Extruded Cables for HVDC Power Transmission

Prysmian Group

PRYSMIAN
Draka
General Cable

Linking the Future

As the worldwide leader in the cable industry, Prysmian Group believes in the effective, efficient and sustainable supply of energy and information as a primary driver in the development of communities.

With this in mind, we provide major global organisations in many industries with **best-in-class cable solutions, based on state-of-the-art technology**. Through our global presence, we're constantly close to our customers, enabling them to further develop the world's energy and telecoms infrastructures, and achieve sustainable, profitable growth.

In our energy business, we **design**, **produce**, **distribute** and install cables and systems for the transmission and distribution of power at low, medium, high and extra-high voltage.

In telecoms, the Group is a leading manufacturer of all types of copper and fibre cables, systems and accessories - covering voice, video and data transmission.

Drawing on almost 140 years' experience and continuously investing in R&D, we apply excellence, understanding and integrity to everything we do, meeting and exceeding the precise needs of our customers across all continents, at the same time shaping the evolution of our industry.

What links power grids to sustainability?

Prysmian Group offers cable solutions to support the development of smarter and greener power grids.

From Asia-Pacific to the Americas, and from Europe to the Middle East to Africa, Prysmian cable solutions sit at the heart of the development of power grids worldwide, helping major utilities in transmit and distribute power to their customers.

Unmatched in our manufacturing capabilities and with an unwavering commitment to R&D, we design, produce and install **low, medium, high and extra-high voltage underground and submarine cables and systems**, along with network components and value-added engineering services.

Always aware of the need to minimise our impact on the planet, we're constantly driving innovation in our industry, aiming to optimise supply chain processes, reduce total cost of ownership for our customers and help them achieve sustainable, profitable growth.

System Solutions and Innovation

HV land and submarine cable systems are the backbone of all power transmission networks.

Offshore interconnections among power networks of different types are needed to meet the greater and ever-increasing demand for power; the need for larger bulks of power and for the transmission of such bulks over longer and longer distances; exceeding existing power generation capacity from offshore-renewable sources.

In addition, the involvement of new players other than the traditional operators and asset owners (e.g. Merchant Lines) in the electricity market requires an increasingly stricter control of the power flows.

HVDC cable systems offer a technologically advanced and reliable instrument to address these issues.

Power transmission cable systems

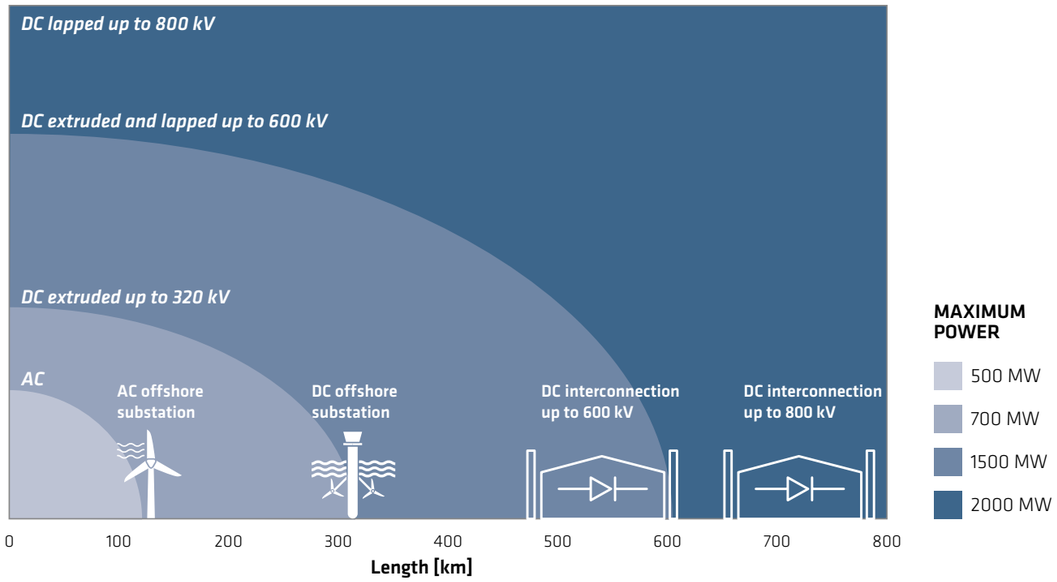
AC transmission is used on **short distances**. It is more cost effective as it does not require converter stations.

In the recent past, more and more connections appeared to be in AC for circuit lengths up to the range 80 - 120 km, however this implies a significant decrease in performance due to the increase of absorbed reactive power.

DC transmission is used for **long lengths**. Use of DC is rapidly increasing following the evolution of power electronics and typologies of AC-DC converters. Different cable system solutions are available for DC applications.

For bulk power transmission, lapped cables still prove to be popular because of the capacity to work up to 800 kV DC.

Recent developments allowed qualifying extruded insulation cables for DC transmission systems up to 600 kV.



Product range

So far, lapped cables (high-density paper tapes impregnated with a high-viscosity compound) have proven suitable for voltages of up 700 kV DC (in their PPL taped version) without requiring fluid pressure feeding, thus allowing these cables to be installed in HVDC links in very long lengths, up to several hundreds of kilometres.

