Overhead Lines and Underground Cables

19

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19.1 Introduction

19.1.1 Background

This chapter deals with cables on land, exceeding 220 kV, both AC and DC. The scope is to give an overview and comparison between Overhead Lines (OHL) and Underground Cables (UGC) regarding technique, costs, lifetime and others.

The objective is also to provide a sound technical base for discussions, to show the newest developments and outlooks for both technologies. It is not the objective to give a technical course on OHL or UGC – such information can be found in other chapters of this green book or the green book from SC B1 or in the papers mentioned in the references at the end of the chapter. OHL are the oldest and most commonly used transmission method worldwide to transport bulk electrical energy over big distances on land. Extra high voltage lines may exceed a length of 1000 km for the transport of several 1000 MW per circuit in AC or DC. Subsea cables cross distances up to 600 km so far with capacities near 1000 MW per circuit.

At present the percentage of UGC on land is rather small. Cigré TB 338 "Statistics of AC underground cables in Power networks" gives information in Table A5 about the installed lengths of AC underground cables and overhead lines and the percentage of total circuit length which is underground at 315–500 kV. Information was received from 28 countries worldwide, showing a percentage of approximately 0.5 % UGC (2007) at this voltage levels. Table A6 of Cigré TB 338 which gives the values for voltages 501–764 kV shows that no UGC exist (2007).

The European 400 kV-grid of entso-e has currently approximately 1.3 % of cables (on land and subsea). Of this 400 kV- cables on land contribute to approximately 0.3 % to the grid of entso-e (mainly in cities).

In future the big majority of new lines will be built overhead. The Ten Years Network Development Plan "TYNDP" 2014 of entso-e estimates the development for the next ten years and amounts to approximately 48.000 km of new or upgraded lines. The following text is an excerpt from the TYNDP 2014.

AC – with about 21.000 km of new lines planned – is expected to remain the prominent technology. Around 10% of the investments actually consist of upgrades or refurbishments of existing AC assets. Most new overhead lines planned will be built using AC technology, which is still the easiest to implement for inland applications. Partial undergrounding of sensitive areas will increasingly complement overhead lines.

However, DC is now heavily utilised, with about 20.000 km of new HVDC lines in the Plan, i.e. more than 40% of the total additional infrastructure. The main drivers for the HVDC choice are:

- *The connection of some offshore RES, especially in the North Sea area (but most offshore connections still being AC);*
- *The integration of the Iberian peninsula, Italy, the Baltic States, Ireland and the UK with mainland Europe in line with the IEM;*
- *The need to bring power generated far from the consumption to cities and industrialised areas (e.g. wind in Scotland, wind in the north of Germany leading to the setting up of German corridors, etc.).*

The expected growth of new cables almost corresponds to the development of the new HVDC projects included in the TYNDP 2014. More than 75% of the total amount of HVDC lines will be built using cables. Submarine cables will represent the greatest length planned, although almost 5.000 km of HVDC projects are planned onshore.

Submarine HVDC cables in the North Sea build an offshore grid, even though they are point to point or in a few cases three-terminal devices.

A significant number of kilometres of HVDC overhead lines has been planned as well.

The question "Overhead or Underground?" is posed frequently in public discussion, from landowners, politicians and other stakeholders. Both have their advantages and disadvantages and have their typical fields of application. High voltage grids are complex systems. Many aspects must be observed during their construction and service and simple answers to this question are not possible. Each project must be seen on a case by case basis.

To overcome these uncertainties and to give reliable facts the European Commissioner for Energy in 2009 asked "entso-e" representing the European Transmission System Operators and "Europacable" representing the leading XLPE EHV cable systems manufacturers in Europe to produce a paper on the possibilities of partial undergrounding with synthetic insulated (XLPE) HV UGC. These two parties published the "joint paper" in 2011. "*The objective of the joint paper is to provide an authoritative source of information for future transmission projects, which shall be made available to any interested party.*"

19.1.2 Technical Basics and Differences Between OHL and UGC

Electrical conductors must be insulated from the earth potential and against themselves. One main difference between OHL and UGC lies in the kind of insulation used.

