Abstract
CIGRE launched a working group within its committee 21 "Underground Cables" to examine the different laying methods and the calculations parameters necessary for the high voltage and extra high voltage cable systems installation. From an international inquiry carried out by the group, it has been possible to present the state of art in 1998 and the future trends for the most effective way of constructing underground links.

The scope of work is related to terrestrial extruded or SCFF (Self Contained Fluid Filled) cables. The Working Group has sent two questionnaires in December 1997 to Utilities (46 replies from 22 countries) and Cable manufacturers (27 replies from 16 countries). The Group expresses their sincere thanks as they contributed effectively by giving part of their time and defining the state of art in their countries. This article focuses on what the Group consider the most significant.

Brief summary of the results
Throughout the world, utilities lay more extruded cables than SCFF ones, 93% of them laying extruded cables against 46% SCFF. Twelve different existing installation techniques were identified: they are detailed in the corresponding sections. Among them, only three are commonly used, (i.e. mentioned by more than

1 J.P.M. ANTONISSEN (The Netherlands), P. ARGAUT (France), R. AWAD (Canada), T. FAGERENG (Norway), M. GENOVESI (Italy), A. GILLE (Belgium), P. HUDSON (United Kingdom) (Secretary), R. JOHNSTON (Australia), G. KATSUTA (Japan), K. LAGERSTEDT

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50% of the companies which replied to questionnaire N° 1 concerning utilities these are: trenches (direct burial), ducts and tunnels. To be more precise, the Working Group detailed the analysis on 2 voltage ranges: 60-170 kV, corresponding to HV and 220-500 kV corresponding to EHV. Therefore, 24 laying techniques can be considered, 12 for HV and 12 for EHV. 6 out of 46 companies have already used 50% of the different techniques (among the 24) and only 1 out of 46 has used 90% of them.

Buried cables are most of the time covered by more than 1 metre of ground.

Utilities are generally in charge of the design of the underground lines but turn-key contracts are also common practice. Several companies have experienced both practices. It appears from questionnaire N° 2 to manufacturers that:
- manufacturers are very often involved in turn-key projects,
- most common installation techniques are the same as mentioned by the utilities,
- cable design is sometimes adapted according to the installation technique,
- flexible cable systems are marginally preferred to rigid cable systems for installations in open air,
- methods of calculations are mainly company methods.

DESCRIPTION OF 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. According to the replies, 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). According to the replies, the material is mainly sand or special backfill.

Trenches (direct burial)

This method consists of digging a trench and directly placing the cables in the trench. 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.

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. 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. In the majority of cases the ducts are encased in concrete.

Troughs

The troughs usually consist of prefabricated concrete segments, usually placed in a trench, after which the cables are laid in the trough. 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.
**Trenches**

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.

**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. One tunnel out of four is equipped with a cooling system. This is the most popular technique to lay cables above 170 kV.

**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.

**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.

**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. 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).
**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;
- 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.

**Horizontal drilling**

This technique is directly derived from the directional drilling techniques used in the oil industry, and is either used for crossing of major obstacles (e.g. rivers, railway tracks, motorways, ...) or longitudinally.

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 reuse 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.

**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.

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.

**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.

When crossing navigable waterways, this method implies that river traffic be stopped or deviated during the excavation and laying operations.
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.

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 accommodated 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.

Usually, flexible cable systems are preferred, but only with a slight margin over rigid systems.

MARKET AND TRENDS

The specification of the cable and installation methods for underground cable links has been and still is, in the majority of cases, defined by the utility.

The cable and installation specification and hence the design and installation methods have developed to ensure circuit reliability over a prolonged lifetime with minimum maintenance.

The combination of cable design and installation design has resulted in a very high standard of performance and reliability for HV cable links but has also contributed to the high differential cost between underground cables and overhead lines ranging from 8:1 to as high as 20:1 [Ref. 1] for extra high voltages. Historically the use of cable installations at extra high voltage has only been considered for special situations where overhead lines are not possible or practical.

The high differential cost has contributed to the relatively low percentage of cable circuits in the supply transmission systems.

In recent years, the environmental impact of overhead lines and electromagnetic field issues have become the focus of general public concern and this has resulted in cable systems being considered in areas where previously overhead lines would have automatically been used.

This, combined with the universal trend towards privatisation of electrical transmission supply utilities, has led to a general focus on the costs associated with cable transmission systems to dramatically reduce the cost differential.

To date the cable industry at transmission voltages is seen to be generally traditional and conservative. Cable engineers tend to use proven installation techniques to ensure reliability. This is confirmed by the fact that in the majority of cases utilities use only three of the twelve identified installation methods.

There are signs, however, that due to the issues mentioned above there is a general trend to reduce the overall cost of installed cable systems while maintaining reliability, with emphasis being placed upon the reduction of the duration and costs of the installation component. This will lead inevitably to the consideration of new installation techniques rather than traditional ones.

The replies to the questionnaires confirm this showing that trends for the future are towards the more frequent use of ducts, tunnels and horizontal drilling with a corresponding reduction in the use of traditional trenching and trenching techniques.

This is seen to be the result of the continuing increase in the problems associated with excavations within urban areas.

The future publications of the Working Group will be:

- a paper in the 2000 Cigre Session about the installation techniques and installation design,
- a final report in 2000 which will be published later as a technical brochure.

References