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GENERAL GUIDELINES FOR THE INTEGRATION OF A NEW UNDERGROUND CABLE SYSTEM IN THE NETWORK

Working Group B1.19

August 2004

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CABLE SYSTEM IN THE NETWORK

PREPARED BY

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The authors of this document wish to acknowledge the assistance of many colleagues throughout ClGRE, who have helped in its publication.

CONTENTS

1 INTRODUCTION TO THE GUIDE

The purpose of this document is to provide a guide for engineers who have to integrate a new high voltage cable system into the network. It provides advice on the general principles, relevant IEC standards and CIGRE Reports, Recommendations or Technical Brochures, as appropriate.

When integrating a new underground cable system, the engineer must consider the technical and environmental implications throughout the lifetime of the cable. The guide considers the issues likely to arise during design, installation, operation, maintenance and upgrading.

Special consideration is given to the design of outdoor transition equipment, considering factors including system requirements, the most suitable site, and design of the equipment to be installed.

In general the guidelines cover equipment within a land transmission AC network although some sections such as those covering site selection and plant will be applicable to other situations such as DC and/or submarine systems. The guide concentrates on extruded cable systems, although mention is made of self-contained fluid filled (SCFF) cables where appropriate.

The document is divided into 12 main chapters.

After a short introduction in chapter one, the second chapter covers system requirements and basic concepts, including network considerations and the particular needs of transition equipment.

The third chapter considers the design and construction issues relating to the underground section of a line.

Chapter four is dedicated to the design of the aboveground equipment relating to the overhead to underground transition. This includes discussion of the technical and environmental factors that must be considered when selecting the most suitable site for locating transition equipment. This chapter also details the criteria that are applied to select layout and to determine the primary and secondary equipment required.

The fifth chapter provides guidance on commissioning.

The sixth chapter covers operation.

Chapter seven deals with refurbishment and uprating of existing equipment.

The eighth chapter introduces in life cycle management (LCM) while chapter nine is a guide for Environmental Impact Assessment.

Chapter ten contains a glossary of appropriate terms.

Chapter eleven is a guide for collecting input data

A list of useful references is provided in chapter twelve.

1.1 BACKGROUND

In December 1995 CIGRE Working Group 37-13 published a Technical brochure entitled ‘Environmental aspects of links between Power System Planners and Decision Makers in the Energy area’ [1]. This report describes experiences in communicating environmental issues when siting and obtaining permits for power plants and transmission lines. This work might also be regarded as an extension of WG 37-09's Technical Brochure ‘Links between Power System Planners and Decision Makers in the Energy Area’ [2].

Some general observations regarding the Environmental thinking of companies were made at this time:

- Overhead transmission lines generally tend to provoke more massive objection, due to a significant visual impact in connection with very limited benefits to those affected. Severe delays, more than 10 years, have in many cases been experienced as a result of public opposition.
- Worries about electric and magnetic fields (EMF) when planning and building transmission lines, are causing conflicts and adverse local opinion in many countries.
- The emphasis on environmental assessment and planning is moving away from environmental control to integrated resource planning taking account of environmental impacts. Methods by which environmental costs (i.e. externalities) and issues can be brought to the forefront of system planning and siting studies are being explored. These can be examined on a level playing field with economic and other costs.

- It is useful to monitor carefully trends in environmental legislation in order to gain a clear view of the future development of requirements. This makes it easier to gain acceptance and the necessary permits.
- There is increasing concern on the part of the electricity supply industry to communicate the actual costs for the desired protection of the environment. Public opinion and the authorities concerned must realise that these entail significant costs, and ensure, with suitable incentives, that the desired solutions can be carried out without exposing the electricity supply industry to excessive costs. The situation is particularly important in singular environmental permit applications, like transmission lines and the associated electromagnetic fields.
- The problem of carbon dioxide is nowadays taken more seriously. The fact that regional and global, and not only local, environmental issues are discussed during siting discussions and permit processing is a trend that is also being followed by many countries.

In recent past years, many countries have experimented with several transformations in their power sectors. These transformations have one or more of the following characteristics:

- Improvement in the efficiency of the electric power sector.
- Introduction of competition in generation, under the hypothesis that this competition will lead to technological improvements, better services and least cost.
- Even though competition in generation may not necessarily involve transferring the ownership of the generators, the majority of countries who are introducing this issue, are privatising companies and new generators. Reasons for privatisation are related to the need for new investment, and also to generate resources for other government objectives.
- The transmission system is being treated either as a "business agent" or as a common carrier, that ensures competition in generation. The transmission system, in the majority of the cases, is a monopolistic grid, subjected to regulations.
- Competition in transmission has not yet been demonstrated to be an economically efficient policy.
- Distribution companies are free to seek economically efficient generation contracts with generation companies.
- Wheeling transactions can be accommodated (i.e.: a generation/load pair, situated at different points that is willing to pay for the corresponding transmissions service).

With the structural modifications that are taking place in power sectors all over the world, it is recognized that the transmission system will be the new paradigm ensuring not only that transactions result in the best economic results for the companies involved, but also the reliability of supply of consumers.

In this context, a correct framework for costing transmission services assumes an extremely important role. The CIGRE Technical Brochure 120 titled "Methods and Tools for Transmission costs" has been published in October 1997 by CIGRE Task Force 38.04.04 in the general prospect [3].

As indicated in this technical brochure, the main functions of a transmission system can be stated as follows:

- to serve as an electric power carrier from sources to large consumers or distribution companies
- to provide interconnection among generating units and loads, in order to take advantage of diversity of generator outages, the diversity of peak loads, and the diversity of hydrological periods (for hydro dominated systems)
- to minimize fuel costs by allowing economic transactions
- to facilitate the location and use of lowest cost generating units
- to facilitate the business of trading electric energy in the market place.

It is important to observe that in modern power systems, with competition in generation, the transmission entities (or transmission providers), responsible for the bulk transmission system may take different forms.

Furthermore, it was observed that traditional large power plants are now challenged by dispersed generation (DG) whose growth will certainly have consequences on the power systems. Several different scenarios are possible. They much depend on the driving forces (economic, legislation, regulation and environmental obligations).

However, many technical effects are awaited. They concern generation, planning the development of the systems or its operation.

In February 1999 CIGRE Working Group 37.23 Published CIGRE Technical Brochure 137 titled ‘Impact of Increasing Contribution of Dispersed Generation on the Power System’ [4] with the following scope:

- Describe the different technologies available for DG and compare their potential development in the future in different situations and different legal and regulatory background.
- Identify possible influences of dispersed generation on the power system.
- Compare the existing network connection rules in different countries.
- Formulate guidelines for the integration of DG in long-term generation and network planning.
- Give indications on the role of DG in an open electricity market.

Scheduling of the large generation facilities will be faced with new constraints and the share of dispersed generators will certainly increase.

DG has influence on the quality of supply and on technical items such as short circuit power of the protection system. Usually in HV-networks, the connection criteria are less of a problem than the current carrying capacity in normal operation and under (N-1) conditions.

DG connections to the HV-network are likely to result in more frequent use of underground cable within existing overhead networks. This is likely to occur:

- in cases where environmental pressures require the undergrounding of sections of overhead transmission line
- in cases where economic pressure leads dispersed generators to seek out the fastest and lowest risk method of gaining a connection to the transmission network, thus providing a more favourable return on investment.

The purpose of the present work is to identify the technical and environmental issues raised by the more frequent use of hybrid overhead/underground systems and to give some guidelines to the user for the design, construction and operation of the cable system. It will be assumed in this document that the system planners have performed a preliminary study that has resulted in the decision to connect point A and point B of the network by underground cable.

1.2 SOCIAL ACCEPTABILITY

When establishing a transition compound and a transmission line it is important to pay attention to the local community's attitude to the project as well as the political power in the area. Despite thorough technical and environmental evaluations to find an ideal location for a transition compound, the solution may not be politically acceptable in the area.

Prior to public introduction of a transmission line project it is important to conduct detailed preparatory studies of the political and social situation in the region affected by the project. It is advantageous to collect information from previous large construction projects in the region (in particular projects concerning roads, railways or pipelines). The reactions before, during and after establishment of these projects may indicate the community's involvement in cases affecting the area. Groups of citizens previously actively protesting against other technical construction projects may quickly re-emerge in connection with a transmission line project.

The political power situation should also be studied, e.g. central politicians or other influential figures with relations to, domiciled or elected in the area. Such figures may often exert strong influence on the final design of a transmission line project. It is also important to consider any alliances between local politicians and protest movements.

The result of the preparatory studies may give an expression of the political difficulties to be faced during the regulatory process of the project and also how to introduce the project to the public.

The decision to use underground cables in a section of a transmission line is often results from failure to gain permission to build an overhead line in the area. Therefore, the local community will often consider the underground cabling as a success in their fight against new overhead lines and the transmission company in question. The public will then often build up strong political pressure to increase the length of the underground section and thus reduce the length of new overhead lines.

In many respects underground cabling is considered to be an environmentally friendly but expensive solution compared to overhead lines. However, when discussing the location of the transition compound and the length of the underground cable section, the public will probably not display any moderation. This is caused by the fact that increased construction costs for transmission line projects normally do not affect the local community's budgets.

Many decision makers have little or no knowledge of underground cable technology and it is common notion that cable projects are totally without problems. There is a great need to supply information to both decision makers and the public about the size of HV underground cable projects.

1.3 GENERAL PROCESS

Once the decision has been made a course of action can be determined. The flow chart in figure 1 gives a typical example where a "step by step" approach to the planning and design process is considered. However, in practice iterative actions may often be involved. It must be emphasised that the decision on whether or not to build a line may depend on different conditions in different countries.

Much of the technical information on installation methods has already been collected and published by CIGRE WG21-17 [5,6] and will only be referred to briefly in this document.

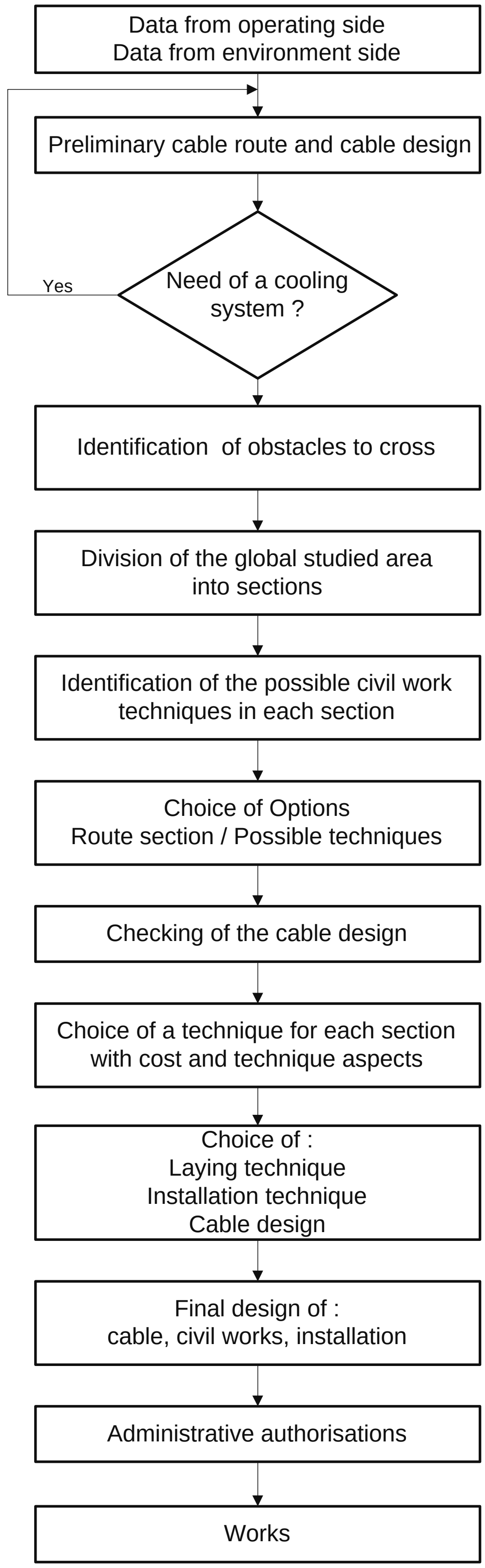


Figure 1: Flowchart indicating the steps involved in delivering an underground cable project

2 SYSTEM REQUIREMENTS AND BASIC CONCEPTS

2.1 INTRODUCTION

The transmission network has two main constituent elements:

(a) Circuits (lines, cables, etc.) that enable power transmission.

(b) Substations that enable the interconnection of these circuits and the transformation between networks of different voltages.

2.1.1 Functions of the Network

The transmission network performs three different functions:

(a) The transmission of electric power from generating stations (or other networks) to load centres.

(b) The interconnection function, which improves security of supply and allows a reduction in generation costs.

(c) The supply function which consists of supplying the electric power to sub-transmission or distribution transformers and in some cases to customers directly connected to the transmission network.

2.1.2 Types of Substations

These three functions of the transmission network are fulfilled through different types of substations listed below:

(a) Substations attached to Power Stations.

(b) Interconnection substations

(c) Step-down (EHV/HV, EHV/MV, HV/MV) substations.

A single substation may perform more than one of these functions.

2.1.3 Main cable circuit configurations

Various configurations such as single circuit, double circuit and triple circuit lines with different arrangements of transformer and generator connections are in use.

Many types of connections comprising overhead lines, underground cables or both are in use today. The length of such transmission lines and cables can vary significantly. In order to provide for high transmission loads, some circuits can consist of more than one cable per phase.

Previous work [6,7] has identified a number of commonly used cable configurations. These are given below and are representative of the most common practical situations.

Note that in the subsequent figures each cable can consist of several cable systems.

2.1.3.1 Meshed underground network

Some parts of a HV network may be entirely underground as is often found in large towns where urbanisation limits the construction of overhead lines. Cables connect the busbars in the system, as indicated in figure 2.

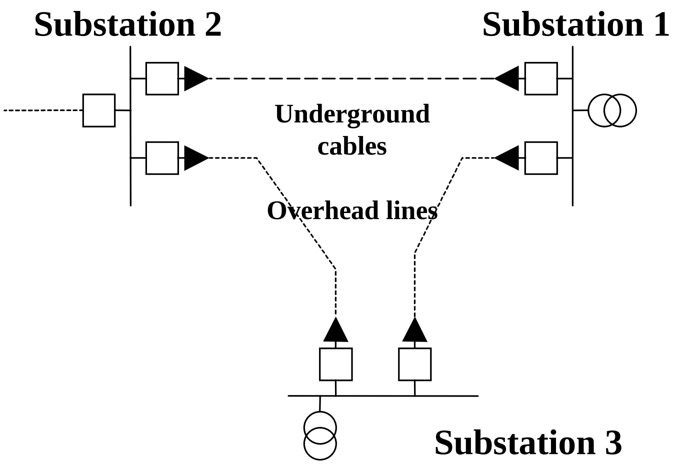


Figure 2: Underground cable system in a meshed network

2.1.3.2 Siphon

A siphon (figure 3) is an underground cable connected between two overhead lines. It is assumed that no switching device is located between line and cable. This configuration allows a HV link to pass through areas too wide for an overhead line span such as rivers or small lakes. The configuration may also permit the transmission line to pass through or near a protected site or an urbanised area. Transition between overhead and underground sections is made either by means of simple terminations installed on poles or towers or in a special fenced area called a ‘Transition Compound’.

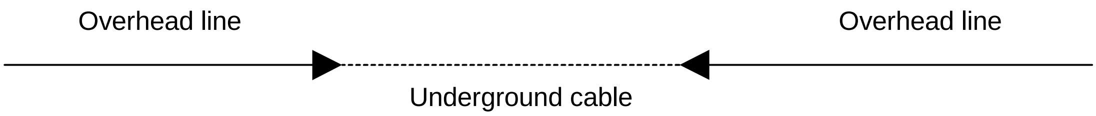


Figure 3: Siphon, an underground cable between 2 overhead lines

2.1.3.3 Substation entrance

An underground cable is often used as the interface between an overhead line and a substation (figure 4), especially when it is a gas insulated substation. This configuration allows the design of more compact stations, in particularly when there is a large number of incoming overhead lines.

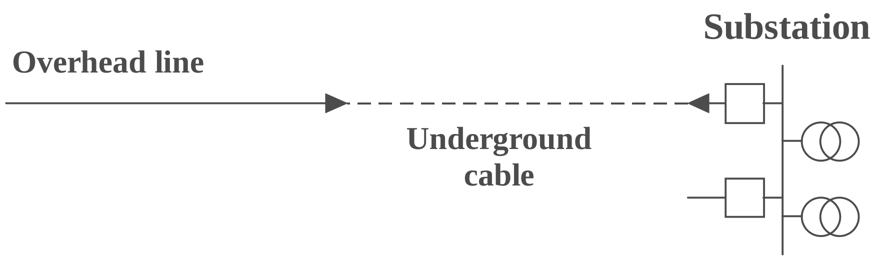


Figure 4: Underground entry to a substation

2.1.3.4 Power generator output

An underground cable may be used to carry power from an inaccessible generator to a busbar, as shown in figure 5. In many hydro power stations the generator is located inside a mountain. In order to save space the generator is connected directly to the step-up transformer, without use of a circuit breaker. The secondary side of the transformer is connected to an outdoor substation via cable, which may have a length up to several kilometres. The substation (air insulated or gas insulated) is connected to one or more overhead lines.

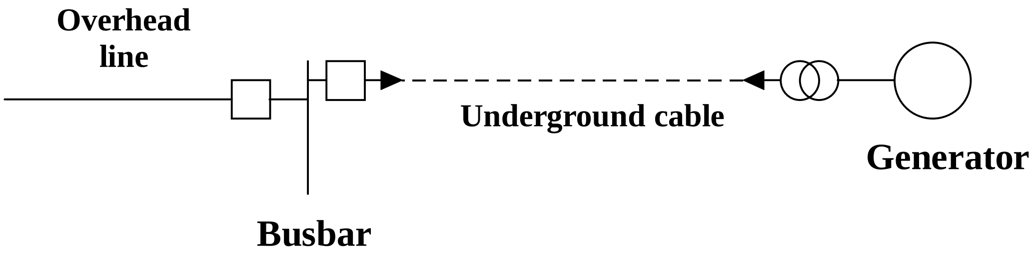


Figure 5: Power generator output

2.1.3.5 Power or auxiliary transformer supply

In this configuration, a cable is connected between a high power busbar and the power transformer or the auxiliary transformer of a power unit (see figure 6). The cable is usually short.

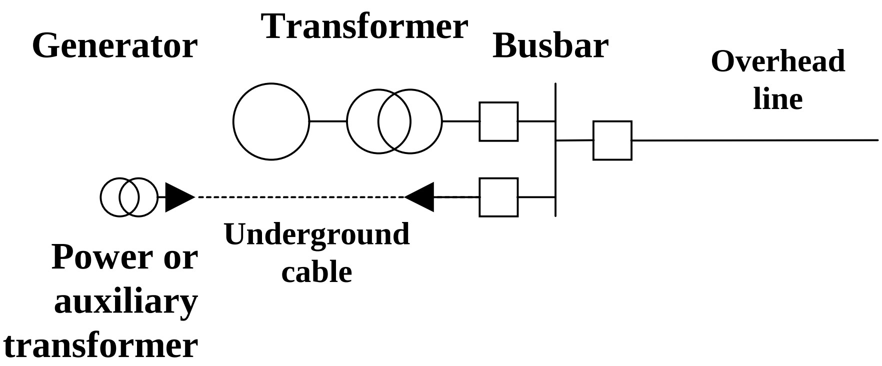


Figure 6: Power or auxiliary transformer supply

2.1.4 The Overhead to Underground Transition

In at least two of the above configurations in transmission systems and in many other configurations in distribution systems, there is need for a transition between overhead and underground sections. For lower voltages, up to 145 kV, this is achieved by means of terminations installed on poles or towers (figures 7 to 9).

Figure 7: Transition on a pole

Figure 8: 66 kV terminations mounted on a tower

Figure 9: Terminations mounted on a platform on a tower

In other cases, and especially for very high voltages, the weight of the equipment, and the electrical clearances required may be such that the equipment cannot easily be located on towers. In these circumstances, the transition is made in special fenced area called a transition compound. This is normally located close to a tower or includes a tower. The transition compound often resembles a small substation, but without switchgear and transformers. Examples of transition compounds are shown in figures 10 to 12. The technical and environmental issues relating to transition compounds are considered in Chapter 4 of this document.

Figure 10: Example of a transition compound (United Kingdom)

Figure 11: Example of a 275 kV transition compound (Japan)

Figure 12: Equipment within a 400 kV transition compound (Spain)

2.1.5 System Requirements

The design of a circuit depends on the functions it has to fulfil. The system planning requirements define these functions and enable the parameters that have to be complied with, to be determined.

Some of these parameters are common for all the circuits that perform similar functions whereas others are completely specific to each circuit.

Standardised parameters are established jointly by system planners and transmission departments by means of system studies, and economic considerations. Particular economic benefits are derived from specifying the technical requirements to allow the use of standardised HV equipment with identical characteristics (such as short circuit rating, maximum current carrying capacity, insulation level). Cables are generally dimensioned for the expected transmission capacity.

2.2 PARAMETERS DETERMINED BY THE NETWORK

System planners seek to optimise the parameters that apply to the complete transmission system. They proceed to network studies that involve mainly insulation co-ordination, transient stability, short-circuit level and load flow.

2.2.1 Main Equipment Parameters

When a utility determines a standardisation policy and the development of technical requirements, the main characteristics of the primary equipment have to be specified by the asset managers in close consultation with designers.

The following parameters may be defined:

(a) The short circuit current ratings of the equipment, including the supporting structures.

(b) The maximum load current passing through the components (which is related to the maximum current carrying capacity of the lines and underground cables) in normal operation and in overload conditions.

2.2.2 Fault Clearance Times

In order to comply with the requirements of the network (system stability), or the specifications of particular utilities, specified fault clearance times must not be exceeded.

Fault clearance times and the policy on reclosing may influence the choice of components, the size of the metallic screen of cables and installation design (depth of burial), and also the dimensioning of the earthing grid and the mechanical strength of the equipment.

3 DESIGN AND CONSTRUCTION ISSUES RELATING TO UNDERGROUND SECTION

3.1 INTRODUCTION

Taking into account the data from both operating and environmental sides, a preliminary route and cable design are selected. Then, in the progress of the study, several technical issues will be faced before reaching the final selection of cable and accessories design and laying technique(s). Main technical aspects which will be examined in this process are [8]:

- 3.3.1 Electrical characteristics
- 3.3.2 Thermal dimensioning
- 3.3.3 Economical optimisation of conductor area
- 3.3.4 Short circuit characteristics
- 3.3.5 Main insulation coordination
- 3.3.6 Choice of grounding technique
- 3.3.7 Protection and reclosure
- 3.3.8 Magnetic Fields

3.2 METHODOLOGY

When an engineer is at the beginning of a new project, the problem is always: how could it be managed in order to be the most effective on the technical and economical points of view ?

The following chart (fig 13-1 to 13-5) proposed in Technical Brochure 194 prepared by WG 21.17 [6] will help the inexperienced engineer in the management of his project. If you are in an organisation accustomed with the underground cable system project management, it is clear that some stages have to be jumped over.

It can be seen that the exercise is very much an integrated process with the impact of the various stages being considered and steps taken to modify previous and subsequent stages of the process to achieve an optimised end result.

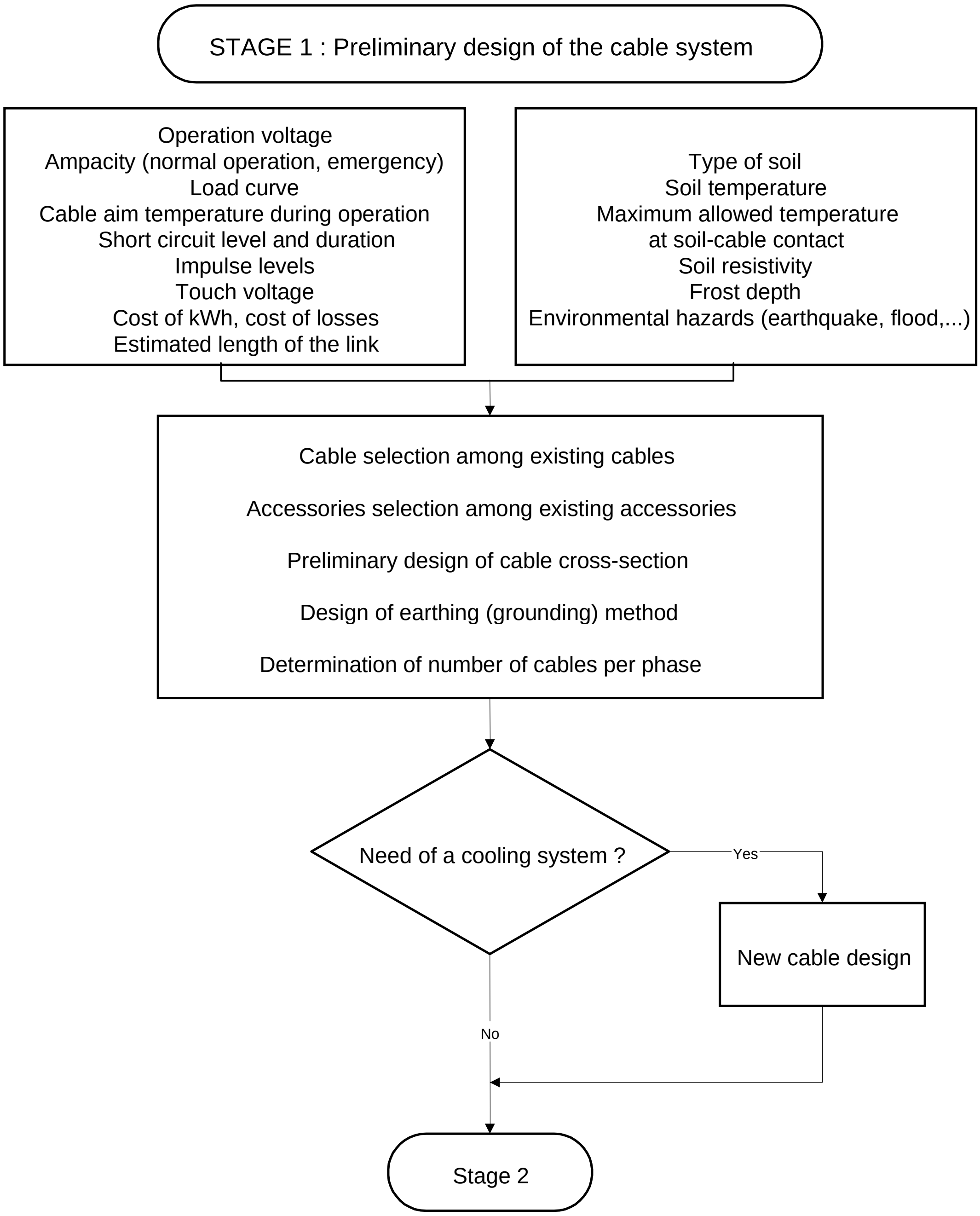

STAGE 1 : Preliminary design of the cable system
Operation voltage
Ampacity (normal operation, emergency)
Load curve
Cable aim temperature during operation
Short circuit level and duration
Impulse levels
Touch voltage
Cost of kWh, cost of losses
Estimated length of the link
Type of soil
Soil temperature
Maximum allowed temperature
at soil-cable contact
Soil resistivity
Frost depth
Environmental hazards (earthquake, flood,...)
Cable selection among existing cables
Accessories selection among existing accessories
Preliminary design of cable cross-section
Design of earthing (grounding) method
Determination of number of cables per phase
Need of a cooling system ?
Yes
New cable design
No
Stage 2

Figure 13-1

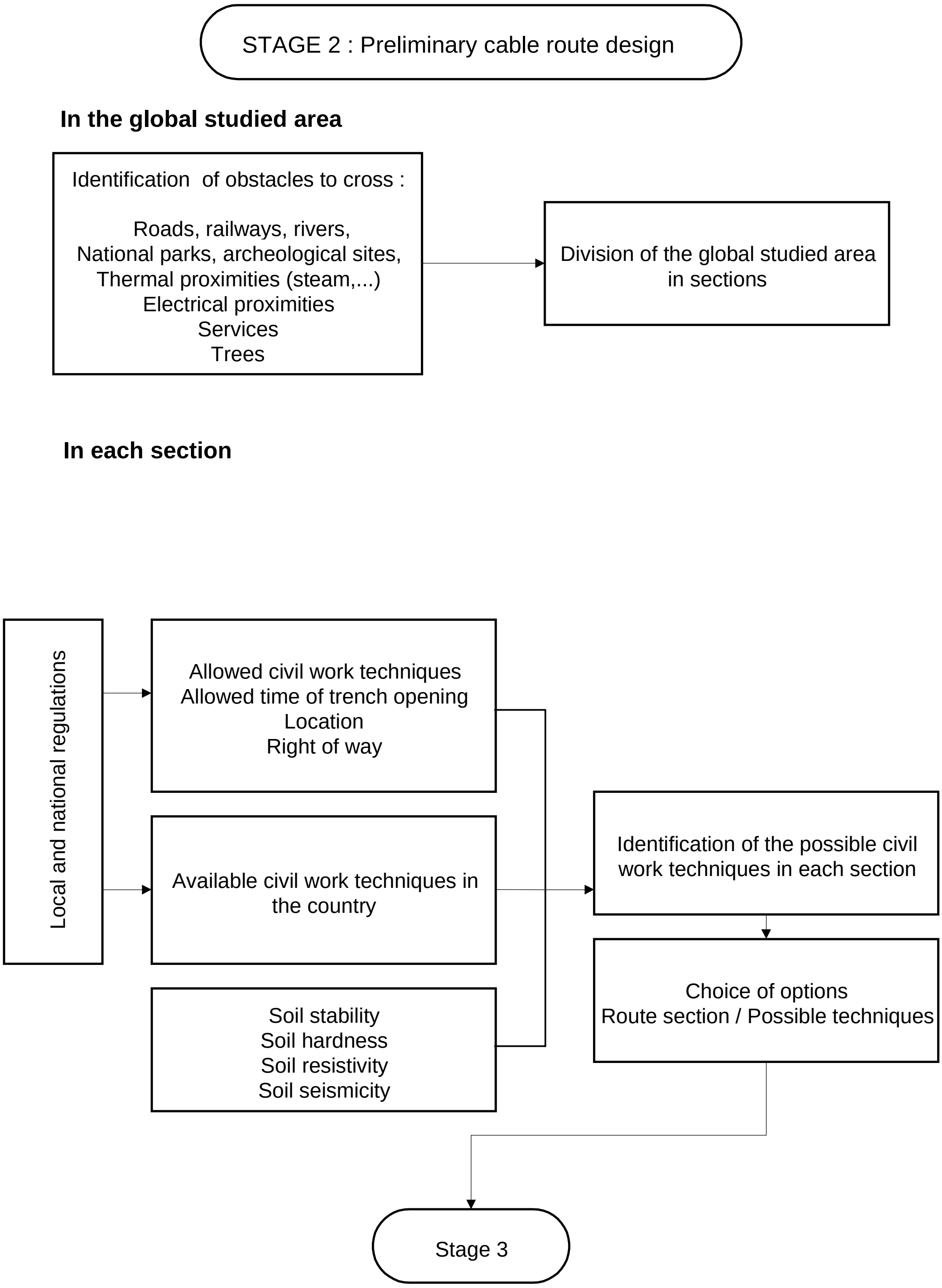

STAGE 2 : Preliminary cable route design
In the global studied area
Identification of obstacles to cross :
Roads, railways, rivers,
National parks, archeological sites,
Thermal proximities (steam,...)
Electrical proximities
Services
Trees
Division of the global studied area in sections
In each section
Local and national regulations
Allowed civil work techniques
Allowed time of trench opening
Location
Right of way
Available civil work techniques in the country
Soil stability
Soil hardness
Soil resistivity
Soil seismicity
Identification of the possible civil work techniques in each section
Choice of options
Route section / Possible techniques
Stage 3

Figure 13-2

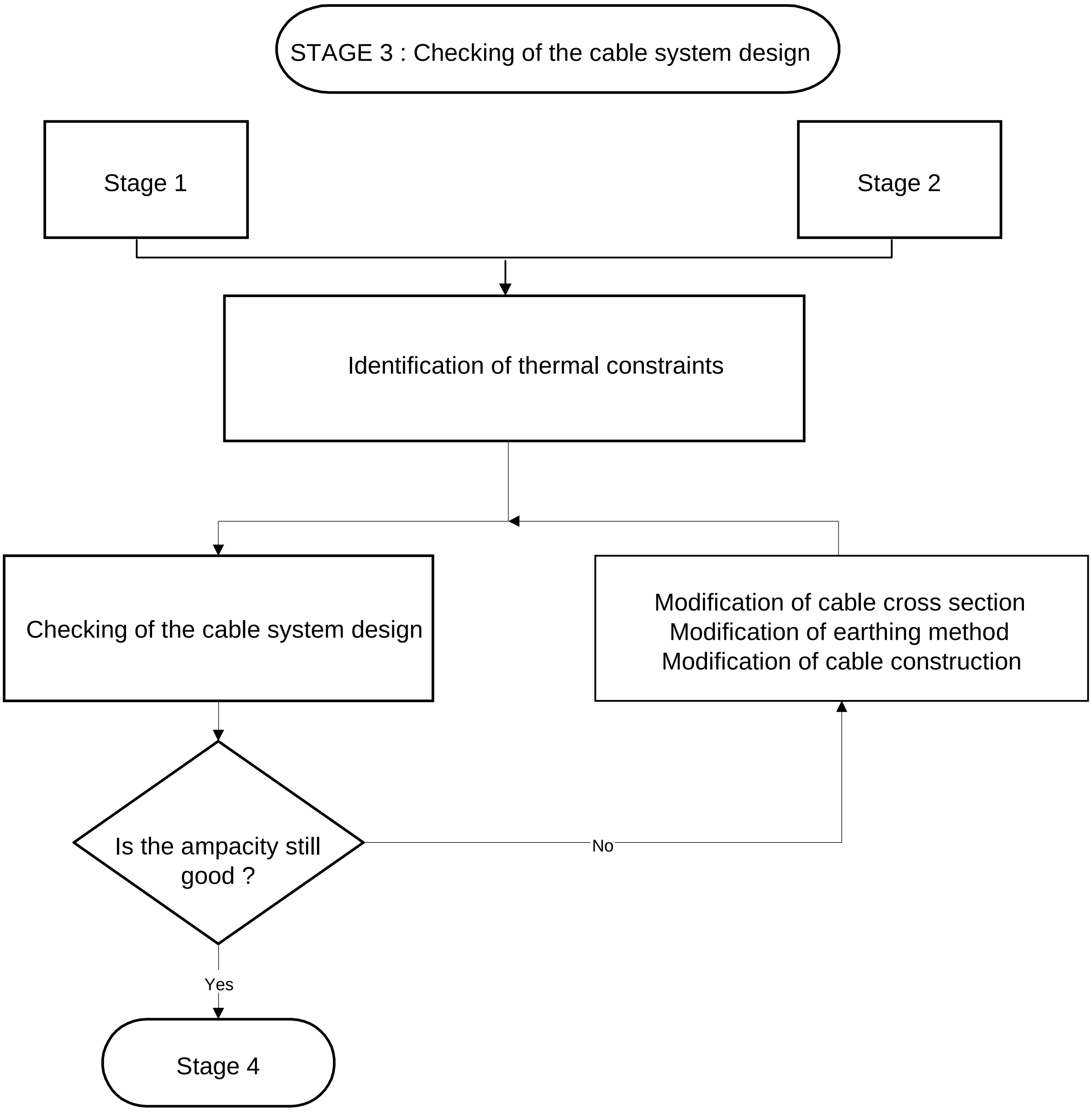

STAGE 3 : Checking of the cable system design
Stage 1
Stage 2
Identification of thermal constraints
Checking of the cable system design
Modification of cable cross section
Modification of earthing method
Modification of cable construction
Is the ampacity still good ?
No
Yes
Stage 4

Figure 13-3

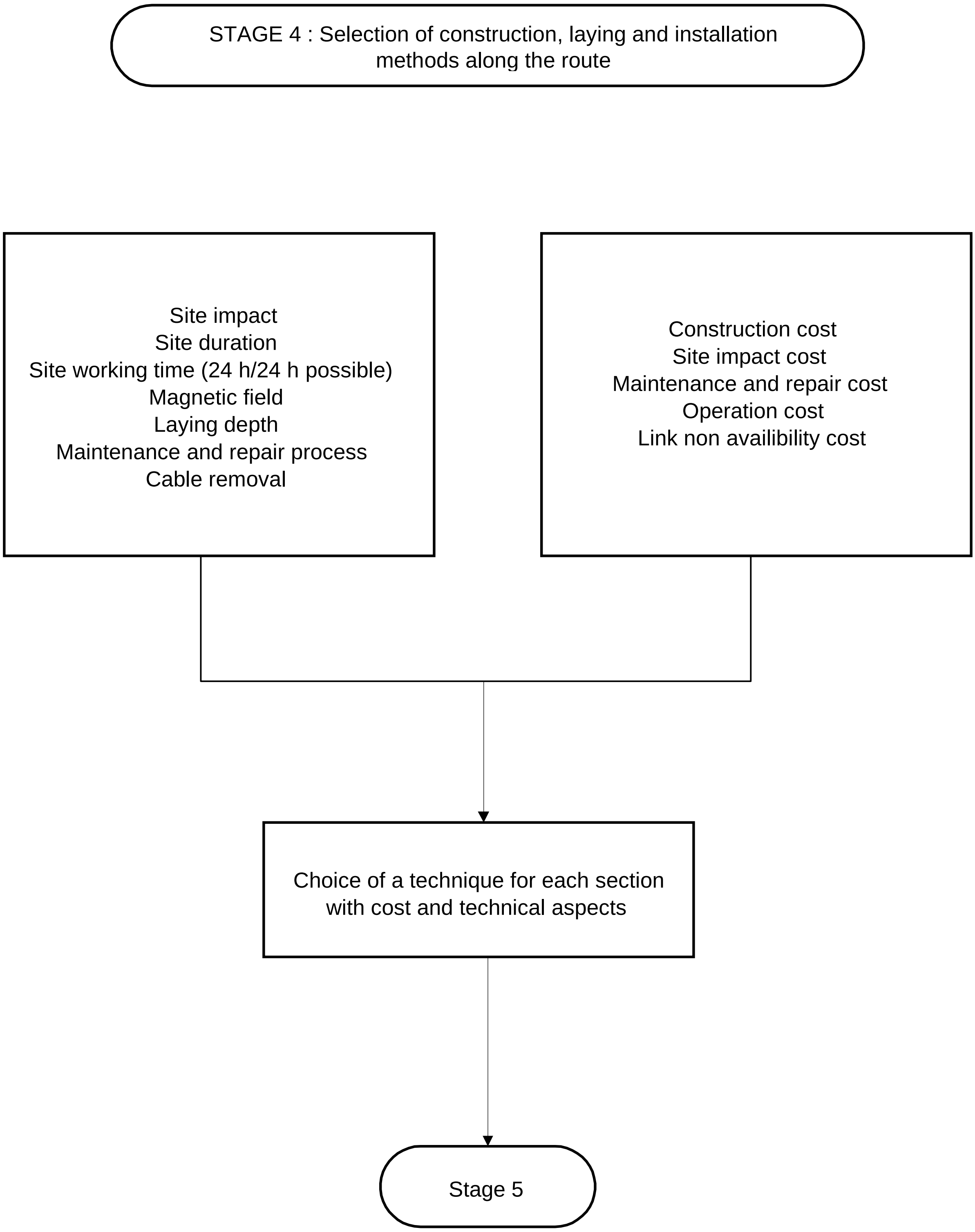

STAGE 4 : Selection of construction, laying and installation methods along the route
Site impact
Site duration
Site working time (24 h/24 h possible)
Magnetic field
Laying depth
Maintenance and repair process
Cable removal
Construction cost
Site impact cost
Maintenance and repair cost
Operation cost
Link non availibility cost
Choice of a technique for each section with cost and technical aspects
Stage 5

Figure 13-4

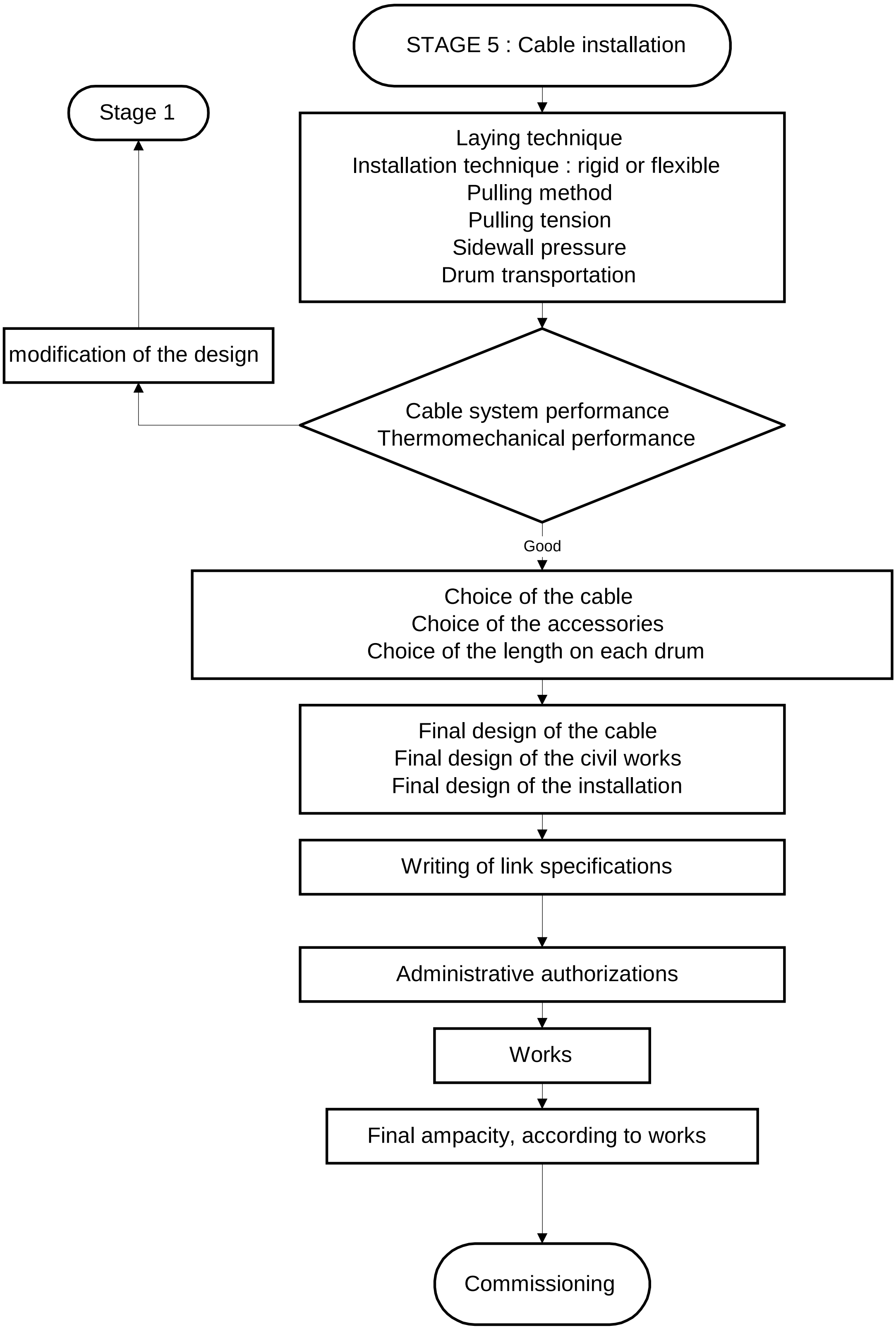

STAGE 5 : Cable installation
Stage 1
Laying technique
Installation technique : rigid or flexible
Pulling method
Pulling tension
Sidewall pressure
Drum transportation
modification of the design
Cable system performance
Thermomechanical performance
Good
Choice of the cable
Choice of the accessories
Choice of the length on each drum
Final design of the cable
Final design of the civil works
Final design of the installation
Writing of link specifications
Administrative authorizations
Works
Final ampacity, according to works
Commissioning

Figure 13-5

3.3 TECHNICAL ISSUES

3.3.1 Electrical Characteristics

This very important question has been studied in detail in Report 21-13 prepared for CIGRE Session 1986 by CIGRE WG 21-13 [9]. The following lines will just remind main issues.

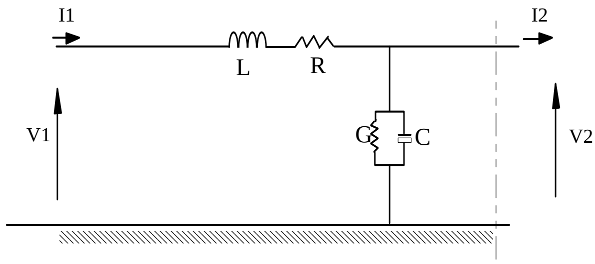


Figure 14 - Equivalent diagram of a line element

A transmission line may be modelled with discrete line elements in a π-link, or by using the exact solutions from the wave equations. In figure 14 above, an equivalent diagram of a line element is shown.

The series impedance consists of the series resistance and inductive reactance (X=ωL for pure sine waves), while the shunt admittance consists of capacitive susceptance (B=ωC for pure sine waves) and the shunt conductance, which for cables is represented by the dielectric losses ($P_{diel} = U^2 \cdot G = U^2 \cdot \omega C \cdot \tan\delta$). The dielectric loss factor, *tanδ*, is normally about 0.0002 for XLPE cables.

The line elements are [10]:

- **Series resistance R.** The resistance may consist of conductor resistance or in case of underground cables the conductor resistance corrected to take into account the screen/sheath ohmic losses, depending upon screen bonding technique.
- **Series inductance L**. An element that stores and releases magnetic energy with changing current.
- **Shunt conductance G**. Represents the heating effect from induced polarisation of the insulation material in case of cables and stray currents in case of Over Head Lines (OHL).
- **Shunt capacitance C**. An element that stores and releases electrical energy with changing voltage.

Different transmission systems have different magnitudes of the line elements. There are, for example, large differences between cables and OHL. The series inductance is about 2-3 times larger for OHL compared to cables (depending on the geometrical configuration) but the shunt capacitance is 10 - 20 times less (depending on material properties and geometrical configuration).

Although each of these impedances must be taken into account when performing detailed cable system design, we will only address the more important items.

3.3.1.1 Critical Length

As a first approximation a cable line can be compared with a shunt capacitance (fig 15). To feed a purely resistive load in a radial network with a given current through a cable line, it is necessary to inject a higher current at the source. The difference being the capacitive current generated in the line (in quadrature with the current in the load). This current is the charging current.

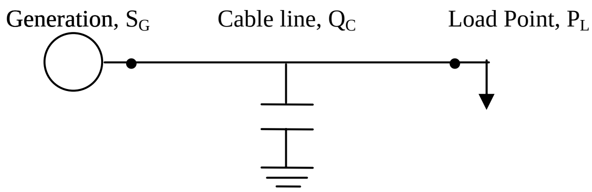


Figure 15 - First approximation of a cable line

In cables, where the shunt capacitance is far higher than that of overhead lines, the charging current generates heat losses. These heat losses caused by the charging current, play a greater role for very long underground cable links. For ordinary cable installations the charging current is normally not a parameter that affects the heat losses to a high degree. However, at a certain length the charging current accounts for all the available heat losses in the cable, i.e.

