

HV and EHV insulated Power Cables: Evolutions and Trends in a Changing Operating Environment

Reinhard Schroth
Pirelli Berlin
Chairman of CIGRE SC B1



Good afternoon, ladies and gentlemen.

My name is Reinhard Schroth and I am coming from Berlin in Germany. I have been busy with the development of HV and EHV cables with SIEMENS Cables for almost 30 years and with PIRELLI Cables and Systems for another 4 years. Since the beginning of this year 2003 I am retired from the actual cable business.

Today I am here in my function as Chairman of CIGRE Study Committee B1 on Insulated Cables. So I am not representing a cable manufacturer rather than an independent international organisation, which is investigating in all kinds of technical issues in the field of the Electric Power Industry.

First of all I want to thank the ICF for their kind invitation to this Congress here in Vancouver. I am very much pleased about the opportunity to give an overview of the Evolutions and Trends in the field of High and Extra High Voltage insulated power cables in the period since the middle of the 1990's. As we all have noticed in our daily business, this period was characterised by substantial changes of the operating environment.

The changing operating environment

A new scenario for the Electric Power Industry:

business changes:
privatisation,
deregulation,
unbundling

environmental constraints:
minimum impact,
right of way, re-
cycling, EIA, LCA

increasing social awareness:
sustainability

new technologies:
improved materials,
information&telecom.,
microelectronics,
fibre optics

new players

new drivers

new needs

new possibilities

new evolutions

The changing operating environment resulted in a new scenario for the Electric Power Industry, which is much more complex nowadays rather than being primarily technical as in the past. The main parameters, which determine this new scenario, can be identified as:

- business changes due to privatisation, deregulation and unbundling of networks and ownership.
- environmental constraints with restrictions to impacts, ROW approvals, recycling, etc. Environmental Impact Assessments (EIA) and Life Cycle Assessments (LCA) are increasingly becoming compulsory in the planning phase of new projects.
- increasing social awareness with growing demands for sustainability of technical concepts and solutions
- new technologies such as improved materials, innovative information and telecommunication techniques, microelectronics, fibre optics etc.

In this new scenario

- new players appeared on the market
- new drivers initiated changes of established solutions
- new needs were identified
- new possibilities for improvements became available and these alltogether eventually initiated
- new developments and evolutions

HV and EHV insulated power cables: evolutions and trends in a changing operating environment

Drivers for adapting and improving conventional designs and concepts of cable systems :

- **economical needs (cost)**
- **environmental constraints**
- **social awareness (sustainability)**
- **technological opportunities**

What is true for the EPI as a whole applies correspondingly to the power cable business, too:

In the field of High Voltage and Extra High Voltage insulated power cables the specific drivers for adapting and improving conventional designs and systems are:

- economical needs due to harder competition
- environmental constraints due to increased public concern
- social awareness with regard to sustainability of cable concepts
- technical opportunities based on new materials and technologies

To cope most effectively with these new demands, developments and evolutions were not restricted to the products themselves but are also including any other aspects, which might determine cable systems performance and image in the eyes of potential customers and the public, respectively.

Evolutions in HV/EHV cable designs

Conventional fluid filled (SCFF) cable:

Standard copper conductor,
max 85/160°C

lapped paper/PPL insulation
with fluid (wet) impregnation,
substantial dielectric losses

solid metallic sheath
(lead, corrugated aluminium)
with high weight and losses

soft PVC outer sheath



Let's start with the Evolutions in the design of HV/EHV cables:

Since more than 70 years conventional self contained fluid filled (SCFF) cables have proven their excellent service performance for bulk power transmission in all voltage ranges from 60 kV to 500 kV:

- Their conductor was designed for a maximum nominal temperature of 85°C and for a short circuit temperature of 160°C, respectively.
- Their lapped paper insulation was impregnated with liquid mass or oil and their intrinsic dielectric losses were accepted or in recent years reduced by Polypropylene paper laminates.
- Generally these cables had a solid metallic sheath of lead or aluminium with a certain weight and specific electrical losses.
- The outer sheath mostly was of soft PVC.