- OHL use air for insulation
- UGC use solid materials for insulation.

Air is an easy insulating material for OHL. In order to insulate a UGC high quality insulating material is needed. This can be a special paper over the conductor and impregnated with insulating liquid (for 400 kV used until the late 1990s, often called "oil filled cables") or synthetic material (XLPE, most used method for new cables) (Figure 19.1).

The kind of insulation used determines the necessary geometrical dimensions of the power circuit. Due to the insulating material used with UGC the electrical phases can be laid closer to each other, than it is possible on overhead towers with air as insulation. UGC are delivered to site on cable drums which are typically 600–1000 m.- a 20 km circuit may be made up of 60 to 90 drums (for three phases). Under favourite situations the length per drum may exceed 100 m.

These single cable lengths are limited by the transport possibilities (dimensions and weight of the drums). The single lengths have to be jointed on site which is a process that needs great care.

There are many methods to lay UGC. Common laying methods are directly buried in trenches in soil, in tunnels or in ducts (Figure 19.2).

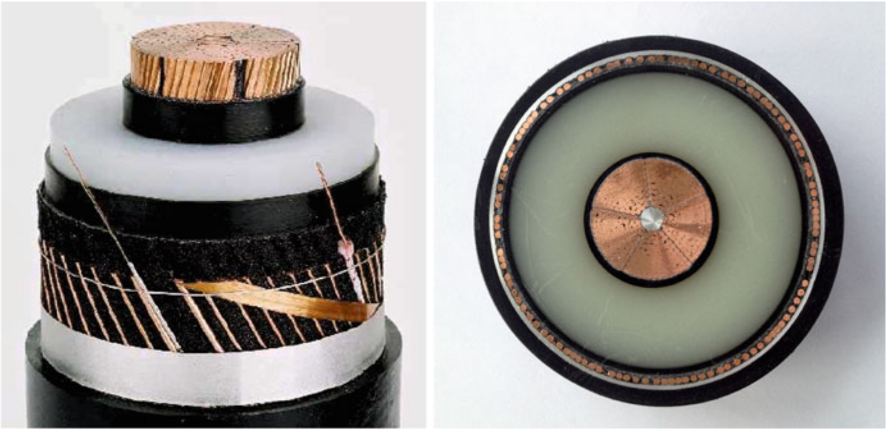

Figure 19.1 Cross linked XLPE-cables with copper conductors. *Left* from Cigré TB 247, page 17; *Right* 400 kV cable with copper conductor 1200 mm^2, 600 MVA without and 1050 MVA with forced cooling.

Figure 19.2 *Left* – one cable system direct buried in soil (from Cigré TB 338, page D.2); *Right* - two XLPE 400 kV cable systems in a ventilated tunnel, 2×1100 MVA, special application in cities (Berlin, picture APG).

Figure 19.3 shows a typical 400 kV AC double circuit transmission tower. If such an OHL with high ampacity is to be undergrounded, twelve UGC become necessary to replace this OHL (see Figure 19.4).

19.2 Advantages and Disadvantages of both Techniques

UGC have their specific field of application. They are normally installed when OHL are not possible or for other specific reasons. Typical examples are lines in the vicinity of airports, in densely populated areas of cities, large river crossings, or in protected areas.

Partial undergrounding of an OHL can be a part of the solution.