The thermal rated current=The capacitive charging current. This length is called the *critical length.*

If the source power $S_G = \sqrt{3}$ UI is equal to the rating power of the cable, the power available to the load at the nominal voltage decreases with length and is zero at the critical length, L_c:

$$L_c = \frac{I}{\omega C} \cdot \frac{\sqrt{3}}{U} \cdot 10^3 \qquad [km]$$

where

- C is the capacitance per unit length [μF/km]
- ω is the angular frequency [s^{-1}]
- U is the phase-phase voltage [kV]
- I is the phase current in conductor [A]

The maximum transmitted power in an underground radial link is then dependant on the frequency, length and voltage across the insulation, according to equation above. However, a large conductor can transfer higher loads than a smaller conductor can. Therefore, the charging current becomes of less importance while the conductor area becomes larger, if the generated power is unchanged. See figure 16 and equation below.

$$P_L = \sqrt{S_G^2 - \left(\omega C \cdot L \cdot U^2 \cdot 10^{-6}\right)^2} \qquad [MW]$$

- P_L is the active power (at cosφ=1) at the load point[MW]
- S_G is the necessary feeding power at the source[MVA]
- C is the capacitance per unit length [μF/km]
- L is the length of the underground link [km]
- ω is the angular frequency [s^{-1}]
- U is the phase-phase voltage [kV]

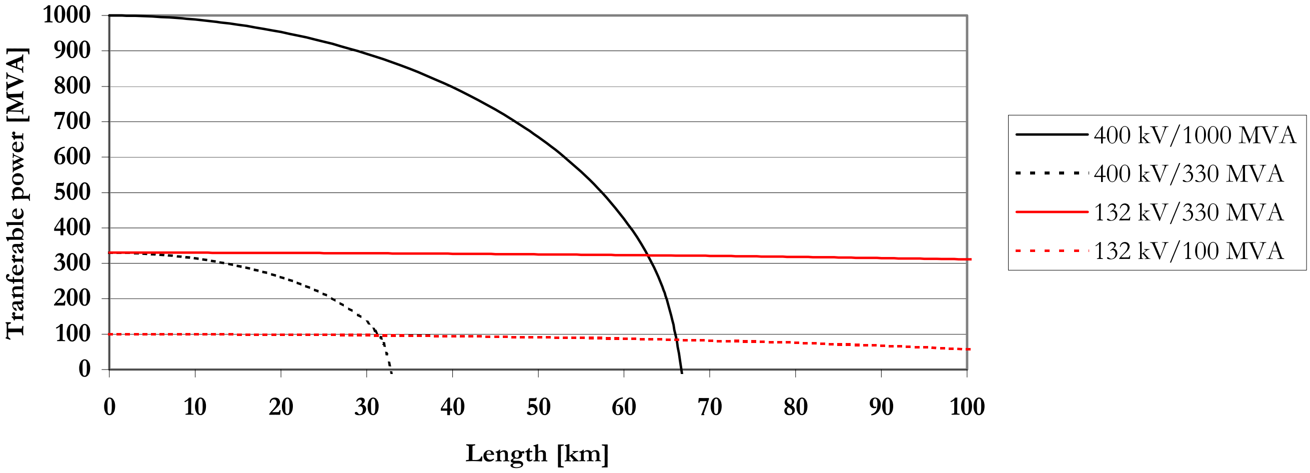


Figure 16 - The maximum transmitted power in a cable system versus the length of the line in a radial network. It can be noted that larger cross-sections (higher ratings) means longer critical lengths.

To calculate the load current I_L, for any phase angle φ, between I_L (load current) and U (voltage at load), the law of cosines states

$$I^2 = I_c^2 + I_L^2 - 2I_c I_L \cos(90° + \varphi) = I_c^2 + I_L^2 + 2I_c I_L \sin(\varphi)$$

Solving this equation for I_L and noting that $I_c = \frac{L}{L_c} I$, the ratio of I_L/I is found to be

$$\frac{I_L}{I} = -\left(\frac{L}{L_c}\right) sin(\varphi) - \sqrt{1 - \left(\frac{L}{L_c}\right)^2 sin^2\left(90° + \varphi\right)}$$

If the load is purely resistive, the following equation can be used for calculating the relation between currents and lengths:

$$\frac{I_L}{I} = \sqrt{1 - \left(\frac{L}{L_c}\right)^2}$$

It is worth noticing when the L/L_c is greater than 0.6 the transferred power is reduced by more than 20 %, according to figure 17. Additionally, when $L=L_c$ then $I_L=0$.

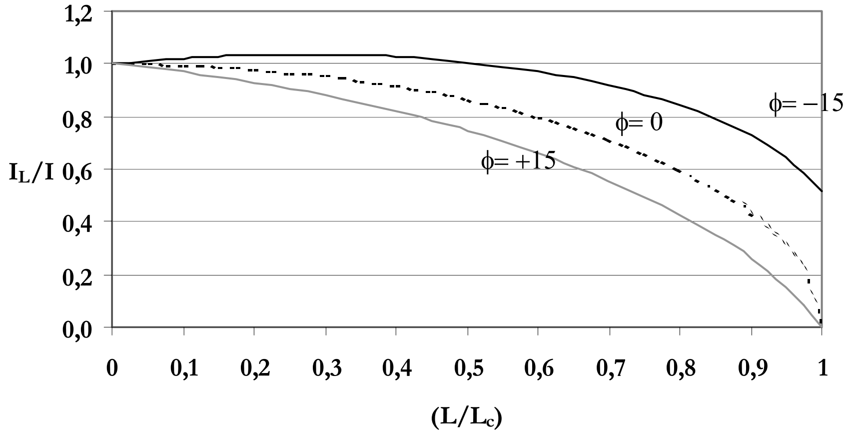


Figure 17 - The current ratio I_L/I as a function of the length ratio L/L_c for different load angles, ϕ. (Radial network)

From accurate modelling of lines, it is possible to calculate length limitations, which are more appropriate than that of critical length, resulting from constraints relating to the network itself.
This length cannot be compared with the maximum allowable length of a link because other limitations arise earlier. For proper operation, certain conditions must be satisfied:

- *Current limits*. The current at any point must be less than a rating capacity, beyond which there is a risk of damage due to the heating effects of losses. It should be noted that if the cable link is long, the highest load in the link is in one of the two ends, since the charging current normally is highest at one of the ends. This is true for both radial and meshed underground cable circuits. However, in the case of meshed networks the critical length can normally be extended significantly since the charging current is passing from two ends. The contribution of the reactive current to heating at the hottest spot (at the ends of the cable circuit) is reduced by a factor of four when the reactive current flows equally out of both ends of the cable as compared to all of the charging current flowing out of one end (radial network).

- *Voltage limits*. The charging current flowing through the series inductance of other transmission lines or transformers can cause a voltage rise on the cable (Ferranti effect). The voltage at any point must be less than the rating data for the equipment. It must not be less than another limit value, below which stability problems can arise.

3.3.1.2 Compensation

The transmission of reactive power reduces the capacity for active power transmission. In order to cope with this phenomenon, series capacitors are employed to compensate for line inductance, in overhead lines. The insertion of an underground section in an overhead line has nearly the same effect, but a distributed parallel capacitive “compensation”, like a cable, is constant at constant voltage, and is therefore not changing the compensation level as the series compensation does

For cables, the solution is to compensate for the capacitance by insertion of shunt inductive reactors. If properly tuned, the adjacent network is insignificantly affected. Shunt compensation is normally only needed for long cable routes, as seen in Figure 17. The rating of the compensation reactors has to be carefully selected in order to cope with voltage limitations during no-load conditions and to the compensation of the charging current for full-load conditions. A rule of thumb is that compensation may be relevant (from technical/economical considerations) when the transferable load has decreased by approximately 15 % or more.

If the consumption of reactive power is located far away from the underground line, the losses in the adjacent network may be increased if not shunt compensation is installed close to the underground line. It is therefore always recommendable to make a system study in order to optimise the cable system solution, with regards to different network aspects.

3.3.2 Thermal Dimensioning

Cables are classified by their type of insulation system. The thermal capability of the material defines the maximum allowed conductor temperature in steady state operation and short circuit condition (about 1 sec. duration). These temperatures are normally used as basis for thermal dimensioning of the cables for a given application.

In operation, there are thermal losses in the various cable layers/components. Each one of these heat sources contribute to rise the temperature of layer in the cable relative the surrounding. At steady state conditions the heat losses equals the heat transfer to the surrounding. The current that gives a temperature rise of the conductor to its maximum allowed steady state is called the nominal current. A cable system, especially with buried cables, is a slow thermal system that from a stable low load condition may carry a load during a limited period with a current higher than the nominal current without exceeding the thermal design criteria/maximum conductor temperature.

Except for the dielectric losses in the insulation, which are voltage dependant, the losses are current dependent heat losses in the conductor and all metallic layers as metallic sheath, reinforcement tapes and armour on submarine cables.

The AC-resistance of the conductor is higher than the DC-resistance due to effects that cause uneven current distribution over the conductor cross-section. For large conductors (usually larger than 800 to 1200 mm^2) segmented conductors might be cost efficient.

Induced currents in metallic sheaths, reinforcement tapes and armour cause losses that may be reduced by various means as:

- Laying configuration as trefoil configuration which in turn gives higher residual thermal influence
- Choice of metallic sheaths technology,
- Transposition of the cores along the circuit length
- Bonding techniques as single point bonding, mid point bonding or cross bonding of metallic sheaths. Maximum allowed sheath voltages limit the length of the cable sections between bonding points.

3.3.2.1 Thermal aspects for continuous loading

As described below, chapter 3.3.5, the choice of the bonding technique has a huge influence on the thermal dimensioning of the cable system.

The three main types of screen bonding influence the current capacity on the cable line: the both-ends bonding technique generates heat due to induced circulation in the screen, which decreases the current capacity of the line by 10 to 25%.

In both both-ends bonding and cross bonding technique cases, the distance between two conductors has to be taken into account (constant spacing / known varying spacing / unknown varying spacing).

In the cross bonding technique case, the difference in the lengths and cable configuration of minor sections (known or unknown) have also an influence on the capacity of the cable line.

If there are frequent transpositions of cables along the laying, the transmission capacity of the line is higher, especially for horizontal or vertical flat formation, in comparison to trefoil formation.

To keep it in mind, the result of the choice depends both on specific rules according to each country (maximum permanent induced voltage allowed for example), and on design standards on cable system (maximum induced voltage allowed on the screen when a fault occurs for example).

In addition to this point, depending on the laying technique and the spacing between conductors, heat is created which must be dissipated to the ambient.
The higher the operating temperature allowed on the conductor and the cable outer sheath, the more important are the thermal parameters listed below for the cable system design: ambient temperature, maximum soil temperature between dry and normal soil, thermal resistivity of the soil, thermal resistivity of the concrete laid around the ducts, soil drying, etc.

Speaking about thermal environment of the line, any electrical link and any hot spot along the cable must be localised so that a correct thermal dimensioning can be realised. The IEC 60287 [11] standard is the reference for thermal calculation on an underground cable with nominal current (continuous loading). In figure 18 some different installations like direct buried, air and forced cooling are presented. For comparative reasons a typical OHL rating is seen for 1 and 2 Al-wires.

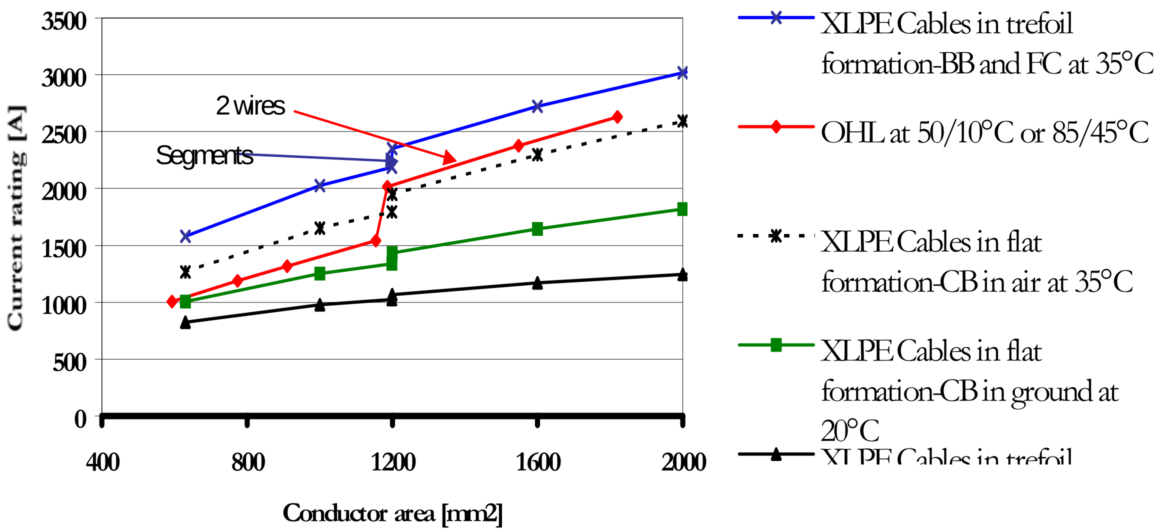


Figure 18 - The figure shows the nominal current (100 %) versus the cross section area of different cable installations and OHL systems.

Regarding the OHL a temperature difference of 40°C[1] ambient between conductor and ambient is assumed. For the XLPE cable 20°C soil temperature is assumed for buried installation and 35°C ambient for air and forced cooling installations. In the example, the effect of segments can be seen for conductor cross sections higher than 1200 mm^2. (usually between 800 mm^2 and 1200 mm^2). Additionally, the increase in current rating for 1 wire to two wires per phase is seen in the case of OHL.

Note: For the OHL only Al-conductors are considered and for XLPE Cables only Cu-conductors are considered. BB=Both-ends Bonding, CB=Cross-Bonding,FC=Forced Cooling

As seen in figure 18, the technical continuous current density for buried XLPE cables is laying between 0.5 to 1.5 A/mm^2 Cu, for XLPE cables installed in tunnels or air between 1 - 2 A/mm^2 Cu and for XLPE cables with external cooling between 1.3 to 2.5 A/mm^2 Cu. For OHL the technical continuous current density is laying between 2 - 3 A/mm^2 equivalent Cu-area.

3.3.2.2 Thermal aspects for non-continuous loading

[1] There is only a minor difference in current rating for different ambient temperatures if the temperature difference between conductor and ambient is the constant.

Cables and OHL show completely different responses to non-continuous (short-term) loads. In case of OHL, the temperature reaches a steady state temperature within minutes. With regards to cables, the steady state temperature may be reached within minutes to several weeks, depending on the magnitude of the increase, the size of the cable, the thermal history of the cable and the laying technique used. As will be shown in the next section, this feature of cables is very important for optimal thermal design of cables installed in the network.
The possible current rating for short-term loads versus duration is shown for 630 and 2000 mm^2, in figure 19.

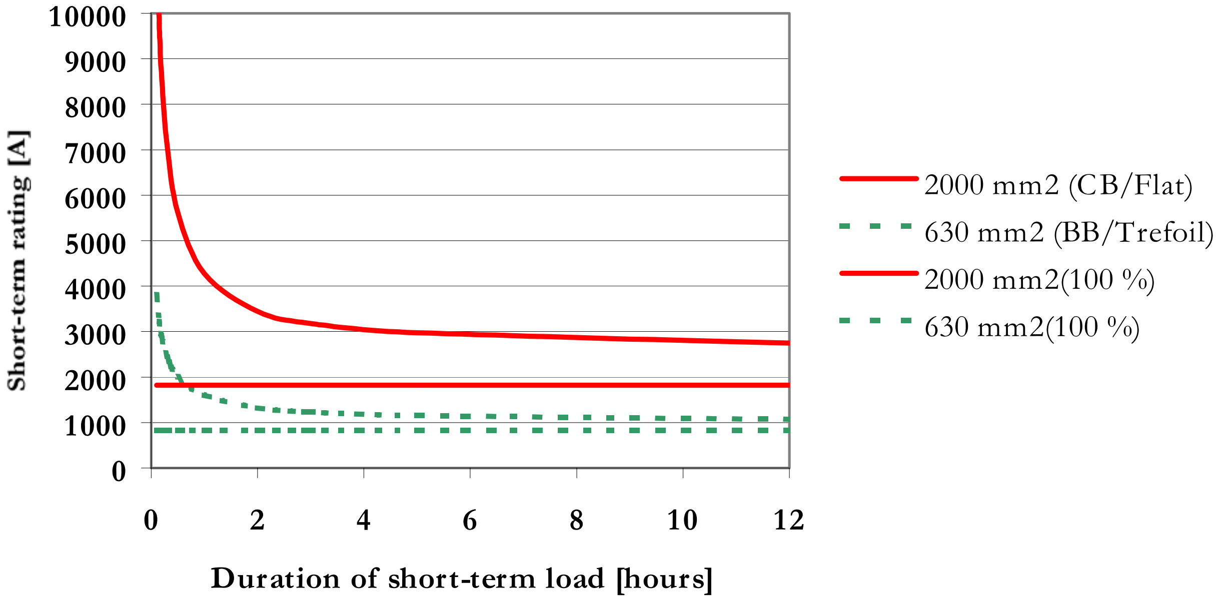


Figure 19 - The possible short-term rating for XLPE cables with Cu-conductors, 630 (installed in BB and trefoil formation) and 2000 mm^2 (installed in CB and flat formation). The pre-load is 50%, which equals 411 A for the 630-conductor and 912 A for the 2000-conductor. The final temperature for the short-term load is 90°C.

In the same way, the relative short-term ratings for Cu-conductors at 50% pre-loading, are shown for 30 minutes and 12 hours duration in figure 20. The relative continuous rating equals 1 for the nominal current at 90°C. The cables are installed in flat formation, the screens are cross-bonded and a final temperature of 90°C in conductor during short-term loading is used.

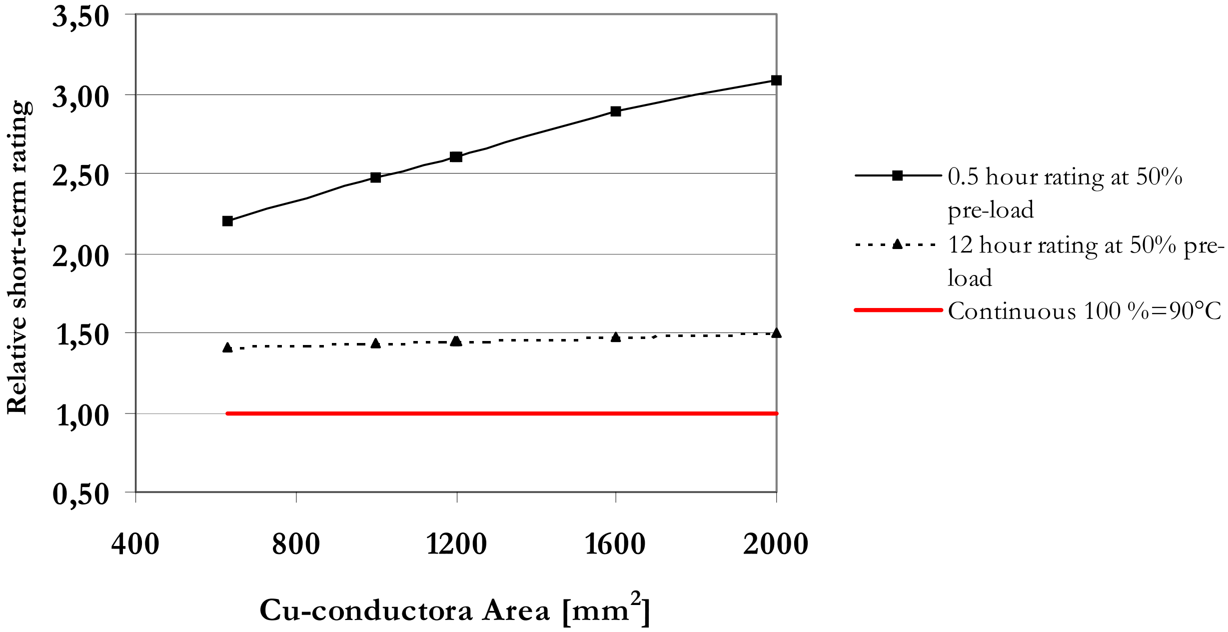


Figure 20 - The possible short-term rating for XLPE cables with Cu-conductor during ½ and 12 hours, when the pre-loading of the cable is 50%. The relative continuous rating equals 1 for the nominal current at 90°C. The diagram is valid for cables in flat formation, cross-bonded screens and a final temperature of 90°C in conductor during short-term loading is used.

This indicates the excellent "short-term" loading properties of buried cable systems. For time durations exceeding 12 hours, the relative short-term rating is almost independent of the conductor cross-section, as seen in figure 20. Furthermore, starting from a pre-load of 50% a buried XLPE cable system is able to carry 110-120 % of the nominal current during 100 hours. All these features can be utilised for optimised design of a cable section installed in the network. For example, 100 hours is in many cases adequate for joint repairs.

The standard reference for calculating the dynamic ratings of cables is given in IEC 60853 [12].

3.3.2.3 Optimised thermal rating for underground systems in the network

The majority of load patterns is varying during day and/or during the year. This aspect is very important to take into account when designing cable links installed in the network, like siphons, cables in meshed networks and entrances to substations, for example. For other network configurations, like generator output or auxiliary transformer connections, the situation may be totally different. In the former case, the cable may be overloaded for quite a long period of time and in the latter case the loading is high and fixed most of time.

In some system configurations as described earlier, the optimisation of the cable dimensioning is rather easy, as far as the transmission current throughout the cable life is well known.

Three systems configurations require more attention:

- Underground cable system in a meshed network
- Siphon
- Underground entrance to a substation.

Underground cable system in a meshed network: Current sharing between cable and OHL coupled in parallel, is settled by the impedances. A cable has lower impedance than the OHL which means that the cable takes most of the current. This must be considered to avoid overloading of the cable. Unequal current sharing is also different for different types of cables. The cable must be dimensioned for the load resulting from the final configuration of the network and not for the additional load to carry.

Underground entrance to a substation and siphon: Second and third configurations are called hybrid systems. In these cases, cable and overhead line are connected in series. As short-term overload rating of underground cables are substantially higher than those of overhead lines, for optimising the cost of the underground section, thermal dimensioning must be done accordingly.

Indeed, overhead lines are essentially insensitive to daily load factor (LF=the average ampacity in percentage of maximum ampacity during 24 hours), while underground lines are strongly influenced by this parameter.
The thermal time constant of a buried cable system is typically measured in weeks. This is due to the great thermal inertia of the earth. Overhead lines have a time constant typically measured in minutes. A short time variation of load produces the same line temperature as a constant load or for most typical utility load cycles. (5, 10, 20, 60 minutes or 1-3 weeks).
In fact, the thermal time constant of the cable itself is typically measured in hours, and has little effect on normal rating for typical utility load cycles, but would have an important effect for load cycles with short periods and peak loading.

As a result of the above, when a cable is connected in series with an overhead line, and as the line is generally operating in the order of 50 to 70 % of its maximum in normal load conditions, cable can be easily overloaded for hours at the maximum rating of the line, for (N-1) configuration, which is most of the time long enough.

The two graphs in figure 21 below show the influence of the thermal time constant for an UG Cable and an OHL, when the ampacity needs and limited load durations are the same for the two systems. We can see that the ratios between normal load conditions and limited duration load conditions are totally different depending on the system used.

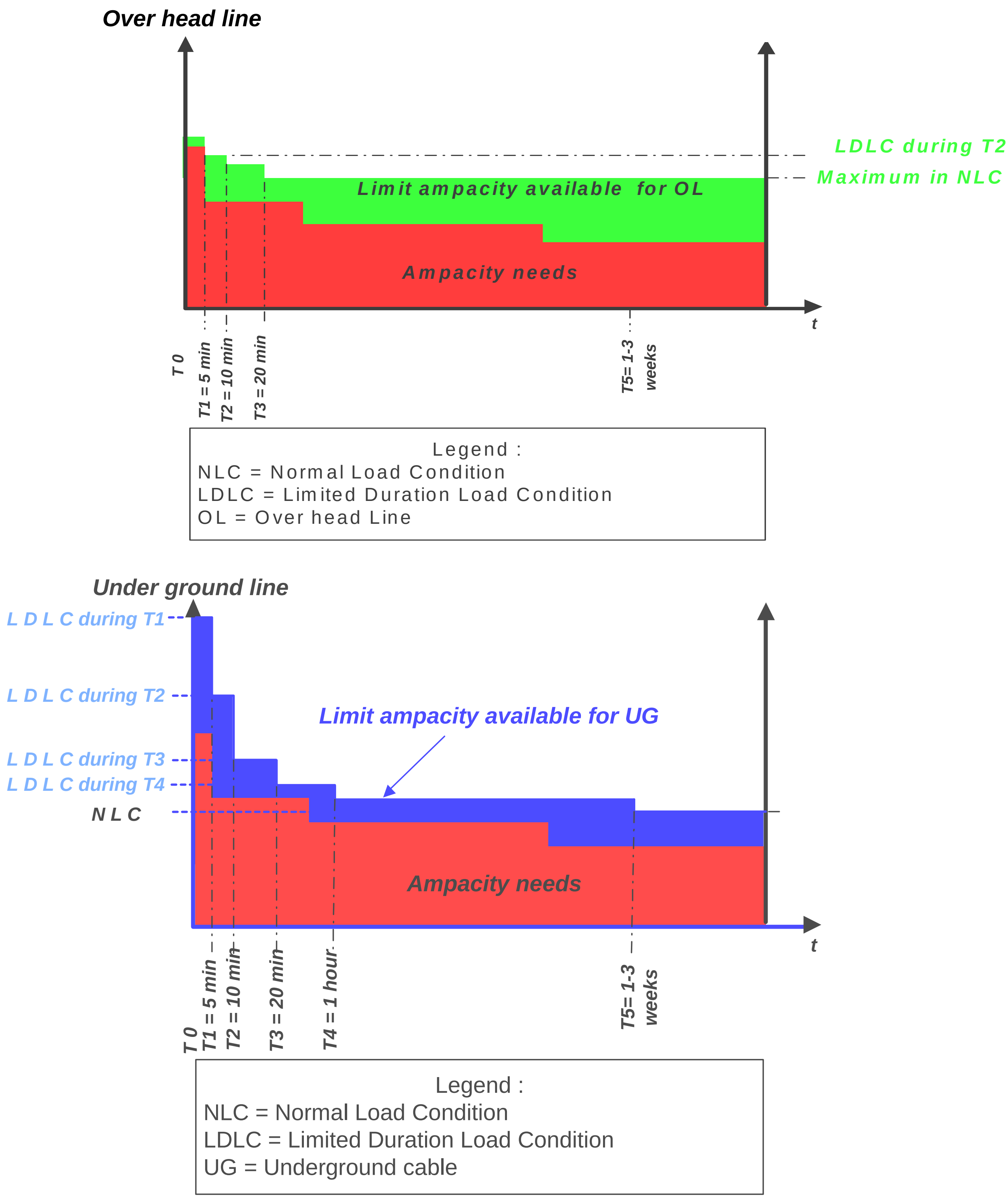


Figure 21 - Difference in thermal capacity of buried UG cable and OH systems.

Taking into account this difference on ratios, different types of dimensioning the underground line can be used.
On the third graph in figure 22 below, underground cables 1 and 2 are both in accordance with the ampacity operation needs of the grid. Underground cable 2 also matches the ampacity available from the OHL. Using the same technique for the cable and the laying conditions, the cable size number two is really bigger than the size of cable number one.
For the same result during operation, a cheaper solution would be to install UG1 and not UG 2.

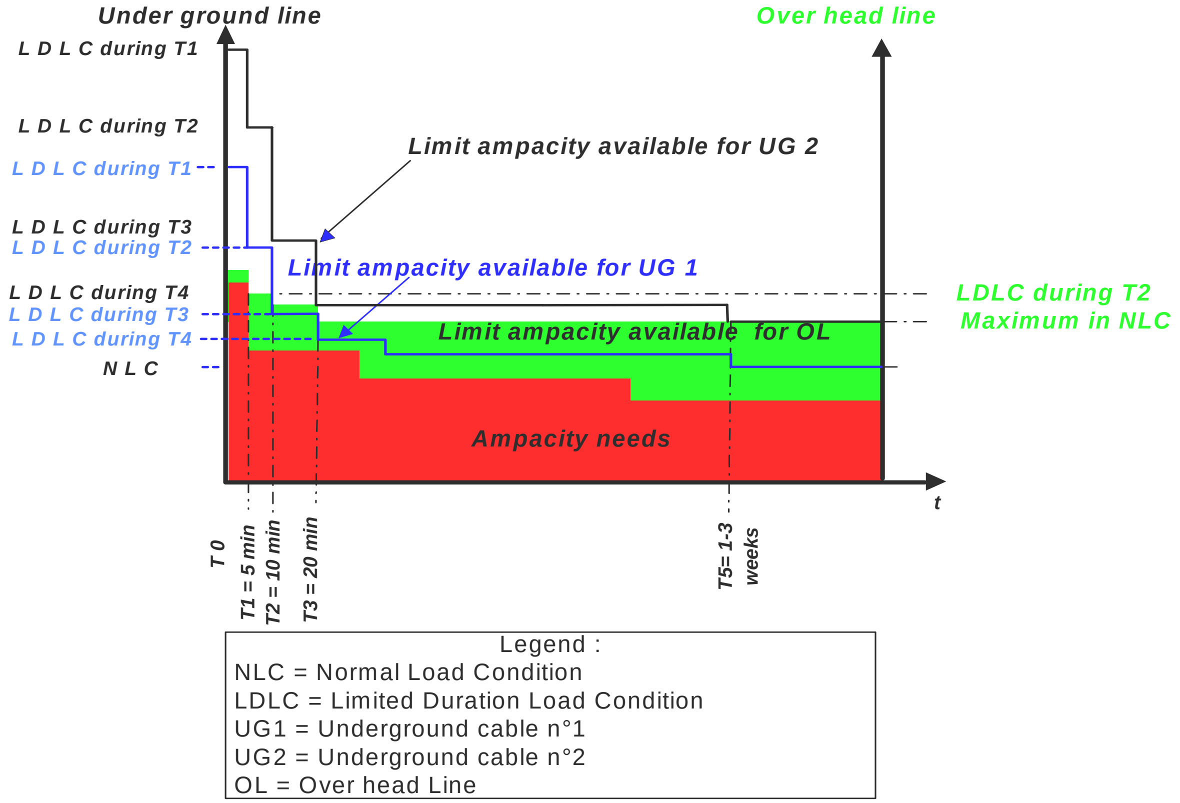


Figure 22 - Difference between two designs of Underground Lines (UGL).

3.3.3 Economical optimisation of conductor area

In addition to the previous paragraph which introduced the conductor's size, the cost of a transmission system consists of investment costs like material, installation and civil work and capitalised costs like losses, maintenance and others. To optimise such a system from an economical point of view is a complex task, since there will always be technical and environmental considerations to take into account during the evaluation process.

Once an optimisation process is started, there are several key elements that are important to consider, however.

- Joule energy losses in conductor and shield/sheath. Those losses are dependent on the current only and it is therefore important to incorporate the "loss factor" for the optimisation process. The loss factor is defined:

$$Loss Factor = 0.7 \cdot LF^2 + 0.3 \cdot LF \qquad where LF \text{ is the daily load factor}$$

- Dielectric energy losses in insulation. Those energy losses are active 100 % of time and may be rather high, especially for oil-filled cables and voltages above 220 kV.
- The utilisation factor of the system during the year.
- The calculation of the cost of energy loss based on a) energy charge and b) the charge for the additional supply capacity to provide the losses.

The procedure for calculating the most economical conductor area is given in IEC 60287-3-2. Today this guide may be difficult to apply since the total cost contains investment cost as a linear function of cross-sectional area, which is not applicable or true in most situations. Other costs like costs of dielectric losses, maintenance etc. are not included, since those costs are eliminated when the optimisation (derivation) takes place. Furthermore, the utilisation factor is not included.

The following formula may be more convenient for evaluation of the total costs.

$Total\ Cost\ per\ year = \alpha \cdot IC + yDL + yJL + yOC$

where

α=annual capital charge factor
IC=Investment Cost for a given conductor cross-sectional area
yDL=yearly cost for dielectric losses
yJL=yearly cost for joule losses in conductor and shield/sheath. $= k \cdot W_{loss} = 3 \cdot R_{ac}(1 + \lambda_1 + \lambda_2) I^2 \cdot LF \cdot u \cdot 8760 \cdot k$ *currency*
k is the charge for 1 kWh of energy.
λ_1, λ_2 are ratio of total losses
u is the yearly utilisation
yOC=yearly cost for environment, maintenance, renovation etc

In this formula the conductor cross-section is already chosen, or different sizes may be tested.
This formula may also be divided by the "average" transmitted power $S = \sqrt{3} \cdot U \cdot I \cdot u$ during the year, where *u* is the yearly utilisation. Thus, the cost is given in currency/year, MVA.

It should be noted that whether small or large conductors, one or more cables per phase etc. are chosen, all decisions will have overall economical and environmental impacts in one or another way. From a system point of view, however, the losses in the system have a big influence on the total environmental impact and should be taken into account, if possible (see section 8.8).

3.3.4 Short Circuit Characteristics

The cross-sectional area of the cable conductor and shield/sheath must be selected to carry fault current until the fault is cleared by a circuit breaker, without exceeding the short-circuit temperature rating of the insulation and/or outer serving. The maximum temperature for XLPE insulation is normally 250°C.

A commonly used formula to calculate the adiabatic temperature, i.e. no heat is dissipated during the fault, is:

$$\left(\frac{I_{sh}}{A}\right)^2 t = k \cdot ln\left[\frac{\theta_2 + \theta}{\theta_1 + \theta}\right]$$

I_{sh}=maximum short circuit current [A]
k=constant for conductor or shield/sheath material, dimensionless
A=conductor or shield/sheath cross-sectional area
θ=temperature of inferred zero resistance
θ_1=temperature of conductor or shield/sheath before short-circuit
θ_2=temperature of conductor or shield/sheath after short-circuit

For transmission cables, the time t, is normally assumed to be the back-up breaker fault clearing time, which should be less than 1 second. If other clearing times are present the following formula can be used:

$$I_t = \frac{I_1}{\sqrt{t}}$$

t=short circuit duration [s]
I_1=short circuit current during 1 second
I_t=short circuit current during t seconds

Auto re-closing of OHL in meshed networks is common. Auto re-closing is performed by the primary protection, which means that tripping time of the fault is short. Short time over-current design of OHL and cables are done for the back-up protection. Total short time over-current at auto re-closing of the OHL against a persisting failure is normally lower then the short time over current when back-up protection clears the fault.
If a cable constitutes a section in an OHL, for example a siphon, the cable must be designed for faults in the OHL and in the cable.

<u>Power frequency faults in the OHL</u>
The cable section in the OHL transmits fault current to the fault in the OHL. Conductor and screen of the cable must be designed for the largest fault currents that may appear or the established fault currents specified for the network. The design of the cable does not differ from design of cables in pure cable networks.

<u>Power frequency faults in the cable</u>
For single point bonding technique earth fault in the cable means that the fault current in the screen is in the same order as the fault current in the conductor. The cable is at least grounded at one end. If the resistance of the grounding is high, the voltage of the local earth grid is high. If the cable is long, the voltage between the screen and the ambient may be high far from the earth grid. This voltage may be too high for the oversheath of the cable. To limit the voltage over the oversheath a bare groundwire must be installed in parallel with the cable. The groundwire is an extension of the earth grid to which cable screens are connected.

In other words, as a conclusion, there is no thermal overheating of the conductor and/or screen if the duration for the back-up protection is the base for the short time current design. The total fault clearing time, including auto-reclosing, of the main protection is lower than the total fault clearing time for the back-up protection. Re-closing of OHL including cable sections is therefore possible from a technical point of view if the described protection philosophy is used. Other considerations, such as personal safety (for example tunnels) and an immediate signal for the location of the fault, may in some cases imply a separate protection of the cable, however.

In CIGRE technical brochure 194 “Construction, laying and installation techniques for extruded and self contained fluid filled cable systems”, other issues are also discussed. [6]

The standard reference for calculating allowable short circuit currents in cable networks is IEC 60949 [13].

3.3.5 Main Insulation Coordination of cables installed in the network

In Cigre brochure 189, “Insulation Co-ordination for HV AC Underground Cable Systems”[7], this topic is covered in more detail. Here some additional information is given

3.3.5.1 Lightning overvoltage

When a cable is introduced in an OHL network, it needs to be protected against overvoltages caused by lightning strokes to the OHL. Normally, the primary overvoltage protection comprises surge arresters mounted in parallel to the cable terminations at both ends of the cable.

If the cable is very short (below 50 m), surge arresters are normally needed at one end of the cable only, considering the typical steepness of the overvoltage wavefront.

If the cable is sufficiently long (above 1-2 km), surge arresters may be used at one end of the cable only, provided that overvoltages cannot enter the cable at the other end. A typical case may be a cable terminated in a substation, with surge arresters installed only at the OHL end of the cable. In this case, it is required that the shielding and grounding arrangements of the OHL are extensive in the vicinity of the cable junction, so that close flashovers and long-duration overvoltage waves are avoided. In practice, the OHL needs to be equipped with shield wires or grounded crossarms in several spans closest to the cable termination.

To keep the overvoltage level at the unprotected endpoint of the cable below the insulation withstand level, the protective level of the surge arresters must be as low as possible. This is because the overvoltage amplitude, which is limited by the arrester’s protective level, may double at the endpoint if the cable is open-ended. Detailed simulations of the lightning overvoltages are anyhow required to determine the risk of insulation failure of the cable when surge arresters are used at only one end, except when the cable is very short. Such studies are of special importance for cables of intermediate length that cannot be protected by surge arresters at both ends, e.g. when the cable is directly connected to a transformer without air-insulated bushings.

Whenever possible, it is suggested to use surge arresters at both ends of the cable except for very short cables (below 50 m). In this way, the overvoltage levels are well controlled at both ends and practically independent of the lightning performance of the OHL. The remaining issue is the overvoltages appearing along the cable due to superposition of reflected and transmitted waves. This phenomenon is illustrated by example of a simplified single-phase overvoltage calculation (fig 23):

A 132 kV cable with a length of 2 km, connected to an OHL at one end, is protected at both ends by typical metal-oxide arresters with a rated voltage of 120 kV and a protective level of 273 kV at 10 kA. A lightning current of 50 kA with typical waveshape causes a back flashover on the OHL in a nearby tower with a grounding resistance of 25 Ω. In the single-phase simulation, these conditions result in an arrester current in the range of 25-30 kA, which can be considered as a very high value.

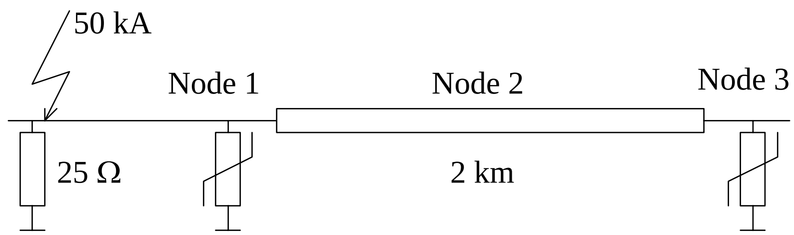


Figure 23 - Simplified circuit for lightning surge to an OHL close to a cable protected by surge arresters at both ends.

The result of the calculation is shown in figure 24. The overvoltages during the first 50 μs are shown at three points: the entrance (node 1), the midpoint (node 2) and the endpoint (node 3) of the cable.

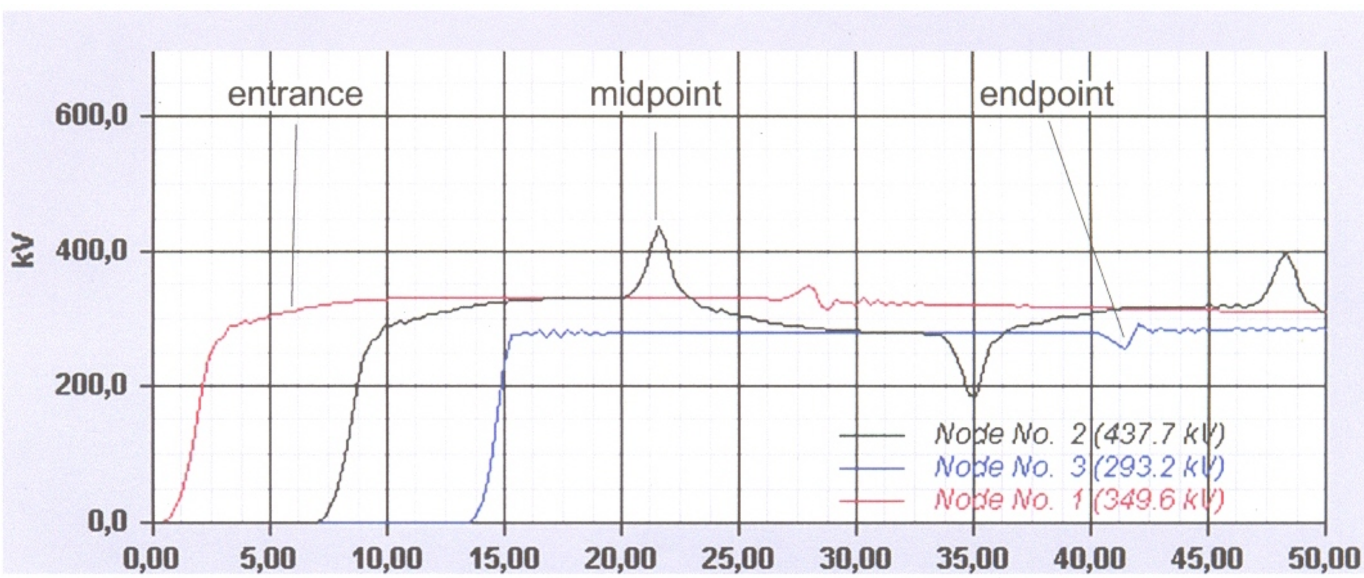


Figure 24 - Calculated lightning overvoltages at cable entrance (node 1), midpoint (node 2) and endpoint (node 3).

As seen in figure 24, an additional overvoltage peak is superimposed on the incoming wave at the midpoint of the cable (node 2). The additional peak is actually the reflected part of the overvoltage that appears at the endpoint of the cable before the voltage level has approached the protective level of the endpoint arrester. This is because the cable appears as open-ended until the arrester starts drawing current, which happens at about 80% of the protective level. The reflected part of the voltage, or about 40% of the protective level of the endpoint arrester, is then superimposed on the incoming wave.

This example shows that, by installing surge arresters at both ends, the maximum overvoltage level anywhere along a cable is less than 140% of the arresters' protective level (for the actual arrester current). For very long cables, the maximum overvoltage levels tend to decrease due to the limited duration of the incoming wave, i.e. the reflected wave is no longer superimposed on the peak of the incoming wave, but at the declining tail portion of the wave.
The example also shows that the standard choices of lightning insulation withstand levels, e.g. 550 or 650 kV for 132 kV systems, are often conservative with respect to the reduced overvoltage levels that may be obtained with adequate application of modern surge arresters. In fact, additional calculations showed that the overvoltage levels could be reduced a further 10-15% if the rated voltage and protective level of the arresters were optimised, e.g. by choosing a rated voltage of 108 kV instead of 120 kV.If the foot resistance is high, a case by case study is however recommended.

3.3.5.2 Switching of cables

Switching of unloaded cables imposes similar conditions as with the switching of capacitors. Breaking capacitive current is generally a simple case for a circuit breaker and gives no severe voltage stresses, as modern breakers prevent re-striking.

Reclosing of OHL and cables can give high overvoltages especially if the other end of the line/cable is open.

Cables have a lower surge impedance than OHL. Short cable sections in the network cause changed conditions for surge reflections and, therefore, voltage stresses on the circuit breaker will be lower rather than higher.

Cables have a high capacitance compared to OHL. However, considering that circuit breakers operations normally are few (compared to switching of capacitor banks) synchronous switching or other means to reduce transients are normally not required, except for very long cables.
Furthermore, surge arresters on the cable also protect the circuit breakers from high switching overvoltages. The arrester energy capability required for discharge of long cables have to be considered.

3.3.6 Choice of grounding technique.

In order to achieve in an economic way the current rating of the cable system, as determined in paragraph 3.3.2 and 3.3.3 hereabove, it is current practice to use special bonding techniques for the cable system.

If this results in a better transmission capacity for the underground cable, or in a much cheaper design for a cable assigned to a given transmission capacity, permanent and transient voltages can appear in the sheath and at the metallic(or conducting) parts at the ends of the cable sections.

The grounding technique has to be designed taking into account the voltage withstand level of cables and accessories, and voltage stresses during normal operation and during a failure on the overhead part or on the underground part of the line.

This design is subdued to:

- electric induction on the sheath, during normal operation and even in case of a fault,
- specific rules depending on each country, relative to the maximum induced voltage allowed on the sheath, next to any point where someone can touch (wiping bell near transition compounds towers for example); the voltage allowed varies between 35 to 400 Volt.
- the resistivity of the ground to eliminate the voltage in the sheath,
- the resistivity of the towers next to both ends of the underground line,
- if it exists groundwires on the overhead line,

- the value of the asymmetric factor taken into account during a fault at power frequency,
- surge arrestors specifications.

3.3.6.1 General approach.

Three types of earthing grid can be distinguished on the underground part of the line.

3.3.6.1.1 The solid bonding method (case 1)

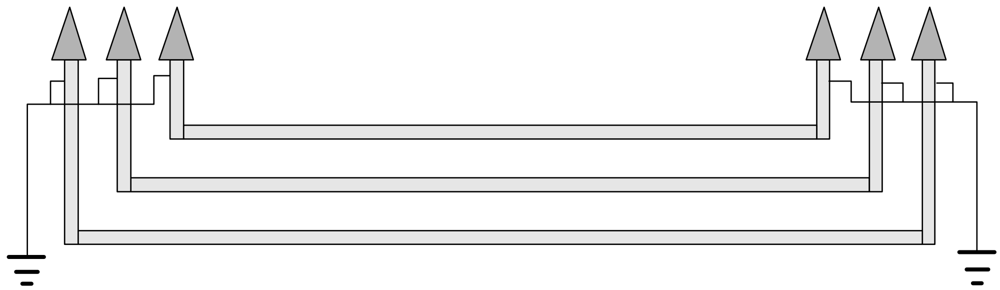


Figure 25

3.3.6.1.2 The single point bonding method (case 2)

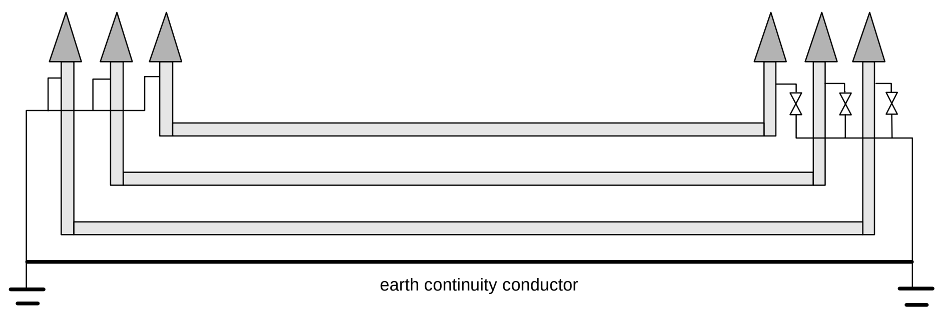


Figure 26 a

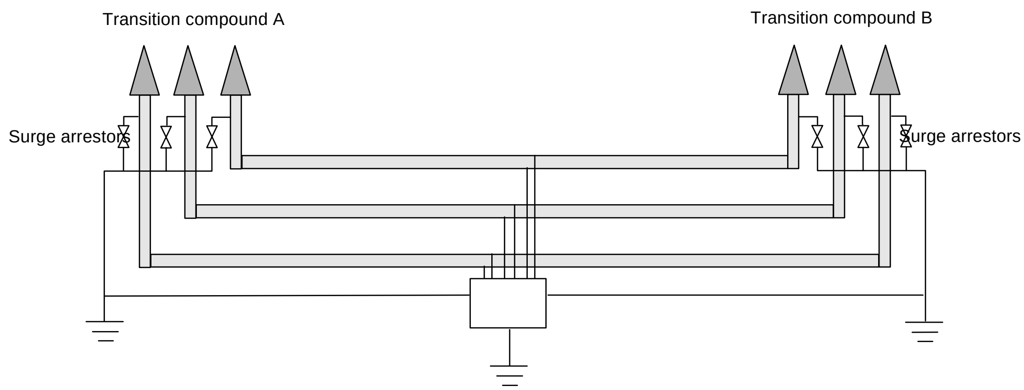


Figure 26 b

In some countries, the Earth Continuity Conductor (ecc) along the line is not used and the earth is used to return the fault current during a failure.

In other countries, no surge arrestor is used.

