue and creep, which can occur in both lead alloy and aluminium sheaths. Thermal-mechanical cycling and vibration are common causes of fatigue and creep. Increased rate of fatigue can be caused by heavy traffic, especially on bridges and transformers. Fatigue and creep properties of lead alloys are greatly influenced by the alloy type, extrusion conditions, grain size, and the temperature to which the sheaths are exposed.

4.1.2 Extruded Cables

For extruded cables and accessories, the ageing factors are summarised in Figure 4.2.

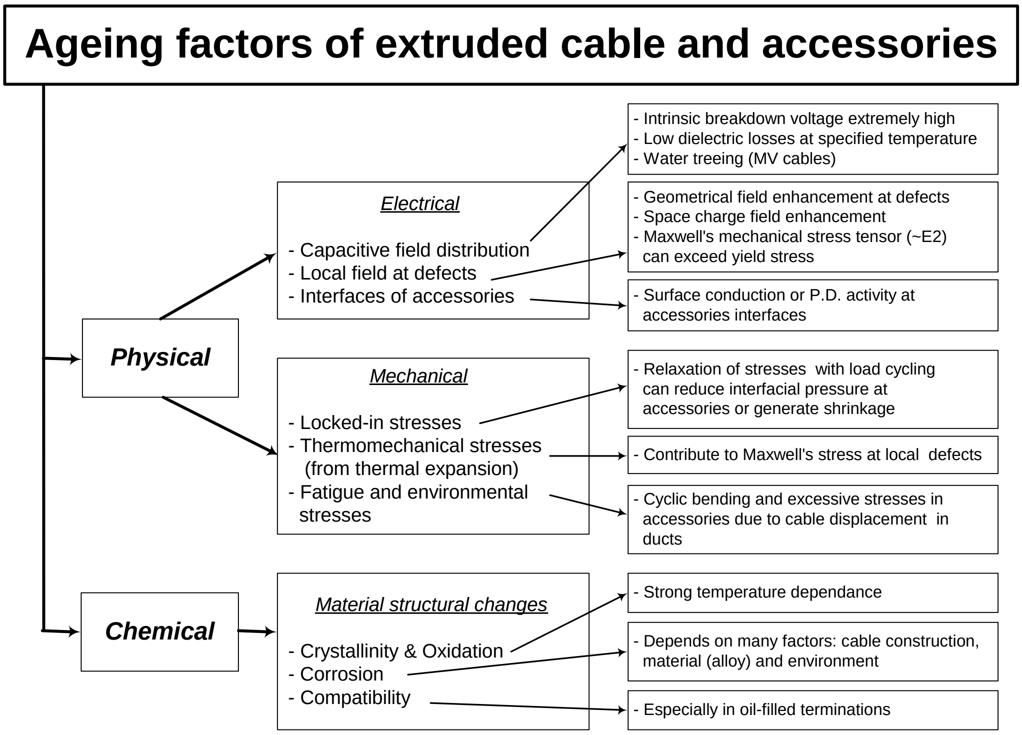


Figure 4.2 – Ageing Factors of Extruded Cables and Accessories

Maximum operating and overload temperatures

The maximum operating and overload temperature for the insulation materials are dictated by their mechanical properties at these temperatures, their electrical performance, effects of expansion, permanent deformation and oxidation resistance. Contrary to paper insulated cables, XLPE and EPR are not affected by thermal ageing at normal operating maximum temperature. Oxidation can indeed occur when XLPE insulation is operated at 130°C and more, but it will not intrinsically affect the breakdown strength. However, the major concerns when operating XLPE insulation at high temperatures are the thermomechanical stresses generated by the expansion of the insulation. EPR is significantly less affected by elevated temperatures. An overload temperature of 105ºC appears to be the safe upper limit for XLPE cables and possibly a slightly higher level for EPR cables. Extruded dielectrics may suffer long-term creep under pressure and temperature. This occurs beyond 90-100ºC for XLPE and EPR insulation. For EPR cables, water treeing is a slower and less common process than for XLPE. Residual deformation in XLPE remains if external pressure is maintained during a cooling transient. Copper wire screens can deform or perforate semi conducting screens under pressure and insulation can be indented or reduced in wall thickness, thereby increasing operational electrical stress.

Electrical Stress (50Hz and impulse)

Lengthy operational service and laboratory testing at 50Hz of extruded polymeric insulation for transmission cables at normal working stresses do not appear to result in reduced AC or impulse performance that is of any practical significance. It has been reported that under some conditions, that repeated applications of impulse voltages can reduce the life of XLPE insulation.

Contamination

Contaminants entering the cable system from external sources, such as organic solvents, oils, bitumen and sulphur compounds may result in swelling and loss of screen adhesion. In such a case, local water-tree degradation could be enhanced.

Water tree ageing

Based on experience in MV cables without metallic water barriers, it has been demonstrated that water treeing is the most significant cable ageing factor for all polymeric insulation. In the case of high voltage XLPE and EPR insulated cables without a water barrier, failures that can be attributed to water treeing have been reported. This suggests that the intrinsic water content of XLPE insulation does not reduce the expected life of the cable. Although radial metallic moisture barriers such as extruded lead or aluminium sheaths with longitudinal moisture barriers provide positive moisture protection, the issue of water ingress due to faulty sheaths, closures and accessory enclosures needs to be considered.

Thermal expansion effects (longitudinal)

Unlike radial expansion, longitudinal expansion is common to all cable types and is addressed by suitable installation design. Thermal expansion in impregnated paper insulated cable (and PPL insulated cable) conductors and sheaths results in considerable forces. Even larger forces may be present in polymeric insulated cables because of their higher operating temperature. High conductor forces can result in buckling of cable and stress cones with gas/oil filled terminations or in joint cans. Conductor and insulation movement can also occur within metallic sheaths in cable routes having a transition in installation mode, such as direct buried to an in-air sagged/cleated installation. Metallic sheath expansion may weaken sheath closures on accessories.

Ageing of metal sheaths

Selection of inferior materials, sheath design, cable manufacturing processes or installations could lead to accelerated mechanical ageing of the sheath and sheath failure. Sheath failure may result in moisture ingress, leading to insulation degradation. The main causes of mechanical sheath ageing are fatigue and creep, which can occur in both lead alloy and aluminium sheaths. Thermal-mechanical cycling and vibration are common causes of fatigue and creep. Increased rate of fatigue can be caused by heavy traffic, especially on bridges and transformers. Fatigue and creep properties of lead alloys are greatly influenced by the alloy type, extrusion conditions, grain size, and the temperature to which the sheaths are exposed. Stainless steel sheaths are less susceptible to these phenomena.

4.1.2 Cable Accessories

Joints

Often, joints are one of the major problems as the joint often is the weakest point in the sense that oil leaks often occur at this point due to bending forces. Even though a fault in a joint is a local problem which can be repaired, the number and cost can be relatively high and can, in extreme cases, strongly influence a decision about replacing the cable system.

Terminations

The termination is, as for joints, a local component, but it has the advantage that it is accessible. The most common cause for failure is water ingress or oil leakage. Only on short links (without joints) is the termination a major factor concerning exchange of the system as it is relatively easy and economical to exchange compared to the replacement of the total system.

4.3 Defects

In the CIGRE WG B1-04 report, the subject of defects has been comprehensively addressed for each cable type. The main causes of failure identified for each type of high voltage cable and accessory are summarised below.

The cable types specifically considered are:

- Self Contained Fluid filled
- High Pressure Fluid filled
- Gas Pressure
- Extruded Cables

Some failure modes are common to more than one cable type (e.g. third party damage). Other failure modes are unique to a particular cable type (e.g. loss of nitrogen pressure in gas pressure cables).

Table 4.1 summarises the failure modes with a higher probability of occurrence for each cable type.

Item	Type of Defect	Self contained fluid filled cables	High pressure fluid filled cables	Gas pressure cables	Extruded cables
1	3rd party cable damage	x	x	x	x
2	3rd party oversheath damage resulting in brittleness, external contamination of oils, solvents, bitumen etc.	x			x
3	3rd party damage to metal sheath, corrosion or fatigue	x			x
4	Ingress of water into insulation	x			x
5	External damage due to cable movement caused by heavy traffic/poor subsoil conditions/unstable ground	x			x
6	External mechanical stress due to ground changes, thermal expansion-contraction / improper clamping	x			x
7	Assembly error causing local increase of electrical stress in joints and terminations	x	x	x	x
8	Leakage of internal insulating oil from termination	x	x	x	x
9	Movement of cable due to thermal cycling or poor clamping	x			x
10	Water ingress into link boxes	x			x
11	Failure of forced cooling system (where fitted)	x	x	x	x
12	Leaking or damaged steel pipe due to corrosion		x	x	
13	Failure of oil/gas feeding and pressurisation system due to oil leaks in associated pipe-work, reservoir tank, oil pump system failure, faulty gauges		x	x	

Table 4.1: Most Common Defects by Cable Type

4.4 Diagnostic Methods

The main diagnostic tools currently available for high voltage cables and accessories are now presented.

The available diagnostic tools for the different cable types are presented in Table 4.2.

Item	Type of Diagnostic Tool	Self contained fluid filled cables	High pressure fluid filled cables	Gas pressure cables	Extruded cables
1	Cable route inspection (for third party activities)	x	x	x	x
2	Indication of falling oil/gas pressure	x	x		
3	Serving test	x			x
4	Temperature measurement.	x	x	x	x
5	Partial discharge measurement	x			x
6	Chemical and physical analysis of insulating oil	x			
7	X-ray of accessories	x	x	x	x
8	Inspection of the cable system	x	x	x	x
9	Inspection of termination for ferrule retraction	x	x	x	x
10	Regular gauge maintenance and calibration	x	x	x	
11	Regular testing of gauge/transducer alarm functionality	x	x	x	
12	Sheath Voltage Limiter test	x			x
13	Bonding System test	x			x
14	Electrical test on pipe coating		x	x	
15	Inspection of the cathodic protection system		x	x	
16	Thermal backfill survey	x	x	x	x
17	Chemical and physical analysis of paper and impregnant		x	x	
18	Inspection of pumping system		x	x	
19	Tan delta measurement				x

Table 4.2: Available Diagnostic Tools by Cable Type

4.3.1 Self contained fluid filled cables

The mechanical characteristics that, in order of decreasing sensitivity, permit evaluation of paper quality and degradation are:

- folding strength
- tear strength
- elongation
- degree of polymerisation
- burst
- tensile strength

Deterioration of paper insulation can be caused by a number of factors, but the main agents are moisture and acids, elevated temperature and oxidising agents. Even atmospheric oxygen can oxidise paper. A wide range of products are formed by paper decomposition, including moisture, gases (especially carbon monoxide and dioxide) and organic acids. The production of moisture is a problem, because it further accelerates the rate of decomposition.

Methods using oil analysis to monitor the degradation of paper insulation in transformers are being developed. It may be possible to develop analogous techniques for cable paper. There is not a consensus among cable manufacturers and cable users in regard of maximum permissible amount of gases in cable oil.

The use of synthetic oils of the type dodecylbenzene (DDB) has improved the performance of oil-filled cables considerably. DDB reduces the rate of ageing, mainly because it is a pure compound whose ageing characteristics are well known. Mineral oil is a mixture of many thousands of compounds, whose ageing behaviour is complex and difficult to define.

In tables 4.3 to 4.6, more information is provided on the main diagnostic indicators for each cable type.

TABLE 4.5 - DIAGNOSTIC INDICATORS FOR GAS PRESSURE CABLE SYSTEM

	Tool	Description of method	Events/cause detected	Comments	On-line/Off-line
1)	Cable route inspection (for third party activities)	Visual inspection of the cable route to observe any third party activities near the cable route	Prevention of damage by third party	Well established	On-line
2)	Indication of falling oil pressure	Continuous measurement of oil pressure and/or low pressure alarms	Damaged metal sheath leakage from termination	Well established	On-line
3)	Serving Test	Measurement of the oversheath insulation resistance by HV testing. Location of any defects and repair	Damaged outer sheath	Well established	Off-line
4)	Temperature measurement	Measurement of temperature along the route by optical fibre (DTS) or by thermocouples, optical fibre point sensors.	Increased temperature causing thermal ageing Failure of cooling system	Well established technique, but requires fibre to be installed on the system	On-Line
5)	Partial Discharge measurement	Measurement of discharges within the cable system	Defects and degradation of insulation	Under development. Effectiveness dependant upon system design	On –Line/Off-line
6)	Chemical and physical analysis of insulating oil	Fluid samples taken from the cable system and tested for: - DGA - Tan delta - Water content - Particles - etc	Thermal ageing of insulation (caused by different events)	Well established technique, relies on regular testing regime since interpretation of individual DGA results not clearly understood	Off-Line
7)	X-ray of accessories	Use of X-ray on accessories	Movement of cable causing ferrule unplugging. Incorrect assembly of joint connector	Well established but significant Health & Safety issues and practical application limitations	Off-line
8)	Inspection of cable system (visible parts)	Visual inspection of all visible components of the cable system for damage, leaks, corrosion etc.	Visual damage, leaks, corrosion etc.	Well established	On-line
9)	Inspection of termination for ferrule retraction	Internal inspection and measurement of ferrule movement	Movement of cable causing ferrule unplugging	Well established	Off-line
10)	Regular gauge maintenance and calibration. Regular testing of gauge/transducer alarm functionality. Also, regular evaluation of historical and real time pressure and environmental data as recorded by condition monitoring system operating continuously.	Hydraulically initiate the gauge/sensor alarm contacts Pressure alarm tests from device to control room	Prevention of failure in alarm system Prevention of false alarm	Well established	Off-line

TABLE 4.5 - DIAGNOSTIC INDICATORS FOR GAS PRESSURE CABLE SYSTEM

Tool	Description of method	Events/cause detected	Comments	On-line/Off-line
11) Sheath voltage limiter test	Measurement of increased sheath standing voltage. Determination of IR and V-I characteristics of SVL	Failure of SVL	Basic test on integrity only	Off-Line
12) Bonding systems test	Checking the integrity of specially bonded systems by measurement of insulation resistance and/or circulating current in the screen /metallic sheath. Verification of SVL integrity and the overall condition of link boxes, link box leads and cable anticorrosion jacket.	Loss of cross-bonding function - Failure of SVL - Link box failure - Anticorrosion jacket failure - Link box lead (cable) failure) - Isolating flanges, barriers and oil-line insulators - Resistance of the local earth mats, - Continuity of earthing (return) conductors, etc.	Well established	Off-line
13) Thermal backfill survey	Measure thermal resistivity of backfill in vicinity of cable	Thermal ageing of insulation caused by overload, short-circuit, hot spots	Effective where a problem is suspected	On-line
14) Chemical and physical analysis of papers and impregnant	Measure the following: - folding strength - tear strength - burst strength - degree of polymerisation - extension to break - tensile strength	degradation of insulation (caused by different events)	Well established, but the interpretation of the results of these tests is not yet clearly understood in terms of deciding the end of life of the cable In case of cable failure they are proper tools to estimate the cable condition. It could be said that a figure of 350 to 400 of Degree of Polymerisation indicates the near end of life of old paper insulated SCFF cables.	Off-Line

<u>TABLE 4.5 -</u> DIAGNOSTIC INDICATORS FOR GAS PRESSURE CABLE SYSTEM

	Tool	Description of method	Events/cause detected	Comments	On-line/Off-line
1)	Cable route inspection (for third party activities)	Visual inspection of the cable route to observe any third party activities near the cable route	Prevention of damage by third party	Well established	On-line
2)	Indication of falling fluid pressure	Continuous measurement of fluid pressure and/or low pressure alarms	Damaged steel pipe leakage from termination	Well established	On-line
3)	Electrical test on pipe coatings	Insulation resistance of jacket	Damaged steel pipe	Under development	Off-line
4)	Inspection of cathodic protection system	Measurement of pipe to soil potential	Damaged steel pipe	Requires cathodic protection to be installed and operating properly. More effective when trends are analysed	On-line
5)	Temperature measurement	Measurement of temperature along the route by optical fibre (DTS)	Increased temperature causing thermal ageing Failure of cooling system	Well established technique, but requires fibre to be installed on the system	On-Line
6)	Thermal backfill survey	Measure thermal resistivity of backfill in vicinity of cable	Thermal ageing of insulation caused by overload, short-circuit, hot spots	Effective where a problem is suspected	On-line
7)	Chemical and physical analysis of papers and impregnant	Measure the following: - folding strength - tear strength - burst strength - degree of polymerisation - extension to break - tensile strength	degradation of insulation (caused by different events)	Well established, but the interpretation of the results of these tests is not yet clearly understood in terms of deciding the end of life of the cable	Off-Line
8)	X-ray of accessories	Use of X-ray on accessories	Movement of cable causing ferrule unplugging. Incorrect assembly of joint connector	Well established but significant H&S issues and practical application limitations	Off-line
9)	Inspection of cable system	Visual inspection of all visible components of the cable system for damage, leaks, corrosion etc.	Visual damage, leaks, corrosion etc.	Well established	On-line
10)	Inspection of termination for ferrule retraction	Internal inspection and measurement of ferrule movement	Movement of cable causing ferrule unplugging	Well established	Off-line
11)	Inspection of pumping system	Visual and mechanical check of pump, pipework, etc. when oil pressure alarm is activated	Oil pump system failure	Very effective	Off-line

<u>TABLE 4.5 -</u> DIAGNOSTIC INDICATORS FOR GAS PRESSURE CABLE SYSTEM

Tool	Description of method	Events/cause detected	Comments	On-line/Off-line
12) Regular gauge maintenance and calibration Regular testing of gauge/transducer alarm functionality	Hydraulically initiate the gauge/sensor alarm contacts Pressure alarm tests from device to control room	Prevention of failure in alarm system. Prevention of false alarm	Well established	Off-line

TABLE 4.5 - DIAGNOSTIC INDICATORS FOR GAS PRESSURE CABLE SYSTEM

	Tool	Description of method	Events/cause detected	Comments	On-line/Off-line
1)	Cable route inspection (for third party activities)	Visual inspection of the cable route to observe any third party activities near the cable route	Prevention of damage by third party	Well established	On-line
2)	Indication of falling gas pressure	Continuous measurement of gas pressure and/or low pressure alarms	Damaged steel pipe leakage from termination	Well established	On-line
3)	Electrical test on pipe coatings	Insulation resistance of jacket	Damaged steel pipe	Under development	Off-line
4)	Inspection of cathodic protection system	Measurement of pipe to soil potential	Damaged steel pipe	Requires cathodic protection to be installed and operating properly. More effective when trends are analysed	On-line
5)	Temperature measurement	Measurement of temperature along the route by optical fibre (DTS)	Increased temperature causing thermal ageing Failure of cooling system	Well established technique, but requires fibre to be installed on the system	On-Line
6)	Thermal backfill survey	Measure thermal resistivity of backfill in vicinity of cable	Thermal ageing of insulation caused by overload, short-circuit, hot spots	Effective where a problem is suspected	On-line
7)	Chemical and physical analysis of papers and impregnant	Measure the following: - folding strength - tear strength - burst strength - degree of polymerisation - extension to break - tensile strength	Insulation (caused by different events)	Well established, but the interpretation of the results of these tests is not yet clearly understood in terms of deciding the end of life of the cable	Off-Line
8)	X-ray of accessories	Use of X-ray on accessories	Movement of cable causing ferrule unplugging Incorrect assembly of joint connector	Well established but significant H&S issues and practical application limitations	Off-line
9)	Inspection of cable system	Visual inspection of all visible components of the cable system for damage, leaks, corrosion etc.	Visual damage, leaks, corrosion etc.	Well established	On-line
10)	Inspection of termination for ferrule retraction	Internal inspection and measurement of ferrule movement	Movement of cable causing ferrule unplugging	Well established	Off-line
11)	Regular gauge maintenance and calibration	Hydraulically initiate the gauge/sensor alarm contacts	Prevention of failure in alarm system.	Well established	Off-line
12)	Regular testing of gauge/transducer alarm functionality	Pressure alarm tests from device to control room	Prevention of false alarm	Well established	Off-line

TABLE 4.6 - DIAGNOSTIC INDICATORS FOR EXTRUDED CABLE SYSTEM

Tool	Description of method	Events/cause detected	Comments	On-line/Off-line
1) Cable route inspection (for third party activities)	Visual inspection of the cable route to observe any third party activities near the cable route	Prevention of damage by third party	Well established	On-line
2) Serving Test	Measurement of the oversheath insulation resistance by HV testing. Location of any defects and repair	Damaged outer sheath	Well established	Off-line
3) Tan δ measurement	Measurements of increased power factor	Ingress of water in insulation area	Under development. The methods have only been developed for medium voltage cables, and are at the moment not possible to use on HV cables	Off-line
4) Temperature measurement	Measurement of temperature along the route by optical fibre (DTS)	Increased temperature causing thermal ageing Failure of cooling system	Well established technique, but requires fibre to be installed on the system	On-Line
5) Thermal backfill survey	Measure thermal resistivity of backfill in vicinity of cable	Thermal ageing of insulation caused by overload, short-circuit, hot spots	Effective where a problem is suspected	On-line
6) Partial discharge measurement	Measurement of discharges within the cable system	Defects and degradation of insulation. Assembly errors in accessories	Well established for accessories, but increased partial discharges are only detectable in cables for a short time before failure. PD measurement on cables and accessories is the subject of much international research. The key issues for this research are: – formulation of test methodology – acceptance criteria considering the site conditions such as noise level – acceptable level of partial discharges for individual service voltage of XLPE cable system – Compilation and evaluation of relevant international experience is also important.	On –Line/Off-line
7) Chemical and physical analysis of insulating fluid of terminations	Fluid samples taken from the cable system and tested for:- - DGA - Tan delta - Water content - Particles - etc	Thermal ageing of insulation (caused by different events)	Well established technique which relies on a regular testing regime. As the interpretation of individual DGA results is not clearly understood, this test is only of limited relevance and applicability at the moment.	Off-Line
8) X-ray of accessories	Use of X-ray on accessories	Movement of cable causing ferrule unplugging. Incorrect assembly of	Well established but significant H&S issues and practical application limitations	Off-line

<u>TABLE 4.6 -</u> DIAGNOSTIC INDICATORS FOR EXTRUDED CABLE SYSTEM

		joint connector		
9) Inspection of cable system	Visual inspection of all visible components of the cable system for damage, leaks, corrosion etc.	Visual damage, leaks, corrosion etc.	Well established	On-line
10) Inspection of termination for ferrule retraction	Internal inspection and measurement of ferrule movement	Movement of cable causing ferrule unplugging	Well established	Off-line
12) Bonding systems test	Checking the integrity of specially bonded systems by measurement of insulation resistance and/or circulating current in the screen	Loss of cross-bonding function	Well established	Off-line

5. Remaining Life Methodology

5.1 ntroduction

In order to assess the remaining lifetime of a power cable, one can essentially take two different routes leading to a well-founded answer. The first route is via failure statistics. If the total lifetime of a group of power cables is known, and if the power cable under consideration belongs to that specific group of cables, the data available on the group's total lifetime can be used to estimate the remaining life of the cable under consideration.