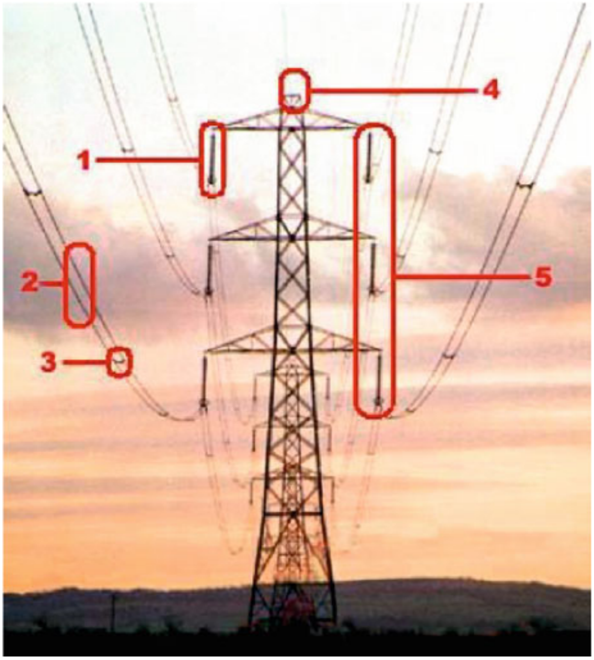

Figure 19.3 Lattice steel tower with two 400 kV electrical circuits (5), Figure 3.1 from Cigré publication 338. *Remark: typical thermal capacity with 2 sub-conductors aluminium 800 mm2 app. 2× 1500 MVA, with 3 sub-conductors app 2×2250MVA*. (*1*) Insulator. (*2*) Phase conductor low-power lines often have a single conductor; higher power lines may use multiple sub-conductors. (*3*) Spacer to hold the two sub-conductors apart. (*4*) Earth to hold of the tower or pylon. (*5*) The three phase conductors on one side of the tower make up one electrical circuit. Most lines have two circuits, one on each side.

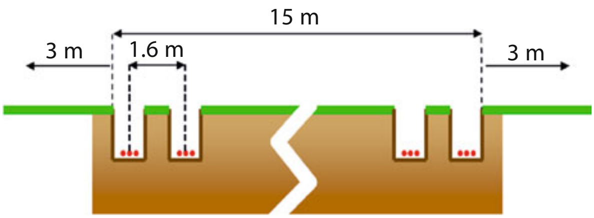

Figure 19.4 Trench cross-section for two 400 kV AC circuits, two "double cables" = 12 conductors (Figure 3.14 from Cigré TB 338) (possible laying arrangement). *Remark: capacity with copper conductors 2500 mm2 app. 2×2200 MVA*.

19.2.1 Costs

Costs are an important and sensitive aspect of a project. A distinction must be made between investment costs which cover the investment only and full costs (lifetime costs) which consider investments plus expenses over the envisaged lifetime of the line -such as maintenance, losses, new investments at the end of the lifetime, inflation, etc. It is important to note that a comparison of costs between OHL and UGC must be done under similar headings (e.g. ampacity, lifetime, availability, the same route length, repair time and cost, etc.

Cigré TB 338 "Statistics of AC underground cables in Power networks" is focussing this problem when it says: "*Cost ratios are often thought of a simple way of comparing costs, for example saying an underground cable is 10 times as expensive as overhead line. In reality there can be a wide range of values quoted for apparently similar circuits and this leads to confusion and mistrust between the various stakeholders*"………"*The only reliable method of comparing overhead and underground costs is on a case by case basis. Generic values of cost ratio are of very limited use and should be avoided. Estimates for the costs of underground and overhead options for a specific project must be calculated and then weighed against the advantages and disadvantages of each option.*"

The "joint paper" from entso-e and Europacable speaks about the following ratios of costs having this approach in mind*: "On 400 kV XLPE projects buried in soil and completed in Europe over the past 10 years the range of* ***investment cost*** *has been generally between 5 and 10 times compared to an overhead line. These cost ratios are directly related to the capacity of the link. Factors down to 3 can be reached for links with limited rating and under special favourable conditions for cable laying or in cases of expensive OHL. Factors above 10 can be reached for high capacity double circuit links and if specific structures are needed like projects involving the construction of cable tunnels (factors above 15 are expected in these cases) due to the cost for civil works. Higher ratios are also observed when compared to OHL consisting of guyed towers.*

For full costs the "joint paper states: "*When* ***lifetime costs*** *and other costs are taken into consideration, cost factor compared to overhead lines (based on self supporting tower structures) can vary between 3 and 10 times for direct burying. Where partial undergrounding is considered, the above multiples apply only to the undergrounded part of the link. This factor needs to be verified against the specific requirements of the project taking also into account the costs of the transition stations and compensation equipment, if required.*"

Recent projects and studies in several countries confirm these factors in principle.