However, where system requirements permit, the use of an **extruded insulation offers several remarkable advantages**, such as lighter, easier-to-handle cables, which can operate at high temperatures and at high electrical stresses. Thanks to recent technology improvement, extruded cables are presently adopted for voltages up to 600 kV DC.

In the field of extruded insulations for HVDC systems, Prysmian focusses on two main classes of insulations:

XLPE (cross linked polyethylene-based insulation) with different degrees of cross linking and **HPTE** (High Performance Thermoplastic Elastomer – Polypropylene based insulation).

The latter is proven to have a higher performance under both thermal and dielectric aspects and have been developed internally by Prysmian with the name of P-Laser.

New Extruded Solutions

XLPE

Insulation:
XLPE
Voltage:
±600 kV
Power[1]:
3,000 MW
Converter:
VSC: any voltage
LCC: up to 250 kV

P-Laser

Insulation:
HPTE
Voltage:
±600 kV
Power[1]:
3,400 MW
Converter:
Both LCC and VSC

Traditional Laminated Solutions

MI paper

Insulation:
Mass impregnated paper
Voltage:
±525 kV
Power[1]:
2,400 MW
Converter:
Both LCC and VSC

MI-PPL paper

Insulation:
Mass impregnated
Polypropylene laminate paper
Voltage:
±800 kV
Power[1]:
4000 MW
Converter:
Both LCC and VSC

NOTE 1: Rating per cable bipole – power rating depends on ambient and installation parameters

XLPE insulation technology

XLPE insulation technology is based on PE (polyethylene) and requires a cross-linking process, which is essential for stabilising the insulation material. This process determines the presence in the insulation of cross-linking by-products (such as methane, cumyl alcohol, acetophenone, etc.). These by-products should be removed, after the cross-linking with a specific thermal treatment process, known as "degassing". The **degassing** operation decreases the amount of residual by-products present in the cable. Electrical and thermomechanical working performance should be selected accordingly, to guarantee reliable system operations at the ever-increasing voltage levels.

The newly developed XLPE material present **higher cleanliness** and **lower electrical conductivity**, allowing for an increase of the maximum allowable electrical stresses in the insulation (if compared to the previous XLPE materials). As a result, it is now possible to reach cable voltage levels up to 600 kV, while reducing thicknesses at standard voltages with lighter and less expensive cables.

FEATURES

- XLPE insulation up to 600 kV DC for underground and submarine applications
- Lower system costs and lighter cables for voltage levels up to 320 kV

PERFORMANCE

- New material with low electrical conductivity
- High material cleanliness
- Same thermal performance of DC XLPE used so far up to 320 kV

SERVICE

- Same technological platform used for XLPE AC and DC cables

Technology

When high DC voltage is applied to an insulating layer, a leakage current will flow through it producing heat and rising the insulation temperature. This increases the insulation electrical conductivity, allowing for more current to flow and thus generating more heat, leading to thermal runaway and ultimately to electrical breakdown. It is therefore necessary mitigate the risk of thermal runaway due to heat generation inside the insulation. The next-generation XLPE material for HVDC cable insulation systems requires an optimised composition with **low DC conductivity**, limitation of space charges effects and **high electrical breakdown strength**.

XLPE cleanliness is of utmost importance in achieving good low DC conductivity. One key aspect was the **reduction of peroxide content** to decrease the quantity of residual by-products: it is in fact well known that cleanliness will affect both DC conductivity and the space charges properties. Peroxide is normally added to the insulation base material at high temperature and pressure right after the extrusion. Its presence is necessary to start the cross-linking process and thus peroxide content shall be enough to ensure the presence of a cross-linked polymer network. The researches were aimed to develop a new technology platform, finding the right balance between material characteristics and production processes and guaranteeing both electrical and thermomechanical performances.

The new XLPE material also produces an electrical conductivity that is less dependent on temperature and electrical stress, meaning that the conductivity is more stable between cold and hot conditions. The electrical field in the insulation also varies less between different cable operating conditions.