The second route is based on ageing. If one knows to what degradation mechanisms the cable under consideration was (historic data on operation has to be available) subjected, and if one is able to describe those degradation mechanisms with time dependent mathematical formulae, it is possible to deduce in theory the total cable degradation. If one can further relate cable degradation to failure risk, one can deduce the remaining lifetime of a power cable up to a certain failure risk.

Unfortunately, both approaches fail in practice. There is not enough statistical data available on the failure behaviour of HV power cables, and it is difficult to determine to what group a specific cable will belong. All cables are operated differently, are installed in different conditions and may be of a (slightly) different design; a specific cable has a very specific history. Formulae, describing degradation mechanism, formulae hardly exist. Where they do exist, the formulae are usually describing one degradation mechanism, while in real practice many degradation mechanisms work simultaneously and even influence each other.

However this does not mean that it is impossible to estimate the remaining life of power cables. Concerning the technical information, some information may be available regarding failure statistics, operation history, design implications and degradation theories. With this information it is not possible to exactly determine the remaining life of a power cable, but it will be possible to categorise power cables according to their remaining life. The proposed guidelines in this report are based on the information available at this moment. Of course, if in future more information becomes available either on the failure statistics (see WG B1-10 on failure statistics for HV power cables) or on degradation mechanisms, the guidelines to estimate the remaining lifetime of power cables which are presented in this report, may need to be updated. However as RL is not a completely technically defined, for the RL management not only the technical information is relevant, but also information from economic and strategic sources will be necessary, as will be explained in the following part.

It is important for Transmission System Operators to know when they may have to replace a cable circuit, even if it is working satisfactorily at the moment. As the replacement of a cable circuit is expensive, the decision to replace must be based on sound information and judgement. In this situation, it is important to determine the upgrading and the extending life for each cable system and if it is possible to determine the remaining life of the cable system. In other words, a classification of the links from the poor links to the good ones has been made to determine the priority of the interventions.

This classification is a complex task because it is based on three important elements:

- Technical criteria
- Strategic criteria
- Economic criteria

The interaction of these factors is outlined in Figure 5.1.

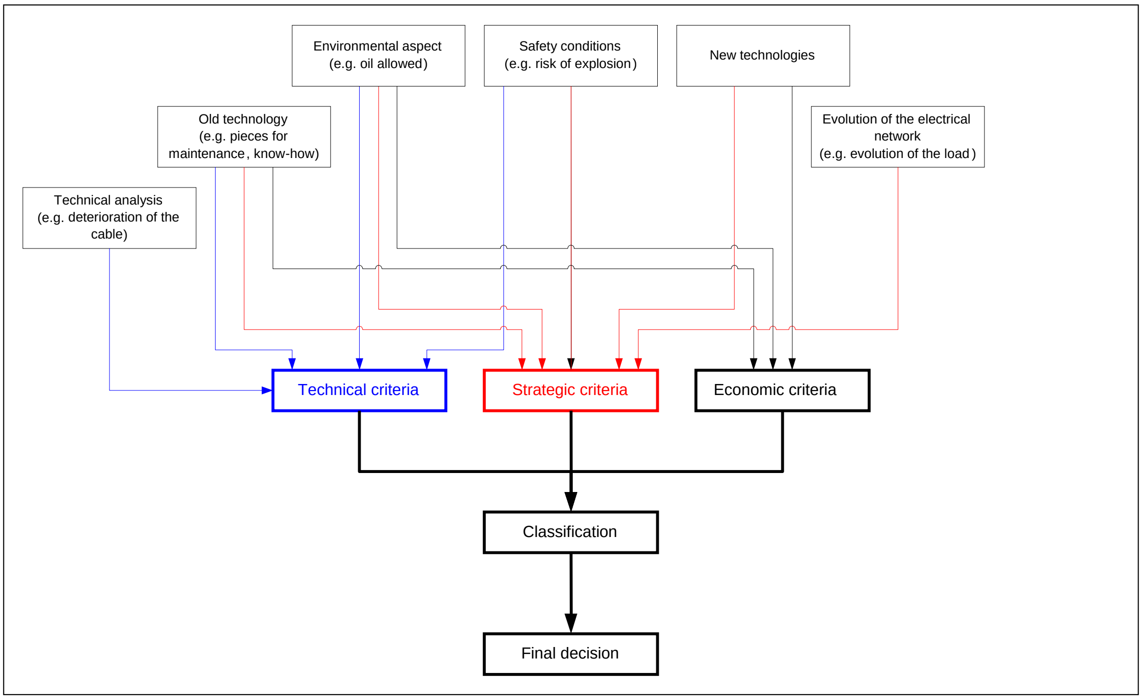


Figure 5.1 – Methodology Summary

These criteria are discussed in detail below. The combination of the three elements forms the basis for the derivation of practical guidelines to perform Remaining Life Estimation.

Remarks:

- Rather than considering a cable circuit from end to end, it is better if we consider each cable segment separately; a cable segment is a part of the cable where the cable and accessories are of the same type.

– This methodology can be used for all cable types.

5.2 Criteria

Remaining Life Management deals with a complex issue, consisting of a combination of technical, strategic and economic factors.

Technical criteria

The process of natural ageing strongly depends on the operating mode of the cable system (nominal load or partial load, continuous or short-time operation, overloads, number of starts, standstill periods) and on the local environment. The so-called TEAM-factors (temperature, electrical stress, ambient conditions, mechanical stress) have a strong influence. Furthermore, the electrical properties of materials and components show substantial scatter in their respective life expectancy under the same TEAM-factors.
Some utilities like RTE, Hydro-Quebec and Elia have developed their own system to assess the technical condition of the cable. Health Index or Global Performance Index are names of systems used by the utilities mentioned to quantify the technical condition of the cable. [9 cable ageing 24,25]

Various characteristics may indicate that a component will reach its end-of-life because of:
- Increased measured deterioration
- Increased number of failures
- Failures of similar components with the same age.

Economic criteria

In some cases it can be shown that the replacement of an old cable is cheaper than its continued operation. The reasons can be:
- Loss reduction (improved design, new materials)
- Lower maintenance costs of a new installation
- Increased maintenance of the old component (missing spare parts)
- Cost of damage repairs become a substantial part of the cost a new -replaced line
- Missing revenues of non-delivered energy
- Penalties

Strategic criteria

Change of (external) conditions may require replacement of a cable, although the technical end of life has not been reached yet. Typical examples would be:

- Original design parameters no longer match the actual operating conditions (higher nominal current on lines, higher short circuit power at certain busses)
- New strategy for the networks (upgrade of voltage levels)
- Increasing risk of operation (risk of explosion, leakage or fire)
- New legal regulations (prevention of water pollution, rules of noise pollution)
- Application of new technologies
- End of the support from the supplier
- Lack of know-how and maintenance personal for old technologies
- Importance of the link
- Obligation of power quality regulations

6. Practical Guidelines to Perform Remaining Life Management

6.1 Introduction

The methodology is based on the definition of remaining life (see Chapter 2). It consists of evaluating the technical, economical and strategic aspects involved. Furthermore, the methodology consists of a simplified and a detailed approach. The simplified approach is used to quickly determine on which cables most of the attention should be focused. The detailed approach is then proposed to categorise the cable circuits identified in the simplified approach.

In the simplified approach, 7 questions are asked and must be answered with Yes or No. If one of the answers is 'Yes', then the detailed approach should be used. When analyzing the cable circuits, start with the links that score highest.

6.2 Simplified approach

The goal of the simplified approach is to separate the power cables which will have a long remaining life from the ones which may not have such a long remaining life.

There are three sets of questions; technical, economical and strategic questions. Each set of questions gives a score, which is used for final categorisation of the power cables. The questions associated with the Simplified Approach are shown in Table 6.1a and the scoring system is outlined in Table 6.1b.

Question	Description	Possible Answer	Answer
	Technical questions		
T1	Has there been more than 1 internal failure in this link in its history?	N=0; Y=1	
T2	Is the age of this link more than 40 years, and have there been failures on similar links?	N=0; Y=1	
	Total Technical Score: **T = (T1 + T2) / 2**	0 < T < 1	
	Economic questions		
E1	Are the costs of maintaining and operating this cable route unacceptably high?	N=0; Y=1	
E2	Are the costs of a repair comparable to renew the power cable?	N=0; Y=1	
E3	Are the costs of possible penalties and/or claims during an outage unacceptably high?	N=0; Y=1	
	Total Economic Score: **E = (E1 + E2 + E3) / 3**	0 < E < 1	
	Strategic questions		
S1	Is the link critical?	N=0; Y=1	
S2	Is there a safety or environmental risk?	N=0; Y=1	
	Total Strategic Score: **S = (S1 + S2) / 2**	0 < S < 1	
	Weighting Factors		
	Technical, a	1 < a < 5	
	Economic, b	1 < b < 5	
	Strategic, c	1 < c < 5	
	Total Overall Score: **X = (a.T + b.E + c.S)/(a + b + c)**		

Table 6.1a: The simplified approach

Score	**Recommended Action**
X = 0	- the remaining life >10 years - Collect data on this power cable - Repeat the simplified approach after 3 to 5 years or after major change in the cable operation, performance or installation.
X > 0	- Analyse the cable circuits using the detailed approach, starting with the links that score highest.

Table 6.1b: Scoring the simplified approach

Scoring and ending the simplified approach

The technical, economical and strategic questions are given in Table 6.1a, and need to be answered with yes or no. When a question is answered with ‘yes’, the score of that question is 1, otherwise it is 0.

To find the total technical score, add the scores of questions T1 and T2 and divide by 2 to find the total technical score.

To find the total economical score, add the scores of questions E1, E2 and E2 and divide by 3 to find the total economical score.

To find the total strategic score, add the scores of questions S1 and S2 and divide by 2 to find the total strategic score.

Ending the simplified approach.

The simplified approach ends with adding all partial scores together according to the following formula:

$$Score = \frac{a \cdot Technical\_Score + b \cdot Economical\_Score + c \cdot Strategical\_Score}{a + b + c}$$

The technical, economical and strategic scores are calculated in accordance with Table 6.1b. The factors a, b and c are weighing factors to emphasise the relative importance to the utility of the technical, economic and strategic issues. The working group suggests to have the weighing factors a=b=c=3 which suggests that the technical, economical and strategic aspects are of equal importance. If a utility has for example a strong focus on particular technical, economical or strategic aspects, the weighting factors can be changed accordingly in a range between 1 and 5. Once a utility has set the weighting factors, the effect of changing the weighing factors in future should be carefully examined.

When the final score of a particular link is 0, the remaining life of this power cable is supposed to be morethan10 years. It is suggested in this case to:

- Collect data on this power cable
- Repeat the simplified approach after 3 to 5 years and in case of a major change in the cable operation/performance/installation.

When the final score of a particular link greater than 0, one ends up with a classification of the links concerning aspects of remaining life. The higher the scoring, the lower the estimated remaining life at this moment. When a number of power cables is scored in this way, it is suggested to:

- Analyse the cable circuits in detail, using the detailed approach, starting with the links that score highest
- Repeat the simplified approach after 3 to 5 years and in case of a major change in the cable operation/performance/installation.

Within a network it is expected that the majority of the links will end up with a low score (0 or almost 0), and that only a minority will end with a score higher than 0. Therefore, this approach helps with selecting the cables which need more attention (use the detailed approach) in order to estimate the remaining life and it does so by creating a prioritised or categorised listing.

Notes on the questions of the simplified approach

Technical questions

The technical questions are based on the assumption (even if this is not extensively proven for power cables) that the failure rate shows a bathtub behaviour as depicted in fig 6.1. When the power cable has not had any internal failures, the power cable seems to be in good condition (fig 6.1 part 1). However, when the power cable is getting older (with 40 years being the generally accepted normal life time), one might expect internal failures to happen because of degradation processes (fig. 6.1 part 4). This explains the different scoring for (so far) well performing power cables of differerent age.

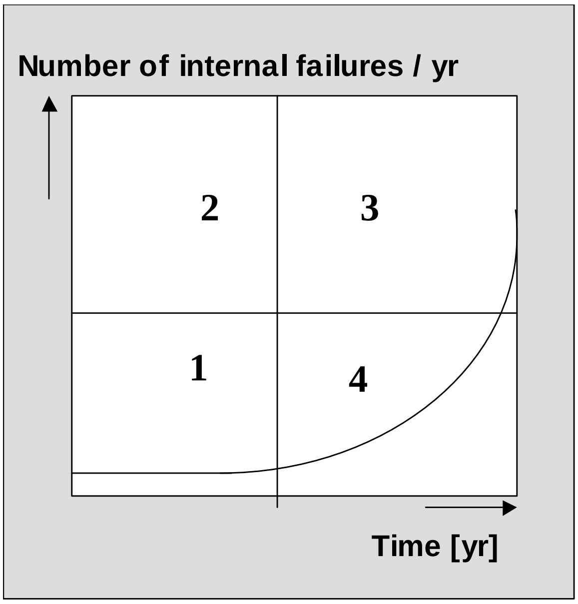


Figure 6.1: Final part of the bathtub curve for power cables

T1: Has there been more than 1 internal failure in this link in its history

If more than one internal failure occurs, there may be processes at play decreasing the remaining lifetime of the particular power cable.

T2: Is the age of the link more than 40 years, and have there been failures on similar links

If the cable is old failures may be expected because of degradation. If they already happen in a similar link, there is a great likelyhood that the cable under consideration will show failures as well.

Economic questions

E1: Are the costs of maintaining and operating this cable route unacceptably high?

The costs of maintenance and operation of certain cable circuits may be higher than others. Because these costs will be present for the total remaining life of the power cable, it may be cheaper to change this cable rather than to maintain it in operation. Therefore, the score of this question influences the remaining life.

E2: Are the costs of a repair comparable to renew the power cable?

Some cables may be installed in a very difficult way such that the costs of a repair are comparable to the costs of a new power cable. For example, in case of links crossing waterways or cables laid in horizontal directional drillings, it may become very difficult to remove cables after a failure. Then, a failure in such a power cable system has serious economical consequences.

E3: Are the costs of possible penalties and/or claims during an outage unacceptably high?

The costs of possible penalties or claims during an outage may be very high for a specific power cable. This all depends on the agreed availability of the power cable in energy delivery contracts between utility and customer. Also, legislation may call for penalties on not delivered energy. When these penalties become high, it may be interesting to decrease the expected failure rate by renewing the power cable.

Strategic questions

S1: Is the link critical?

A critical link is a link where there is no redundancy. If something goes wrong with this link, it has critical technical, economical or strategic consequences.

To assess the criticality of the link, think of asking questions like:

- is a large amount of energy / power connected?
- are there costumers with a special contract connected?

Each utility should define the critical links in the network themselves. Be aware that the criticality can change in a fault situation.

When a link is critical, a simplified approach to estimate the remaining life of the link on itself poses risks. This is reflected with this question.

S2: Is there a safety or environmental risk?
Two distinct areas of the definition of remaining life are addressed which may have serious strategic consequences for utilities: safety and environmental impact. When there is a risk that cable systems for example explode or pollute the environment, this is of strategic importance for the utility. It may cause bad publicity, dissatisfaction under customers or employees or even changes in legislation. Therefore, these two specific topics are evaluated in a special question.

6.3 Detailed Approach

The result of the simplified approach may be that the user is referred to the detailed approach. This detailed approach consists of 23 questions related to technical, economic or strategic issues.

The detailed approach is presented in table 6.2a and the scoring is detailed in table 6.2b.

Question	Description	Possible Answer	Answer
	Technical questions		
T1	Is the failure rate of the cable under consideration increasing significantly?	N=0; Y=6	
T2	Is only the failure rate of the reference cable increasing significantly?	N=0; Y=2	
T3	Is the failure rate of the accessories under consideration increasing significantly?	N=0; Y=3	
T4	Is only the failure rate of the reference accessories increasing significantly?	N=0; Y=1	
T5	Is the age of the system between 40 to 60 years?	N=0; Y=1	
T6	Is the system older than 60 years?	N=0; Y=2	
T7	Is there regular fluid/gas leakage along the link?	N=0; Y=2	
T8	Is the sheath integrity doubtful?	N=0; Y=2	
T9	Is the cable thermally highly loaded or overloaded?	N=0; Y=1	
T10	Is there an increased risk of corrosion for this link?	N=0; Y=1	
T11	For solid insulated cables only: is the cable system without water barriers and in a wet environment?	N=0; Y=1	
T12	Is the cable subjected to large mechanical forces or vibrations?	N=0; Y=1	
	Total Technical Score: **T = (T1 + T2 + … + T12) / N, where N is the maximum score of the applicable questions for the cable type.**	0 < T < 1	
	Economic questions		
E1	Make a life cycle cost comparison of the cable under consideration versus a new cable. Is replacement of the cable the best economical option?	N=0; Y=1	
	Alternative Economic questions		
E2	Are the operating and preventive maintenance costs of the cable system unacceptably high?	N=0; Y=2	
E3	Are the costs of not delivering power unacceptably high?	N=0; Y=2	
E4	Is there an economic window of opportunity to enhance the circuit?	N=0; Y=1	
E5	Are the costs of a repair unacceptably high?	N=0; Y=2	
	Total Economic Score: **E = E1, or (E2 + E3 + E4+E5) / 7**	0 < E < 1	
	Strategic questions		
S1	Is there a significant risk of unsafe situations?	N=0; Y=4	
S2	Is there an environmental risk, which disables the use of the cable system under consideration?	N=0; Y=2	
S3	Is the circuit critical in the network?	N=0; Y=1	
S4	Is the cable type no longer maintainable and	N=0; Y=1	

	properly repairable?		
S5	Is the total time to locate and repair a circuit unacceptable?	N=0; Y=1	
S6	Is the cable, joint and termination design no longer appropriate for its operating conditions?	N=0; Y=1	
S7	Is there a window of political opportunity to spend money on this circuit?	N=0; Y=1	
	Total Strategic Score: **S = (S1 + S2 + … + S7) / 11**	0 < S < 1	
	Weighting Factors		
	Technical, a	1 < a < 5	
	Economic, b	1 < b < 5	
	Strategic, c	1 < c < 5	
	Total Overall Score: **X = (a.T + b.E + c.S)/(a + b + c)**		

Table 6.2a: Summary of detailed approach

Score	**Recommended Action**
X > 0.4	Red: the system is approaching its end of life. - Act directly to change the red to orange or green by simple means (e.g. change the accessories only, mitigate a safety issue, solving technical problem - see Chapter 7). - If there is nothing that can be done, change the complete cable system starting with the cable system that scores highest.
0.1 < X < 0.4	Orange: the system needs particular attention - Find out what can be done to change the orange to green. - Collect data on this power cable, and perform adequate maintenance - Repeat the **detailed** approach after 1- 3 years, after a corrective maintenance action, and in case of a major change in the cable operation/performance/installation.
X <= 0.1	Green: the system does not need immediate actions - Carry on collecting data on this power cable - Repeat the **simplified** approach after 3 to 5 years and in case of a major change in the cable operation/performance/installation.

Table 6.2b: Scoring the detailed approach

Scoring detailed questions:

The questions associated with the Detailed Approach are shown in Table 6.2a and the scoring system is outlined in Table 6.2b.

Scoring the detailed approach:

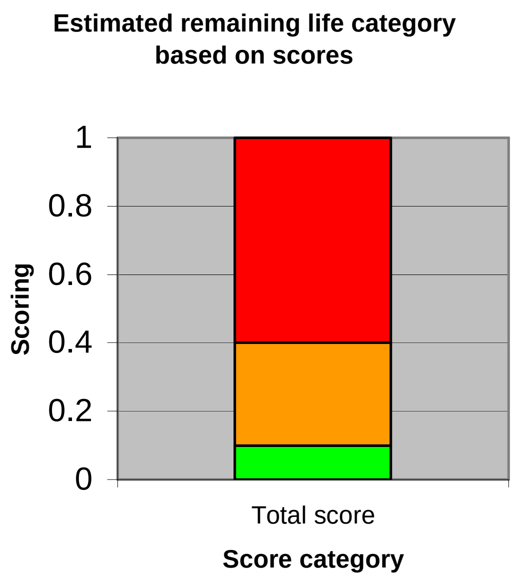
The technical, economical and strategic scores are discussed above. The factors a, b and c are weighting factors. The working group suggests to have the weighting factors a=b=c=3 as the WG is of the opinion that the technical, economical and strategic aspects concerning the remaining life of a power cable are of equal importance. If a utility has another opinion, or has for example a strong focus on either technical, economical or strategic aspects, it is suggested to change the weightng factors accordingly in a range between 1 and 5.

$$Total\_Score = \frac{a \cdot Technical\_Score + b \cdot Economical\_Score + c \cdot Strategical\_Score}{a+b+c}$$

The score may be between 0 and 1.

