ZIEHL IX

Beschleunigung. Effizienz. Nachhaltigkeit: **Supraleiter**

ZIEHL IX
Herausforderungen im Netzausbau

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TenneT

Content

TenneT Figures
2023

Workforce
8,300
Employees

EBIT
1,817
EUR million

Grid
99,99%
Availability

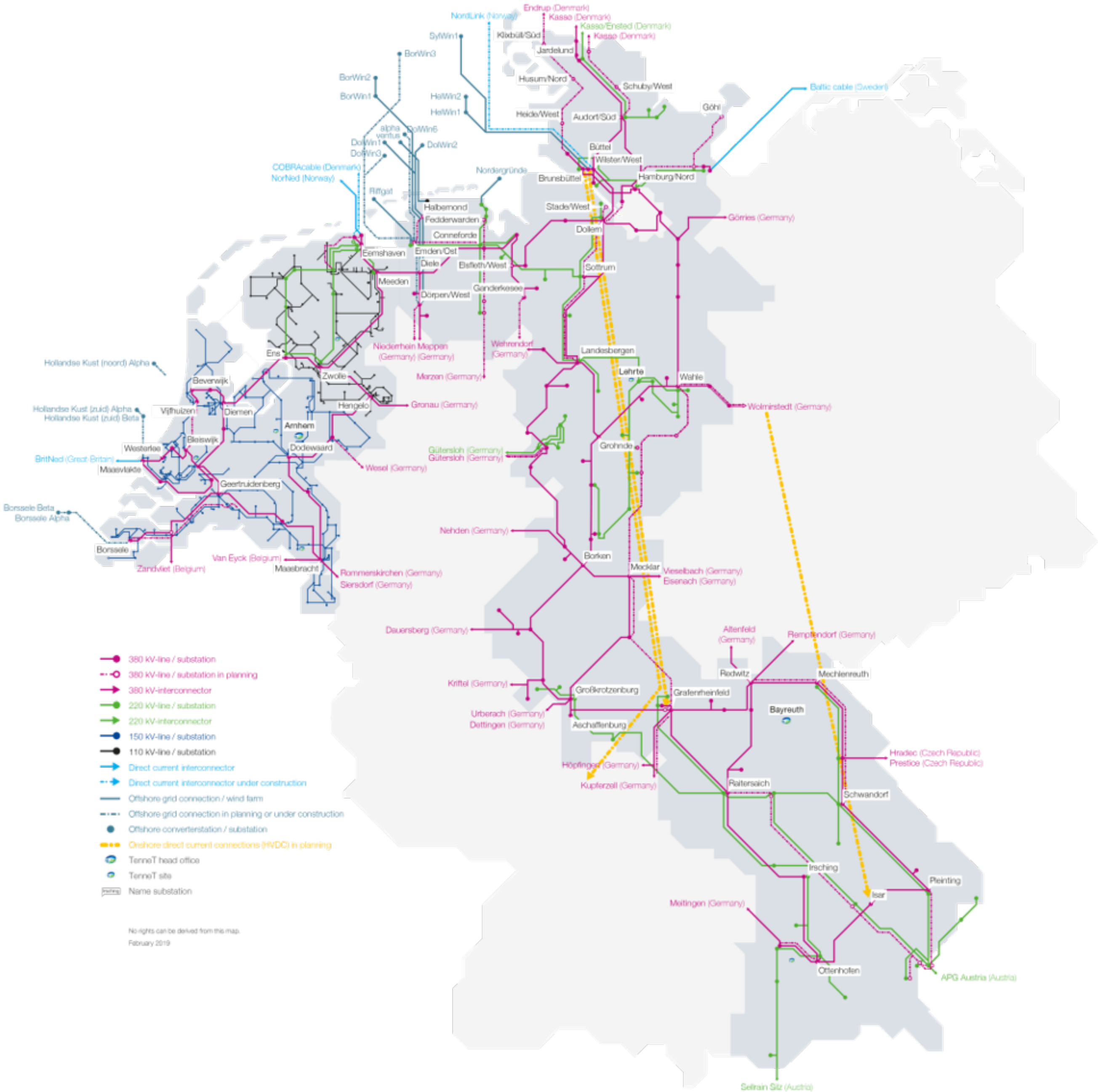
Grid length
25,000
Km

Assets
45
EUR billion

Investments in 2022
7,7
EUR billion

Dutch State
100%
Shareholder

Footprint
33%
Greened



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Energy transition – What does this mean for TenneT?