No doubt, with regard to purely technical requirements this was a most appropriate design. These cables did not show any signs of premature ageing and many of them reached service ages of 40, 50 or more years. Their reliability was mostly outstanding and from that point of view, no changes were needed.

However, this type of cable proved not optimal under the newly arising aspects of increased environmental constraints, minimised losses, ease of installation, low maintenance and least cost.

Evolutions in HV/EHV cable designs

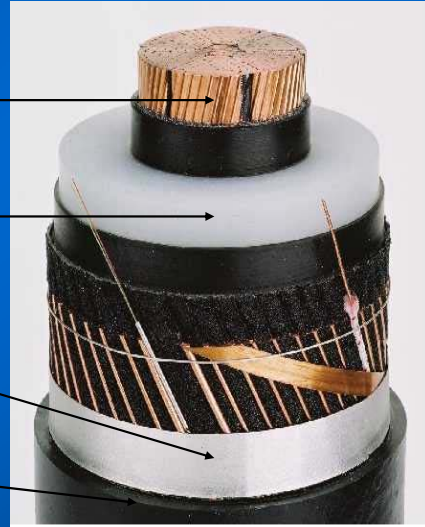
Modern cross-linked polyethylene (XLPE) cable:

optimised conductor
max. 90/250°C

dry, extruded insulation,
low dielectric losses

laminated metallic sheath
with low weight and
reduced losses

rigid PE outer sheath



As a substitute for conventional SCFF cables, extruded HV/EHV cables were developed. Since the 1970/80's they were increasingly introduced into HV networks and since the middle of the 1990's applied for 400 kV in Europe and for 500 kV in East Asia..

Their typical characteristics are:

- conductors, which are designed for 90°C nominal and 250 °C short circuit temperatures, thus allowing higher currents compared to corresponding cross sections of SCFF cables. If needed, these conductors can be optimised with regard to their current dependent losses by insulating the single wires.
- dry triple extruded insulation with reduced dielectric losses (by a factor of ten compared to paper insulated cables)
- as there is no internal overpressure from a liquid impregnation a thin laminated metallic sheath with low weight and least losses is sufficient (which serves as radial water barrier and partly as screen)
- rigid PE outer sheaths improve withstand against tough laying stresses.

Evolutions in HV/EHV cable designs

Actual trends:

- "dry" extruded cables are increasingly replacing "wet" paper insulated mass-/oil impregnated cables
- Polypropylene paper laminates (PPL) help to reduce losses and cable dimensions, but remain "wet" designs
- Cross linked polyethylene (XLPE) is dominating extruded insulation due to its higher operating temperatures ($>LDPE, HDPE$) and lower cost ($<EPR$)
- XLPE is available for all voltages, transmission ($HV \leq 170 \text{ kV}$, $EHV \leq 500 \text{ kV}$) and distribution ($MV \leq 45 \text{ kV}$)

The actual trends with HV/EHV cable designs can be described as follows:

- dry extruded cables are increasingly replacing wet paper insulated cables
- Polypropylene paper laminates help reduce losses and insulation wall thickness, but have to be considered an intermediate solution, as the insulation remains wet
- XLPE is dominating extruded insulation and surpasses low density (LDPE) and high density (HDPE) polyethylene due to its higher operating temperatures (thus allowing higher loads) and ethylene propylene rubber (EPR) due to its lower cost
- XLPE is now available for all transmission applications as it is service proven for HV cables since > 25 years, for EHV since > 5 years and for MV since more than 30 years.

Evolutions in HV/EHV cable designs

Latest trends and advanced concepts:

- from wet designs to dry insulation
- from substantial to reduced losses
- from lower to higher electric stresses
- from larger to smaller cable dimensions
- from heavier to lighter cables
- from shorter to longer shipping lengths
- from costly to less expensive cables

Latest trends and future concepts for HV/EHV cable designs can thus be summarised as follows:

- from wet designs to dry insulation with benefits for the environment
- from substantial to reduced losses with benefits for operational cost

Based on improved cleanliness of materials and extrusion processing

- electric stresses of extruded cables can be increased with benefits
- for smaller insulation wall thickness and reduced overall cable diameters

