Prysmian Group

66 kV Submarine Cable Systems

FOR OFFSHORE WIND

PRYSMIAN
Draka
General Cable

Prysmian Group

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?

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 transmitting and distributing 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 minimize 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.

Prysmian 66 kV array cable systems

Renewable energy resources are abundant, inexhaustible and have the potential to fully meet global energy needs while reducing emissions and mitigating climate change.

Offshore wind is an essential component of renewable energy which is significantly improving its cost competitiveness over the last few years. Nevertheless **wind farm developers are always looking at ways to reduce Levelized Cost of Energy (LCE).**

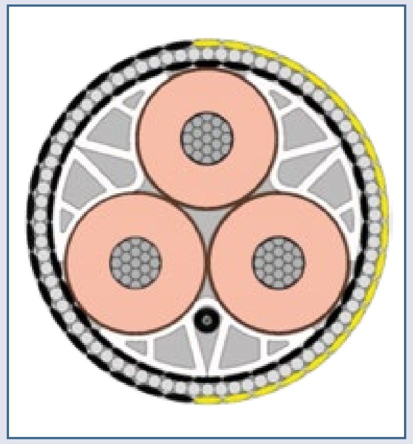
Among the technology developments enabling LCE reduction several independent studies have shown that use of **array cables operating at 66 kV instead of 33 kV** presents considerable advantages on typical offshore wind farm systems.

The main cost reduction drivers for using 66 kV, instead of 33 kV whilst maintaining the same overall output power, are:

- **Two times more power** can be transported over a single array cable, which reduces the length of cable required and consequently the investment in these cables and their installation.
- **Lesser number of cables** are entering the offshore substation, therefore the number of J-tubes, transformers and switches, as well as the space these items require can be reduced.
- **Larger turbines unit power** to reduce the number of turbines and associated array cables

Offshore wind applications require high reliability cables with easy installation at a competitive cost. Prysmian's aim is to provide the offshore wind industry a **proven cable design with a long-standing track record of operating systems** as well as with the lowest impact for the installation teams.

Typical 66 kV cable design for offshore wind



Conductor	Copper or aluminum conductors longitudinally water blocked
Conductor screen	Extruded semi conductive compound
Insulation	EPR
Insulation screen	Extruded semi conductive compound
Screen	Individual Cu-tape screen on each phase
Fibre optic unit	Up to 3 FO units with metal tube
Lay up	Three power cores laid up with extruded fillers
Armour Bedding	Polypropylene yarns
Armouring	One layer of galvanized steel wires, flushed with bitumen
Outer protection	Polypropylene yarns in customisable colours

Prysmian Group carried out a **comparison** among three 66 kV submarine array cables with 800 mm^2 aluminum conductors **in order to assess the different designs available for this market.**

Current rating for the three cable designs has been calculated under the same ambient conditions:

Design	Weight (kg/m)	Overall diameter (mm)	Transmission power (MVA)
Dry	**57,9**	**183**	**90**
Semi-wet	**39,4**	**175**	**90**
Wet	**36,2**	**163**	**90**

Table 1: *Comparison of three possible 66 kV array cable designs*

Where
- Dry design is a cable with an extruded lead sheath over insulation
- Semi-wet/Semi-dry design is a cable with a PE sheath over a non-fully impervious metallic screen (e.g. metal tapes or thermoglued foils)
- Wet design is a cable without any polymeric sheath over a non-fully impervious metallic screen (e.g. metal tapes)

Insulation material of 66 kV cables operates at higher electric stress than 33 kV cables, requiring rigorous cable design and insulation material selection.

Therefore, **Prysmian's 66 kV array cable is based on wet design EPR insulation, with 50 years successful operational experience up to 72.5 kV**, which is a reliable and cost effective solution for offshore cable systems.

The **technical features of these cables are outstanding**, with no equal among any other cable insulation types at this voltage level.

Prysmian EPR insulated cables are compatible with Prysmian's full range of accessories including Click-Fit®, Elaspeed™ and hang-off systems.

EPR insulated cables

Background

EPR insulated cables are covered by the **IEC standards** and by many **National Standards** worldwide, with **successful operational experience** in several countries **at voltages up to 150 kV**.

Natural rubber-based compounds were the only polymeric materials used as cables electrical insulation from the middle of the 18th century until 1930s, when the first suitable synthetic materials became available. During the following years, new technologies boosted the development of new rubber based insulations with better characteristics for the cable industry.

In the **early sixties** the inventions of Carl Ziegler and Giulio Natta (who were awarded the Nobel Prize) enabled the manufacture of Ethylene Propylene Rubber (EPR). A few years after this breakthrough, the **first EPR insulated cables appeared in the market and since that time they have achieved an excellent track record in terms of operational reliability**.

Utilising the natural qualities of EPR, **Prysmian Group** strove to enhance its performance and **achieved the development of a suitable compound for wet-design cables**.

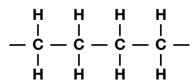
Use of **EPR insulated cables** reached its **peak** during the **seventies and eighties following the failures** in service **caused by water treeing phenomenon** in the first generation **of polyethylene insulated cables. Utilities have been using EPR insulated cables for submarine and land cables up to 170 kV for more than 40 years**.

Nowadays the use of EPR insulated cables is preferred for applications requiring superior mechanical and thermal performances including industrial, oil and gas, nuclear, submarine, and renewables systems.