The goal:
Climate neutrality in Europe by 2050 and in Germany by 2045

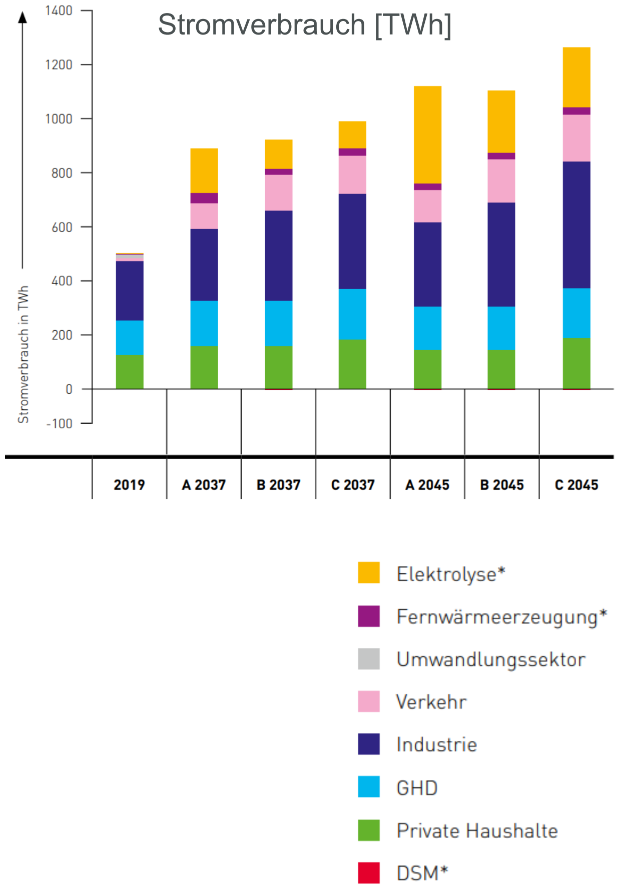
The challenge:
Actively managing with multiple variables in times of resource scarcity

The solution:
Comprehensive grid expansion, efficient operation & maintenance, ongoing innovation and digitalisation, system integration

TenneTs contribution:
Creating a holistic system by integrating renewable energies, transmission and distribution grids at sea and on land, large industrial consumers and electrolysis projects

