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Panel “HVDC Systems in Türkiye’s Grid Transformation Process”

The Boom of HVDC Interconnections: Opportunities, Challenges and Market Dynamics

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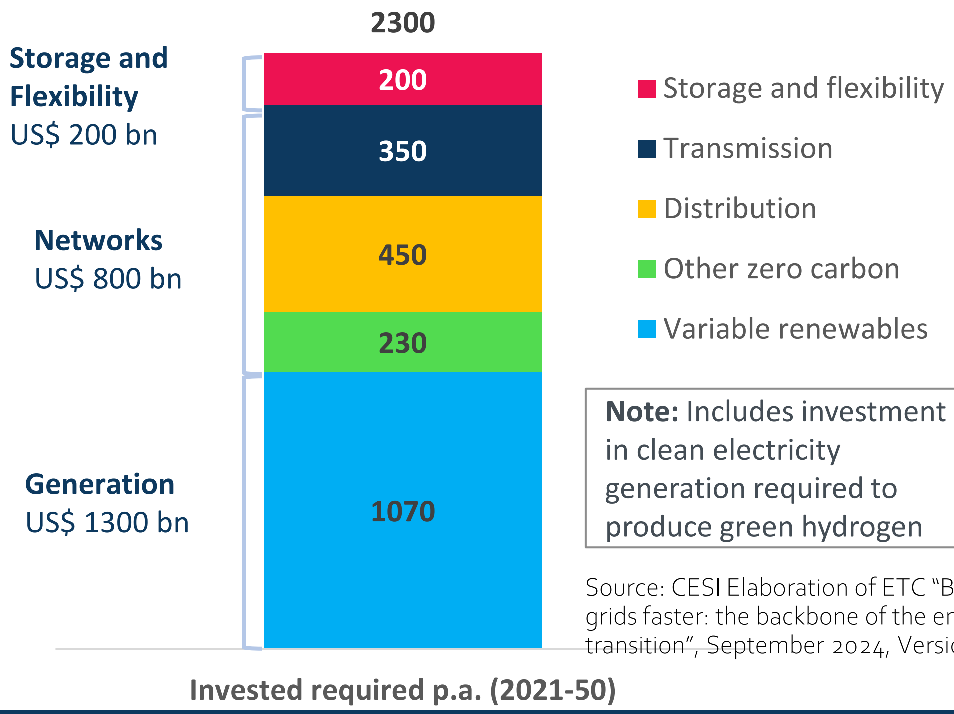
The grid: the backbone of the energy transition

COP29 Baku Azerbaijan UN CLIMATE CHANGE CONFERENCE

Priority of **accelerating investments on grid and storage** has been recognized at **COP29** held in Baku in November 2024

- ✓ **Global Energy Storage and Grids Pledge,** committed to
  - add or refurbish **25 million kilometres of grids globally** by 2030, recognising the need to add or refurbish an additional **65 million kilometres by 2040**
  - a collective goal of deploying **1,500 GW of energy storage globally by 2030**—more than six times the capacity of 2022.
- ✓ **Green Energy Pledge,** promoting connecting **green energy zones** and corridors by developing **larger intraregional and interregional interconnections**

In the next years annual investment in transmission and distribution networks needs to rise to $**800 billion per year**, growing by over **2.5 times** compared with today's levels [~$300 billion]



Note: Includes investment in clean electricity generation required to produce green hydrogen

Source: CESI Elaboration of ETC "Building grids faster: the backbone of the energy transition", September 2024, Version 1.0

The grid: need for accelerated investments

ITALY

In Italy the forecast (TYNP) on the ten-year Transmission Grid Investment has increased from 6,7 billion € in 2015 to **23 billion € in 2025**
(source: Terna)

FRANCE

In France, **RTE** announced to invest **€ 100 billion from 2025 to 2040** on the transmission grid (source: RTE)

GERMANY

Investment on transmission grid: **about € 300 billion in the next 20 years**
(source: Bundesnetzagentur)