Most premoulded type accessories for EHVAC and HVDC cable systems are also made of EPR.

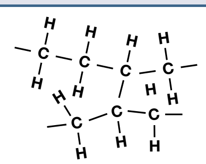
Chemical structure of LDPE, XLPE and EPR

Low Density Polyethylene (LDPE)
Polyethylene consists of a sutured chain of carbon atoms. A section of the long chemical chain of LDPE is shown in figure A1. In LDPE there are significant numbers of side chains which limit the crystallinity and density of the material.



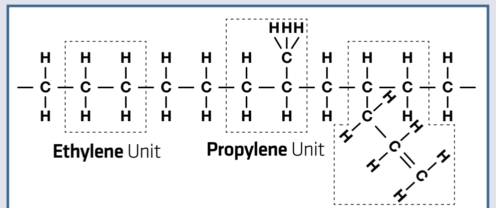
A1 - ***Structure of low density polyethylene***

Cross Linked Polyethylene (XLPE)
Cross-linking of the compound to form XLPE is achieved by a chemical reaction at elevated temperatures. The links of bridges between chains connect the whole structure together preventing the normal melting from taking place. Figure A2 shows the site of a cross-link in the structure.



A2 - ***Structure of cross-linked polyethylene***

Ethylene Propylene Rubber (EPR)
Other terminology which may be encountered includes EPDM and EPM. EPR'S are the EPDM type (shown in figure A3), and include fillers and other additives to optimise electrical performance. The polymer chains in the compound are chemically cross-linked in the same way as XLPE.



A3 - ***Structure of EPDM***

Prysmian EPR insulation compound, although being based on a **proprietary formulation**, can be **duly fingerprinted to ensure its compliance** with the qualified compound.