Note that the simplified approach and the detailed approach score in a different way and that the results of both approaches should not be compared or mingled as this is meaningless.

The detailed scoring can be used to select circuits with less remaining life from other circuits. Also, the score can be related to the estimated remaining life of the circuit. Find the colour belonging to a certain score, and find the meaning of the colour below:



Categories:

Red	: the system is approaching end of life (e.g. RL < 1 y)
Orange	: the system needs particular attention (e.g.RL 1-10y)
Green	: the system does not need immediate action (e.g. RL>10y)

Now: what does this mean? And what has to be done if the colour appears to be red or orange?

Green:
- Carry on collecting data on this power cable
- Repeat the **simplified** approach after 3 to 5 years and in case of a major change in the cable operation/performance/installation.

Orange:
- Find out what can be done to change the orange to green.
- Collect data on this power cable and perform adequate maintenance
- Repeat the **detailed** approach after 1 to 3 years, after a corrective maintenance action and in case of a major change in the cable operation/performance/installation.

Red:
- Act directly to change the red to orange or green by simple means (e.g. change the accessories only, mitigate a safety issue, solving technical problem, see chapter 7). If there is nothing that can be done, change the complete cable system starting with the cable system that scores highest.

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Notes on Questions for Detailed Approach

Technical Questions

<u>T1: Is the failure rate of thecable under consideration increasing significantly?</u>
If there have been a number of failures in the cable under consideration and the rate of failure shows an increasing pattern, then this may indicate serious underlying problems.

<u>T2: Is only the failure rate of the reference cable increasing significantly?</u>
In this case, if it is known that there is an increasing failure rate in other similar cables, then there is a concern that these problems could occur in the particular cable system under consideration.

<u>T3: Is the failure rate of the accessories under consideration increasing significantly?</u>
If there have been a number of failures in the accessories under consideration and the rate of failure shows an increasing pattern, then this may indicate serious underlying problems.

T4: Is only the failure rate of the reference accessories increasing significantly?
In this case, if it is known that there is an increasing failure rate in other similar accessories, then there is a concern that these problems could occur in the near future in the particular cable system under consideration.

T5: Is the cable in between 40 to 60 years old?
Cables above 40 years of age are more likely to have experienced significant ageing effects which could contribute to end of life issues.

T6: Is the cable older than 60 years?
Cables above 60 years of age are more likely to have experienced even more significant ageing effects.

T7: Is there regular fluid/gas leakage along the link?
This question seeks to identify:
- Oil leakage from SCFF or terminations,
- SF6 leakage from terminations,
- Inability of gas pressure cables to hold full pressure.

T8: Is the sheath integrity doubtful?
A cable in good condition should show a history of good sheath test results. When sheath faults have occurred (e.g. after third party activities), repairs should have been carried out.

T9: Is the cable thermally highly loaded or overloaded?
If the cable has been subjected to temperatures similar or higher than the design temperature, then the cable is subjected to ageing.
Examples would be normal load greater than 85% of the rated load, frequent overloads, and unknown hotspots.

T10: Is there an increased risk of corrosion for this link?
Increased risk of corrosion could be caused by DC stray currents in a link parallel to a railway, or a pipe type cable without cathodic protection.

T11: For solid insulated cables only: is the cable system without water barriers and in a wet environment?
Cables without water barrier are more susceptible to water treeing.

T12: Is the cable subjected to large mechanical forces or vibrations? Cable installed in unstable soils, on bridges or similar installations could be subject to mechanical vibration which could cause ageing. For example, fatigue can occur in lead sheaths under such conditions.

Economic questions

E1: Make a life cycle cost comparison of the cable under consideration versus a new cable. Is replacement of the cable the best economical option?

Alternative economic questions

E2: Are the operating and preventive maintenance costs of the cable system unacceptably high relative to other cables?
E3: Are the costs of not delivering power unacceptably high relative to other cables?
Factors to be considered include undelivered energy, penalties and claims.

E4: Is there an economic window of opportunity to enhance the circuit ?
Is there an opportunity available to offset the cable replacement costs against another project?

E5: Are the costs of a possible repair unacceptably high relative to other cables?
This includes cleaning the environment if applicable.

Strategic questions

S1: Is there a significant risk of unsafe situations?
Examples of unsafe situations would include:

- Explosion
- Fire
- Gas leakage
- Short circuit considerations
- Cable in tunnel

S2: Is there an environmental risk, which disables the use of the cable system under consideration?
e.g. EMF regulations, oil leakage

S3: Is the circuit critical in the network?
See chapter 2 for definition of critical link.

S4: Is the cable type no longer maintainable and properly repairable?
Items to consider:

- spare part availability
- availability of experienced jointers
- Is the knowledge still available?
- Can a repair be carried out in a reasonable timescale
- Is the cable, or cable section, accessible for repair?

S5: Is the total time to locate and repair a circuit lunacceptable?

- If so, then the score is 1

- When the total time is in between 1 week and 1 month, the score is 0.5, otherwise it is 0.

S6: Is the cable, joint and termination design no longer appropriate for its use today?
Factors to consider due to changing operating conditions are:
- loading requirements
- Voltage requirements
- Short circuit current requirements
- Harmonic requirements)?

S7: Is there a window of political opportunity to spend money on this circuit?
Examples would include:
- changing or emerging new laws
- public sponsoring

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7. Options for Life Extension

Introduction

Underground cable systems are generally installed for an expected service period of 30, 40 or 50 years depending on the voltage rating and insulation type of the cable system. However, these expected lifetimes were not obtained from ageing studies but they result more from a combination of technical and economical factors. The main factors that contribute to the establishment of expected lifetimes of underground cable systems are:

- The assessment of electrical performances of new cable systems obtain from testing (routine and factory tests following national and international standards);
- The utility and international service failure statistics of the specific cable systems since they were introduced in the market;
- The utility accounting standards;
- The utility maintenance programs.

Nowadays one of the main concerns of utilities is to determine if the underground cable systems that attained their expected service period can still be operated for 5, 10 or more years at a low maintenance cost and with a good reliability. Life extension could thus be defined as a combination of maintenance or operation actions on cable systems that would extend the initial expected lifetime of the cable systems. However, life extension options are also very important for cable systems that have not reached their expected life limit due to:

- Accelerated ageing of some specific components;
- Changes in environmental conditions that may jeopardise the dielectric integrity of the cable system under normal operating conditions.

Thus, options for life extension addresses any new implementation of maintenance or operating procedures that would differ from the complete replacement of the cable system, whatever its age.

7.1 Ageing assessment

From a technical perspective, the lifetime of underground cable systems totally depends on the ageing of the insulating materials under operating and testing conditions. Insulation ageing of each line depends on the so-called TEAM-factors (temperature, electric stress, ambient conditions, and mechanical stress). These ageing factors indeed result from variations of the applied voltage (service, transient), the load (temperature, thermomechanical stresses), the dielectric tests

(after laying, fault location, after repair) and the environment (soil resistivity, water).
The insulation ageing can be expressed as two distinct processes:

- Slow progressive and global ageing of the insulation under normal service conditions;
- Accelerated local degradation of the insulation (defect type) under normal operating conditions and/or under special conditions such as dielectric tests (fault localization, after installation (or repair) tests, diagnostic tests).

The knowledge of the insulation ageing is fundamental to determine the most cost effective life extension option.

The global ageing of the different insulating materials can in principle be assessed from:

- Proposed ageing models of insulating materials under electrical and thermal stresses;
- Off-line diagnostic testing of complete underground lines or laboratory testing of components recuperated from service.

The theoretical determination of ageing from models requires the knowledge of the TEAM factors. The main problem with this approach is that in general, utilities don't have detailed recordings of all the operating factors over a time period of 30, 40 or 50 years for each line. Thus, ageing extrapolation cannot be obtained from any proposed models. Diagnostic testing is certainly one of the most cost effective approaches since identical underground lines can be compared and a maintenance priority list of similar lines can be set from the measured parameters. A line presenting very low insulation degradation would not require any investment compare to a similar one with more advanced insulation degradation if they have been in service for the same number of years. Any difference between two similar lines results simply from different TEAM factors experienced by the respective lines.

The accelerated ageing of components can be assessed from:

- Off-line and On-line diagnostic testing of complete underground lines or laboratory testing of components recuperated from service.
- Utility failure statistics of the specific component.

Many diagnostic test methods are proposed to assess the insulation degradation of cable systems and a list of them is presented in chapter 4. Diagnostic methods that can perform non-destructive electrical tests in the field on a complete line are to be privilege. Repeated failures of specific components can also be sufficient to assess an accelerated ageing phenomenon under normal operating conditions.

The electrical field test methods can be classified in three families:

- Withstand (“Go-no-go”) at higher than service voltage;
- Dielectric loss measurements for global ageing assessment;
- Partial discharge (PD) measurements for local degradation characterization.

The withstand test is simple and useful to reveal any “weak point” in the cable system but does not provide any information on the global ageing of the insulation. The dielectric loss characterization is the only electrical field test method that correlates to the global ageing of cable insulation. However, any major local insulation degradation could dominate the dielectric loss response and results in a misleading diagnostic of highly degraded cable insulation. The consequence of this misinterpretation would be to replace completely the cable system when probably only the replacement of an accessory would be sufficient. The partial discharge (PD) testing on the complete line can be use to “clean” the weak points of a cable system. On-line method will in general detect local degradation in accessories while off-line testing at higher voltages than service voltage can also reveal defects in the cable insulation.

For a complete picture of the cable system condition, other indicators need to be addressed and a list is given for the different cable systems in chapter 4:

- Low pressure fluid filled cables Table 4.3
- High pressure fluid filled cables Table 4.4
- Gas pressure cables Table 4.5
- Extruded cables Table 4.6

7.2 Life extension decision strategy

The strategy to determine which life extension option is best suited for a specific cable system is based on the information available to each utility. The options for life extension depend not only on the insulation type but also on the components design and on the type of installation. The life extension decision strategy for cable systems of a utility should not be based on the age of the system, but should be based on the following:

- Assessment of insulation global ageing or local degradation mechanism using diagnostic tools;

- Assumptions of ageing based only on the years in service of the cable system;
- Analysis of reported field experience from other utilities with similar cable systems and operating conditions;
- Analysis of reported laboratory results on recuperated from service components or from accelerated ageing of such components;
- Analysis of reported data on proposed successful options from service providers;
- Analysis of the utility failure statistics of the cable systems.
- Usage of this CIGRE guide, Chapter 4.

The life extension decision strategy listed before does not pretend to be exhaustive and utilities could decide on options based on other criteria. However, it is clear that a sound understanding and assessment of the cable system ageing (chapter 4) will help to choose the best options for life extension.

7.3 Practical Options for life extension

Some techniques are available, which if implemented by the network operator, can extend the remaining life of XLPE and SCFF underground cable systems. Some techniques are well proven. The suitability of the techniques would need to be assessed before implementation on the network. The inclusion of any particular technique in this section does not mean it is being endorsed by CIGRE.

<u>Implement a proper cable maintenance programme</u>
If not already being done, locate and repair fluid leaks and sheath faults as soon as possible. Put measures in place to reduce the risk of third party damage (e.g. regular cable patrols). Refer to CIGRE Report from Working Group B1-04 for recommendations for maintenance for each cable type.

<u>Decreasing mechanical stresses</u>
By decreasing the operating stresses of the cable and accessories, the ageing processes can be slowed down. The stresses can be decreased by better clamping, supporting of the cable, mitigating mechanical forces.

<u>De-rating the cable</u>
This could involve operating the cable at a lower current rating.

<u>Decrease the hydraulic pressure in SCFF to avoid leakage</u>
The hydraulic pressure in a fluid filled cable system can be reduced by the installation of additional stop joints in the circuit. This reduces the stress on old lead wipes and may reduce fluid leakage from the circuit.

Fluid Flushing of SCFF systems

If the key condition indicators for the cable fluid (breakdown strength, moisture content, RGP level) are found to be unsatisfactory, the cable can be flushed with treated fluid until the gases are reduced to a lower level. Time is required to allow the new fluid to absorb the gases from the core insulation and a considerable amount of pumping (up to several days) is required to achieve the necessary effect. Of course, in addition to flushing out the dissolved gases, the cause of the presence of the gases should be identified and eliminated if possible.

Carry out selective replacement of cable accessories

Sometimes, the condition of the accessories may be inferior to that of the cable itself. In this case, it may be feasible for carry out selective replacement of accessories only (i.e. terminations, joints, link boxes). This would also include the replacement of components with design problems.

Carry out selective replacement of cable sections

In some cases it could be more cost effective to replace some fluid-filled cable sections by XLPE cable sections with transition joints.

Use of on-line sensing techniques

Remote on-line sensing techniques are now available for fluid pressure monitoring, distributed temperature sensing (DTS), and monitoring of mechanical stresses.

Reduce the exposure to short circuits

Older circuits may have been designed with parameters that are no longer valid for today’s operating environment. Network planners need to be made aware of the importance of obey the design limits of older cables. Exposure to high short circuits can further damage aged cable, so if the network can be configured or designed in such a way that short circuits are reduced, particularly on old cables, then this will benefit the remaining life.

Silicon injection

More information needs to be provided on this technique. The effectiveness of this option to extend the life of XLPE cable insulation plagued with water trees is incomplete. The operating and environmental limitations need to be clearly documented before its implementation. The potential effectiveness needs to be clearly identified for the different cable designs (i.e. cross-linked semi-conductor screens or not) and type of installation (i.e. in ducts, directly buried, underwater).

8. Case Studies on Remaining Life

Introduction

The purpose of this chapter is to apply the proposed remaining life methodology to a few actual cases to demonstrate the feasibility of the methodology. The outcome of this has been discussed in relation to the actual actions taken in each case. The following cases are included;

1. Old 150 kV oil-filled cable with problem with pressure decrease (indicating leakage).
2. Service failures in old 50 kV oil-filled cables
3. Service failure in an old 132 kV oil-filled XLPE termination with porcelain housing
4. Service failure in an old 110kV gas compression cable
5. Old 220 kV oil-filled cable with no failures or service problems
6. Service failures in several high voltage (52-132 kV) oil-filled XLPE termination with porcelain housing
7. Heavy oil leakage in a 220kV oil filled cable circuit

Case Study No. 1 - Belgium

1. Introduction

A 150 kV fluid filled cable has been in service for 70 years. This cable is installed in city streets at 1 metre depth with associated fluid feeding chambers along the route. Tram rails also run along part of the cable route.

For one year, a slow pressure decrease has been observed in one of the tank chambers, indicating the presence of a fluid leak in the cable between two stop joints. The cause is believed to be a fatigue stress due to mechanical vibrations and thermal cycling or by third party damage. The result is the ageing of the lead sheath.

2. Test methodology

2.1 Defect Localisation

The freezing methodology was used to localise the leak point. As there is an element of trial and error with location by freezing, it can take a up to several weeks to pinpoint the leak.

- The freezing operation is made at the middle of the faulty cable segment
- After the freezing operation, the pressure variations indicate on which side of the freeze the leak is. In this situation the length of the bad cable may be reduced by a 2 coefficient (the bad cable = x/2 % of the length of the liaison).
- The two formal operations are repeated whenever the length of the cable segment is considered oversized.

2.2 Defect estimation

With the know-how of the state of the links (based on other faults) and a visual inspection of the defect lead sheath, it is possible to estimate the ageing of the lead.

3. Solution

The final decision was based on three important issues:

- The circuit is routed along busy congested streets and an alternative new cable route was not feasible.
- It would be difficult to obtain the necessary permissions and consents to the installation of a new cable along a different route. Issues such as EMF, traffic disruption and inconvenience to the public would be difficult to overcome.

- It would not be acceptable for the circuit to be out of service for a prolonged period.
- The ageing was localised and not a problem on other parts of the circuit.

In view of the local ageing, the localisation of the leak in busy city streets, and the importance for the circuit, it was decided to replace the bad cable segment by a new fluid cable segment over a length of 100 to 200 metres.

Application of Scoring System

QUESTIONNAIRE (SIMPLIFIED APPROACH)		Answer	Score
	Technical Questions		
T1	Has there been more than 1 internal failure in this link in its history ?	No	0
T2	Is the age of this link more than 40 years, and have there been failures on similar links?	Yes	1
T	*Total Technical Questions*		*0.50*
	Economic Questions		
E1	Are the costs of maintaining and operating this cable route unacceptably high ?	No	0
E2	Are the costs of a repair comparable to renew the power cable?	No	0
E3	Are the costs of possible penalties and/or claims during an outage unacceptably high?	No	0
E	*Total Economic Questions*		*0.00*
	Strategical Questions		
S1	Is the link critical ?	No	0
S2	Is there a safety or environmental risk ?	Yes	1
S	*Total Strategical Questions*		*0.50*
	Weighing factor		
a	Technical (1 < a < 5)	3	
b	Economic (1 < b < 5)	3	
c	Strategical (1 < c < 5)	3	
X	**SCORE TOTAL**		**0.33**

QUESTIONNAIRE (DETAILED APPROACH)		Answer	Score
	Technical Questions		
T1	Is the failure rate of the cable under consideration increasing significantly?	No	0
T2	Is only the failure rate of the reference cable increasing significantly?	No	0
T3	Is the failure rate of the accessories under consideration increasing significantly?	No	0
T4	Is only the failure rate of the reference accessories increasing significantly?	No	0
T5	Is the age of the system between 40 to 60 years?	Yes	1
T6	Is the system older than 60 years?	No	0
T7	Is there regular fluid/gas leakage along the link?	Yes	2
T8	Is the sheath integrity doubtful?	Yes	2
T9	Is the cable thermally highly loaded or overloaded?	No	0
T10	Is there an increased risk of corrosion for this link?	Yes	1
T11	For solid insulated cables only: Is the cable system without water barriers and in a wet environment?	No	0
T12	Is the cable subjected to large mechanical forces or vibrations?	No	0
N	Maximum score of the applicable questions for the cable type	*20*	
T	*Total Technical Questions*		*0.30*
	Economic Questions		
E1	Make a life cycle cost comparison of the cable under consideration versus a new cable. Is replacement of the cable the best economic option ?	No	0
	Alternative Economic questions used ?	Yes	
E2	Are the operating and preventive maintenance costs of the cable system unacceptably high?	No	0
E3	Are the costs of not delivering power unacceptably high?	No	0
E4	Is there an economic window of opportunity to enhance the circuit?	No	0
E5	Are the costs of a repair unacceptably high?	Yes	2
E	*Total Economic Questions*		*0.29*
	Strategical Questions		
S1	Is there a significant risk of an unsafe situations?	No	0

S2	Is there an environmental risk, which disables the use of the cable system under consideration?	Yes	2
S3	Is the circuit critical in the network?	No	0
S4	Is the cable type no longer maintainable and properly repairable?	No	0
S5	Is the total time to locate and repair a circuit unacceptable?	Yes	1
S6	Is the cable, joint and termination design no longer appropriate for its operating conditions?	No	0
S7	Is there a window of political opportunity to spend money on this circuit?	No	0
S	*Total Strategical Questions*		*0.27*
	Weighing factor		
a	Technical (1 < a < 5)	3	
b	Economic (1 < b < 5)	3	
c	Strategical (1 < c < 5)	3	
X	**SCORE TOTAL**		**0.29**

Category	Total score	Result of detailed approach
green	0.10	0.00
orange	0.30	0.29
red	0.60	0.00

Case Study No. 2 - Denmark

Exchanging of 50 kV OF cables.

1. Situation

50kV SCFF cables have been in use in Denmark since 1950. In the last 10 years, the failure frequency for this cable type has been increasing due to problems with oil-leakage in joints.
(see included appendix). The cost to locate and repair these faults is significant, which means that a rise in frequency for these failures gives reasons for concern.

In 2001, the situation on four cable links that supplies to one specific 50 kV substation gave cause for concern. The links had several failures and during the previous 3- 5 years a rise in failure frequency has occurred. The total length of these four links is 25km
It was decided to make an investigation of the different solutions to the problem.

2. Test Methodology

No methods for measuring the electrical condition of the cable insulation or detection of any oil leaks, or the condition of the lead sheath were applied.

3. Solution

It was decided to replace the old SCFF-cables with two new 132 kV XLPE cables.

Use of new oil-filled cable was not considered as the policy of the company since late 1980 has been to use XLPE cables only. This was due to the fact that XLPE cables have low maintenance costs and give less risk for the environment.

4. Strategic and economic outcome

The possible solutions for solving the problems were found to be:

A. Continue operation with the old SCFF cables for another 10 years before exchanging with new XLPE cables.

B. Extending life of cable link by renewal of welding in every joint in the four cable systems. Cracks in the welding at the ends of the joint were the main reason for oil leakage.

C. Replacement of old 50 kV SCFF cables with new 132 kV XLPE cables

A technical and economic study was made to decide which of the three solutions to choose.

A comparison of the 3 solutions was carried out based on NPV for the cost.