3.3.6.1.3 The cross bonding method (case 3)

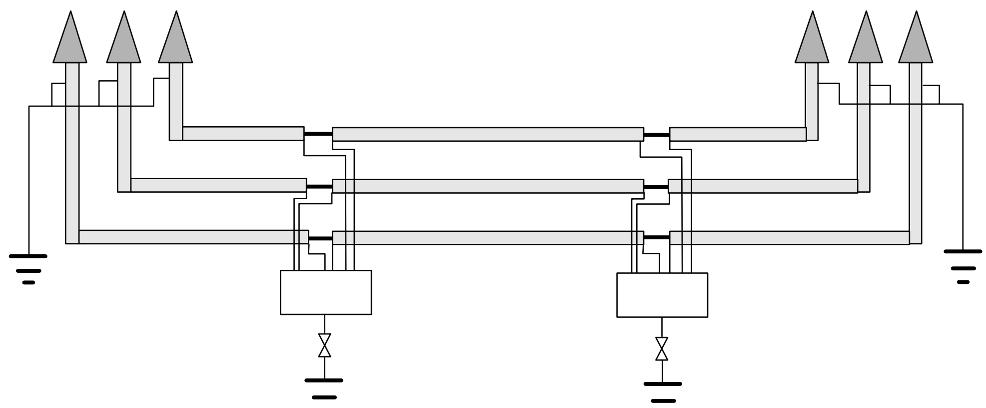


Figure 27

3.3.6.1.4 Comments on those methods

All those methods are available but

- as losses are created in the first case, it's better to have low ampacity in the line. The voltage level in the sheath is close to zero along the line because it is only due to capacitive currents,
- in the cases 2 and 3, surge arrestors have to be well chosen. Indeed, like any diode, they have to be inoperative when it's a AC failure, but operative to protect the line from lightning and switching impulses,
- in case 3, the method can be used even for a long distance line,
- while operating, the techniques used to detect a fault on the underground part of the line are not the same and depend on the earthing method used. Moreover, the costs are really different.

3.3.6.1.5 Design of single point bonded and crossbonded systems.

Articles in Electra 28, 47 and 128 [14] [15] [16] have addressed the subject of bonding and serve as fundamental basis for many present day designs.

CIGRE WG B1-18 is preparing a Technical Brochure to extend certain issues which have not been sufficiently covered and to update some others in order to take advantage of more recent developments in analytical techniques.

Formulae given in Electra are generally suitable for systems where the underground link is connected between 2 substations.
In some occasions, they may turn into overestimating voltage stresses in the system, and, so, lead to a design on the safe side.

Hybrid systems, where the underground link is connected to an overhead line at one end or at both ends (siphon systems) generate some difficulties which do not exist for underground links connected to substations at both ends.

These difficulties concern:

- The voltage rises due to single phase to earth fault, occuring either on the overhead line or the underground link.
- The transient potential rises due to switching or lightning impulses.

The determination of sheath overvoltages affecting a specially bonded cable link during single-phase faults is relatively complex because these overvoltages strongly depend on the distribution of the fault current in the ground network. [14] [15]

3.3.6.2 Detailed approach of bonding of hybrid systems.

3.3.6.2.1 Introduction

The calculation of voltages and currents in special bonded high voltage cable systems (either power frequency or transient) is generally based on a model, in which the cable system and its relevant surrounding is represented by distributed impedances.

The general model is very complicated and does not allow a fast and easy calculation of voltages and currents.

For power frequency applications, by introducing some assumptions, it is possible to derive simplified equations for induced voltages, which can be handled with simple tools like pocket calculators or universal spreadsheet programs without the need of special numeric computer programs.

To derive Electra formulae, the following assumptions are made:

- Phase currents are known for all cases
- Symmetric currents flow during normal operation and 3 phase faults
- No currents flow other than currents in phase conductors for normal operation, phase to phase fault and 3 phase fault
- For single phase faults the fault current returns 100 % via the ecc in single point bonded systems or via the cable screens in cross bonded systems
- Cross bonded systems have either balanced minor and major sections (sectionalised cross bonding) or a number of uniform elementary sections exactly divisible by three (continuous cross bonding)

The calculation of induced sheath voltage under fault conditions was performed by CIGRE WG B1-18, using different methods such as Complexe Impedance Matrices (CIM) or ElectroMagnetic Transient Program (EMTP) [17] with different worked examples.

For most applications the studies support the use of methods previously published in Electra to within good accuracy and with the benefit of being simple to apply.

Significant discrepancies with Electra formulae were found only for single phase faults, coming from the assumption that the the fault current returns 100 % via the ecc in single point bonded systems or via the cable screens in cross bonded systems

In some cases, especially hybrid systems, this condition is not fulfilled.

Under single phase to earth fault conditions the return current divides between the three sheaths in parallel for crossbonded systems or the Earth Continuity Conductor (ecc) for single point bonded systems, and the earth, the proportion of current returning via the earth depending on the sheath resistance and the earthing resistances at the ends of the circuit.

Precise calculations are not straightforward since the proportion of the return current which flows in the earth, depends on a number of factors which are not usually accurately known. Indications are given in reference [18] to work out an estimate.

3.3.6.2.2 Specific characteristics of hybrid systems

In practical situations, underground links are often connected to a substation at one end.

This configuration is illustrated below in figures 28 and 29: the UG link is connected directly to a substation, at the left hand end.

Figure 28 represents a solid-bonded link or a cross-bonded link, where cable screens are grounded at both ends.
Figure 29 is for a single-point bonded link with an earth continuity conductor (ecc) installed.

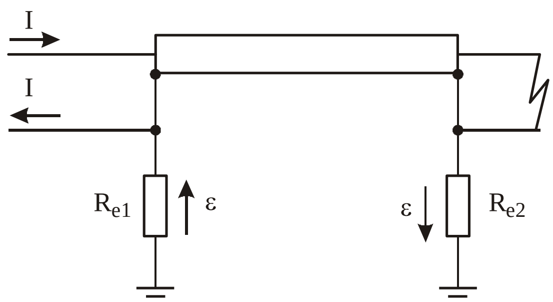


Figure 28

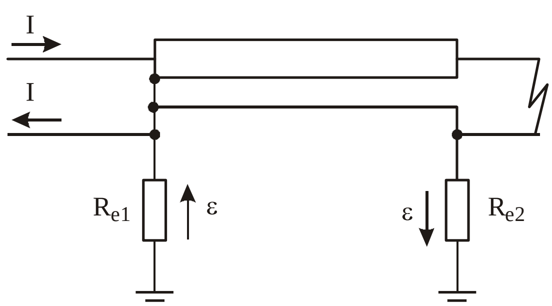


Figure 29

The earth resistance at the right end is expected to be low, as it is the substation earth resistance.
If the earth impedance at the right hand end (UG to OH compound) is much higher than the earth resistance of the substation, then, in the case of a single-phase fault, the short-circuit current returns mainly through the metallic screens or the ecc and the Electra formula is applicable.
In the unlikely case where the earth impedance at the UG to OH compound is very low, the return short-circuit current flows mainly in the ground and the Electra hypothesis is no longer fulfilled. Using it results in overestimating stresses.

When considering siphon systems, the situation is quite different.

This situation, where the cable is connected via an overhead line without groundwire to the substation is explained with figures 30 and 31.
Figure 30 shows a cable with screens both ends bonded for solid-bonded or cross-bonded systems.
In these figures, the fault is assumed occurring on a termination at right end. The fault current is injected in the grounding at the cable end.

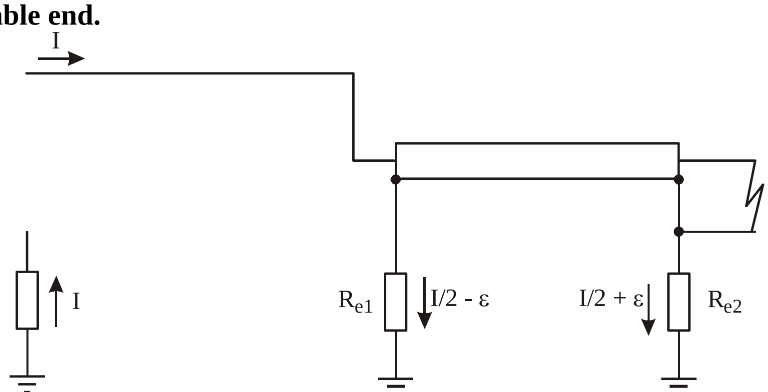


Figure 30

Figure 31 shows an accompanied ecc installed along the cable.

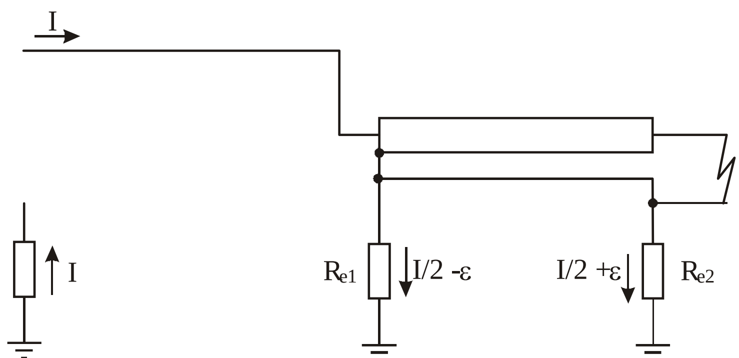


Figure 31

Assuming that the earth resistances at both ends have the same magnitude, then the short-circuit return current divides roughly equally between the screens or the ecc and the earth rod at the fault position. So the Electra hypothesis that the whole return current flows in the ecc is not fulfilled.

If the overhead line involves a groundwire, the situation is not different, except that the path for the short circuit return current is no more the earth resistance at the ends, but these resistances in parallel with the groundwire. This turns into lower earth impedances.

3.3.6.2.3 Earth potential rise at the cable ends

It is worth calculating earth potential rises at cable ends for hybrid systems, during single-phase faults.
For cross-bonded systems, the sheath-to-earth voltages at sectionalising joints result from the vectorial sum of the voltage gradient on sheaths (E_s) and the earth potential rise (V_e) at the cable termination (see figure 32).
The earth potential at the sectionalising joint location is assumed to be zero. This assumption is valid if the cable section is long enough (a few hundred metres or more) to be outside the zone of influence of electrodes dissipating earth current and if there is no extraneous metallic connection between earth electrodes along the cable circuit.

If the overhead line has not a groundwire, the entire fault current is injected in the earth electrodes at the cable system extremities, when a fault occurs on a termination.

Very high earth potential rise values (V_e) are to be expected in such cases.
For example, a 10 kA fault current injected in a 10 Ω HV tower earth electrode should produce an earth potential rise of 100 kV.
In practical situation, the short-circuit current would not have the magnitude calculated when assuming a zero ohm fault resistance. In addition, the generation of power behind the fault is limited, the voltage will tend to decrease when the current becomes high. This will in a practical situation also contribute to a lower short-circuit voltage. So that the injected current will not be equal to the nominal short-circuit current, derived for a zero ohm fault resistance. This turns into less high earth potential rise (see example hereunder).

If a groundwire is used, it carries a fraction of the fault current. Steel groundwires have a high resistance and carry typically 5 to 20% of the fault current. If aluminum is used, this fraction can reach 50%. Furthermore, groundwires contribute to reduce the impedance of the earthing system by connecting the tower footings of the overhead line. Earth potential rise values (V_e) typically ranging between 5 and 50 kV are to be expected in such cases.

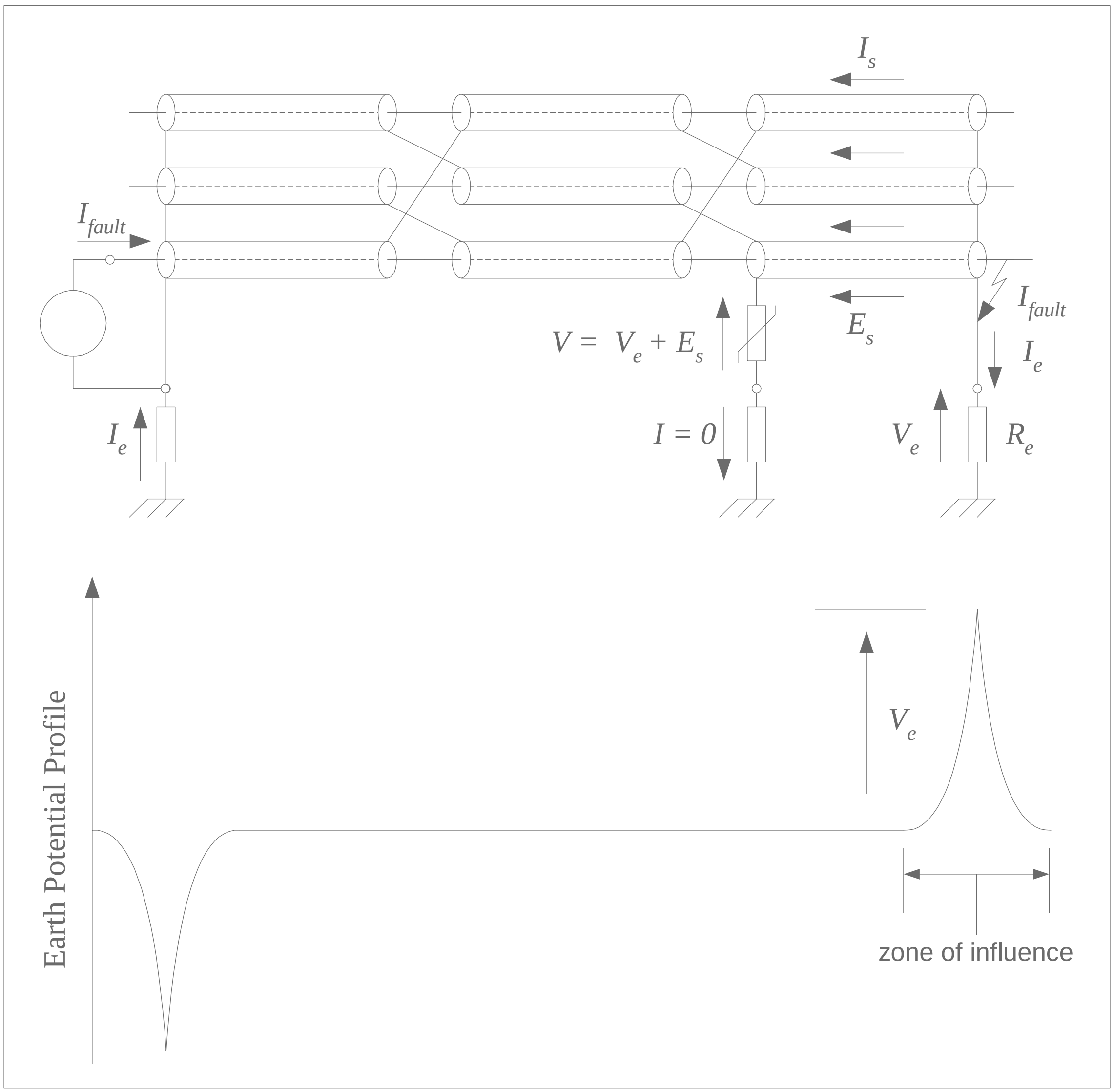


Figure 32 - Sheath-to-earth voltages on cross-bonded cable systems in case of phase-to-earth faults

The Surge Voltage Limiters (SVL) do not have the energy handling capability to limit voltages during power faults. In cases where the voltage exceeds 20 to 30 kV, the SVLs should have a voltage rating of at least 15 kV_{rms} if they are star connected with the neutral point earthed. Such an arrester would produce voltages in the order of 50 kV under transient conditions. The voltage across the sheath interrupt reaches 100 kV (two SVLs in series) to which the voltage drop across the bonding leads must be added. These voltages may reach or exceed the BIL of the sheath interrupt.

In such cases, a lower voltage rating for the SVLs can be used if the neutral point connection of the SVLs is isolated from earth or if they are delta connected. Another option is to install an ecc.

To reduce the overvoltages applied on SVL, an ecc may be used.

For single point bonded systems, it is also worth considering earth potential rises since they affect the voltages that cable oversheaths have to withstand outside of the zone of influence of electrodes dissipating current.

Calculation of the earth potential rises and the resulting sheath-to-earth voltages is complex because they are sensitive to the current distribution between cable sheaths and earth. Detailed calculation methods such as CIM or ATP/EMTP are required. The accuracy of the calculation depends on the information available on the impedance of the earthing system. Furthermore, the location of the cable circuit can influence significantly the current distribution between sheaths and earth.
A method for approximate calculations is reported in Jicable paper [18].

3.3.6.2.4 Practical example:

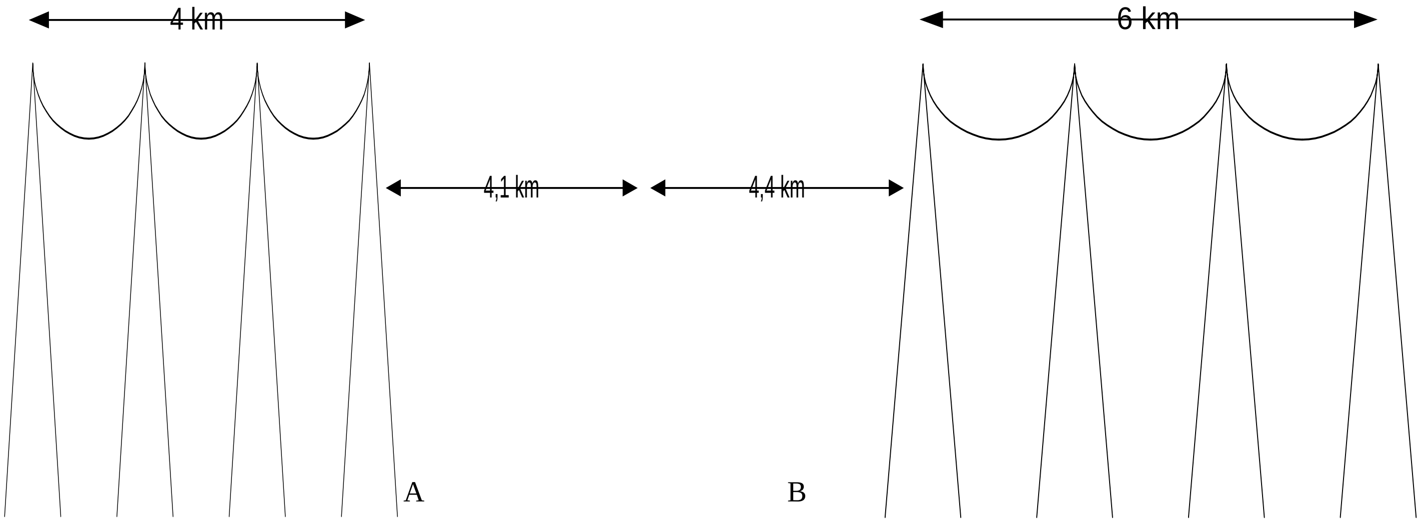


Figure 33 - Practical example

We consider that the line has groundwires, and the values of Zo and Zd are:

	Zo	Zd
Transition compound A	11.7	14.5
Transition compound B	18.5	36.5

3.3.6.2.4.1 In case of a fault on the undergroung line:

The induced voltages on the underground line depend on the resistivities of the towers, and on the localisation of the fault. In the example above, no asymetric factor is taken into account.

- **<u>The fault is supposed to be next to transition compound A:</u>**

	Induced voltages (V)		
Resistivities of the towers:	Transition A	Middle	Transition B
10 Ω,	19203	6751	8500
20 Ω,	20141	7718	8003
30 Ω,	20454	8282	8515

- **<u>The fault is supposed to be next to the middle:</u>**

	Induced voltages (V)		
Resistivities of the towers:	Transition A	Middle	Transition B
20 Ω,	9937	6788	7023

3.3.6.2.4.2 In case of a fault on the over head line:

The induction on the sheath must be kept lower than the cable and accessories design value. No specific calculation is needed because the problem is mainly when there is a fault on the underground part.

3.3.6.3 Optimization of the bonding technique

To minimize the cost of an underground section, one tries to reduce the number of joints and thus to increase the length of cable between joints or between joints and terminations. This results in an increasing voltage at the metallic screen of the cable as well under permanent conditions as during short-circuit or transients. If the maximum allowable screen voltage under permanent conditions can be decided by utility and/or authorities, screen voltage rises during faults or transients are depending on several parameters as explained hereabove. In the same way as main insulation must be protected by arresters, the cables sheaths, and the cross bonding joints, must be protected both during lightning impulses and faults at network frequency.

The maximum allowable screen voltage raise under permanent conditions can be fixed at a high value as 400V, such that the length of elementary sections may be limited by overvoltages due to fault conditions.

The choice of protective surge arresters for cable sheaths has to be optimized in order to obtain the longest possible elementary sections and thus the lowest cost.

The rated voltage of surge arresters must be determined as a function of two conflicting considerations:
* surge arresters must be designed to provide a level of protection against transient overvoltages compatible with equipment withstands,
* they must resist the highest possible overvoltages at power frequency under fault conditions.

Transient constraints.

The behavior of specially bonded links under transient conditions was studied using the latest version of the EMTP (Electro Magnetic Transient Program) software[17], taking account of variations in the modal characteristics with frequency according to the J. and L. Marti models.

It was verified experimentally that overvoltages were correctly estimated; an overestimate of constraints by about 10% results in insulation conservative coordination rules for the protection of sheaths.

Studies were made on overvoltages caused by a lightning stroke on the ground wire or a phase conductor in the overhead part of a siphon (overhead line containing an underground segment).

In the case of a lightning stroke close to the tower at the transition overhead to underground or the first tower on the supply side of an underground line, overvoltages of the order of a hundred kilovolts are recorded, caused by arcing of the spark gaps.

For other cases, overvoltages may be kept at an acceptable level; very simple calculation formulas have been determined to evaluate stresses applied to the equipment as a function of the rated voltage of the surge arrester and the length of the bonding leads.

Constraints at power frequency.

Overvoltages applied to equipment can be determined with good precision for a three-phase fault condition, but overvoltages that occur during a single-phase fault are more difficult to estimate.

They depend on the return path of the short-circuit current into the earthing grid (cable screens, earthing conductor, earthing rods, etc.).

Screen voltage rises depend very much on the voltage raises of earthing rods in overhead-underground transitions.

These may be evaluated fairly precisely using calculation formulae that take account of the detailed characteristics of the underground link (cable structure, laying method, length of elementary sections, etc.)

An estimate can be obtained being sufficiently accurate, at least at the preliminary design stage, by treating the underground link as a single span of an overhead line.

For the short circuit current return, there are two major differences between an underground link and an overhead line, that have opposite effects and tend to cancel each other:
Firstly, the impedance of the return path in underground links is higher than the impedance of the ground wire of an overhead line.
And secondly the mutual impedance with the phase in fault is higher for the underground link.

Asymmetry of the short circuit current must be taken into account in evaluating the energy to be dissipated by surge arresters.

Under a three-phase fault condition, the overvoltages applied to cable sheaths are induced voltages due to current circulation in cable conductors; they are "filtered" by inductive coupling and their asymmetry can be neglected.

The situation under single-phase fault conditions is different: overvoltages are the result of voltage drops caused by the passage of the short circuit return current in the earthing conductor and/or cable screens.

A factor λ was introduced equal to the ratio of the asymptotic voltage allowable for the surge arrester at his rated voltage, depending on the shape of the applied voltage (asymmetry coefficient and damping constant) of the order of 0.82 for single-point bonded links and 0.67 for cross-bonded links.

Design rules.

The diagrams shown in the following pages summarize the approach adopted for designing the earthing of specially bonded links.

The construction of cross-bonded links with elementary section lengths longer than 1 kilometer is possible, if non-linear resistances with a rated voltage of 15 kV are used as surge arresters, connected in a star configuration with isolated neutral point, and for bonding leads lengths up to 10 m.

For single-point bonded links, it is also possible to consider elementary section lengths longer than 1 kilometer if non-linear resistances with a rated voltage of 15 kV are used, by limiting the length of bonding leads to 2 m.

3.3.6.4 Practical example

Typical withstand levels for EHV cables are the followings:
- sheath: 20 kV (AC) and 50 kV_p (lightning impulse);
- cross bonding joint: 12 kV (AC) and 100 kV_p (lightning impulse).

The choice of the phase arresters is made according to the overvoltages calculated in the system configuration. In the coming lines, we will focus on the choice of the sheath Surge Voltage Limiters (SVLs).

During AC faults, generally speaking, the sheath or cross bonding joint overvoltages depend on the underground length, or on the length of the major sections, not always in a linear fashion, whereas there is nothing critical concerning the main insulation.

General practice is to consider that the sheaths SVLs must withstand the applied voltage in case of an overhead line fault, because it happens comparatively rather often. Conversly, in the case of a very rare underground cable fault, that implies a repairing time of the link, we admit that the SVLs could be destroyed.

The protection of the sheaths is based on the following approach:

1) determine the proper SVL nominal voltage and discharge current, for the protection of the sheaths and cross bonding joints during lightning impulses;
2) compute the voltage applied to the sheaths, to the cross bonding joints, and to the SVLs, during overhead line faults and cable faults. The maximum feasible underground length will be the shortest of the lengths determined during the various faults. Besides, it will allow us to clarify the frontier separating single point bonding and cross bonding.
3) check the ability of the SVLs to withstand the voltages, taking into account the possible asymmetry of the voltage.

A Lightning impulse protection

Different cases must be studied, as the lightning may hit either the ground wire or the phase conductor on the overhead line.

The current peak values are very different in those two cases. The electro-geometrical model, used to study the protection supplied by the ground wires, shows that the high lightning currents are intercepted by the ground wires, while smaller currents may force their way down to the phase wires. That is the reason we consider:

- 10 kA lightning current, with direct hit on the phase wire,
- 100 kA lightning current, intercepted by the ground wire.

In both cases, the wave is a 1.2 µs/50 µs impulse wave.

Digital models must be used to compute the electromagnetic transients: for the overhead lines, for the underground cables, and for the towers.

We consider that the model used in EMTP for the overhead lines is valid. We have shown that the frequency dependent model used in EMTPv3 for underground cables is the best available so far, though the attenuation is lower than the actual one. The model we use for the towers consists of a characteristic impedance and a propagation speed. This quite simple model certainly needs some further investigations to prove (or invalidate) its dependability.

The general results are as follows:

On the one hand, some features, such as the cable cross section, the towers earth resistances, or even the underground length in case of single point bonding, have little influence on the results. On the other hand, some features, like the bonding lead length, are very important.

More precisely, we can say that in case of single point bonding, the 100 kA lightning wave hitting the ground wire is more severe than the 10 kA hit on the phase wire. The situation is often reversed in case of cross-bonding, for which the 10 kA hit on the phase wire can be the most harmful.

Single point bonding: if the lightning hits the last span of the overhead line, the results are worrying. Indeed, the computations show that even for a 10 kV ZnO SVL and for short bonding leads (2 metres), the sheath voltages exceed 50 kV. Even if some improvements exist, such as the reduction of the earth resistances, they do not reduce the peak voltages below the 50 kV limit. But if the lightning hits another span of the overhead line, further from the terminations, the results show that a 15 kV ZnO SVL correctly protects the cable sheath.

Cross-bonding: 6 kV ZnO SVLs are suitable for the protection of the cross bonding joints. The computed voltages seldom exceed the withstand levels, even for 10 metre long bonding leads. An efficient way to reduce the sheath voltages is to use a Y connection of the SVLs, with an insulated neutral.

B Stresses due to overhead line single phase fault

As an example, let us consider a 225 kV link, made up of an overhead line (570 mm² phase conductor and 147 mm² ground wires), and in which an underground cable is inserted (1200 mm² copper conductor XLPE insulated cable). Let us assume that the overhead line is 10 km long before and after the underground link, and that a single phase fault occurs at the underground/overhead transition.

Figure 34 shows the sheath voltage (RMS, 50 Hz) for different values of the short circuit current for a single point bonded link.

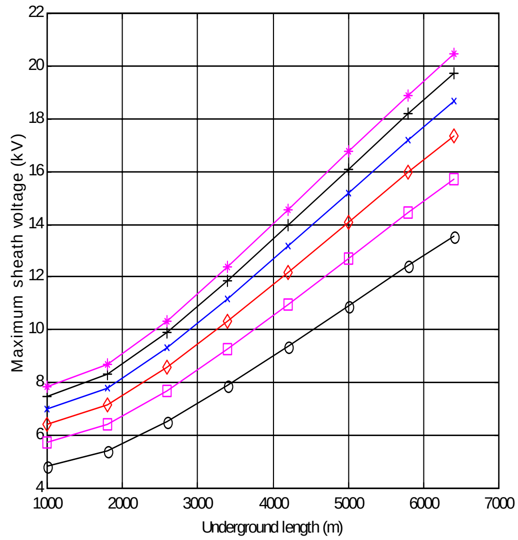


Figure 34 - single point bonding: maximum sheath voltage versus total underground length, in the case of a single phase overhead line fault. The voltage rises with the short circuit current: 12, 16, 20, 24, 28 and 31.5 kA.

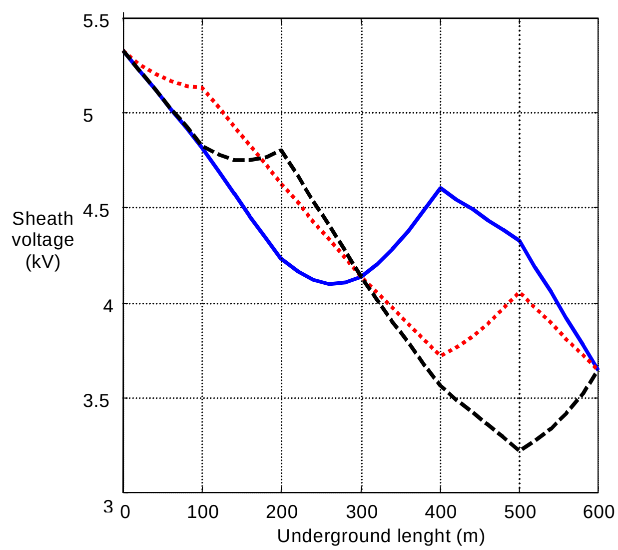


Figure 35 - cross bonding: sheaths voltages along the underground link. All the 3 sheaths voltages are plotted. The major sections are 3000 metre long. The sheath to sheath voltages are about 2000 V. They are not plotted.

Figure 35 shows the sheath voltage (50 Hz) for a cross bonded link (31.5 kA short circuit current), in which the major sections are 3000 metre long.

C Stresses due to cable fault

The link is the same as that of B.

Figure 36 shows the sheath voltage (RMS, 50 Hz) for different values of the short circuit current for a single point bonded link. The fault location is the one yielding the highest sheath voltage values.

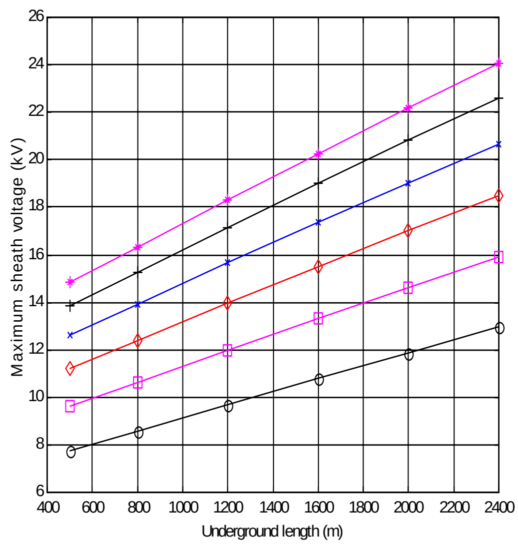


Figure 36 - single point bonding: maximum sheath voltage versus total underground length, in the case of a cable fault. The voltage rises with the short circuit current: 12, 16, 20, 24, 28, and 31.5 kA.

Figure 37 shows the sheath voltage (50 Hz) for a cross bonded link (31.5 kA short circuit current), in which the major sections are 3000 metre long.

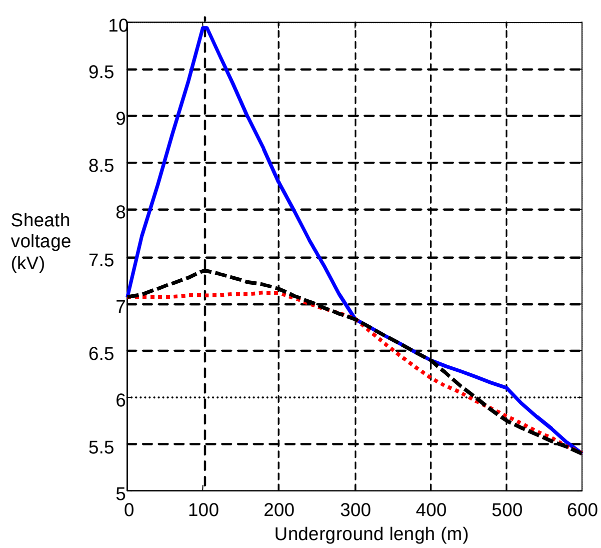


Figure 37 - cross bonding: sheaths voltages along the underground link, in the case of a cable fault. All the 3 sheaths voltages are plotted. The major sections are 3000 metre long. The sheath to sheath voltages are about 4000 V. They are not plotted. The fault is located 1050 metres far from the beginning of the underground link.

D Behaviour of the SVL during asymmetric phenomena

During a fault, whether an overhead line fault or an underground cable fault, the short circuit current, depending on the phase angle at the time of the fault, may be different from a pure sine wave, and include a decreasing exponential. The time constant of this transient is 160 ms for the 225 kV grid adopted in this example, which means that the current will become a sine wave after 3 times the time constant of the phenomenon: 480 ms.
The maximum current asymmetry is 2.74 (peak current divided by the final RMS current) or 1.94 (peak current divided by the final peak current).
Thus, the voltages at all the different points of the grid will also be asymmetric: in particular, the voltages applied to the surge voltage limiters.

For single point bonded links, in the case of an overhead line fault, the voltages applied to the SVLs are induced voltages, via the inductive coupling between the sheath and the conductor. In this case only, the asymmetry of the SVL voltage is reduced to 2.24 (peak voltage divided by the final RMS voltage) or 1.58 (peak voltage divided by the final peak voltage).

With the time constant given above, calculations show that 6 kV/5 kA SVLs are able to withstand an asymmetric wave with a 5 kV RMS value at the end of the transient. For 15 kV/5 kA, the figure is 12 kV.

E Summary

Single point bonding: it has been shown that 15 kV/5 kA SVLs are adequate to protect cables sheaths against lightning impulses. 3000 metre long underground links are feasible, since the voltage applied to the sheaths and to the SVLs remain below 12 kV.

Cross bonded links: it has been shown that 6 kV/5 kA SVLs are adequate to protect cables sheaths against lightning impulses. 3000 metre long major sections are feasible, since the voltage applied to the cross bonding joints and to the SVLs remain below 5 kV.
Relevant information can be found in differents documents [19][20][21].

3.3.7 Protection and reclosure

Cigre Working Group 34 01 published in April 1999 a Technical Brochure intitled "Reliable Fault Clearance and Back-up Protection"[22]**.** As indicated in this document, cable faults are almost exclusively permanent faults. For this reason, in most cases, there is no reclosure on cable systems. In some cases there may be concerns with ground lifting during short circuit faults, then auto-reclosing should be omitted.

The protection of hybrid lines, due to the distance to the substations is critical. In accordance with the reclosure policy on cables faults, detection or protection systems, more or less complex, have to be installed.
Questions are:

- is it possible to reclose on overhead lines faults and/or on underground cables faults ?
- how can we protect the underground section, and distinguish overhead lines faults from underground cables faults?

On a general basis, an underground cable is expected not to be damaged on a reclosure, wherever the fault occurs. Thus, the possibility to reclose on an underground cable fault is determined by the thermal withstand level of the cable: indeed, the cable is designed to withstand the temperature rise of the sheath entailed by a single 31.5 kA short circuit, during 0.5 s. For example, practices are:

Example 1 = European TSO:

- If the maximum value of the single phase short-circuit current is lower than 25 kA (which represents the huge majority of the situations), the reclosures on overhead lines and underground cables faults are feasible. In case of a permanent fault, the location of the fault (either on the overhead line or the underground link) can be achieved.

Example 2 = JAPAN: Table 1

Example 2 = TABLE 1: Condition of automatic re-closure in Japan

		Tokyo Electric Power Company	Hokkaido Electric Power Company	Kansai Electric Power Company	Chubu Electric Power Company
Overhead Line + Underground Line	XLPE	(a) Automatic re-closure system should satisfy either one of the following three conditions. 1. All of the following conditions are satisfied. 1-1. Power transmission line is equal to or below 154kV. 1-2. Length of underground line is shorter than about 1km, and about 1/3 of the length of the overhead line. 1-3. The accident should not affect other cables, because the cable and joints are installed alone or far away from other circuits. 2. All of the following conditions are satisfied. 2-1. In case of 154kV or 66kV system, grounding current is equal to or below 1,000A. In case of 22kV system, grounding current is equal to or below 600A. In either case, time to remove fault should be equal to or below 1 second. 2-2. When cables are installed in tunnel, manhole or pit, exposed portion of the cable and adjacent cables should be covered by fire prevention tape or fire prevention sheet. 3. All of the following conditions are satisfied. 3-1. Power transmission line is more than 154kV. 3-2. When automatic re-closure is locked if accident occurs at underground part. 3-3. Above-mentioned conditions 1-2, 1-3 are satisfied. (b) Automatic re-closure system should satisfy all of the following conditions. 1. The cable fault occurred at overhead part. 2. When route of automatic re-closure line and route of extra-high voltage underground line are same. ● A fire prevention method is applied at joints. ● Equipment which detects the section of the accident should be changed to Pilot Wire Relay, or Equipment which detects the section of the accident should be doubled. ● Extra-high voltage OF or XLPE cable should be taken measures against fire where they are placed along the automatic re-closure line. 3. When automatic re-closure line is installed in common culverts or beside other company's facilities without barrier. ● A fire prevention method is applied at joints.	Whether automatic re-closure is applied is judged individually considering line conditions (number of circuits, length of line, etc). In case equipment which detects the section of the accident is installed, automatic re-closure is applied when the equipment judges the accident doesn't occur at part of underground cable.	**The same as TEPCO.**	**The same as TEPCO.**
	OF	(a) Automatic re-closure system should satisfy the following conditions. 1. All of the following conditions are satisfied. 1-1.The same as (a)-1-1, 1-2 of the above-mentioned XLPE. 1-2.There is no joint and manhole at the case of direct burying system or duct system. 1-3. Exposed portion of the cable and adjacent cables should be covered by fire prevention tape or fire prevention sheet. (b) Automatic re-closure system should satisfy the item (b) of XLPE.	Automatic re-closure is not applied.	Fundamentally the same as TEPCO. (Difference from TEPCO) The 77kV duct line system whose length is below 500m.	The same as TEPCO.
	Overhead Line	(a) Automatic re-closure system should satisfy the following conditions. 1. For overhead transmission line that passes overcrowded area or is installed together with trolley wire, nominal cross-section of electric wire is equal to or more than $100mm^2$.	The same as TEPCO.	The same as TEPCO.	The same as TEPCO.
Underground Line	XLPE OF	Automatic re-closure is not applied.	The same as TEPCO.	The same as TEPCO.	The same as TEPCO.

3.3.8 Magnetic Fields

The magnitude of the magnetic field adjacent to underground cable systems has been addressed by WG 21-17 in Technical brochure 194 [6] and previously in the work of Joint Task Force 36.01/21 [23] [24].
Although the delicate question of magnetic fields is usually discussed regarding overhead power lines, increasingly attention is being paid to magnetic fields when selecting the configuration of the cables and the routes of buried links.
Indeed many countries now have recommendations, limits or standards regarding the magnitude of magnetic fields. These concerns may eventually dictate changes in planned routes, but, above all, they may increase the burial depth or require other precautionary techniques to limit the magnetic field.
We should bear in mind that buried cables have an earthed metallic screen and so do not generate external electric fields. The electric field in a cable is contained between the conductor and the earthed screen.
Several three-phase single core cable configurations can be considered.
A number of factors influence the magnetic field from a cable system, e.g. phase spacing, burial depth, phase arrangement in systems of several three-phase circuits, distance between them, load current and induced currents in the sheaths (which are themselves influenced by many factors).

3.3.8.1 Flat arrangement

A system of three single core cables in flat formation is first considered. It is characterised by geometrical parameters which are phase spacing (s) and burial depth (d). Height above ground (h) is also defined (fig 38).

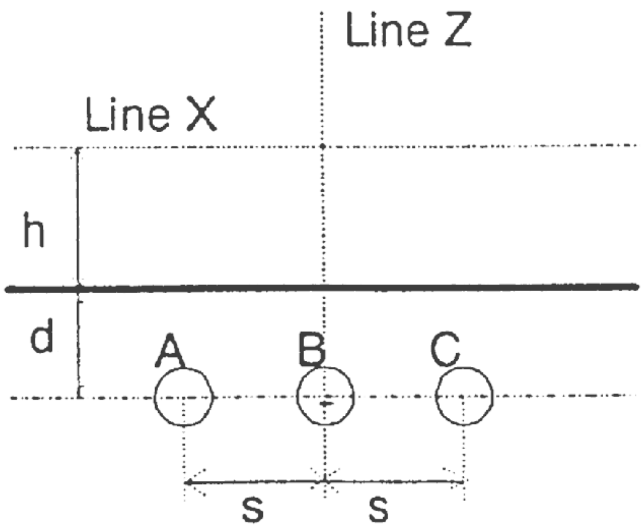


Figure 38: Flat arrangement, 1 circuit

The currents in cables are assumed to be balanced, i.e. $I_A = I < 0°$, $I_B = I < -120°$,
$I_C = I < -240°$, and the frequency is 50 Hz. The current will be fixed to a reference value of I = 1000A.
The two diagrams below represent the magnetic flux density along a horizontal line at 1 metre above the ground surface, considering various burial-depths and spacings of the phases.

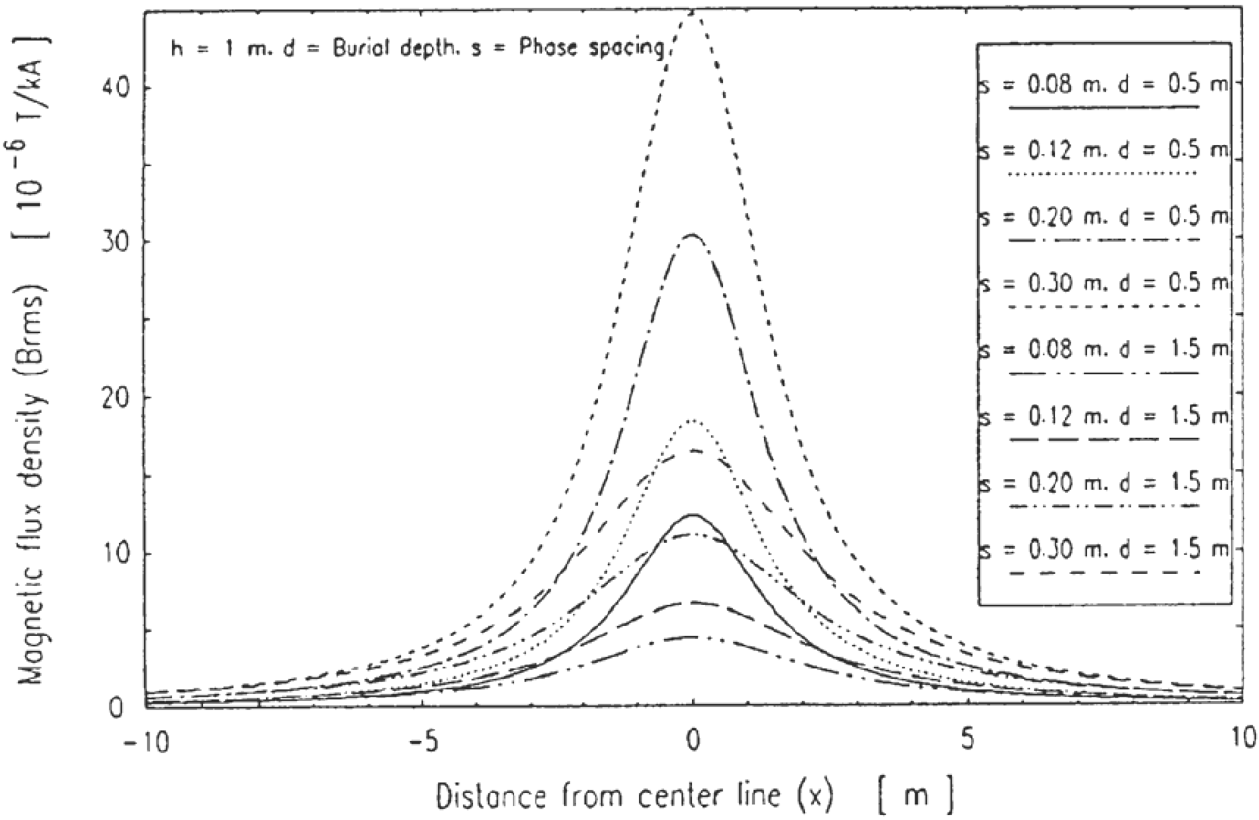


Figure 39: B_{rms} profiles along line X with h = 1m and s=(0.08m, 0.12m, 0.20m, 0.30m), d=(0.5m, 1.5m)

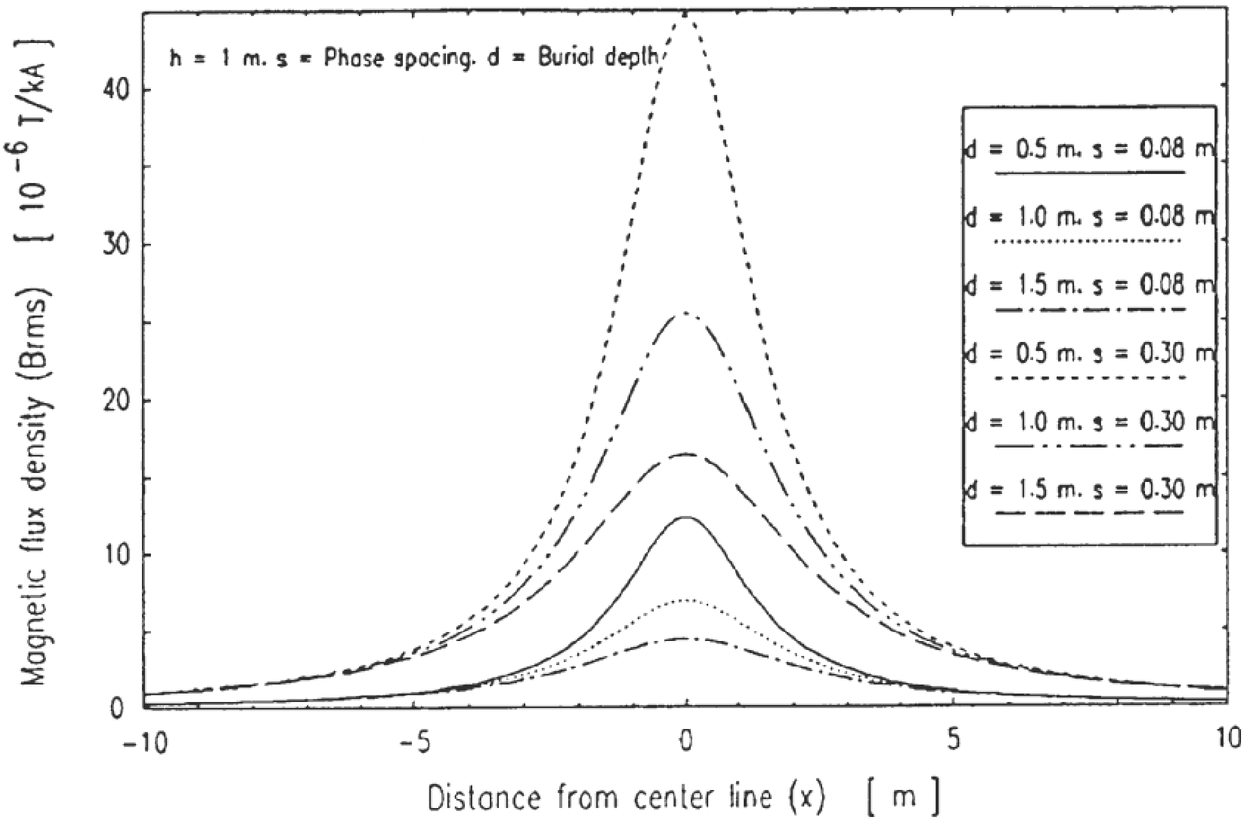


Figure 40: B_{rms} profiles along line X with h = 1m and d=(0.5m, 1.0m, 1.5m), s=(0.08m, 0.30m)

The highest magnetic field value immediately occurs above the cables. The distance from the cables (h + d) as well as the phase spacing appear to have an important influence on the flux density whose values are higher for low burial depths and high phase spacings. Moreover, it particularly appears that, for a fixed phase spacing,

burial depth has no effect on the flux density at horizontal distances from the system center line that are greater than several times this depth. Further, the reduction of magnetic field away from the center line is higher for a low burial depth.
Two systems of three core cables in flat formation can also be considered. Their geometrical parameters are phase spacing (s), burial depth (d) and distance between systems (g). Height above ground (h) is also defined (fig 41).