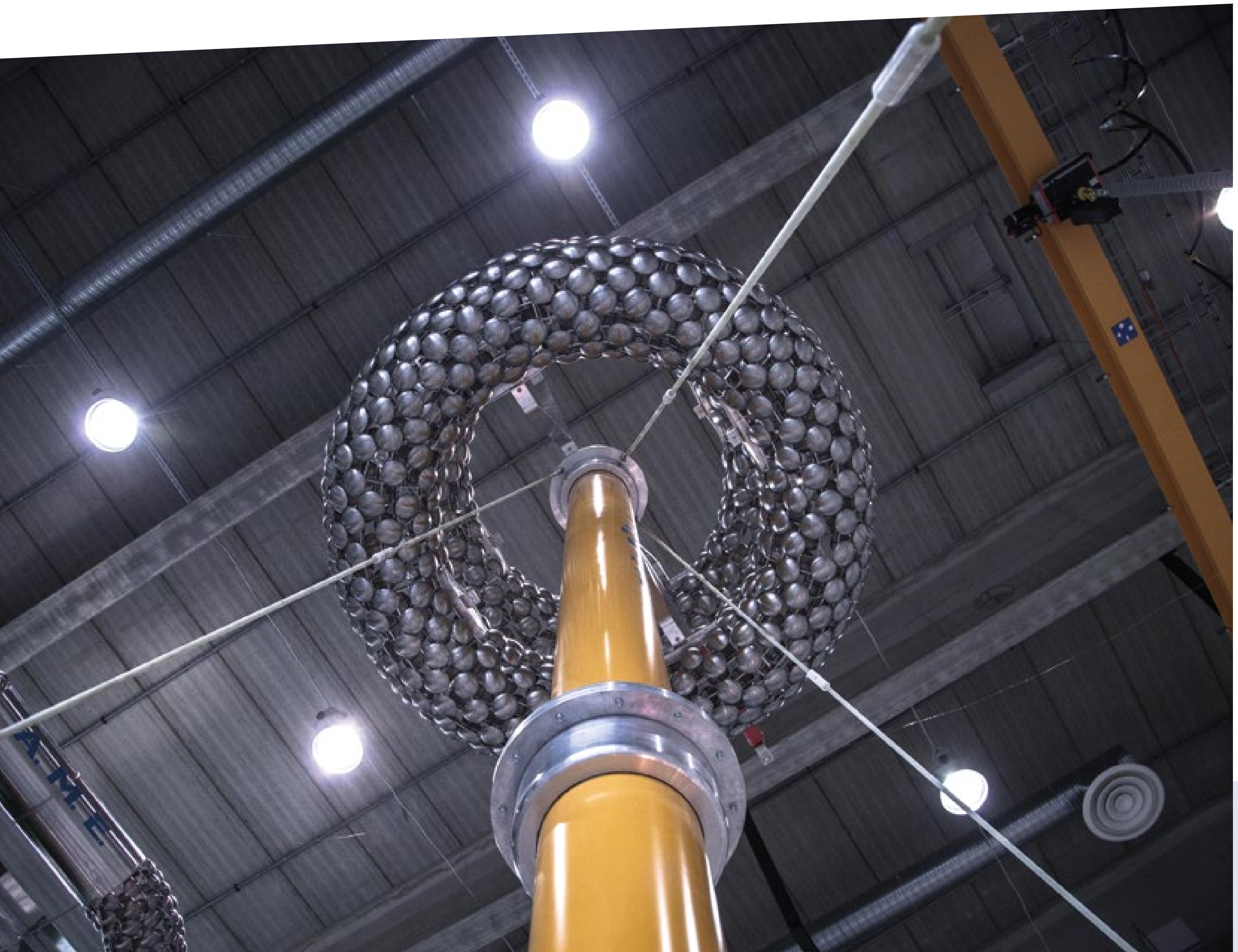
Performance

Cable performance under current overload

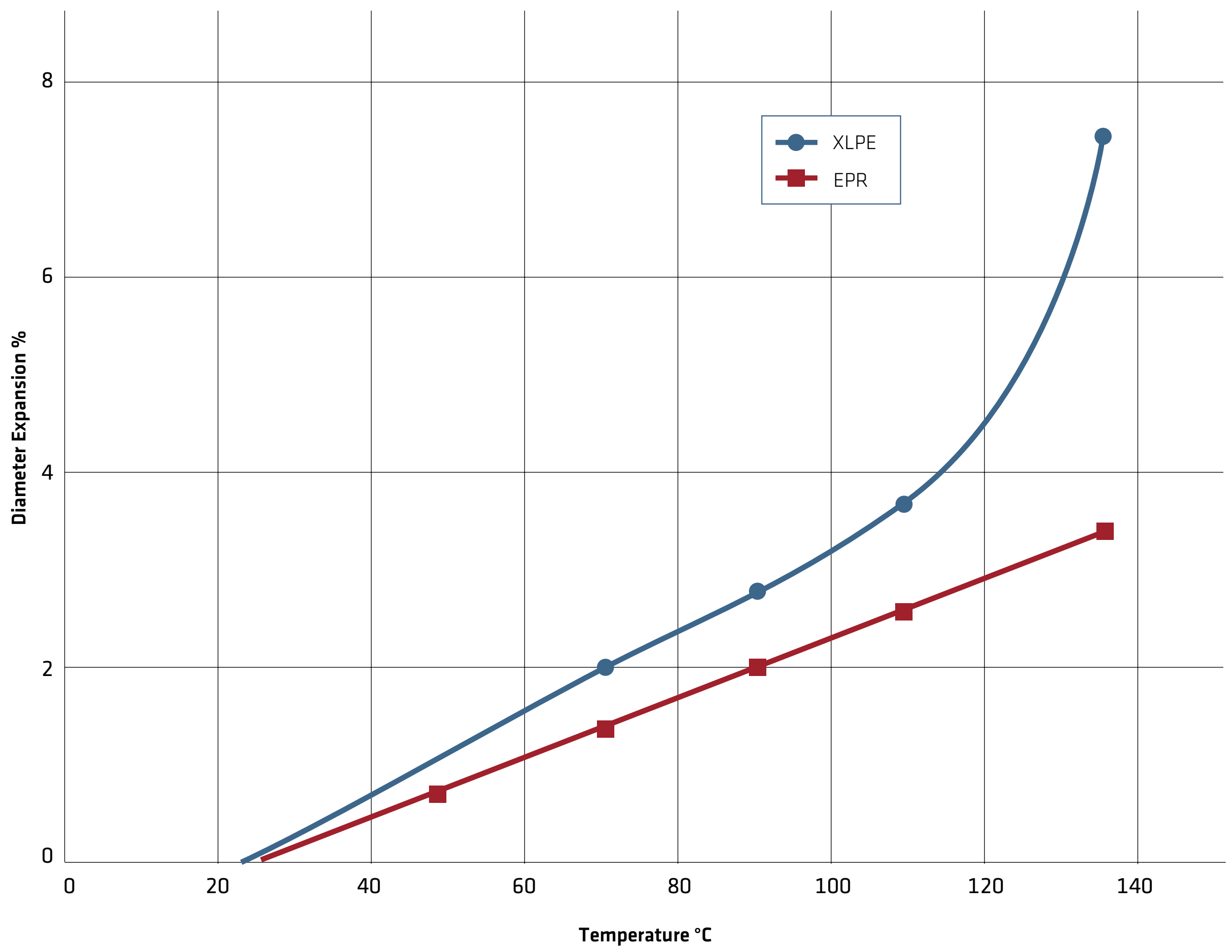
The major cable problem resulting from **current overload** (generally due to emergency operation, fault or short circuit) is that the **heat generated can damage the cable and reduce its life**. EPR and XLPE have the same nominal conductor operating temperature, i.e. 90 °C, but can withstand different overload current because of the differing high temperature properties of the compounds.

EPR is a highly amorphous compound with little crystal structure, and its **physical properties are little affected by temperature increases up to 130 °C**. XLPE has a lower crosslink density than EPR and relies for its strength and its ability to maintain its original shape on its crystalline structure. When the temperature exceeds 90 °C XLPE begins to undergo "crystalline melting" which makes the compound soften, deforming more easily and reduces its tendency to return to original shape. **XLPE** is thus far **more likely to incur damage when temperatures are elevated above standard operating conditions.**

The lower level of expansion of EPR reduces risks associated to physical stress in the cable, against external restraints, or other cable system components.



Diameter expansion of 150 kV EPR and XLPE insulated cables



Cable performance during over-voltage

Over-voltage performance is usually tested by "impulse testing" of cable samples at room temperature.

Results clearly show **XLPE to have a peak voltage breakdown level some 20-30% higher than EPR**, with both stresses being well above the operating levels. **However** the effect of raising the temperature of the cable sample to the upper operating ranges is marked and shows once again the **resilience of EPR compared with the degradation of performance of XLPE**.

The next chart shows the results of **peak voltage testing** of XLPE clearly demonstrating the **small difference in performance between EPR and XLPE at high temperatures**.