For long AC UGC the additional costs and locations of reactors must also be considered.

In case of a DC line the converter stations at each end of the line add costs to both – OHL and UGC – and may shift the ratio.

19.2.2 Reliability and Repair Time

Cigré has issued TB 379 "*Update of Service Experience of HV Underground Cable Systems"*. The paper reports failures in the years 2000–2005. It seems outdated as since 2005 several UGC on 400 kV level have been installed. Nevertheless, no more comprehensive and up to date data has been published in the meantime. Outage times less than 1 day and longer than 6 months were not considered in the survey. In any case, the paper states that the failure rate of OHL and UGC on land is approximately the same (a little higher for OHL), but the repair time for OHL is less - on average 8 hours per fault and is higher for UGC with 600 hours repair time per fault. All these statistics have the problem of small quantities of 400 kV UGC on land compared with the large number of 400 kV OHL.

Another aspect is how important the circuit is for the supply of energy. It is therefore essential to consider the destination of the circuit in question and how the line is embedded in the grid. In other words: is the line a city-feeder, a line from a power station, a distribution or a transmission line, in a meshed grid (many connections between the lines) or not. Depending on these aspects the question of reliability and repair time may or may not be essential. It is important again to consider on a case-by-case-basis and not to generalise.

19.2.3 Lifetime

The cable industry estimates the lifetime of 400 kV XLPE cables to be about 40 years, based on tests in laboratories (the first 400 kV XLPE cable in Europa was installed 1996 in Copenhagen/DK). The replacement of a cable in a tunnel or duct is easier and cheaper compared to directly buried.

OHL have a lifetime of 80–120 years, if well maintained, though some components may need to be replaced (e.g. conductors and fittings after 40–60 years, corrosion protection 25–35 years). In addition, OHL are more accessible for maintenance work or in case of faults, emergency restoration structures can be used.

19.3 Operational Aspects

Due to the different components, electric characteristics and structure of an UGC line compared to an OHL, differences exist for their operation.

UGC produce reactive current. When exceeding a certain length of UGC, compensation measures become necessary to reduce this reactive current. Otherwise the ampacity of the line would be reduced. This is done by reactors. The order of switching must be kept according to a given concept (e.g. which substation and which reactor first, etc.).

The protection of an OHL allows automatic re-closure which results in fault clearance in most of the cases. A mixed line (OHL with partial UGC) needs a reliable protection concept which allows to be distinguished between failures in the OHL section and in the UGC section. Depending on this, automatic reclosure is possible or not.

The different impedances of OHL and UGC can lead to load shifting in the grid depending on the actual load.

Modern UGC use optical fibres either in the sheath of the cable or in separate ducts. They can indicate the temperature distribution along the route and can assist the load dispatcher in his decisions.

19.4 New Techniques (Superconducting Cables, Gas Insulated Lines "GIL", High Temperature Conductors for OHL, AC to DC, New Tower Design, DC with VCS)

19.4.1 UGC: Superconducting Cables

Superconducting cables use the effect, that special materials have a very low electrical resistance below a certain temperature, which is typically below minus 170 °C for so called "high temperature superconductors". This allows the transport of electricity with reduced losses. The conductors must be permanently cooled down to this low temperature.

Demonstration projects of such systems have been running for many years in several countries all over the world. The first applications in grids are in service now. The results of these experiences are awaited with much interest (Figure 19.5).

Typical applications will be to upgrade existing urban grids in places with limited space requirements over some hundred meters. A promising 10 kV superconductivity cable project is installed in Germany with approximately 1 km route length (2014). Presently such cables are not foreseen for long distances nor very high voltages (from Cigré TB 538: highest voltage so far 138 kV installed in Long Island USA over 600 m).