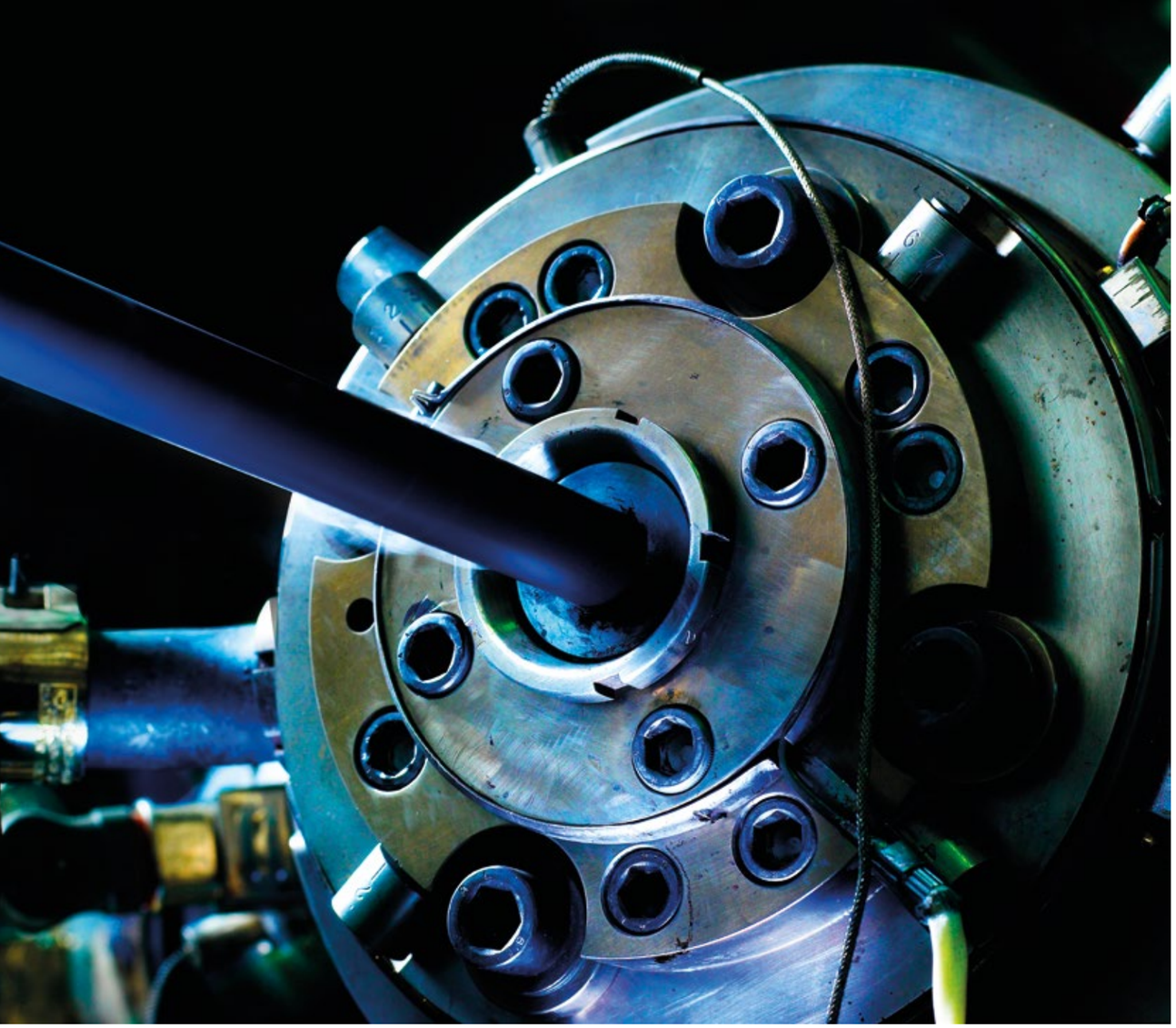
It allows the use of the same technology platforms used for manufacturing XLPE cables, and shows lower tendency to scorch. Having decreased the quantity of by-products allows degassing times to become compatible with industrial processes.

Performance

The XLPE cables successfully passed Type Tests and Pre-Qualification Tests at voltages up to 600 kV, proving that the insulation properties achieved with the new material and specific process parameters are aligned with expectations.

The main advantages are:

- Higher voltages
- Longer transmission lengths with lower system losses
- Lightweight cables



P-Laser

P-Laser cable technology is based on High Performance Thermoplastic Elastomer (HTPE) insulation which, compared to Cross-Linked Polyethylene (XLPE)-based , does not require the crosslinking process and, not having cross-linking by products, does not require the time-consuming degassing process.

A further very important advantage is that the material itself is fully recyclable, which will become mostly relevant for the decommissioning stage of old HVDC links.

Moreover, it is important to point out that the P-Laser technology is fully compatible with existing cable accessories and can be integrated in networks using different insulation technologies.

Prysmian's breakthrough in Extruded Power Transmission Cables

Prysmian developed the breakthrough P-Laser cable technology that ensures **improved electrical characteristics** in HVDC cable systems, more efficient cable manufacturing and lower environmental impact than traditional XLPE based insulation technologies, using an in-house developed insulation material based on polypropylene, called HPTE (High Performance Thermoplastic Elastomer).

The excellent electrical properties of polypropylene are already well known, however development was needed in order to achieve a combination of excellent values of flexibility and thermomechanical properties.

FEATURES
- Innovative HPTE insulation up to 600 kV DC for underground and submarine applications
- Fully compatible with existing networks
- Over 30,000 km experience in MV networks
- Increased power transmission capacity and lower system costs by more than 30%

ENHANCED PERFORMANCE
- Higher thermal performance properties for increased power transmission capability
- Operating temperature range increased

SUPERIOR SERVICE
- Uninterrupted, single line production (thermoplastic elastomer = no degassing)
- Shorter production times
- High level of insulation material filtration

ENVIRONMENTAL SUSTAINABILITY
- Reduced energy consumption and lower greenhouse gas emissions thanks to reduced production times
- 100% eco-friendly HTPE and fully recyclable materials*

**Refers to the end-of-life phase of Life Cycle Assessment (LCA) evaluation*

Technology

Electrical performance of HVDC cables depends on electrical resistivity of the insulation, which is a function of temperature, electrical field intensity and space charges distribution. The presence of space charges can significantly affect the electrical properties of the cable insulation system, limiting the possibility of having stable and therefore reliable performance of the insulation at the highest voltage levels (which are increasingly required in the market).

