An Introduction to Medium and Low Voltage Cables in Distribution Networks as support of Smart Grids

Brussels, 16 June 2014

An Introduction to Medium and Low Voltage Cables in Distribution Networks as support of Smart Grids

Table of content

1. Introduction

Today, distribution networks are the electricity connections that deliver electricity to its ultimate point of consumption: households and businesses. They are the link connecting high and extra high voltage power lines coming from electricity generation points to the end users.

Figure 1: Design of transmission and distribution networks in Europe

In Europe, around 260 million customers are connected to the European electricity distribution grids today, representing 99% of residential customers and small businesses in Europe. According to Eurelectric, 2.400 electricity distribution companies employing 240.000 people generally provide a very high level of reliability and quality of supply to their customers. Europe´s electricity distribution networks are critical for the functioning of our societies. They need to be reliable, secure a high quality service at all times, environmentally sustainable and affordable.

Voltage ratings for distribution networks vary considerably among EU member states for historical reasons. Ranges may go up to 132 kV.

For the purpose of this paper electricity distribution networks are defined as carrying voltages up to 36kV in accordance with CENELEC harmonised documents HD 603 for LV and HD 620 for MV. These represent the vast majority of distribution networks in Europe. Two technologies can be deployed to distribute electricity in this range:

- overhead lines; or
- underground cables.

With this paper, Europacable seeks to provide an authoritative source of information about medium voltage (MV) and low voltage (LV) underground cables and overhead lines deployed in distribution networks. We will be considering a system approach, i.e. including network components, special electrical devices and environmental aspects. In doing so, we will also provide an outlook on the relevance of these power distribution technologies for future smart grid systems.

With a view to increasing security of supply and due to the continued decrease of cost of underground solutions, Europacable firmly believes that we will see a gradual shift from overhead distribution lines towards an eventually fully undergrounded electricity distribution network across Europe. Accordingly, this paper will focus more on underground cable technology and only provide a brief introduction to medium and low voltage overhead systems.

2. Medium and low voltage cables systems as core technology in distribution networks as support of Smart Grids

Underground Medium and Low Voltage Cable Systems up to 36 kV

Medium voltage (MV) cables up to 36 kV are deployed for the connection of the LV network to the primary distribution network.

Low voltage (LV) cable systems up to 1 kV serve to connect buildings and carry power over short distances of not more than several hundred meters. A transformer connects the LV cable with the medium voltage system.

Together MV and LV cables represent the distribution system. Please see figure below for explanation.

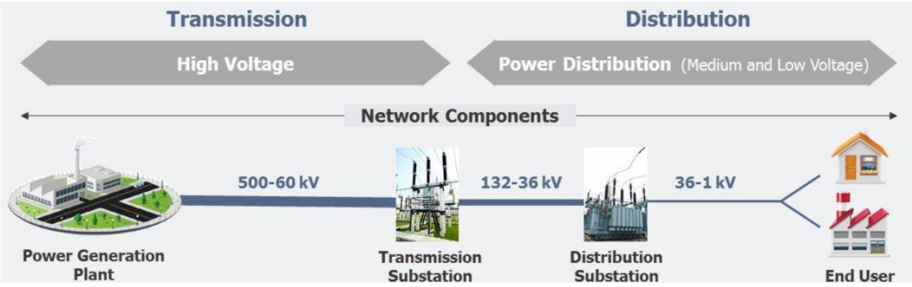


Figure 2: Voltage levels and characteristics of transmission and distribution networks

Design

Since the 1960s, MV and LV voltage cable technology moved from paper mass impregnated to polymeric insulations. While still today many mass impregnated cables are in service in large part of the European distribution network, they are no longer produced in Europe except for replacements and repairs. Any new MV and LV cable uses polymeric insulation technology.

The standard design of MV and LV cables consists of a metallic conductor surrounded by an insulation system. In case of higher voltages (>1 kV) a metallic screen shall be added. The screen is necessary to provide a homogeneous electric field to carry fault currents and for touch protection of the high voltage part. The cable, containing one or more conductors, is surrounded by an outer sheath which serves as mechanical protection as well as a protection against water.