Alternative	A **DKr (million)**	B **DKr (million)**	C **DKr (million)**
Capital invested	49,2	73,0	79,3
Service cost including losses	34,9	18,0	7,7
Other benefits			13,4
Total costs in NPV	84,1	91,0	73,5
INDEX for costs related to A	100	110	87

Capital invested:

A. Investment in new XLPE cable system in 10 years .
B. New welding of every joint in the existing 50 kV SCFF cable system today
   Investment in new 132 kV XLPE cable systems in 20 years.
C. Investment in new 132 kV XLPE cable system today.

Service cost.

Cost for operation, maintenance and repair of the cable system (including and losses)

Other benefits.

By choosing solution C, cost savings are obtained by re-using some of the old components in other substations. Circuit breakers and transformers with a remaining life from the old 50 kV substations can be used to replace older components in other substations, which lead to postponement of investments.

This case shows that even though the technical end of life for the cable as a component is not reached, it is from a economic point of view the best solution to replace the four old 50 kV SCFF cables systems with two new 132 kV systems.

5. Application of scoring system.

Scoring of this case using the questionnaire from the working group is performed.

The simplified questionnaire gives a total score of 0.61; therefore, a detailed approach is needed to evaluate the cable systems.

The score for the detailed approach is calculated to 0.42, which indicates that the situation is critical. The main part of the scoring is due to economic reasons as an investigation shows that it is economically feasible to exchange the links. Adding that there are also technical and environmental problems underlines the decision taken to exchange the all four links.

Appendix to case no. 2.

Fault rate of fluid-paper cables.

The fault rate for the four old 50 kV SCFF cable system are primarily based on the leakage rate on the joints; this rate is shown to rise within time.

The mechanism of failure is characteristic for the last part of the bathtub curve. This part if often named the wear out period and can be described with a Weibull distribution a characteristic rise and time to failure.

This model is used on the four critical cables systems which have a length of approximate 25 km and includes in total 93 joints. The total number of faults on these cables up to and including 2003 was 13.

This date is found to give a good match with a Weibull distribution with a rate of raise 7.8 and a characteristic time of 55 years.

The expected number of faults can with reasonably accuracy be calculated using the following equation:

$$\text{Number of faults}_{\text{year n}} = \text{Number of joints} * (1-\exp(-(\text{year n} - 1960)/55)^{7,8})$$

Expected number of failure for the coming years.

A calculation based on the Weibull distribution shown above on the 4 critical cables indicates that it is to be expected to have 36 failures on these cables systems in the coming 10 years with a yearly rise in failure rate.

Application of Scoring System

QUESTIONNAIRE (SIMPLIFIED APPROACH)			
		Answer	Score
	Technical Questions		
T1	Has there been more than 1 internal failure in this link in its history ?	Yes	1
T2	Is the age of this link more than 40 years, and have there been failures on similar links?	Yes	1
T	*Total Technical Questions*		*1.00*
	Economic Questions		
E1	Are the costs of maintaining and operating this cable route unacceptably high ?	No	0
E2	Are the costs of a repair comparable to renew the power cable?	Yes	1
E3	Are the costs of possible penalties and/or claims during an outage unacceptably high?	No	0
E	*Total Economic Questions*		*0.33*
	Strategical Questions		
S1	Is the link critical ?	Yes	1
S2	Is there a safety or environmental risk ?	No	0
S	*Total Strategical Questions*		*0.50*
	Weighing factor		
a	Technical (1 < a < 5)	3	
b	Economic (1 < b < 5)	3	
c	Strategical (1 < c < 5)	3	
X	**SCORE TOTAL**		**0.61**

QUESTIONNAIRE (DETAILED APPROACH)			
		Answer	Score
	Technical Questions		
T1	Is the failure rate of the cable under consideration increasing significantly?	No	0
T2	Is only the failure rate of the reference cable increasing significantly?	No	0
T3	Is the failure rate of the accessories under consideration increasing significantly?	Yes	3
T4	Is only the failure rate of the reference accessories increasing significantly?	No	0
T5	Is the age of the system between 40 to 60 years?	Yes	1
T6	Is the system older than 60 years?	No	0
T7	Is there regular fluid/gas leakage along the link?	No	0
T8	Is the sheath integrity doubtful?	No	0
T9	Is the cable thermally highly loaded or overloaded?	No	0
T10	Is there an increased risk of corrosion for this link?	No	0
T11	For solid insulated cables only: Is the cable system without water barriers and in a wet environment?	No	0
T12	Is the cable subjected to large mechanical forces or vibrations?	No	0
N	Maximum score of the applicable questions for the cable type	*20*	
T	*Total Technical Questions*		*0.20*
	Economic Questions		
E1	Make a life cycle cost comparison of the cable under consideration versus a new cable. Is replacement of the cable the best economical option ?	Yes	1
	Alternative Economic questions used ?	No	
E2	Are the operating and preventive maintenance costs of the cable system unacceptably high?	No	0
E3	Are the costs of not delivering power unacceptably high?	No	0
E4	Is there an economic window of opportunity to enhance the circuit?	No	0
E5	Are the costs of a repair unacceptably high?	No	0
E	*Total Economic Questions*		*1.00*
	Strategical Questions		
S1	Is there a significant risk of an unsafe situations?	No	0

S2	Is there an environmental risk, which disables the use of the cable system under consideration?	No	0
S3	Is the circuit critical in the network?	Yes	1
S4	Is the cable type no longer maintainable and properly repairable?	No	0
S5	Is the total time to locate and repair a circuit unacceptable?	Yes	1
S6	Is the cable, joint and termination design no longer appropriate for its operating conditions?	No	0
S7	Is there a window of political opportunity to spend money on this circuit?	No	0
S	*Total Strategical Questions*		*0.18*
	Weighing factor		
a	Technical (1 < a < 5)	3	
b	Economic (1 < b < 5)	3	
c	Strategical (1 < c < 5)	3	
X	**SCORE TOTAL**		**0.46**

Category	Total score	Result of detailed approach
green	0.10	0.00
orange	0.30	0.00
red	0.60	0.46

Case Study No. 3 - Denmark

Exchanging of 132 kV XLPE terminations

1. Situation

In 2002, a 132 kV termination failed in a 400/132 kV substation. The termination was part of an internal 100 metre long cable link in the substation. This link consisted of 6 cables (2 * 3 * 2000 mm2 Al XLPE).
This cable type, which is from 1975, previously had some internal faults. Therefore it was decided to investigate the condition of the cable.

2. Test Methodology

The cable termination was dismantled and a visual inspection was performed. The cause of failure was found to in be the welding of the top bolt as this was not perfect - only 30-40% of the bolt area was welded. The consequence of the bad welding was high impedance and a high temperature at high current. This led to high pressure and an explosion of the joint (porcelain)

Internal failure had previously occurred on this cable type in other systems. It was decided to make a sample test. A 2 metre cable sample was sent for investigation. The report from the investigation stated that the cable was aged and impurities were found in the cable insulation, but a remaining life of 15-20 years could be expected for the cable.

A mechanical test was performed on the 5 remaining terminations by loosening the top bolt and thereafter twisting the conductor slightly. This simple test led to breakage in 3 of the last 5 terminations. After dismantling the termination, it was clear that the problem with bad welding was in all the terminations.

3. Solution

It was decided to replace all 6 terminations. Two solutions were considered:

- make 5 new shorter terminations on the un-failed ends and make a joint and a short cable length of 15 metres on the failed terminations. This would postpone the exchange of the total cable system for 15 years.
- Exchange the total cable system at once including terminations.

4. Strategic and economic outcome

The two possible solutions were investigated technical and economical. The result was that the preferred solution was to postpone the replacement of the cable.

5. Application of scoring system.

Scoring of this case using the questionnaire from the working group is performed.

The simplified questionnaire gives a total score of 0.33 a detailed approach is therefore needed to analyse the cable systems. The detailed approach shows a score of 0.21, which indicates that a closer follow up on the system was needed. The individual scoring shows that the main part is related to technical issues, especially on the accessories. This underlines the decision actually taken which was to exchange all terminations on the system.

A scoring on the new system after exchange of termination results in a details scoring of 0.08, which is in green area. The actions taken has resulted in a “safe” cable system

Application of Scoring System

QUESTIONNAIRE (SIMPLIFIED APPROACH)			
		Answer	Score
	Technical Questions		
T1	Has there been more than 1 internal failure in this link in its history ?	Yes	1
T2	Is the age of this link more than 40 years, and have there been failures on similar links?	No	0
T	*Total Technical Questions*		*0.50*
	Economic Questions		
E1	Are the costs of maintaining and operating this cable route unacceptably high ?	No	0
E2	Are the costs of a repair comparable to renew the power cable?	No	0
E3	Are the costs of possible penalties and/or claims during an outage unacceptably high?	No	0
E	*Total Economic Questions*		*0.00*
	Strategical Questions		
S1	Is the link critical ?	Yes	1
S2	Is there a safety or environmental risk ?	No	0
S	*Total Strategical Questions*		*0.50*
	Weighing factor		
a	Technical (1 < a < 5)	3	
b	Economic (1 < b < 5)	3	
c	Strategical (1 < c < 5)	3	
X	**SCORE TOTAL**		**0.33**

QUESTIONNAIRE (DETAILED APPROACH)			
		Answer	Score
	Technical Questions		
T1	Is the failure rate of the cable under consideration increasing significantly?	Yes	6
T2	Is only the failure rate of the reference cable increasing significantly?	No	0
T3	Is the failure rate of the accessories under consideration increasing significantly?	Yes	3
T4	Is only the failure rate of the reference accessories increasing significantly?	No	0
T5	Is the age of the system between 40 to 60 years?	No	0
T6	Is the system older than 60 years?	No	0
T7	Is there regular fluid/gas leakage along the link?	No	0
T8	Is the sheath integrity doubtful?	No	0
T9	Is the cable thermally highly loaded or overloaded?	No	0
T10	Is there an increased risk of corrosion for this link?	No	0
T11	For solid insulated cables only: Is the cable system without water barriers and in a wet environment?	Yes	1
T12	Is the cable subjected to large mechanical forces or vibrations?	No	0
N	Maximum score of the applicable questions for the cable type	*20*	
T	*Total Technical Questions*		*0.50*
	Economic Questions		
E1	Make a life cycle cost comparison of the cable under consideration versus a new cable. Is replacement of the cable the best economical option ?	No	0
	Alternative Economic questions used ?	No	
E2	Are the operating and preventive maintenance costs of the cable system unacceptably high?	No	0
E3	Are the costs of not delivering power unacceptably high?	No	0
E4	Is there an economic window of opportunity to enhance the circuit?	No	0
E5	Are the costs of a repair unacceptably high?	No	0
E	*Total Economic Questions*		*0.00*
	Strategical Questions		
S1	Is there a significant risk of an unsafe situations?	No	0

S2	Is there an environmental risk, which disables the use of the cable system under consideration?	No	0
S3	Is the circuit critical in the network?	Yes	1
S4	Is the cable type no longer maintainable and properly repairable?	No	0
S5	Is the total time to locate and repair a circuit unacceptable?	No	0
S6	Is the cable, joint and termination design no longer appropriate for its operating conditions?	No	0
S7	Is there a window of political opportunity to spend money on this circuit?	No	0
S	*Total Strategical Questions*		*0.09*
	Weighing factor		
a	Technical (1 < a < 5)	3	
b	Economic (1 < b < 5)	3	
c	Strategical (1 < c < 5)	3	
X	**SCORE TOTAL**		**0.20**

Category	Total score	Result of detailed approach
green	0.10	0.00
orange	0.30	0.20
red	0.60	0.00

Application of Scoring System (new terminations)

	QUESTIONNAIRE (SIMPLIFIED APPROACH)		
		Answer	Score
	Technical Questions		
T1	Has there been more than 1 internal failure in this link in its history ?	No	0
T2	Is the age of this link more than 40 years, and have there been failures on similar links?	No	0
T	*Total Technical Questions*		*0.00*
	Economic Questions		
E1	Are the costs of maintaining and operating this cable route unacceptably high ?	No	0
E2	Are the costs of a repair comparable to renew the power cable?	No	0
E3	Are the costs of possible penalties and/or claims during an outage unacceptably high?	No	0
E	*Total Economic Questions*		*0.00*
	Strategical Questions		
S1	Is the link critical ?	Yes	1
S2	Is there a safety or environmental risk ?	No	0
S	*Total Strategical Questions*		*0.50*
	Weighing factor		
a	Technical (1 < a < 5)	3	
b	Economic (1 < b < 5)	3	
c	Strategical (1 < c < 5)	3	
X	**SCORE TOTAL**		**0.17**

	QUESTIONNAIRE (DETAILED APPROACH)		
		Answer	Score
	Technical Questions		
T1	Is the failure rate of the cable under consideration increasing significantly?	No	0
T2	Is only the failure rate of the reference cable increasing significantly?	Yes	2
T3	Is the failure rate of the accessories under consideration increasing significantly?	No	0
T4	Is only the failure rate of the reference accessories increasing significantly?	No	0
T5	Is the age of the system between 40 to 60 years?	No	0
T6	Is the system older than 60 years?	No	0

T7	Is there regular fluid/gas leakage along the link?	No	0
T8	Is the sheath integrity doubtful?	No	0
T9	Is the cable thermally highly loaded or overloaded?	No	0
T10	Is there an increased risk of corrosion for this link?	No	0
T11	For solid insulated cables only: Is the cable system without water barriers and in a wet environment?	Yes	1
T12	Is the cable subjected to large mechanical forces or vibrations?	No	0
N	Maximum score of the applicable questions for the cable type	*20*	
T	*Total Technical Questions*		*0.15*
	Economic Questions		
E1	Make a life cycle cost comparison of the cable under consideration versus a new cable. Is replacement of the cable the best economical option ?	No	0
	Alternative Economic questions used ?	No	
E2	Are the operating and preventive maintenance costs of the cable system unacceptably high?	No	0
E3	Are the costs of not delivering power unacceptably high?	No	0
E4	Is there an economic window of opportunity to enhance the circuit?	No	0
E5	Are the costs of a repair unacceptably high?	No	0
E	*Total Economic Questions*		*0.00*
	Strategical Questions		
S1	Is there a significant risk of an unsafe situations?	No	0
S2	Is there an environmental risk, which disables the use of the cable system under consideration?	No	0
S3	Is the circuit critical in the network?	Yes	1
S4	Is the cable type no longer maintainable and properly repairable?	No	0
S5	Is the total time to locate and repair a circuit unacceptable?	No	0
S6	Is the cable, joint and termination design no longer appropriate for its operating conditions?	No	0
S7	Is there a window of political opportunity to spend money on this circuit?	No	0
S	*Total Strategical Questions*		*0.09*
	Weighing factor		
a	Technical (1 < a < 5)	3	
b	Economic (1 < b < 5)	3	
c	Strategical (1 < c < 5)	3	
X	**SCORE TOTAL**		**0.08**

Category	Total score	Result of detailed approach
green	0.10	0.08
orange	0.30	0.00
red	0.60	0.00

Case Study No. 4 – Ireland

Case Study on Replacement of 110kV Gas Compression with 3-core XLPE cable

1. Situation

A fault occurred on a 110kV gas compression cable in Dublin in January 2000. The circuit is a 3 x 500mm² copper gas compression cable, installed in steel pipe with 137mm inner diameter and 4.25mm wall thickness. The overall route length is 3km and the circuit was commissioned in 1967.

The repair of such a fault would normally not be a major problem. However, in this case, the failure occurred in a tunnel under the River Liffey in which no jointing was possible. It was therefore considered necessary to replace the 400m section between joints.

The circuit arrangement is shown in Figure 1.

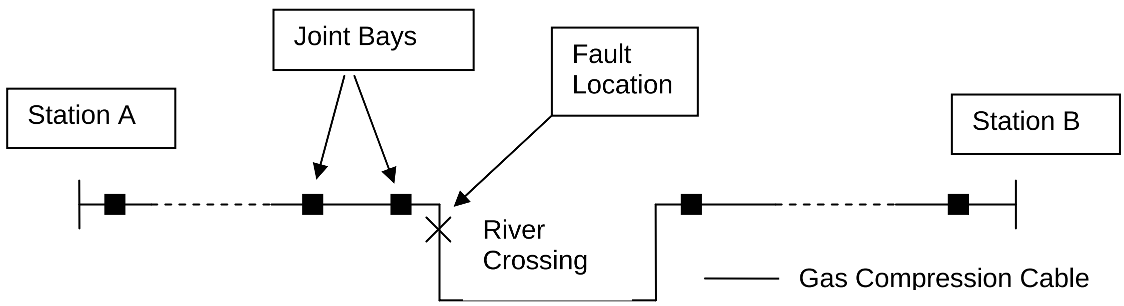


Figure 1 – Circuit Schematic in January 2000

2. Test Methodology

No particular methods for measuring the electrical condition of the cable insulation or pipe were applied in this case.

3. Solution

Three possibilities were considered for repair:

a) Replace the cable with similar gas compression cable (including steel pipe, as the existing tunnel section of steel pipe was not in good condition) and tie in to the existing circuit with normal gas compression straight joints.

b) Replace the tunnel section with standard single core XLPE cable, and tie in with two transition joints to gas compression cable.

c) Replace the river crossing with 3-core XLPE Cable in the existing pipe using transition joints to gas compression cable.

It was decided go for option (c) – to replace the section of the circuit in the tunnel by new 3-core XLPE cable that was installed in the pipe that had been used for the original cable.

The reasons behind this decision were as follows:

- It was known that the condition of the pipe was poor. And it would not be possible to reliably maintain a pressure of 14 bar for the gas compression cable without also replacing the pipe.
- At that time, transition joints from 3-core gas compression to single core XLPE cable were not available.
- The 3-core XLPE cable does not rely on high gas pressure for its operation. Therefore the existing pipe can be re-used without the need to replace pipe.

A comparison of the cable types is given in Table 1.

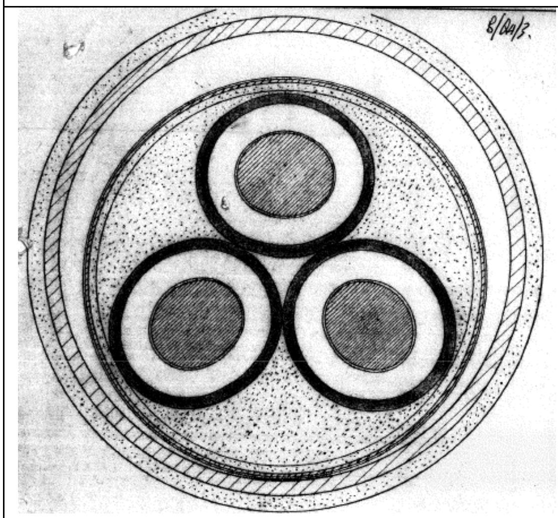
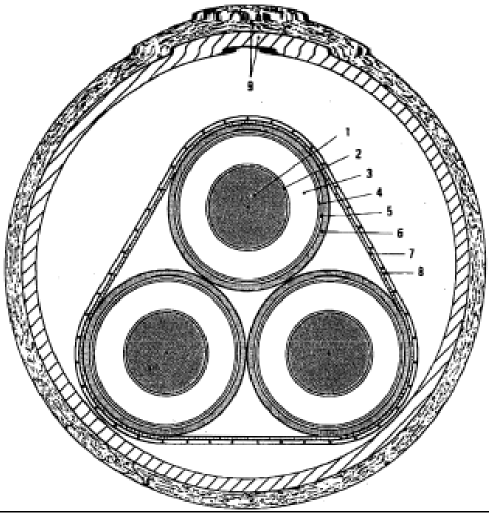
Gas Compression Cable		**3-core XLPE cable**	
			
Conductor	500mm² Cu	Conductor	500mm² Cu
Insulation incl. carbon black paper	9.5mm	Diameter over conductor	26.5mm
Thickness of lead sheath	2.1mm	Conductor screen	0.8mm
2 tinned copper tapes	0.2mm	XLPE insulation	9.5mm
Thickness of flat armouring wires	1.2mm	Insulation screen	0.45mm
Diameter over armouring approx.	137.5mm	Semiconducting swelling tape	0.3mm
Wall thickness of steel pipe	4.25mm	Aluminium plastic laminated (APL) sheath	
Diameter over pipe insulation approx.	157mm	– Coated aluminium tape	0.25mm
		– PE sheath	2.0mm
		Bedding	
		Armouring (flat steel wires)	43 no.
		Wall thickness of steel pipe	4.25mm
		Diameter over pipe insulation approx.	157mm

Table 1 – Comparison of the Gas Compression and XLPE Cables

In order to fit into the existing pipe, the 3-core XLPE cable must be of a high stress design. The stresses were similar to those on EHV cables.

Following the completion of this repair, the circuit arrangement is as shown in Figure 2.

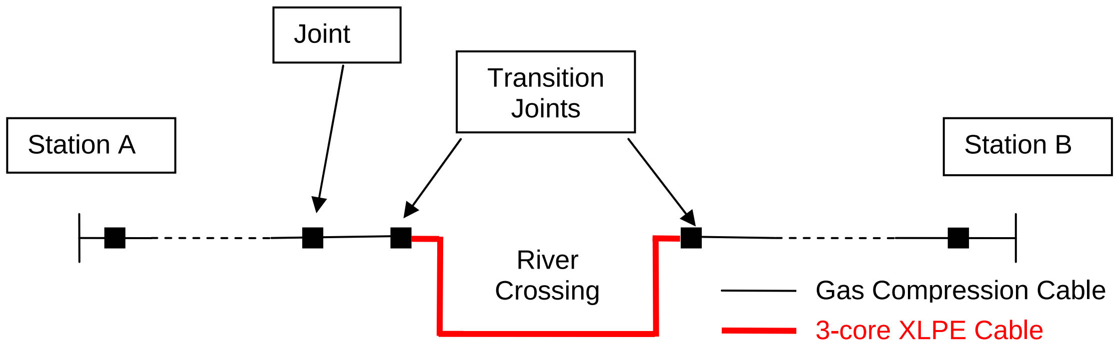


Figure 2 – Circuit schematic following tunnel section replacement

Further problems were experienced after the tunnel repair was completed because of the difficulties in maintaining gas pressure on the section of circuit between the repair location and Station A. This resulted in the circuit being out of service for considerable periods. There were significant costs associated with the efforts to maintain the gas pressure on the circuit. This is unacceptable as it provides an important link in the network. In addition, a new 110kV substation was planned to be connected to this circuit.