HPTE technology doesn't require chemical reactions to achieve the properties needed for long-term electrical integrity of HVDC insulation systems. It is also suitable for **very fine filtration** during the insulation phase, just upstream of the extrusion crosshead. This feature helps **avoid by-products**, making this the most simple and effective solution against the well-known problem of space charge traps created by the by-products themselves, as proved by P-Laser performance under high electrical gradient at high temperature.

Due to the thermoplasticity of HPTE material, the ambers generated by scorch are also completely absent, with advantages for cable reliability and for practical aspects. It is, in fact, possible to carry out a very long production campaign and with a very high level of filtration, without the risk of affecting cable quality.

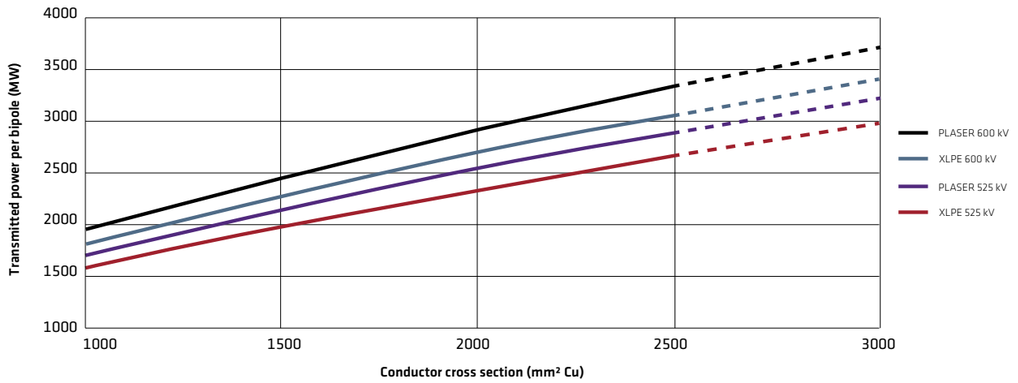
Performance

Extensive laboratory tests showed that in general, P-Laser performance based on HVDC yielded better results than XLPE-based insulation materials, both in terms of accumulation of residual space charge under voltage, and dielectric behavior under high electrical gradient at high temperatures (**with conductor temperature up to 90°C**).

The main advantages are:
- The option to use both with VSC and LCC converter technology
- Higher transmittable power
- Reduction of cable cross-section
- Avoiding hotspot issues along the route
- Use of cheaper aluminum conductors instead of copper

New frontiers for Power Transmission

The new breaching results achieved for HVDC allow the transmission of high powers through long distances, opening the field for new projects and interconnections. The graphs show typical rating curves in specified ambient conditions[1].

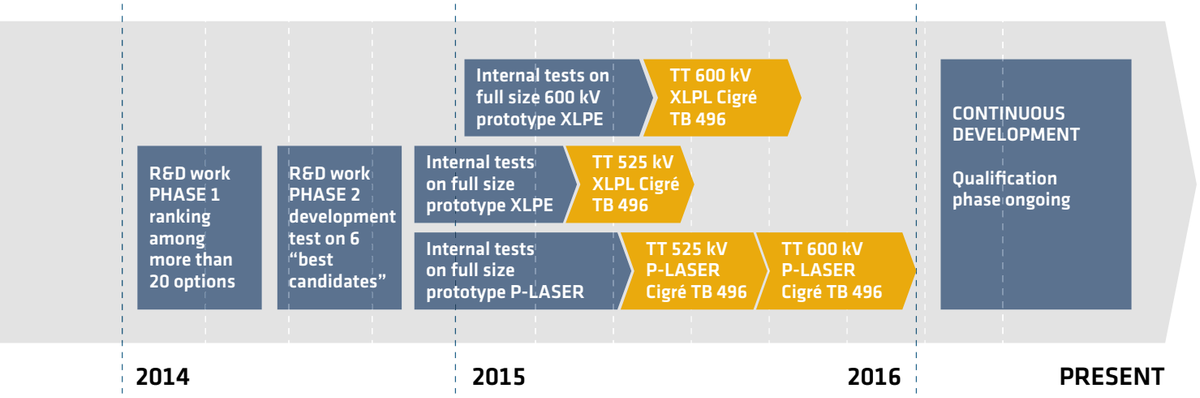


1) Assumed data: ambient temperature 15°C; burial depth 1.5 m; spacing between cables 20 m; soil thermal resistivity 0.8 m K /W

The Technology Boost

The development of HVDC cables for voltages **up to 600 kV** started from Prysmian's wide experience, which relies on knowledge gained from different aspects of cable manufacturing, ranging from **AC** to **DC applications**. The time between selecting the best new insulation and raw materials, to creating final full-sized qualified cables took less than 3 years, thanks to in-house thanks to in-house R&D, material compounding and HVDC testing laboratories.