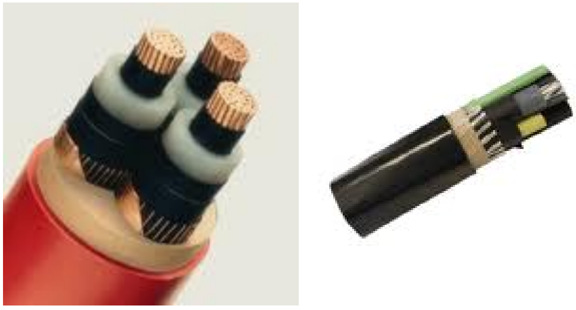
LV cables normally have a low electric field around the conductor, therefore screening is not mandatory, but it can be helpful to carry fault currents and to give touch protection to the cable. A screening function can also be provided by metallic armour.

Examples for LV cables: From left to right: Single core cable, multicore cable, multicore cable armoured

MV cables need a special insulation system because of the higher electric field. As the electric field is dependent on the geometry of the electrodes (in our case the conductor forms one and the screen the other) the surface of these electrodes needs to be as smooth as possible. This can be reached by introduction of semi conductive layers between the conductor and the insulation as well as between the insulation and the metallic screen. Medium voltage cables are available in single-core, triplex single core and three-core designs.

Examples for single-core and triplexed single-core MV cables

Typical for a three-core design is that the three cores are under a common outer sheath. The left example shows a cable with individual screen, the right example shows a cable with common screen.



Examples for 3-core MV cables

Installation

Traditionally, MV and LV voltage cables are installed in trenches. Typically, installation in trenches usually comprises one line of cables, i.e. three single cables or one triplex cable. Trench dimensions vary according to the requirements of the Distribution System Operators (DSO). Installing MV and LV cables in trenches requires careful planning as numerous factors need to be accounted for.

Examples for installation in open trench and by direct ploughing

In urban areas, today, all cables are installed in ducts as this allows maintenance and future expansion with low impact to the environment. The key challenge in urban installations lies in the coexistence with other services such as telecom networks, gas and water supply, which may have been previously installed.

Example for urban installation

Single core medium voltage cables can be delivered in up to 1.000 meter lengths, multicore medium voltage cables will typically be delivered in lengths of around 500 meters depending on installation circumstances. Standard lengths for LV cables can be up to 1.000 meters even though most connections will be shorter.

MV and LV cables are connected by the use of joints. On medium voltage the geometry of the cable has to be rebuilt also in the joint area. On LV cables this is just an insulated connection with a housing that protects against water ingress.

Drawing of a MV joint (left) and the example of a LV joint (right)

MV cables are connected to transformers or substations via terminations or pre-moulded connectors.

Example for a MV termination and a separable MV connector

Overhead Medium and Low-Voltage power lines up to 36 kV

Historically, MV and LV power has been distributed via overhead lines. Starting at the end of the 19th century overhead distribution networks were installed both in urban as well as in rural areas. Still today, distribution networks are mainly relying on overhead line technology in North and South America. In Europe, distribution networks in urban areas are today on the way to be fully undergrounded due to customer demand for reliability and environmental concerns. Increasingly we see overhead lines being replaced by underground solutions also in rural areas. However, overhead lines still today can be an alternative to underground cables in areas with low population density or to serve remote areas.

Design

MV and LV overhead line towers require dedicated corridors through which the lines will be carried. They can be installed on wooden, metal, concrete or steel poles usually not higher than 7 meters.

Example for a medium voltage overhead line with bare conductors

MV overhead lines are normally made from bare conductors. Covered versions have been developed to reduce the space needed and to reduce the possibility of earth faults by fallen trees or branches.

Example for a LV-ABC overhead line

LV overhead lines are today mainly designed as aerial bunched cables (ABC). They are insulated to save space and to make installation easier and safer.