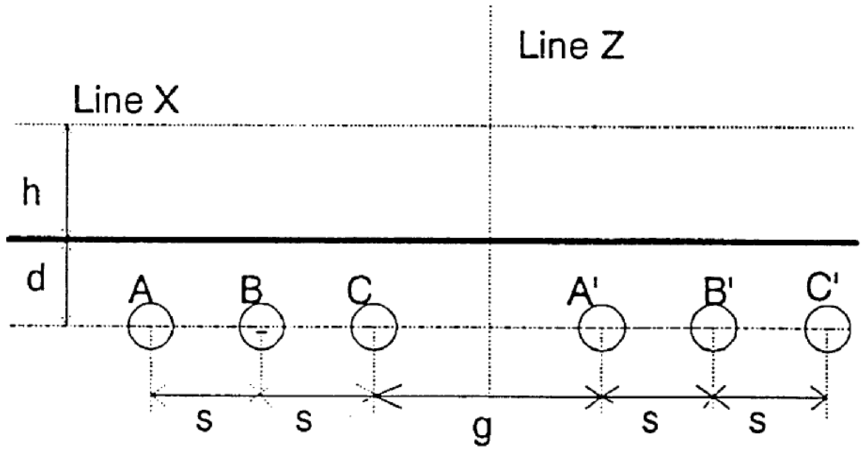


Figure 41: Flat arrangement, 2 circuits

The hypotheses are identical to those referred to above. Furthermore, two configurations have been retained: ABC-ABC (same order of phases) and ABC-CBA (inverted order of phases).
The figure 42 illustrates the evolution of the magnetic field considering various heights above the cables, at the set parameters g and s.

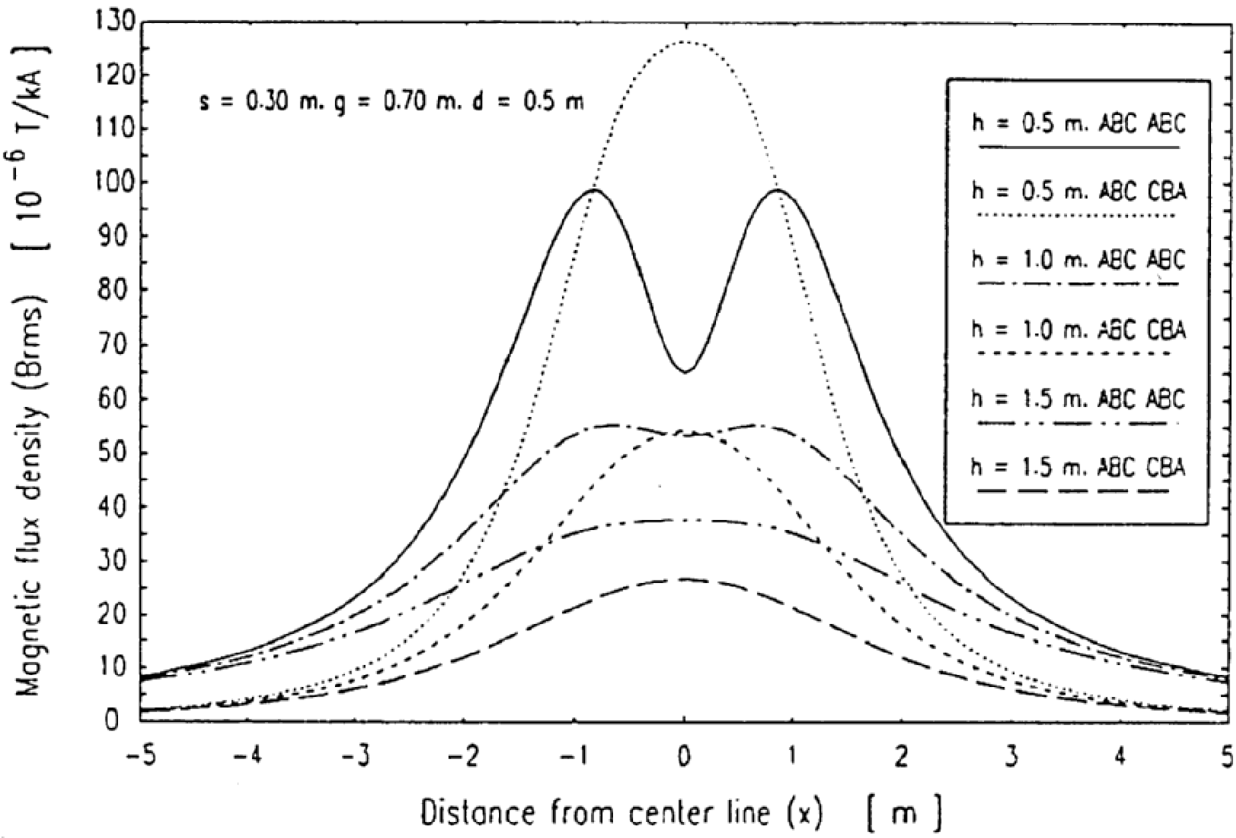


Figure 42: B_{rms} profiles along line X for two cable system configurations with s = 0.30m, g = 0.7m, d = 0.5m and h = (0.5m, 1.0m, 1.5m)

The ABC-ABC configuration appears to give a lower magnetic flux density near the cables than the ABC-CBA configuration. However this last configuration gives the lowest magnetic flux density from a certain distance from the cables.

Figure 43 shows profiles of magnetic flux density along a horizontal line one meter above ground for both configurations and for several system spacings.

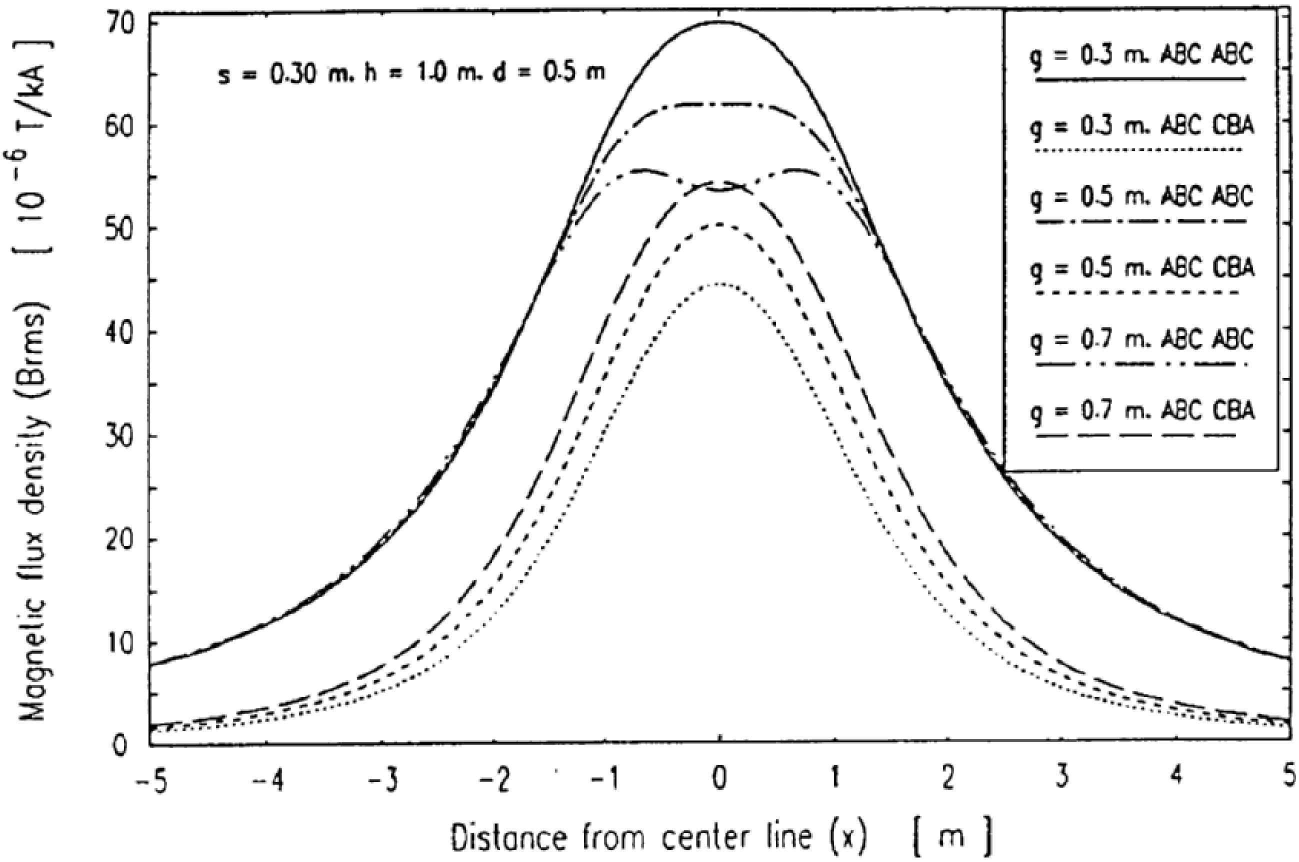


Figure 43: B_{rms} profiles along line X for two cable system configurations with s = 0.30m, h = 1.0m, d = 0.5m and g = (0.3m, 0.5m, 0.7m)

It can be seen that increasing system spacing respectively decreases or increases the magnetic field for ABC-ABC and ABC-CBA configurations.
We must also mention that the magnetic field is often higher at locations where junctions are made, i.e. where connections are made between power cable screens and the ground wires (if any), especially if these connections are made in an aboveground junction box (for paralleling of the screens).
Judicious connection of the screens and ground wires (connection between portions of the buried link made underground instead of in an aboveground junction box) or connection made in a buried junction box can significantly reduce the value of the magnetic field.

3.3.8.2 Trefoil arrangement

A system of three single core cables in trefoil formation is now considered. Its geometrical parameters are phase spacing (s) and burial depth (d). Height above ground (h) is also defined (fig 44).

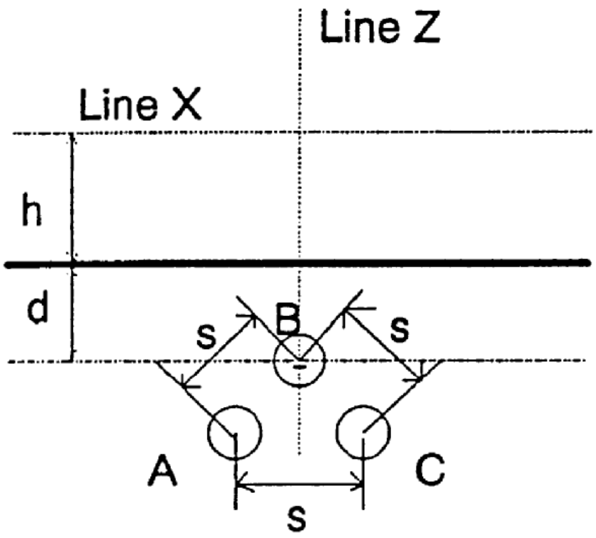


Figure 44: Trefoil configuration, 1 circuit

In fact, usually, the three cables touch each other and variations of phase spacing allow to consider cables of several outer diameters.
The first of the two next figures (fig 45) compares the magnetic flux density profiles along a horizontal line one meter above ground with a burial depth of one meter for both flat and trefoil formations with several phase spacings. The second one (fig 46) compares the magnetic flux density profiles along a horizontal line one meter above ground for several burial depths and a fixed phase spacing for both formations.

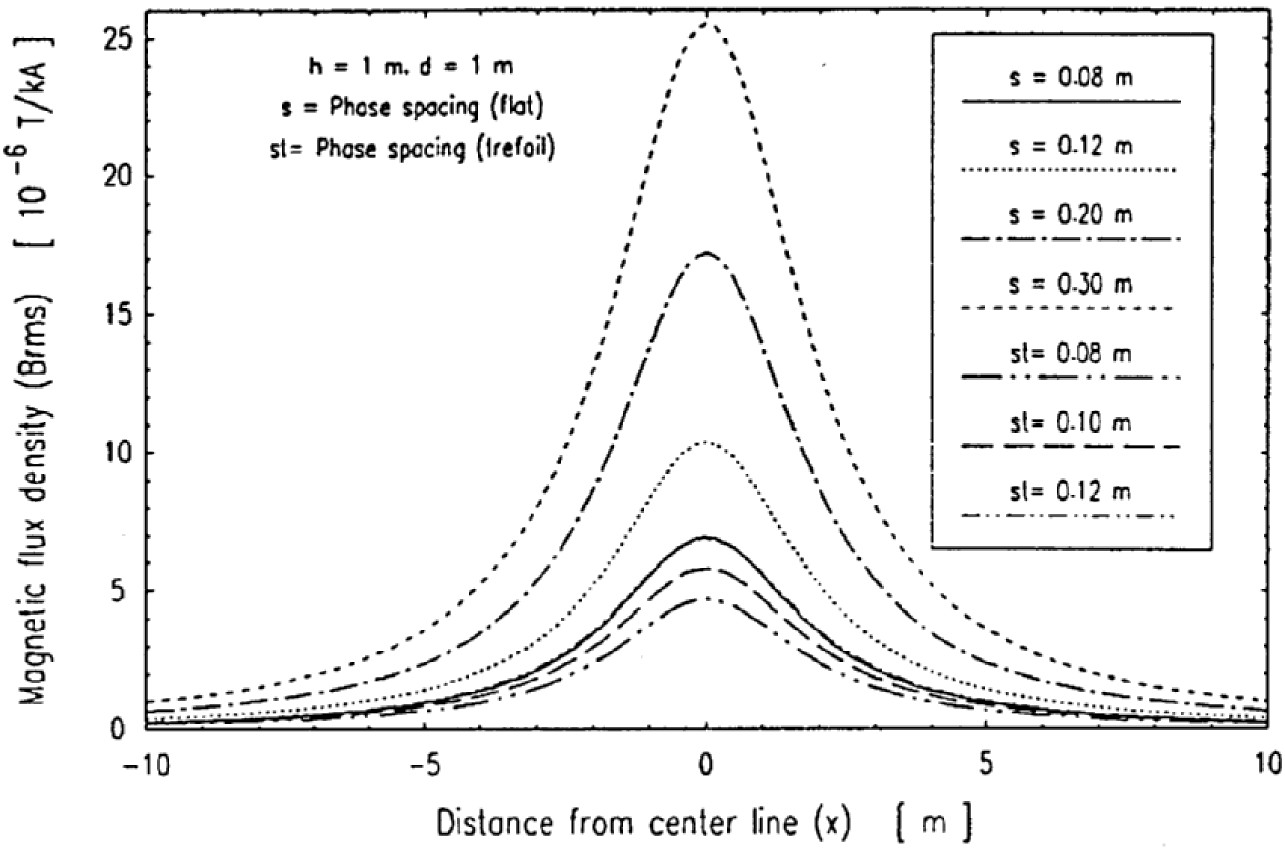


Figure 45: B_{rms} profiles along line X with h=1m and d=1m for both flat and trefoil formations with respectively s_{flat}=s=(0.08m, 0.12m, 0.20m, 0.30m) and st_{refoil}=st=(0.08m, 0.10m, 0.12m)

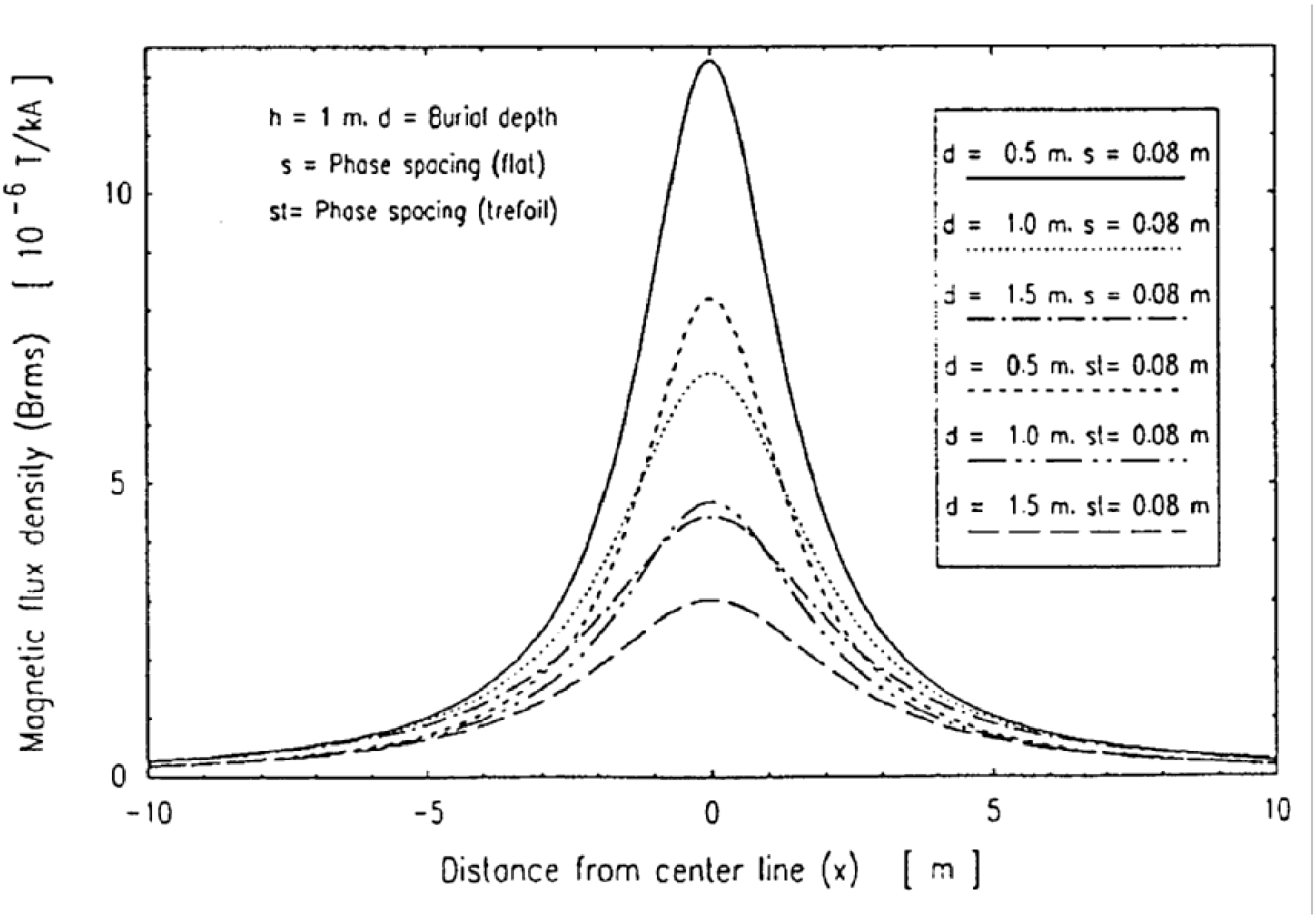


Figure 46: b_{rms} profiles along line X with h = 1m and d = (0.5m, 1.0m, 1.5m) for both flat and trefoil formations with respectively s_{flat}=s=0.08m and $s_{trefoil}$=s_t=0.08m

The trefoil formation gives clearly the lowest magnetic field which is more than 30 % lower than the one of the flat formation whatever phase spacing is.

Two systems of three single core cables in trefoil formation are also considered (fig 47).

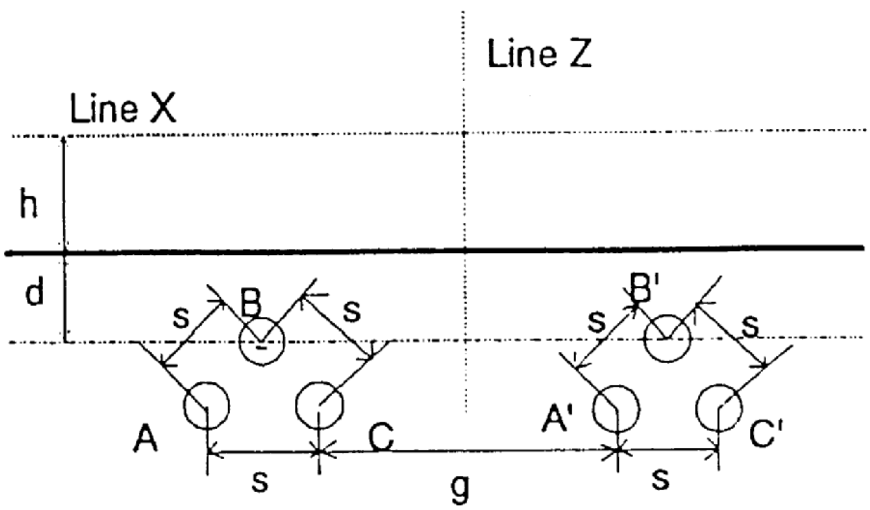


Figure 47: Trefoil configuration, 2 circuits

The hypothesis are the same as those made in paragraph 3.3.8.1.

The next figure (fig 48) shows again the profiles of the magnetic fields for the configurations ABC-ABC and ABC-CBA considering various heights above the cables, at the set parameters g and s.

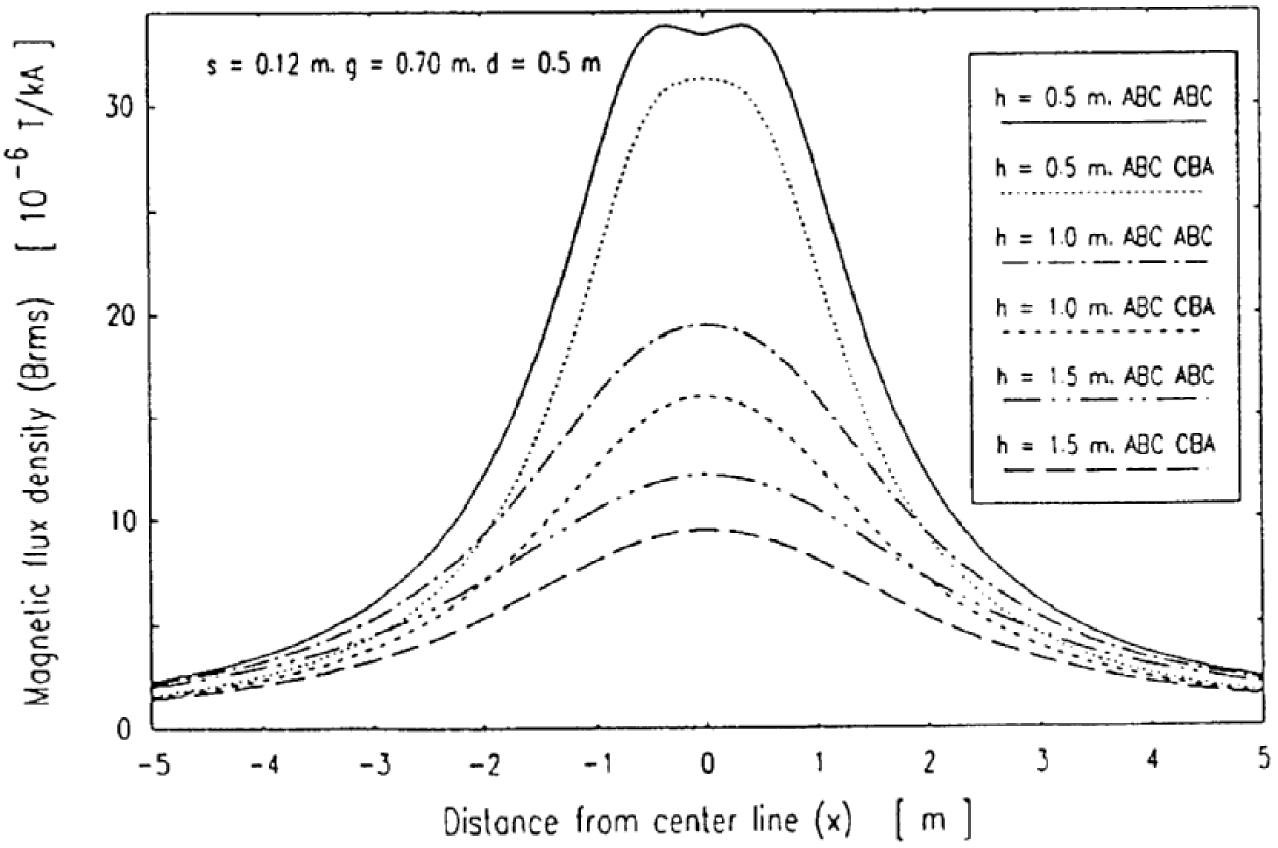


Figure 48: B_{rms} profiles along line X for two cable system configurations with s = 0.12m, g = 0.7m, d = 0.5m and h = (0.5m, 1.0m, 1.5m)

The ABC-CBA configuration appears to give a lower magnetic flux density then the ABC-ABC configuration.

The next figure(fig 49) shows again the profiles of the magnetic fields along a horizontal line 1 metre above ground level, for the two configurations and with various spacings.

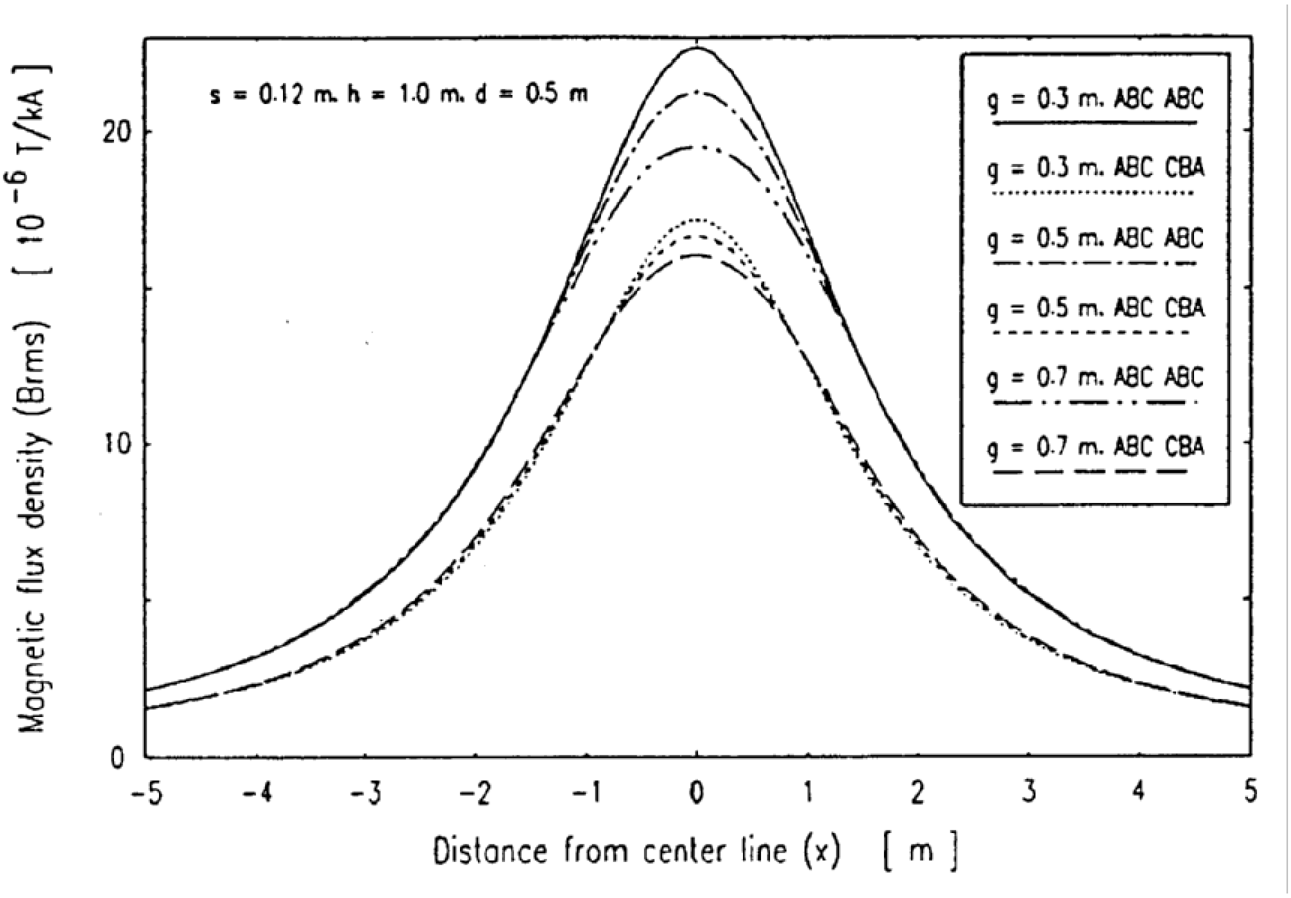


Figure 49: B_{rms} profiles along line X for two cable system configurations with s = 0.12m, h = 1.0m, d = 0.5m and g = (0.3m, 0.5m, 0.7m)

Unlike in the horizontal arrangement, here we can see that the increase of spacing between the two systems results in a lower magnetic field in the two configurations ABC-ABC and ABC-CBA.

3.3.8.3 Vertical arrangement

A system of three single core cables in vertical formation can also be considered. Its geometrical parameters are phase spacing (s) and burial depth (d). Height (h) above ground is also defined (fig 50):

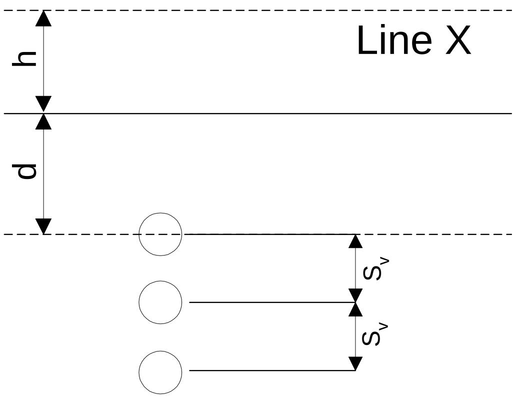


Figure 50: Vertical arrangement, 1 circuit

This configuration is in fact an artifice considered for the purpose of enabling to compare the magnetic field values of this configuration with those of the two configurations discussed above (trefoil, flat). In reality a vertical configuration is only adopted in tunnels, bridges or other structures, practically never for buried lines.
The next figure (fig 51) shows the magnetic flux density profiles along a horizontal line 1 metre above ground, with a burial depth of one metre for flat, trefoil and vertical configurations and several phase spacings.

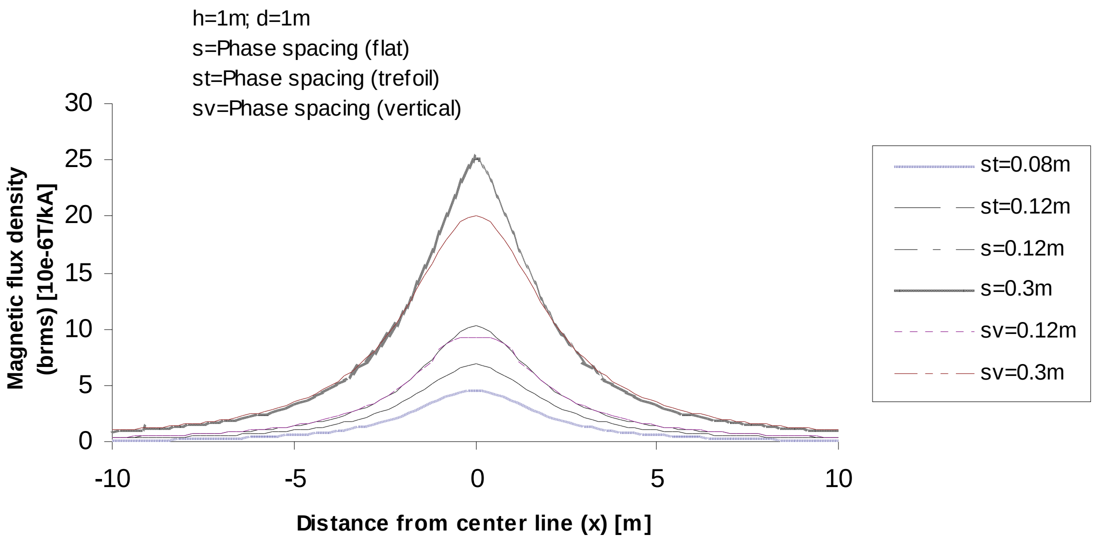


Figure 51: B_{rms} profiles along line X with h = 1m and d = 1m for flat, trefoil and vertical formations with respectively s_{flat} = s = (0.012m, 0.3m), $s_{trefoil}$ = st = (0.08m, 0.12m) and $s_{vertical}$ = sv = (0.12m, 0.3m)

The values of magnetic field for the vertical configuration are lower but close to the flat configuration. They rapidly match when departing from the vertical axis.
It results that the trefoil formation clearly remains the most advantageous option with respect to magnetic field.
Two systems of three single-core cables in vertical formation are also considered (fig 52).

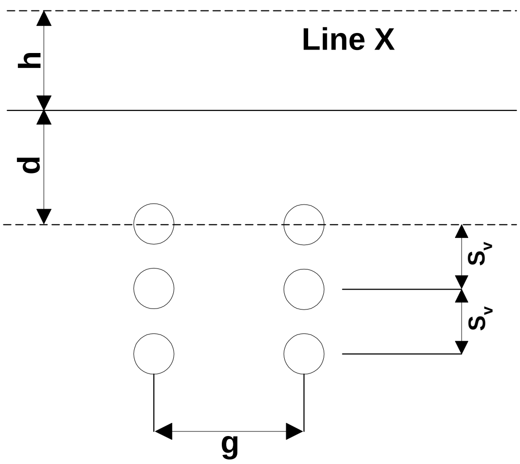


Figure 52: Vertical arrangement, 2 circuits

The hypotheses are identical to those made in paragraph 3.3.8.1.
The last figure (fig 53) below shows the magnetic field profiles for the ABC-ABC and ABC-CBA configurations for vertical, trefoil and flat formations.

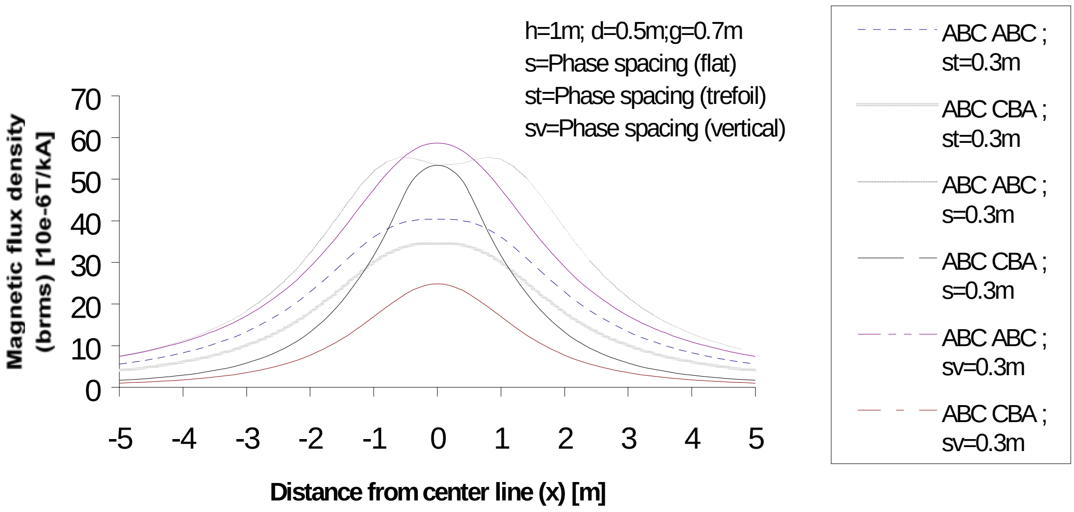


Figure 53: B_{rms} profiles along line X for two cable system configurations with h = 1m, d = 0.5m, g = 0.7m and $s = s_t = s_v$ = 0.3m

It appears that in the ABC-ABC assumption the magnetic field of the vertical formation is higher in the middle of the 2 systems that it is with the flat formation.
Conversely, for the ABC-CBA configuration, the magnetic field is clearly less in vertical formation than in flat and trefoil formations. At higher distances of the center line, it appears that the decreasing of the values of magnetic field for the trefoil configuration is slower.

3.3.8.4 Shielding techniques

The effects of magnetic fields (MF) on health have become an issue of public concern. The considerable numbers of studies performed in recent years in this respect have resulted in various conclusions being drawn, many of these in agreement, but several also contradictory, leaving the public in doubt.
This lack of certainty has resulted in several countries imposing MF limits that are much more stringent than those normally adopted, such as the recommended limit for public exposure, which is set at 100 µT by the International Commission on Non-ionising Radiation Protection working in cooperation with the World Health Organization.
However, a number of pressure groups have emerged that are striving to have even lower MF limits imposed, or demanding that utility companies apply methods to reduce magnetic fields. These pressure groups may have significant political leverage or impact, and electrical utilities must therefore consider the impact of these demands on their HV cable link design and technical specifications.
As shown Sections 3.3.8.1 to 3.3.8.3, the magnetic field generated by a cable link depends on many parameters such as:

- system parameters: ampacity, phase current balance, system grounding
- installation parameters: depth of laying, configuration
- construction parameters: electrical characteristics of the cable screen
- external factors that can interact with the cable circuit (for example, the presence of other cables or metallic tubes)

By varying some of these parameters (not all are easily modifiable), it is possible to obtain a reduction in the magnitude of the MF.

In particular, with the aim of generating the lowest possible MF, it should be advisable to:

- select an appropriate phase configuration when the underground link has more than one cable circuit
- select an installation configuration that places the three cables as close as possible to each other (for example close trefoil)
- use the multi-point grounding of the screens and design them with the lowest value of electrical resistance to ease the circulation of the induced currents
- increase the depth of burial.

However some considerations need to be voiced regarding the above-mentioned measures:

- the first provision has no consequences regarding the transport capability of the link and should be undertaken if possible
- the adoption of the close trefoil geometry, even if it produces a (limited) reduction of the transfer capability of the line (with regard to the same cable in a plane configuration), allows a narrow trench installation, but may require the use of a conductor with a larger cross sectional area
- multi-point grounding results in a significant reduction in capacity for a given conductor size. The present design of the cables does not foresee the return of the current through the metallic screen as happens, for example, in GIL and in HTS cables
- increasing the burial depth leads to a decrease in carrying capacity and an increase in the cost of the installation.

The simplest method of limiting the MF remains that of routing the link at a further distance from the ‘areas at risk’, or preventing public access to the terrain where the MF is considered high. However, in practice it is rarely possible to apply these solutions at reasonable cost.

The considerations reported in the following paragraphs refer to current-balanced systems (with the presence of the positive sequence only). In the case of circuits carrying a certain amount of zero sequence current, the value of the MF may be notably higher with respect to the case of the pure positive sequence current [25] [26]. This is due, in particular, to the fact that zero sequence currents are not reduced by shielding if the return current is in the ground.

Phase splitting is another possible method to lower MF: phase splitting is done by subdividing one or more phases and placing them in the geometrical configuration that gives the lowest MF value in the area of interest. This technique has been applied to HV overhead lines, but only in a few cases. For cable links, phase splitting is not used, because of the increase of both the cost of the link and the complexity of cable installation works.

If, in spite of the above-mentioned measures, the MF value were still too high, it would be necessary to shield the cable link.

There are two types of shielding: active and passive.

Active shielding refers to any system that reduces the magnetic field in a certain area of space, by forcing a current to circulate in a material (conductors, for instance) of which the magnitude, direction and phase angle creates fields that oppose the fields initially present, resulting in the final value of the magnetic field being reduced. The drawback of this type of system resides in the injected current having to be adjusted each time the magnetic field changes.

Passive shielding reduces the overall value of the MF by using either the currents induced in a material by the existing magnetic fields or the low reluctance characteristics of ferromagnetic materials. For example, the introduction of an additional circuit (current-carrying wires) is based on the fact that induced currents flowing in it oppose (partially) the field that you want to reduce. The conductors of the additional circuit are laid in parallel to the phase cables and connected as a closed loop. To increase the effectiveness of the measure it is important that the resistance of the additional loop is as low as possible. Inserting a capacitor to compensate the inductance of the circuit can increase the current flowing in the loop. The loop can be used as an active shield if an external device injects a suitable current having the characteristics (value, frequency and phase) that oppose the main field.

There are other possibilities to install passive shielding. Their design mainly considers:

- the use of ferromagnetic or conductive-only materials
- the adoption of an open or a closed shield

Open shields are generally flat sheets made of highly conductive materials, such as copper or aluminium. Closed shields surround the field source and generally consist of pipes of ferromagnetic materials such as iron, low carbon steel or other magnetic alloys.

With reference to the shielding shape, closed shields are only practical if installed with a new cable links whereas sheets can be employed to reduce MF values on pre-existing lines also.

3.3.8.4.1 Magnetic field evaluation with numerical and analytical methods

To evaluate and compare the effectiveness of different shielding designs, some unitless parameters are used. Consider a cable system, which produces a MF of magnitude Bo. If this is reduced to a value B by the presence of a shield, the following parameters can be defined:
- Shielding Factor: SF = Bo/B
- Shielding Effectiveness: SE = 20 log (B/Bo) [dB]

Evaluation of the MF produced by electrical links, in the presence of ferromagnetic and/or conductive materials is made difficult by the geometry of the problem and by the non-linear behaviour of the ferromagnetic materials.
To solve this problem, it is possible to use different numerical methods, but it is very time consuming to set up the configuration and to obtain the results in the desired format.
In particular cases, such in bi-dimensional problems, it is possible to use analytical methods that make it possible to evaluate the influence that different parameters have on MF value. These cases are important because, even if simplified, they allow us to understand the role played by the various design parameters, and provide valuable indications for practical applications.
It must be stressed, however, that besides the evaluation with any of the mentioned methods, it is always very important to confirm with measurements on a real circuit the results obtained by simulation

3.3.8.4.2 Shielding with Conductive materials

Sheets of conductive (non-ferromagnetic) materials can be used to reduce the MF produced by underground links. The reduction of the field is due to the effect of induced currents flowing in the shield that oppose the MF produced by the cables (principles based on the circulation of eddy currents).
Shielding with conductive materials may performed with flat sheets or shaped sheets (for example, ‘U’ or ‘H’ sections).

Design parameters

One of the main design parameters is the thickness of the sheet. For conductive materials, the shielding effectiveness generally increases with the thickness of the shield, particularly when the thickness is lower than the skin depth (this, for example, is about 12 mm for aluminium).
In practical installations sheet thickness ranging from 3 to 5 mm have been chosen.

The conductivity of the material is a constant parameter (at a certain temperature). The materials employed in practical applications are copper and aluminium. The higher the conductivity, the more effective the shield. This effect is practically linear [27]. This means, for example, that a 5 mm-thick aluminium sheet gives an attenuation equivalent to that of a 3 mm-thick copper sheet.

Also, the location of the shield relative to the source (cables) has an influence on the MF distribution. The closer the sheet is, the higher the attenuation of the MF in the aboveground area.

Another parameter is the width of the sheet. The wider the shield is, the higher the shielding factor. In the design phase of a flat sheet shield it is necessary to verify the MF distribution near the edges of the plate. In these areas in fact, the MF value can be even higher than that at the centre of the shield [28]. The edge effect depends on the width of the plate and on its distance from the source. In order to avoid this problem, it is necessary to use a sheet having a sufficient width. Practical applications show that the width is about 1 m (for one-circuit links) with variations between 0.6 and 1.2 m [29].
If the width of the sheet exceeds that of the trench, then installing the sheet may affect the cost of the civil works and hence the overall cost of the link.

Figure 54: Example of shielding with copper sheets [30]

To avoid having to dig a wider trench, a different configuration of shield may be used such as the U-shape shield. This is also referred to as the inverted trough.

As previously seen, the shielding effectiveness depends on the induced currents in the metallic sheets. It is important to verify that the shield 'electric circuit' has no discontinuities. However for practical reasons (transport, handling) the shield must be constructed from individual sheets. Gaps between sheets prevent the circulation of the induced currents between subsequent shielding elements. Therefore it is essential to ensure good electrical contact between elements (fig 54).

A drawback of the U-shield remains the difficulty of installation, as during backfilling there is a considerable risk of voids remaining above and under the sheets, which may have an impact on the thermal behaviour (and therefore also the carrying capacity) of the link.
That is why another configuration (H) has been investigated (fig 55). Here the two vertical sheets are placed in the trench prior to backfilling. After the laying of the cables, the horizontal sheet is installed at the suitable depth during the backfill of the trench.
This method, however calls for the following comments:

- only the portions of vertical sheets situated below the horizontal sheet, and the horizontal sheet itself, are effective;
- as for flat sheets or "U" shape sheets, a good continuity is necessary between the vertical sheets;
- the electric circuit formed by the vertical sheets needs to be closed at each extremity of the shielded portion;
- contrary to horizontal sheets alone, having longitudinal contact between the horizontal sheets is of less importance.

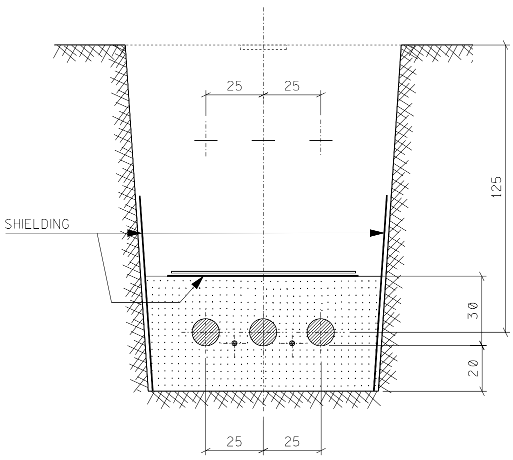


Figure 55: Cross section of a trench with a shielding in "H" configuration

The best way to ensure electrical continuity and to give a shielding effectiveness that approaches the theoretical results is by welding (fig 56a and 56b): this solution is the best from the MF reduction point of view, but is of course expensive and time consuming. Other possibilities are under consideration but offer lower shielding effectiveness.

Figures 56a and 56b: Welding on site of aluminium sheets

Measurements carried out placing a horizontal sheet above or under the cables (at the same relative distance) showed that attenuation of the MF is only slightly higher (on the axis of the link) in the first case, but practically equivalent at a few meters distance from the axis.
The installation of the shield under the cables has quite obvious advantages in terms of maintenance (for example after a cable fault).
The distance of the shield from the cables has a direct influence on the induced losses in the sheet. The losses increase considerably when the shield is very close to the source, and a compromise has to be found between shielding effectiveness and the reduction in power transfer capability.

Shielding with conductive sheet is particularly worthwhile when the three cable phases are in a flat-touching configuration. In some applications it could be favourable to depart from the usual configurations (flat spaced or trefoil) in favour of the flat-touching geometry that produces, in combination with conductive sheet, a reduced value of the MF.

From several experiences of conductive shields, typical shielding factors between 4 and 10 can be achieved above the ground in which HV cables are buried (the former for flat sheet, the latter for a more complex configuration).

3.3.8.4.3 Ferromagnetic shielding

The use of ferromagnetic materials allows us to control the MF, modifying the flux path towards the lower reluctance circuit. The higher the shield permeability, the better the shielding performance. The electrical conductivity is an important parameter also, and the best shielding materials are those characterised by high values of permeability and conductivity.
Among ferromagnetic materials, two classes can be roughly identified:
- high permeability materials (with value of $\mu_r > 1000$)
- low permeability materials (with value of μ_r around 200). These materials have generally a better electrical conductivity than high μ_r materials.

In circumstances where it is necessary to reduce the MF to a very low value, closed ferromagnetic shielding gives the best results [31].

Figure 57 shows the influence of the shape of the shield going from a plate through to a completely closed geometry [32]. The advantage of using closed ferromagnetic shielding is obvious. However, good ferromagnetic materials are often expensive and highly sensitive to corrosion. (This is also true a problem for aluminium and copper sheets.) Hence, they need a good protective coating. Furthermore, tubular shields can be adopted only along rectilinear routes and have the same advantages and drawbacks as laying cables in a duct.