Innovation Milestones



Main Projects

Offshore windfarms connections

HELWIN 1 (North Sea)
The project involved supply, installation and commissioning of an HVDC connection of approximately 130 km for subsea and land cable types at a voltage of ± 250 kV DC along a 85 km sea route passing to the east of Helgoland continuing along a 45 km land route to the land converter station in Büttel, north-west of Hamburg.

HELWIN 2 (North Sea)
Prysmian supplied and installed 130 km HVDC connection at a voltage of ± 320 kV DC to link the the offshore wind park Amrumbank West with a 690 MW cable connection to the mainland Germany land converter station in Büttel, north-west of Hamburg.

SYLWIN1 (North Sea)
The project marks a series of significant milestones, being the highest ever rated system for VSC technology, with a power rating of 864 MW, operating at the highest commercially available voltage level of ± 320 kV DC and employing an extruded cable connection along a total route of approximately 205 km (160 km offshore and 45 km onshore).

BORWIN 3 (Germany)
The project involves supply, installation and commissioning of a High Voltage Direct Current (HVDC) 320 kV extruded submarine and land power bipole connection with a rating of 900 MW and associated fibre optic cable system, comprising of a 29 km land route and of a subsea route of 130 km.

Submarine interconnections

TOTAL KM OF CABLE INSTALLED

- EXTRUDED SUBMARINE **1598**
- MI SUBMARINE **4280**

COBRAcable (Netherlands - Denmark)

The most recent HVDC submarine interconnection is the COBRAcable, that will link Denmark and the Netherlands. It will use single core cables with extruded insulation technology that will operate at a voltage level of ±320 kV with a rating of approximately 700 MW, equivalent to the annual electricity consumption of all households in the cities of Rotterdam and Amsterdam combined. It will run along a total route of around 325 km, from Eemshaven (NL) to Endrup (DK) via the German sector of the North Sea, and will include two onshore lengths of 1 km on the Dutch side and 25 km on the Danish side to link to the onshore converter stations.

Trans Bay Cable (USA)

Prysmian installed the first HVDC submarine interconnection in 2009, the Transbay cable project. It's the first turnkey system that includes the engineering, production and installation of two 200 kV DC cable interconnections, consisting of 80 km of extruded submarine cables and 5 km of extruded land cables (AC and DC), with a total transmission capacity of 400 MW.

Land interconnections

TOTAL KM OF CABLE INSTALLED

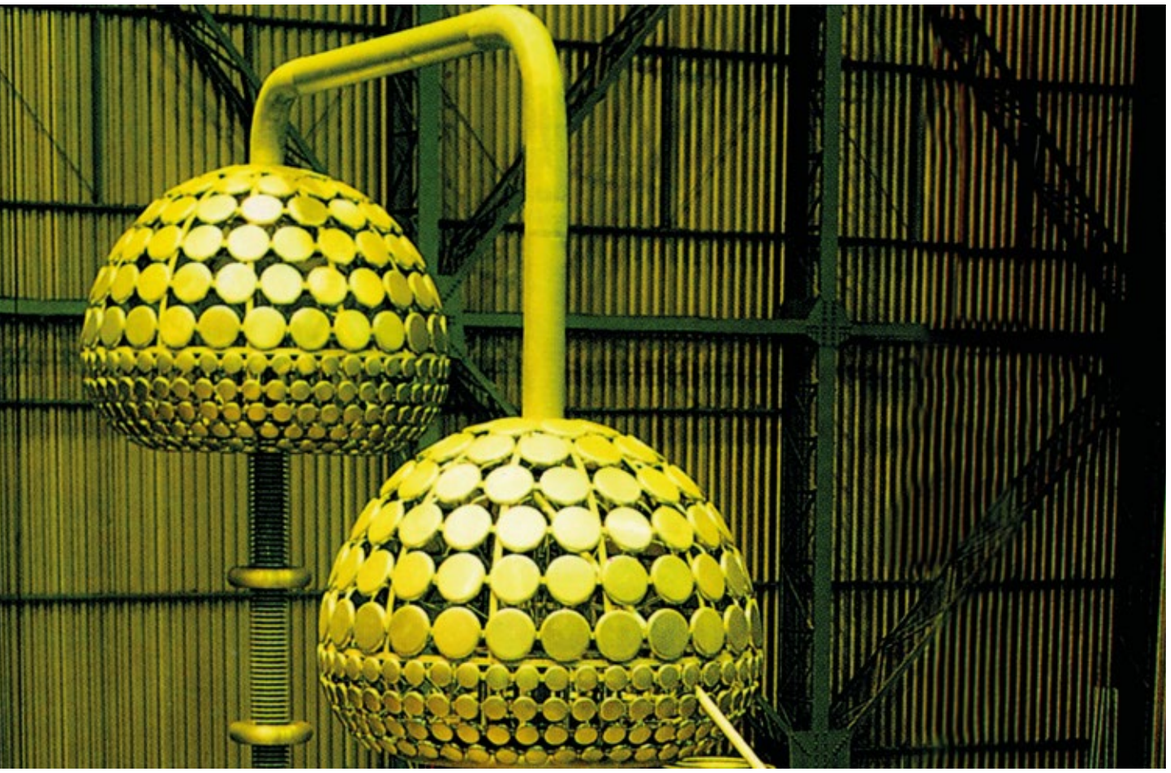
- EXTRUDED LAND **2479**
- MI LAND **320**

INELFE (France - Spain)

A world record for underground interconnection transmission capacity, with the highest direct-current voltage level ever achieved with cables using extruded technology. The project comprises 252 km a ± 320 kV extruded HVDC underground cable turnkey system that includes the engineering, production and installation of two 1,000 MW bipolar circuits along a 64 km land route .