Transition Underground – Overhead

The transition from underground cable to overhead line is normally done on the last pole of the overhead line section with the underground cable attached to the pole. The connection from the underground cable to the overhead line is either done directly from cable terminations to the line or over a separation switchgear which is also fixed to the pole.

Examples for the transition from overhead line to cables

Across Europe, over recent years we have seen an increasing trend to replace existing overhead distribution lines with underground cabling and to give preference to undergrounding when new projects are planned. Drivers for this development can be seen in

- a higher reliability and safety of supply of underground solutions
- a higher acceptance due to a reduced environmental impact
- a continuous decrease in the cost factor compared to overhead line solutions.

Europacable expects this trend to continue.

3. Environmental aspects

When considering environmental aspects, temporary effects arising from installation need to be distinguished from environmental aspects during operation.

The installation of MV and LV cables in rural areas represents a temporary, limited impact on the environment depending on soil conditions. Cables can either be directly ploughed into soft soils or installed in pre-excavated trenches. Cables are directly buried in the ground and soil or thermal stabilised backfill material will be used to refill the trench. Use of land will however be limited as well as the use of heavy machinery. There are no legal restrictions to the farming or agriculture on top of the cable trench during operation. The thermal impact of MV and LV underground cables is minimal.

In urban areas, as stated above, existing infrastructures including gas, water or telecommunications will have to be accounted for and may make urban installations more complex. This said, there will be no interference of MV and LV cables during operations with other infrastructure. In new build areas, interferences between different utilities can be best coordinated.

In comparison to high voltage cables the current in MV and LV distribution cables is limited and the cables are often installed as 3-core, triplex cables or in trefoil formation as shown in the examples for MV cables above. The Electro Magnetic Field (EMF) is therefore limited and stays well below any EU health and safety requirements.

4. Reliability of the Electrical Network

Reliability of electricity supply is fundamental to the functioning of today´s society. Given the continuous increase in electrification, the relevance of security of supply can only further increase. Distribution networks are just as critical as transmission networks as they cover “the last mile” to the end users.

MV and LV overhead lines are exposed to environmental impacts hence supply may be compromised by adverse weather conditions (storms, lightning, ice, etc.). MV and LV voltage underground cables, on the other hand, are well protected against such conditions.

MV and LV voltage cables systems are proven to offer long-term reliability. CENELEC harmonised documents HD603 or HD620 define the design and the requirements that MV and LV cables need to comply with to ensure reliable power distribution. In addition, MV and LV cables have been tested before authorization for use on the distribution network.