Consequently, it was not feasible to maintain this circuit in service and provide an acceptable standard of reliability and therefore it was recommended that the section between the river crossing and Station A be replaced by extending the 3-core XLPE cable from the river crossing to Station A for the following reasons:

- the very bad leak history of the cable particularly the northern section, and the consequent cost, and the disruption caused to work programmes in pumping, finding and repairing leaks, postponing other work dependent on outages.

- there were now two short gas sections north and south of the tunnel, rather than the previous single section over the full length of the cable, means that it is harder to maintain the cable pressure to keep it in service when leaks arise.

- The utility now had experience of pulling in the cable on the most difficult section that we would encounter (i.e. the tunnel), and based on this we know that the remainder of the job should not pose undue difficulty.

- The cost of this replacement cable was not as great as expected because the installation used the original gas pipe and therefore required minimal excavation and reinstatement.

4. Strategic and economic outcome

Although this would require more cabling and jointing work in the short term, it was considered that the payback in terms of reduced disruption and resources in the tasks of pumping and leak location/repair, was justified.

The steps involved were as follows:

1. Break down the existing transition joint at the northern quays and remove.
2. Remove 5 sections of gas compression cable and terminations in Station A.
3. Lay 5 sections of 3-core XLPE cable into refurbished joint bays.
4. Joint and terminate the new cable sections.
5. Commission the circuit.

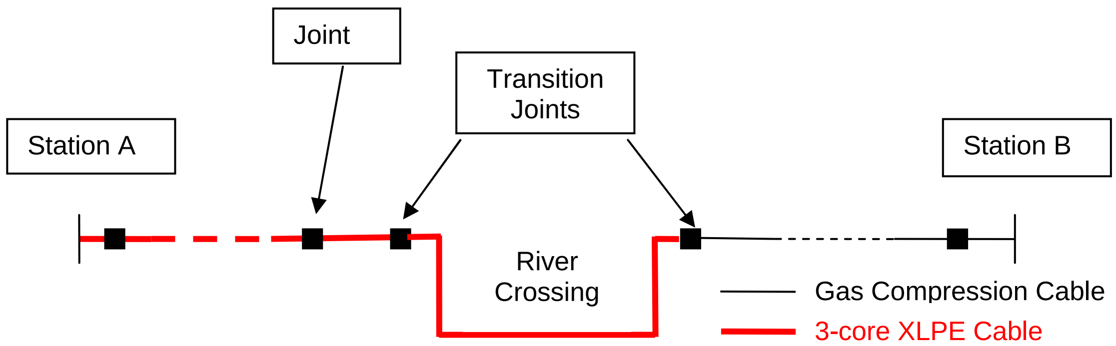


Figure 3 – Circuit schematic showing the current arrangement

It is now proposed to replace the final section of gas compression cable from the river crossing to Station B using a similar process. When this is complete, the entire gas compression cable circuit will have been replaced by 3-core XLPE cable.

Application of Scoring System

QUESTIONNAIRE (SIMPLIFIED APPROACH)		Answer	Score
	Technical Questions		
T1	Has there been more than 1 internal failure in this link in its history ?	No	0
T2	Is the age of this link more than 40 years, and have there been failures on similar links?	No	0
T	*Total Technical Questions*		*0.00*
	Economic Questions		
E1	Are the costs of maintaining and operating this cable route unacceptably high ?	Yes	1
E2	Are the costs of a repair comparable to renew the power cable?	Yes	1
E3	Are the costs of possible penalties and/or claims during an outage unacceptably high?	No	0
E	*Total Economic Questions*		*0.67*
	Strategical Questions		
S1	Is the link critical ?	Yes	1
S2	Is there a safety or environmental risk ?	Yes	1
S	*Total Strategical Questions*		*1.00*
	Weighing factor		
a	Technical (1 < a < 5)	3	
b	Economic (1 < b < 5)	3	
c	Strategical (1 < c < 5)	3	
X	**SCORE TOTAL**		**0.56**

QUESTIONNAIRE (DETAILED APPROACH)		Answer	Score
	Technical Questions		
T1	Is the failure rate of the cable under consideration increasing significantly?	No	0
T2	Is only the failure rate of the reference cable increasing significantly?	No	0
T3	Is the failure rate of the accessories under consideration increasing significantly?	No	0
T4	Is only the failure rate of the reference accessories increasing significantly?	No	0
T5	Is the age of the system between 40 to 60 years?	No	0
T6	Is the system older than 60 years?	No	0
T7	Is there regular fluid/gas leakage along the link?	Yes	2
T8	Is the sheath integrity doubtful?	Yes	2
T9	Is the cable thermally highly loaded or overloaded?	No	0
T10	Is there an increased risk of corrosion for this link?	No	0
T11	For solid insulated cables only: Is the cable system without water barriers and in a wet environment?	No	0
T12	Is the cable subjected to large mechanical forces or vibrations?	No	0
N	Maximum score of the applicable questions for the cable type	*22*	
T	*Total Technical Questions*		*0.18*
	Economic Questions		
E1	Make a life cycle cost comparison of the cable under consideration versus a new cable. Is replacement of the cable the best economical option ?	Yes	1
	Alternative Economic questions used ?	No	
E2	Are the operating and preventive maintenance costs of the cable system unacceptably high?	Yes	0
E3	Are the costs of not delivering power unacceptably high?	No	0
E4	Is there an economic window of opportunity to enhance the circuit?	Yes	0
E5	Are the costs of a repair unacceptably high?	No	0
E	*Total Economic Questions*		*1.00*
	Strategical Questions		
S1	Is there a significant risk of an unsafe situations?	Yes	4

S2	Is there an environmental risk, which disables the use of the cable system under consideration?	No	0
S3	Is the circuit critical in the network?	Yes	1
S4	Is the cable type no longer maintainable and properly repairable?	Yes	1
S5	Is the total time to locate and repair a circuit unacceptable?	Yes	1
S6	Is the cable, joint and termination design no longer appropriate for its operating conditions?	No	0
S7	Is there a window of political opportunity to spend money on this circuit?	No	0
S	*Total Strategical Questions*		*0.64*
	Weighing factor		
a	Technical (1 < a < 5)	3	
b	Economic (1 < b < 5)	3	
c	Strategical (1 < c < 5)	3	
X	**SCORE TOTAL**		**0.61**

Category	Total score	Result of detailed approach
green	0.10	0.00
orange	0.30	0.00
red	0.60	0.61

Case Study No. 5 – Italy

Fluid-Filled Cable

1. Situation

A 220 kV fluid filled cable had been in service for 45 years (since 1954) and installed in a deep shaft /1./. No service failures had occurred. However, the main concern was a possible fluid leak by fatigue stress due mechanical vibrations and thermal cycling and consequent ageing of the lead sheath. In addition, a high fluid pressure was present due to the high difference in level and therefore fluid leakage was of a great concern. No fluid leak had been detected during service.

2. Test Methodology

No methods for measuring the electrical condition of the cable insulation or detection of any fluid leaks, or the condition of the lead sheath were applied.

3. Solution

The fluid-filled cable was replaced by radially water-tight 220 kV XLPE cables. It was not considered any new fluid-filled cables despite the good service experience of this particular cable. It was “decided” that the cable circuits had reached their operating lives based on the fear of possible future fluid leaks.

In the same country there had also been other cases with fragile lead sheaths causing fluid leakage from fluid-filled high voltage cables. It is not known weather the decision for replacement was based on service experience made by other utilities using similar cable circuits, but it is likely.

4. Strategic and economic outcome

The technical end of life had by no means been reached in this case. It was probably expected by experience from other fluid-filled cables that cracks could be formed in the lead sheath causing fluid leaks in this cable within a relatively short time frame.

The economic outcome was that the cost (workmanship) for replacing the cable was low as at the same time the rotating machinery was subjected to special maintenance, as well as all the transformers were replaced. No risk of unwanted shut-down (loss of income from power delivery) of the power station due to cable replacement e.g. after a failure was taken.

Application of Scoring System

QUESTIONNAIRE (SIMPLIFIED APPROACH) - CASE STUDY N°5 - ITALY			
		Answer	Score
	Technical Questions		
T1	Has there been more than 1 internal failure in this link in its history ?	No	0
T2	Is the age of this link more than 40 years, and have there been failures on similar links?	Yes	1
T	*Total Technical Questions*		*0.50*
	Economic Questions		
E1	Are the costs of maintaining and operating this cable route unacceptably high ?	No	0
E2	Are the costs of a repair comparable to renew the power cable?	No	0
E3	Are the costs of possible penalties and/or claims during an outage unacceptably high?	No	0
E	*Total Economic Questions*		*0.00*
	Strategical Questions		
S1	Is the link critical ?	No	0
S2	Is there a safety or environmental risk ?	Yes	1
S	*Total Strategical Questions*		*0.50*
	Weighing factor		
a	Technical (1 < a < 5)	3	
b	Economic (1 < b < 5)	3	
c	Strategical (1 < c < 5)	3	
X	**SCORE TOTAL**		**0.33**

QUESTIONNAIRE (DETAILED APPROACH) - CASE STUDY N°5 - ITALY			
		Answer	Score
	Technical Questions		
T1	Is the failure rate of the cable under consideration increasing significantly?	No	0
T2	Is only the failure rate of the reference cable increasing significantly?	No	0
T3	Is the failure rate of the accessories under consideration increasing significantly?	No	0
T4	Is only the failure rate of the reference accessories increasing significantly?	No	0
T5	Is the age of the system between 40 to 60 years?	Yes	1
T6	Is the system older than 60 years?	No	0
T7	Is there regular fluid/gas leakage along the link?	No	0
T8	Is the sheath integrity doubtful?	Yes	2
T9	Is the cable thermally highly loaded or overloaded?	No	0
T10	Is there an increased risk of corrosion for this link?	Yes	1
T11	For solid insulated cables only: Is the cable system without water barriers and in a wet environment?	No	0
T12	Is the cable subjected to large mechanical forces or vibrations?	Yes	1
N	Maximum score of the applicable questions for the cable type	*22*	
T	*Total Technical Questions*		*0.23*
	Economic Questions		
E1	Make a life cycle cost comparison of the cable under consideration versus a new cable. Is replacement of the cable the best economical option ?	No	0
	Alternative Economic questions used ?	Yes	
E2	Are the operating and preventive maintenance costs of the cable system unacceptably high?	No	0
E3	Are the costs of not delivering power unacceptably high?	No	0
E4	Is there an economic window of opportunity to enhance the circuit?	Yes	1
E5	Are the costs of a repair unacceptably high?	No	0
E	*Total Economic Questions*		*0.14*
	Strategical Questions		

S1	Is there a significant risk of an unsafe situations?	Yes	4
S2	Is there an environmental risk, which disables the use of the cable system under consideration?	Yes	2
S3	Is the circuit critical in the network?	No	0
S4	Is the cable type no longer maintainable and properly repairable?	No	0
S5	Is the total time to locate and repair a circuit unacceptable?	No	0
S6	Is the cable, joint and termination design no longer appropriate for its operating conditions?	No	0
S7	Is there a window of political opportunity to spend money on this circuit?	Yes	1
S	*Total Strategical Questions*		*0.64*
	Weighing factor		
a	Technical (1 < a < 5)	3	
b	Economic (1 < b < 5)	3	
c	Strategical (1 < c < 5)	3	
X	**SCORE TOTAL**		**0.34**

Category	Total score	Result of detailed approach
green	0.10	0.00
orange	0.30	0.34
red	0.60	0.00

Case Study No. 6 – Norway

XLPE Cable Terminations

1. Situation

Several service failures had occurred on fluid filled high voltage XLPE cable terminations with porcelain housing during the late 90’s /2./. This includes cables rated from 52 up to 132 kV. Several modes of failures were detected for the terminations during laboratory examinations (destructive analysis). The main cause for failures was presence of liquid water within the housing causing discharges (surface) leading to catastrophic service failure. This could occur by super-saturation of water vapour in the fluid due to temperature cycling or diffusion of liquid water into the construction by capillary action at boundaries (bad/aged o-rings).

There was a concern of personal safety when operating close to such terminations due to the explosions causing fragments of the construction to be spread over a certain area. Some installations were also close to public area.

2. Test Methodology

Initially it was considered that such installations did not need any maintenance. However, several utility companies started to take fluid samples from the terminations and then measured the water content as well as the breakdown voltage for the same sample. During this measurement campaign several installations were detected having particular high water content (some with presence of liquid water). The fluid in some of the installations was also measured again after some few years.

3. Solution

The fluid was replaced and the o-rings and other aged parts of the installations were also replaced when high water contents on the fluid were measured. No new service failures have occurred after this action.

However, after the occurrence of some severe service failures, some few other companies choose a different solution; they changed all such installations independent of the condition of the terminations.

4. Strategic and economic outcome

The utilities had different approaches; some made decision based on technical end of life criteria, and some made decision based on service experience (made by other companies) without the technical end of life had been reached for the installation.

Most of the utilities made the decision of replacement using a technical end of life criteria based on maintenance / on-site sampling of data. One of the reasons for using this approach was that the number of the actual installations was too high for replacing them all at the same time (high costs). The economic outcome of this was to significantly postpone reinvestment of the "old" installation.

The utilities that replaced all terminations without using any technical end of life criteria had relatively few actual installations. In addition, some of the installations were situated close to a popular public beach. Due to personal safety issues and secondly any economic responsibilities, the risk was considered too high for keeping such installations in service.

Application of Scoring System

QUESTIONNAIRE (SIMPLIFIED APPROACH)			
		Answer	Score
	Technical Questions		
T1	Has there been more than 1 internal failure in this link in its history ?	No	0
T2	Is the age of this link more than 40 years, and have there been failures on similar links?	No	0
T	*Total Technical Questions*		*0.00*
	Economic Questions		
E1	Are the costs of maintaining and operating this cable route unacceptably high ?	No	0
E2	Are the costs of a repair comparable to renew the power cable?	No	0
E3	Are the costs of possible penalties and/or claims during an outage unacceptably high?	No	0
E	*Total Economic Questions*		*0.00*
	Strategical Questions		
S1	Is the link critical ?	Yes	1
S2	Is there a safety or environmental risk ?	Yes	1
S	*Total Strategical Questions*		*1.00*
	Weighing factor		
a	Technical (1 < a < 5)	3	
b	Economic (1 < b < 5)	3	
c	Strategical (1 < c < 5)	3	
X	**SCORE TOTAL**		**0.33**

QUESTIONNAIRE (DETAILED APPROACH)			
		Answer	Score
	Technical Questions		
T1	Is the failure rate of the cable under consideration increasing significantly?	No	0
T2	Is only the failure rate of the reference cable increasing significantly?	No	0
T3	Is the failure rate of the accessories under consideration increasing significantly?	No	0
T4	Is only the failure rate of the reference accessories increasing significantly?	Yes	1
T5	Is the age of the system between 40 to 60 years?	No	0
T6	Is the system older than 60 years?	No	0
T7	Is there regular fluid/gas leakage along the link?	No	0

T8	Is the sheath integrity doubtful?	No	0
T9	Is the cable thermally highly loaded or overloaded?	No	0
T10	Is there an increased risk of corrosion for this link?	No	0
T11	For solid insulated cables only: Is the cable system without water barriers and in a wet environment?	No	0
T12	Is the cable subjected to large mechanical forces or vibrations?	No	0
N	Maximum score of the applicable questions for the cable type	*20*	
T	*Total Technical Questions*		*0.05*
	Economic Questions		
E1	Make a life cycle cost comparison of the cable under consideration versus a new cable. Is replacement of the cable the best economical option ?	No	0
	Alternative Economic questions used ?	Yes	
E2	Are the operating and preventive maintenance costs of the cable system unacceptably high?	No	0
E3	Are the costs of not delivering power unacceptably high?	Yes	2
E4	Is there an economic window of opportunity to enhance the circuit?	Yes	1
E5	Are the costs of a repair unacceptably high?	No	0
E	*Total Economic Questions*		*0.43*
	Strategical Questions		
S1	Is there a significant risk of an unsafe situations?	Yes	4
S2	Is there an environmental risk, which disables the use of the cable system under consideration?	No	0
S3	Is the circuit critical in the network?	Yes	1
S4	Is the cable type no longer maintainable and properly repairable?	No	0
S5	Is the total time to locate and repair a circuit unacceptable?	No	0
S6	Is the cable, joint and termination design no longer appropriate for its operating conditions?	No	0
S7	Is there a window of political opportunity to spend money on this circuit?	No	0
S	*Total Strategical Questions*		*0.45*
	Weighing factor		
a	Technical (1 < a < 5)	3	
b	Economic (1 < b < 5)	3	
c	Strategical (1 < c < 5)	3	
X	**SCORE TOTAL**		**0.31**

Category	Total score	Result of detailed approach
green	0.10	0.00
orange	0.30	0.31
red	0.60	0.00

Case Study No. 7 – Spain

Substitution of 220kV Fluid-Cable Cable by XLPE Cable

1. Situation

This case concerns a 220kV double circuit (line + cable) with an overall length of 9.5 km, of which 4.715 km is underground cables.

One of the circuits is an XLPE cable (451 MVA) and the other one is an fluid filled cable (231 MVA).

The fluid filled cable was directly buried in a trench except for one particular point where the cables are laid inside tubes and protected by concrete over a slab due a tunnel below the line.

A diagram of the circuit is included at the end of this document.

Picture 1: Cables inside tubes and protected by concrete.

The hydraulic circuit of the fluid-filled cable is divided into two parts:

From CLP to EE: 1,925 metres
From EE_6 to OH-VIV: 2,970 metres

The original fluid filled cable had a cross-section of 500 mm^2. At present, and due to several other circumstances, there are parts of the route with different cross-sections:

EN_2-EN_3: There was a change of the route due to the construction of M-40 motorway. 490 m of fluid filled cable 700 mm2 were installed.

EN_9-EN_{10}: There was a change of cable due to a fire in the tunnel. 145 m of fluid filled cable 1,400 mm^2 were installed.

EN_{10}-EN_{11}: There was a change of the route due to a change of site of the substation. 300 m of fluid filled cable 700 mm^2 were installed.

EN_{11}-CPL: There was a large fire in the substation (Nov 2004). 50 m of fluid filled cable 700 mm^2 were installed at the end of 2006 (2 years out of service).

The sheaths are connected directly to earth at both ends of the underground line. There are 11 joint bays, all of which are buried underground and filled with soil along an important street in Madrid. Only one of the joint-bays (EE_6 with the joints that divide the hydraulic circuit) is easily accessible and has expansion deposits for the oil. The street where the cable is laid is a small 2-way street which has a lot of traffic.

Test on the circuit

All the changes mentioned above were made before March 2003.

Before the end of the 2005, there was no evidence of any test made on the line before the commissioning in 1992.

On December 2005 one over-sheath test was done due to work carried out in the surroundings of the cable due to the widening of a tunnel below the line.

Picture 2. Widening of a tunnel below the line.

The result of the test was bad in the three phases with a direct connection between the sheath and earth. We were measuring voltage differences in the area of the work and leakages were not detected in this area.

The circuit was out of service from November 2004 to December 2006 due to a large fire in CPL. Once the substation was re-built and the new cable from E_{11} to CPL were installed, tests for the insulation and for the over sheaths were carried out.

The result of the insulation test was ok but the result of the over-sheath test was wrong in the three phases.

From this point, works to locate the defects of the over sheaths were started, but they were not able to find them and the installation was connected to the grid due to a third part damage in another important line because two important substations were only fed by the XLPE circuit.

Maintenance works

From 1 January 2006, maintenance patrol began to walk along the route of the cables every day from Monday to Friday in order to avoid third part damage. Moreover, once a week, the values of the pressure in the ends of every hydraulic circuit were written down.