Figure 19.5 Example of superconductor cables; *Left* - single core cable, *Middle* - three core cable, *Right* - triaxial cable; (Pictures from Cigré TB 538).

19.4.2 Gas Insulated Line "GIL"

GIL use SF6 gas for insulation. Each phase conductor is made of an aluminium tube, fixed in a larger outer aluminium tube with app. 0.6 m diameter (for 400 kV). Typical transport lengths of the tubes are 12–15 m. GIL have a similar electrical behaviour as OHL (e.g. operation, ampacity, capacitive load).

Costs of GIL are by factors higher than for OHL, but can be an economic alternative to UGC in cases where double cables would become necessary.

Modern GIL of the "2nd generation" use a mixture of SF_6 and N_2 instead of pure SF_6 and their elements are welded. Experiences with GIL exist from the 1970ies.

Present typical GIL are used in power stations, substations and power plants over some hundred meters route length. GIL for partial undergrounding of OHL exists in Geneva/CH for 220 kV, Frankfurt-Kelsterbach/DE (with app 1000 m the longest GIL as partial undergrounding, 2×1800MVA) and Munich/DE, both 400 kV. GIL are mostly built in tunnels or overhead, seldom directly embedded in soil (Figures 19.6 and 19.7).

19.4.3 OHL: High Temperature Conductors

High temperature conductors are made of special alloys and can be used at temperatures of up to 210 °C. Such conductors can carry more electric current than standard conductors with an allowable temperature of 80-90 °C. These materials limit the sag and conductor pull to prevent resp. minimize adaptions of towers including replacements by higher towers. Such high temperature conductors are used for reconductoring as well, as for new lines (Figure 19.8).

19.4.4 OHL: Conversion AC to DC

The conversion of an existing AC overhead line to DC can increase the ampacity. The big advantage is in general the better control of the grid with a DC line. The

Figure 19.6 220kV GIL in Geneva/CH, energized in 2001, two electric systems in a tunnel, welded GIL of "2nd generation", 2×760MVA (Picture APG).

Figure 19.7 400kV GIL in Saudi Arabia, 780 MVA per system, installation above ground, connection of a power plant with the GIS (Cigré TB 218).

Figure 19.8 Different types of High Temperature Conductors (from left: 3 M, CTC, Lumpi-Berndorf).

efforts for adaptions on the line, including the new built AC/DC- and DC/AC-converter stations at the ends of the connection must be counterbalanced with the advantages gained. In general DC lines are used to transport large quantities of energy over long distances (typically exceeding 600 km). For shorter lengths AC lines are usually more economic.

A pilot-project with a so called "hybrid line" (one circuit at an existing OHL changed to DC, the other one remaining AC) is planned in Germany to check technical possibilities and electrical influences (Figure 19.9).

19.4.5 OHL: New Tower Design

Over the decades of OHL industry typical standard tower configurations have been developed, which are optimized in terms of material, transportation, erection, maintenance, costs, lifetime and appearance. Many utilities started considerations for a new tower design to get or to increase the acceptance for new OHL. Several towers

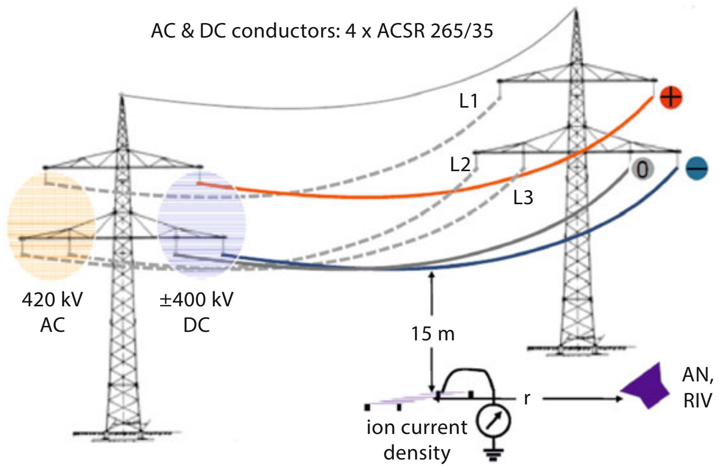

Figure 19.9 Line configuration for AC-DC conversion, one system AC, the other one DC (Source: B2 Session 2013 Auckland, Symposium papers 141, 142).

in alternative design are known from countries all over the world. Most of them are single solutions, some even have the function as eye-catchers. The Cigré TB 416 shows examples (Figure 19.10).