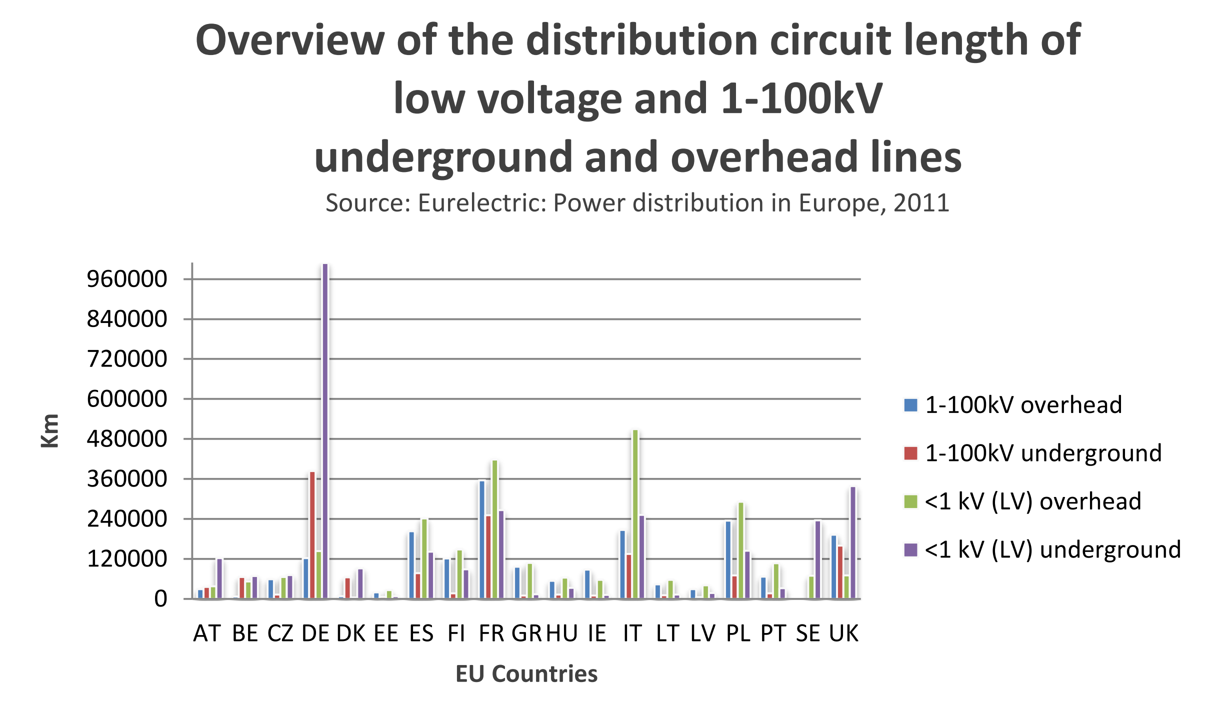
Installation of MV and LV underground cables shall only be performed by qualified personnel to ensure correct handling and installation. Once installed into the ground, MV and LV underground cables systems are well protected against all external weather influence.

There is now an important volume of MV and LV underground cables installed on the European Distribution Network

- over 35,000 km above 100kV;
- over 1,3 million km between 1 – 100 kV;
- over 3 million km of 1 kV underground cables.

According to Eurelectric statistics, already today in Europe 55% of all 1kV distribution lines and 41% of all distribution lines above 1 up to 100kV are underground.

Looking into the future, more and more EU member states are moving towards full undergrounding of their electricity distribution networks.



Best Practice: EDF of France commits to underground 90% of new MV lines to increase security of supply since 2000

On 27 December 1999, gales associated with a low pressure area named Martin hit France with extreme gusts over 78kn. 20.000 MV supports have been damaged impacting 6.000 km of overhead lines and 4 million electricity customers. According to Piketty Report these damages would have reached Euros 4 billions, had the storm not hit France during the Christmas period with lower economic activity levels.

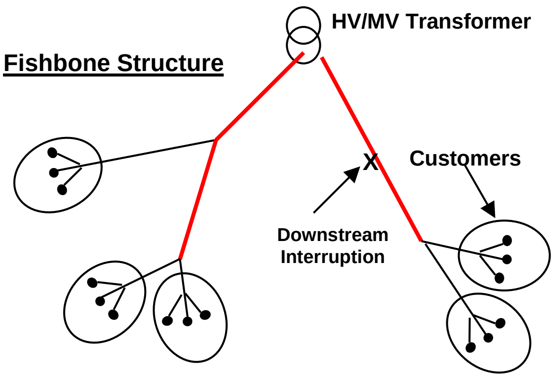
Responding to this catastrophic impact, the French distribution operator EDF implemented a plan with the objective to safeguard security of supply against future storms. It was decided to increase the amount of underground MV lines and EDF committed itself to install 90% of new MV lines underground.

The benefit of this strategic decision became evident over time. A significant reduction of the service interruption level in minutes per year could be noted. It dropped by a factor of 3 therewith substantially improving the electricity quality delivered to low voltage customers in France.