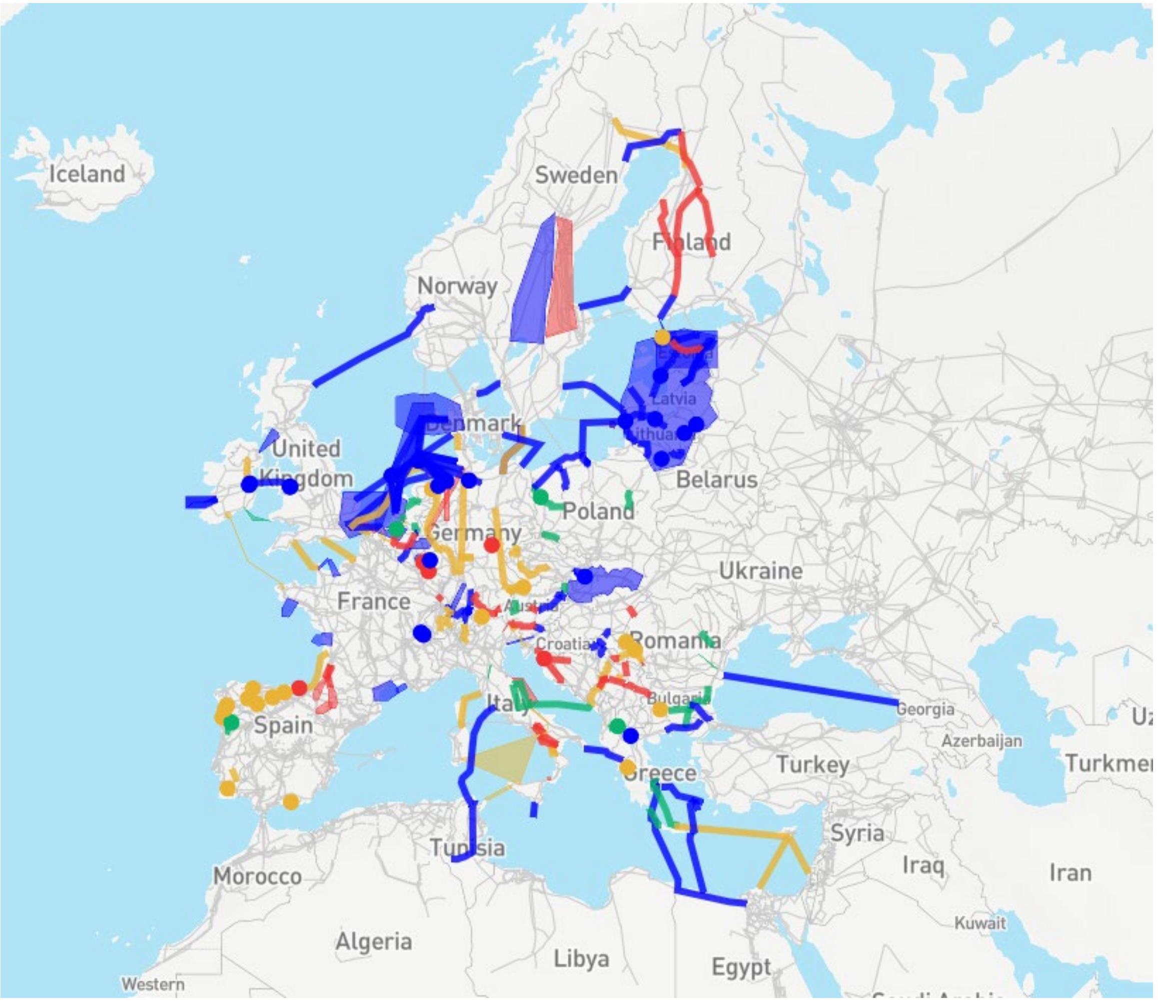
Scenario Framework (selected key figures)
NEP 2037/2045 (2023)

	Status quo	NEP 2021 B 2040		NEP 2023 B 2045 (B 2037)
Gross elec. consumption [TWh]	533	688,6	+60%	1.106 (961)
Wind onshore [GW]	56,1	88,8	+80%	160,0 (158,2)
Wind offshore [GW]	8,1	40,0	+75%	70,0 (58,5)
Photovoltaics [GW]	59,3	125,8	+218%	400,0 (345,4)
Battery storages [GW]	1,8	18,7	+654%	141,0 (91,1)
Electrolyzers [GW]	<0,1	10,5	+376%	50,0 (26,0)