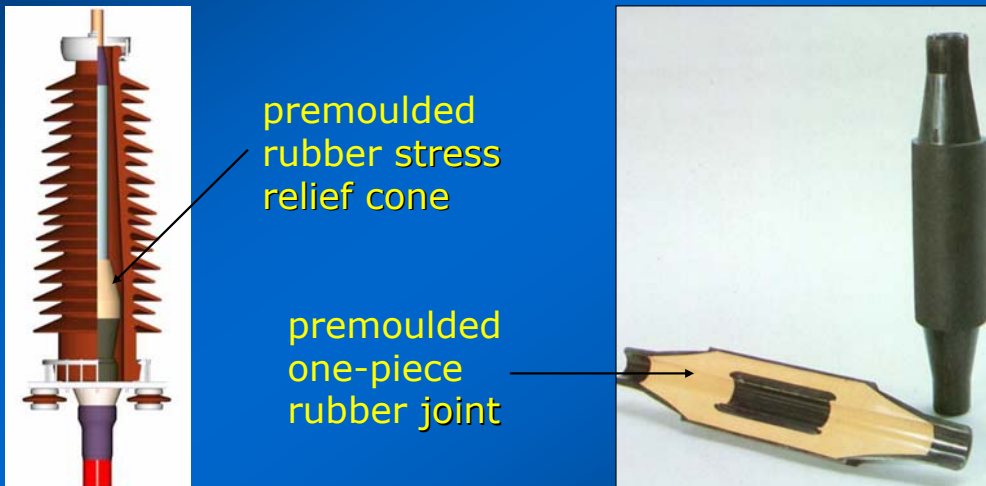
Smaller insulation and thinner metallic sheaths

- reduce weight of cables with benefits for
- longer shipping lengths with, in turn, benefits for less joints.

•All these measures contribute to the reduction of cable cost and improvement of competitiveness.

Evolutions in HV/EHV accessories

Progressive slip-on accessories for XLPE Cables:



Respective evolutions as in HV/EHV cable designs have been achieved with accessories:

Instead of hand made, mostly taped accessories for SCFF cables, which after taping had to be encapsulated with tight housings and subsequently evacuated, impregnated and pressurised,

progressive accessories for XLPE cables are of the prefabricated slip-on design, e.g.:

- pre-moulded rubber stress relief cones for terminations and
- pre-moulded one-piece rubber joints

Within these prefabricated accessories all field control elements are already included and jointing work is restricted to slip-on of the elastic bodies onto the prepared cable cores.

2nd generation of XLPE cable terminations don't even need a fluid filling underneath the insulator, but are completely dry.

Evolutions in HV/EHV accessories

Latest trends and advanced concepts:

- from fluid filled casings to dry designs
- from on-site assembly of a multitude of components to a few prefabricated pieces or single bodies
- from hidden jointing errors to factory tested components and on site AC & PD tests
- from complicated, long and costly jointing work to simpler, shorter and cheaper procedures

So, the latest trends and advanced concepts for HV/EHV accessories can be summarised as follows:

- from fluid filled casings to dry designs as with cables
- from on-site assembly of a multitude of components such as insulating or conductive tapes, to a few prefabricated pieces or even single bodies.
- formerly hidden jointing errors are widely excluded by electrical tests in the factory which are supplemented by
- appropriate after-laying tests with AC voltage combined with partial discharge tests
- Jointing procedures, which in the past frequently were complicated, long and costly, have now become simpler, shorter and thus cheaper

Evolutions in HV/EHV test specifications

CIGRE test recommendations:

- 1993: Recommendations for electrical tests on extruded cable systems $150 \text{ kV} < U_n \leq 400 \text{ kV}$
- 1997: Recommendations on after laying tests on HV extruded insulation cable systems
- 1998: Recommendations on electrical tests on extruded cable systems $150 \text{ kV} < U_n \leq 500 \text{ kV}$

All efforts to improve designs and reduce cost of cables and accessories by introducing new materials, smaller dimensions, cheaper jointing etc. apparently included the risk of reduced quality and reliability.

In the early years of the XLPE cable technology this issue was not sufficiently covered by adequate test specifications. Consequently, test specifications for HV and EHV cable systems needed due consideration and evolution, too.

To close this gap, CIGRE started in the early 1980's to thoroughly investigate in appropriate test procedures and requirements.