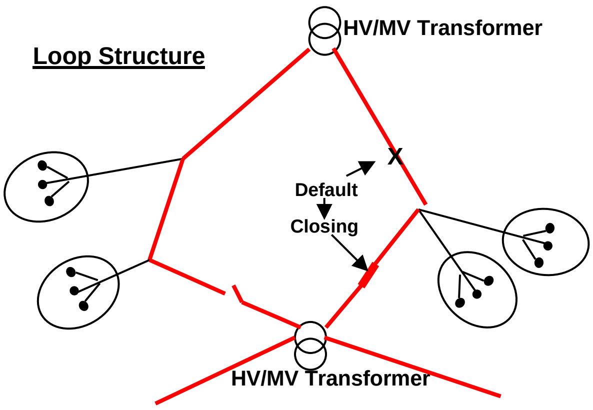
As can be seen from the graph in page 12, electricity supplies were much less affected by the December 1999 storms in Germany than in France. This is due to the fact that already at that moment, Germany had a much more important part of its LV and MV distribution networks undergrounded and therefore less exposure to the extreme weather conditions that hit Europe during that period.

The reliability of distribution systems not only depends on the reliability of the distribution technology but is also dependent on the network configuration. Two major models are to be distinguished.

In Fishbone network configuration, customers may lose energy only in case of a breakdown on a circuit below the HV/MV transformer.
Most of the overhead MV networks are based on this principle and may be subject to failures specifically in rural areas with forests. This has been the configuration in France during the 1999 storm.



Contrary to that, underground MV network configurations are well interconnected in loops. In case of a breakdown on one branch, low voltage customers can be supplied through another branch from another transformer with very little interruption of the service. Most utilities are working in this direction thus increasing the lengths of underground lines.

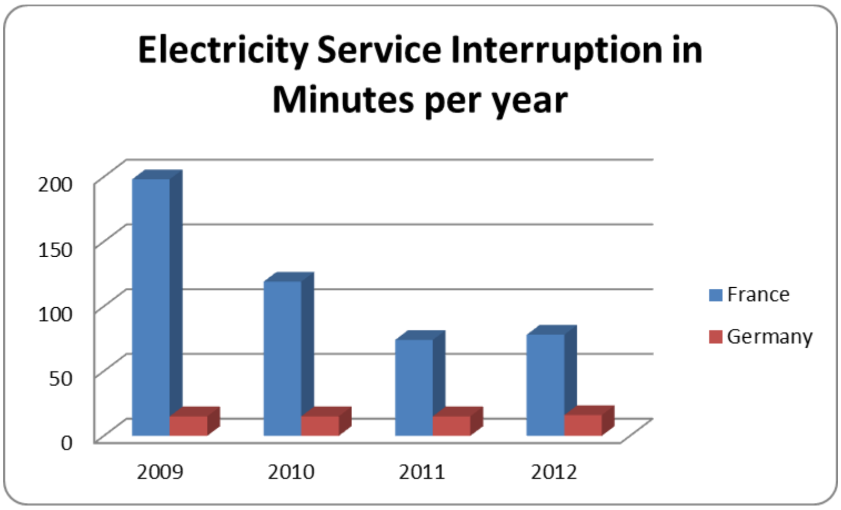


Well interconnected network configurations are particularly important to secure electricity supplies in the case of individual failure on either overhead or underground cable transmission systems. While single faults on MV or LV overhead lines are likely to entail shorter repair times than single faults on MV or LV underground cables, a failure resulting from a series of overhead poles being broken will relate to similar repair times. In order to shorten repair times on MV and LV underground cable systems, it is advised that DSO keep spare parts in stock, notably spare accessories.

Consider the ratio of underground MV network
As demonstrated by the EDF case study, the main reason to develop a policy of underground network is to increase security of electricity supply to customers. This said, there are additional benefits from undergrounding that may arise for various stakeholders such as utilities, their customers, local residents and all the community.

- Reduced transmission losses, lower maintenance costs and reduced storm damage are benefits for utilities;
- Improved electricity service benefits for customers;
- Reduced accidents (electrocutions);
- Improved views/property values, Health & Environment (noise, EMFs) for local residents.

Utilities have the objective to increase the security and quality of electricity supply for the benefit of all their customers and so avoiding any major differences in the service provided to urban and rural customers.
A good way to track the electricity supply quality is to measure and follow the level of average service interruption in minutes per year for the low voltage customers.
We note that this service interruption ratio is higher in rural regions and lower in cities where undergrounding is more frequent. This service interruption ratio is also lower in countries where the ratio of undergrounding MV cables is higher. The Electricity Service Interruption ratio is higher in France vs. Germany as undergrounding ratio is still lower in France vs Germany.