It is worth noting the **outstanding results achieved for 20 m samples of 250 mm² 145 kV Prysmian EPR cables** manufactured with the latest technologies. The average breakdown voltage for these cables was **88 kVp/mm at 95 °C, better than most results for XLPE.**

AC withstand voltage and expected reliability

AC over-voltage testing however gives a different picture for the breakdown levels as RMS voltages are usually considered.

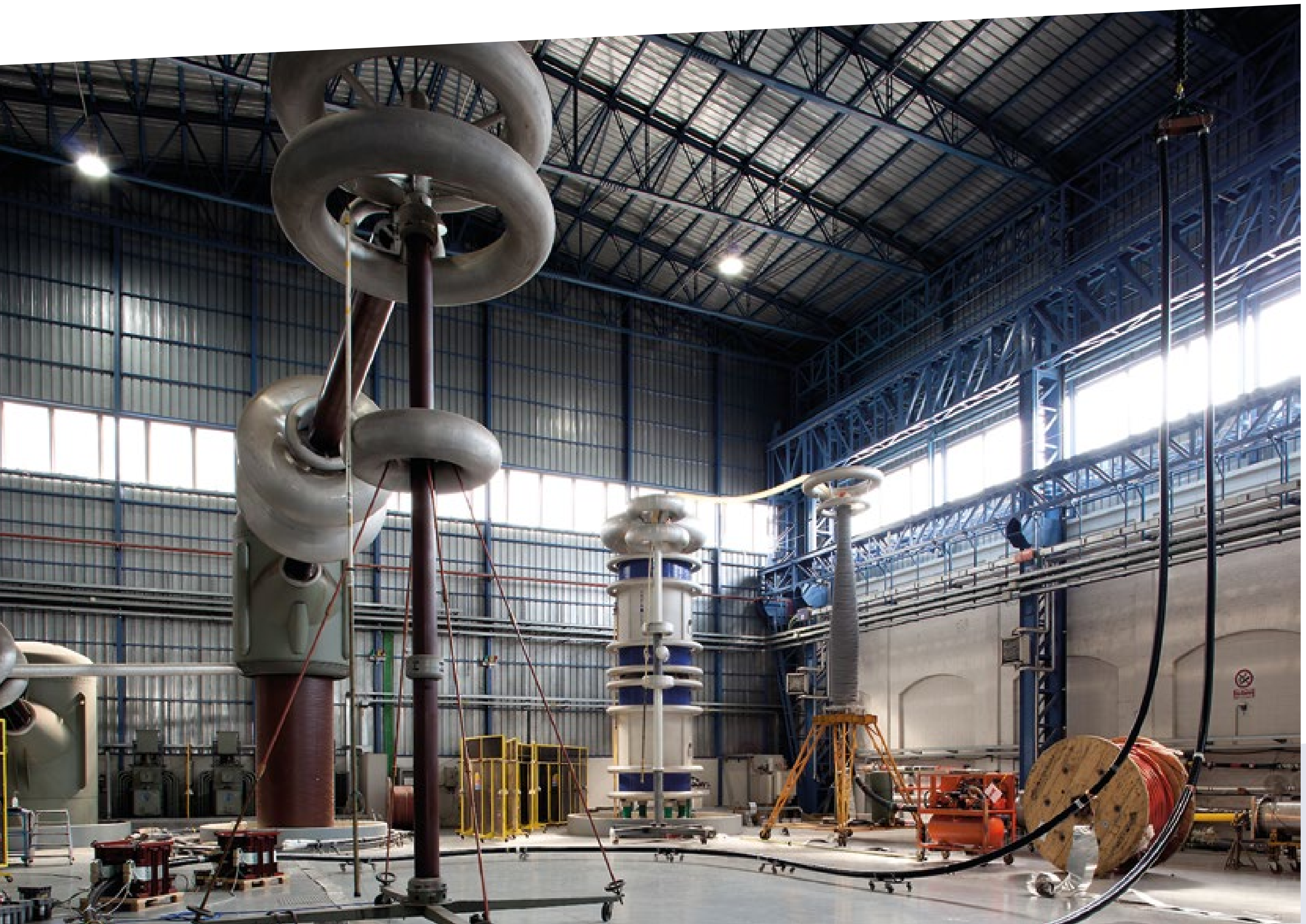
The breakdown test is generally carried out on a standard test cable, 20 m long with a 70 mm^2 conductor and rated at 12/20 kV. Once again **XLPE is seen to have higher breakdown stresses than EPR**, 60-70 kV_{rms}/mm compared to 50-55 kV_{rms}/mm, **but XLPE exhibits far greater scattering of results**.

The consequence of this scattering is only apparent when different dimensions of cable are tested. With **increasing length and conductor radius the breakdown voltage of the cable system falls more rapidly than that of EPR** because of the wider spread of results (in a larger cable it is more likely that there will be some part of the cable that will fail at a lower stress).