Only a few new designs are suitable as new standard configurations. One of them is built in The Netherlands, where this "wintrack tower" will be erected more frequently in the future (Figure 19.11).

19.4.6 UGC: DC with Voltage Source Converters

The technology DC with VSC is actually used on applications for connections of offshore wind resources. VSC is used for the underground connection between France and Spain with XLPE DC cables. It has financial advantages compared with traditional UGC lines in DC.

19.5 Mitigation Measures

19.5.1 Visual Impact

As with many other aspects, different points of view of visual impact must be considered. UGC in general have less visual impact than OHL. On the other hand OHL can be camouflaged by appropriate coating of towers and even conductors, or can be "hidden" if the landscape allows this. The picture shows a "camouflage line" in the Austrian Alps with coated towers and coated conductors (Figure 19.12).

Figure 19.10 New tower design; from left: Finland, France, USA, Finland, Spain (Source: Cigré TB 416).

Figure 19.11 Wintrack tower in the Netherlands (APG).

Figure 19.12 Two 400 kV towers can be seen. *Left*: galvanized steel tower, clearly visible. *Right*: "camouflage line" with *dark green* coated tower and conductors, nearly invisible (APG).

19.5.2 Electric and Magnetic Fields (EMF)

During the operation of a line electric fields are produced by the voltage, and magnetic fields are produced by the current. Due to the metallic sheath of an UGC there is no electric field outside the cables.

There is a magnetic field for both OHL and UGC and it depends on the magnitude of the current flowing through the circuit. These values vary with the phase arrangement as well as the clearance to ground for OHL and the depth of cables for UGC. Under normal construction conditions the magnetic field has approximately the same value above an UGC as under an OHL, when both are carrying the same current. The lateral values of the magnetic field decreases faster for UGC when moving away from the axis of the link.

Methods to reduce EMF for OHL are optimisation of the configuration of towers and phases, and for UGC optimization of the laying geometry, or shielding.

19.5.3 Audible Noise, Induced Voltages, Impact on Other Services

OHL may produce audible noise under unfavourable weather conditions. Methods are available to reduce this (e.g. multiple subconductors, phase arrangement, see chapter "environmental issues" in this green book). UGC do not produce audible noise.

Induced voltages are created by the electric field. Appropriate measures at objects in question ensure that the level of such voltages does not exceed given values. As UGC do not create electric fields, there are no induced voltages from cables, but are from OHL.

Impacts on sensitive facilities may come from both techniques. Such influences from OHL may come from the electric and magnetic field and in case of UGC from the magnetic field only. This can lead to shielding measures or to greater clearances to objects.

Underground long distance heating pipes, pipelines for gas and oil, may cause hot spots in a UGC line if not investigated properly during the design, and vice versa UGC may create heat problems for such underground infrastructural facilities. Mitigation measures after laying are complicated and costly.

19.6 Public Debate

The discussion about OHL and UGC in the public often suffers from incorrect comparison of the facts which apply to each technology. Typical examples for such misinterpretations are cost factors related to different capacities or even different voltage levels when comparing OHL and UGC. Comparisons between different projects make no sense; each project has to be estimated separately on a case-by-case-basis. Otherwise expectations or disappointments may be triggered which can lead to completely wrong perspectives. This discrepancy is not new and can be found in many other infrastructural projects.

Many parameters need to be considered in a comparison. The following breakdown presents examples of principal design parameters for a line (OHL and UGC):

- **destination of the line**: (city) feeder, transmission grid, distribution grid, feeder from a power plant, merchant line
- **environment, topography:** urban, rural, flat/hilly/alpine, climate, other heat sources in the soil, parallel cable systems, soil conditions
- **technical requirements:** ampacity, lifetime, voltage, AC/DC, number of electric circuits, route length
- **standards:** design standards, material standards, limits for EMF and audible noise.