Source: For France (Commission de Régulation de l'Electricité)
http://www.cre.fr/reseaux/reseaux-publics-d-electricite/qualite-de-l-electricite
For Germany: http://www.bundesnetzagentur.de

5. Costs aspects

Respecting EU competition requirements, Europacable can only provide general considerations on cost aspects.

This said, we would like to highlight the need for a full life cycle approach when looking at costs. Only by moving beyond a consideration of mere investment costs, still predominant in most cases today, a truly valuable approach can be achieved.

Each project is unique and a full macroeconomic assessment of the cable system should be made that takes installation costs, life costs, maintenance costs, impact on land /property and environmental protection into consideration. This concept is generally referred to as "Total Cost of Ownership" (TCO).

Europacable would like to propose to distinguish four essential cost aspects:

1) *Costs related to permitting and planning of the project*

   For MV and LV underground cable systems, cost related to permitting and planning are subject to installation contractors considerations.

2) *Cost of installation*

   For MV and LV underground cable systems, generally speaking, it can be said that about 1/3 of the investment costs derive from the cost of the cable and up to 2/3 will derive from the cost of installations, notably civil works.

3) *Cost of operations*

MV and LV underground cable systems are in principle maintenance free. Electric losses in insulated cables are lower than in overhead bare conductors, reinforcing the interest of the underground insulated cables.

4) *Cost of possible end of life*

At the time of this report, MV and LV underground cables are only rarely removed from the ground. Life cost aspects are difficult to assess.

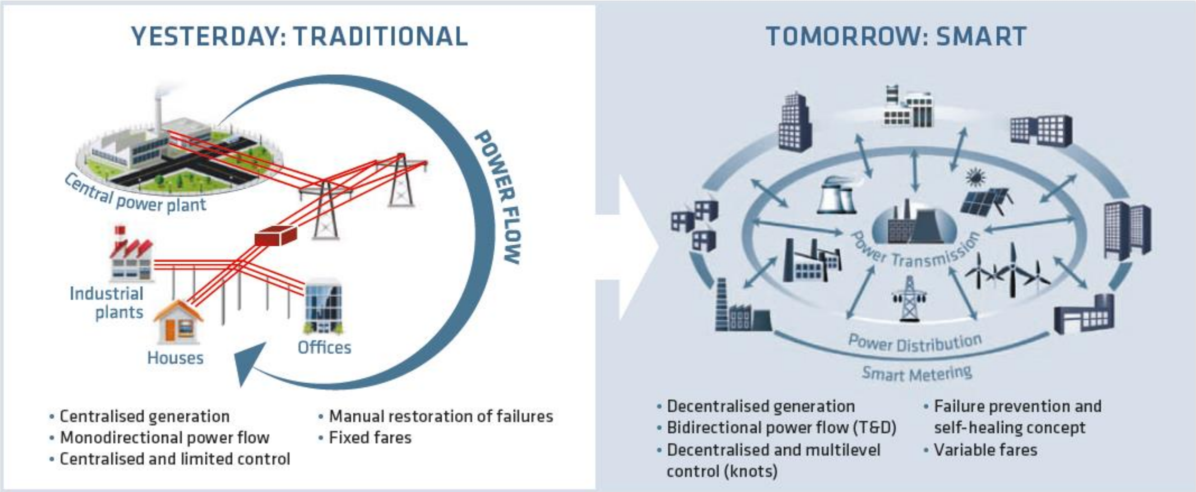
Concluding, Europacable would like to stress that cost factors for MV and LV underground cables have been continuously decreasing over the past years. This is mainly due to efficiency gains in production and improved installation techniques. Depending on soil conditions and project specifications, MV and LV underground cables are in the range of maximum twice the cost of installation of an overhead line solution. This cost factor is more than neutralised when considering a TCO approach.