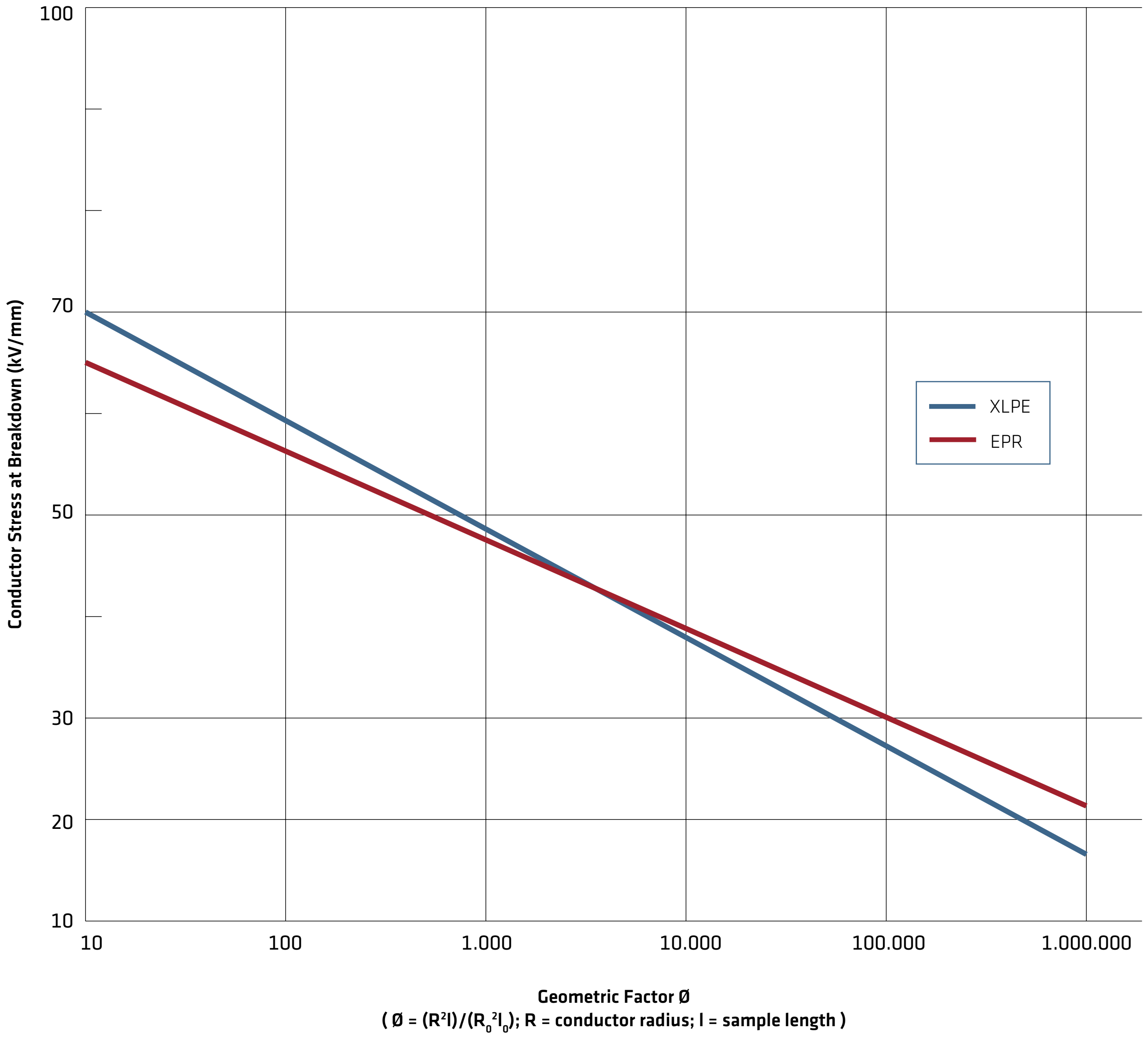
The test parameter "b" is used to describe the amount of scatter of results (Weibull theory) with high scatter giving a lower value. The band of scatter for XLPE has a median of 10 compared to 14 for EPR and the consequence of this can be seen in the next chart.

The graph plots breakdown voltage against a coefficient proportional to the square of the conductor radius times the length of the sample.

The larger gradient of the XLPE samples show a fall in failure voltage with increased cable size and length. It is clear from this that **the larger the quantity of installed cable and the bigger the cables installed, the greater the reliability of EPR compared with XLPE**.



Short term AC tests on XLPE and EPR



Dielectric losses

XLPE is well known to be a compound which exhibits an **extremely low dielectric loss** and the more pure the polymer, the lower the losses. **EPR has a somewhat higher dielectric loss, but at 66 kV the effect on current rating is negligible** (less than 0.3% of current rating difference on a typical 66 kV array cable when considering either XLPE or EPR).

Installation

The first stage in using a cable is obviously **installation**, and a **primary reason for the move from paper to elastomeric insulated cables is ease of installation and handling**.