TÜRKIYE

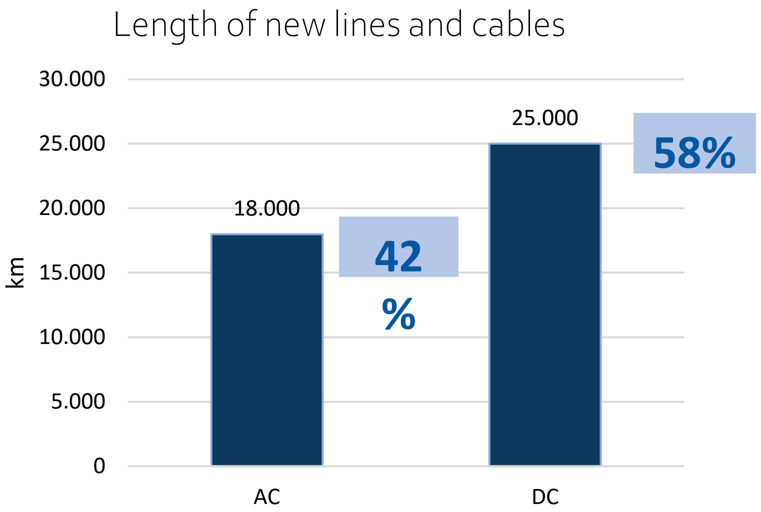
The **World Bank** and **Clean Technology Fund** approved a landmark financing package (≈660 M€) aimed at **modernizing Türkiye's national grid** to integrate large-scale renewable energy, including HVDC corridors.

This transmission system upgrade will directly enable **1.7 GW in new wind and solar capacity** and aligns with Türkiye's ambitious targets of reaching **120 GW of installed wind and solar capacity by 2035**.

At the heart of the plan is the creation of **Türkiye's first HVDC corridors**

Technologies and solutions for long distance energy corridors

DC is becoming the most relevant technology in the ENTSO-e grids of the future



Source: TYNDP 2022

HVDC Evolving Drivers

CLASSICAL DRIVERS

- ✓ Interconnection between systems with different rated frequency (50/60 Hz)
- ✓ Interconnection between systems with different frequency regulation policies
- ✓ Marine crossings
- ✓ Very long lines

+

NEW DRIVERS

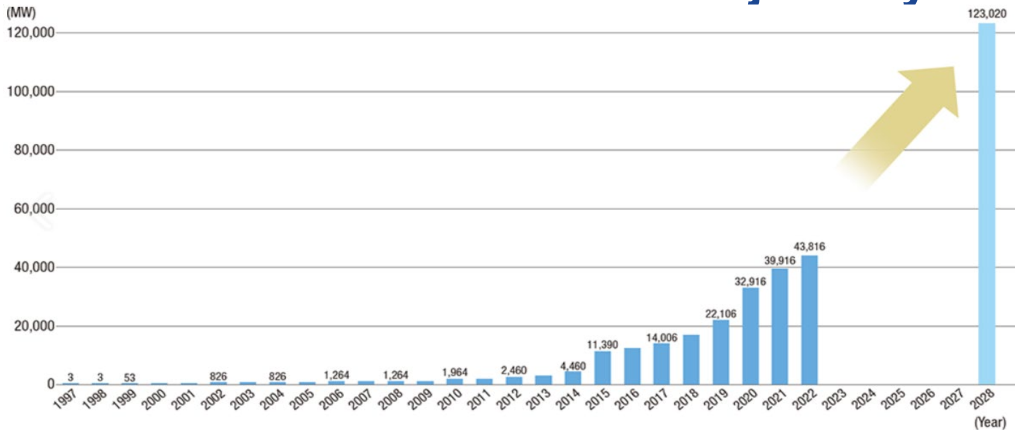
- ✓ Social acceptance (e.g. undergrounding, static EMF)
- ✓ Enhancement of power transfer capacity (AC to DC conversion of existing links)
- ✓ Transfer of massive amount of power (Loss Reduction)
- ✓ Decarbonization of the power sector: off-shore DC grids

Key Challenges

- ✓ High sea depth cables
- ✓ Fault clearing in meshed DC grids: HVDC circuit breakers
- ✓ Bottlenecks in the supply chain
- ✓ No new overhead lines construction