MV and LV undergrounding is becoming an ever more attractive technology option.

6. Smart Grids

The upgrade and development of energy networks is one of the key challenges to securing a sustainable and competitive energy future in Europe.

Today's energy networks are primarily based on large central power stations with one way power flow from the network to the passive consumer. As it can be seen from the picture below, future energy networks need to become "smarter".



Smart energy networks will be more resilient and will be able to avoid blackouts. They will allow significant savings in electricity with better interconnections and enable consumers to play a more active role. In addition, smart energy networks will favour a better integration of renewable energy resources, therefore increasing their use

The re-engineering process from current networks to smart energy networks encompasses a complex range of issues covering market design, organizational, regulatory and technical issues. Research activities are needed to develop new technologies which will make transmission and distribution networks stronger and smarter. In particular, this means enriching the networks with information technology such as sensors, digital meters and a communication network.

Europacable acknowledges the definition of a Smart Grid from the EU Commission*:*
"A Smart Grid is a modernized electricity network that efficiently integrates the behaviour and actions of all the players connected to it with assets' current and foreseeable exploitation situation, in order to ensure an economically efficient and sustainable power system that includes generation, transmission, distribution and consumption, with low losses, high levels of quality, security of supply and safety".

As it can be seen, cables systems will play a central role in enabling this evolution towards smarter power networks. For Europacable, this will encompass both distribution and transmission networks. For the purpose of this document, we will continue to focus on MV and LV distribution.

Existing and future Power Distribution Networks need to integrate more sensors to measure all kinds of parameters, possibly in real time. For instance, the measure and control of voltage is of major importance when it comes to the connection of renewable energy, which are inherently variable and difficult to forecast. Additionally, sensor data, together with several other type of information (data from Smart Meters for example) need to be communicated and monitored.

This can be achieved, for example, by using so called "hybrid power and communication cables" which enable powerful information transmission systems, allowing both data collection and network monitoring. This enables adequate response to an always evolving situation of the distribution network. It also allows better monitoring of power flows on the existing distribution networks.

Hybrid Power & Communication cables with blown Fibre Optics for data transmission

7. Technical outlook

The European Union is currently defining its climate and energy targets beyond 2020. To meet these future targets, major initiatives and investments in renewable energy sources will be required. Moving towards these targets will require different system solutions for the generation, supply and consumption of energy. Achieving these energy targets will not be possible without a step change in the way our electricity systems operate. These considerations have led to the development of the so called Smart Grids. Through the gradual implementation of Smart Grid zones and a continuing electrification of our society, Europe´s low and medium voltage distribution networks will become increasingly important. With that security of supplies in distribution networks will move even further to the centre of attention of Distribution System Operators and technology providers.

Against this background, Europacable firmly believes that we will see a gradual shift from overhead distribution lines towards an more and more undergrounded electricity distribution network across Europe. Low and medium voltage cables will hence be a critical component in any future smart grid infrastructure. The usage of adequate and advanced cable technologies will enhance grid reliability and efficiency, guarantee correct operation in all circumstances, prevent black-outs, failures and damage of other grid components, thereby reducing maintenance costs and avoiding penalties for grid owners and operators. Moreover, deployment of the right solutions will allow better grid exploitation and far-sighted asset management. Last but not least, considering that in each km² under our soil and over our heads are laid hundreds of km of cables, the usage of environmentally friendly cables, with a low carbon footprint and that are really fully recyclable, can considerably enhance the grid's sustainability.

Underground low and medium voltage distribution networks supporting smart grids will hence provide:

- a higher quality of electricity supplies;
- a better service of electricity for end consumers;
- a higher environmental acceptance; and
- a cost effective solution in accordance with the concept of Total Cost of Ownership.