Failure

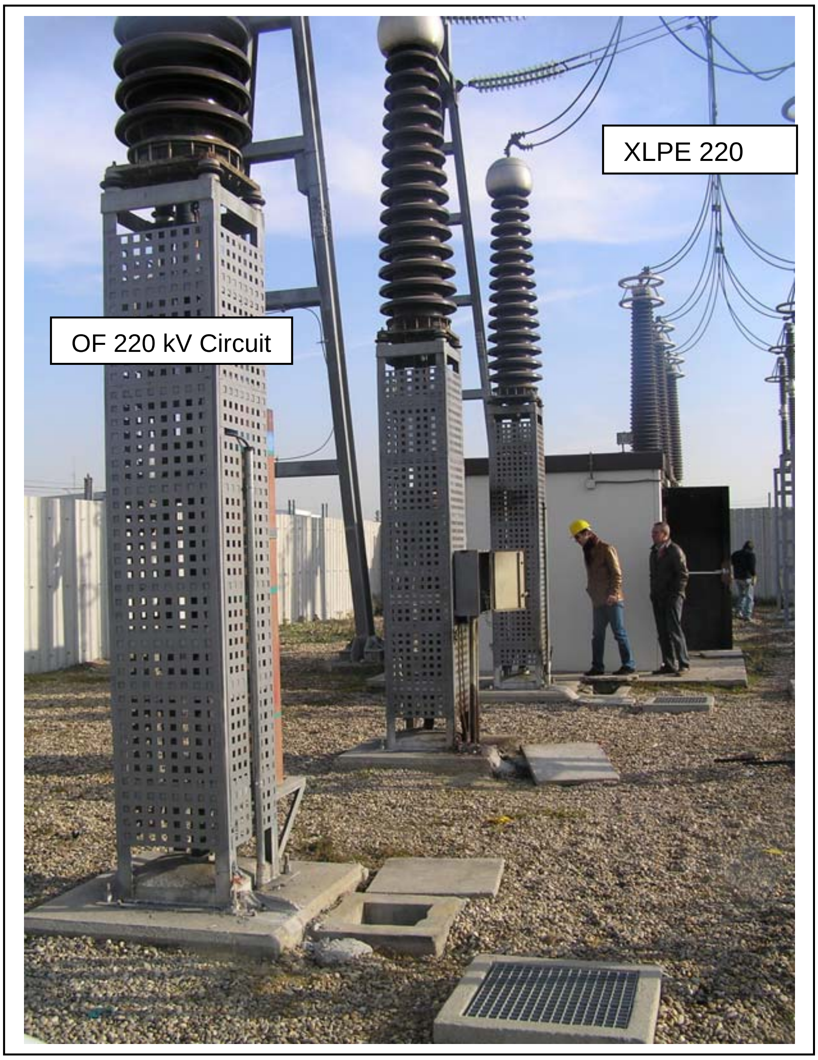
4 January 2007. The pressures were measured and the values of phases T and S had a small pressure reduction in EE_6-CPL from the previous week (0.2 bar).

At 18:25 a person tried to steal the copper connections from the 220 kV surge arrester to the earth and the connections from the terminations of phases R and S to the earth.

At 23:00 there was an alarm in the control system due to a drop in the level of oil pressure

5 January 2007. At 4:13 there was a single-phase short circuit without an automatic connection. At the same time there was an important disturbance in other lines in Madrid with several disconnections, but automatic re-connections.

There was a fire in the relay room and the second circuit was disconnected for security reasons.



Picture 3: OH-VIV. Transition from underground cable to overhead line.

The pressures in the cable were measured again and in EE_6 – OH-VIV the values were ok, but in EE_6 – CPL there was no pressure in phases S and T. Phase R had the same pressure as the previous day.

The second circuit was connected again when the earth connections were installed.

Damages

The measures of the cable show that there were oil leakages in S and T phases in the hydraulic section EE_6 – CPL

More measures:

Phase S:

The cable was completely broken in EN_8.

The cable was frozen in EN_8 and EN_9 and there was, at least, other leakages in EN_9 – CPL. The exact location was not know, but it was not in EN_{10} and EN_{11} because both bay-joints were opened.

Phase T:

Cable was frozen in EN_9 and one leakage, at least, was detected in EN_9 – EE_6
Cable was frozen in EN_8 and electric test was carried out to try to locate the defect. At least other two defects were detected in EN_8 – EN_9 and EN_8 – EE_6
When EN_8 was opened, further damage in the over sheath of T phase was detected.

Phase R:

This phase was apparently ok at the beginning of the works, but after the day of the incident there was a decrease in the pressure and a leakage of 5.7 litres/day was estimated.

Based on all the test and works carried out, it was possible to assure that there are leakages in all the phases. At least there are 4 more, but it is not possible to say how many there are. At the beginning two possible leakages were suspected but after one month working, there were 6 leakages, at least. It was assumed that if location and reparation works continue the number of defects increase. One month later, it was not possible confirm how many leakages and defects the line had.

The oil poured was around 6.500 litres having taken into account the big leakages of phases S and T and the oil injected to try to locate the leakages. The contaminated land and part of the oil were extracted and carried to an authorised disposal point.

On 8 March 2007, after 2 months, works stopped. Two defects were found and repaired (new cable and two new joints), but there were, at least 4 other defects. It was impossible to establish the time needed to repair.

During these two months €1M was spent.

2. Test Methodology

- The link is considered very important. During the first two months distributor companies with substations connected (directly or close related) with this line were worried about a possible failure in another line. Mobile substations were installed in order to prevent possible failures.

- The time needed to completely repair the failure was not known, as was the previous state of the line; therefore it was not easy to evaluate the state of the line. Otherwise, it was clear that the short circuit badly affected the cable. After two months working only two defects were clearly detected and repaired. The area were the works were carried out was a complicated area, due to the heavy traffic in the street, and the secure zone surrounding the area. The traffic problem in the city was another important inconvenience. The main problem was that it was not possible to say how much time was required to repair the link.

- During the 2 month period 1 M€ were spent in repairs and it was not possible to know how much money would be necessary to completely repair the link and what would be the real state of the link once repaired. What is possible though, is to estimate the money needed to install a new cable.

- The ampacity of the link is 231 MVA, very small (half) compared with new standard underground cables installed in Madrid (Cu 2000). So it was a good opportunity to increase the ampacity of the cable.

- Change of technology. All the new installations are based on standardised systems, in other to reduce the maintenance and spare costs. Moreover, fluid filled cables are not well accepted in urban areas due to possible leakages and contamination.

- There is a project to increase the length of the cable by 1 km more, due to the construction of new buildings. The new cable will be XLPE, and it will be necessary to maintain the area in order to connect fluid filled cable (4.7 km) with the new xlpe cable (1 km more). If all the line is removed, it would be no necessary to maintain the area to connect fluid filled cable with xlpe cable through an overhead connection.

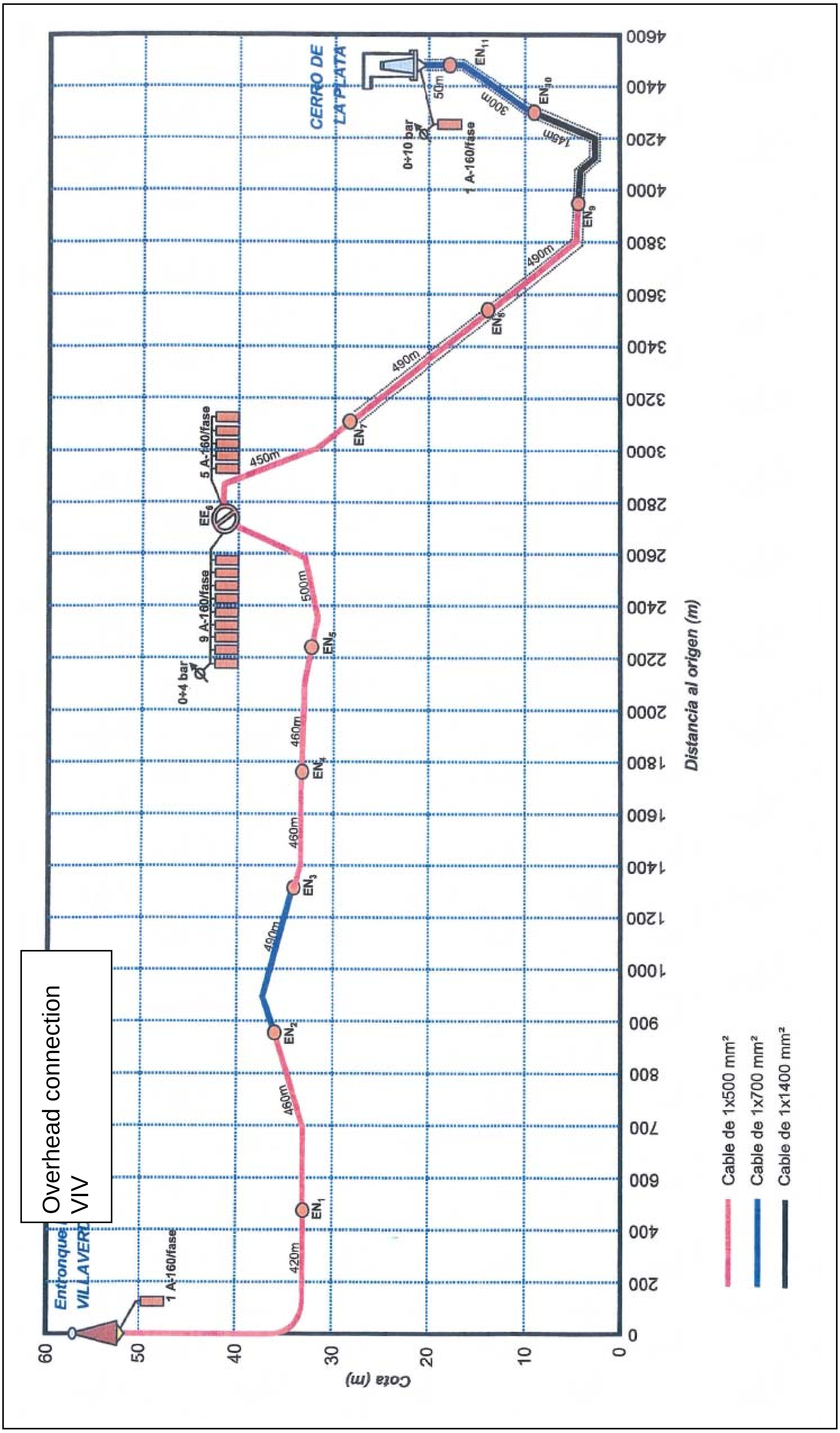
3. Solution

According the analysis made in the previous point, the fluid filled cable was replaced by radially water-tight 220 kV XLPE cable.

4. Strategic and economic outcome

There are important strategic and economic issues in this case. The strategic point was that there was an opportunity to increase the capacity of the link that was very interesting and necessary for the network.
The economic aspect was that the cost of the repair was becoming significantly high, compared with the replacement of the link. Of course they are not the same, but it was more interesting to change the installation in order to have a new link. Moreover, the ampacity of the new

cable is bigger than the old one, and the new technology is according with the new standards.



Application of Scoring System

QUESTIONNAIRE (SIMPLIFIED APPROACH)		Answer	Score
	Technical Questions		
T1	Has there been more than 1 internal failure in this link in its history ?	No	0
T2	Is the age of this link more than 40 years, and have there been failures on similar links?	No	0
T	*Total Technical Questions*		*0.00*
	Economic Questions		
E1	Are the costs of maintaining and operating this cable route unacceptably high ?	No	0
E2	Are the costs of a repair comparable to renew the power cable?	Yes	1
E3	Are the costs of possible penalties and/or claims during an outage unacceptably high?	No	0
E	*Total Economic Questions*		*0.33*
	Strategical Questions		
S1	Is the link critical ?	Yes	1
S2	Is there a safety or environmental risk ?	Yes	1
S	*Total Strategical Questions*		*1.00*
	Weighing factor		
a	Technical (1 < a < 5)	3	
b	Economic (1 < b < 5)	3	
c	Strategical (1 < c < 5)	3	
X	**SCORE TOTAL**		**0.44**

QUESTIONNAIRE (DETAILED APPROACH)		Answer	Score
	Technical Questions		
T1	Is the failure rate of the cable under consideration increasing significantly?	No	0
T2	Is only the failure rate of the reference cable increasing significantly?	No	0
T3	Is the failure rate of the accessories under consideration increasing significantly?	No	0
T4	Is only the failure rate of the reference accessories increasing significantly?	No	0
T5	Is the age of the system between 40 to 60 years?	No	0
T6	Is the system older than 60 years?	No	0
T7	Is there regular fluid/gas leakage along the link?	Yes	2
T8	Is the sheath integrity doubtful?	Yes	2
T9	Is the cable thermally highly loaded or overloaded?	No	0
T10	Is there an increased risk of corrosion for this link?	Yes	1
T11	For solid insulated cables only: Is the cable system without water barriers and in a wet environment?	No	0
T12	Is the cable subjected to large mechanical forces or vibrations?	Yes	1
N	Maximum score of the applicable questions for the cable type	*20*	
T	*Total Technical Questions*		*0.30*
	Economic Questions		
E1	Make a life cycle cost comparison of the cable under consideration versus a new cable. Is replacement of the cable the best economical option ?	No	0
	Alternative Economic questions used ?	Yes	
E2	Are the operating and preventive maintenance costs of the cable system unacceptably high?	Yes	2
E3	Are the costs of not delivering power unacceptably high?	Yes	2
E4	Is there an economic window of opportunity to enhance the circuit?	Yes	1
E5	Are the costs of a repair unacceptably high?	Yes	2
E	*Total Economic Questions*		*1.00*
	Strategical Questions		
S1	Is there a significant risk of an unsafe situations?	Yes	4

S2	Is there an environmental risk, which disables the use of the cable system under consideration?	Yes	2
S3	Is the circuit critical in the network?	Yes	1
S4	Is the cable type no longer maintainable and properly repairable?	No	0
S5	Is the total time to locate and repair a circuit unacceptable?	Yes	1
S6	Is the cable, joint and termination design no longer appropriate for its operating conditions?	No	0
S7	Is there a window of political opportunity to spend money on this circuit?	Yes	1
S	*Total Strategical Questions*		*0.82*
	Weighing factor		
a	Technical (1 < a < 5)	3	
b	Economic (1 < b < 5)	3	
c	Strategical (1 < c < 5)	3	
X	**SCORE TOTAL**		**0.71**

Category	Total score	Result of detailed approach
green	0.10	0.00
orange	0.30	0.00
red	0.60	0.71

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10. Conclusions

Conclusions

The subject of Remaining Life Estimation has kept the technical world busy for a long time. If so much knowledge has been collected over the past decades about ageing and degradation, would it then not be possible to predict end of life accurately? That seems to be a reasonable question; however, the answer cannot be given easily. It does not need explanation that the capability of predicting end of life is considered to be extremely valuable, not only technically, but rather economically. If one can predict end of life, all technical secrets are obviously uncovered and it would prove the superiority of the technical world to have reached such a milestone. Additionally, the related financial benefits would be attractive too and it would bridge the technical and the economical worlds and make them cooperate effectively for ever.

What are the present facts when focussing on the subject of Remaining Life on HV cables? Just after starting the job in 2005, the working group issued a questionnaire asking the utilities about details on the subject of Remaining Life Policy of the company. One of the surprising conclusions was that the utilities are only interested in Remaining Life of power cables as far as it concerns the exchange management of power cables. That means the average utility does not want to know when the end of life of a particular cable or cables is reached technically, but wants to know what the right time is to exchange that particular cable or cables? That is a different question. For that last decision there are not only technical criteria but also economical and strategic criteria needed. The utility wants guidance in the process of exchanging a cable or cables using the different criteria in a balanced way.

The same situation is true for Remaining Life of automobiles. Almost nobody (except owners of vintage cars) is really interested in the technical end of life as a criterion for exchanging the car. The car is usually exchanged based on other criteria like costs, fashion or technical improvements mostly related to safety issues. The car owner is usually successful when he is able to converge the different criteria to a balanced decision.

The WG prepared this report about Remaining Life in a more or less similar way. The idea to fully understand ageing and degradation of cable insulation was given up. Not only because there is at present not enough knowledge available, but rather because it is unnecessary with a view to the present purpose of Remaining Life Management for HV cables, as explained above. The change of title from Remaining Life Estimation to Remaining Life Management is symbolic for the change in considering this subject. There does not seem to be an immediate need for more knowledge, however there is a strong need for guidance to deal with the subject of remaining life in a practical way focussed on the exchange policy of cables.

What has been accomplished? The main part of the report is undoubtedly the Remaining Life Methodology and the related Practical Guidelines to Estimate the Remaining Life. In the chapters 5 and 6 it is explained that there is not enough statistical data available on the failure behaviour of cables and on the ageing processes that may play a part in cables. However as for RL, not only is technical information needed, but also economical and strategic data are of importance; the combination of such different data is the solution the WG offers the user to manage remaining life. The methodology is based on evaluating the technical, economical and strategic aspects involved in separate sections, consisting of a simplified approach and a detailed approach. The evaluation happens by answering questions and receiving related scores. The sum of individual scores for a particular section contributes to the total score and the related classification or recommendation.

The simplified approach is used to determine quickly on which cables most of the attention should be focussed. Quite often the conclusion of the simplified approach is that there does not seem to be anything wrong with the cable. However if there is any doubt, then it is recommended to follow the detailed approach to receive the right information. The detailed approach has the ultimate purpose to categorize the cable circuits in three groups:no immediate action needed, e.g. RL >10y (Green light), particular action needed, e.g. RL between 1-10y (Orange light) and immediate action needed, e.g.RL< 1y (Red light)

Next to the methodology and practical guidelines, the WG also collected information on so called international case studies on RL, in Chapter 8. In those cases, it is demonstrated how RL Management works in practice and what the results are if the methodology described is being applied on those cases.

Finally in this report attention has been paid not only to methods to indicate RL, but also attention has been paid in Chapter 7 to a number of actions to extend life. Because if a cable is in a critical position with respect to remaining life (red light), the cable can be exchanged or can be treated in such a way that life is extended .The red light will then be converted into orange or even green light. As many of the life extension actions are depending on the cable type, those actions are in the report separately specified per cable type.

What actions can be expected in the future. The WG recommends to use this guide for the next 5 years, collecting experience. After that 5 year period the results should be evaluated and with a view to progress on basic parts of the guide (for instance failure statistics) the guide can be adapted to the developments and make it more suitable for effective use.

Appendix 1 Questionnaire

Appendix 1: Detailed results of the questionnaire on the existing end of life strategies for high voltage power cable systems

In this appendix the issued questionnaire and the average results on the questions are presented. Details are given about how the results were obtained from the answers received.

General data:
The questionnaire was issued to utilities worldwide via the working group's members and corresponding members and via the members of Study Committee B1. In total, 43 utilities responded to the high voltage (>50 kV) questions and 37 utilities responded to the medium voltage (< 50 kV) questions. Subsequently, the results were analysed and it was decided to use rather straightforward averaging procedures to obtain generalised results.

The original reason to state questions both for high voltage as well as for medium voltage cables is to be able to compare these two groups, knowing that reliable failure statistics for high voltage cables are very difficult to obtain (because of the small group size). However, it was later decided by the working group not to relate the two groups of cables because of obvious difficulties in the interpretation of the results, although there are technical similarities between high voltage and medium voltage cables with regard to degradation, maintenance and remaining life.

The following questionnaire (excluding introductory texts) was distributed. The answers are provided in blue italic writing, directly following the concerning question.

Questionnaire:

<table>
<tr><td>1</td><td>What is the size of your utility?

• amount of MWh sold in a year</td><td>MWh
Sizes range between 15 and 522,000 GWh. The average utility size is 75,000 GWh.</td></tr>
<tr><td>2</td><td>What is the extent of your network?
Note 1: MV means voltages > 3 kV, < 50 kV.

Note 2: HV means voltages > 50 kV.</td><td><table><tr><td colspan="3">Length per voltage class</td></tr><tr><td colspan="3">Overhead lines</td></tr><tr><td>HV AC</td><td>Between 0 and 99,458 Total: 544,250</td><td>ckm</td></tr></table></td></tr>
</table>

<table>
<tr>
<td></td>
<td>

total length of HV AC <u>overhead lines</u>
total length of MV AC <u>overhead lines</u>

total length of HV AC <u>power cables</u>
total length of MV AC <u>power cables</u>

</td>
<td>
<table>
<tr><td>MV AC</td><td>Between 0 and 234,000. Total: 1,191,749</td><td>ckm</td></tr>
<tr><td colspan="3">Power cables</td></tr>
<tr><td>HV AC</td><td>Between 12 and 7,899. Total: 28,496</td><td>ckm</td></tr>
<tr><td>MV AC</td><td>Between 7 and 141,000. Total: 426,656</td><td>ckm</td></tr>
</table>
ckm = circuit kilometer

Adding and averaging all stated numbers gives the percentage of underground cables:
HV: 5 % underground cables
MV: 26 % underground cables
</td>
</tr>
<tr>
<td>3</td>
<td>
Which HV cable types are used in your network?
Note: HV means voltages > 50 kV.

SCFF (self contained fluid filled)
SCFF including PPL (polypropylene paper laminate)
HPFF (high pressure fluid filled)
GP (gas pressure)
XLPE insulated cables
PE insulated cables

Other, please specify:
</td>
<td>
<table>
<tr><td colspan="3">Length per cable type</td></tr>
<tr><td>SCFF</td><td>31.7 %</td><td>ckm</td></tr>
<tr><td>SCFF (PPL)</td><td>3.0 %</td><td>ckm</td></tr>
<tr><td>HPFF</td><td>2.8 %</td><td>ckm</td></tr>
<tr><td>GP</td><td>1.7 %</td><td>ckm</td></tr>
<tr><td>XLPE</td><td>59.9 %</td><td>ckm</td></tr>
<tr><td>PE</td><td>0.3 %</td><td>ckm</td></tr>
</table>
ckm = circuit kilometer

<table>
<tr><td>EPR</td><td>0.3 %</td><td>ckm</td></tr>
<tr><td>Screened belted PILC</td><td>0.2 %</td><td>ckm</td></tr>
<tr><td>Belted PILC</td><td>0.2 %</td><td>ckm</td></tr>
<tr><td>GIL</td><td>0.0 %</td><td>ckm</td></tr>
</table>
Note that the 'other' cable types are given by the utilities. GIL is 8.1 ckm, but 0.0 % of the total.
</td>
</tr>
<tr>
<td>4</td>
<td>
Which MV cable types are used in your network?
Note: MV means voltages > 3 kV, < 50 kV.