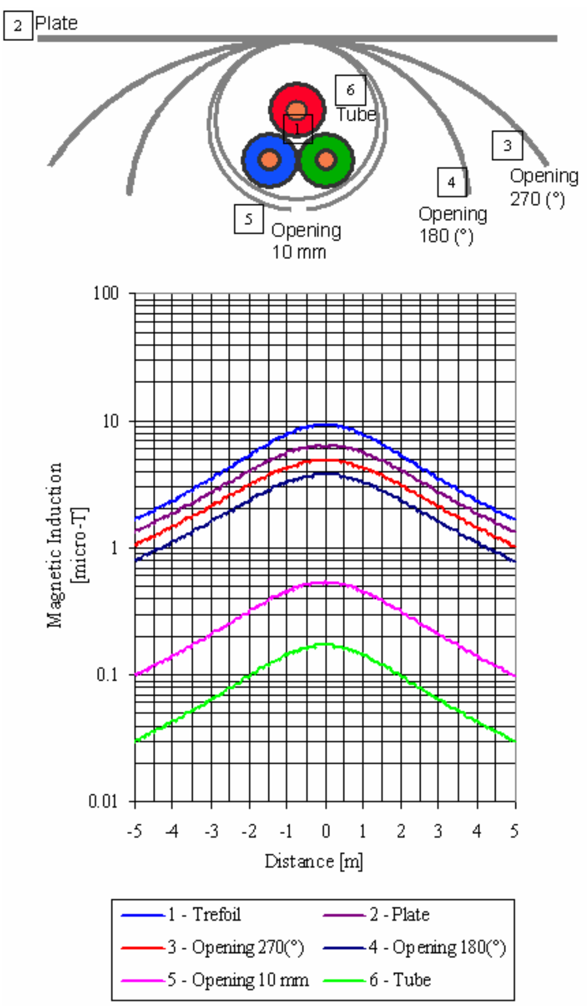


Figure 57: MF distribution at 1 m above-ground with 1500 A and different shielding opening levels

In addition to relative permeability, thickness and conductivity of the material employed are important parameters in the design of a shield. Diameter is also a factor when tubes are used.
For ferromagnetic shielding, Shielding Effectiveness is not linearly correlated with thickness and conductivity. An increase in these parameters causes the SE to increase more than proportionally. However, practical difficulties in the handling of heavy shielding tubes limits the impact of thickness increase.

Ferromagnetic tubes adopted in practical installations have a thickness ranging from 5 to 10 mm and diameters from 250 to 500 mm. Figure 58 shows an example of ferromagnetic tubular shielding.

Figure 58: Example of ferromagnetic tubular shielding

To give an idea of the value of the Shielding Factor achievable with closed ferromagnetic shielding, reference can be made to the above curve (SF of about 50). This value is consistent with the results of the CIGRE document JTF 36-01/21, "Magnetic field calculation in underground cable systems with ferromagnetic components" (Electra No 174, October 1997) [24].

Besides the ferromagnetic tube, other closed shapes have been considered: for example, a ferromagnetic rectangular shielding [28]. Different geometric parameters such as thickness and the placement of the cables inside the box have to be taken into account.
Numerical evaluations show that if materials with a relative permeability in the range 700 - 1000, thickness of 3 - 5 mm and dimensions of 300 x 200 mm are adopting, then reduction factors of 30 are feasible.

Since MF attenuation for ferromagnetic and conductive materials is based on different principles (offsetting effect of the induced currents flowing in the conductive material versus generation of a preferential path through ferromagnetic materials), tests involving a combination of the two different materials are underway.

Figure 59 is an example of the different behaviour of the two types of material [32]. It shows that for the ferromagnetic material, attenuation of the MF is particularly effective close to the shield, while for conductive materials the attenuation effect is more evident further from the shield.

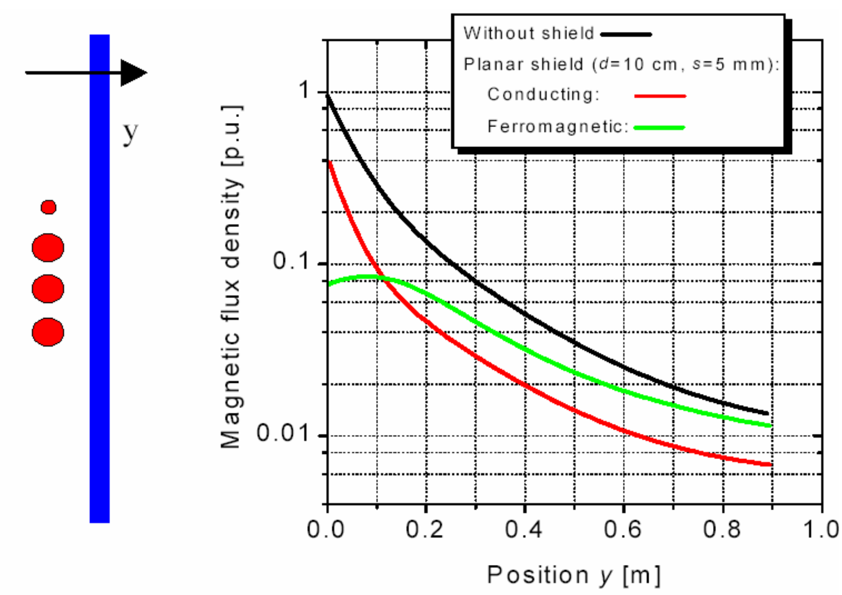


Figure 59: Example of the different behaviour of conducting and ferromagnetic shielding

3.3.8.4.4 Considerations

Using the different types of shielding described above, it is in principle possible to achieve shielding factors of between 3 and 50, but this takes no account of the practical difficulties.

For any of the described shielding methods, it is always very important to carry out both the theoretical evaluation of the effectiveness (to optimise the geometry of the shield) and the laboratory tests with measurements on full-scale samples. This permits a full evaluation of the shield design, examining critical aspects that are not easily revealed when using two-dimensional models (such as the need of a good electrical contact between subsequent sheets).

The selection of a particular type of shielding mainly depends on the required residual MF value and on the distance between the electrical link and the sensitive area.

If it is necessary to shield an existing cable link, it is important to choose a method that causes the lowest possible impact on other utilities and on the cable itself. In this case conducting sheets could be used. For a new link, the designer may be free to choose any solution and closed shielding could be installed.

The final choice of the type of shield is influenced by various parameters, and may be different from the best solution that would be derived from computer simulations alone. Examples of these parameters are corrosion sensitivity (with regard to the life of the shielding), the weight (to ease the installation of the shield), the stability of the ferromagnetic characteristics of material supplied in different batches and the cost. In evaluating the cost, special attention must be paid to the recurrent costs incurred by the losses in the shielding: the better the shielding, the higher the losses and the higher the recurrent costs.

In real applications, where flat (or 'U' or 'H' shaped) shielding has been used, conductive materials were preferred.

With the installation of any type of shielding the following drawbacks must be generally taken into account:

- the additional cost of the shield
- the increased time required for the installation phase (the increase of time and cost can lead to an increase of about 20% of the overall costs)
- the possible need to increase the conductor area of the cable
- restricted access to the cable circuit in case of a fault.

On the other hand, shielding can have applications where a reduced MF is required and no other solution is practical.

A dramatic reduction in MF can be achieved by installing cables in deep tunnels (tens of metres underground), but this comes at significant cost. Increasing a cable's installation depth by some tens of centimetres produces only a small reduction in MF (and causes a significant decrease in the power transfer capability); installation at high depth solves the problem of the MF at ground level.

This use of deep tunnels for cable installation is becoming more frequent, particularly in densely populated urban areas, where it is difficult to find near-surface corridors for the cables and traffic management problems are difficult to solve. These circumstances may favour solutions that are highly expensive but can simplify the construction of the link and reduce the time required for permitting and for negotiations with the landowners.

Figure 60: Example of MF shielding on 132 kV circuit crossing the city of Genoa (Italy)

3.4 LAYING TECHNIQUES AND INSTALLATION METHODS

Laying and installation techniques have been reviewed in detail by CIGRE WG 21-17 and are described in Technical Brochure 194 [6]. This Technical Brochure describes a comprehensive state of art shared by the technical cable systems community, established starting from two questionnaires sent to Utilities and Manufacturers.Two papers propose a summary of the main results obtained from the completed questionnaires [5,35].
Twelve existing construction techniques are reported and explained in Technical Brochure 194 [6]. They are shortly recalled hereunder.

3.4.1 Laying techniques

The following twelve techniques are now used: trenches, ducts, troughs, tunnels, microtunnels, shafts, bridges, mechanical laying, horizontal drilling, pipe jacking, embedding, use of existing structures.

Backfill

For the first three methods, the cables, ducts and troughs are usually placed on a bed of materials suitable for protecting them against sharp rocks that can often be found at the bottom of the trench. The material is mainly sand.
The trench within which cables, ducts and troughs are installed, is backfilled with materials which may be the original excavated soil, concrete, sand or any other suitable materials. In certain countries, special backfill is used in order to improve the thermal environment assisting the removal of the heat released by the power cables (hence increasing their transmission capacity). The material is mainly sand or special backfill.

3.4.1.1 Trenches (direct burial)

This method consists of digging a trench and directly placing the cables in the trench (fig 61).

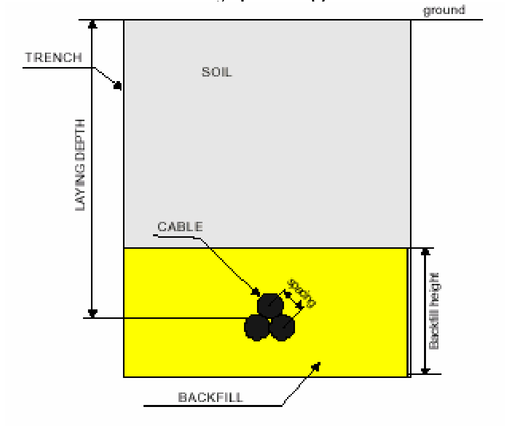


Figure 61: Direct burial

The cover over the cables is generally 1 m or more. The most common installation techniques used are the trefoil formation up to 170 kV and flat formation above 170 kV.

3.4.1.2 Ducts

This laying method consists of placing ducts or pipes in trenches, (by horizontal drilling or other methods) and then pulling the cables into them (fig 62).
These ducts or pipes can be of PVC, concrete, polyethylene (PE), steel or fibre-reinforced epoxy (FRE), but according to the replies mainly PVC or PE ducts are used.
The ducts or pipes can be filled with air, bentonite, mortar, sand or water.
Usually only one cable is placed in each duct and the ducts are air filled or filled with bentonite or other material

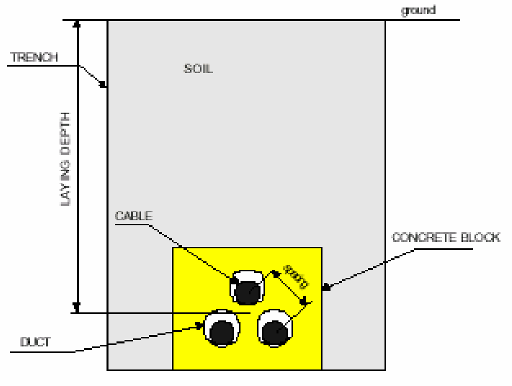


Figure 62: Laying in ducts

3.4.1.3 Troughs

The troughs usually consist of prefabricated concrete segments, usually placed in a trench, after which the cables are laid in the trough(fig 63). The troughs are generally filled with sand and usually three cables are laid in each trough. Excavated soil is usually used as backfill around the troughs.

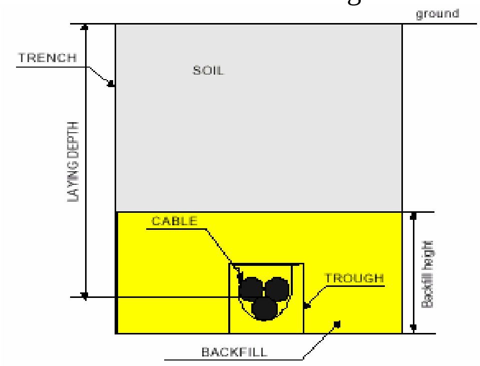


Figure 63: Laying in troughs

3.4.1.4 Tunnels

Tunnel boring machines can bore large diameter tunnels (in excess of 2 m).
Tunnels, which can be built for a variety of purposes other than cable laying, have practically no technical limit regarding tunnel length.
The positioning of the cables in the tunnel (on steel trays, in the concrete, …) will depend on what the tunnel was built for (metro, etc.). It is common for tunnels to share with other utilities such as gas or water.
The most common installation techniques used are a flexible design with cables installed in trefoil formation (fig 64).
One tunnel out of four is equipped with a cooling system.
This is the most popular technique to lay cables above 170 kV.

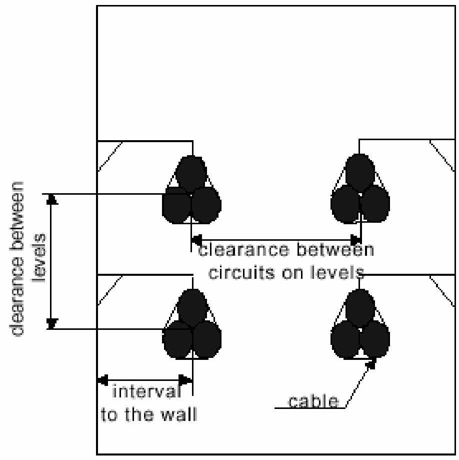


Figure 64: Laying in tunnel

3.4.1.5 Microtunnels

This technique consists of thrust-jacking through the soil prefabricated pipe sections having the exact diameter of the final pipe, from a pit equipped with a thrust-jacking station (fig 65).

Tunnel boring is always mechanical: a remote-controlled microtunnel boring machine is placed at the head of the pipes, and makes it possible to build small-diameter horizontal tunnels (diameters 0.3 m to 1.2 m).
The section lengths do not generally exceed 150 m. If the drilling length is too long, it can be divided into two with a central work shaft and two lateral exit shafts.

Microtunnels are generally dedicated to only one user.
The cables are generally pulled in ducts that are installed in the microtunnel when it is finished. If required, the ducts and the space between ducts and microtunnel can then be filled.

Figure 65: Microtunnelling

3.4.1.6 Shafts

These are circular or rectangular excavations that are made vertically or at an angle less than 30° to vertical. Such shafts are dug, for example when constructing a microtunnel, for the start and end stations of the microtunnel.
The cables in these shafts are usually placed on a steel structure, the length of the shaft defining the type of system (rigid or flexible systems – see corresponding section).
The most common installation techniques used are a flexible design with cables installed in trefoil formation.

3.4.1.7 Bridges

At special or delicate crossings, this method makes it possible to avoid having to use costly and sometimes technically difficult methods.
The cables are placed either inside the bridge or on the outside of it, mainly depending on the type of structure of the bridge.
The most common installation techniques used are a flexible design with cables installed in trefoil formation.

3.4.1.8 Mechanical laying

There are three ways of organising the mechanical laying site:
- mechanically excavated narrow trench, and separate laying of the cables: laying and backfilling is done by traditional methods after the trench has been mechanically excavated;
- trench excavation and cable laying both mechanical: trench excavation, cable laying and sometimes the backfilling are performed by a machine(fig 66).
- trench excavation, cable laying, backfilling all continuous and mechanised: with this method, trench excavation, cable laying and sometimes trench backfilling can all be done simultaneously in a continuous process over the full length of a homogeneous portion of the link (the joints have to be prepared beforehand).

This technique is only used for voltages under 170 kV.
The cables are usually buried directly in trefoil formation with a minimum cover of one metre.

Figure 66: Mechanical laying (French site)

3.4.1.9 Horizontal drilling

This technique is directly derived from the directional drilling techniques used in the oil industry, and is used for crossing of major obstacles (e.g. rivers, railway tracks, motorways, …) or longitudinal drilling.
The method involves three phases:
- drilling of the pilot hole
- back reaming
- placing of the final pipe (s)

The drilling mud (generally bentonite) washes cuttings to the surface, reduces friction, stabilises the bore hole and cools the drill head.
Generally the mud is screened and recycled for re-use in a closed circuit.
The nature of the soil is essential when considering using this technique.
After the pipes are installed, the cables are pulled into them.
Three PE ducts are usually pulled in one drill with one cable per duct. These are air filled or filled with bentonite.

3.4.1.10 Pipe jacking

This technique consists of thrusting through the soil portions of prefabricated pipes that have the required final cross-section. A work pit or shaft is excavated to install the jacking equipment and the pipe portion to be jacked.
As the pipe jacking progresses the earth works are done, either manually or mechanically, according to the requested diameter (fig 67).
The first portion of pipe may be provided with a cutting curb made of steel which attacks the soil in place and protects the personnel who excavate the soil.
Pipe jacking can be done for pipe diameters comprised between 0.4 m and 3.2 m. This technique is advantageous for lengths exceeding 100 m and it is possible to do pipe jacking work over great lengths of 500 or 600 m. Pipes are usually of concrete or steel type.
The cables are placed as in tunnels or microtunnels, depending on the diameter. If required, the ducts and the space between ducts and pipe can be filled.

Figure 67: Pipe jacking (French site)

3.4.1.11 Embedding

This technique consists of excavating the river bed from a barge or an amphibious vehicle, and embedding the pipes or cables themselves in the river bed (fig 68).
When crossing navigable waterways, this method implies that river traffic be stopped or deviated during the excavation and laying operations.

Figure 68: Embedding

3.4.1.12 Use of existing structures

It may sometimes be decided to use existing (or ancient disused) structures (racks, trays, …) or disused utility ducts (water, gas, pipeline, …) to place the cables in them.
In that case it is essential to thoroughly inspect these structures and completely clean them, especially in the case of ducts.

3.4.2 Installation techniques

Rigid or flexible systems

When certain methods are used (tunnels, microtunnels, bridges, pipe jacking), the question may arise whether to install the cables in rigid or flexible systems.
In a rigid system the cable is held in such a manner that virtually no lateral movement occurs and the cable absorbs the thermal expansion by developing a high internal compressive force.
In a flexible system the cable is held in such a manner that the expansion movement is accomodated by lateral deflection of the cable. The design of the cable system ensures that the movement does not cause excessive strain in any of the cable components which could result in a short fatigue life.

3.5 ACCESSORIES INSTALLATION

Assembly of the accessories onto cable with extruded insulation is the most vulnerable part of a project involving the manufacture and installation of a new cable circuit [36]. Accessories and cables are manufactured and tested under controlled factory conditions, whereas the in-service performance of the accessory is dependent upon the training, skill and reliability of the personnel, who are often required to work under adverse site conditions.

For many project applications one company will manufacture the cable and accessories and undertake to complete the installation of the circuit. In other applications the installer may complete the circuit using cable and accessories supplied by different manufacturers. In some applications the installer may only assemble the accessories. For each application the requirements of the Quality Assurance (QA) system are equally rigorous.

3.5.1 Quality Assurance approval for installation

The User should ensure that the installer provides evidence of an approved quality assurance system for installation to an internationally recognised standard.

3.5.2 Quality Plan

The installer is required to produce a Quality Plan for each project, this includes the project time schedule together with the requirements for suitably qualified personnel, training, on-site storage of components and accessories, tools, testing equipment, constructing materials, assembly instructions, preparation of the jointing environment and records of the assembly work. It is important that the records of assembly are traceable to the location of each accessory in the cable circuit. If purchasing separately, the User is advised to ensure that, for the purposes of traceability, the quality systems of the cable manufacturer, accessory manufacturer and installer are compatible.

3.5.3 Training of Personnel

When selecting the designs of accessories the User should ensure that training courses are available for the jointing and supervisory personnel. It is strongly advised that personnel receive training on the particular designs of accessories and cable.

Examples of the elements of a training course for assembly personnel are:

- General training at specific system voltages with the standard range of accessories required by the User
- Repeat training after a defined period for those personnel who have completed general training
- Specified training on a new accessory or cable design for those personnel who have completed general training.

At the end of the training course the proficiency of the assembly personnel is normally assessed, for example, by a verbal or written examination, by a practical test and preferably by performing on the assembled accessories an electrical partial discharge test and voltage withstand test.

Proficiency is recognised at the completion of training by the issue of a certificate, which should be checked by the User as part of the quality plan for a specific project. In many instances a kit of general jointing tools and a set of general assembly instructions is also issued to the personnel following satisfactory completion of training.

3.5.4 Assembly instructions

The accessory manufacturer is required to supply a complete set of assembly instructions together with drawings of the particular accessory.

The instructions should also include lists of the specified assembly tools, the specified consumable materials and the health and safety precautions. Recommendations for the preparation of the assembly environment should also be given.

It is important that the User studies the instructions before work begins to ensure that the workplace is correctly prepared and that all the tools and consumable materials are available.

3.5.5 Special assembly tools

Most designs of accessories, particularly those operating at higher system voltages, require special tools which are purchased or hired from the accessory manufacturer. The User should ensure that full instructions are provided and that the personnel are trained in their use. These tools may take the form, for example, of a) hydraulic compression presses or welding equipment for connecting the conductors, b) cutting equipment to remove the insulation screen and to shape the cable insulation c) assembly machines which stretch and position pre moulded elastomeric components, d) taping machines that apply tape and e) heated mould tools and mobile extruders for field moulded joints.

3.5.6 Preparation of the assembly environment

It is strongly recommended that the assembly area for both joints and termination to be enclosed within a tent or temporary building (fig 69), with the objective of providing a clean and dry environment. The enclosure should be a) well lit to facilitate accurate preparation of the cable insulation, b) provided with a sound floor and c) lined with sealed materials to facilitate cleanliness. In extremes of climate it is good practice to provide control of temperature and humidity to ensure a) consistent performance of the personnel and b) consistent properties of the polymeric materials.

Figure 69: temporary enclorure for jointing

Joint assembly:

- An appropriately sized joint bay or chamber.
- The provision of a temporary and/or permanent support for the completed joint.

Figure 70: temporary enclosure for terminating

Termination assembly:

– A permanent support structure.
– A temporary weatherproof structure during assembly (70).
– Means of lifting the cable and insulator into position (fig 71,72a,72b).

Figure 71

Figure 72a

Figure 72b

4 DESIGN AND CONSTRUCTION ISSUES RELATING TO OVERHEAD TO UNDERGROUND TRANSITION

4.1 OPTIONS FOR TRANSITION OVERHEAD/UNDERGROUND

Any underground line is connected to the network by means of terminations. In general cases, the terminations are located within substations.

In the case of siphon (fig 2) or underground entrance to a substation (fig 3), transition equipment is needed, in accordance with all technical issues listed in previous chapters 2 and 3. For example they must allow:

- Easy access to connections of the main circuit for operational changes in circuit configuration.
- Easy access to phase protecting device: surge arresters etc.
- Easy access to shield protective devices and bonding connections.
- Easy access to diagnostics sensors or pressure and level monitoring devices.
- Easy access to optical fibers for thermal monitoring.

Power supply may also be needed.

In addition, protection of people, protection from vandalism, visual impact may dictate or influence the choice of the transition solution between:

- Transition towers or poles where all the equipment is located on platforms installed on the lattice tower (fig 73) or pole (fig 74) or beside them.

Figure 73: Transition tower

Figure 74: Transition pole

Transition compound which is a fenced area, similar to a small substation which could eventually be remote operated (fig 74).

Figure 75: 400 kV transition compound **Figure 76: 120 kV Transition compound**

In some countries, regulations require to prevent access to cable terminations from shooting and the only acceptable solution would be transition compounds protected by concrete walls (fig 77).

Figure 77: 400 kV transition compound surrounded by concrete walls

In other cases, polymeric or composite terminations may offer better safety and environmental performances and make transition towers and poles acceptable (fig 78).

Figure 78: 100 kV Transition tower with synthetic terminations

When choosing a solution, due to the permanent presence of tension, special care must be given to the authorization of people in charge of maintenance of the various equipments involved.

4.1.1 Transition on towers/poles

Figure 79: Transition on a lattice tower

Figure 80: Transition on a pole

The design of transition towers or poles has to take into consideration the method of installation of the cable on the structure.

Some of the available options are:

- Cable installed inside the structure. This method gives a better mechanical protection for the cables from external aggression, but requires special considerations for the installation of cables. A special foundation design is required for the pole. Good coordination between the cable installation and the tower installation is also very important in that case (fig 81).

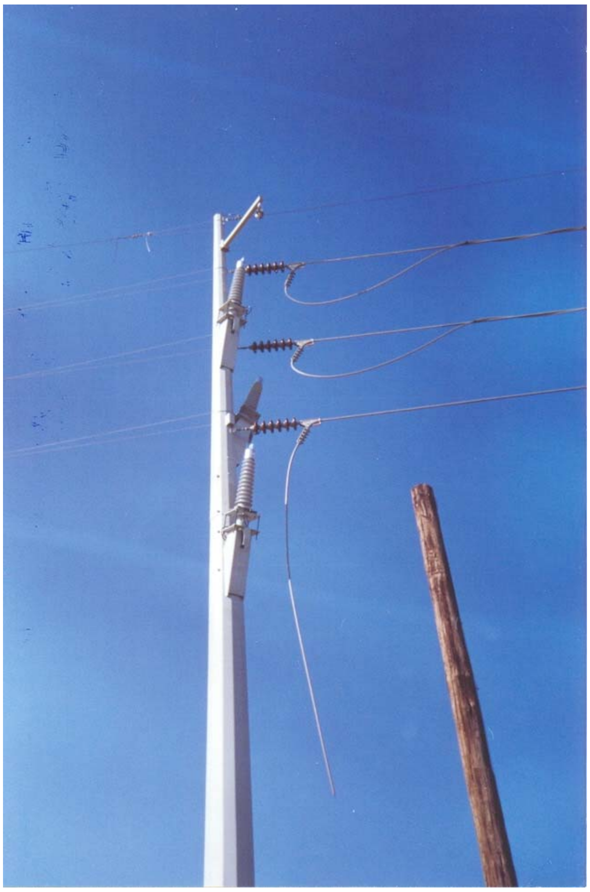


Figure 81: Transition on a pole: cables are installed inside the pole

- Cables installed outside the tower in conduits: The conduits give a suitable mechanical protection and facilitate the cable installation. Cable clamping at the top end of the conduit must be designed carefully, and may limit the height of the termination in the tower.
- Cables clamped on the outside of the pole: In this option, the cables are clamped on the outside of the pole. For mechanical protection of the cables, cover plates are usually installed, especially in the lower part of the structure that can be accessible to public (fig 82).

Figure 82: Transition on a pole: the cables are installed outside the pole and protected at the lower part of the structure

- Cables installed on a platform next to the foot of the tower: the platform may be integrated to the tower design or may have independent foundations (fig 83).

Figure 83: Transition tower with equipment on a platform

4.1.2 Transition compounds

Chapter 4.2 covers the selection of transition compound type and the detailed design of an insulated transition compound.

The three component parts of the transition compound are defined as follows

(a) Primary System

The primary system comprises all equipment which, in whole or in part, is in service at the highest operating voltage of the system.

(b) Secondary System

The secondary system comprises all equipment which is used for the control (local and remote), protection, monitoring automation and measurement of the primary system.

(c) Auxiliary System

Auxiliary systems are those which are required to enable the primary and secondary equipment to operate.

4.2 TRANSITION COMPOUND

A transition compound is similar to a small substation with a limited number of equipments, mainly terminations, surge arresters, and occasionally disconnectors, depending on the connection scheme. The following sections highlight the most important considerations for a transition compound but do not go into details about the specifications of each type of equipment. More considerations about the design of substations can be found in CIGRE Technical Brochure 161 "General Guidelines for the Design of Outdoor Substations" [37].
Due to the many points Substations and Transition Compounds have in common, this paragraph refers to and summarise the main aspects highlighted by the Technical Brochure 161.

4.2.1 Planning

This section will give information helpful for planning the transition compound and for defining the general scope equipment, depending on the system requirements. The options of extending or uprating the existing equipments and/or lines should have already been evaluated.
The starting point for a transition compound design procedure is as follows
(a) The need for the new equipment has been approved.
(b) The range of its duties, loading and general location have been determined.

4.2.1.1 Extent of the Transition compound

The area available for the compound, the connection schemes and the possibility of extension as well as compensating equipment options should be selected for the needs of the future. It should be noted that the lifetime of the compound may be between 30 and 50 years.
It is very important to allow sufficient space for extension. Sophisticated network planning is needed to estimate the necessary reserve space. The space required depends essentially on the function of the compound.
Extension work such as building, reconstruction or extension may be rather difficult and expensive if there has been no previous planning for them.
It is important to define the size of the compound at the final stage of development. The initial peak load of a cable system is dependent upon a number of factors such as the network configuration, standby philosophy and rate of load growth.
The outgoing line corridors should be planned so that there is a minimum number of crossings between different circuits.

4.2.1.2 Connection scheme

The selection of a connection scheme and its possible extensions for a particular arrangement is an important initial step of the design. Among the matters that affect this decision are operational flexibility, reliability and availability, and costs.

4.2.1.2.1 Operational Flexibility

In order to reduce the risk of disconnection of generators or consumers, due to faults in system components, circuits between two substations are often doubled so that power transfer is shared, for instance between two separate overhead/underground line circuits. Consequently, in the transition compounds, one can find doubled transition equipment.

4.2.1.2.2 Reliability and Availability

The failure rates of the equipment and the choice of the transition compound scheme have a considerable effect on reliability and availability i.e. forced outages and planned shutdowns. Calculations can give only approximate results. This is because the available failure statistics is always based on an older generation of apparatus and the occurrence of a severe outage during the lifetime of the transition compound is likely to be quite small.

However, for a comparison of different schemes, reliability calculation is a valuable instrument for the transition compound engineer, which can assist in the choice of scheme and layout.

Recent publications have indicated that not only the primary equipment but also the secondary equipment, e.g. the location and number of instrument transformers and the arrangement of the secondary circuits can have a great influence on the over-all reliability. Special attention has to be paid to the secondary wiring and cabling.

The proposed scheme and layout must allow simple and efficient performance of normal operational life, changes of connections and planned outage for maintenance or extension.

4.2.1.2.3 Service Continuity

When choosing a specific arrangement one of the prime considerations should be the effect of a loss due to fault conditions or for maintenance. Such effects may include loss of generating plant, loss of transmission and loss of supply to customers.
In all the examples given, if line or transformer faults or maintenance (of e.g. line disconnector, instrument transformers or line traps) are considered, continuity cannot be maintained on the affected circuits. Apart from these limitations, a measure of service continuity can be maintained.

An assessment of the continuity that can be obtained has been categorised as follows:

Categories definitions and examples

The transition compound may be classified in three categories, according to availability in default conditions:

- Category I: the circuit is fully redundant (in N-1, no overload is produced)
- Category II: the circuit is not fully redundant (in N-1, one overload is acceptable, at least temporarily, or the circuit is derated)
- Category III: the circuit is not redundant (in N-1, the connection is lost)

The following table shows the analysis of reliability for typical configurations for a single circuit transition compound. It should be noted that the duration of service interruption will depend upon the time required to transfer the load to the spare cables.

Table of categories for single circuit configurations (availability of link in "N - 1" configuration)

Configuration (1 circuit)		State in N-1	Categorie
1 cable per phase	0 spare	Loss	III
	1 spare	No overload	I
	2 spares	No overload	I
2 cables per phase	0 spare	Overload or derated	II
	1 spare	No overload	I
	2 spares	No overload	I

The two first categories may be further analyzed in sub-categories to observe the conditions of the exploitation in N-2 configuration:

- Category I: a second fault
  - induce no overload (Ia) or
  - induce an acceptable overload (Ib) or
  - induce the loss (Ic)

- Category II: a second fault
  - induce an acceptable overload (IIa) or
  - induce the loss (IIb)

Table of sub-categories for single circuit configurations (availability of link in "N - 2" configuration)

Configuration (1 circuit)		State in N-1	State in N-2	Sub -categorie
1 cable per phase	0 spare	Loss	Loss	III
	1 spare	No overload	Loss	Ic
	2 spares	No overload	No overload	Ia
2 cables per phase	0 spare	Overload or derated	Overload or derated or Loss	IIa or IIb
	1 spare	No overload	Overload or derated	Ib
	2 spares	No overload	No overload	Ia

Summary:

	N-1configuration		*N-2 configuration*	
	Categories	Description	Sub categories	Description
Healthy state	I	No overload	a	No overload
			b	Acceptable overload or derating
			c	Loss
	II	Overload or derated	a	Acceptable overload or derating but no loss
			b	Loss
	III	Loss		

As seen in the examples for single circuit transition compounds, determination of the reliability to achieve can assist significantly in the choice of layout for the transition compound.

Similar analysis can be done for double circuit layouts, or any other conditions, for example, when the spare cables are of different size (ampacity) than the cable from the links.

4.2.1.2.4 Choice of connection Arrangements

In addition to the functions of a transition compound, choice of switching arrangements may be influenced by:

(a) The level of skill and experience of operating staff.
(b) The future growth and development of the supply system
(c) Economy in the early stages of development.
(d) The ease of facilitating future extensions.
(e) Duplication of circuits to give alternative supply routes
(f) Amount of power to be transmitted.
(g) Strategic importance of the circuits.
(h) The service continuity of other significant parts of the network.
(i) The reliability, both of the transition compound as a whole, and the individual components within the transition compound
(j) The standardisation policy of the organisation.
(k) Maintenance requirements and techniques
(l) National regulations (for example whether or not it is permissible to operate a disconnector remotely to change a particular switching arrangement without visual confirmation).

4.2.1.3 Fault Current Levels

Fault current dimensioning depends on the neighbouring network. System planning usually defines the following fault current ratings for a new equipment:

(a) Maximum three-phase effective short-circuit current for the lines and the transition compound for the foreseeable future.
(b) Duration of the effective short-circuit current.
(c) Peak short-circuit current.
(d) Maximum earth fault current and corresponding time.
(e) Maximum current through the neutral point of transformers.
(f) Minimum short-circuit current (for protection).
(g) Minimum earth fault current (for protection).

4.2.1.4 Neutral Point Earthing

The electrical networks may be:

(a) Effectively earthed (earth fault factor up to 1.4).
(b) Non-effectively earthed (earth fault factor e.g. 1.7). e.g. resistance earthed or resonant earthed.
(c) Isolated.

In the first case earth current may be 60... 120 % of the short-circuit current. If the conductivity of the soil is poor (resistivity of 2000 Ohm*m or greater), special attention has to be paid to the magnitude of station potential during an earth-fault. In this case it is possible to limit the earth-fault current and dimension the insulation level correspondingly. Alternatively the potential rise of the earthing grid may be limited by ensuring that the earth wires of outgoing overhead lines are of good conductivity and, in extreme cases, have cross sectional areas equivalent to those of the phase cables

4.2.1.5 Protection in general

The transition compound has to be designed and constructed so that all possible faults can be eliminated:
The need for telecontrol and telecommunication links depends on the needs of the automation, remote control, data transmission and operation of the network.

4.2.2 Site Selection

4.2.2.1 General

The choice of a site for a transition compound is a compromise between technical, economic, environmental and political factors.
In simple terms the problem is to find the most suitable place within a fairly large geographic region, where the compound can be built, given the total number of circuits and the destination of the lines. Typically, in the whole region, climate and altitude are almost the same, but technical and environmental factors vary.
The first step is to locate possible sites, which are as level as possible, with enough available area, at reasonable costs, with easy access, within the general location and without important restrictions on line corridors, where the transition compound can be erected with minimum environmental impacts. It is advantageous to locate sites near to existing line corridors or even at crossing points. Sometimes such places simply do not exist and the choice will be confined to places that have only some of the above characteristics.
Once the possible sites have been located, an analysis is then made for all the technical and environmental aspects of each one, including costs, potential environmental impacts and the preventive or corrective measures that can be taken to avoid or reduce them. It is also worthwhile to assess the social acceptance of project. A more detailed discussion about this analysis can be found in Chapter 9.

This analysis then furnishes the criteria for deciding on the most suitable transition compound site, bearing in mind the degree of feasibility and the project cost of each alternative. If no suitable site is found, the process may be reinitiated with another general area.

4.2.2.2 Environmental aspects

This aspect has the greatest effect in terms of reducing the possible impacts on the natural or social environment; since many of the potential effects of a transition compound, and especially the magnitude of such effects, depend largely on whether its siting avoids the more sensitive areas.
Some of the aspects given below are the limitations including technical point of view. Negligence in taking account of these aspects could have an indirect effect on environmental protection;

4.2.2.2.1 Land

The site should preferably be on fairly flat land. This would significantly cut down the possible effects on the substratum by reducing the need for earth movements.
The area of the transition compound site must not be flood-prone / water stagnation.
The transition compound site should not come within areas or spots listed in the inventories of sites of geological interest.
The terrain should be big enough and have a suitable layout for housing all transition compound equipment and services, including any future extensions thereof, and for the development of a landscaping project.

4.2.2.2.2 Water

The site should be chosen so as to avoid any damage to the natural drainage network, especially to permanent surface watercourses, avoiding their interruption, and to ground-water recharge areas, to avoid any damage to the underground network.

4.2.2.2.3 Vegetation

Where possible the transition compound should be sited in low-productivity farming areas or uncultivated land, avoiding areas in which the existing plant formations have a high ecological or economic value.

All wooded areas should in general be avoided, especially woodland formed by protected species, singular groups or riverside copses.
The impact on vegetation of the future line corridors should be considered.

4.2.2.2.4 Fauna

The site should be chosen so as to avoid any areas or spots listed as protected areas due to the importance of their animal communities, specially those protected because of birds. Attempts will also be made to site the transition compound as far from such areas as possible to pre-empt future problems in the incoming and outgoing lines.

4.2.2.2.5 Population and Economy

As far as possible the transition compound will be sited away from population centers, isolated dwellings and areas of potential urban development. This obviously does not hold for distribution transition compounds that have to be close to the consumers they serve.
Proximity to all mines and mining concessions in general will be avoided, as these impose limitations on the transition compound's incoming and outgoing lines
Any zones with a tourist and/or recreational potential will be avoided.

4.2.2.2.6 Town Planning

The local town planning policy needs to be taken into account when siting the transition compound to avoid urban areas, development land or land held in reserve for possible future development.
Transition compound landscaping may be covered by local regulations and should be considered in detail when siting the transition compound

4.2.2.2.7 Cultural Heritage

All areas should be avoided that contain items belonging to the cultural heritage, to prevent either direct damage, such as the deterioration or destruction of archaeological remains, or indirect, resulting from placing the transition compound in the vicinity of a monument and affecting its visual setting.

4.2.2.2.8 Infrastructures

Consideration should be given to the presence of any infrastructure such as radio and television antennae and/or relays, airports and aerodromes, other projects, generating plant or infrastructures belonging to other electricity companies, deposits of fuel or flammable material, dumps, military sites or any other infrastructure that might impose limitations on the siting of the transition compound and the incoming lines.
The proximity of other infrastructures has to be considered: train stations and main roads (equipment transfers), water supply, medium voltage electricity network and telephone service network.
Existing devices for the treatment and evacuation of rainwater and sewage water should also be considered.

4.2.2.2.9 Protected Natural Sites

Enlarging on the points already made under the heading of fauna, the transition compound should be sited outside and as far as possible from any areas listed as protected natural sites, especially national and natural parks, or other listings of similar standing.

4.2.2.2.10 Landscape

Wherever possible, the transition compound will be sited in areas of little scenic value, avoiding any areas or spots listed in the natural inventory of outstanding landscapes.
Sites in woodland should also be avoided, given the tree-felling that would be necessary and the visual impacts that would ensue. The nearby presence of woods, however, would cut down the visibility of the transition compound, thereby reducing its landscape impact.
The best site, as far as landscaping is concerned, is such that the transition compound is not visible from the most common views points.
An analysis will be made of the nearby presence of roads and railways, as these would greatly boost the number of potential observers and the consequent visual impact of the compound.
The choice of the site should take into account the size and shape of the visual field affected.

With the aim of minimising the scenic impact of the transition compound and helping it to blend in with the background, a landscaping project should be drawn up in the interests of definitive landscape restoration.
Landscape restoration should achieve the best possible harmonisation of the transition compound with the shapes, textures and colour of the surroundings. The project thus has to deal with such matters as earth movements, the definition of surface coverings and the use of plantations of trees and bushes, as these are basic means to that end**.**

4.2.2.2.11 Access Route

When designing the access route, consideration will be given to the same factors as in the choice of site, preventing the access route from producing undesirable impacts that the siting of the transition compound had managed to avoid.
The definitive transition compound access route will be designed to reduce the visual impact as far as possible. A study should therefore be made for the possibility of making an independent access route for the work, especially for bringing the equipment for the transition compound.
Other considerations to take into account are: the possibility of setting up the access route by purchase of the land or by establishing the corresponding rights of way, determination of the access with the minimum length, and negotiability of the route for the special vehicles needed for bringing in the heaviest and biggest items of the electric equipment.
Once a decision has been taken on the area that meets the characteristics for setting up the route, attention will then be paid to the following aspects when laying down the definitive access route: effecting the definitive access route from secondary roads of the public road network to cut down the number of potential observers; avoiding straight-line junctions with the road network, using curves and exploiting the natural relief; minimising earth movements and the creation of unnatural shapes, thus avoiding the creation of banks difficult to plant up afterwards, avoiding tree cutting and felling and/or damage to other important elements of the environment such as nests, underground lairs, cultural monuments, etc.

4.2.2.2.12 Site Preparation

Special care will be taken with all watercourses, whether permanent or temporary, ensuring their continuity by means of any necessary channels or under-apron tubes, according to the solution decided upon.
The site should be made so that the banking around the station has a gentle slope, less than 30% if possible, to ward off any significant erosion. This measure should be taken into account in the banking of both embankments and cuttings, in the first case due to their greater proneness to erosion, and in the second, due to the greater difficulty of carrying out corrective measures as the substratum here is much poorer and it is therefore more difficult for plants to take root.
Banking work will also be finished off so as to present a homogeneous surface, with a certain roughness to facilitate seeding. As far as possible they should be made to chime in with the natural forms of the land, avoiding the creation of abrupt changes of gradient, sharp edges or unnatural shapes at the top of the banking.
Where the plot lies close to a road, a study should be made of the feasibility of distancing the apron from it as far as possible to cut down the scenic impact
Care should be taken when creating the outdoor yard not to interrupt any existing paths on the plot, to avoid balking the free movement of the owners of other property. Where necessary an alternative route will be set up. The ideal solution would be an internal ring road round the edge of the plot, so as to respect rights of way and fulfil the same function as before, improving existing paths in terms of width and roadbed. Consideration will in any case be given in the construction project to the repositioning of paths and all types of services thereby affected.
The definition of earth movements should make due provision for the definitive disposal of the topsoil, which in no case should be covered by poorer quality material. It should rather be collected and put to good use elsewhere.
When designing the equipment disposition, and when work is underway thereon, all attempts will be made to conserve all trees on the plot that are not directly affected by the platform, so that they shield the transition compound from outside observers.

4.2.2.2.13 Other Environmental Considerations.

Other considerations or aspects to take into account in the design, as aesthetics, noise, of leakage / spills, waste management, etc., are described in chapter 9

4.2.2.3 Technical aspects

4.2.2.3.1 Topography

It is convenient, for reasons of standardisation of supporting structures, economy of space, access to equipment, even distribution of stresses between equipment terminals and easy connection of equipment, to level the ground where the transition compound is to be built. (small slopes, to allow necessary drainage, must, of course, be provided).
To level the area required by a transition compound may be a costly and time consuming task, so it is better to choose a site as flat as possible but not subject to flash floods.
Taking into account topographic characteristics it is convenient to evaluate the consequences, concerning levelling works, of small displacements and changes of geographic orientation.
In the mountain regions, a transition compound must be placed as far as possible from avalanche corridors. Levelling costs may force the reduction of the dimensions of the transition compound.

4.2.2.3.2 Geological and Geotechnical Characteristics of Soil

The soil must allow the construction of roads and foundations. The minimum bearing load is usually about *50* kN/m^2. The existence of geological faults is usually sufficient reason to reject a particular location.
Siting a transition compound in the areas of unused mines can lead to severe problems due to ground subsidence and such locations are best avoided.
In zones subject to earthquake hazards a careful study is essential, as earthquake intensity may vary dramatically in places located only some kilometres apart.
A high water level may require the construction of drainage facilities, increasing costs and causing construction delays. Terracing costs and maximum possible inclination of the talus are a consequence of geological and geotechnical characteristics of soil.
A low value of soil resistivity is desirable and this should be measured before erection of the transition compound. Additional actions such as increasing the site area and inputting earthing facilities may be necessary.

4.2.2.3.3 Access

The equipment is generally of shape and weight compatible with any common transportation network.
The transport procedure must be checked both ways (to and from transition compound site) and measures taken to maintain it during the transition compound lifetime.
Small difficulties may be solved by the use of lower loader, or by temporary reinforcement of bridges.
In the most difficult cases, improvements in the transportation network may be necessary.
Another aspect to be considered is the access of operators (for manned transition compounds) and maintenance teams (for unmanned transition compounds).

4.2.2.3.4 Line Corridors

The cost of modifications to existing lines to allow their connection to the transition compound must also be evaluated.
The consideration of future extensions with additional line entries may have different consequences upon the various sites being analysed.
Line corridors have great influence on the geographical orientation of the transition compound and may impose the choice of a transition compound layout.

4.2.2.3.5 Pollution

Pollution causes the deposition of small particles on the insulators. The relationship between creepage distances and pollution level is indicated in IEC Standard 60071-2 [38]. As pollution levels may change (increase) with time, a small over-dimensioning is recommended. In extreme cases, in heavily polluted or dry zones, cleaning facilities or the use of protective products may be necessary.
Saline and some types of industrial pollution can cause corrosion in supporting structures, and protective coating or the use of concrete supporting structure may therefore be needed.
Nevertheless, whatever measures are taken, the risk of failure and the equipment and maintenance costs will always increase with the pollution level.
Whenever possible the prevailing winds should flow through the transition compound towards the origin of the pollution (sea, industrial zones, highways...) or, the transition compound should be protected by some natural barrier (e.g. hills or trees).

4.2.3 Overvoltage and Insulation Levels

All equipment installed in a transition compound must be designed by taking the rated power frequency voltage of the network into account. The temporary overvoltages at power frequency caused by e.g. sudden loss of load or earth faults switching overvoltages and lightning overvoltages. In order to determine its capability, it is subject to voltage tests as follows:

(a) Lightning Impulse Withstand Voltage. *(1.2/50 µs)*
(b) Switching Impulse withstand voltage *(250/2500 µs).*
(c) Power frequency *(50* or 60 Hz) (wet and/or dry).

The set of test voltage values determines the insulating level. Standard insulating levels are defined in IEC Standard 60071 although the network parameters may dictate other values (IEC 60071-1, -2) [38].

The necessary insulation level depends on the insulation co-ordination, i.e. on the properties of different parts of the network (mainly lines), the protection used against overvoltages (surge arresters ZnO are very effective), on altitude and also on the required reliability of the transition compound (permissible probability of flashover).

4.2.4 Current Rating and Overcurrents

The instantaneous load flow within a transition compound depends on the state of the entire electrical network.

Usually a complete network analysis including development of network in future is required to determine the nominal values of currents flowing in an individual transition compound circuit. It is theoretically possible for maximum current flow to occur with a relatively low total production of electricity in the network. e.g. the supply to a pumped storage power station or when utilising the by-pass facility within a transition compound.

While designing a transition compound it is necessary to consider the following two aspects of the effect of current

(a) The thermal effect (including induced currents).
(b) The mechanical effect on conductive items of plant and their support structures.

Precise thermal modelling of equipment is very difficult as many factors influence the resultant temperatures of conductive parts e.g. previous loading, ambient temperature, wind speed, and solar conditions.
Thermal design is therefore empirical and is proven by type test covering nominal current rating and short-circuit current rating.
Standard procedures have been devised to predict the thermal behaviour of conductors, particularly with respect to sag.
It may be possible to assign a short-term current rating in excess of the nominal but the analysis leading to this must be to ensure that no "hot spots" are overlooked.

Methods of calculating short-circuit current values are given in IEC Standard 60909 [39] and the effects of short circuit current can be evaluated in accordance with IEC Standard 60865-I [40].

4.2.5 Electrical Clearances

It is not possible to test the whole HV installation by corresponding test voltage. Therefore minimum clearances in air between live parts or between live and dead parts in the air are stated, to obtain the required insulation level in arrangements which have not been tested. As the clearances are stated universally, they must assume the insulation in the worst case of spark gap with sufficient reliability. Smaller clearances are permissible if the particular arrangement has been tested by the prescribed insulation test (IEC 60071) [38].

The values of minimum distances to live parts in the air also depend upon practical experience and therefore, some differences can be found when comparing rules in different countries.

The specified electrical clearances must be maintained under all normal conditions. Exceptionally reduced electrical clearances may be allowed. For example, in the case of conductor movement caused by short-circuit current or by extremely strong wind.

4.2.6 Direct Lightning Stroke Shielding

A transition compound should be protected against direct strikes by lightning, where there is a significant probability that lightning discharges will occur. The following are characteristics of the lightning phenomena that make it difficult to engineer the direct stroke protection:

- The unpredictable, probabilistic nature of lightning
- The lack of data due to the infrequency of lightning strokes.
- The complexity and economics involved in analysing a system in detail

There is no known method of providing 100% shielding short of enclosing the equipment in a solid metallic enclosure. The uncertainty, complexity, and cost of performing a detailed analysis of a shielding system has historically resulted in simple rules of thumb being utilised in the design of lower voltage facilities. Extra high voltage (EHV) facilities, with their critical and more costly equipment components, usually justify a more sophisticated study to establish the risk vs. cost benefit.

A four-step approach can be utilised in the design of a direct lightning stroke protection system.