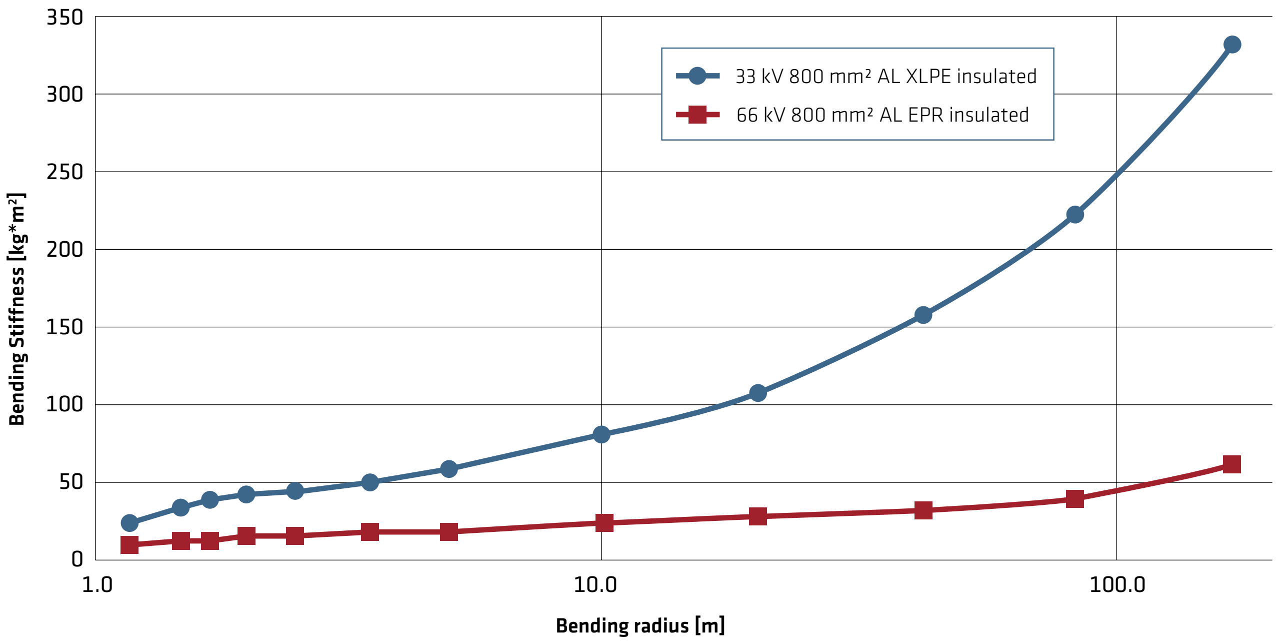
The use of an **appropriate elastomeric insulation removes the necessity for a metal sheath, thus considerably simplifying cable installation**.

EPR has the advantage of an elastic modulus lower than XLPE which makes it **easier to install, particularly if the operation has to be undertaken in restricted spaces** (such as underground passages, ducts or offshore structures), or into internal switchgear. **Increased flexibility** of the cable core could be a **significant advantage** to the jointing and termination operations where careful alignment is necessary in a limited space.

The **reduced external bending forces** in an EPR insulated cable also **reduce the internal stresses** between insulation and screen which, in extreme cases, could cause problems with the formation of voids.

Joints and terminations are generally the same as those used for installation of XLPE cables, hence **minimising the need for jointer training**.

Bending stiffness at slide speed of 10 mm/sec for different bending radii



Dynamic cables

Example of 46 kV submarine dynamic cable

The economical exploitation of **oil fields** in deep water is generally achieved by means of **floating platforms**.

Floating structures are not yet widespread in offshore wind farms **but several concepts** and some **pilot projects** have been **deployed in recent years**.

These early applications are **encouraging the study of larger full scale floating offshore wind** turbines.

The submarine cables intended for these applications, require superior fatigue resistance and better mechanical performance.

Prysmian Group has gained significant experience with dynamic cables to connect Oil & Gas floating platforms, **based on EPR insulation**.

Accessories

Prysmian **EPR insulated cables are compatible with Prysmian's full range of accessories including Click-Fit®**.

All products within the Click-Fit® range - including outdoor terminations, joints, Y (branch) joints and GIS/Transformer connectors - are **based on the Click-Fit® "Plug&Power" concept** for high voltage extruded cable accessories that enables **optimum ease and speed of assembly, maximum reliability and maintenance-free operation**, by ways of factory prepared (identical) cable ends.