Interconnections: technical challenges - Feasibility stage

HVDC Market overview : + 100 Projects by 2030



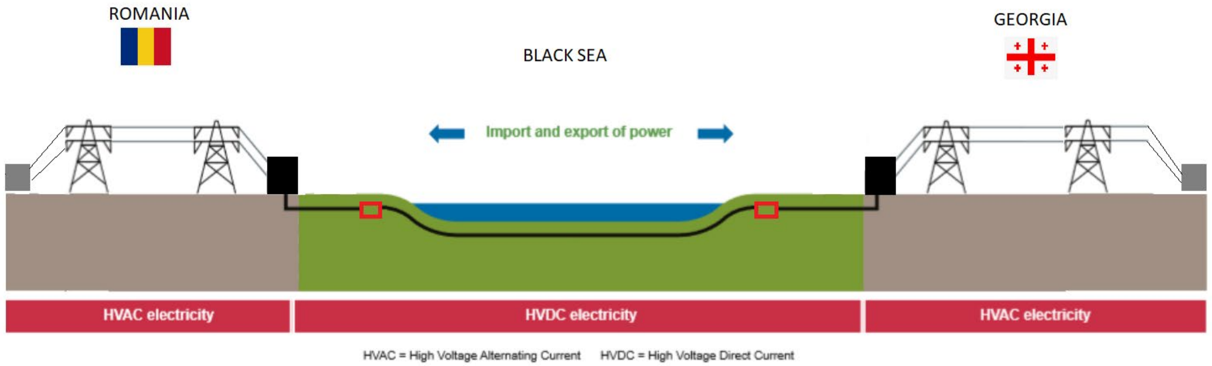
Planning of interconnections calls for a multi-disciplinary team and different studies

Scenarios definition: to identify the most interesting scenarios for the new HVDC link and to pinpoint the possible solutions of connection on the basis of technological feasibility

Technical assesment: to analyze the impact on the AC electric system and to define the suitable system configuration together with the optimal power and voltage rating of the new link

Environmental Analysis: to analyze the new link feasibility from the environmental point of view, including suitable routes of submarine cables (satisfying environmental constraints) and the converter station location

Economics: to estimate preliminarily the cost of the solutions and assessment of energy exchanges and related revenues (economical viability)



Tender Phase: preparation, in accordance with Financing Institutions, of the Scope of Work, Technical Specifications and Prequalification documents including, for submarine interconnections, Seabed Investigations

Interconnections: capital intensive investments – High performances

Converter stations Technologies

	Line Commutated Converter	Voltage Source Converter Half Bridge	Voltage Source Converter Full Bridge
Switching device	Thyristor	IGBT	IGBT
Voltage	±800 / ±1,100 kV	±525 kV	±380 kV
Power	8,000 - 12,000* MW (*) Changji-Guquan (China) 3,000 km OHL	3,000 MW	2,000** MW (**) ULTRANET (Germany) 340 km OHL

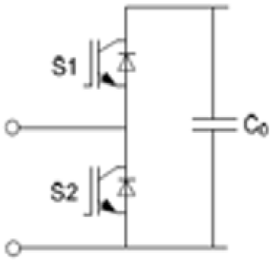
Cables and OHTLs

Recommended DC Voltage (kV)	Power Range (GW)	Overhead Lines	Cables – Extruded	Cables – Mass Impregnated
± 100, 150, 200	**Specific application**	**No inherent limit**	Up to 525kV	Up to 600kV
± 250	**< 0.5**			
± 320	**(0.5) – 1.0**			
± 400	**(1.0) – 1.5**			
± 500	**(1.5) – 3.0**			
± 600	**(3.0) – 4.0**			
± 800	**(4.0) – 8.0**			
± 1100	**< 12**			

Source: CIGRE TB 684 Recommended Voltages for HVDC Grids

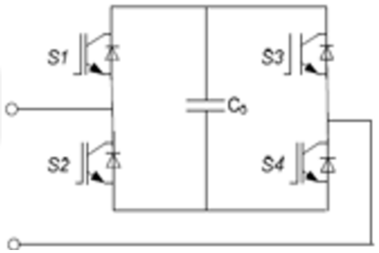
Applications with weak AC systems (Black Start Capability)

Half bridge



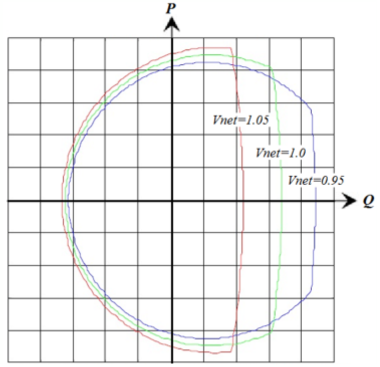
Vs.