(a) Evaluate the importance and value of the facility being protected.
(b) Investigate the severity and frequency of the lightning phenomena in the area of the transition compound facility and the exposure of the transition compound.
(c) Select an analysis method consistent with the above evaluation and then lay out an appropriate system of lightning stroke protection.
(d) Evaluate the effectiveness and cost of the resulting design.

The frequency of the lightning phenomena is often defined by the Ground Flash Density (GFD) or by the keraunic level. GFD is defined as the average number of strokes per unit area per unit time at a particular location. Keraunic level is defined as the average annual number of thunderstorm days or hours for a given locality.

Two typical methods for the analyses of the effectiveness of a direct lightning stroke protection system are:

1. The classical empirical method with:

    (a) Fixed angles
    (b) Empirical curves

2. The electrogeometric model

For additional information about severity and frequency of lightning phenomena, and protection system analyses, see IEEE 998 - Guide for direct lightning stroke shielding of substations [41].

4.2.7 Earthing for Personnel Safety

An earthing system, engineered for personnel safety, ensures that a person is not exposed to a dangerous electric voltage gradient, when in the vicinity of facilities that are connected to earth. A personnel safety earthing system controls the effects of the temporary earthing path, established by a person exposed to a voltage gradient in, or in the vicinity of the transition compound.

During earth fault conditions, the flow of current to earth will produce voltage gradients within and around a transition compound.

During an earth fault, the maximum voltage gradients along the earth surface may endanger a person in the area. Moreover, hazardous voltages may develop between metal structures or equipment frames that are connected to earth, and nearby surfaces on which a person may stand.

The following circumstances can contribute to hazardous voltage gradients and a risk to personnel:

(a) Relatively high earth fault current
(b) High soil resistivity
(c) Distribution of earth fault currents such that a significant ground return current flows.
(d) Presence of an individual at such a point, time, and position that the body is bridging two points with a voltage difference
(e) Insufficient contact resistance to limit current through the body to a safe value under the above circumstances
(f) A fault duration such that the duration of the flow of current through the human body is for sufficient time to cause harm

The effects of an electric current passing through the vital parts of a human body depend on the duration, magnitude, and frequency of this current. The most dangerous consequence of such an exposure is a heart condition known as ventricular fibrillation, resulting in immediate arrest of blood circulation.

The magnitude and duration of the current conducted through a human body at 50 or 60 Hz should be less than the value that can cause ventricular fibrillation of the heart. The safety earthing system should be engineered to limit the magnitude of the human body current by limiting the step voltage and the touch voltage during earth faults.
High speed clearing of earth faults reduces the probability of exposure to electric shock, and reduces the duration of current flow through the body, which limits the severity of bodily injury. The allowable earth fault current value may therefore be based on the clearing time of primary protective devices, or that of the back-up protection

For additional information about the criteria, and the design of safety earthing systems, see IEEE 80 [42], Guide for safety in AC substation grounding. For guidance on the effects of current on the human body refer to IEC 60429 [44].

4.2.7.1 Safety Rules

Definitions:

Step Voltage - The difference in surface potential experienced by a person bridging the distance of a human step without contacting any other conductive part (IEEE 80) [42].

Touch Voltage - The maximum potential difference between the accessible earth surface and dead part which can be touched by a hand of person standing on the surface (IEEE 81) [43].

Safe Current - The current which can flow through the human body without threat to the life and health of exposed person (IEC 60479-I, -2) [44].

Maximum step and touch voltages are set to levels which will limit the current flowing through an exposed person to the safe current level.

The proposed methods of service and repair work must be considered in the design of a transition compound.

In most of the countries, the minimum clearance between live parts and personnel is standardised. The following parameters are usually defined

(a) Minimum height of live parts above the accessible surface.
(b) Minimum height of the lowest parts of insulators above the accessible surface.
(c) Minimum horizontal distance between a live part and protective rails, fences, etc.
(d) Minimum distance between a live part and a human body (or conductive tools) during the work in the transition compound.

The main circuit, once isolated, must be considered a live part until it is earthed. It is generally required to check for voltage on the conductor before applying the earthing device.

4.2.8 Corona and Radio Interference

All devices must satisfy the specified level of radio noise. The limits of radio noise are stated by national standards.

4.2.9 Acoustic Noise

National regulations or standards generally give the permissible acoustic noise level.

An acoustic study for the planned transition compound should be carried out to determine the acoustic conditions of the various items of equipment.

Within the framework of this study, the nature, distribution and number of sources of noise for the final installation and at intermediate stages has also to be considered.

4.2.10 Water Contamination

All noxious materials in the transition compound must be used and handled without leakage. The vessels must be, where possible, leakproof.

In most countries additional measures against detrimental materials are required. Oil pits are designed to catch some proportion of the oil (or other liquid) and to prevent oil from burning. If a central underground tank is used, it must be large enough to contain the volume of the largest oil-filled equipment, any rainwater collected since the tank was last emptied and the volume of water resulting from operation of the water spray fire protection system (where used). When no oil leakage occurs, the rainwater may be drained off. Otherwise decontamination is necessary by such means as mechanical separation, filtering or chemical cleaning.

4.2.11 Mechanical Forces

4.2.11.1 Weight

In addition to the normal weight of apparatus, conductors, structures etc, temporary loads must be considered, especially the weight of frost and ice (depends on local climate) and loads imposed by maintenance staff access. The strain during erection must also be considered (lifting of structures, asymmetric pull of conductor etc.).

4.2.11.2 Wind loading

The wind pressure may substantially influence the strain exerted on structures and footings and may also reduce the clearances between conductors (in the case of turbulent wind) or between the conductors and grounded structures (consideration should be given to insulators in V formation where problems occur). Standard values for wind speed are recommended by IEC but local conditions must always be considered. When calculating the wind loads on bundle conductors the screen effect from the other subconductors may be taken into consideration. The effect of wind on insulator strings should be taken into account. The wind loads can be transmitted to apparatus through either rigid or flexible connections.

4.2.11.3 Earthquake

Earthquakes occur in different parts of the world. Designers should consider the probability and the expected severity of a possible earthquake. Because the horizontal acceleration is about 0,3...0,5g (the vertical acceleration is less than 50% of the horizontal) and the frequency of the earthquake is 0,5-10 Hz, EHV equipment that resonates in this frequency band may be damaged. Support insulators are particularly vulnerable. Tubular aluminium conductors are also thought to resonate during earthquakes and, if required, "dampers" or "slide supports" may be fitted.

Equipment in the transition compound is liable to suffer from damage where the ground conditions are not stable. Therefore, particular attention should be paid to site preparation to ensure 'solidity' of the ground.

4.2.11.4 Short-circuit

Generally equipment is type tested in a short-circuit laboratory to determine its dynamic behaviour with the exception of support insulators. Insulators are generally tested to meet loads in static mode. The short-circuit strength of the conductors is usually only calculated, the calculation methods being verified by testing of typical arrangements. IEC 60865-1 can be used both for rigid and flexible connections, the background to the calculation methods is detailed in CIGRE Brochure N° 105 [45], published in 1996. Equations presented in these publications do not take into account the flexibility of insulators and this may result in over-specification of the required strength of insulators, especially where the application is of non-ceramic insulators. Advanced methods can be used for specific arrangements, to validate simple evaluations, or to limit short-circuit tests to the minimum number of configurations. They give access to much more comprehensive data than simple methods (for example dynamic effects, supporting structure stress and strain, spacer compression, connection to apparatus, insulator and supporting structure flexibility, etc)

4.2.11.5 Combinations of forces

The probability of simultaneous occurrence of various mechanical forces will be dependent upon local conditions
Calculations should normally include specified combinations of:

a) Wind loads on conductors and equipment
b) Ice loads
c) Short circuit loads
d) Earthquake loads whenever necessary
e) Maintenance and/or erection loads
f) Weight of equipment and reaction forces
g) Static conductor tension

Additionally mechanical loads due to low ambient temperatures should be taken into account.

4.2.12 Civil Design

Civil design includes supporting structures, foundations, facilities (internal roads, rails, site surface...), fencing and buildings.

4.2.12.1 Supporting Structures

Supporting structures include terminal gantries and support. Whereas reinforced concrete may be used for HV transition compounds, supporting structures of EHV transition compounds are commonly made from welded or bolted open profile steel lattice, or of tubes. In some cases aluminium structures are used for their low weight, resistance to corrosion and suitability for using in strong magnetic fields but it should be noted that the buried portion must be made of steel in order to avoid electro-chemical corrosion.

Calculation of loads is usually covered by national standards and regulations which specify safety factors and load combinations.

4.2.12.2 Foundations

Calculation methods are given by national or company standards. Dimensioning is carried out according to the loads on the structures and additional forces.

Depending upon the type of soil and the loads, foundation types can be:

(a) Poured concrete with or without steel reinforcement
(b) Prefabricated reinforced concrete
(c) Concrete slab (mostly used in indoor applications)
(d) Drilled (suitable in hard soil)
(e) Auger bored piles

Steel stubs or anchor bolts, to which the structures are attached, are usually cast into the foundation, a template often being used to locate such fixings prior to the concrete being poured. Alternatively, the foundation pads can be drilled (after setting) using the structure as a template and anchor bolts secured using epoxy cement..

4.2.12.3 Site Facilities

Facilities for maintenance and operational needs must be taken into account in transition compound design. Where access by crane or trucks has to be provided for installation, maintenance or replacement operations, roads or tracks have to be constructed.

The surface of the site will also influence access. Usually stone chippings or grass are used to reduce dust levels. Stone chippings are also effective in limiting 'touch' and 'step' voltages (see earthing).

4.2.12.4 Fencing

External fencing reduces the possibility of entry to the site by unauthorised persons. Special measures are usually defined in national standards. Special attention should be paid to 'touch' voltages where metallic fencing is used.

Internal fencing is used mostly for defining areas where access is restricted, rails or wire fencing can be used for this purpose.

4.2.12.5 Buildings

The design of buildings has to conform, where relevant, to national and utility standards. Their main role is to contain and give shelter to protection relays, SCADA equipment, auxiliary equipment, battery systems, fire protection pumps etc.
For economic reasons (reduction of the length of cable runs, reducing auxiliary supply voltage, minimising first investment) several dispersed buildings rather than one central building can be built in a transition compound.

Whether a transition compound is manned or unmanned will determine the extent of the facilities required locally for the operators. Normally a transition compound building is provided with a septic tank.

Fences, buildings, civil works and supporting structures can influence the aesthetic impact of the transition compound on the environment.

4.2.13 Fire Protection

The use of fire protection systems and/or measures is mainly based on:

(a) Minimising the hazard for the operators and the public and protecting the environment.
(b) Limiting the damage to adjacent apparatus, equipment and buildings.
(c) Minimising the loss of customer's service.

To minimise the risk of fire damage, passive protection measures should also be taken to prevent a propagation of fire or to limit damage, e.g fire resistant materials, synthetic terminations.

Fire protection of cables in indoor and outdoor HV transition compounds is usually only by passive measures to reduce the fire propagation - fire stops (concrete, steel, mineral wool, sand, silicone) and/or fire resistant painting. In installing fire barriers care must be taken to ensure that hot spots are not introduced. Power and control cables should be installed along separate routes e.g. separate cable racks or separate trenches.

4.2.14 Transition compound Security

To control entry to a transition compound by unauthorised persons, the site should be equipped with security measures. These measures serve two purposes: protection of public and personnel safety and protection of assets against toss and/or damage. Transition compounds are a high voltage environment which can present potential safety hazards to untrained and/or unaware people. Furthermore, the theft of copper grounding wires from perimeter fencing or from inside a transition compound could affect the integrity of the transition compound grounding system, thus potentially compromising the safety of the intruder as well as Utility staff. Damage or loss of transition compound operating equipment could also result in loss of supply to customers and material/property losses.

Transition compound security measures may include: fences (in some cases with electrified wires), walls, entrance/equipment locks, photoelectric motion sensing equipment, video surveillance systems, computer security systems, lighting or landscaping. For each transition compound an assessment should be made to determine which measure and/or combination of measures are most appropriate.

For guidance on the effectiveness of transition compound security measure and criteria for security refer to the IEEE Std. 1402 "Guide for Electric Power Substation Physical and Electronic security"[46].

4.2.15 Energy Efficiency in Transition compounds

Internal energy efficiency improvements should be treated as an integral part of every day good business practice and responsible asset management. Energy savings reduce operating costs and contribute to the overall efficiency and competitiveness of the business. Sale of the energy saved could contribute to the annual gross revenue. In transition compounds energy savings could be achieved through equipment selection, installation of energy efficient buildings and design of the compound services.

Energy efficiency measures to be considered by electrical designer include: reducing the corona effect in HV switchyards and use of compact conductors. For station services, use of alternative energy sources for station services (e.g. solar panels, wind turbine generators) should be economically evaluated for energy efficiency purposes. For outdoor lighting, use of energy efficient lamps, minimising the number of fixtures, manual on/off switches, timers, and use of motion sensors will reduce the energy consumption at very little additional cost.

4.2.16 Specification and selection of main components of the transition compound

4.2.16.1 Introduction

When the maximum load currents have been determined the rated current of the equipment should be selected from the IEC series. Nowadays, it is probable that the lowest current rating available on the market may be over-dimensioned for most purposes, especially in the networks of developing countries.

4.2.16.2 General

The following are the common rated characteristics of equipment which should be specified (IEC 60694)[47]

(a) Rated voltage.
(b) Rated insulation level.
(c) Rated frequency.
(d) Rated normal current.
(e) Rated short-time withstand current.

(f) Rated peak withstand
(e) Rated duration of short circuit
(f) Rated supply voltage of auxiliary circuits.
(i) Rated supply frequency of auxiliary circuits.
(j) Rated pressure of compressed gas supply.
(k) Pollution Level.
(l) Corona and RIV requirements.

Equipment should be type tested in order to verify its compliance with the specified ratings.

Note: Other rated characteristics may be necessary and are specified in the relevant lEC standards.

4.2.16.3 Surge protection devices

The effectiveness of any surge protection device is dependent on the quality of the earthing system and the geometrical arrangement of the device. In particular the surge impedance, the length of the connection between the protected conductor and the earthing system and the earth resistance play an important role.

(a) Overvoltage Protection

Transition compound overvoltage protection should be designed to minimise the risk of rated lightning and switching impulse voltage levels being exceeded. Protection may be provided by spark gaps (co-ordinating gaps) or by surge arresters. The necessity to install surge arresters for protection of equipment and the required distance from equipment is generally decided by overvoltage analysis (insulation co-ordination study), e.g. using a modelling package such as EMTP.

(b) Lightning Protection

In some areas it is necessary to ensure protection against direct lightning stroke. (see 4.2.6)

When overhead lines are not protected against direct lightning stroke it is necessary to take measures to protect the system. An earthwire should be installed on each overhead line for a distance of approximately 1-2 km from the compound, in many cases this earthwire is extended over the total circuit length. This measure does depend, however, on the rated voltage of the system and is not normally applied to medium voltage distribution networks.

(c) Spark Gaps

The spark gap or coordinating gap is a surge-protective device which consists of an air gap between an electrode at line voltage and an earthed electrode. This provides the simplest possible form of surge protection.

There are several disadvantages in the use of co-ordinating gaps as a means of surge protection. Firstly, if the gap breaks down a system fault results; secondly, if the gap is set for positive impulses the protection against negative switching impulses is poor at the higher voltages; thirdly a higher insulation level is generally required if gaps are installed; lastly the increasing threshold voltage causes inadequate protection against steep fronted surges.

(d) Surge Arresters

The use of a surge arrester provides superior protection compared to a co-ordinating gap, and it is not sensitive to polarity. A big advantage is that a system fault is not caused by the operation of a surge arrester. The margins between the protective level and insulation levels of a system are covered in IEC standard 60071.2[38].

The two principal types of arrester are gapped silicon carbide and gapless zinc oxide, the latter is now most commonly used.

The silicon carbide arrester consists of a stack of silicon carbide blocks with series gaps. There is some variation in the voltage at which "sparkover" occurs, especially for steep fronted surges where the threshold voltage rises.

The zinc oxide arrester is gapless and consists of a stack of zinc oxide blocks. It is, therefore, very simple to construct. Its characteristics can be set very precisely and unless temporary overvoltages are relatively high (such as in a noneffectively earthed system) then it is usually possible to obtain lower protective levels compared with the gapped types of arrester.

4.2.16.4 Instrument transformers

Instrument transformers are the devices used to transform the values of current and voltage in the primary system to values which are suitable for measuring instruments, meters, protection relays and other similar apparatus. An essential property of an instrument transformer is that it isolates primary voltages from the accessible parts of the secondary system.

External insulation may be either the porcelain or polymeric type.
Internal insulation may be oil-impregnated paper, polypropylene film, SF6, cast resin, mixed dielectric, etc.

Traditionally instrument transformers have been either of the electromagnetic or, in the case of voltage transformers, capacitive type. These provide an analogue secondary output at a modest power level. During the recent years a new concept of instrument transformers design has been introduced providing a digital output on an optical communication link. A number of sensors have been developed, some are based on new concepts such as Faraday's phenomena (current transformers) and Pockel’s phenomena (voltage transformers), others are based on conventional sensors (Rogowski coil as current sensor; resistive devider as voltage sensor) with analogue to digital signal conversion. There are options to combine digital optical instrument transformers with other HV equipment (e.g. circuit-breakers).

When discrimination between a fault in the underground cable vs the overhead section of a line is needed, for example for reclosing purposes, current transformers are usually installed around the cables, at the base of the terminations. In that case, a termination failure may be wongly interpreted as an overhead failure.

4.2.16.5 Connectors

Connexions may be either flexible stranded conductor or of tubular construction. Aluminium alloy, aluminium steel reinforced (ACSR) and copper are the most commonly used materials.

Connectors may be bolted, welded or crimped or any combination of these. Fittings should allow for expansion and contraction with temperature.

Mechanical strength must be considered in addition to the general ratings. Aeolian vibration of tubular conductor can cause fatigue failure and steps may need to be taken to limit this, for example, stranded conductor laid inside a tubular busbar is often a very effective damper or special clamps with built in dampers may be used. Bi-metallic joints require special construction and jointing techniques to prevent corrosion. All busbars, fittings and joints should be designed to mechanically avoid the ingress of moisture and electrically to avoid corona discharge.

4.2.16.6 Post insulators

A post insulator consists of one post insulator unit or an assembly of such units and is intended to give rigid support to a live part that is to be insulated from earth or from another live part.

The dimensions of post insulators have been standardised and details are given in IEC standard 60273 [48]. The testing requirements are given in IEC standard 60168 [49].

4.2.16.7 Earthing grid

This issue has been addressed in detail in Technical Brochure 213 “Engineering Guide on Earthing Systems in Power Stations”[50].

The transition compound earthing grid is formed of buried conductors and is complemented, in some cases, by conductors that are above ground.

The underground conductors are buried at a depth of about 0.5... 0.8 metres, laid out to form a grid and jointed at points of intersection. The grid is designed so as to limit conductor temperature, touch voltages and step voltages to the maximum allowable values under specified fault conditions.

Earth rods may be driven into the ground around the perimeter of the earthing grid to reduce the overall resistance to earth and are bonded to the grid. The quantity and length of the earth rods will depend upon the resistivity of the soil and the required resistance value. Additional earth rods are sometimes required immediately below (or adjacent to) certain items of equipment which require high frequency earthing such as capacitor voltage transformers and surge arresters.

The buried grid is usually made of copper strip or stranded copper cable and the earth rods of copper-covered steel, although other materials such as galvanised steel and cast iron may be used. When copper conductors are used precautions should be taken to prevent electrochemical reactions with steel structures.

All conductors (other than circuit conductors) which might become charged as a result of induction or electrical fault are bonded to the earthing grid as well as the neutral points of primary equipment (according to the requirements of network neutral point effective grounding).

In order to limit touch and step voltages the earthing grid should be bonded to other buried conductors such as metal pipelines, metal amoured cables and rail lines. Where these buried conductors extend outside the transition compound, special attention must be paid to earthing in order to prevent a hazardous rise in ground potential.

If there are telephone lines or low-voltage power supply cables in the vicinity of the transition compound, limitation of ground potential rise to acceptable levels may cause considerable extra costs. The most effective way to limit the ground potential rise is to use buried shield wires of high conductivity.

The layout of the earthing grid has an effect on high frequency transient ground potential rise phenomena.

4.2.16.8 Specification of auxiliary power supply equipment

Requirements for auxiliary power supply equipment in transition compounds depend mainly on station layout, measurement and protection devices, telecommunication equipment and auxiliary systems installed (fire detection and protection, access control and security systems, etc.). Power supply equipment requirements can vary from:

- No auxiliary power supply required in case of very simple layouts, with no active equipment: disconnectors, Remote Terminal Units (RTUs) or telecom units, monitoring systems, etc.. This would be the case of a simple compound including just cable terminations and surge arresters.

- Full auxiliary power supply equipment, similar to a substation, including AC supplies (grid connection and backup diesel generators) and DC back up systems (chargers-inverters and batteries), with the required control panels. As an example, auxiliary power supply is required for instruments transformers, as well as oil pumping stations (for oil-filled cables).

Additional information is given in CIGRE Technical Brochure 197 [51] prepared by WG 23.04 in February 2002 “Design Guidelines for Power Station Auxiliaries and Distribution Systems”.

4.2.16.9 Telecommunications and telecontrol

4.2.16.9.1 Telecommunications

External telecommunication from the transition compound may utilise both the private network of the utility and, in many cases, the public telecommunication network. The most important telecommunication services provided by the private network are telecontrol, operational telephony and teleprotection, however new services (e.g. telefax and video transmission) are coming into use. The normal connection to the public network is a telephone subscriber line.

4.2.16.9.2 Telecontrol

The telecontrol system and remote terminal units are specified in IEC60870 [52]. This standard is divided into several parts:

Part 1 deals with general considerations in section 1 and section 2 is a guide to specification. The rest of part 1 deals with more specific items.

Part 2 is concerned with standardising operating conditions such as environmental conditions, mechanical influences and power supplies.

Part 3 is concerned with standardising various RTU interfaces and their characteristics such as nominal voltages, current classes and signal levels. It also standardises an interface with the communication system.

Part 4 standardises various performance requirements such as operational parameters, expandability and influence cf telecontrol equipment on the environment.

Transmission protocols are standardised in part 5. Requirements for data transmission and protocol specifications are dealt with.

It is very valuable to consider the requirement for telecontrol when planning the transition compound equipment, even though the utility may not have a telecontrol system. Readiness for telecontrol includes installation of all measuring transducers, interposing relays, status contacts, etc needed for telecontrol and wiring there to a marshalling cabinet.

4.2.16.10 Specification and selection of secondary equipment

The term « secondary equipment » covers protection, control and measuring circuits. These items are dealt with in different documents [53][54].

5 COMMISSIONING

Commissioning covers all the measures that need to be taken on-site in order to assure the correct functioning of single components of equipment and the transmission system as a whole. Besides the type test, routine test, and sample tests which are done in the factory, additional on-site tests are required; these tests help to ensure that the equipment specifications are met and they serve to detect any damage caused by transportation, shipping, or erection which may modify the characteristics.

In general all installations are subject to commissioning tests.

Typical examples of commissioning tests are:

- Proving the wiring that provides remote control, signalling and measurement functions.
- Tests for correct operation of remote control, signalling and measurement equipment.
- Checking of electrical clearances and conductor sag for the jumpers
- Tests after installation of underground sections

Commissioning tests are the most important quality assurance checks when an installation is transferred to the user after erection. The extent of contractual and system acceptance tests, the responsibilities, and the procedure of repair or correction in case of detected defects is subject to agreement between the companies concerned.

Test after installation of cable systems has the purpose to check the integrity of the system when the installation has been completed. The cables are routine tested in the factory; the accessories are assembled at site. A DC oversheath test and an AC insulation test are recommended.
With the oversheath test, it is common practice, to check the bonding equipment of the cable and to verify that appropriate connections have been made.

DC voltage test on oversheath at 10 kV as prescribed by IEC 60229 [55], allows to assess the cable conditions after the unreeling and installation.

For installations where only the oversheath test is carried out, quality assurance procedures during installation of accessories may, by agreement between the purchaser and the contractor, replace the insulation test.

The basic approach for an insulation test after installation of cable systems is that typical faults originated during assembly of accessories should be detected effectively by exposing the system to adequate electrical stresses, without harming the system under test. The crucial question is the level, duration and the availability of test voltages.

A DC Voltage test is an appropriate and easy way to test laminated cables after installation but DC testing is not recommended for testing extruded cable systems as reminded in recommendations for on site testing after installation published in **Electra 1997** [56] by CIGRE WG 21.09/02.

Nowadays**, IEC has issued IEC 62067 (EHV cable systems)** [57] and Edition 3 of **IEC 60840 for HV cables and systems** (cable and accessories) [58]. The requirements in those standards for test after installation are in line with the CIGRE recommendations of 1997.

AC testings of the main insulation at Uo for 24 hours combined with stringent accessory installation quality assurance procedures, have been proven to be satisfactory to guarantee the quality of the cable system.

Where an AC testing at higher test voltage within the range of 1.1 to 1.7 Uo is required, the use of dedicated test equipment such as series - resonant test system must be planned: it is necessary to have access to terminations and to disconnect the underground cable system from the network. As the Series-resonant test equipment commonly used is rather cumbersome (lorries of 40T), access must be provided in the vicinity of the terminations and HV connections from the testing equipment to the cable system must be established while respecting sufficient distances between live parts and surrounding equipment (fig 84).

Figure 84: Tests on HV/EHV cable circuits

6 OPERATION

Extruded cable systems are generally designed for a service life of 30 years and even more.
As far as there is no external aggression and no water ingress, there is no reason for a reduced service life if they have been manufactured and tested appropriately and if they are operated within their rating limits.
Nevertheless, in case of breakdown, in order to limit the duration of the unavailability of the cable system, it is necessary to have an established repairing procedure.
Consequently, the main issues to be addressed during Operation are:

- Operation within the design rating limits
- Prevention from external aggression
- Repairing procedure

6.1 OPERATION WITHIN DESIGN RATINGS LIMITS

Historically, underground cable systems have not generally been loaded to their design ratings. This situation is changing and cable systems are likely to be more heavily loaded in the future as Utilities work their systems harder and make more use of their assets**.**

Although rare, there have been examples of failures within cable systems that have been operated above their maximum operating temperatures.

Increased congestion of services are having an impact on circuit ratings arising from closer proximity of other circuits and other heat sources. Changes in depth due to construction activities can also reduce ratings. Lack of understanding of the external thermal environment, including inadequate attention to the thermal backfills etc present further risk to the performance of underground cables.

Continuous or at least periodic monitoring of cable temperatures can reduce or even eliminate this risk. As a consequence temperature monitoring systems are being installed with new underground distribution and transmission cable systems. Retrofitting of such systems would also be of great interest but complete distributed monitoring is unfortunately not practical.

The output of such monitoring systems is now being used in conjunction with other parameters to forecast and provide guidance regarding the short term overload capability of cable circuits under emergency conditions.

At the CIGRE Study Committee 21(Underground Cables) meeting held in August 2000 it was agreed that a Working Group be established to review ‘Thermal Monitoring of Underground Cables’(CIGRE WG B1.02).

The work of CIGRE WG B1 02 is now published in Technical Brochure which is introduced in Electra 213 (April 2004) [59][60].

6.2 PREVENTION FROM EXTERNAL AGGRESSION

Prevention from external aggression is depending on Utility Company Policy. Following is an example from a Japanese Utility.

6.2.1 Route patrol

The route patrol is mainly performed for investigation of the existence of the abnormalities on the all route, and prevention of the equipment damage by digging construction of other companies.
There are three kinds of route patrols “usual patrol”, “special patrol” and “accident patrol”. Usual patrol is carried out periodically. Special patrol is carried out at the time of the rainstorm and earthquake and other special occasions. Accident patrol includes investigation of abnormalities along the cable route in case of cable failure.
The route patrol includes investigation of equipment visible from on the road, such as manhole lids, ventilation entrances and outdoor cable terminations, etc.

6.2.2 Route patrol interval

“Usual patrol” is basically carried out once in three months. In overcrowded areas, it is carried out two times in a week.

6.3 REPAIRING PROCEDURE

As well as the Policy for prevention from external aggression, the repairing procedure is strongly depending on the utility, the teams in charge of repairs, and the availability of civil contractors.
Following is given an example from a Japanese Utility.

6.3.1 Check and repair

Check is done for all equipment which is not covered by route patrol. There are two kinds of check, ”usual check” and ”special check”.
Repair includes amendment and change of the poor portion discovered by the route patrol and check.

Check interval

Check interval is decided individually according to line importance, ageing, degradation condition, and the kind of check..

6.3.2 Electric fault

Generally, electric fault includes cable fault, and the cable ancillary-facilities accident, such as cooling or alarm equipment, only cable fault is described here.
When the electric fault happens, cable insulation does not recover unlike overhead line. And, re-closing is not carried out for cables of 7 kV or above. In case of Y shaped line and overhead-underground mixed line, a fault section detector is installed.

6.3.2.1 The mode of the accident

Mode of the electric fault is usually single phase ground fault.

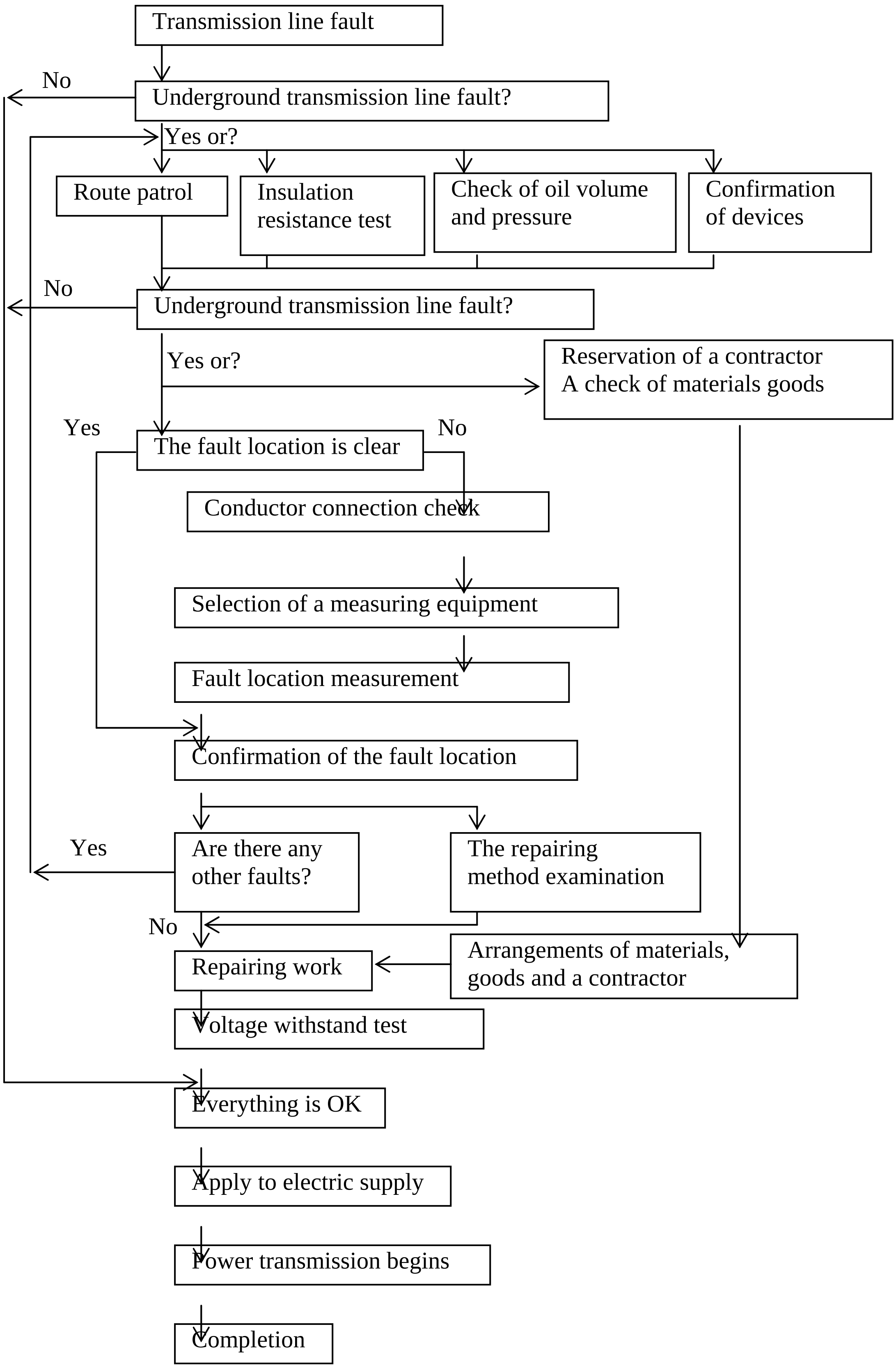
6.3.2.2 Grasp of a fault state and fault location measurement

6.3.2.2.1 Initial investigation

Since the quality of initial investigation and processing influence the whole fault repairing work greatly, information collection and judgment of exact information are needed.

- Route patrol
- Insulation resistance test

6.3.2.2.2 Repairing procedure



7 REFURBISHMENT AND UPRATING OF EXISTING SYSTEMS

7.1 INTRODUCTION

The difficulties involved in obtaining planning permission for new sites favours the life extension of existing facilities.

Life extension of existing facilities can be divided into two main categories:

(a) refurbishment - the like-for-like replacement at the end of the equipment's lifetime.
(b) uprating - improvement of the equipment's specifications by replacement of equipment independent of condition.

In many cases, both these factors play a part in the decision to carry out life extension works.

7.2 REFURBISHMENT

The equipment in a transition compound is ageing. Over many years of operation equipment will, although maintained correctly, wear out or will become obsolete. Economic and/or reliability considerations may suggest replacement rather than further maintenance and repair.

The lifetime of equipment depends on many factors (materials, ambient conditions, Stress during service, fault and defect history, availability of spare parts, philosophy of service and maintenance, etc.).

Most power systems operate with equipment of different ages. To establish the optimal time for replacement is one of the key elements of life cycle management of power system apparatus and components. This time is determined by technical, economic, environmental and/or strategic factors.

During refurbishment it may be necessary to meet new official requirements: laws, regulations, standards etc. Voluntary improvements may be appropriate, e.g. to increase safety for personnel.

Refurbishment can also include the addition of fences, screens, partitions and walls to keep unauthorised persons away from transition compound equipment. Appropriate lighting can enhance transition compound security, access at night and equipment status inspections. Improvements in visual impact should be assessed against the background of local land use particularly where land use has changed and/or the level of public acceptance has altered. Paragraph 7.4 will describe in a more detailed way the possible improvement of Environmental Impact of existing Transition Compounds.

Waste management is an important part of renovation planning, and adds to refurbishment costs.

Sometimes it can be advantageous not to update the whole transition compound at one time but to carry out the work in stages. Partial refurbishment allows better correlation with the condition of individual items of equipment or groups of equipment and can reduce the peak of manpower and investment required. However, partial refurbishment can result in higher outage costs and requires more data for assessment of the equipment condition.

Refurbishment requires the commitment of significant manpower and investment resources. It is therefore necessary to predict the end of lifetime of equipment for long term planning. The decision on how and when to refurbish equipment, components or the complete transition compound will differ from utility to utility and even from compound to compound. Lifetime assessment is the basis of planning and performing refurbishment (see chapter 8 in this guide).

7.3 UPGRADING/UPRATING

The exact meaning of Upgrading and Uprating is not yet completely defined.

The difficulties involved in obtaining planning permission for new sites favour the life extension of existing facilities, with the goal of transmitting higher power with higher reliability to minimise the time of unavailability of assets. This can be achieved:

- by running existing equipments closer to their rated power levels,
- by refurbishing existing components or replacing them by higher performance components,
- by tracking hotspots along the cable route to improve the thermal environment of the cable system and eliminate bottle-necks to increase the rated current of existing underground systems.
- by increasing the voltage levels on existing cable systems to achieve higher power transfer on the installed cables.

Further work in this area is necessary to detail all the possible solutions to achieve this goal and to review all the technical issues to be addressed in this field.

Where it is proposed to uprate/upgrade a cable system and some individual components of a transition compound then the capability of other transition compound equipment should also be assessed to ensure compatibility.

Environmental reasons may force the decision to upgrade/uprate equipment: noise problems, electromagnetic fields inside/outside the site, avoidance of oil spills in water catchment areas etc.

In order to reduce design cost, standardised principles should be applied enabling the same solution to be applied in each type of transition compound. This will also make the control and the maintenance of the transition compound easier.

7.4 IMPROVING THE ENVIRONMENTAL IMPACT OF EXISTING TRANSITION COMPOUNDS

7.4.1 Impact of existing Transition Compounds on Environment

In 2003, CIGRE WG B3-03 published Technical Brochure No 221 entitled ‘Improving the impact of existing substations on the environment’[61].
Due to the many points Substations and Transition Compounds have in common, this paragraph refers to and summarise the main aspects highlighted by the Technical Brochure 221.
Existing Transition Compounds have had and continue to have a significant impact on the environment, if not adequately addressed.
Furthermore, the impact of existing Transition Compounds may be growing due to the changes in the surrounding land use, operation of ageing equipment, changes in environmental laws and regulations and changes in the community perception.
Even if the greatest environmental concerns regard new installations, some aspects need to be analysed as effective methods to reduce the impact of existing facilities.

The improvement works will depend on the commitment of resources and on the initiative of the community and the influence of governmental entities.
Community concerns are oriented towards aesthetic and noise/EMF production. Regulations evolve in the areas of water and air contamination and migration of unwanted substances from contaminated soil.
The applicability of a given method will depend on the specific environmental issues, local legislation, economic feasibility and company polices.

Aesthetics

Existing Transition Compounds were built years ago and may not have had the benefit of an environmental impact evaluation during their initial installation.
Furthermore they were originally located outside densely populated areas where they are nevertheless presently immersed.
The size of a Transition Compound depends on the voltage level and the number of outgoing/incoming lines. In any case an area of some thousand of m^2 and tall metallic gantry of heights up to 30 meters may have a significant visual impact on the surrounding landscape.
The improvement of aesthetic impact is carried out by conventional methods which aim to reduce the visual impact of the Compound by concealing it from public view.

Landscaping options address the land surrounding the Compound and also its main elements including buildings and enclosures, access routes and entrance gates, gravel surfaces lighting and plant cover.
The ultimate objective is to improve the visual impact of the Transition Compound by blending it into its surrounding environment.
The improvement result will be influenced by the location, surrounding land use, availability of land and should be adapted to meet the needs of local environmental legislative bodies and the local community.

Audible noise

Unlike for Substations Audible noise sources in Transition Compounds are mainly represented by Corona Discharges as no transformers or reactors should be installed.
This gives an equal importance impact for Transition Compounds and the incoming Overhead Lines.

Release of insulating oil

Older Transition Compounds were built under environmental regulation that was less stringent than present regulation, probably without requirements to contain any potential leaks of electric insulating liquids within the Compound perimeter.
Beyond the threat to the environment and potential legal consequences, cleanup costs associated with oil spills could be significant.
The probability of an oil spill occurring in a Transition Compound is very low and practically limited to links where SCOF (Self Contained Oil Filled) Cables are employed.
However some installations due to their proximity to ground water resources, open water or designated wetlands, the quantity of oil on site, etc., have or will have a higher potential for discharging harmful quantities of oil into the environment.
The possible remedial actions foresee:

- the construction of a ditch around the outside perimeter of the Transition Compound
- the realization of collecting pits

Site contaminants and remediations

Transition Compound sites are likely to have been exposed to some form of contamination during their use or may have been built upon sites that had previously been used as land fill sites or oil wells and may contain contaminants from these earlier uses.

Common contaminants that can be found in Transition Compounds include mineral/synthetic insulating oils, asbestos, arsenic or other herbicides that may have been used to manage the plant life within and surrounding the Compound.
To address these issues it is recommended that a site assessment and remediation process be conducted to identify, qualify quantify and manage the existence of chemical compounds that may have potentially adverse human and ecological effects.

Remediation may also become important during de-commissioning and selling of Transition Compound.
Remedial technologies fall into two basic categories: passive remediation methods (such as bioremediation) and Active remediation methods.

Bioremediation is a process by which living organisms act to degrade hazardous organic contaminants to environmentally safe levels in soils, subsurface materials and water.
Active remediation methods generally involve removal of the source of contamination from the site.

7.5 OTHER ENVIRONMENTAL CONSIDERATIONS

7.5.1 SF_6

This gas has become an environmental concern in recent years, as scientists begin to document changes in the temperature of the earth. Various efforts have been instituted to reduce the emission of SF_6 from electrical installations. Concerted actions include the use of equipment with improved sealing, procedures for appropriate gas handling and recycling.

SF_6 impact caused by Transition Compound is very low compared to substation if an air insulated configuration is chosen to pass from Overhead to Underground.

7.5.2 EMF

Regulations and guidelines concerning EMF levels mainly apply to new electric installation. However there may be cases where existing Transition Compounds are extended or modernised and regulations would then come into consideration. In existing Transition Compounds it is recommended that measurements be taken for both electrical and magnetic fields.

Electric field levels outside the Compound are more or less the same intensity as the electric fields associated with the incoming transmission overhead Lines. The highest magnetic field levels can be found directly underneath or above incoming and outgoing overhead Lines or underground cables.

Reduction of electric field levels can be accomplished by increasing the height of the buses, decrease the phase spacing and making use of vegetation and shielding.

Methods for reducing magnetic field levels include increasing the distance from the sources, optimising phase configuration to achieve magnetic field cancellation. Magnetic field levels can be further reduced by balancing currents on lines and by shielding conductors.

8 LIFE CYCLE MANAGEMENT

Life Cycle Management (LCM) is an approach, that takes optimisation of the chain of products (or services) using the life-cycle concept, i.e. to follow a product from ‘the cradle to the grave’ with all the related implications in terms of cost, efficiency, social issues and environmental impacts.

LCM deals with all the phases involved in a project from its Definition to the Retirement passing through Design, Development, Deployment, Operation and Maintenance.

The original inspiration behind LCM comes from Product Life Cycle Assessment (LCA), a technique to assess the environmental impacts related to a product, with the aim of minimising these impacts over the entire life cycle of the product. In LCM, the life cycle concept is expanded to other areas of concern, notably management of economic costs and quality. [62]

Referring to Cable Systems, after the Need of the link, its Design, Construction and Operation steps have been analysed in the previous chapters, LCM should also cover the following issues:

(a) Maintenance
(b) Training and technical support
(c) Consumable/ strategic spare parts
(d) Reliability and availability
(e) Disposal/ recycling
(f) Environmental Impact

8.1 MAINTENANCE

An appropriate maintenance plan should be prepared to ensure that the equipment continues to function correctly. Quite often maintenance is supposed to be a repair action after a component failure (corrective maintenance), however the ultimate purpose of maintenance should be to avoid failing of the component. Therefore failure modes of all major components have to be identified, together with the diagnostic tools to perform proper condition assessment, resulting in preventive maintenance or condition based maintenance.The condition based maintenance actions intend to repair a part of the component or even to exchange completely the component (see 8.6), because it is at the end of life. CIGRE WG B1-04 deals with the subject "Maintenance of HV cables and accessories" and prepares guidelines for practical use, to be completed in 2004.

8.2 TRAINING AND TECHNICAL SUPPORT

In order that maintenance and repairs can be performed quickly and effectively it is often important that the utility staff (or staff of the utility's maintenance contractor) are familiar with the equipment. Training may have to be provided to ensure that necessary skills and experience are retained throughout the life cycle of the equipment.

Where local staff may require technical support and advice it should be ensured that this continues to be available, either from the original manufacturer or from another source (such as utility central engineering group).

8.3 CONSUMABLE/STRATEGIC SPARE PARTS

Consumable spare parts are those required to carry out preventive maintenance. These will need to be available throughout the life of the equipment either from the original equipment manufacturer, from alternative suppliers or from utility stock. Where spare parts are stocked for a long period of time it should be ensured that storage conditions are suitable and that component shelf lives are not exceeded. Spare lengths of cable must be kept perfectly sealed to prevent any water ingress.

Strategic spare parts are those that may be required to replace equipment or parts damaged as a result of a major failure. Reliance may be made on the original equipment manufacturer to provide this service, as required, although in some cases the utility may hold these spare parts (either themselves or through a pooling agreement with other partners). Availability of strategic spare parts is often critical to achieving reasonable return to service times after a fault and delivery times may be extended once equipment goes out of normal production.

8.4 RELIABILITY AND AVAILABILITY

It is recommended that data be collected by applying condition assessment techniques to allow monitoring of the reliability and availability of the equipment. Reliability may deteriorate as equipment gets older or may become unacceptable in comparison with other parts of the system. Causes of unavailability should be investigated and, where necessary, action taken to address problems.

8.5 FUNCTIONALITY

It must be ensured that, as the transmission network develops, the equipment installed underground and in the transition structure has adequate strength and capability to safely carry increasing load and fault currents.

Additionally, new equipment designs may offer enhanced functionality which may be beneficial to the utility.

8.6 RENOVATION / REPLACEMENT

At some stage, where there is a continuing need for the cable system and the transition equipment, it will be necessary to consider renovation of specific equipment or complete replacement. The decision on when to renovate or replace is often a difficult one but can be based on an assessment of the condition of the equipment..

It is recommended that, where renovation by partial equipment replacement is to take place, a thorough assessment be made of the total equipment before finalising a work program. This will allow all necessary work to be identitied and carried out at the same time to give a long period of continued service without further intervention.

8.7 DISPOSAL / RECYCLING

Following decommissioning, the equipment must be disposed of in accordance with local regulations.

It is recommended that, where possible, materials are recycled and reused. This is particularly appropriate in the following cases

(a) SF6 gas
(b) Insulating oil
(c) Copper or Aluminium
(d) PVC
(e) Lead.

It must be mentioned that the laying technique is of great influence on the "end of life" impact of the system. Ducts allow simpler retrieval when other techniques make it much more difficult.

8.8 ENVIRONMENTAL IMPACT

Some environmental factors favour undergrounding:

- Visual impact
- EF/MF concerns
- Noise reduction during operation
- Use of land

However, undergrounding is not free from environmental impacts:

- Impact during construction and operation/maintenance
- Magnetic field close to the cable
- Elevation of temperature of the soil and its impact on fauna and flora
- Problems to hydrology

Political pressure from local authorities or economic pressure from independant producers (dispersed generation) requiring rapid connection to the system may finally favour undergrounding. When undergrounding has been decided, LCA is a tool to compare solutions between different technologies and constructions of cables, to achieve an "environmental conscious design"

8.8.1 Life Cycle Assessment (LCA)

The environment impact of the construction, operation, maintenance, and disposal of a cable system and its transition equipment may be evaluated by Life Cycle Assessment techniques. These are defined and described in the ISO 1400 series of standards.
Society for Environmental Toxicology and Chemistry describes Life Cycle Assessment as (1993):

"The Life Cycle Assessment is an objective process to evaluate the environmental burdens associated with a product, process or activity by identifying, and qualifying energy and materials used and wastes released to the environmental, and to evaluate and implement opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing raw materials, manufacturing, transportation and distribution, use, reuse, maintenance, recycling and final disposal.
The Life Cycle Assessment addresses environmental impacts of the system under study in the areas of ecological health, human health and resource depletion. It does not address economic considerations or social effects. Additionally, like all other specific models, LCA is a simplification of the physical system and cannot claim to provide an absolute and complete representation of every environmental interaction.

The prime objective of carrying out LCA are:

- *To provide as complete picture as possible of the interactions of an activity with the environment.*
- *To contribute to the understanding of the overall and independent nature of the environmental consequences of human activity.*

To provide decision makers with information which identifies opportunities for environmental improvements."

8.8.2 Practical Application of LCA

As stated hereabove, the life cycle assessment of a product is a method of evaluating all the effects of a product on the environment. This method is based on an inventory of the components and by-products of the studied product, and on analysis of the environment impact of these components and by-products.

It follows, that the more simple the product (i.e. it consists of few elements and it can easily be recycled), the more easily its life can be managed. On the other hand, for a very complex product, this analysis will be extremely difficult to perform and achievement of useful results may prove impossible. Such study would be more accurate with a good share of information between manufacturers (cables and transition compound) and utilities.

Different softwares are now available for Environment Conscious Design. Several papers published in CIGRE sessions, in IEEE/ICC or in Jicable describe methods and results [63][64][65].

All the existing publications mention the major impact resulting from losses. For precise evaluation of the losses, one must take into account the load factor.

For a good evaluation of the impact of losses during operation, one must be aware that the results are depending on the energy production process which can change during the cable system life.