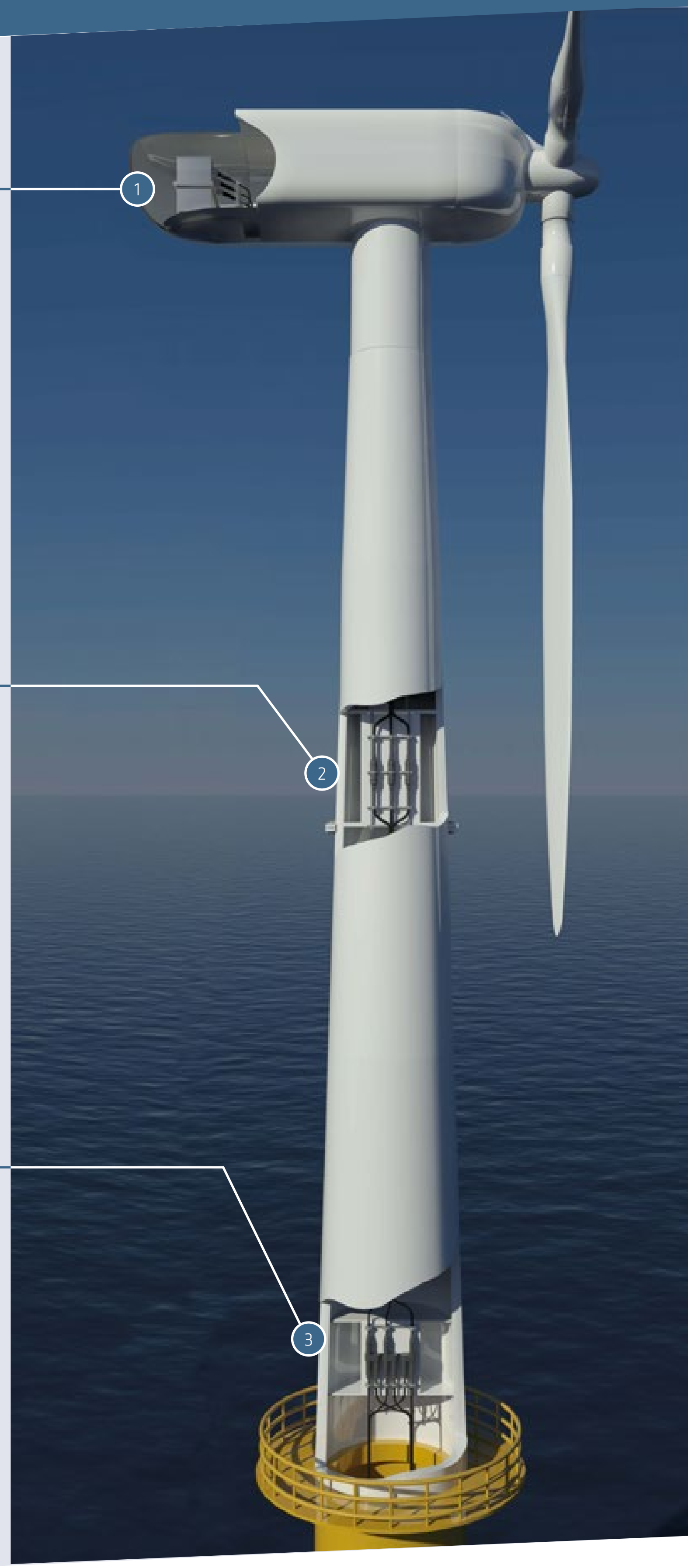
To **minimize offshore installation times, cable ends can be prepared onshore** and then installed and clamped inside the offshore turbine.

The 66 kV Turbine Click-Fit® cable connections can be divided into three main groups of dry-type accessories: **Click-Fit® Connector type CFC(O)-72 (Compact), Click-Fit® Joint type CFJ-72 and Click-Fit® Branch (Y) joint type CFYJ-72**.

1. Click-Fit® Connector type CFC(O)-72 (Compact)
It is designed to connect extruded high voltage cables with Switchgears (GIS) and Transformers. This connector can be installed in any position, regardless of the orientation of the system's configuration. The epoxy socket insulators can be pre-installed in the factory, thus avoiding offshore oil or gas treatment.

2. Click-Fit® Joint type CFJ-72
This straight joint type is designed to connect two extruded high voltage cables. It can be installed in any position, regardless of the orientation of the system's configuration. After completion of the installation, the cables need to be fixed with clamps. Different cable and joint clamps are available on request.

3. Click-Fit® Branch (Y) joint type CFYJ-72
It is designed to connect three extruded high voltage cables, such as inter array subsea cables, to the tower cable. Y-joints can be installed in any position, regardless of the orientation of the system's configuration. After completing the installation, the cable needs to be fixed with clamps. Different cable and joint clamps are available on request.



More than 40 years of experience

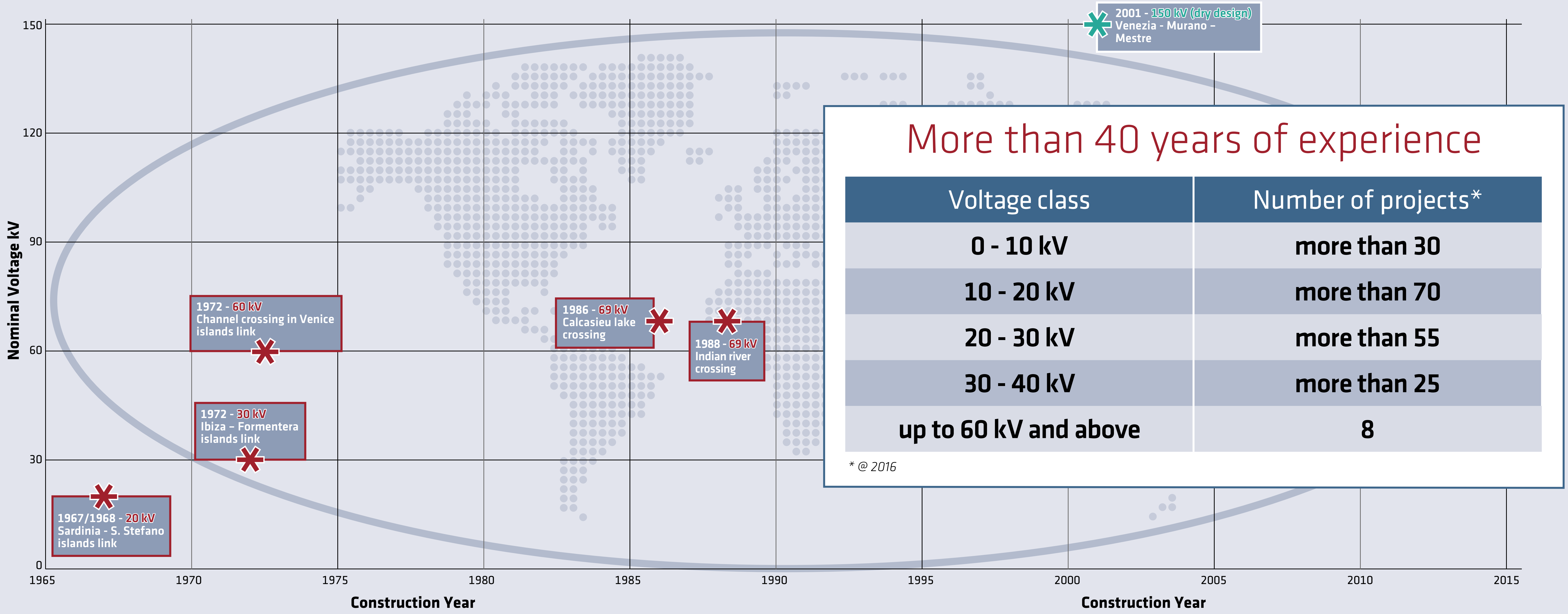
The **application of EPR** has varied widely, from industrial locations where **flexibility is the key**, to wet-design submarine cables where **reliability and performance** are the key criteria.