Full bridge



H.B. : AC Circuit Breaker intervention is required for fault clearing

VSC: reactive power control capability (continuous and inherent within the conv. control)



Technologies and solutions for long distance energy corridors – high depth cables

Much longer cable length

Much higher mechanical tension when laying down cables

Forces (Tension) applied to the MI cable during laying or recovery - SAPEI HVDC link (Italian peninsula – Sardinia Island)

- Length: 435 km / Max sea depth: 1650 m
- Maximum pulling force of approx. 50 tons

Evolving limits of high depth DC Cables	
Tyrrhenian link	≈ 2200 m
Georgia – Romania	≈ 2200 m
Great Sea Interconnector	≈ 3000 m

Vessels

Overall length 170 metres | **Carousel Capability Up to 10,000 tons** | **100 tons cable pulling tension**

Overall length 155 metres | **Carousel Capability Up to 10,000 tons** | **75 tons cable pulling tension**

New vessels will allow a higher pulling tension and simultaneous cable lay and burial

Cables

Eco-friendly and High-sea-depth innovative cables

High strength synthetic fibres armour (light weight design)

Max depth up to 3000 m

New extruded solutions, thermoplastic (HPTE) for terrestrial applications

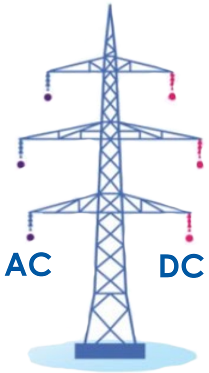
Source: Prysmian

Technologies and solutions for mid-short distance energy corridors: no new-grid solutions

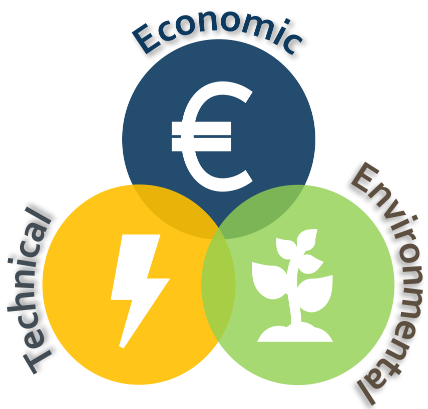
Upgrading power transfer capability

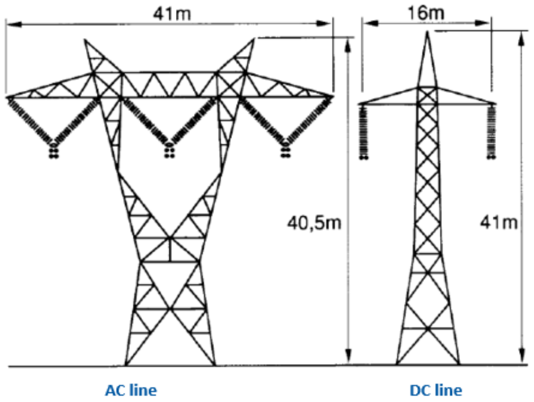
HVDC Ultranet project (Germany)

- ✓ 2 GW HVDC connection from the Osterath to Philippsburg Region
- ✓ ≈ 340 km
- ✓ VSC MMConverter
- ✓ Multi-terminal capability