Belted paper insulated cable
Screened paper insulated cable

</td>
<td>
<table>
<tr><td colspan="3">Length per cable type</td></tr>
<tr><td>Belted PILC</td><td>22.2 %</td><td>ckm</td></tr>
</table>
</td>
</tr>
</table>

<table>
<tr>
<td></td>
<td>

SCFF (self contained fluid filled)
XLPE insulated cables
PE insulated cables
PVC insulated cables

Other, please specify:
</td>
<td>
<table>
<tr><td>Screened PILC</td><td>36 %</td><td>ckm</td></tr>
<tr><td>SCFF</td><td>0.6 %</td><td>ckm</td></tr>
<tr><td>XLPE</td><td>33 %</td><td>ckm</td></tr>
<tr><td>PE</td><td>2.9 %</td><td>ckm</td></tr>
<tr><td>PVC</td><td>1.4 %</td><td>ckm</td></tr>
</table>
ckm = circuit kilometer
<table>
<tr><td>GP</td><td>0.1 %</td><td>ckm</td></tr>
<tr><td>Submarin e</td><td>0.0 %</td><td>ckm</td></tr>
<tr><td>EPR</td><td>3.8 %</td><td>ckm</td></tr>
<tr><td>HPFF</td><td>0.0 %</td><td>ckm</td></tr>
</table>
Note that the ‘other’ cable types are given by the utilities. Submarine is 59.9 ckm, but 0.0% of the total. HPFF is 6.5 ckm, but 0.0% of the total.
</td>
</tr>
<tr>
<td>5</td>
<td>
What causes of (potential) failure of <u>paper insulated cables</u> (not accessories) are dominant in your network?
Note 1: failure means the unforeseen termination of the ability of a cable to transport energy
Note 2: only paper insulated cables (PILC, SCFF, HPFF, GP) are considered, not extruded cables (XLPE, PE, EPR) or overhead lines

third party damage and other exterior failure causes as switching, lightning, et cetera.
overloading
ageing
oil leakage

Other, please specify:
</td>
<td>
<table>
<tr><td>Cause</td><td>HV [%]</td><td>MV [%]</td></tr>
<tr><td>1</td><td>67 %</td><td>51 %</td></tr>
<tr><td>2</td><td>0 %</td><td>3 %</td></tr>
<tr><td>3</td><td>11 %</td><td>29 %</td></tr>
<tr><td>4</td><td>12 %</td><td>8 %</td></tr>
<tr><td>Other</td><td>9 %</td><td>9 %</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>TOTAL:</td><td>100 %</td><td>100 %</td></tr>
</table>
Please fill in this table so that in total 100 % of all failures in paper insulated cables is accounted for
Other causes mentioned (several answers): poor installation, manufacturing, construction, operation. Mentioned once: gas leakage, corrosion and soil subsidence Same for HV and MV.
</td>
</tr>
</table>

<table>
<tr>
<td>6</td>
<td>
What causes of (potential) failure of <u>extruded cables</u> (not accessories) are dominant in your network?

Note 1: failure means the unforeseen termination of the ability of a cable to transport energy

Note 2: only extruded cables (XLPE, PE, EPR) are considered, not paper insulated cables (PILC, SCFF, HPFF, GP) or overhead lines

1. third party damage and other exterior failure causes as switching, lightning, et cetera.
2. overloading
3. ageing
4. water treeing
Other, please specify:

• Manufacturing defect
</td>
<td>
<table>
<tr><td>Cause</td><td>HV [%]</td><td>MV [%]</td></tr>
<tr><td>1</td><td>65 %</td><td>51 %</td></tr>
<tr><td>2</td><td>2 %</td><td>3 %</td></tr>
<tr><td>3</td><td>7 %</td><td>17 %</td></tr>
<tr><td>4</td><td>13 %</td><td>16 %</td></tr>
<tr><td>Other:</td><td>13 %</td><td>13 %</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>TOTAL:</td><td>100 %</td><td>100 %</td></tr>
</table>
Please fill in this table so that in total 100 % of all failures in extruded cables is accounted for

Other causes mentioned: poor installation, manufacturing, construction (several answers). Soil subsidence mentioned once. Same for HV and MV.
</td>
</tr>
<tr>
<td>7</td>
<td>
Regarding the total number of failures, how many failures occur per year?

• in underground cables (both paper and extruded types)?
• in joints of underground cables?
• in terminations of underground cables?

There is a problem with this question. Some utilities probably stated faults per 100 km per yr and others mentioned absolute numbers. These can’t be matched with each other in a simple way; therefore, the results are given in percentages, which are invariant under the differences mentioned.
</td>
<td>
<table>
<tr><td></td><td colspan="2">Number of failures</td></tr>
<tr><td></td><td>HV</td><td>MV</td></tr>
<tr><td>Cables</td><td>46 %</td><td>58 %</td></tr>
<tr><td>Joints</td><td>28 %</td><td>26 %</td></tr>
<tr><td>Termi-nations</td><td>26 %</td><td>16 %</td></tr>
</table>
Note that cables seem to fail more often than accessories. Although this is strongly related to the country of the respective utility, this is the average outcome of the questionnaire.
</td>
</tr>
</table>

<table>
<tr>
<td>8</td>
<td>What maintenance strategy is used?
3 <u>Note: answer by erasing the inappropriate answers</u>

1. corrective maintenance (repair or replace failed items)
2. time based maintenance (maintain according to a predetermined time schedule)
3. condition based maintenance (maintain according to the present condition of the component)
Other, please specify:</td>
<td>Most utilities answered this question with more than one answer. To provide insight in the results, the table below is given:

<table>
<tr><th>Strategy</th><th>HV</th><th>MV</th></tr>
<tr><td>1+2</td><td>5 %</td><td>3 %</td></tr>
<tr><td>2+3</td><td>18 %</td><td>17 %</td></tr>
<tr><td>1+3</td><td>21 %</td><td>33 %</td></tr>
<tr><td>1+2+3</td><td>26 %</td><td>17 %</td></tr>
<tr><td>1 only</td><td>21 %</td><td>31 %</td></tr>
<tr><td>2 only</td><td>5 %</td><td>0 %</td></tr>
<tr><td>3 only</td><td>3 %</td><td>0 %</td></tr>
</table></td>
</tr>
<tr>
<td>9</td>
<td>Regarding a cable replacement program:
4 <u>Note: answer by erasing the inappropriate answers</u>

• Is there a plan according to which cables are replaced by new cables?
• At what age do cables appear in the replacement program? (When this depends on the cable type, please specify this age per cable type)</td>
<td>51% of the utilities answered this question with “yes”.

About 15 utilities provided ages, 4 utilties stated that it depended on a condition assessment.

Ages stated in general range in between 30 to 70 years, with 40 as the most mentioned.

Ages stated for a particular type are:
- XLPE: 15-80 years, typical answer: 40 years.
- Paper cable: 20 to 50 years, typical answer: 50 years.
- GP cable: typical answer 40 years.</td>
</tr>
</table>

<table>
<tr>
<td>10</td>
<td>What decision criteria are being used to replace old HV cables?

technical
(cable does not fulfill technical criteria anymore)
economical
(it costs too much money to remain in service)
environmental
(cable type is not allowed anymore because of environmental issues)
strategical
(company decision because of other reasons)

A combination of technical and economical criteria can be that cables are replaced when there are too many failures per year in a single cable route. Is this approach used in your utility?</td>
<td>
<table>
<tr><td colspan="6">High voltage
Note: mark with ‘X’</td></tr>
<tr><td></td><td>never</td><td>sometimes</td><td>regularly</td><td>frequently</td><td>always</td></tr>
<tr><td>tech</td><td colspan="5">3.6</td></tr>
<tr><td>econ</td><td colspan="5">2.8</td></tr>
<tr><td>envir</td><td colspan="5">1.6</td></tr>
<tr><td>strat</td><td colspan="5">2.2</td></tr>
<tr><td colspan="6">Medium voltage</td></tr>
<tr><td>tech</td><td colspan="5">3.6</td></tr>
<tr><td>econ</td><td colspan="5">2.6</td></tr>
<tr><td>envir</td><td colspan="5">1.4</td></tr>
<tr><td>strat</td><td colspan="5">2.5</td></tr>
</table>

About two third of the utilities answered this question (left) with “yes”. The number of failures per year in a single cable route is typically 3 to 4, although the answers differ very much from each other.

Note: the table could only be marked with “x”. When ‘never’ has a score of 1 and ‘always’ a score of 5, the average score is given as the averaged result on this question.
</td>
</tr>
</table>

11

How do you assess the technical condition of power cables?

5 <u>**Note: answer by erasing the inappropriate answers**</u>

- via diagnostic tests
  - DC or AC test
  - tan delta test
  - PD test
  - material test
  - other, please specify below
- via laboratory tests
  - on aged cable samples
  - on faulted cables
- via desk studies
  - determining cable loading
  - determining cable ageing and cable condition roughly
  - using degradation process models

Other, please specify:

HV	*MV*
49 %	*54 %*
33 %	*27 %*
26 %	*38 %*
21 %	*19 %*
33 %	*27 %*
44 %	*38 %*
56 %	*57%*
33 %	*33 %*
33 %	*33 %*
14 %	*16 %*

Mentioned under others more than once: DGA, DS, TAI+PD, leakage current, isothermal relaxation current method, residual charge measurement.

<table>
<tr>
<td>12</td>
<td>What <u>paper insulated cable</u> failure behavior do you expect in your network in the future if there would be no replacement program?

6 <u>Note 1: answer by erasing the inappropriate answers</u>
Note 2: only paper insulated cables (PILC, SCFF, HPFF, GP) are considered, not extruded cables (XLPE, PE, EPR) or overhead lines

• number of failures low and constant in time
• number of failures rising linear with time
• number of failures rising exponential with time
Why, please specify: adopted above and will be reviewed if the failure behaviour changes</td>
<td><table>
<tr><td>HV</td><td>MV</td></tr>
<tr><td>57 %</td><td>47 %</td></tr>
<tr><td>30 %</td><td>41 %</td></tr>
<tr><td>14 %</td><td>13 %</td></tr>
</table>
This question is answered in many different ways. In general, the utilities expecting a low and constant to linear future failure behavior refer to experiences so far and utilities expecting an increasing to exponential failure behavior refer to increased loading and sheath problems inducing failures as well as to reaching the end of a bathtub curve.</td>
</tr>
</table>

<table>
<tr><td>13</td><td>What <u>extruded cable</u> failure behavior do you expect in your network in the future if there would be no replacement program?

7 <u>Note 1: answer by erasing the inappropriate answers</u>
Note 2: only extruded cables (XLPE, PE, EPR) are considered, not paper insulated cables (PILC, SCFF, HPFF, GP) or overhead lines

• number of failures low and constant in time
• number of failures rising linear with time
• number of failures rising exponential with time
Why, please specify: experience to date supports this with water treed cable</td><td><table><tr><td>HV</td><td>MV</td></tr><tr><td>36 %</td><td>34 %</td></tr><tr><td>40 %</td><td>38 %</td></tr><tr><td>24 %</td><td>28 %</td></tr></table>
This question is also answered in many different ways. In general, the utilities with cables with water trees expect an increasing to exponential failure behavior and overall, utilities seem to be more pessimistic compared with Q12 because of a lack of knowledge.</td></tr>
<tr><td>14</td><td>Need for more knowledge / information:

8 <u>Note: answer by erasing the inappropriate answers</u>

• Is there a need to assess the technical condition of cables better (related to question 11)?
• Is there a need to better understand degradation processes?
• Is there a need to assess the economical, environmental or strategic issues better (related to question 10)?
• Is there a need for a remaining life estimation procedure for power cables?

If you answer the last question with</td><td><table><tr><td>HV</td><td>MV</td></tr><tr><td>90 %</td><td>94 %</td></tr><tr><td>90 %</td><td>91 %</td></tr><tr><td>76 %</td><td>74 %</td></tr><tr><td>98 %</td><td>100 %</td></tr></table>
A ‘no’ answering utility (1 out of 2) stated: “We do not perceive a threat of large scale cable failure, therefore, info value is considered very low, consequently this info should not cost much”</td></tr>
</table>

	'no', please state why:	
15	Regarding the remaining life estimation for power cables: • How important is this issue for your utility? • What do you want to be improved / made available for practical use? (please use space below) *To be improved / made available:* - *Practical remaining life estimation method to determine reinvestment moments* - *Simplified end of life estimation model* - *Program to determine which links to focus on* - *Practical guide to estimate risk of failure* - *PC program that helps to estimate RL also in case of little available data* - *Better diagnostic tests* - *Remaining life field test* - *Program estimating RL via the cable database of a utility* - *Table with standard lifetimes* - *Accumulation of failure data*	*70 % (MV) to 86 % (HV) answered this question with "very important" or "specially important" etc* -

Appendix 2 Survey of Cable and Accessories

SURVEY OF CABLES AND ACCESSORIES IN THE SCOPE OF THIS WORK :

For a detailed description of accessories, refer to the CIGRE WG 21-06 work published in the technical brochure nb 89 (1994) and 177 (2001).

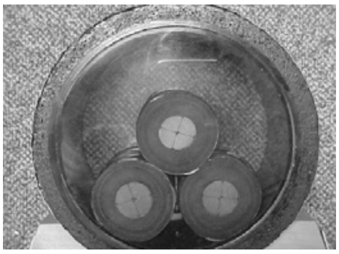
CABLES
There are mainly three type of cables :

<u>Self contained oil filled cables (SCOF):</u>

They usually consist of (from centre to outside):

- An oil duct
- A conductor (copper or aluminium)
- A conductor screen (lapped conductive paper)
- An insulation (lapped insulating paper)
- An insulation screen (lapped conductive paper)
- A metallic shield (extruded lead alloy or aluminium)
- A reinforcement (metallic tapes)
- An outer protective sheath.

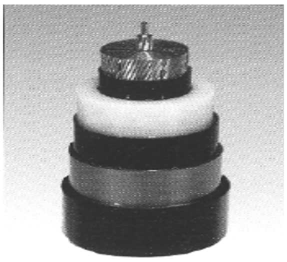
Pipe type cables :



Three cables are immersed together in a metallic pipe that is filled with oil under high pressure.
Each cable usually consist of (from centre to outside) :

- A conductor
- A conductor screen (lapped conductive paper)
- An insulation (lapped insulating paper)
- An insulation screen (lapped conductive paper)
- A composite metal shield and metallised mylar tape
- Skid wires

Synthetic cables

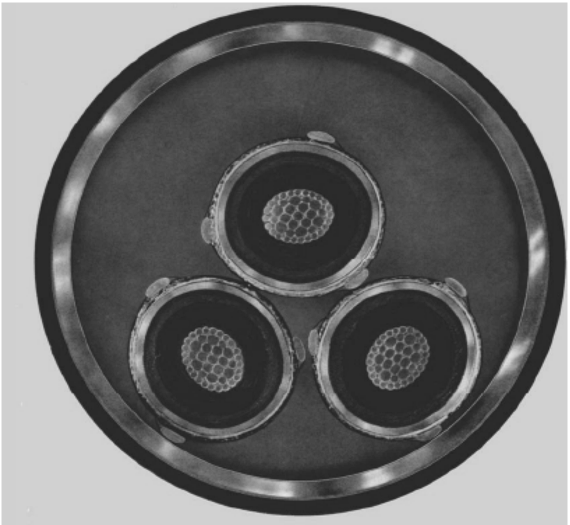


They usually consist of :

- A conductor (copper or aluminium)
- A conductor screen (extruded conductive polymer compound)
- An insulation (EPR, HDPE, LDPE or XLPE)
- An insulation screen (extruded conductive polymer compound)
- A metallic screen/shield
- An outer protective sheath (extruded polymer compound).

Gas pressurised cables

Gas insulated cables are used up to 132kV.



110 kV gas pressurised cables from the 1950

Three cables are immersed together in a metallic pipe that is filled with GAS under high pressure.

Each cable usually consist of (from centre to outside) :

- A conductor
- A conductor screen (lapped conductive paper)
- An insulation (lapped insulating paper)
- An insulation screen (lapped conductive paper)
- A lead metal shield and metallised mylar tape
- Skid wires

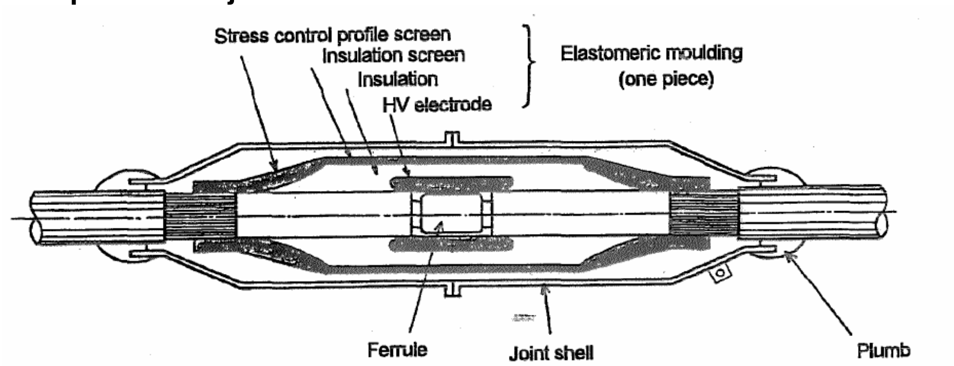
Type of joints :

Straight joint

They joint two cables together, ensures the continuity of all cables constituents.

Examples of straight joints :

One price premolded joint

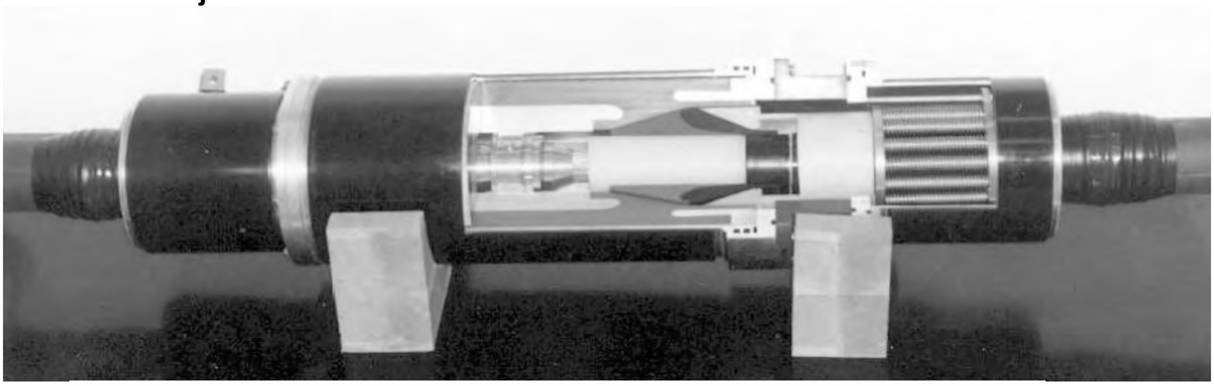


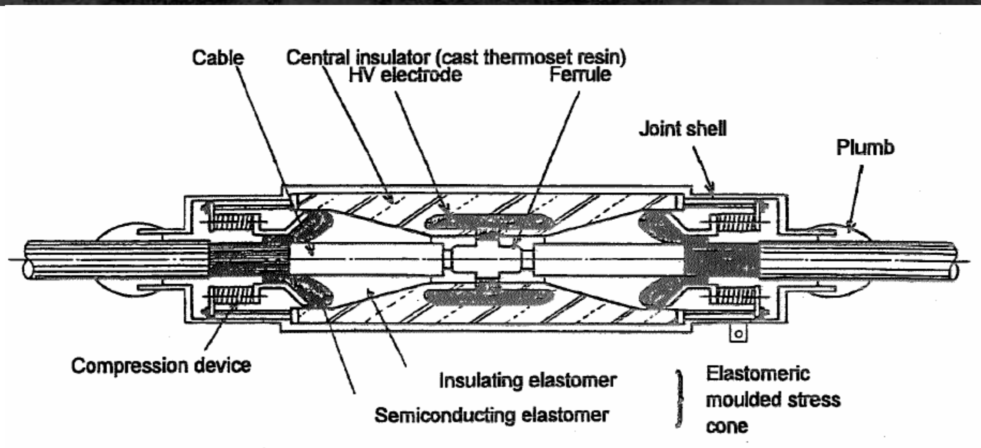
One piece premolded straight joint between two XLPE cables.

The one piece premolded joint consists of:

- A conductor connection ferrule
- A one piece dielectric body in elastomer. This body includes semi-conductive parts to extend the equipotential lines from the main cable to the body insulation
- A connection between the screens of the two cables
- A protection box.

Prefabricated joint



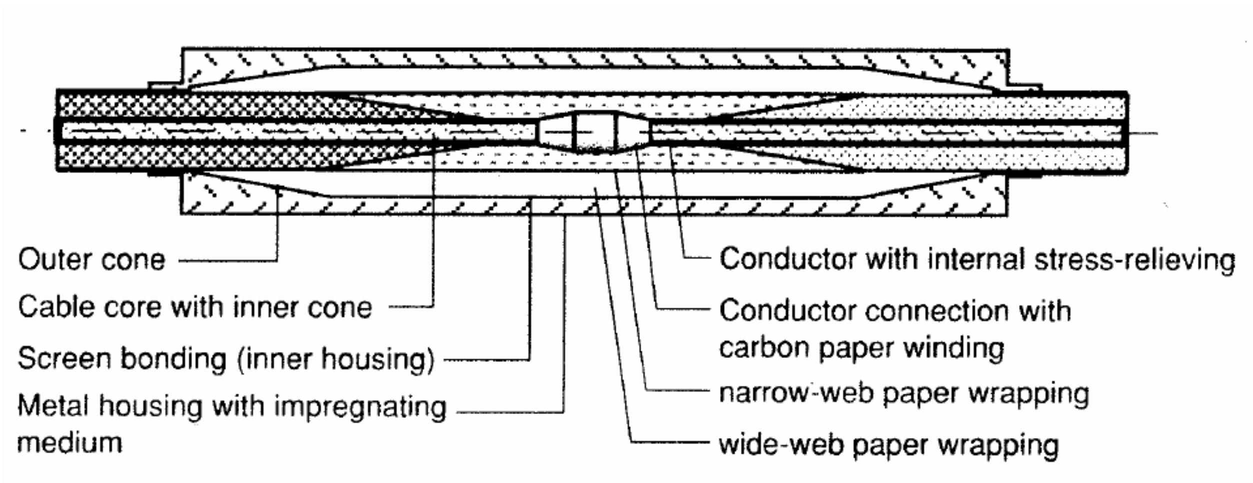


Prefabricated straight joint between two XLPE cables

The prefabricated joint consists of:

- A conductor connection ferrule, which is mechanically linked to a metallic insert in the central insulator.
- A three-piece dielectric body in elastomer. This body includes two elastomeric stress cones and a central insulator made of cast rigid thermosetting resin. Semi-conductive and metallic parts extend the equipotential lines from the main cable to the body insulation
- A connection between the screens of the two cables
- A protection box.