Prysmian Group experience with EPR insulated cables dates back to the **early sixties**.

In the last 50 years **more than 200 submarine cable circuits** have been installed worldwide with excellent operational results.

The only 72.5 kV class wet design systems with more than 40 years operational experience are EPR insulated.

Prysmian service experience with submarine wet design EPR insulated cables



More than 40 years of experience

Voltage class	Number of projects*
0 - 10 kV	more than 30
10 - 20 kV	more than 70
20 - 30 kV	more than 55
30 - 40 kV	more than 25
up to 60 kV and above	8

* @ 2016

An outstanding track record

Historical Milestones

- "Sardinia - S. Stefano" islands link - ENEL, Italy (1967/1968) - 20 kV, 3x50 mm^2
  First EPR supply (wet design)
- "Ibiza - Formentera" islands link - GESA, Spain (1972) - 30 kV, 3x50 mm^2
  First 30 kV (wet design)
- "Channel crossing in Venice" - FF.SS., Italy (1973) - 60 kV, 1x120 mm^2
  First 60 kV (wet design)
- "Calcasieu lake crossing" - Jefferson Davis Elec. Corp, USA (1986) - 69 kV, 1x350 MCM
  First 69 kV (wet design)
- "Venezia - Murano – Mestre" - ENEL, Italy (2001) - 150 kV, 1x1000 mm^2
  First 150 kV (dry design)

Other key projects

- "Lanzarote – Fuerteventura" - Unelco Endesa, Spain - 60 kV 3x300 mm^2 + 48 F.O.
- "Nantucket Island I & II" - New England Power Co., USA - 46 kV, 3x500 MCM+48 F.O.
- "Indian river crossing" - City of Vero Beach – Florida, USA - 69 kV, 1x750 MCM
- *Tidal*
  "Minas Basin" - ITT TELECOM/FORCE, Canada - 34.5 kV 3x120+1x4 pilot cable + 12 F.O.
- *Static & Dynamic*
  "Exxon Mobil Santa Ynez (California)" – Exxon Mobil, USA – 35 kV, 3x1000kcmi / 3x700 mm^2+24 F.O.
- *Offshore wind farms*
  "Gunfleet Sands" - DONG Energy, UK - 33 kV, 3x500 mm^2 and 3x150 mm^2+24 F.O.
  "Thanet" – Vattenfall, UK – 33 kV, 3x95 mm^2; 3x300 mm^2; 3x400 mm^2+48 F.O.
- "Carbon Trust OWA qualification project" – Carbon Trust, UK – 66 kV 3x800 mm^2 Al + F.O.

Carbon Trust 66 kV qualification project

Prysmian Group has successfully type tested its 66 kV cable system in accordance with CIGRE and IEC test protocols, as part of the Carbon Trust's Offshore Wind Accelerator (OWA) programme.

The Carbon Trust is an independent UK company with a mission to accelerate the move to a sustainable, low-carbon economy. The OWA is Carbon Trust's flagship collaborative R&D programme, involving nine offshore wind developers and supported by the UK Department of Energy and Climate Change (DECC) and the Scottish Government, which aims to reduce the cost of offshore wind through innovation, developing innovative concepts into commercial solutions.

To encourage an accelerated development of a competitive 66 kV cable system market, the OWA supported selected cable manufacturers, including Prysmian, with the testing and certification of their 66 kV cable system designs.

Prysmian has type tested a 3-core, 66 kV EPR insulated "wet-design" cable system with 800 mm^2 aluminium conductors and integrated optical element.

The solution includes factory, field joints and plug-in terminations (using proprietary Click-Fit^{TM} technology) and combines the use of state-of-the-art EPR insulation - a material with excellent performance in direct contact with water, with the cost effectiveness of a lighter and lead-free design.

The qualification process was carried out in Prysmian laboratories in the UK and in Italy. 66 kV copper designs are also available from Prysmian; however for this Carbon Trust type test Prysmian considers an aluminium design more onerous, especially with respect to the flexible factory joints.

Although the qualified cable technology is innovative in its application, Prysmian has experience of over 40 years with such "wet design" EPR insulated cables up to 72.5 kV in a wide range of applications.

This success in the qualification of its 66 kV system will provide the necessary confidence to offshore wind developers to reap the benefits by raising their inter-array system voltage to achieve significant overall cost reductions and a higher competitiveness of offshore wind energy systems.

66 kV submarine cable type test loop according to CIGRE TB 490

1 Factory Joint

2 Repair Joint

Linking power grids
to sustainability

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