HVDC key advantages

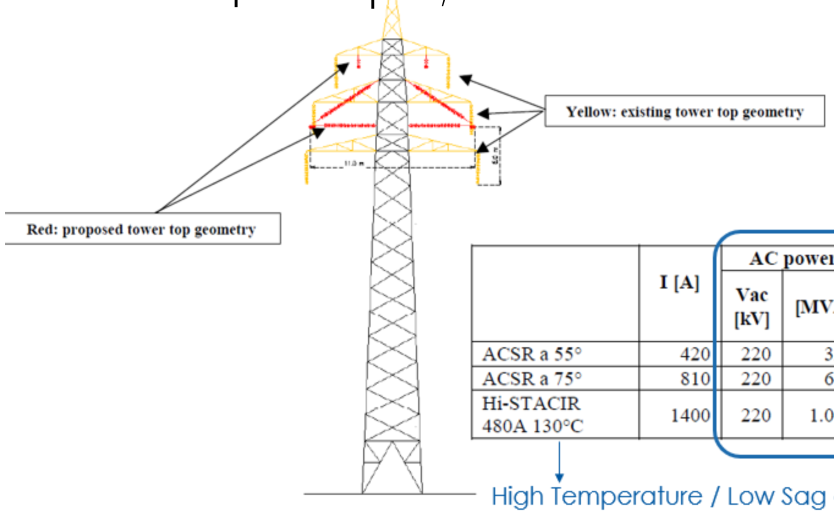




- Reduced land use (less ROW) and visual impact
- Static Electro-Magnetic Field

AC DC Conversion and coupling studies

Conversion of a **220kV AC** double circuit to a **DC ± 400kV bipole**, with metallic return conductors



x2

	I [A]	AC power Vac [kV]	AC power [MVA]	DC power Vdc [kV]	DC power [MW]
ACSR a 55°	420	220	320	400	672
ACSR a 75°	810	220	617	400	1.296
Hi-STACIR 480A 130°C	1400	220	1.067	400	2.240

High Temperature / Low Sag conductors

Env & Social acceptance

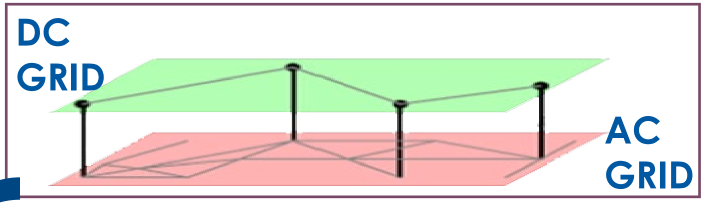
- The "**human-style" tower**, is a combination of the existing tower body, with the top part outline like a human being

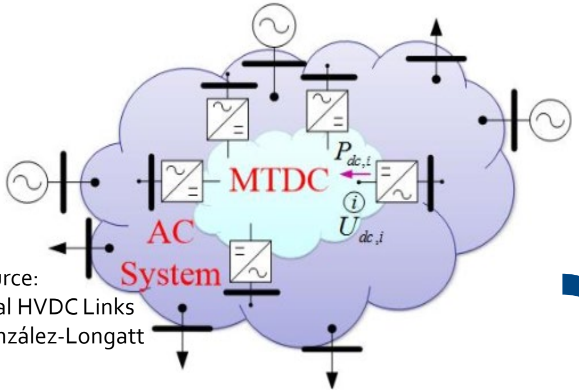
Network of the future – Multi Terminal DC (MTDC) Grid

Challenges are present to build a DC grid in term of system design and configuration:

- **DC grid Multi-terminal operation :** load flow & power control, telecom, etc.
- **C&P Systems with a guaranteed interoperability of different systems from different manufacturer**
- **Standardization & tests**
- **DC breakers** : sectionalization of faulted zone & DC fault current limitation