9 GUIDE FOR ENVIRONMENTAL IMPACT ASSESSMENT

9.1 INTRODUCTION

In the technical brochure 194 **"Construction, laying, and installation techniques for extruded and self contained fluid filled cable systems"** published in October 2001, Chapter 6 includes a description of the design process of an underground cable link project from the technical standpoint. The process includes many steps that lead to the commissioning of the underground link [6].

The environmental issues must be tackled progressively and simultaneously with the technical problems, as well as all interactions between them.

During the preliminary studies, it is suggested to make a preliminary environmental impact evaluation. This preliminary evaluation will allow to identify all the subsequent required studies, their magnitude, costs and duration, to better integrate them in the project realization process.

Depending on countries, some activities may be subjected to Environmental Laws, rules or regulations. In those cases, a full environmental impact assessment is mandatory.

In other cases not subjected to those rules, the preliminary evaluation allows to make a well documented choice of the magnitude of the impact assessment (reduced or full) needed for the project. If the preliminary evaluation indicates that some elements of the environment are significantly affected by the project, a full impact assessment must be considered. If this is not the case, a reduced impact assessment will be suitable.

The purpose of this guide is to describe the environmental evaluation process for the integration of underground lines and transition compounds in a network. It presents a general method for the evaluation of impacts, and offers a typical table of contents for an environmental evaluation report.

Section 9.2 includes definitions to the specific terminology used in the guide.

Section 9.3 and 9.4 describe the evaluation process during the preliminary phase as well as the project phase and show the interactions between the environmental process and the technical process.

Section 9.5 describes in details a general method used to evaluate environmental impacts caused by a project and suggest a list of commonly used mitigation measures and techniques.

Section 9.6 offers examples the typical content for an environmental impact assessment report: some impact matrices, a typical table of contents, and a summary table of impact assessment. The final content of each impact assessment report has to be adapted to each specific project, and according to local regulations.

9.2 DEFINITIONS

Impact	Measurable effect of a project on the environment. Impacts may be of a temporary nature (as noise during construction) or of a permanent nature (visual impact of a transition station).
Environmental Impact Assessment:	The impact assessment consists in an analytical evaluation of all potential effects of a project on the environment. It is divided in six main activities: ➢ technical knowledge of the project ➢ knowledge of the environment ➢ evaluation of the project ➢ communication ➢ selection of the final project and environmental assessment ➢ environmental surveillance The process covers all stages of the life of the equipment, including planning, preliminary studies, construction, operation and decommissioning.
Study Area	The Study area is the area where the impacts are assessed. It includes the location of the two ends of the underground cable system, and the likely extent of the physical and visual influence of the potential underground cable route corridors between these two points. The criteria to define this area are: ➢ physical ➢ natural (flora, fauna…) ➢ land use: agricultural, urban or peri-urban ➢ technical ➢ cultural heritage ➢ administrative boundaries Then the area is delimited by administrative boundaries where the local authoritie are identified.
Preliminary evaluation:	Analysis of all basic information available at the beginning of the environmental evaluation during the preliminary studies phase to establish a basic knowledge of the technical aspects of the project and the environment. This evaluation leads to a decision regarding a full or reduced impact assessment.
Reduced Impact Assessment:	This evaluation is done with much less formality. The choice of this type of evaluation is made when the preliminary evaluation identifies that no element of the environment will be affected significantly by the project.
Full Impact Assessment:	Detailed impact assessment. The choice of this type of evaluation is made when the preliminary evaluation identifies that one or more than one element of the environment may be affected significantly by the project. Legal obligations may also lead to the choice of this type of evaluation.

9.3 PRELIMINARY STUDIES PHASE

In this phase, it is customary to complete only a preliminary environmental evaluation of the project. In order to complete this evaluation, only basic information is required. The required precision needed at this stage is very approximate.

A rough inventory of available technical and environmental data is required. The evaluation must allow, by analysis of this preliminary data, to identify all elements that could be affected by the project. The identification of the required permits is also needed at this stage.

This preliminary evaluation leads to the choice between a full impact assessment or a reduced impact assessment for the project.

9.3.1 Brief inventory of technical and environmental data

Technical data

The technical data needed at this stage include a brief technical description of the project, the preliminary lists of new equipments and apparatus, their location in the existing network, as well a general plan of all existing and planned equipments, limits of properties, and access roads to those equipments.

In order to identify sources of impacts, technical characteristics of the new equipments, construction methods and cable installation methods must also be defined.

Environmental data

The environmental data are based on site visits, but also includes consultation of all available data regarding soil contamination, noise, land use, sensitive areas, according to local planning. Most data would come from previous studies in the same area.

9.3.2 Basic analysis

The basic analysis consists in the identification of elements that could be affected by the project, considering the sources of impact related to the planned activities and construction work.

9.3.3 Selection of the magnitude of the impact assessment study

Following the analysis, the magnitude of the impact assessment study is selected, either reduced of full impact assessment.

9.3.3.1 Reduced impact assessment

This process is suitable when all the impacts on the environment caused by the project are evaluated as non significant. A final report is issued, describing the basic information on both the technical and the environmental data, identifying the elements of the environment and justifying the absence of significant impact on those elements.

9.3.3.2 Full impact assessment

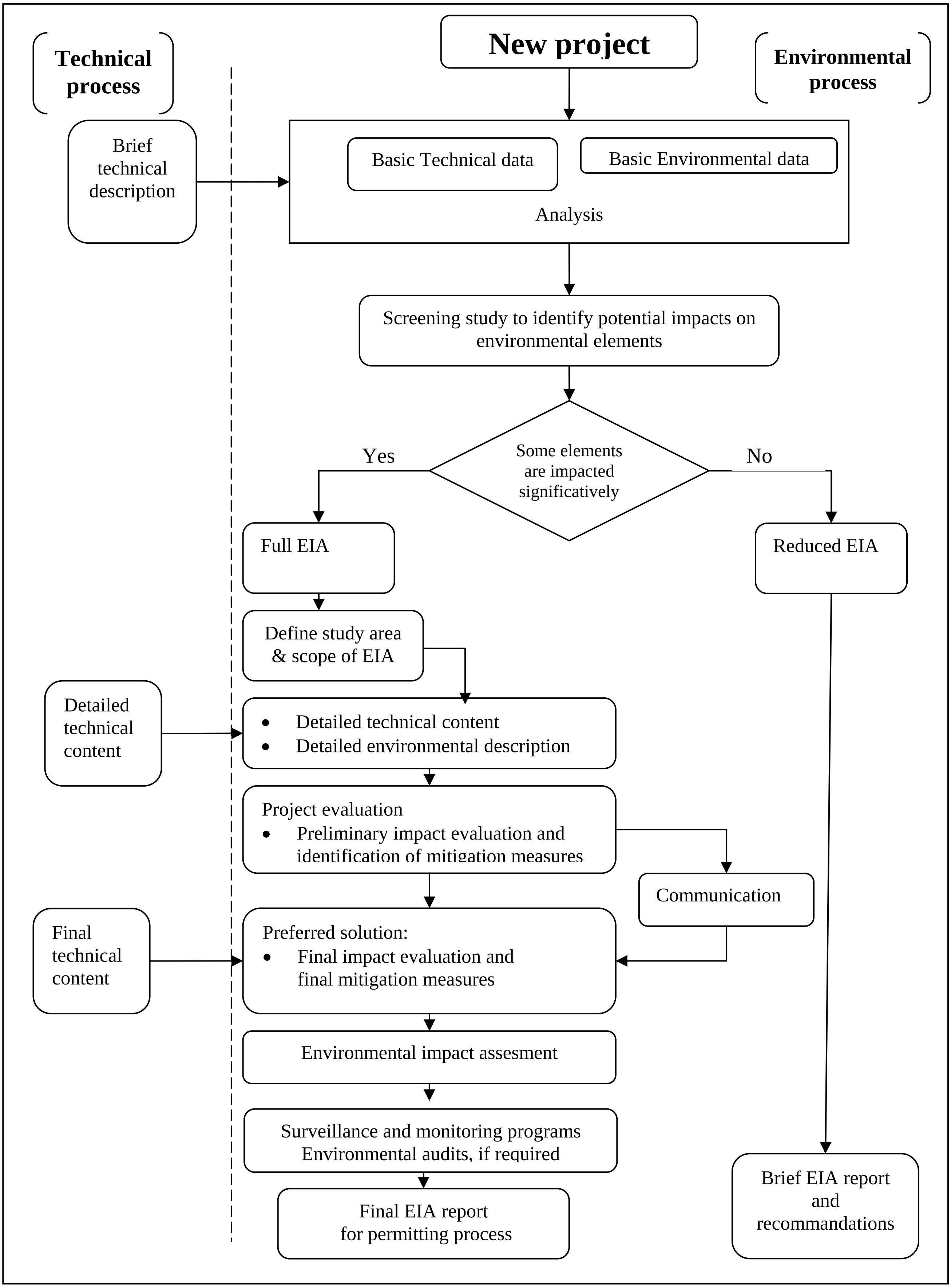
This process may be needed by regulation or is required when the preliminary evaluation shows that some elements of the environment may be significantly affected by the project. It includes the following activities:

- Identification of impacted elements
- Identification of evaluation tools required for impact assessment;
- Delimitation of study area;
- Detailed description of technical content of the project;
- Detailed environmental description of the project location;
- Impact evaluation: preliminary impact assessment and preliminary description of mitigation measures;

- Internal and external communication;
- Detailed description of the final technical content of the project;
- Recommendation for the preferred solution including final impact evaluation and description of final mitigation measures;
- Impact assessment for the project;
- Surveillance program
- Post-construction audit and monitoring program, if required;
- Drafting of the complete environmental assessment report

The following diagram shows the interactions between environmental and technical process in the preliminary studies phase.

Interaction between environmental and technical processes
Preliminary studies Phase



9.4 PROJECT PHASE

From the construction standpoint, the project phase includes four steps:

- Engineering
- Pre-construction (surveying)
- Construction
- Post construction (restoration)

The project phase includes those specific environmental processes:

- Permitting process
- Environmental surveillance
- Environmental monitoring and audits
- Compensation or community work program

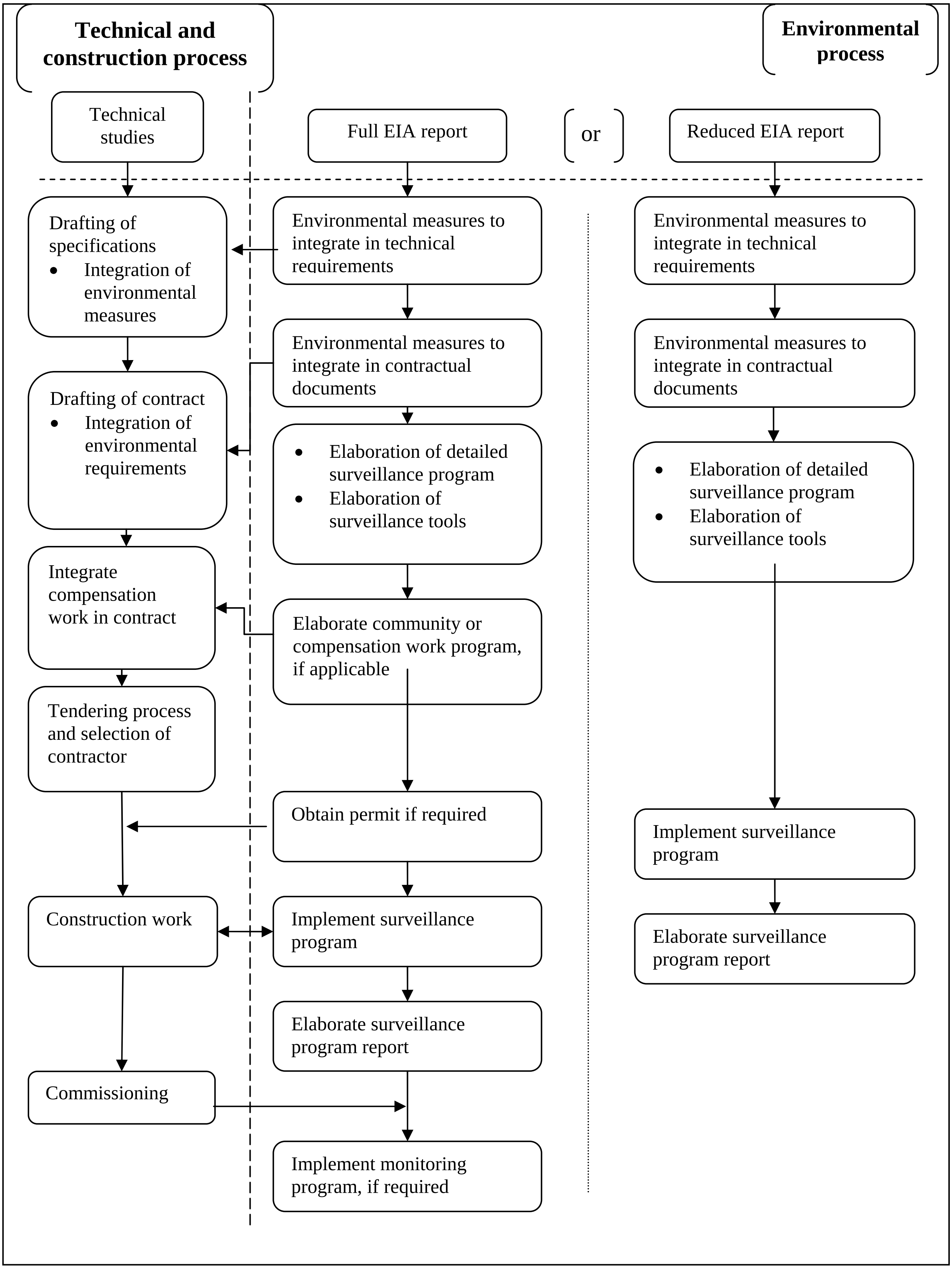
The permitting process may be performed during the preliminary phase or in parallel with the project engineering step.

During the engineering step, the surveillance program is put into place. It consists in integrating the following elements in the output of the permitting process and the engineering step:

- All measures integrated in the environmental policies of the utility;
- Mitigation measures described in the impact assessment study;
- Commitments to the local communities and land owners;
- Conditions imposed by the authorities, namely those included in the permits;
- Laws, rules and regulations, imposed by national, regional or local authorities.

The following diagram shows the interactions between the environmental and construction processes in the course of the project phase.

Interaction between environmental and technical processes
Project Phase



9.5 METHODOLOGY OF THE IMPACT ASSESSMENT STUDY

The suggesteded methodology of the impact assessment study follows three steps, described in details in this section:

- Step 1: Identification of all environmental elements that can be affected by a project
- Step 2: Identification of all the steps of a project and their possible impacts on the environment
- Step 3: Systematic correlation of all elements and possible impacts and elaboration of mitigation measures

Section 9.5.1 gives a detailed description of the environment and the main elements (resources) where the various equipment will be inserted in the network.

Section 9.5.2 elaborates the various sources of impact resulting from the many steps of the project (pre-construction, construction, operation and maintenance, retrieval).

In Section 9.5.3, for the many elements identified in the first part, a systematic approach is detailed for the following activities:

- inventory of technical and environmental elements
- assessment of the impacts
- mitigation measures (examples)
- surveillance program.

In section 9.5.4, the methodology is summarized in a matricial tool.

9.5.1 Environmental elements

Environmental elements are all components that may suffer some impact because of activity during the four phases of implementation and operation of an underground line or transition compound. They are subdivided into three categories: the natural environment, the human environment, and the landscape. All of them are common to both underground line and transition compounds projects.

9.5.1.1 Natural environment

Ground

Element #1. Soil quality

Soil quality depends on the physico-chemical parameters that characterise the soils at a given time and on preserving the arrangement of the horizontal layers produced by pedological processes. Soil contamination through leaks or spills of contaminant substances from machinery or equipment, and modification to the surface of the ground during transport, traffic, excavation, or earthwork are among the types of impact suffered by this element of the environment.

Element #2. Equilibrium slope

The slope of the ground surface is in equilibrium when it ceases to tend to increase or decrease significantly; this equilibrium is reached when the actions of the agents of accumulation and the agents of erosion are in balance. The equilibrium of the ground surface slope may be broken when activities requiring the movement, deforestation, and reworking of the ground favour the action of the agents of erosion.

Element #3. Surface water quality

Surface water quality depends on the physico-chemical and biological parameters that characterise the water in lakes and watercourses at a given time. Leaks and spills of contaminant substances from machinery and equipment are sources of interference of the chemical quality of bodies of water. The production and storage of ligneous and other wastes is another source of contamination of bodies of water.

Element #4. Profiles of bodies of water

The profile of a body of water includes all materials constituting the bed and banks of the lake or watercourse. The installation of culverts, traffic, and the construction of equipment cause modifications of the profiles of bodies of water, including subsidence, embankment, and excavation.

Element #5. Ground water quality

Ground water quality depends on the physico-chemical parameters that characterise expanses of ground water at a given time. Leaks and spills of contaminant substances from machinery and equipment can modify the physico-chemical parameters of ground water.

Element #6. Flow of watercourses

"Flow of watercourses" refers to the configuration of the hydrographic network in a given environment, and to the hydraulic characteristics of the watercourses that are part of it (flow rate, speed, type of flow, mixture of waters, etc.). The flow of water is perturbed when the work causes debris or infrastructure in the bed of the watercourse, either temporary or permanently.

Element #7. Runoff and infiltration

"Runoff" designates the flow of water on the surface of the ground, whereas "infiltration" refers to phenomena connected to the percolation of water into the ground. The accumulation of debris and the installation of equipment are the main causes of modification of the flow of surface waters. The interference of the normal runoff may result in temporary accumulations of water in a period of heavy rain or a thaw.

Air

Element #8. Air quality

Air quality is defined by all physico-chemical parameters of the air at a given time and in a specified location. The emission of pollutant gases and dust during construction work temporarily modifies the chemical composition of the air. Furthermore, deforestation in the natural environment, and the construction or dismantling of bulky infrastructure causing a modification of the arrangement of the volumes in an urban environment, may locally interfere with the force and direction of the wind and may also influence local temperature conditions.

Element #9. Noise environment

The noise environment is all usual sounds at a given place that occur at more or less regular intervals and can be identified in a given time. The operation of noisy vehicles, machinery, or equipment modifies the composition of the usual sounds and amplifies them temporarily or permanently.

Flora and fauna

Element #10. Species

A species is a set of individuals having shared characteristics and capable of reproduction. Four groups of animal species can be considered - terrestrial, semi-aquatic, aquatic and avian - and three groups of plant species - riparian (intertidal and supratidal), paludal, and terrestrial. The work modifies the abiotic components of the environment and interferes with the activities of wildlife (marking of territory, search for food, reproduction, etc.) and the growth and expansion of plant populations. The work usually does not influence, at least not significantly, the actual survival of the species.

However, in the case of endangered or vulnerable species, as identified in the official lists recognised by the competent authorities, characterised by limited distribution or a small population, some activities may have repercussions.

Element #11. Habitat

Wildlife habitat and plant habitats is the set of biotic and abiotic conditions necessary for the survival of the species. Some habitats receive special protection because they are essential to the development of a species. All actions in the natural environment that modify its components in any way have an impact on habitats.

9.5.1.2 Human environment

Element #12. Urban and peri-urban space

The urban space corresponds to a unit of territory used or worked for urban purposes. A portion of territory has an urban function if there is an urban fabric there, in other words housing and a network of streets and, possibly, ancillary activities: trade, industry, recreational spaces, etc. These spaces are broken down into current and planned uses corresponding to the subdivision of the territory as determined by regional or local planners.

The peri-urban space corresponds to a portion of territory used or worked for peri-urban purposes. A portion of territory has a peri-urban function when it is associated with residential, commercial, institutional, or industrial development outside the urban fabric; the peri-urban space includes, in particular, linear habitat, large industrial zones, sand pits, quarries and mines, landfills, spaces occupied by public utilities, storage areas, etc.

All actions that require noisy work to be carried out, the use of heavy vehicles and machinery, and the construction of new infrastructure in urban and peri-urban spaces interfere with the activities that take place there.

Element #13. Leisure and tourism

The space allocated to vacationing, leisure activities, and tourism corresponds to a portion of the territory used for recreational, tourist, or vacation purposes. A portion of territory has a recreational function (outside of urban spaces) when it is allocated to relaxation, entertainment, open-air activities, sports, or tourism. A portion of territory has a vacationing function when it welcomes tourist accommodations and holiday homes. These spaces are broken down into current and planned uses corresponding to the subdivision of the territory as determined by regional or local planners.

All actions that require noisy work to be carried out, the use of heavy vehicles and machinery, and the construction of new infrastructure in a space assigned to vacation, leisure, and tourist use interfere with the activities that take place there and modify their composition.

Element #14. Agriculture and fisheries

Agricultural space corresponds to a portion of territory used for agricultural purposes. A portion of territory is used for agricultural purposes when it is developed for fodder, specialised, horticultural, or tree-borne crops. These spaces are broken down into current and planned uses corresponding to the subdivision of the territory as determined by regional or local planners.

Fisheries correspond to the commercial rearing or exploitation of fish stocks.Non commercial activities are usually considered under elements #10 Species,#11 Habitat or #13 Leisure and tourism.

All actions that require noisy work to be carried out, the use of heavy vehicles and machinery, and the construction of new infrastructure in an agricultural space interfere with the activities that take place there and modify their composition.

Element #15. Forestry

Forestry correspond to the use of a portion of territory for the commercial growth and harvesting of timber.. A portion of territory has a forestry function when it is intended to support forest cover for forest working. These spaces are broken down into current and planned uses corresponding to the subdivision of the territory as determined by regional or local planners.
The forrestry area is also a specific ecostructure and its function as a habitat has to be considered.

All actions that require noisy work to be carried out, the use of heavy vehicles and machinery, and the construction of new infrastructure in a forest space interfere with the activities that take place there and modify their composition.

Element #16. Heritage space

"Heritage" can be broken down into three parts, as follows:

. cultural heritage;
. architectural heritage;
. archaeological heritage.

- **Cultural heritage**

"Cultural heritage" covers the history of human occupation. It thus includes the use of the land by the indigenous populations, traditional and craft activities, the history and prehistory of human occupation.

- **Architectural heritage**

"Architectural heritage" includes sites or buildings having architectural and/or historical value. In it are found buildings and sites protected by the governmental authorities (listed or recognised monuments and buildings, protected areas, historical districts, historical sites, etc.), buildings or sites recognised by town councils or regional county councils, and buildings or sites identified in the evaluation process.

- **Archaeological heritage**

"Archaeological heritage" includes sites that are known, recognised, or protected by the competent authorities, together with the results of studies of archaeological potential (fig 85). The archaeological heritage includes the underground heritage, but also heritage elements or sites bearing witness to historical ways of life (e.g. industrial heritage).

Figure 85: Archaeological findings during the construction of an underground system

All actions requiring the occupation of a territory, that interfere with the underground, and the construction or the dismantling of buildings may limit access to territories linked to traditional uses, modify protected architectural components, and damage sites of recognised archaeological value.

Element #17. Services

Services correspond to the physical components of the various current uses linked to human activities. These equipments group a great variety of elements. The most usual are

. Drainage systems	. electric lines
aqueducts	. airports, heliports
. sewers	. seaplane bases
. telecommunications antennas	. telephone lines
. forest roads	. gas or oil pipelines
. public highways and roads	. public water intake and supply basins
. railways	. dams, dykes
. footpaths	. cycling paths
etc.	

Work which, when carried out, requires the occupation of a used space, and movements of vehicles and machinery are sources of damage to existing infrastructure and interfere with the services and activities linked to those existing equipment.

9.5.1.3 Landscape

Element #18. Field of view

The field of view is defined as the whole of the area that can be perceived from a place or from a place of observation. It is defined according to its composition and its configuration.

Composition of the field of view: refers to the type and arrangement of the elements contained and perceived in the field of view. The elements or the components of the field of view may be physical or pictorial:

The physical components are associated with the shape and size of the current elements of the environment, plant cover, and relief, and to the orientations likely to influence the development of the environment. The physical components help the structuring of the concrete landscape.

The pictorial components can be depicted in terms of shapes, lines, hues, and textures. The shapes or masses can be studied via the volumes created by the physical components of the landscape. The lines correspond to the limits of the shapes and masses and determine their dimensions. The hues result from the combination of the colours, light, and shadows present. As for the texture, it consists of the arrangement or apparent organisation of the components (or materials) of the environment.

Configuration of the field of view: refers to the overall shape, dimensions, or proportions of the field of view. The configuration of the field of view is linked to the degree of depth and degree of openness of the perceived space: depth refers in particular to the distance separating the observer from the various planes of vision (foreground, middle-ground, and background) that may partially or totally obstruct the field of view; openness is defined by the lateral amplitude of the angle of vision determined by the shape of the physical components of the environment (shape and size of the elements of the environment, plant cover, and relief that bound and structure what the observer sees.

Element #19. Special Feature

Physical component of the environment that plays a decisive role in the composition, visibility, and enjoyment of the landscape; refers to visual reference points, visual attractions, strategic observation points, and interesting views of the landscape.

9.5.2 Sources of impact from underground lines and transition compound

Sources of impact correspond to the various activities of the project and operating phase. From a project standpoint, there are four main categories of activity: pre-construction, construction, post-construction, and operation and maintenance. When the sources of impact are the same for both underground line and transition compound projects, the definitions are adapted to reflect the particularities of each type of project. On the other hand, when the sources of impact are specific to only one type of project, the type of project is clearly identified. It should be kept in mind that sources of impact may be either of a temporary or a permanent nature.

In addition to the definition, each source of impact is accompanied by a list of relevant factors that characterise the activity in question and can be used to narrow down the types of potential impacts. This list is intended to help to identify the elements affected by the activities.

9.5.2.1 Pre-construction phase

Impact source A. Surveying and technical surveys

Technical surveys and general surveying is performed to characterise and prepare working areas. Technical surveys are also performed in the other phases of work. However, there they are not a main activity, as in the present case, but a support activity.

The technical surveys are carried out to establish the type of surface materials with a view to the siting of the work camps, the transition equipments, joint pits, grounding grid, and the above ground equipment. These surveys require machinery to be moved (drilling machines, seismographic equipment, etc.) and drilling operations to take samples and install probes.

Surveying serves to prepare the location of the site and mark out the construction works. It normally includes surveying to prepare profile drawings of the land, and legal surveying to negotiate easement or purchase.

Relevant factors:

- *scope of the surveys;*
- *type of environment (natural, rural, developed, urban)*
- *environmental considerations*
- *volume and duration of the noise produced by the equipment*
- *direction and quantity of runoff waters*
- *waste produced by sampling work*
- *presence of contaminants*
- *duration of the work and size of the teams used*
- *extent of the cutting work necessary for the work*

Impact source B. Obtaining rights

In order to obtain a swath and a building site studies and surveys on the area are carried out, firstly to establish the value of the buildings and land required, and then to obtain the needed easement or ownership, by private negotiation or by compulsory acquisition. If appropriate, specific compensation for any disturbance can be negotiated with the owners, as well as special compensation for rights of way or access roads outside the Utility's easements and properties.

Relevant factors:

. *changes in land use;*
. *inconvenience to local residents;*
. *duration of the various work and size of the teams used.*
. *temporary office space*
. *storage space*

Impact source C. Transport and traffic

Transport and traffic for signalling and surveying purposes are sources of direct impact when they require the use of heavy vehicles and when they cross watercourses or drainage ditches. Generally, signalling and surveying are done on foot or with lightweight equipment

Relevant factors:

. *type of installation*
. *type of transport vehicle required;*
. *volume and duration of the noise caused by moving vehicles;*
. *sensitivity of the watercourses crossed;*
. *locations and use of existing highways and roads;*
. *type of road surfacing and foundations of the roads used;*
. *conflict with users of the land (hunting, fishing, etc.);*
. *volume of road traffic.*
. *fisheries (transportation by boat)*
. *vibration*

Impact source D. Site access arrangements

Managing the site access involves building and maintaining temporary or permanent access roads, bypass roads, bridges, culverts, or passages, to transport necessary materials and equipment for the construction of the line (civil works, cable laying, splicing) and/or transition compound.

Arranging site access may be done in the swathe itself or outside of it or, in the case of above or below ground movement works, inside or outside the property boundaries.

Relevant factors

. *role of the road in the highway network,*
. *type of road surface;*
. *importance of the roads;*
. *type and characteristics of the land being crossed;*
. *type of bed of the watercourses to be crossed;*
. *mode of crossing and sensitivity of the watercourse;*
. *proximity of developed and inhabited sectors;*
. *location of additional work;*
. *environmental considerations;*
. *habitat of wildlife;*
. *particular seasons (e.g. agricultural activities, activities of wildlife, etc.);*
. *surface drainage;*

. *presence of wet areas;*
. *period when work undertaken,*
. *proximity to bodies of water, watercourses, and drinking water wells.*

Impact source E. Clearing an area

For an underground line, clearing consists of cutting trees in the swathe according to the clearance methods specified in the construction plans and estimates; for a transition compound, it means totally clearing the required surface area. Clearing may be performed by the Utility or by contractors on public land, or by the owners themselves on private land.

Generally, clearing is done using skidders, except in fragile areas of line swathes where cutting is done manually. The choice of clearance method has a direct effect on the impact generated.

The felling may be done with or without recovering trees of marketable size. Clearing (using the method specified) also includes the stacking and burning of the cutting residues.

Relevant factors:

. *size and weight of the equipment required;*
. *proximity to developed and inhabited sectors;*
. *modification of habitat;*
. *regional surface waters;*
. *plant species;*
. *volume and duration of the noise made by the work;*
. *clearing method;*
. *amount of deforestation;*
. *protection required by nearby plants;*
. *topography;*
. *risk of erosion;*
. *aesthetics of the landscape;*
. *use of the sector by wildlife;*
. *use of the deforested sectors for hunting;*
. *particular wildlife habitat (e.g. herons, deer, etc.);*
. *proximity to bodies of water, watercourses, and drinking water wells.*
. *disposal method*

9.5.2.2 Construction phase

Impact source F. Transport and traffic

Transport and traffic concern movements of workforce and machinery for supply and construction, together with crossing sensitive areas. Storage materials in storage depots and distributing materials (specially drums and shielding plates or tubes) and equipment for civil works, cable laying, assembling above ground structures, requires movement inside and outside the easements and the property boundaries (fig 86 anf 87). Generally, construction work requires the use of heavy transport vehicles and machinery and various modes of transport for personnel, using all-terrain vehicles.

Figure 86: Crane for unloading of drums

Figure 87: Storage area for drums with steel plates for soil protection

Relevant factors

- *existing flows of traffic outside the site;*
- *practicability of the highways and roads for vehicles;*
- *duration of use of the equipment, level of noise produced, volume of exhaust gases;*
- *method of crossing and sensitivity of watercourses;*
- *presence of sensitive areas;*
- *volume of road traffic;*

- *period when work undertaken.*
- *transfer of mud and dust to public highways*
- *safety (appropriate signaling)*
- *movement of heavy vehicles during evening and early morning*
- *work schedule*

Impact source G. Work in quarries and sand pits

Work in quarries and sandpits consists of open-face extraction of consolidated and unconsolidated mineral substances for constructing, among other things, access roads, foundations, and environmental improvements. Generally, work in quarries and sandpits for the sole purpose of building an underground line and a transition compound is necessary only in built-up areas.

Relevant factors:

- *level of need;*
- *size of the operation;*
- *proximity to noise-sensitive areas;*
- *need to modify the water table;*
- *surface water drainage;*
- *topography;*
- *restoring to condition;*
- *modification of habitat;*
- *environmental considerations.*

Impact source H. Excavation and earthworks

Excavation includes drilling and digging the ground before laying. The type of excavation varies according to the type of installation:

<u>For transition compound:</u>

1. foundations on dead-ground: wire mesh foundations, foundations on slab and concrete shaft or foundations made of boxes with wide bases;

2. foundations on rock: concrete footing anchored to the rock or wire mesh bolted to the rock;

3. foundations on piles: anchoring alongside piles or slabs at a depth equivalent to foundations on dead-ground.

Earthwork modifies the ground profile with a view to arranging or setting up equipment or infrastructure (fig 88).

Excavation and earthwork generate large quantities of uncontaminated building debris and, at times, contaminated materials that have to be managed in conformity with local regulations, with the agreement with the agricultural producers, and with the standards in force.

<u>For underground line</u>

Depending on the installation method adopted for the project, and on the obstacles on the cable route, specific construction techniques can be used, as described in Technical Brochure 194 "Construction, laying and installation techniques for extruded and self contained fluid filled cable systems": open trench, drilling, open trench tunnel, pipe-jacking…The choice of construction technique may have a great influence on the quantity of excavation and earthwork needed.

Figure 88: Excavation before construction of a 400 kV Transition Compound

Relevant factors:
- *type of soil excavated;*
- *interception of existing drainage systems;*
- *presence of contaminants;*
- *scope of the work;*
- *orientation and quantity of runoff waters;*
- *depth of water table;*
- *volume and duration of the noise caused by the equipment;*
- *risk of erosion;*
- *volume and destination of excavated waste;*
- *stripping and storing of top-soil;*
- *difficulty of transporting the equipment off site;*
- *archaeological value of the site;*
- *storage and use of explosives;*
- *agricultural use of the site;*
- *proximity to inhabited areas*
- *vibration*

Impact source I. Building the equipment and ancillary structures

Different components and machinery are required in the construction of equipment and ancillary structures for a cable system and a transition compound. These elements are presented separately for line and transition compounds projects, while the relevant factors are grouped.

<u>For underground line</u>

The construction of an underground line generates numerous but generally temporary impacts. To achieve the required transmission capacity, it may be necessary to lay two feeders in parallel. To limit the thermal influence of a feeder on the other one, feeders are generally laid at a distance of several meters from each other, resulting in a wide swathe and an important environmental impact (fig 89), which is generally only temporary if appropriate mitigation measures are taken.

Figure 89: Temporary impact during construction of a 400 kV Cable system

In some cases, it may be necessary to lay the cables in a dedicated tunnel which could require important civil works (fig 90).

Figure 90: Civil works for the construction of a tunnel where a new 400 kV Cable system will be installed

Together with the works for the installation of the cables (civil works, laying or pulling of the cables), the construction of an underground line includes putting in place of supporting structures, transition towers or poles, cable terminations and jumpers for connection to the overhead network, and ancillary equipment. This operation requires the use of vehicles, which travel on the swathe for various activities. Special provisional tracks may be necessary for soil preservation (fig 91).
In some cases, when the preliminary study has highlighted the problem, besides cable and ancillary equipment, the erection of MF shielding must be taken in due consideration.

Relevant factors:

- *size and weight of the equipment required*
- *proximity of sensitive developed areas (housing, schools, hospitals, etc.);*
- *volume and duration of the noise caused by the machinery;*
- *dust and vibration produced during the work;*
- *environmental considerations;*
- *orientation and quantity of runoff waters;*
- *direction of prevailing winds;*
- *time of year of construction*

Figure 91: Provisional track during the construction of a 400 kV cable system

For transition compound

Transition from underground to overhead may vary from pole-mounted terminations (fig 92) at lower voltage ranges to a full transition compound for the highest voltages (fig 93).

Figure 92: 66 kV Transition tower

Constructing a transition compound includes implanting the base of the structure, which may require, in addition to drilling, the use of explosives to excavate or eliminate rock debris, setting up the equipment as well as the ancillary apparatus, connecting up to existing power and distribution networks, the control building and the service building. The use and handling of insulating oils and other contaminant substances during the installation of the equipment must also be anticipated. Important temporary visual impact may occur during construction (fig 94).

For highest voltages, the transition equipment might include:

1. Several items of electrical equipment:

. measuring transformers;
. reactors;
. disconnectors;
. earthing switches;
. line terminal towers or gantry;
. busbars;
. surge arrestors;

2. Other infrastructures:

. control and service buildings;
. service areas;
. access roads;
. drainage
. fences or walls

3. Different services

. water and sewer
. telecoms
. auxiliary power
. lighting

Figure 93: 400 kV Transition Compound with busbars, disconnecting switches, surge arresters and measuring transformers

Relevant factors:

. *quantity, size and weight of the equipment required*
. *proximity to sensitive inhabited areas (housing, hospitals, etc.);*
. *proximity to bodies of water, watercourses, and drinking water wells.*
. *volume and duration of the noise made by machinery;*
. *dust and vibrations produced during the work;*
. *environmental considerations*
. *orientation and quantity of runoff waters;*
. *time of year of construction;*
. *storage locations.*

Figure 94: Temporary visual impact during the construction of a 400 kV Transition Compound

Impact source J. Management of contaminants and wastes

Construction work often requires handling substances such as paints, solvents, mineral oils, hydrocarbons, diesel, etc. Handling these substances during storage, at specific locations in the work area, during the work itself, and finally when the residues and unused volumes are evacuated, entails a risk of contaminating the environment.

Construction generates a quantity of solid and liquid wastes that must sometimes be stored temporarily at the work site. The volumes of these wastes are large enough that their temporary storage on the site presents a significant source of impact.

Relevant factors:

. *type and quantity of contaminants;*
. *type of solid wastes;*
. *level of contamination;*
. *management method;*
. *recycling potential;*
. *preparation of an emergency plan;*
. *storage areas*

. *decontamination areas;*
. *locations of suitable disposal sites.*

9.5.2.3 Post-construction phase

Impact source K. Demobilisation

Demobilisation corresponds to the removal of the equipment from the work site: moving machinery, dismantling equipment, evacuating equipment and fuel storage sites, dismantling work camps, temporary offices, tracks and site facilities.

This demobilisation therefore requires work and vehicle movements that are sources of various impacts on the environment.

Relevant factors

. *site isolation with respect to storage areas;*
. *difficulties involved in transporting the equipment off site;*
. *recovery of debris and wastes left on site;*
. *weather conditions preventing recovery of the equipment.*

Impact source L. Improvement and restoration

The environment, for which various impacts linked to construction and demobilisation work have been identified, requires restoration work and, in some cases, improvement work (fig 95).

Restoration returns a place which has been modified by construction work to a condition as close as possible to its original state, so that it can once again be a part of the environment in which it is located. Restoration can be subdivided into two categories: physical restoration, which refers to work generally done by machine, such as dismantling, earthwork, etc., and restoration of the plant life.

Improvement either on site or off site corresponds to the modification or physical improvement of an area to render it usable for purposes other than its original use: for example development of a cable right of way for use as a cycling path.

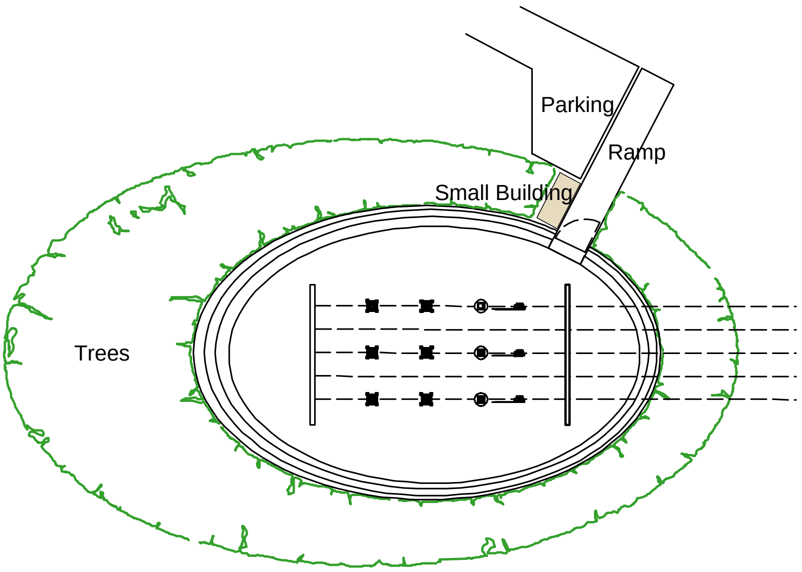


Figure 95 a: Example of vegetal restoration and improvement around a transition compound

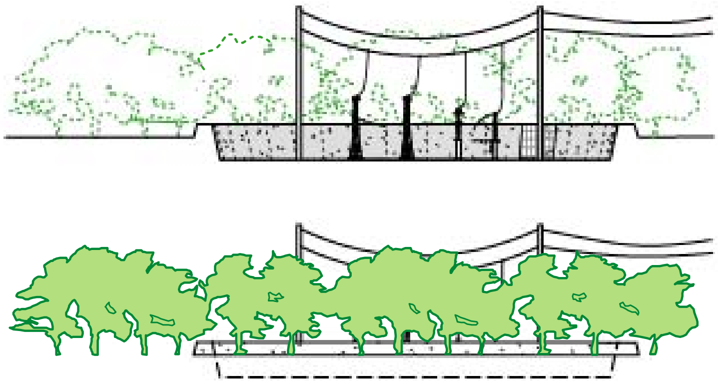


Figure 95 b: Example of vegetal restoration and improvement around a transition compound

Relevant factors:

. *drainage modifications to bodies of surface water;*
. *destruction of habitat of wildlife;*
. *introduction of flora previously absent;*
. *plant life restoration program and species used;*
. *modifications of human activities on the site;*
. *favoured introduction of some species of wildlife*

9.5.2.4 Operation and maintenance phase

Impact source M. Presence, operation, and maintenance of equipment

A transition compound and an underground cable generate, through their presence, their operation, and the maintenance they require, a series of impacts specific to each project. Furthermore, the presence of a power line requires the presence of a swathe, the very existence of which is a source of impacts.

<u>For underground line</u>

Presence of the equipment

The main components of a project that can generate impacts through their very presence are:

. the joint chambers or manholes
. the types of grounding devices;
. the presence of foundations (fig 96);
. the link boxes for the bonding circuits;
. the possible MF shielding plates or tubes;

Figure 96: Foundations for direct buried 400 kV Joints

The grounding devices and the foundations are buried in the ground and may cause problems simply as objects, in particular for agricultural uses (ploughing, drainage),

Relevant factors:

. *discontinuity in habitats;*
. *orientation and quantity of runoff waters;*
. *local configuration of air flow;*
. *physical and visual integration of the equipment with the environment.*

Operation of the equipment

When the underground line is in service, the sources of potential impact linked to operation are:

- the magnetic fields which can induce voltages and currents in the existing structures in the vicinity of the line (under or above ground: fences….)
- the thermal flow from the conductor to the surrounding, which increases the temperature of the soil, and can initiate local drying of the soil with possible consequences on flora and fauna.
- the effects of the power cable on telecommunication cables
- the circulation of currents in the grounding devices specially in case of flashovers in overhead parts
- the consequences of a breakdown of a cable, following an internal failure or external aggression

Relevant factors:

. *heat flow and risk of drying*
. *noise produced by operating the equipment*
. *proximity to equipment sensitive to magnetic fields.*
. *risks associated to a cable breakdown: soil lifting, pressure rise in a manhole…*
. *risk of oil leak for oil filled cables*

Maintenance of the equipment

Maintenance consists above all of preventive measures - checking the equipment.

Repair consists of reconditioning defective equipment. Depending on the type of breakage or defect, light or heavy machines may have to travel through the swathe. In case of major fault, a new length of cable and two joints have to be installed, which may require excavation works

Relevant factors:

- *size and weight of the equipment required;*
- *duration and volume of the noise caused by the work;*
- *dust and exhaust gases produced during the work.*
- *duration of works and selection of the laying technique*
- *in case a MF shielding has been installed, repair of a faulty cable become a more complex task, due to the presence of the metallic plates or tubes*

<u>For transition compounds</u>

Presence of the equipment

Transition Compounds are generally a constraint on development because of the space they occupy and a visual nuisance by their sheer size. The size of the equipment, often visible from far away, and the lighting, if any, are two other drawbacks linked to the presence of the equipment.

Relevant factors:

- *physical and visual integration of the equipment with the environment.*
- *vandalism*

Operation of the equipment

The operation causes various types of impact:

- impacts linked to electric and magnetic fields
- impacts linked to the noise emitted by various components of the transition compound, especially near inhabited areas;
- impacts linked to the lighting of the installations at night;
- impacts linked to the potential leakage of liquid or gases;
- interference with telecommunications
- impacts linked to risks of explosion or fire.
- corona effects

Relevant factors:

- *volume of the noise produced by operating the equipment;*
- *proximity to equipment sensitive to magnetic fields.*

Maintenance of the equipment

Maintenance and repairs inside a transition compound may be of several orders. The activities mainly concern filling equipment containing oils and greases (transformers, inductors, disconnecting switches, auxiliary services) and the recovery of the waste oils. They also concern:

. the replacement of equipment or the addition of new electrical equipment;
. the addition of equipment aimed at improving the quality of the environment;
. oil containment systems;
. firewalls;
. boundary walls, etc.

The maintenance may also require the transport of solid, liquid and dangerous wastes, and of contaminated soil (soil, aggregates, snow, various dry materials, etc.) to disposal sites.

This source of impact is not limited to maintenance and repair activities strictly speaking. It also concerns the effects of malfunctions and any impacts of their causes (fire, explosion, coolant leaks).

Relevant factors:

. *size and weight of the equipment required;*
. *duration and volume of the noise produced by the work;*
. *dust and exhaust gases produced during the work;*
. *type of contaminants;*
. *management method;*
. *preparation of an emergency plan*
. *recovery of wastes;*
. *types of wastes produced;*
. *storage areas;*
. *decontamination areas;*
. *suitable disposal sites*

Impact source N. Presence, access to, and maintenance of the swathe

By its presence and the maintenance it requires, and by the means of access that must sometimes be developed to reach it, the swath of an underground cable may impact the natural and human environment and the landscape.

The presence of the swathe concerns only underground projects. The swathe is normally a strip of land on which the Utility has a right of way or an easement for the purpose of the construction, repair, operation, maintenance, and protection of one or more underground power systems..

The use of the swathe is regulated. Furthermore, on certain conditions, it may be authorised to use the ground - for agriculture, recreation, parking, or infrastructure. Generally, the construction of buildings is restricted in the swathe.

Even though some types of use of the ground are tolerated, the swathe is a source of drawbacks and a limitation on the full use of the property. It is therefore a source of impact on the use of the ground and resources for the life of the line.

Relevant factors:

. *size of the swathe*
. *location of the swathe*
. *possible land uses;*

Impact source O. Decommissioning and dismantling

When all or part of an underground cable or of a transition compound is decommissioned and dismantled, the resulting equipment must sometimes be stored on site before being removed. Later, this equipment must be recovered and taken to a storage site or a solid waste disposal site according to its type (contaminated, reusable, or obsolete equipment).

The dismantling work is a source of various disturbance because of the presence and operation of heavy machinery. The use or presence of contaminant substances may also have impacts. Many of the impacts are similar to Construction phase.

In some circumstances, the impact of removing a cable can be more severe than leaving it in place. In such cases, fluid-filled cables should be drained, capped and monitored periodically.