Straight joint between two oil filled cables (SCOF) :

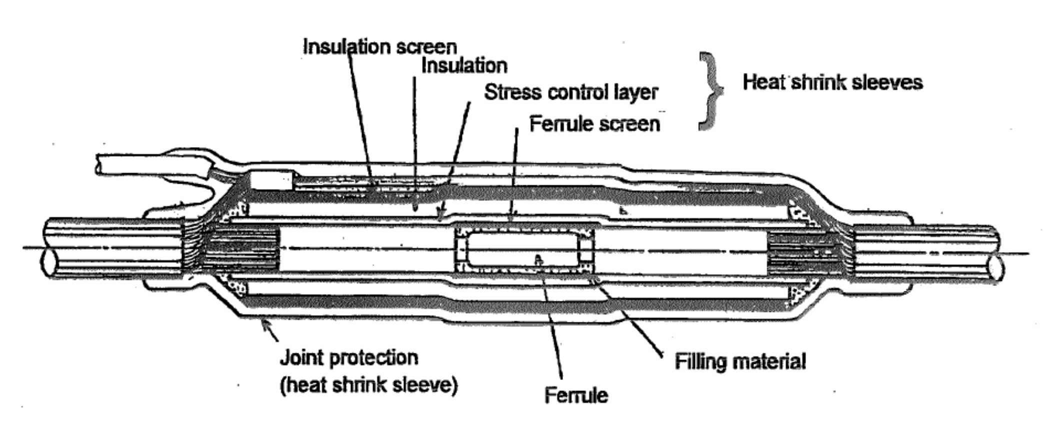


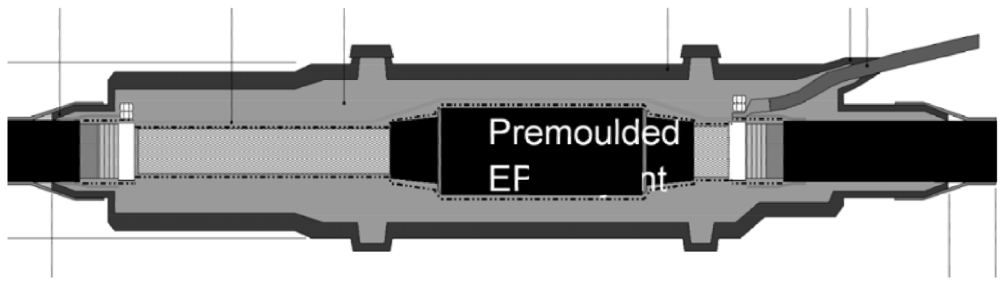
Outline of a straight joint between two oil filled cables.

<u>**Earthing joint :**</u>

Joint two cables together, ensures the continuity of all cables constituents. And provides a grounding of the cable screen.

Example of earthing joints :





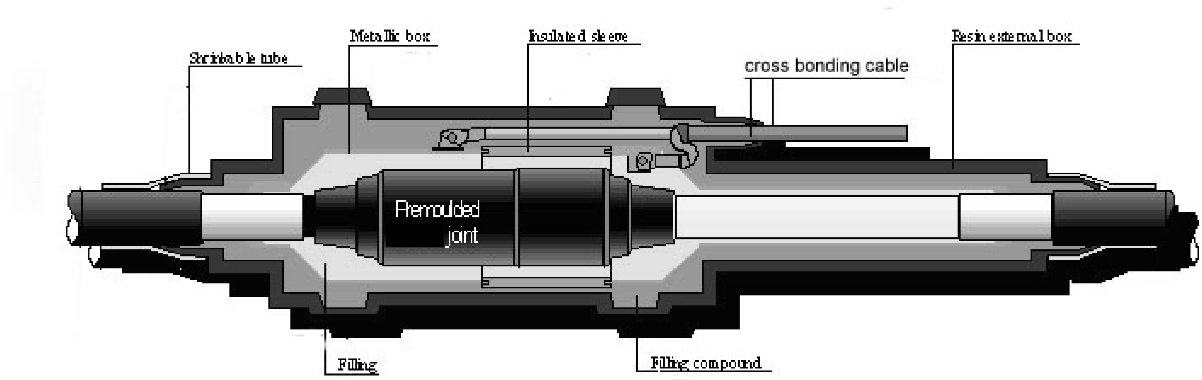
One piece premolded earthing joint between two XLPE cables

The earthing joint is similar to the straight joint. In addition, a grounding cable is linked to a cable screen.

Shield break joint :

Joint two cables together, ensures the continuity of all cables constituents. And provides a direct insulated access to the screen of each of the cables. This type of joint is used at the cross bonding points of a long HV link.

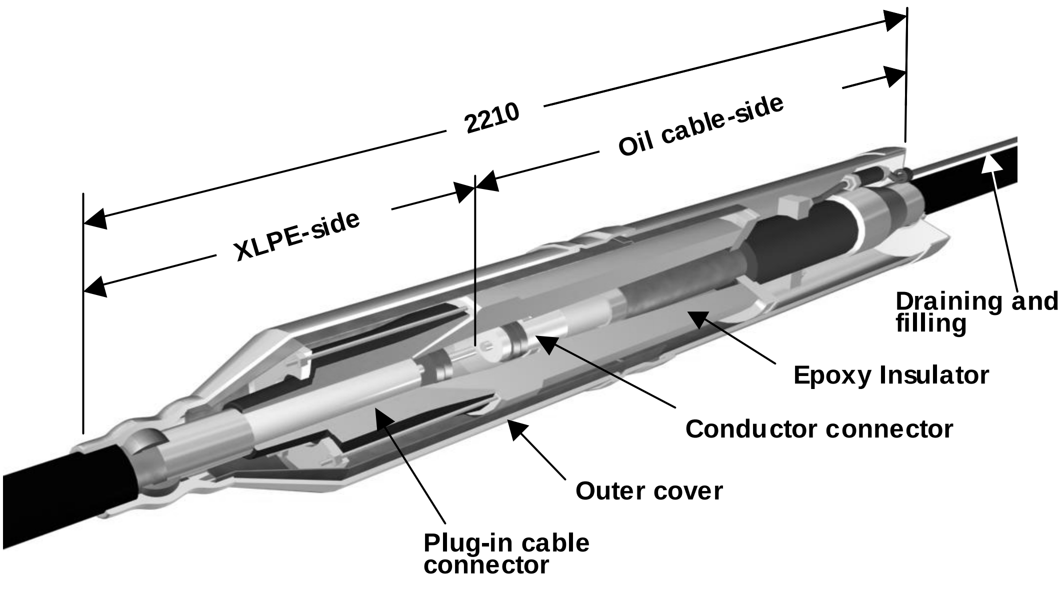
Example of a one piece premolded cross bonding joint :



The shield break joint is similar to a straight joint, but the screens of the two cables are insulated from each other, and a coaxial cable (or two single core cables) is connected to each of the screens.

Transition joint :

A transition joint is used to link two cables technologies.

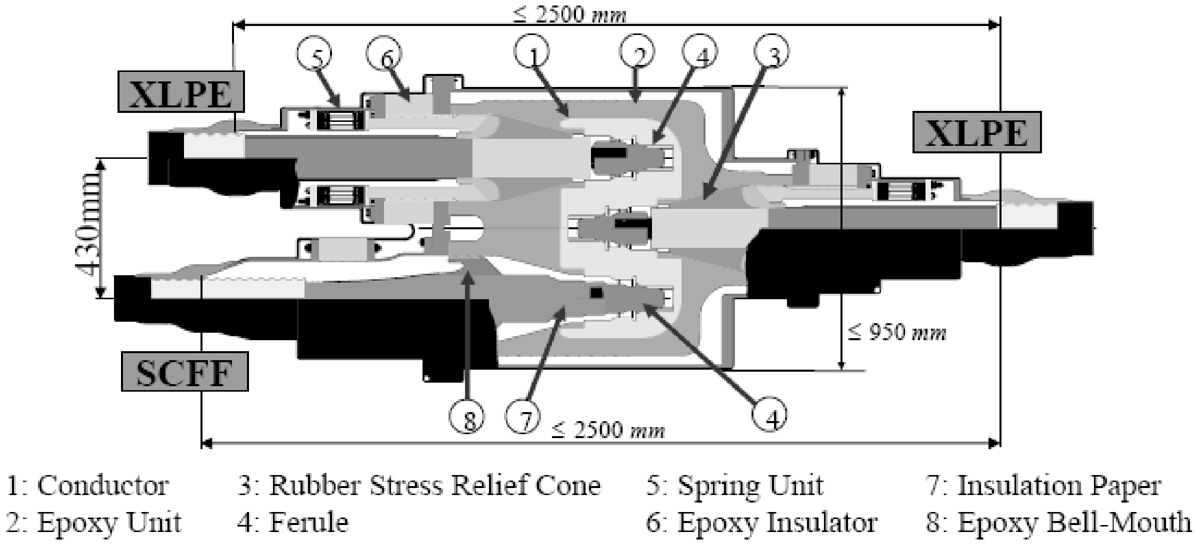


:

Example of a transition joint between an XLPE cable and an oil filled cable

Y branch joint :

In some cities, the network of insulated cables is dense an extended. The need for derivation joints, i.e. Y branch joints has appeared.



After J-Power - ICC fall 2004

Example of a Y branch joint with 2 XLPE cables and one oil filled cable

Type of terminations:

Outdoor oil filled terminations :

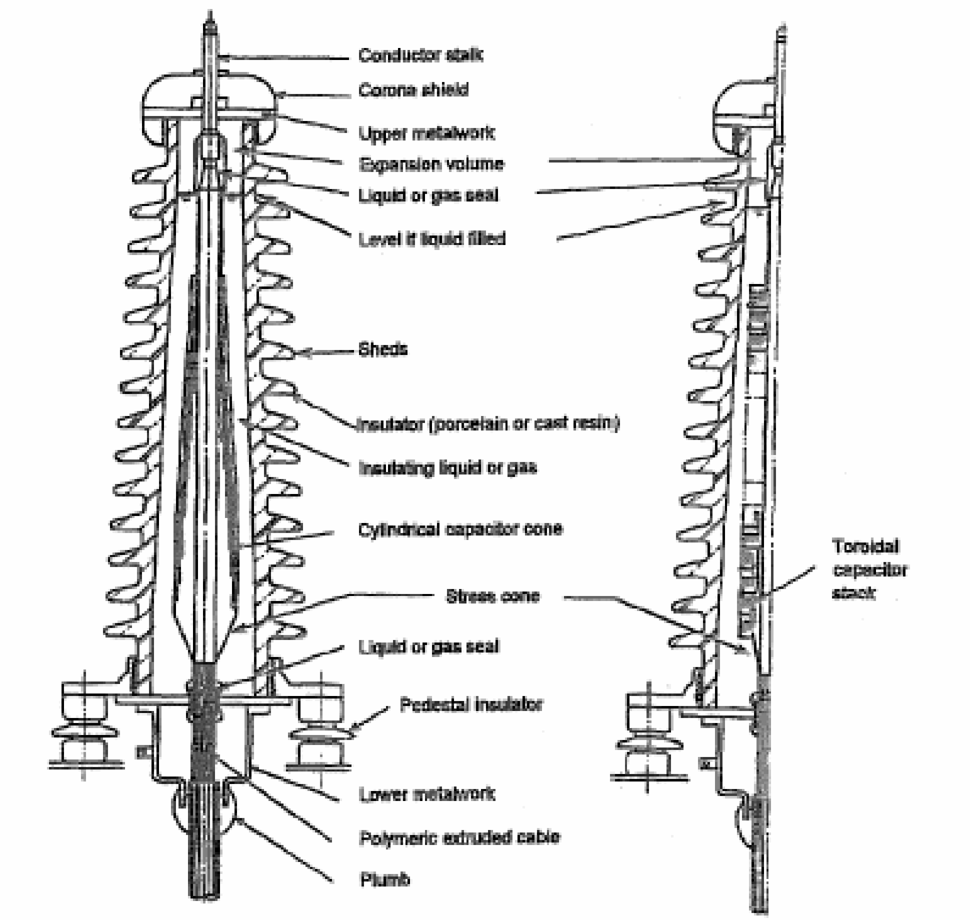
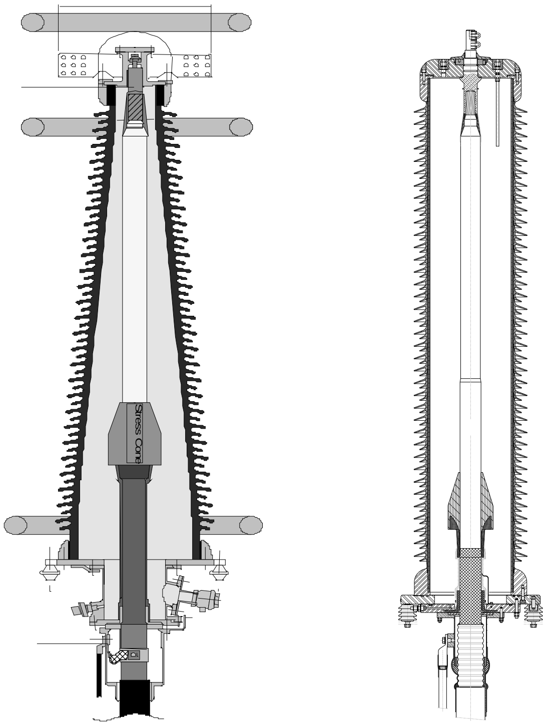


Figure 31. 'Capacitor cone and insulator' 'cylindrical capacitor cone type' outdoor termination

Figure 32. 'Capacitor cone and insulator' 'toroidal capacitor type' outdoor termination

Outdoor SF6 filled termination :

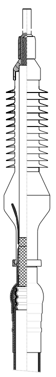


example of SF6 filled outdoor terminations for XLPE cables, with porcelain insulator (left) and composite insulator (right)

The terminations consist of, from bottom to top :

- A screen connection
- A gasket
- A bottom plate
- A stress relief component (here a stress cone)
- A rigid insulator
- A top conductor connection

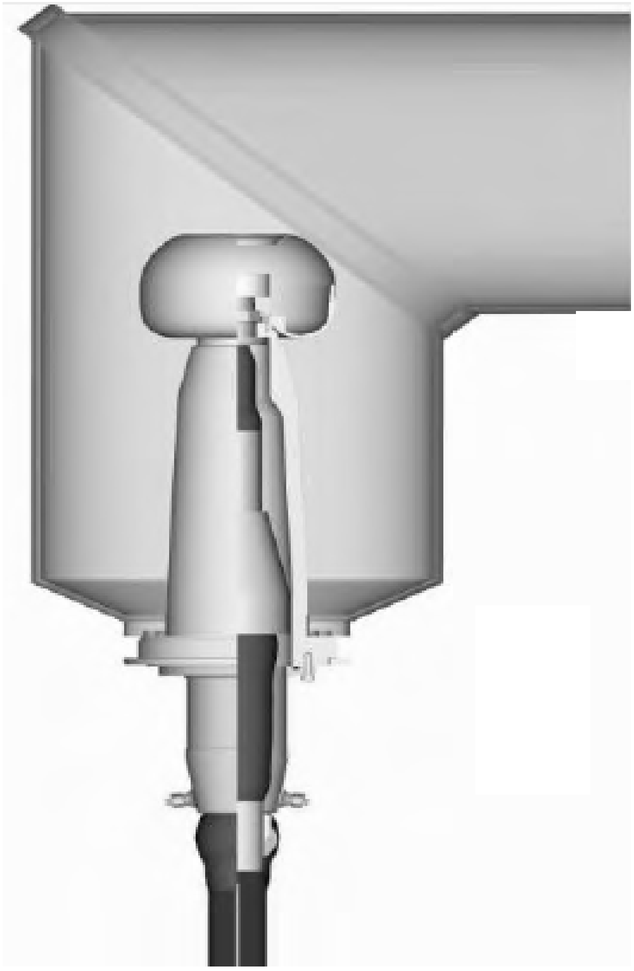
Outdoor dry terminations :



The outdoor dry terminations does not contain any fluid,

It consist of :
The screen connection
The insulation
The top connection.

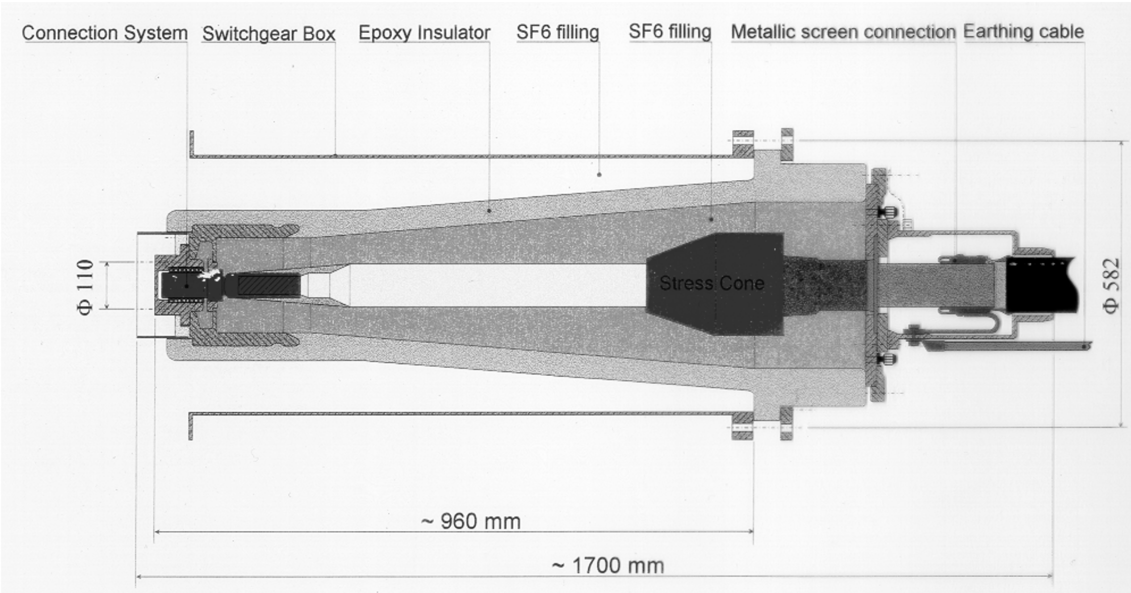
Transformer terminations :



Example of a transformer termination for an XLPE cable

The design of a transformer termination is similar to the one of an outdoor termination, but the insulator is shorter and surrounded by the transformer fluid.

GIS terminations :
Example of an SF6 filled GIS termination in accordance with IEC 60859



Indoor special terminations :

Short HV terminations installed in an indoor substation.

Appendix 3 Template for Failure Statistics Data Collection

CIGRE WG B1-09, R.L.E.: SIMPLIFIED FAILURE STATISTICS DATA COLLECTION

For HV & EHV Cable Links (voltage ranges according to IEC 60840 & 62067)

This table is not intended for use for remaining life estimation; more and different data should be included. This simplified table contains only the minimum of information deemed necessary for a very rough statistics; it is intended to facilitate the work to be carried out, allowing in this way to collect as many cases as possible. For the most significant ones it would then become possible to ask more specific and detailed information	Filling up company: Date:

A	B	C	D	E	F	G	H
Voltage	**Link name / country**	**Installation**	**Insulation**	**Year of**	**Year of**	**Failure**	**Notes**
(kV)		**Type**	**Type**	**Installation**	**Failure**	**Location**	

Filling up help:

A: Uo/U (e.g.: 87/150)
B: Official name of the link & install. country
C: Buried, Tunnel, Pipe...
D: Solid, Fluid Filled
E: Year only
F: Year only
G: Cable, Joint, Termination
H: Possible remarks(repeated failure, identified cause, ...)

CIGRE WG B1-09, R.L.E.: SIMPLIFIED CABLE CIRCUITS DATA COLLECTION

For HV & EHV Cable Links (voltage ranges according to IEC 60840 & 62067)

This table is intended to help gathering data for a simplified approach for remaining life estimation.
More and different data should be included for a more detailed analysis.

Filling up company:

Date:

A	B	C	D	E	F	G	H
Voltage	**Link name / country**	**Installation**	**Insulation**	**Year of**	**Service**	**Failures**	**Notes**
(kV)		**Type**	**Type**	**Installation**	**Life**	**(Y/N; n°)**	

Filling up help:
A: Uo/U (e.g.: 87/150)
B: Link Official name & install. country
C: Buried, Tunnel, Pipe...
D: Solid, Fluid Filled
E: Year only
F: Years
G: Yes/No; number
H: Possible remarks(repeated failure, identified cause, ...)