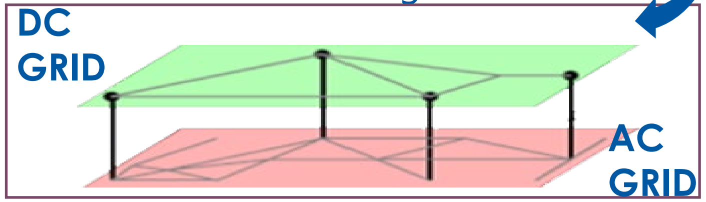
Multiterminals with tappings





Source:
Multi-terminal HVDC Links
Prof. F. M. González-Longatt

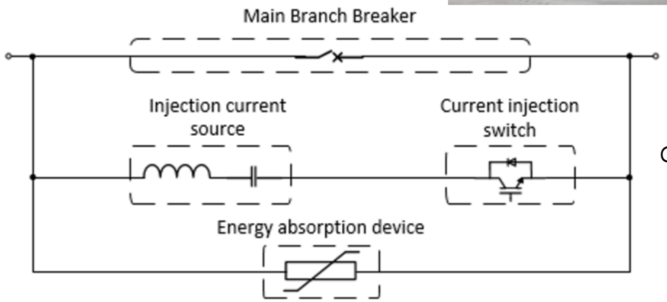
DC meshed grid



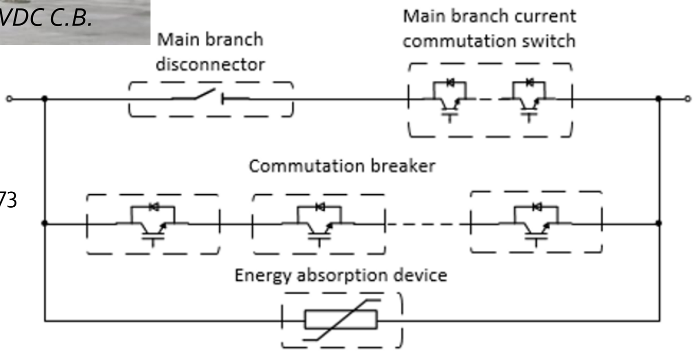
HVDC Circuit Breaker Active Current Injection Technology