Relevant factors:

. *type of equipment to be recovered;*
. *quantity of equipment to be recovered;*
. *distance to be travelled for recovery or disposal;*
. *types of vehicle required for the transport and handling of equipment;*
. *noise level generated, volume of exhaust gases;*
. *presence and types of contaminant.*
. *sensitive areas*

9.5.3 Systematic approach

In the proposed methodology, for each element described hereunder, environmental evaluation is conducted using a systematic approach including the following four activities relating to the study area:

- Inventory of technical and environmental content
- Evaluation of impacts
- Elaboration of mitigation measures (typical examples are given)
- Elaboration of surveillance program

9.5.3.1 Ground

Inventory

- Obtain authorizations required from land owners
- Identify contaminants present in the ground over time (historical data)
- Collect technical data for contaminants to identify chemical properties (flammability, corrosion, toxicity, etc) and physical properties (liquid, solid, gaseous, other) of contaminants
- Design and implement a sampling process for analysis of soils
- Identify geological features of ground (nature and layers)
- Note odors related to contaminants
- Establish the level of contamination of soils and water relative to regulations (concentration level and estimated volumes)

Evaluation of impacts

- Evaluate the behavior of contaminants in soil
- Evaluate the danger to human health and environment related to contaminated soils
- Evaluation vulnerability and sensitivity of local environment to dangers related to accidental spill of contaminants during operation of equipments

Elaboration of mitigation measures

- Plan and prepare a site and method for temporary storage, elimination or reutilization of soils with light levels of contamination
- Plan and prepare a site for temporary storage and a method for treatment or elimination of soils with high level of contamination
- Elaborate a warning process in case of accidental spill of contaminants
- Elaborate a strategy of intervention in case of accidental spill and take adequate measures to limit the risks and consequences of such accident on the work site
- Plan the presence, on site, of adequate equipment to reduce the risks due to contamination
- Put in place adequate measures to protect the soils
- Limit intervention on wearable or vulnerable grounds, with more or less important slopes. Choose vehicles and machinery according to the nature of the ground and the least likely to cause disturbance
- Avoid building access roads in long continuous slopes: favor winding access roads
- Reduce the slopes in storage areas to insure stability. If impossible, build some stabilizing works
- Limit the number of access roads and restrict machinery movements to working areas and mark out access. Do regular maintenance of access roads and working areas to minimize the creation of mounds and ruts that could impact natural runoff waters
- According to soil stability, restrict access to work area to machinery that can circulate without causing soil disturbance or ground compacting
- After works, level reworked grounds. Stimulate the growth of flora (grass or bushes) to stabilize slopes
- Before starting work, assess contamination of grounds within or nearby the work areas
- Take all necessary precautions while refueling machinery or equipments to eliminate the possibility of spills

Surveillance programs and monitoring programs

- Perform a continuous surveillance of all works to insure that they are done adequately, thus permitting to avoid contamination of clean soils and manage effectively and securely all excavated materials
- If an accidental spill occurs during construction, confirm the effectiveness of cleaning of the site according to regulations concerning contaminated materials
- Elaborate and implement an environmental surveillance program and a monitoring program for the storage of contaminated soils
- Perform a monitoring program on sites where contaminated materials were used as backfilling
- Elaborate and implement an environmental surveillance program and a monitoring program for the treatment of contaminated soils

9.5.3.2 Surface waters

Inventory

- Make a list of contaminants presently on site or previously present on site and identify storage site and quantities
- Collect technical data for contaminants to identify chemical properties (flammability, corrosion, toxicity, etc) and physical properties (liquid, solid, gaseous, other) of contaminants
- Design and implement a sampling program for surface water
- Determine the physical characteristics of surface water bodies (dimensions, speed of flow, nearby slopes, distance to work site, etc)
- Obtain reference water levels of water bodies, if possible
- Identify usages related to the water body (recreational, drinking water, fauna, etc)
- Identify, water circulation ways (drainage fosse, transition station drainage, etc)

Evaluation of impacts

- Evaluate the risks of that contaminant can get to water bodies
- Evaluate the behavior of contaminants in water bodies
- Evaluate the danger to human health and environment related to contaminated water

Elaboration of mitigation measures

- Take adequate measures to reduce or eliminate running water or accidental spill on site
- Insure surface water protection during works that modify local drainage (control of water flow and drying out of water bodies)
- Insure proper management of water collected during excavation in contaminated area (secure storage, evaluation of contamination level, local treatment or elimination by specialized firms)
- Elaborate a process for warning and for emergency intervention during construction and plan for adequate accessible on site equipment to reduce the risks of contamination
- Put in place adequate measures to protect the water bodies
- Cover bared areas, sensible to erosion, with mulch or similar material, to eliminate the loss of soils or seeds by runoff waters
- Collect all running water around the work site to a point where adequate treatment is available
- During construction work with important risk of contamination to nearby water bodies, make some water physical and chemical analysis before, during, and after construction work
- Avoid the circulation of machinery near drinking water wells, other water inlets and sewage treatment fields. A buffer zone should be defined and signaled on site by means of fences or other similar signaling materials
- Deviate surface running water away from areas vulnerable to erosion. If it is not possible, set up some protective devices (mounds, ditches)
- Avoid blocking water courses, drainage, ditches or other canals. Remove any wastes that could alleviate normal water course
- Avoid starting work in areas subjected to flooding in flooding season
- When crossing of water courses is mandatory, follow environmental protection rules
- After work is completed, remove all temporary works permitting the water way crossing; reinstate the water ways to their original state. Upon agreement with the landowner, bridges or other construction may be left on site permanently
- In order to avoid possible spills, restrict the refueling of vehicles and machinery near water bodies

Surveillance programs and monitoring programs

- When starting construction, reassess the actual quality of the water bodies
- Perform a continuous surveillance of all works to insure that they are done according to procedure and that a secure management of contaminated water is implemented
- Perform the surveillance of emergency procedure for confinement and recuperation, and insure a proper clean up of water bodies. If required, perform a monitoring program

9.5.3.3 (Under) Ground water

Inventory

- Identify activities that could affect underground water
- Make a list of contaminants presently on site and identify storage site and quantities
- Collect technical data for contaminants to identify chemical properties (flammability, corrosion, toxicity, etc) and physical properties (liquid, solid, gaseous, other) of contaminants
- Determine the hydrogeological context of site (depth of water table, local hydrogeological network, topography, nature and location of soft materials and rock, etc)
- Make a list of ground water users
- Obtain, if possible, reference data for ground water

Evaluation of impacts

- Evaluate the risks of contamination to wells and ground water
- Evaluate the behavior of contaminants in ground water
- Evaluate the danger to human health and environment related to contamination of ground water

Elaboration of mitigation measures

- After land survey implying boreholes, make sure to fill all holes correctly to eliminate the possibility of migration of contaminants to the underground water table
- Avoid modifying the behavior and quality of ground water
- Insure an adequate management of ground water pumped during excavation works in contaminated area (safe storage, level of contamination, elimination by a specialized firm)
- Elaborate an emergency warning structure in case of accidental spill of contaminants
- Elaborate an emergency plan in case of accidental spill of contaminants and take adequate measures permitting to limit the risks and consequences of such an occurrence on work site
- Plan for availability on site of adequate equipment to reduce the risks of contamination

Surveillance programs and monitoring programs

- Perform a continuous surveillance of work, avoid the contamination of ground water and insure a safe management of pumped water
- When starting construction, reassess the actual condition of the ground water
- In case of accidental spill of contaminants, perform a hydrogeological survey and a monitoring program of quality of ground water to better assess the situation, take adequate measures and insure the quality of ground water
- In case of temporary drying out of an underground water body, perform a hydrogeological survey and a monitoring program of the level of ground water to better assess the situation, take adequate measures and insure the reinstatement of the element

9.5.3.4 Quality of air

Inventory

- Make a list of contaminants on site and identify storage site as well as all other sources of contamination present during construction
- Collect technical data for contaminants to identify chemical properties (flammability, corrosion, toxicity, etc) and physical properties (liquid, solid, gaseous, other) of contaminants
- Determine the physical properties of air (wind direction and strength, relative humidity, etc)
- Identify and localize human occupancy sectors and area of concentration of animals located near the work site

Evaluation of impacts

- Evaluate the risks for human health and environment related to the emission of pollutants in the air
- Evaluate the behavior of pollutants in the air

Elaboration of mitigation measures

- Install systems permitting the confinement or elimination of fire or leaks on storage sites and in equipments using polluting products
- Define a warning procedure and emergency intervention plan during construction and plan for available resources and equipment to limit the risks of contamination
- Maintain all vehicles and machinery in good working conditions to avoid any oil or gas leaks or any other pollutants spills, and minimize gaseous emissions

- Use dirt control methods approved by competent authorities

Surveillance programs and monitoring programs

- In case of accident, perform a regular characterization of quality of air for assessment of the situation

9.5.3.5 Noise

Inventory

- Identify applicable regulations
- Characterize the work location according to noise sensibility
- Identify sources of noise other than permanent equipment
- Characterize the actual and future level of noise
- Evaluate the conformity of future noise level of location according to regulations

Evaluation of impacts

- Evaluate the change in noise level in the work area, before, during and after construction

Elaboration of mitigation measures

- Elaborate appropriate mitigation measures according to regulation (noise barriers, low-noise equipment, buffer zone, etc)
- In the vicinity of populated areas, restrict circulation of heavy machinery and noisy construction work to agreed working hours
- Take all necessary measures to insure that the noise generated by the new equipments is within limits of all applicable rules and regulations: for example, noise barriers, or adequate landscaping (mounds) can be used

Surveillance programs and monitoring programs

- Perform tests to evaluate the effectiveness of mitigation measures

9.5.3.6 Flora

Inventory

- Elaborate the inventory of main species located near or in construction site and identify endangered and vulnerable species

Evaluation of impacts

- In case of extension to existing compound, identify and localize, near construction site, species representing particular difficulties with the implementation of transition compound (rapid growth, tall height, low density of leaves)
- Identify sectors where species can cause a problem inside substation (herbaceous plants)

Elaboration of mitigation measures

- Plan the transition compound site to minimize the possibility of plant growth
- Identify clearly which group of plants to keep inside the limits of propriety and select species compatible with the land use for landscaping
- Elaborate a reinstatement and landscaping program for vegetal cover destroyed during construction
- Use appropriate methods for deforestation in sensitive areas and make no intervention where vegetation growth does not interfere with proper operation and maintenance of equipments
- Take advantage of local topography when locating the towers and transitions compounds to maintain the

maximum of wooded areas. Maintain all vegetation and wooded areas that does not interfere with the equipments

- Stack wooden scrap far enough from water courses
- During construction work, protect adequately all trees to be left near the swathe or transition compound by restricting circulation in immediate proximity
- Favor vegetation growth after construction, seed all bared areas with indigenous (local) species compatible with the operation of the equipment

9.5.3.7 Fauna

Inventory

- Identify species sensitive to construction work or accidental spill

Evaluation of impacts

- Identify elements of transition compound or line representing risks for fauna

Elaboration of mitigation measures

- Identify work periods where construction work will cause the least problems to fauna
- Avoid the use of working techniques causing random violent noises near sites of fauna activities (nesting areas, etc.)
- Define a warning procedure and emergency intervention plan during construction and plan for available resources and equipment to limit the risks of contamination
- No work shall be permitted in the reproductive zones of (name of species) during the period of (specify dates). While elaborating the working program and schedule, take into account land use of specific areas by fauna
- When crossing a river upriver from spawning grounds, do not cross in the spawning season

9.5.3.8 Human environment (land use, urban areas, tourism, agriculture, wooded areas)

Inventory

- Identify permitted land use and buildings and equipments, private and public, near work site

Evaluation of impacts

- Assess the sensitivity of nearby usages and future land developments with regards to work to be done
- Assess the possibility that a building or an equipment might be moved or damaged by the works

Elaboration of mitigation measures

Land use

- Integrate specific elements (noise barriers, landscaping, architectural walls, lower lighting, MF shielding, etc.) for the planned equipment (line or transition compound) that can minimize the impact on adjacent land usage
- Plan the movement of building or existing equipment when road traffic disturbance would be minimal
- For buildings sensitive to construction work, identify zones in which equipment movements or materials storage is restricted

Urban and peri-urban areas

- Staying in accordance with applicable rules and regulations, favour the use of swathe for recreation purpose, gardens, greens spaces or public infrastructures
- Warn in advance all affected residents of the work program for all disturbing works (dynamiting,

boring, pile driving) and put in place adequate mitigation measures to minimize their impacts

- Adjust working schedule to minimize perturbation to local traffic. Establish clear signalisation and detours
- During construction, keep clean roads and traffic ways used by machinery and construction vehicles
- Perform road washing and tire washing at the exit of the construction site
- If required by authorities, select the most appropriate MF shielding measure, choosing a suitable installation configuration (i.e. cables in closed trefoil) or shielding to reduce MF to values admitted by local regulations.
- Minimize the extent and duration of excavation by using a suitable installation technique (multipurpose tunnel, ducts, existing manholes)

Tourism, holidays and leisure activities areas

- Avoid blocking footpath, hiking or equestrian trails, cycling roads, etc.

Agricultural and wooded areas

- All construction work shall be done to minimize impact to agriculture in accordance to agreement with landowners
- Identify on site and protect underground and above ground drainage piping. In case of breakage, repairs must be done as soon as possible. In case of piping network interruption, repair the network
- Preserve top soil or vegetal soil adequately and store it in specific storage area for reutilization
- Before starting construction, confirm with farmer the planned use of crossed land. Construction and maintenance of permanent and temporary fences around the work sites is required to permit the use of nearby land for farming or pasture. Always maintain access to isolated areas.
- In agricultural areas, access the work site using existing roads or trails or circulate at the limit of fields or elaborate new access in consultation with land owner.
- In agricultural areas, locate tower on the limits of fields or properties using a minimal number of towers
- Use land survey pickets not too tall, but still visible, so they are not hit by farming equipment. Make sure all pickets are removed during harvest season or field preparation.
- Choose preferably sites with less agricultural value for line stringing areas. The areas must be minimal and their limits well defined. Plan for steel plates if required to minimize damage to the soil.
- After consultation with land owner, if the swathe is located in a wooded area adjacent to a cultivated area, consider putting the new swathe in cultivation.
- Use preferably tower with reduced footing.
- Plan a consultation process with local wood producers for selling the wood harvested on private properties, or with land owners to recover firewood.

Services

- Use adequate methods to impede all interferences with communication equipments used in vicinity of electrical infrastructures, after consultation with land owners

Surveillance programs and monitoring programs

- Verify that all planned mitigation measures are well respected
- Monitor the restoration of damaged buildings or equipments

9.5.3.9 Heritage

Inventory

- Identify and localize sites with archaeological potential and patrimonial interest

Evaluation of impacts

- Assess the impact of future construction on archaeological and patrimonial sites

Elaboration of mitigation measures

- Make some archaeological digs in sites offering high archaeological potential
- Integrate specific elements (architectural, landscaping, etc) in the compound for a better integration near or inside a patrimonial site
- Provide adequate protection to known archaeological sites. If construction work is planned in vicinity of those areas, establish a protection perimeter. If the construction is planned in that perimeter, proceed, before construction, to archaeological digs, and favour analysis of all remains.
- During construction, in case of unexpected findings, suspend all activities and inform the competent authorities.

Surveillance programs and monitoring programs

- Make a continuous surveillance of excavation work to immediately identify all new archaeological discovery

9.5.3.10 Landscape

Evaluation of impacts

- Assess the importance of visual impact generated by existing and planned equipment
    - Degree of resistance of landscape unit
    - Degree of integration and perception of the equipment according to field of view of observers
- Assess the importance of resultant visual impact

Elaboration of mitigation measures

- Integrate specific elements (architectural, landscaping, etc) in the compound for a better integration in landscape
- Use preferably lower equipments, aesthetic, or of an appropriate color.
- Eliminate mercury lighting in favour of sodium lighting.
- Plan for landscaping around new equipment or substation, and confirm on site the expected efficiency.
- In accordance with maintenance rules, maintain if possible wooded areas and plantations nearby roads and water courses to minimize the swathe impact. If needed, negotiate special arrangements with land owners.
- Maintain and favour natural regrowth in vicinity of equipments and substations, favour replanting at the limit of the swathe to create the illusion of smaller swathe.
- When locating towers, avoid the focal point in the continuation of roads and streets.

Surveillance programs and monitoring programs

- Make a list of all visual impacts and mitigation measures to establish a reference data base

9.5.4 Summary of the method: an example of impact table

The systematic evaluation of potential impact from all sources (or activities) from a project on any element of the environment may be summarized as a table, with all relevant impact sources shown as columns and all elements of the environment shown as different lines. An example of such a table is given on the next page.

This tool allows, by ticking the appropriate box, to quickly identify which element of the environment is impacted, and also what activity or source causes the impact. It is an excellent indicator of all potential impacts of a project.

It can also be a methodological tool to identify mitigation measures. It is possible, for each ticked box, to establish a particular index card detailing the identified impact and proposed mitigation measures, as shown in the following example:

Box 14 F
Impact of the Source F "Transportation and traffic" on the element 14 "Agricultural space"

Description of impact:

The repeated passage of transport vehicles and heavy machinery leads to a deterioration of access roads and can cause damage to drainage piping in agricultural areas, as well as ground compacting.

Mitigation measures:

- Build a temporary access road suitable for heavy vehicle transportation
- Restore drainage piping to its original condition at the end of the project

				Impact sources														
				Project phase												**Operation phase**		
				Pre-construction					**Construction**					**Post-construction**		**Operation maintenance**		
				A. Surveying and technical surveys	B. Obtaining rights	C. Transportation and traffic	D. Site access arrangements	E. Clearing an area	F. Transportation and traffic	G. Exploitation of quarries and sand pits	H. Excavation and earthworks	I. Construction of equipment and ancillary structures	J. Management of contaminants and wastes	K. Demobilization	L. Improvement and restoration	M. Presence of equipment	N. Presence, access to and maintenance of the swathe	Q. Decommissioning and dismantling
Environmental element (resources)	**Natural environment**	**Ground**	1.Soil quality															
			2. Equilibrium slope															
		Water	3. Surface water quality															
			4. Profiles of bodies of water															
			5. Ground water quality															
			6. Flow of watercourses															
			7. Runoff and infiltration															
		air	8. Air Quality															
			9. Noise															
		flora-fauna	10. Species															
			11. Habitat															
	Human environment		12. Urban and peri-urban space															
			13. Leisure and tourism															
			14. Agriculture and fisheries						X									
			15. Forestry															
			16. Heritage space															
			17. Services															
			18. Field of view															
			19. Special features															

9.6 Typical content of environmental assessment report

This section gives a few examples of the typical content of an environmental assessment report. As pointed out throughout the guide, the content of the report has to be adjusted for each specific project according to local regulations. Although the organisation and the format of the report will vary for each country, the basic content of an environmental assessment report is always very similar.

Three examples and formats are given blow:

- A typical table of contents from England,
- An impact matrix from Norway:
- A summarized table from Japan

9.6.1 A Typical Table of Content from England

PART 1 INTRODUCTION AND BACKGROUND

CHAPTER 1 INTRODUCTION

Purpose
The Transmission Network
Need for the project
Project Overview
Background
Alternatives considered and proposed option
Statutory planning procedure
Other statutory processes
Landowner consents
Statutory duties
Scope of Environmental report
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CHAPTER 15 CONCLUSIONS
General
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Planning policy
Electric and Magnetic Fields
Electro-magnetic Compatibility
Noise
Summary

CHAPTER 16 SURVEILLANCE PROGRAMM
Engineering
Construction
Operation

9.6.2 An impact matrix from Norway

The content and extent of the Enironment Impact Assessment report is defined prior to the licence application process. A brief description of the planned technical installation that are distributed to authorities, organisations, and land owners include a proposal for content of the EIA report.

The licence application will include an EIA report based on the proposed content or extended on spesiific subjects if so requested and the request is approved by the authority governing the licencing. process.

			Impact sources														
			Project phase												Operation phase		
			Pre-construction				Construction								Operation maintenance		
			A Surveying and technical surveys	B Obtaining rigths	C Transportation and trafic	D Site access arrangements	E Clearing an area	F Transportation and trafic	G Exploitation of quarries and sand pits	H Excavation and eathworks	I Construction of equipment and ancillary structures	J Management of contaminants and wastes	K Demobilization	L Restoration and means to reduce visual impact	M Presence of equipment	N Presence, access to and maintenance of the awathe	Q Decommissioning, dismantling and restoration
Environmental element (resources)	Plan staus regarding area use and protection	1. Governmental area plans															
		2. Regional area plans															
		3. Local community area plans															
	Land-scape	4. Field view															
		5. Special features															
	Cultural heritage and cultural environment	6. Cultural heritage															
		7. Architectural heritage															
		8. Archaelogical heritage															
	Recreation and outdoor sports environment	9. Recreation															
		10. Training and sports															
		11. Hunting and fishing															
		12. Swamps and berries															
	Natural environment	13. Type of nature and terrain damage															
		14. Wildlife															
		15. Red list species															
		16. Treathened type of vegetation															
		17. Fresh water and ground water changes															
		18. Soil pollution															
		19. Protection staus according to Law for nature conservation															
	Agriculture, Forestry and fishery	20. Agriculture															
		21. Forestry															
		22. Fisheries															
	Proximity and electro- magnetic fields	23. Proximity to living facilities, recreation facilities and work facilities															
		24. Electric fields															
		25. Magnetic fields															
		26. Ship trafic, anchor locations etc															
	Noice, vibrations etc	27. Audible noice															
		28. Vibrations															
		29. Radio/telecom noice															
	Property impact	30. Reduced value of property															
	Lakes, subsea and fjord crossings	31. Influence on biological divercity															
		32. Magnetic fields															
		33. Fishing activities															
		34. Ship trafic															
		35. Anchoring locations															
		36. Cultural heritage															
		37. Seabed pollution															
		38. Choral reefs															
		39. Exsisting technical installations in sea															

9.6.3 A summarized table from an environmental management report from Japan

1.Electrical work section (1/2)

Design and construction	Environmental items	Object	Measures	Results and evaluation
Cable pulling construction	Noise	• Cable hauling machine	• Use of low noise equipment	• The construction was executed to control the noise below legislation value in various places by using the low noise equipment
	Water Quality	• Cable insulation oil	• Installation of sump and adsorption mat when oil-filled cable is cut	• It was confirmed that there was no leaked oil in the cave and manhole by using the sump and the adsorption mat when the oil-filled cable was cut.
	Appearance	• Vegetation	• Restoration of street trees and Greenbelt	• It was confirmed that the vegetation is restored as before according to discussions with the road administrator.
	Life	• Working zone on Road	• Installation of working zone and detour to prevent traffic trouble	• The condition on road use permission certificate was observed and the work was executed without a traffic trouble.
	Waste recycling	• Scraps of Iron, aluminum, and copper	• Storehousing • Warehousing in another construction	• Warehousing was executed for the removal cable, the oil feeding pipe, and steel materials.
		• SF6 gas	• Recycling	• All the SF6 gas was recovered and was recycled.
	Waste disposal	• Scraps of Polyethylene, vinyl, and FRP, and insulating oil	• Disposal of Industrial waste	• The complete disposing of industrial waste was confirmed on waste disposal report (manifesto: certificate).
Ventilating installation design	Noise	• Electric Fan	• Design of silencer	• It was confirmed that the noise measurement result was below the noise regulation value when the electric fan was working.
	Atmosphere	• White smoke(steam)	• Design of white smoke control	N. A.
	Life	• Wind velocity of opening exit on Ventilating facility	• Control of wind velocity (by expanding sectional area of ventilation opening exit)	• It was confirmed that the measurement result of the exit velocity was below the regulation value. (wind velocity on exit: Our company area: 8m/s, other area: 5m/s)
Cooling system design	Noise	• Cooling tower	• Design of silencer	• It was confirmed that the noise measurement result was below the noise regulation value in various places when the cooling tower was working.
	Atmosphere	• Refrigerant gas in refrigerator	• Use of Alternative flon	• Alternative flon (HFC134a) was used without any problem.
Building facility design	Sunshine	• Building	• Design of Building by which sunshine is considered	N. A.
	Appearance	• Building	• Design of Building suitable for surroundings	• Buildings were constructed considering the appearance of the vicinity buildings, such as making fake windows.
		• Vegetation	• Restoration of planting	• It was confirmed that the vegetation was restored as before or better than before by executing the afforestation etc. suitable for the environment. • Moreover, the construction was finished without trouble with the locals.

1.Electrical work section (2/2)

Design and construction	Environmental item	Object	Measures	Results and evaluation
Electromagnetic induction design	Life	• Electromagnetic induction	• Design of Electromagnetic induction control	• In the plans of transmission lines, the induced voltage was confirmed by both telecom company (NTT) and us not to exceed the agreed maximum value. [limiting value of Induced voltage to NTT's communications line] • Normal induced noise voltage : Subscriber's line 0.5mV, trunk circuit 0.7mV • Normal induced voltage : 15V • Short circuit induced voltage : 650V, 430V (depending on power cable system)
Oil facility design	Water quality	• Cable insulation oil	• Design of facility against oil leakage	• The oil retaining wall was set up in the circumference of the oil tank to prevent from flowing outside.

2.Earthwork section (1/3)

Design and construction	Environmental item	Object	Measures	Results and evaluation
Excavation	Traffic	• Position of, Shaft, Ventilation hole, Manhole and Attainment shaft	• Prevention of traffic jam by reducing a period of construction • Reservation of pedestrian passage space by changing shaft position • Security of schoolchild's safety by reducing shaft size etc.	• The set backing of the shaft position was excuted to hold two-way two-lane traffic. • Member to control the traffic was adequately arranged.
	Noise	• Pile driver etc. • Heavy machine etc.	• Decrease of noise by using of low noise machine	• Noise was decreased by using the machine off the subject of noise regulation, and it was confirmed that noise level is below regulation value by measuring the noise of the main kind of construction. (measurement: once for each kind of construction) [Machine to which noise regulation is not applied] • Adoption of multi pulley type pile-extractor • Adoption of auger drilling bored precast type machine [Restriction standard of noise Pollution Regulation Law specific construction work] Reference value: 85 dB • Rivet hummer • Pile driver • Rock drill • Air compressor(15kW) • Concrete-mixing plant etc.
	Vibration	• Pile driver etc • Heavy machine etc	• Decrease of vibration by using of low vibration machine	• Vibration was decreased by using the machine off the subject of vibration regulation, and it was confirmed that vibration level is below regulation value by measuring the noise of the main kind of construction. (measurement: once for each kind of construction) [Machine to which vibration restriction is not applied] • Adoption of multi pulley type pile-extractor • Adoption of auger drilling bored precast type machine [Restriction standard of noise Pollution Regulation Law specific construction work] Reference value: 75 dB • Rivet hummer • Destroying the workpiece with the steel ball • Pavement slab breaker • Breaker

2.Earthwork section (2/3)

Design and construction	Environmental item	Object	Measures	Results and evaluation
Shield construction / excavation	Underground water	• Water leak and diffusion • Solidified muddy water wall • Shielded drilling	• Observation of seasonal variation of groundwater level in observation well • Investigation of the flow direction of underground water • Investigation of well • Preventing muddy water from diffusing into ground on quality control of muddy water and observation of monitor well and observation well • Preventing muddy water from diffusing into ground on quality control of muddy water, management of shielded drilling, observation of seasonal variation of groundwater level in observation well,and observation of quality of wayside well and watch of observation well	• In the result of investigation of water level in observation well on excavation and shield construction, the change of water level was not found. • The flow direction of underground water was investigated. • The well was investigated, and abnormality was not found. (minimum isolation 2.6m with shield)
	Water quality	• Chemicals injection	• Prevention of Ground-water contamination by selecting chemicals and watching observation well	• In the water examination result of the observation well, abnormality was not found. [Tentative reference concerning constructing of construction works by chemicals grouting] pH-value:5.8-8.6 pH
	Drain	• Turbid water treatment	• Prevention of the pollution for the public waters and so forth by watching turbid water treatment plants	• The water examination result of the turbid water treatment plant was below effluent standard. [Effluent standard by city Sewage Water Law] pH-value:6.4-7.0 pH BOD :25 mg/l SS :20 mg/l

2.Earthwork section (3/3)

Design and construction	Environmental item	Object	Measures	Results and evaluation
Shield construction / excavation	Subsidence	• Digging • Shielded drilling	• Prevention of the Influence to the house and road by investigating house and measuring the movement of road	• Transformation is not found in the before and after study of the house. • The result of the road movement measurement (once a week) was below the tolerance. Absolute subsidence variation: ±2mm (shield wayside)
	Recycling	• Earth and sand • Asphalt etc.	• Promotion of recycling by applying the shield surplus soil to shaft backfill and shaft surplus soil to park • Promotion of the recycling by adoption of reproduction macadam and asphalt concrete	• The surplus soil generated in construction was diverted to a park. • Recycled resource is adopted for the paving material in each shaft base.
	Industrial waste	• Earth and sand • Asphalt etc.	• Proper processing of earth and sand • Proper processing of industrial waste	• It is processed properly by the transportation slip and the management of the load. • The Proper processing of the manifest was confirmed, and the follow-up survey was done by the contract company.
	Nature conservation	• Work base	• Reduction of deforestation by pruning afforestation	• Deforestation was done. The Permission in the urban park low was obtained.
Shield tunneling	Noise	• Plant	• Decrease of noise by installing soundproofing house	• The noise measurement was done around the soundproofing house. Reference value :55dB(daytime) :45dB or less(nighttime) Calculated value:40dB(nighttime) (background noise:44dB)
	Vibration	• Plant	• Decrease of vibration by installing soundproofing house	• The low frequency measurement was done around the closest private house Reference value: 60dB(daytime) :55dB or less(nighttime)
	Appearance	• Soundproof house	• Adoption of building coloring harmonious with surrounding	• The cream coloring harmonious with surrounding was adopted.

10 APPENDIX 1: Glossary

Automatic reclosing	The automatic reclosing of a *circuit-breaker* associated with a faulted section of a network after an interval of time which permits that section to recover from a transient *fault*. IEC 60050(604)-1987.
Automatic reclosing equipment	Automatic equipment which is designed to initiate the reclosing of *circuit-breaker(s)* after operation of the protection on the associated circuit. Note: If the *autoreclose open time* is of interest it should be mentioned after the expression. Thus the term may be described as high speed, low speed, delayed, as appropriate to the application. Example: *automatic reclosing equipment* with an *autoreclose open time* of o.s.s. IEC 60050(448)-1995.
Availability	The state of an *item* of being able to perform its required function. IEC 60050(603)-1986.
Availability performance	The ability of an *item* to be in a state to perform a required function under given conditions at a given *instant of time* or over a given time interval, assuming that the required external resources are provided. Note 1: The ability depends on the combined aspects of the reliability performance, the maintainability performance, and the *maintenance* support performance. Note 2: Required external resources, other than *maintenance* resources do not affect the *availability performance* of an *item*. Note 3: In French the term *disponibilité* is also used in the sense of *instantaneous availability*. IEC 60050(191)-1990.
Backfill	The material used immediately around the cable(s).
Bay of a substation	The part of a substation within which the switchgear and controlgear relating to a given circuit is contained. Note: According to the type of circuit, a substation may include: *feeder bays*, transformer *bays*, bus coupler *bays*, etc. IEC 60050(605)-1983.
Bentonite	A clay derivative which when agitated becomes liquid, allowing injection into pipes/ducts and becomes semi-solid after a short period of time.
Blocking protection	A *protection*, generally *distance protection*, in which the receipt of a signal blocks the local *protection* from initiating *tripping*. IEC 60050(448)-1995.
Branch line	An *electric line* connected to a main line at a point on its route. Note: A *branch line* which is a final circuit is called a *spur*. IEC 60050(601)-1985.
Busbars	(commonly called *busbar*) In a transition compound, the *busbar* assembly necessary to make a common connection for several circuits. Example: three *busbars* for a three-phase system. See: *busbar*. IEC 60050(605)-1983.
Cable	An insulated conductor designed for underground electricity transmission (see Underground Cable).
Cable Accessories	Cable terminations which provide connections to other items of transmission system or joints which connect lengths of cable.
Cable Ancillaries	Equipment, other than cables and accessories, used to complete a cable system including that which is used to provide monitoring and maintenance facilities.
Cable Basement	An enclosure within a substation in which power cables, cable accessories and ancillary equipment are housed and which personnel may be required to work for construction, routine inspection and maintenance purposes. Cable basements are usually below substation buildings. *Informative: Passages carrying cables between substation buildings are sometimes know as cableways and they should generally be dealt with in same manner as cable basements.*
Cable Bridge	An enclosure above ground level in which power cables, cable accessories and ancillary equipment are housed and in which personnel may be required to work for construction, routine inspection and maintenance purposes. They may be used to facilitate the passage of power cables over road, railways or rivers.
Cable Sealing Ends	The points at the end of the underground cables where there is a transition from underground cable to overhead line or substation.
Cable Tunnel	An enclosure which is significantly below local ground level in which power cables, cable accessories and ancillary equipment are housed and in which personnel may be required to work for construction, routine inspection and maintenance purposes. The boundary between a cable tunnel and a cable basement or cableway should be clear from the context.
Classification of Potentials Associated with Earthing Systems	When earth fault currents passes through an earth electrode, equipment connected to it will experience a potential rise with respect to earth and potential gradients will develop in the surrounding ground. Under these circumstances the following potentials may be created: Transferred Potential: Where a metallic conductor extends from one earth system into

	another it will be able to transfer the potentials between the two systems. The Transfer Potential s the potential difference that a person will experience by hand to hand contact between the two earthing systems via the conductor. Touch Potential:The Touch Potential is the potential difference between a metallic earthed conductor, and the ground on metre away. Step Potential: The Step Potential is the potential difference between two points on the ground level one metre apart.
Closing	The closing of a *circuit-breaker* by either manual or automatic control of *protective devices. Note:* The expression *closing* of a network *item* (line, transformer) in fact means *closing* of the associated circuit-breakers. IEC 60050(604)-1987.
Conservation Area	Areas which the local planning authority has determined to be of special architectural or historic interest, the character or appearance of which it is desirable to preserve or enhance.
Corrosion Interaction	The corrosion of plant caused by the current flow in the soil from a cathodic protection system installed to protect another structure.
Current Impulse Front Time	The Current Impulse Front Time is associated with the part of the impulse which occurs prior to the peak.
Current Impulse Time to Half Value	The Current Impulse Time to Half Value is associated with the part of the impulse that occurs after the peak value.
Current in the fault	The current flowing through the *fault*. IEC 60050(603)-1986.
Current in the short circuit	The current flowing through the short circuit. IEC 60050(603)-1986.
Dead time	The time during *automatic reclosing* when the power line or phase is not connected to any network voltage. Note: For radial fed power lines the *dead time* is equal to the *autoreclose open time*. IEC 60050(448)-1995.
Defect	Imperfection in the state of an item (or inherent weakness) which can result in one or more failures of the item itself or another item under the specific service or environmental or maintenance conditions for a stated period of time..
Directly Buried Cables	Cables buried in the ground with a depth of cover greater than 0.7 m – usually about 1 m. Installation requirements and details of the backfill materials surrounding cables are specified in *National or Utility requirements*
Distance protection	A *non-unit protection* whose operation and selectivity depend on local measurement of electrical quantities from which the equivalent distance to the *fault* is evaluated by comparing with zone settings, IEC 60050(448)-1995.
Electric	Containing, producing, arising from, actuated by, or carrying electricity, or designed to carry electricity and capable of so doing. Examples: electric eel, energy motor, vehicle, wave. ANSI/IEEE C37.100-1981.
Electric Field	A measure of the force experienced by a static electric charge in the presence of other electric charges.
Electric line	An arrangement of conductors, insulating materials and accessories for transferring electricity between two points of a system. IEC 60050(601)-1985.
Electrical	Related to, pertinent to or associated with electricity but not having its properties or characteristics. Examples: electrical engineer, handbook, insulator, rating, school, unit. ANSI/IEEE C37.100-1981.
Electrical Clearances	Specified minimum clearances that must be maintained between overhead lines and things such as the ground, obstacles, railway property and other power lines.
Electrical power system	Particular installations, substations, *lines* or *cables* for the transmission and distribution of electricity. Note: The boundaries of the different parts of this *network* are defined by appropriate criteria, such as geographical situation, ownership, voltage, etc. IEC 60050(601)-1985.
Environmental Impact Assessment	The impact assessment consists in an analytical evaluation of all potential effects of a project on the environment.
External fault	*Power system fault* outside the *protected section*. IEC 60050(448)-1995.
Failure	The termination of the ability of an item to perform a required function. 1 - After failure the item has a fault. 2- "Failure" is an event, as distinguished from "fault", which is a state. 3 - This concept as defined does not apply to items consisting of software only.

Fault	The state of an *item* characterised by inability to perform a required function, excluding the inability during preventive *maintenance* or other planned actions, or due to lack of external resources. Remark: A *fault* is often the result of a *failure* of the *item* itself, but may exist without prior *failure*. IEC 60050(191)1990. An unplanned occurrence or defect in an *item* which may result in one or more *failures* of the *item* itself or another associated equipment. IEC 60050(604)-1987.
Fault clearance	The disconnection from the electrical system of a defective *item*, by automatic or manual operations, in order to maintain or restore supply. IEC 60050(604)-1987.
Fault clearance system	An arrangement of *protection equipment*, equipment necessary to interrupt primary *fault currents*, and other devices intended to perform specified *fault clearance* functions. The *fault clearance system* is the *protection system* supplemented with *circuit-breakers* or sometimes other equipment necessary to interrupt primary *fault currents*.
Fault clearance time	The time interval between the *fault* inception and the *fault clearance*. Note: This time is the longest *fault current interruption time* of the associated circuit-breaker(s) for elimination of *fault current* on the faulty *item of plant*. IEC 60050(448)-1995.
Fault current	The current flowing at a given point of a network resulting from a *fault* at another point of this network. IEC 60050(603)-1986.
Forced outage	Outage due to the unscheduled putting out of service of an *item*. IEC 60050(604)-1987.
Forced outage duration	Within a specified period of time, the time during which an *item* was incapable of performing its function because of a *fault*. IEC 60050(603)-1986.
Full distance protection	*Distance protection* generally having separate measuring elements for each type of phase-to-phase *fault* and for each type of phase-to-earth *fault* and for each zone measurement. IEC 60050(448)-1995.
Ground-fault protection (USA)	See: *earth-fault protection*. IEC 60050(448)-1995.
Hand Auger	Hand held tool used to take soil samples.
High Current Impulse	The High Current Impulse is used to represent the effect induced by a direct lightning strike. The waveform is a defined in Clause 2.31 of IEC 60099-4. Note this impulse has a front time duration of 4 $\pm$ 0.5 µs and a time to half value of 10 $\pm$ 1.0 µs.
Impact	Measurable effect of a project on the environment. Impacts may be of a temporary nature (as noise during construction) or of a permanent nature (visual impact of a transition station).
Impedance earthed (neutral) system	A system whose *neutral point(s)* is (are) earthed trough impedances to limit earth *fault currents*. IEC 60050(601)-1985.
Induced Voltage Working	The method of working to protect persons against dangerous induced voltages or differences in earth potential.
Lattice Tower (Pylon)	Steel overhead electric line structures formed from angle sections in a triangular lattice arrangement (see Towers).
Lightning Current Impulse	An 8/20 current impulse with limits on the adjustment of equipment such that the measured values are from 7 ms to 9 ms for the virtual front time and from 18 ms to 22 ms for the time to half value on the tall. (As defined Clause 2.17 of IEC 60099-4).
Line fault	A *fault* occurring at a more or less well-localised point of an electrical line. Note For protection purposes the limits of the line are usually given by the location of the *current transformers*. IEC 60050(604)-1987.
Load impedance	At a given measurement location, the quotient of phase voltage and phase current during power transmission assuming no *power system faul*t exists. IEC 60050(448)-1995.
Magnetic Field	A measure of the force experienced by a moving electric charge, due to the motion of other charges.
Maintenance	The combination of all technical and administrative actions, including supervision actions, intended to retain an item in, or restore it to, a state in which it can perform a required function.
Major Section	A major section comprises three adjacent Minor Sections. At the two joint positions connecting the three minor sections, the sheath is sectionalised and cross connected with a phase transposition to create three continuous sheath runs, electrically insulated from each other and each containing approximately equal lengths for all three power cable sheaths.
Microtesla	Unit of measure of magnetic field.
Minor Section	A Minor Section comprises the run of three single core power cables between adjacent sheath sectionalising positions.

Monitoring	Activity, performed either manually or automatically, intended to observe the state of an item.
Multi-circuit line	A *power line* with three or more *circuits* supported by commons towers. Compare: *double-circuit line* and *single-circuit line*.
Neutral	The designation of any conductor, terminal or any element connected to the *neutral point* of a polyphase system. IEC 60050(601)-1985.
Outage	The state of an *item* of being unable to perform its required function. IEC 60050(603)-1986.
Overhead Conductor	The metal wires strung form pylon to pylon to carry electric current.
Permanent Easement	The permanent right to install and keep installed an electric line on, under or over land and to have access to the land for inspecting, maintaining, adjusting, repairing, altering, replacing or removing the line..
Persistent fault	A *fault* of an *item* that persists until action of correction *maintenance* is performed.
Phase-to-earth fault	An *insulation fault* between one phase conductor and earth only.
Phase to earth voltage	The voltage between phase and earth.
Phase to neutral voltage	The voltage between a phase in a polyphase system and the *neutral point*.
Phase to phase voltage	The voltage between phases..
Planning Policy	Set out the Government's policies on difference aspects of planning and explain statutory provisions. Local planning authorities must take their content into account in preparing their development plants and the guidance may also be material to decisions on individual planning applications and appeals.
Planned outage	Outage due to the programmed taking out of service of *item*. IEC 60050(603)-1986.
Planned outage duration	Within a specified period of time, the time during which an *item* was not available to perform its function because it had been withdrawn from service according to program. IEC 60050(603)-1986.
Power frequency	Conventionally, the values of frequency used in the *electricity supply systems*. IEC 60050(601)-1985.
Power line	See: *electric line.*
Power station	An installation whose purpose is to generate electricity and which includes civil engineering works, energy conversion equipment and all necessary ancillary equipment. See also: *electrical generating station*. IEC 60050(601)-1985 and IEC 60050(602)-183.
Preventive maintenance	The maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item
Protection	The provisions for detecting *faults* or other *abnormal condition* in a *power system*, for enabling *fault clearance*, for terminating *abnormal conditions*, and initiating signals or indications. Note 1: the term *protection* is a generic term for *protection equipments* or *protections systems*. Note 2: the term *protection* may be used to describe the *protection* of a complete power system or the *protection* individual plant *items* in a power system, e.g., transformer protection, line protection, generator protection, Note 3: *protection* does not include *items* of power system plant provided, for example, to limit overvoltages on the power system. However, it includes *items* provided to control the power system voltage or *frequency deviations* such as automatic reactor switching, load-shedding, etc. IEC 60050(448)-1995.
Reliability (performance)	The ability of an item to perform a required function under given conditions for a given time interval. 1 - lt is generally assumed that the item is in a state to perform this required function at the beginning of the time interval. 2 - Generally, reliability performance is quantified using appropriate measures. In some applications, these measures include an expression of reliability performance as a probability, which is also called reliability
Repair	That part of corrective maintenance in which manual actions are performed on the item
Safe Current	The current which can flow through the human body without threat to the life and health of exposed person [IEC 60479-1, -2] [44].
Sheath Voltage Limiter	A Sheath Voltage Limiter (SVL) is the common name which is used to describe a metal

	oxide surge arrestor which is used to protect any part of the sheath insulation from transient over voltages.
Short-circuit current	The current flowing at a given point of a network resulting from a short circuit at another point of this network. IEC 60050(603)-1986.
Span	The distance between one tower and the next.
Stabilised Backfill	A stabilised composite material which has a dried out thermal resistivity not greater than 1.2 K n/W.
Step Voltage	The difference in surface potential experienced by a person bridging the distance of a human step without contacting any other conductive part [IEEE 80] [42].
Study Area	The Study area is the area where the impacts are assessed. It includes the location of the two ends of the underground cable system, and the likely extent of the physical and visual influence of the potential underground cable route corridors between these two points. The criteria to define this area are: ➢ physical ➢ natural (flora, fauna…) ➢ land use: agricultural, urban or peri-urban ➢ technical ➢ cultural heritage ➢ administrative boundaries
Substation	Electricity generated at power stations is fed into the Network through substations. They control the flow of power through the system by means of transformers and switchgear, with facilities for control, fault protection and communications.
Terminal Tower	Towers erected at the end of an overhead line to terminate it, usually at a substation or sealing end compound. Because of the uneven load on one side of the tower, terminal towers have deeper and heavier foundations on the unloaded side.
Touch Voltage	The maximum potential difference between the acessible earth surface and dead part which can be touched by a hand of person standing on the surface [IEEE 81] [43].
Towers	Overhead electric transmission line supports, also know as pylons (see Lattice Towers).
Transition Compound	A securely fenced compound of about half an acre, containing the cable sealing end structures, the terminal tower and associated equipment at one end of the underground cable. These required wherever underground cables are connected to overhead lines at HV/EHV levels.
Underground Cable	An insulated conductor designed for underground electricity transmission (see Cable).

11 APPENDIX 2: Guide for collecting Input Data

11.1 SITE CONDITIONS

The pollution level is defined according to IEC 60815 standard.

Climate data:

Mean ambient temperature (minimum):
Mean ambient temperature (maximum):
Recorded minimum value:
Recorded maximum value:

Mean relative humidity:
Recorded minimum relative humidity:
Recorded maximum relative humidity:

The maximum air temperature.

Ground parameters.
Thermal resistivity
Electrical resistivity
Ground temperature at one meter depth: average,mini,maxi:
Level of the ground water
Transport parameters
Access

Existing services and structures

11.2 OPERATING CONDITIONS

Operating Voltages:

a- Rated system voltage:
b- Rated frequency:
c- Highest system voltage:
d- Lowest system voltage:
e- Rated Insulation level:
f Lightning Impulse voltage:
g Switching Impulse voltage:
- h Max. Induced Screen voltage:
i Maximum acceptable voltage on accessible parts :

Short Circuit Conditions:

j- Rated three phase current:
k- Rated single phase current:

Load conditions:

l- Maximum conductor temperature:
m- Nominal ampacity (per circuit):
n- Overload ampacity (per circuit):
o- Load Factor (IEC 60853-2):

Cost of transmission losses

Cost for no load losses
Cost for load losses

Specified Maximum Electro-Magnetic Field

11.3 NORMATIVE REFERENCES

All contract equipment shall be designed, manufactured and tested in accordance with the pertinent provisions of the standards and publications of the following listed institutes.

IEC: International Electrotechnical Commission

ISO: International Standards Organisation

CIGRE: Conseil International des Grands Réseaux Electriques

IEEE: Institute of Electrical and Electronics Engineers

A tentative list of standards the equipment shall comply with is indicated hereafter:

REFERENCE	YEAR	TITLE
IEC 60060-1	1989	High Voltage Test Techniques - Part 1: General definitions and test requirements
IEC 60228	1978	Conductors of Insulated Cables
IEC 60228 A	1982	First Supplement to Publication 60228
IEC 60229	1982	Tests on cable oversheaths which have a special protective function and are applied by extrusion
IEC 60230	1966	Impulse Tests on cables and their accessories
IEC 60287-1-1	2001	Calculation of the continuous current rating of cables (100% load factor)
IEC 60811-1-1	1993	Common tests methods for insulating and sheathing materials of electric cables - Part 1: Methods for general application Section 1: Measurement of thickness and overall dimensions - Tests for determining the mechanical properties
IEC 60811-1-2	1985	Common tests methods for insulating and sheathing materials of electric cables - Part 1: Methods for general application - Section 2: Thermal ageing methods
IEC 60811-1-3	1993	Common tests methods for insulating and sheathing materials of electric cables - Part 1: Methods for general application - Section 3: Methods for determining the density - Water absorption test - Shrinkage test
IEC 60811-1-4	1985	Common tests methods for insulating and sheathing materials of electric cables - Part 1: Methods for general application Section 4: Tests at low temperature
IEC 60811-2-1	1998	Common tests methods for insulating and sheathing materials of electric cables - Part 2: Methods specific to elastomeric compounds - Ozone resistance, hot set and mineral oil immersion test
IEC 60811-3-1	1985	Common tests methods for insulating and sheathing materials of electric cables - Part 3: Methods specific to PVC compounds - Section 1: Pressure tests at high temperature - Tests resistance to cracking
IEC 60811-3-2	1985	Common tests methods for insulating and sheathing materials of electric cables - Part 3: Methods specific to PVC compounds - Section 2: Loss of mass test – Thermal stability test
IEC 60811-4-1	1985	Common tests methods for insulating and sheathing materials of electric cables - Part 4: Methods specific to polyethylene and polypropylene compounds - Section 1: resistance to environmental stress cracking - Wrapping test after thermal ageing in air – Measurement of the melt flow index
IEC 60815	1986	Guide for the selection of insulators in respect of polluted conditions
IEC 60840 Edition 3.0	2004	Power cables with extruded insulation and their accessories for rated voltages above 30 kV (Um=36 kV) up to 150 kV (Um=170 kV) - Test methods and requirements
IEC 60853	1989	Calculation of the cyclic and emergency current rating of cables
IEC 60859	1999	Cable connections for gas insulated metal enclosed switchgear for rated voltages of 72.5 kV and above
IEC 60885-2	1987	Electrical test methods for electric cables - Part 2: Partial discharge Tests
IEC 60885-3	1988	Electrical test methods for electric cables - Part 3: Test methods for partial discharge measurements on lengths of extruded power cable
IEC 60949	1988	Calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects
IEC 62067	2001	Power Cable Systems - Cables with extruded insulation and their accessories for rated voltages above 150 kV (U_m = 170 kV) up to 500 kV (U_m = 525 kV) – Test methods and requirements
ISO 9001	1994	Quality Systems – Model for quality assurance in design, development, production installation and servicing
ELECTRA No. 28	1973	The design of specially bonded cable systems (Part I)
ELECTRA No. 47	1976	The design of specially bonded cable circuits (Part II)
ELECTRA No. 128	1990	Guide to the protection of specially bonded cable systems against sheath overvoltages

11.4 CABLE INSTALLATION

Cable Installation techniques are detailed in Technical Brochure No 194 published in October 2001[6]

11.5 RELIABILITY/AVAILABILITY/MAINTENANCE

Requirements concerning the repairing process in case of failure (duration,space required….).
Requirements concerning the accessibility of components for maintenance.

11.6 GENERAL REQUIREMENTS

<u>Health and Safety</u>

<u>Construction Regulations</u>

<u>Degre of Protection for Outdoor Housed Equipment</u>

<u>Environmental Impact Requirements</u>

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