As a result, CIGRE published a number of test recommendations, some of the most important examples of which are:

- 1993: Recommendations for electrical tests....up to 400 kV
- 1997: Recommendations on after laying tests...
- 1998: recommendations on electrical tests...up to 500 kV

These test recommendations proposed for the first time a complete test program which covers all aspects of cable, accessory and systems performance under short and long term service conditions.

Evolutions in HV/EHV test specifications

IEC test specifications:

- 1988: IEC 840, 1.ed.: Power cables with extruded insulation for voltages $30 \text{ kV} < U_n \leq 150 \text{ kV}$
- 1999: IEC 60840, 2.ed.: Power cables with extruded insulation and their accessories for $30 < U_n \leq 150 \text{ kV}$
- 2001: IEC 62067: Power cables with extruded insulation and their accessories for $150 \text{ kV} < U_n \leq 500 \text{ kV}$



These CIGRE test recommendations were directly influential on the progress of IEC Test Specifications:

- in 1988 the IEC 840 spec. only covered tests on HV extruded cables themselves, however, accessories were not included.
- in 1999 the second edition of IEC 60840 was extended to include accessories, too
- eventually in 2001 IEC 62067 was published on EHV extruded cable systems up to 500 kV

The availability of these test specifications were of prime importance for purchasers of newly developed extruded cable systems, as IEC specifications are effective as binding obligations when being included in a contract.

Evolutions in quality management

ISO specifications for quality & environmental management (QEM) systems:

- 1994: ISO 9001 Quality Management
 from random to systematic quality checks
- 1996: ISO 14001 Environmental Management
 from casual to consistent environmental assessment

 Stringent quality control systems are prerequisites for high levels of reliability and availability

In addition to the new test specifications on products, overall quality and environmental management systems according to ISO specifications were established:

- 1994: ISO 9000/9001 on Quality Management
which introduced systematic quality control at manufacturers instead of previously more random checks
- 1996: ISO 14001 on Environmental Management
which introduced consistent environmental assessment instead of previously more casual checks

As a result, it was commonly accepted by suppliers and customers, that stringent quality control systems are prerequisites for the indispensable high levels of reliability and availability which were expected from the newly developed cable systems.

Evolutions in installation techniques

Basic construction techniques:

Traditional techniques

- open trenches
- direct burial
- ducts
- troughs
- tunnels
- large manholes

Innovative techniques

- mechanical laying
- horizontal drilling
- micro-tunnels
- multi-purpose tunnels
- retrofitting
- small joint bays

Evolutions did not happen only with cables and accessories themselves but also with construction and installation techniques:

Traditional construction techniques for cable systems are:

- open trenches with large volumes of excavate, causing extended construction sites with heavy impact on route surfaces, traffic, public life etc..
- direct burial of cables, requiring open trenches until completion of laying
- installation of ducts or troughs can help reduce duration of open trenches.
- where applicable, special cable tunnels are built
- as compartments for joints often large manholes are erected

In recent years innovative construction/installation techniques have been developed, which are increasingly being adopted, such as

- mechanical laying where excavation of trench, laying of cable and refilling of trench is done in one simultaneous operation
- horizontal drilling and micro-tunnels avoid huge open trenches and external disturbances
- multi-purpose tunnels are used commonly for different infrastructure such as electricity, water, gas, telecom etc.
- retrofitting of new cables in existing constructions, preferably old ducts, save construction cost
- small, partly prefabricated joint bays reduce volume of excavate and construction cost

Evolutions in installation techniques

Innovative construction concepts and trends:

- from open trenches to more trench-less methods
- from social & environmental impacts to convenience due to placing work underground
- from heavy material's movements (excavation, backfill) to reuse of native ground
- from shorter to longer laying lengths & less joints
 - from laying and jointing methods determined by type of construction to undisturbed work

The latest evolutions in construction/installation techniques can be summarised:

- from open trenches to more trench-less, i.e. underground work
- these methods help to drastically reduce social and environmental impact, e.g. on traffic and public life
- abandoning large open trenches reduces volumes of excavate and backfill materials
- straight routes of tunnels, which avoid sharp bends, facilitate longer laying lengths and less joints (e.g. in Japan >2 km lengths with 275 kV)
- cable laying and jointing are independent from third parties in tunnels whereas highly disturbed in open trenches on public roads etc.
- Most of these innovative construction and laying methods contribute to considerable cost savings during the erection of new cable systems.