PIEDMONT – SAVOY (Italy - France)

With a route of approximately 190 km through the Alps, it is the longest HVDC link ever realised and will enable increasing transmission capacity between the two countries up to 1200 MW. The project comprises of a ± 320 kV extruded HVDC underground cable turnkey system that includes the engineering, production and installation of two 600 MW bipolar circuit.



HVDC laboratories

From Research & Development to Product Qualification

Prysmian Group can count on **around 25 R&D excellence centres** located worldwide, many of which are equipped with HVDC test bays and mechanical test benches.

These in-house test facilities allow Prysmian to constantly work on identifying new materials and/or technologies for HVDC applications. Most cable systems are also custom-designed to suit the specific environmental parameters and operating requirements of specific route and installation conditions. Prysmian products are designed to meet the service-life duty and to comply with the applicable requirements, such as Pre-Qualification Test and Type Test approvals, given against each product type available.

The **Electrical Laboratories** study, design and perform tests focused on evaluating the electrical behaviour of cables, accessories, and other components. A challenging number of different tests can be performed: voltage levels (**up to 1,600 kV DC**), different waveforms and impulse levels, different parametres (temperature, pressure, current, etc.) and physical properties (conductivity, dielectric loss angle, permittivity, space charges, partial discharges, etc.) can all be measured and monitored.

The **Mechanical Laboratories** are supplied with heavy equipment for mechanical tests on submarine cables. During installation, submarine cables are subject to mechanical stresses that depend on the installation method, cable weight, water depths and weather conditions. This can result in high pulling forces and severe bending that the cable has to withstand. We can perform pulling tests **up to 100 t** and bending tests over a wheel **up to 6 m diameter**.

Test procedures and equipment are guaranteed to be **always aligned to the state-of-the-art Standards and Technical Recommendations** developed by international scientific bodies - such as IEC and CIGRE. Prysmian can in fact rely on a long-standing tradition of participation and on a strong presence within such bodies, acquired thanks to its undisputed expertise developed during project execution everywhere in the world.

Quality excellence in action

We deliver **market-leading quality** and **excellence** around the world, thanks to rigorous monitoring processes at every single stage of a product's lifecycle. From the procurement of raw materials to the delivery of the finished article; from supplier selection to strict quality testing and certification; and from our '"zero defects" to our "right first-time" approach to everything we do.

We have numerous **polices** and **processes** in place that guarantee **best practice** and deliver added value across the Group and our business locations and manufacturing sites. Operation units are certified according to **ISO 9001** and **ISO 14001 Quality Management System international standards** for their specific activities and products, and environmental quality standards.

Sustainability

At Prysmian, **sustainability** is an **all-encompassing concept**. It influences the entire lifecycle of every product: from the research and development of innovative and sustainable solutions, to the most technological power link.
This contributes to the steady industrial development of the sectors in which we operate. Our products are vital to a sustainable world. They are used to construct **major wind and solar farms**; for infrastructure that accelerates the flow of information and communications worldwide to reduce energy losses; and in terrestrial and submarine electricity links that improve the efficiency of entire power networks.
We are aware of this responsibility throughout the entire lifecycle of each product, from design to delivery, and constantly monitor performance against specific standards. We are continuously developing **innovative and technologically-advanced solutions** that meet, and often anticipate, the needs of our partners and end users. We are strongly oriented towards the creation of value for all stakeholders. Day after day, we draw inspiration from the concepts of customer centricity and value creation for shareholders.

Global Solutions Provider

The energy market has been changing dramatically in recent years, as a result of deregulation and privatisation. To face the challenge of competition, Transmission Systems Operators (TSOs) are optimising their existing resources and new investments.
To support its customers, Prysmian has evolved over the years from the traditional role of cable manufacturer to that of a **Global Solutions Provider**.

Prysmian focuses on a total system approach, to give its customers the lowest cost of ownership for their new and installed cable networks and to provide them with real advantages in terms of asset optimisation.

Besides increasing activity on product innovation to lower investment costs, Prysmian is developing additional pre and post sales services for its customers - including network services, enhanced logistics and engineering studies - to optimise **asset management** and give the best possible utilisation of transmission and distribution networks.

Following this philosophy, Prysmian provides complete **turnkey solutions**, including cable installation, which makes it possible to employ its own fleet without having to rely on external contractors.

The Group relies on a fleet of **three world-class vessels** - Giulio Verne, Cable Enterprise and Ulisse - as well as its extensive range of well-proven in-house cable protection equipment to provide an extended and strengthened submarine cable installation capability.

Thanks to our focus on technological innovation and our project execution capabilities, Prysmian plays a leading role in partnering with customers in the strategic sector of HVDC submarine cable transmission systems.