Here under are the parameters for UGC in addition to principal parameters above:

- **laying of cables:** directly in soil/trench, ducts, tunnel, natural/forced cooling
- **construction**: insulation fluid filled/XLPE, cross section, copper or aluminium, screen cross section, lead sheath, etc., joints, terminations
- **laying formation:** flat, triangular, delivery length per drum, single cable or double cable per electric system
- **soil**: soil conditions, other heat sources in the soil, parallel cable systems
- **electrical aspects:** compensation needed or not, configuration and dimension of transition compounds, earthing conditions
- **earthing:** earthing conditions, cross bonding

- **routing:** urban, rural, flat/hilly/alpine, climate, other heat sources in the soil, parallel cable systems, soil conditions, other services, ditches, roads, terrain suitable for cable laying
- **installation:** type of access road for cable laying,
- **flexibility:** are more developments in the area expected in the future
- **repair:** fault finding and repair.

Finally here under are the parameters for OHL in addition to principle parameters:

- **structures**: tower configuration, number of circuits per tower
- **tower material**: lattice steel, tubular steel, concrete, wood, compound
- **conductors**: cross section, number of sub-conductors per phase, material
- **corrosion protection**: galvanized, coating
- **repair**: fault finding and repair
- **weather parameters**: wind, ice.

This shows clearly that comparisons or statements about UGC or OHL make no sense without detailed and specific project information. "Cables are different and overhead lines are also different."

19.7 Main Applications of UGC, Technical Challenges

The big majority of new transmission lines worldwide will be built with OHL (planned and under construction). Especially for extra high voltage lines EHV, different and additional aspects gain more importance.

- **Economic aspects**: investment costs, losses, lifetime, financing, full costs, economic situation of the relevant country and utility
- **Environmental aspects**: visual impact, EMF, audible noise, use of land, right of way, influences from climate and topography
- **Technical aspects**: multiple systems, capacity, time for installation, length of line, influences/integration into the existing grid, reliability and repair time, access, converter stations, possible need for reactors
- **Legal aspects**: criteria for beginning and end of an OHL and a UGC section, time of authorization.

A detailed worldwide overview can be found in Appendix G of the Cigré TB 338 (data collection ended 2007) (Table 19.2).

In the last few years laws covering UGC-policy were put into force in some countries.

- 2009: Denmark: agreement between the TSO and the central politicians about transmission grid expansion policy to underground all existing lines up to and including 150 kV combined with a restructuring of the whole grid in DK. The precondition is that the envisaged development of renewable energy production plants will be built and that the financial situation will allow the additional costs

Table 19.2 Overview of main EHV AC XLPE Installations in Europe at 400 kV (source: joint paper 2011 with updates March 2014)

Location	Project	Type of Project	Cable circuits × route length (km)	Cables per Phase	Power MVA	Erection Time	Method of Laying and Cooling
Copenhagen	Elimination of overhead lines in urban area	City feeder	1 × 22	1	1 × 995	1996	Direct buried
DK			1 × 12			1999	
Berlin	Connect West/ East system	City feeder	2 × 6	1	2 × 1100	1998	Tunnel ventilated
DE			2 × 6			2000	
Madrid	Barajas Airport Expansion	Airport runway crossing	2 × 13	1	2 × 1720 winter	2002/3	Tunnel ventilated
E					2 × 1390 summer		
Jutland	Area of outstanding beauty, waterway & semi urban areas	Partial under- grounding	2 × 14 in 3 sections	1	2 × 500 nominal	2002/3	Direct buried & ducts
DK					2 × 800 temporary overload		
London	London St. Johns Wood-Elstree	City feeder	1 × 20	1	1 × 1600	2002/5	Tunnel ventilated
GB							
Rotterdam	Rhine waterway crossings	Waterway crossings	2 × 2.1	1	2 × 1470	2004/5	Direct buried & pipes
NL							