Evolutions in cable systems technology

Maintenance of cable systems:

- from maintenance requiring (fluid filled) products
 ➡ to maintenance free (dry) designs
- from regular precautionary measures
 ➡ to least maintenance
- from stand-by maintenance staff
 ➡ to reduced personnel
- from substantial permanent maintenance cost
 ➡ to considerable savings

There are evolutions, too, in cable systems technology, i.e. at the complete system in operation.

A costly and permanent issue with fluid filled cable systems used to be their maintenance.

- Now we are going from maintenance requiring to maintenance free designs, i.e. dry extruded XLPE cables and prefabricated accessories
- precautionary maintenance at SCFF cable plants as e.g. control of pressure tanks and gauges, oil leaks etc. are not necessary any more
- this allows conventional stand-by maintenance staff to be significantly reduced if not completely abandoned or at least being outsourced
- all these reductions help to considerable cost savings at utilities

Evolutions in cable systems operation

Thermal monitoring and dynamic current rating:

Distributed temperature sensing (DTS) systems (using an optical fibre as sensing element) are monitoring continuous profiles of

- actual temperatures along cable route

Dynamic cable rating (DCR) systems (using sophisticated computer programs) are providing continuous calculation of

- actual ground thermal resistances
- current carrying capabilities
- prospective conductor temperatures

Further evolutions of auxiliary means like thermal monitoring and dynamic current rating provide detailed information on the actual state of the cable system to network's operators:

- Distributed temperature sensing (DTS) systems are monitoring continuous profiles of
 - actual temperature along cable routes
- dynamic cable rating (DCR) systems are providing continuous calculations of
 - actual ground thermal resistance,
 - current carrying capabilities and
 - prospective conductor temperatures

Evolutions in cable systems operation

Benefits of DTS and DCR systems:

- from static "safe side" current calculations
 ➡ to dynamic real time thermal rating
- from undetected changes in thermal environment
 ➡ to continuous hot spot assessment
- from restricted operation of existing plants
 ➡ to optimised load management
- from conservative asset utilisation
 ➡ to upgrading & uprating

With the help of such DTS and DCR systems Transmission System Operators (TSOs) are now able to optimally load their cable systems without violating the physical limits, i.e. the maximum admissible conductor and insulation temperatures, respectively:

- from traditional static safe-side current calculations, which were based on worst case conditions, i.e. 100% continuous load and least heat loss dissipation, to dynamic real time thermal rating, which takes advantage of the actual thermal reserves of the system.
- from undetected changes in the thermal environment to continuous assessment of any deterioration (hot spot) due to e.g. new installations, dry-out of soil, local increase of thermal resistance etc.,
- from restricted operation within "once for ever" limits set at the initial systems design to optimised load management including controlled overload based on actual data.
- from conservative asset utilisation to upgrading and uprating

With this slide I want to finalise my considerations on recent Evolutions and Trends in cable and accessories designs, test specifications, quality management, installation techniques and system's technologies and operations.

In the last part of my presentation I will discuss how these advanced underground cable systems compare to overhead lines.

HV/EHV underground cables (UGC) vs. overhead lines (OHL)

1. Transmission lengths of AC UGC < OHL ?

- limitations due to cable capacitance/charging current
- maximum cable system lengths (50 to 100 km) sufficient for most applications (who needs more?)
- shunt reactor compensation available for extension to double lengths or more (100 to 200 km) (extra cost)
- “problem” to be considered as part of system’s engineering (integration of cables in the network)

There are a number of alleged problems with cables compared to overhead lines.

The first issue I want to comment is

Transmission lengths of AC cables which are alleged to be much shorter than OHL systems lengths.

- It is true that AC cable lengths are limited due to their capacitance and charging current, respectively
- however, maximum AC cable system lengths are in the range between 50 and 100 km, dependent on cable dimensions and voltage levels. This is sufficient for most practical applications.
- If need should be, system lengths can be extended to double or more by shunt reactor compensation, though this requires extra cost.
- The issue of maximum transmission length seems not a real practical problem with cables and normally can easily be coped with as part of the networks overall design.