GIULIO VERNE

OUR STATE OF THE ART CABLE-LAYING FLEET

KEY FEATURES:
- DP2 cable lay vessel
- 7,000 tonne carousel
- Bundled cable lay capability
- Simultaneous laying and burial capabilities
- Conducted the world's deepest power cable lay at 1,650 m water depth

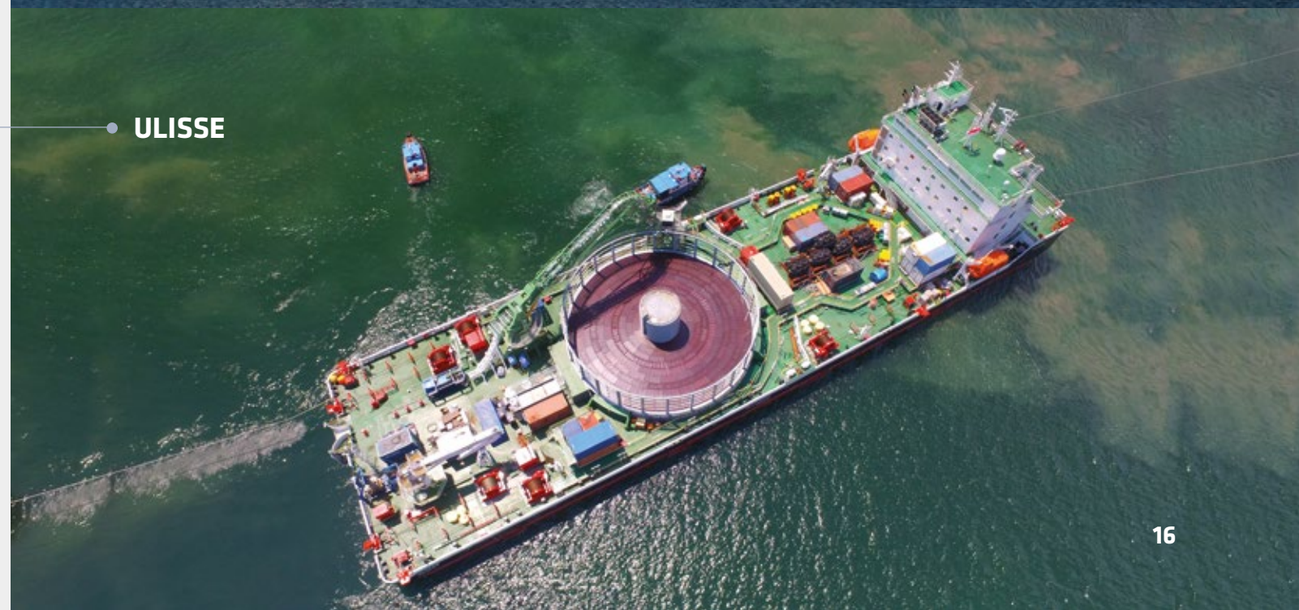
EXTRUDED HVDC REFERENCE PROJECTS
- BorWin 2
- TransBay
- Sapei
- Helwin 1 & 2

CABLE ENTERPRISE

KEY FEATURES:
- DP2 cable lay barge (DP2 conversion in 2015)
- 4,300 tonne carousel
- Bundled cable lay capability
- 180 tonne pull ahead winch for ploughing operations
- Ability to ground output