Vienna	Provide power to centre of city	City feeder	2×5.5	1	2×620 without, and 2×1040 with forced cooling	2004/5	Buried in concrete block
AT							
Milan	Section of Turbigo-Rho line	City feeder	2×8.5	2	2×1100	2005/6	Direct buried & ducts
IT							
London	West Ham – Hackney	City feeder	2×6.3	1	1×1660 summer	2007/8	Tunnel ventilated
GB					1950 winter		
Switzerland/Italy	Mendrisio – Cagno	Interconnection, Merchant Line	1×8	1	1×560	2007/8	Direct buried
Randstad	Randstad South	Partial undergrounding of transmission line	2×10	2	1980	2013	Direct buried and ducts
NL					2635 short time		
Jutland	Kassø-Tjele	Partial undergrounding of new line	2×2.5	2	2×1800	2013	Direct buried
DK			2×4.5	2	2×1800	2014	
			2×1.6	2	2×1800	2014	
Jutland/Funen	Lillebælt	Partial undergrounding of two existing lines	2×5 UGC	1	2×600	2013	Direct buried
DK			2×7 Submarine	1	2×600	2013	

- 2009: a law in Germany confirms the need for more than 800 km new transmission lines respective upgrading including four 400 kV UGC - pilot projects (EnLAG). They are considered as pilot projects to gain experience with EHV UGC.

In Europe current major UGC projects on land exist in

- *The Netherlands*: 400 kV AC Randstad North OHL with 10 km partial undergroundings (4 sections), planned to be energized 2017
- *France/Spain*: crossing the Pyrenees with a 63 km ± 320 kV DC-cable, energized 2014 using VSC technology
- *Germany*: according to the EnLAG partial 400 kV AC undergrounding on pilot projects till app. 2019
- *Switzerland/Riniken*: partial undergrounding 400 kV AC app, 1.3 km, in authorization process
- *UK/London*: several 400 kV AC city cable projects, mostly in tunnels, to replace old 275 kV cables, in the next few years
- *Belgium, Stevin*: 10 km partial 400 kV undergrounding, realization planned 2018
- *Austria, Vienna*: Simmering-Wien Südost, partial 400 kV undergrounding 4.5 km, realization planned 2019
- *Denmark, Jutland*: Vejle, partial undergrounding existing 400 kV AC line, 2 × 6.9 km, 2015
- *Denmark, Jutland*: Aalborg, partial undergrounding existing 400 kV AC line, 8.6 km, 2015

19.8 Conclusions

OHL and UGC both have their fields of application. UGC are normally installed when OHL are not possible. Typical examples are lines in the vicinity of airports, lines in densely populated areas of cities, large river crossings, lines in protected areas, connections at sea including their landfalls.

The discussion about OHL and UGC in the public arena often suffers from incorrect comparison of the factors which apply to each technology. Examples for such misinterpretations are cost factors related to different capacities or even different voltage levels when comparing OHL and UGC.

The large majority of new transmission lines worldwide will be built with OHL (planned and under construction).

For both techniques new and challenging technical approaches exist (superconducting cables, GIL, high temperature overhead line conductors, change from AC to DC, new tower design).

19.9 Abbreviations

OHL: overhead line
UGC: underground cable
AC: alternating current

DC: direct current
HVDC: high voltage direct current
EMF: electric and magnetic fields
Entso-e: Association of European Transmission System Operators
Europacable, the representative of cable systems manufacturers in Europe
EHV: extra high voltage
TYNDP: Ten Years Network Development Plan
GIL: Gas Insulated Line
VSC: Voltage Source Converters for DC lines

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Cigré TB 294: How OH lines are re-designed for uprating/upgrading (2006)
Cigré TB 353: Guidelines for increased utilization of existing overhead transmission lines (2008)
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Cigré TB 396: Large overhead line crossings (2009)
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Cigré TB 426: Guide for qualifying high temperature conductors for use on overhead transmission lines (2010)

UGC

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