Underground cables vs. overhead lines

2. Environmental constraints

	UGC	OHL
• visual impact	none	substantial
• audible noise	none	substantial
• radio interference	none	substantial
• electromagnetic field	adjustable	intrinsic
• land occupation	little	substantial
• depreciation of land	minor	substantial
• construction impact	varying	limited
• right of way approval	possible	difficult
• public image	positive	negative

The 2nd issue are Environmental constraints:

- visual impact of cables is nil, with OHL it is substantial
- audible noise from cables is nil, with OHL it is considerable
- radio interference is nil from cables (as there is no external electrical field) whereas substantial with OHL
- electromagnetic fields of UGC can be adjusted as needed whereas those of OHL are more or less fixed (see details next slide)
- occupation and depreciation of land are severe problems with OHL, but of least importance, if any, with UGC
- maintenance for UGC is negligible, but considerable with OHL
- impact during construction depends with UGC on the method, whether underground or above ground, but is immanent above ground with OHL
- ROW approval nowadays faces very difficult and long procedures with OHL but is much less complicated with UGC
- public image is in favour of UGC (“bury and forget”) and against OHL (“visible for ever”)

Underground cables vs. overhead lines

3. Electromagnetic fields (EMF) UGC > OHL ?

System's configurations determine ground level EMF:

	UGC	OHL
• conductor position	depth \geq 1m	height \geq 10 m
• ground field strength	higher	lower
• ground field width	narrow	wider
• field adaptability	as needed	intrinsic

EMF of UGC is adaptable to actual or anticipated legal exposure limits by selected measures (cost)

With this slide I am specifically addressing the issue of EMF. This is obviously one of the most critical subjects of public concern when new transmission lines are discussed.

- The EMF at ground level is determined by the geometrical position of the conductor and the current, respectively, which produces the magnetic field
- With cable systems the conductors are normally in a depth of about 1 m, for OHL in a height of more than 10 m
- it is clear that at ground level the immanent EMF of UGC will be higher than that of OHL
- However, the width of the OHL field is much wider
- The most important advantage of UGC systems is that their EMF can be adjusted by special means such as optimised laying configurations, compensation conductors or magnetic shielding. This is not practical with OHL.

The conclusion is that EMF of UGC is adaptable to actual and anticipated future legal exposure limits by special technical measures which can be applied wherever and whenever needed. As such measures cost money and increase losses, they are, of course, introduced only at locations where necessary.

Underground cables vs. overhead lines

4. Outages and repair times of OHL

- OHL are subject to a great variety of external disturbances (ice, snow, pollution, storms, birds, trees, flashover etc.), which do not exist with UGC
- Weather and climatic impacts can affect larger parts of OHL (many towers & longer sections)
- OHL disturbances can cause short interruptions (auto-reclosure), but also very long outages

Outages and repair times of OHL are often declared less severe than those of UGC.

The truth with OHL is:

- OHL are subject to a great variety of external disturbances which do not exist with cables

(topical examples of huge network outages due to initial failures on OHL are apparently the August 14th 2003 blackout in greater parts of the US and Canada and the severe blackout of half of Italy in September 2003 due to a failure at a 400 kV OHL in Switzerland)

- weather and climatic impacts can affect larger parts of OHL networks (remember the recent widespread damages from Hurricane Isabel in the US and the extended OHL damages from winter storms in France in 1999)

- Though the majority of OHL disturbances are flashovers in air, which mostly can be overcome by short term auto-reclosure*), others can be very severe, long lasting and costly.

*) the effect of short supply interruptions on electronic equipment has to be considered

Underground cables vs. overhead lines

5. Outages and repair times of UGC > OHL ?

- UGC are well protected against ambient impact
- UGC internal electrical failures are rare & singular
- UGC breakdowns are mostly caused by third party damage
- UGC repairs, if any, are sometimes complicated and can last long time
- UGC repair times are reduced by spare parts (cables & prefabricated joints)

Outages and repair times of UGC are completely different from OHL, as cable insulation is thin and solid and OHL insulation is large and gaseous.