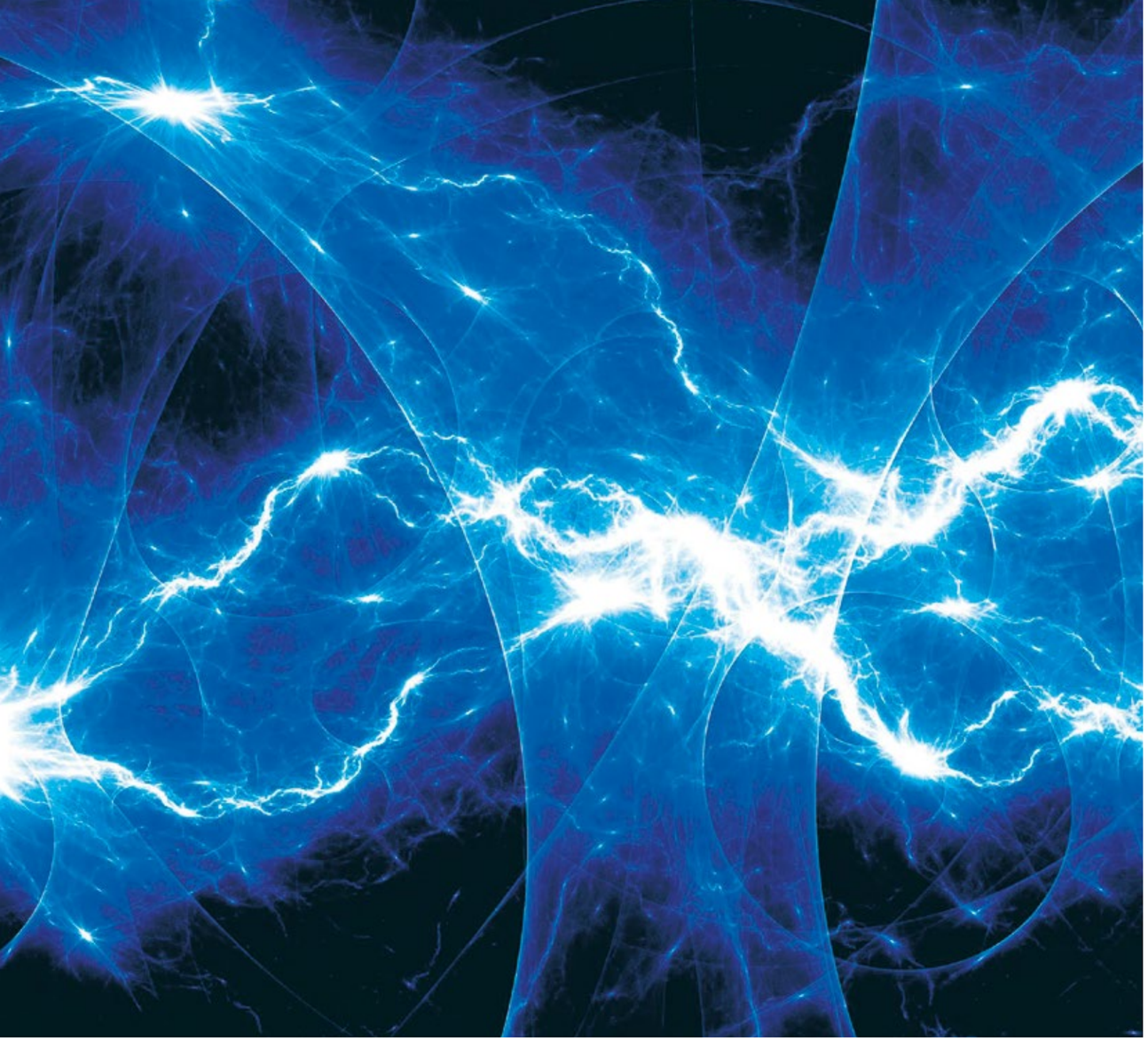
MAIN EXTRUDED HVDC REFERENCE PROJECTS
- BorWin 3
- DolWin 3
- COBRAcable

ULISSE



KEY FEATURES:
- 7,000 tonne carousel
- 8-point mooring system
- Bundled cable lay capability
- Ability to ground out

EXTRUDED HVDC REFERENCE PROJECTS
- COBRAcable



Asset Management Services

Partial Discharge (PD) is a form of measurement that is crucial when assessing the condition of electrical systems because it helps us identify a very high percentage of potential faults. In fact, it's one of the critical parameters evaluated during product manufacture, installation and normal operation.

PRY-CAM

Prysmian has developed a piece of breakthrough technology that allows wireless sensing and monitoring of PDs. The **Pry-Cam HVDC** monitoring system employs two PD sensors , which are placed along the component that is to be monitored. By comparing the arrival time of the pulses to the sensors, the pulses coming from outside the component (noise) can be distinguished from the pulses originating inside the component (real PDs) with a high level of reliability.

POWER LINK
CABLE SOLUTIONS
Always on your business

Powerlink Cable Solutions is the result of the Group's subsea cables know-how, cutting edge technologies, deep water installations and maintenance capabilities.
All integrated in a one-stop service provider package. Thanks to our technologies and asset management services, we improve effectiveness in the event of a power outage, and reduce costs for our clients.

Permanent Surveillance

Damage prevention. Real-time fault detection.
Cable protection begins with the comprehensive and continual surveillance of conditions. Power Link Cable Solutions offers a complete set of cloud-based asset monitoring systems, providing **24/7 remote control** of subsea cables, and a **full team of Prysmian specialists**, capable of reading and interpreting any collected data. This service represents a revolution in asset management, as it features non-invasive measurement and provides accuracy and deep diagnostic information. It also includes programmed intervention to prevent any faults and system malfunctions. Prysmian's cable monitoring systems are based on PRY-CAM solutions: a set of cutting-edge products for condition-assessment and asset management that incorporates state-of-the-art monitoring technologies.

Preventive Maintenance

Dedicated marine base, fully equipped for all needs.
Preparation is key when providing effective and fast maintenance. That's why Prysmian has established a **marine base in Middlesbrough**, UK, fully equipped with all that is needed for maintenance interventions, including spares storage and management.

- Multiple sheltered storage areas for cables and accessories
- Easy access to the facility from sea for easy loading/offloading of spares and equipment
- Accessibility to service providers for VOO mob/demob and for survey equipment/services
- Additional planned and recurring surveys that verify the state of the system and rectify any possible issues that could lead to future cable faults.

Immediate Repair

Fastest repair times, guaranteed.
Every single day of outage means costly losses. So reducing downtime is vital. Prysmian has the capability to react promptly, thanks to a dedicated task force located at a marine base on the UK East Coast.
Following the notification of an interruption of power availability to Power Link Cable Solutions' **24/7 call centre**, Prysmian crews are able to mobilise the **DP2 vessel** within just 5 days, so it can arrive at the required destination within an additional 2-3 days.
That means we are ready on-site in no more than 10 days.
And, thanks to in-house resources and personnel, Prysmian is able to perform all repair activities more quickly and efficiently than anyone else in the industry.

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