Source NR Electric : *500 kV hybrid HVDC C.B.*

HVDC Circuit Breaker Hybrid Technology

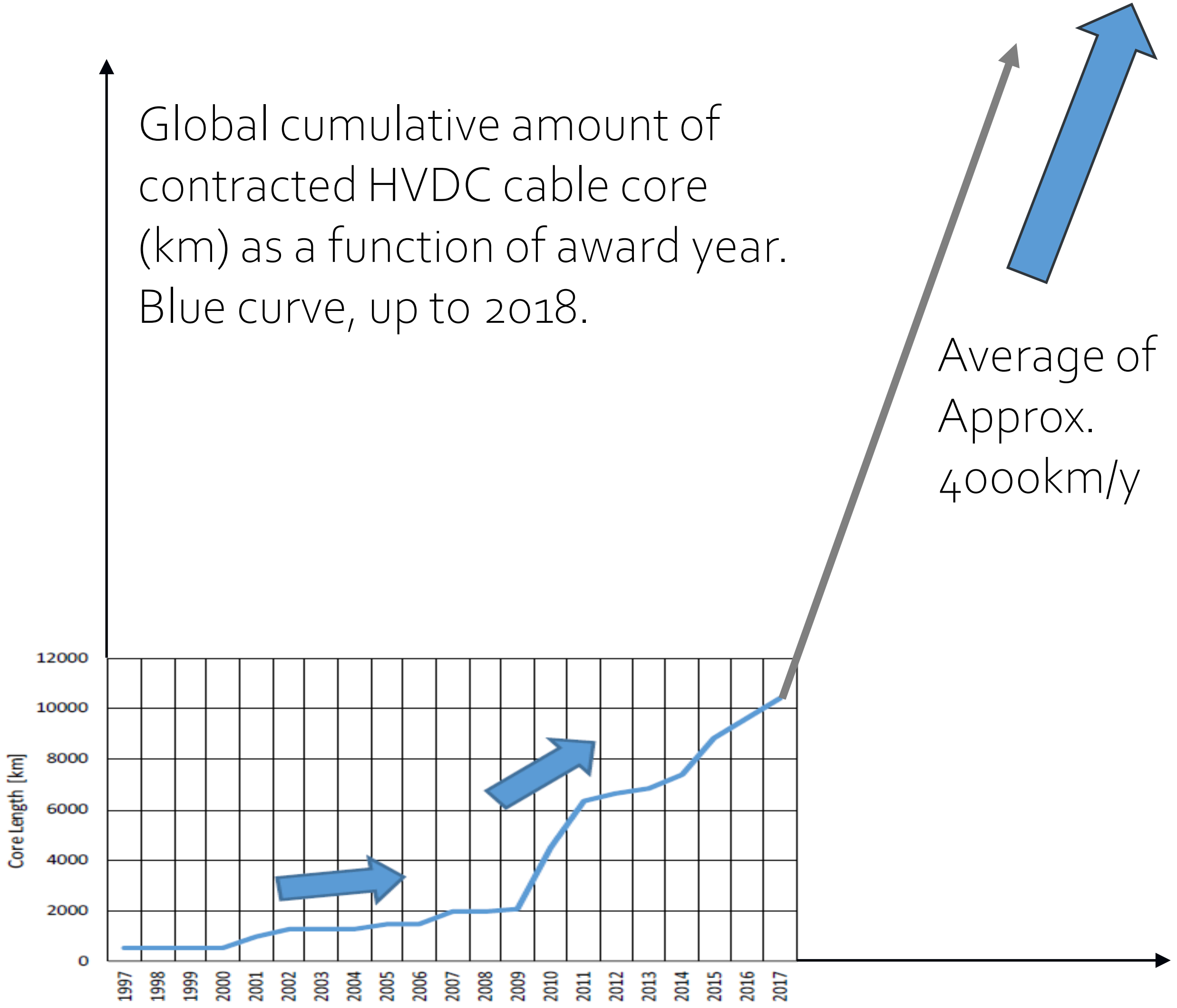


Source:
CIGRE Tech. Broch. n 873



- **DC breakers** have been tested in KEMA laboratories as part of the "**Promotion project**"

Cables supply chain issues



EUROPACABLE estimates that in total, Europe will need some 45,154 cable kms of HV land and submarine cables in the period to 2019-2029

This figure should be updated with more recent projects

Congestion in the cable market, due to high demand of HVDC and HVAC cable for both interconnections and RESs

Manufacturers are investing in new manufacturing plants; nevertheless, the supply chain of HV cable will be a challenge for the upcoming decade

Source: JICABLE HVDC 2019 Paper D8-3 and Europacable

Cables supply chain issues

	MIND (paper lapped)	Extruded
Transmissible Power	1000 MW (1)	1500 MW
Nr. of 525 kV cable systems in operation	Many (since > 15 years)	None
Potential suppliers for 525kV submarine cable systems (shallow water)	4	6
Potential suppliers for 525kV submarine cable for high-water depth	2	1
High water depth experience	Existing for 500/525kV (Monita, Sapei, Tyrrhenian link)	Limited to few hundred meters and up to 320 and 400kV – New projects on going
Manufacturing capability for high water depth application	Approx 1000 km/y	Approx 1200 km/y

(1) Depending on final max water depth, seabed profile and cable design, slightly higher values could be considered

Converter stations supply chain issues

	VSC CONVERTER STATIONS
Years of experience in VSC technology	> 20 Years
VSC Technology	Up to 3000 MW / 525 kV
Half Bridge technology	Standard solution for VSC
Full Bridge technology	Only one project (2000 MW / 380 kV) under implementation. In case of special needs, eventually in hybrid HB+FB configuration
DC Breaker	Pilot projects up to 535 kV
Preferred type of contract	Preferred EP (engineering and procurement, final commissioning of link)
Delivery time	Expected for 2032-33 for final order confirmed by 2027-2028
Need of a pre-agreement to set production slots	Yes, required to confirm production slots

Owner’s Engineering

Owner’s Engineering services are focused on supporting the **entire life cycle of a HVDC Power Transmission Development…**

Key Questions

- How to address the main technological challenges of Converter Stations and Power Cables?
- Which are the main opportunities and constraints of the industry?

Owner’s Engineering Service

1° Phase

System Studies

- Potentialities & Limits of the HVDC
- System integration in the AC networks
- Definition of Performances and Requirements
- Reliability Requirements

2° Phase

Technical Specifications & Tendering Assistance

- Preparation of Technical Specifications
- Preparation of Tender Documents
- Bid Evaluation & Comparison

3° Phase

Design Review

- Third-party validation of power system studies
- Third-party validation of Converter Stations / OHLs / Cables design

4° and 5° Phases

Supervsion of Construction and Commissioning, Quality Assurance, Factory Tests Witnessing Activities

- In-production inspection
- Validation of acceptance criteria for FAT specific. and procedures
- Factory Tests of the main equipment.:
  - ✓ Converter transformers
  - ✓ Smoothing reactors
  - ✓ Thyristor/IGBT valves
  - ✓ Control & Protection system
  - ✓ Cables and OHLs
- Support during erection phase
- Analysis of the specifications & planning for site tests
- Supervision of all in-field tests
- Witnessing during commissioning phase and third-party validation of correct performance

Conclusions

Carrying out

- detailed **feasibility studies**
- **owner's engineering** activities

we can reach the goal to ensure a sustainable **energy future for the HVDC interconnections**

Adopting

- new **procurement strategies**,
- different **contractual solutions**
- investing in **manufacturing capabilities**

we can overcome the **supply chain** issues

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