One final aspect that Europacable wishes to highlight is the fact that only deploying high quality underground cables will ensure that Europe´s distribution networks will be "future proof". With that Europacable means that high only quality cables shall be deployed to:

- ensure optimized safety levels for installers and users;
- reduce threat of black-outs; and
- ensure a "future- proof" investment of the network with Smart Grid technologies

8. Evolution of distribution network technology

Medium and low voltage cable system technology will continue to evolve thus contributing to make Europe´s distribution networks "smarter". With the three examples below, Europacable would like to provide an outlook on developments increasing the network capacity, limit the environmental footprint and reducing the total project cost.

Superconductors for network expansion – transporting high capacities in an energy-efficient manner

Superconductor cable systems can provide high capacities for energy-efficient, space-saving and low-emission power transmission. The AmpaCity project in Essen, Germany, shows the way with the longest superconductor medium-voltage cable to date. It has been in regular operation since February 2014

Design of the Essen superconductor cable

Route of the cable in the city of Essen

The superconductive fault current limiter

A current limiter, also based on superconductor materials, protects the cable against excessive currents, e.g. in case of a short circuit in the grid. The combination of both technologies is exemplary for the modernisation of electricity networks in major cities throughout the world.

The system solution provides cables with a very high current-carrying capacity (or “ampacity”) which enables power distribution with minimal line losses and no electric fields or heat emission. It can replace 110 kV high-voltage lines and transformers in densely populated areas. Because of its high ampacity and because the cable doesn’t need a large screen (due to the fault current limiter) the cable is extremely compact.
As a consequence construction work is reduced, existing routes can be used for the network expansion, and high-ampacity superconductor cables can even be operated in close proximity to data lines and other utility systems without causing any problem. Hence AmpaCity provides a model for the urban network development.
In the medium term, superconductor medium-voltage technology will also play an important role in the upgrading of wide-area distribution networks and in connecting renewable energy sources.

Eco-sustainable Medium Voltage cable installation in Spain as means to reduce environmental Impact

Many European Utilities are firmly committed to reduce as much as possible their Carbon Footprint due to 2020 EU targets and they strongly support any development in that direction.

For this reason, new insulation materials have been developed, bringing new technologies into the Medium Voltage production scenario.

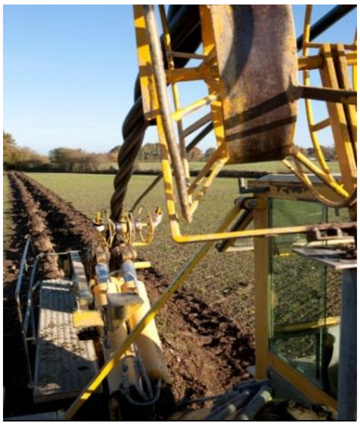
A clear evidence is the complete installation of eco-sustainable network done in Castellon, Spain.

The innovative thermoplastic insulation used for the medium voltage cables can guarantee same or even better performance of the traditional materials, with the advantage of being completely recyclable and using less energy for their production.

Other Italian and Dutch Utilities have already experienced this innovative product and we can easily foresee a further extension within the Distribution Network operators, in order to help them in decreasing their CO2 emissions.

All Ground® Medium Voltage cable as means to reduce Total Cost of ownership of an undergrounding distribution cable project





The All Ground ® concept is an innovative technology intended to reduce the problems encountered when laying low or medium voltage distribution cables.
Through an improved mechanical protection bringing excellent mechanical, shock and abrasion resistance without limiting thermo-mechanical behaviour, the cable can be buried in shallower and narrower trenches without addition of sands or other costly backfill materials..

9. References

Eurelectric: Power Distribution in Europe: Facts & Figures, 2011

For further information please visit our website www.europacable.com or contact:
Dr. Volker Wendt, Director Public Affairs, Europacable, v.wendt@europacable.com

About Europacable
Europacable is the voice of the European wire and cable industry in Brussels. Our member companies include European multinationals providing global technology leadership, as well as highly specialized small- and medium sized producers of energy, telecommunication and data cables. In 2009, the industry had a total consumption of €20 billion in wire & cables resulting in the manufacture in Europe alone of some 38 million km of cables. Europacable is listed in the European Commission’s transparency register under: 453103789-92.