- UGC are well protected in ground
- UGC internal failures, if any, are rare and singular
- UGC outages are mostly caused by external mechanical damage
- UGC repairs, if any, depend on the kind of damage and will last a respective time
- UGC repair times can be reduced by precautionary measures, i.e. availability of spare parts of cables and accessories

The conclusion is:

- the “light” failures with OHL (temporary flashovers in air), which can often be overcome by auto-reclosure, do not exist with cables and thus cannot be compared.
- The “heavy” failures at OHL and UGC, which are characterised by damage of solid components (poles, insulators, conductors, insulation etc.) are different in each case and thus cannot be compared either.

A discussion of this issue seems not to be very helpful for an objective assessment of benefits and drawbacks of the different transmission systems.

Underground cables vs. overhead lines

6. Cost comparison UGC vs. OHL

$$\Delta \text{ total cost} = \Delta \text{ investment cost} + \Delta \text{ land cost} + \Delta \text{ operational cost}$$

- basic investment cost OHL << UGC
- land compensation cost OHL >> UGC
- operational cost (losses, maintenance, unavailability, end of life disposal) OHL >?< UGC
- cost ratios between OHL & UGC are widely varying
- case by case analyses necessary for final assessments

One of the most important issue when comparing UGC and OHL is the ratio of cost: The total cost difference derives from

- the difference in basic investment cost
- the difference in land cost
- and the difference in operational cost
- basic investment cost, i.e. transmission system's hard ware and installation, are generally lower with OHL than with UGC due to less expensive materials, components and handling
- land cost, i.e. compensation for occupation and depreciation of the land where the line is passing through, are generally higher with OHL, where the land sometimes has to be purchased by the utility or rent over the whole life time of the installation whereas UGC in public roads mostly are "free of charge"
- operational cost, i.e. all cost during the life time of the systems, which include losses, maintenance, unavailability, end of life disposal etc., depend very much on the individual conditions and therefore are difficult to estimate on a general basis. In most cases they are not explicitly registered and duly considered in the systems comparison.
- As a conclusion cost ratios between OHL and UGC can vary in a wide range and need case by case analyses.

There will be more information on this issue from my speaker colleagues in their forthcoming presentations.

HV and EHV insulated cable systems: Evolutions and trends:

- selected materials, small dimensions, easy handling characterise advanced cable & accessory designs
- high reliability and availability are safeguarded by stringent test specifications and QEM systems
- social and ecological constraints are coped with by adequate materials and new installation techniques
- monitoring, diagnostic and DCR systems enhance network operational management and asset utilisation
- cost savings and improved competitiveness are prime objectives of adaptations and evolutions

With these considerations I am coming to the end of my presentation on Evolutions and Trends in HV and EHV insulated cable systems, the state of the art of which is:

- selected materials, small dimensions and easy handling characterise advanced cable and accessory designs
- high reliability and availability is guaranteed by stringent test specifications and consistent QEM management systems
- social and ecological constraints are coped with by adequate materials and innovative installation techniques
- monitoring, diagnostics and dynamic current rating systems enhance operational management of cable systems and improve asset utilisation
- cost savings and improvement of competitiveness are prime objectives of ongoing technical adaptations and evolutions

HV and EHV insulated power cables: evolutions and trends in a changing operating environment

Conclusions:

- Technical cable solutions are available for all practical transmission tasks and applications
- Environmental and social constraints can be widely satisfied
- Economical competitiveness is being enhanced by ongoing developments
- UGC share in transmission networks will increase, but OHL share will remain important

As a conclusion we can state that the changing operating environment has encouraged the international HV/EHV power cable industry to engage in developments and evolutions, which are focussed to appropriately satisfy the new demands and challenges.

Results so far achieved can be summarised as follows:

- technical cable system solutions are available for all practical transmission tasks and applications up to 500 kV
- environmental and social constraints can be widely satisfied, in most cases much better than with OHL
- economical competitiveness of UGC with other types of transmission systems, e.g. OHL or Gas Insulated Lines (GIS), is being enhanced by ongoing developments
- UGC share in transmission networks will increase in the future, however the share of OHL will remain important.

Thank you for your kind attention!