TYNDP* 2022

Under construction
In permitting
Not yet permitted
Under consideration



*Ten Year Network Development Plan

Source: ENTSO-E

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NOVA

NOVA-Typ im NEP 2037 / 2045 (2023) gem. § 3 NABEG

(Netz-) Optimierung – NO

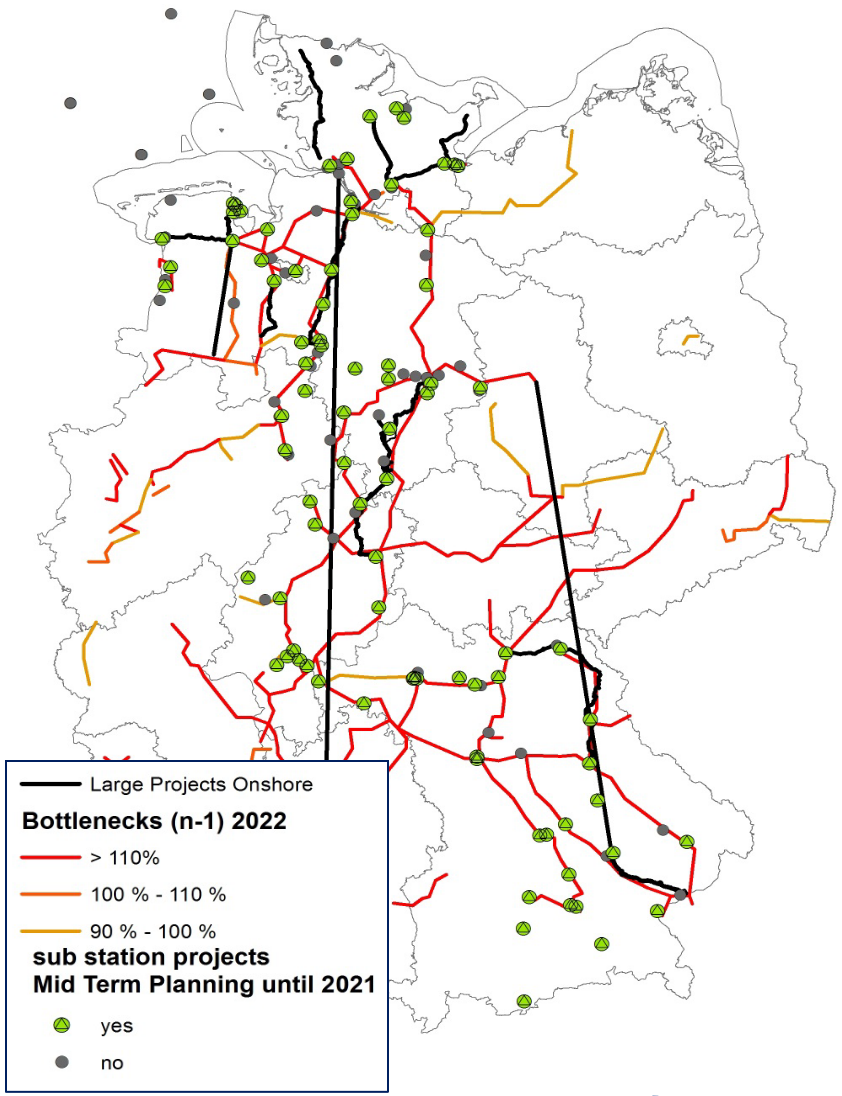
- Topologiemaßnahmen
- Leistungsflusssteuerung
- Spannungsumstellung (220 kV → 380 kV)
- witterungsabhängige Belastbarkeit von Freileitungen

Verstärkung – V

- Änderung oder Erweiterung einer Leitung: Zu- oder Umbeseilung
- Errichtung einer Leitung: Ersatzneubau
- Errichtung einer Leitung: Parallelneubau

Ausbau – A

- Errichtung einer Leitung: Neubau in neuer Trasse (Seekabel)
- Errichtung einer Leitung: Neubau in neuer Trasse (Freileitung)
- Errichtung einer Leitung: Neubau in neuer Trasse (Erdkabel)



Our offshore projects until 2031
Offshore grid connections

Target Offhore Wind:
2030 30 GW
2035 40 GW
2045 70 GW

We already operate **19 offshore grid connections** in the Netherlands and Germany and four interconnectors across European borders. **With 20 new connections to come until 2031.**

Offshore Grid Expansion GER:
9 OWFs acc. FEP23 in 2029-2031
(6 TenneT)
12 new OWFs in 2032-2037
(4 TenneT)
8 new OWFs after 2037
(3 TenneT)

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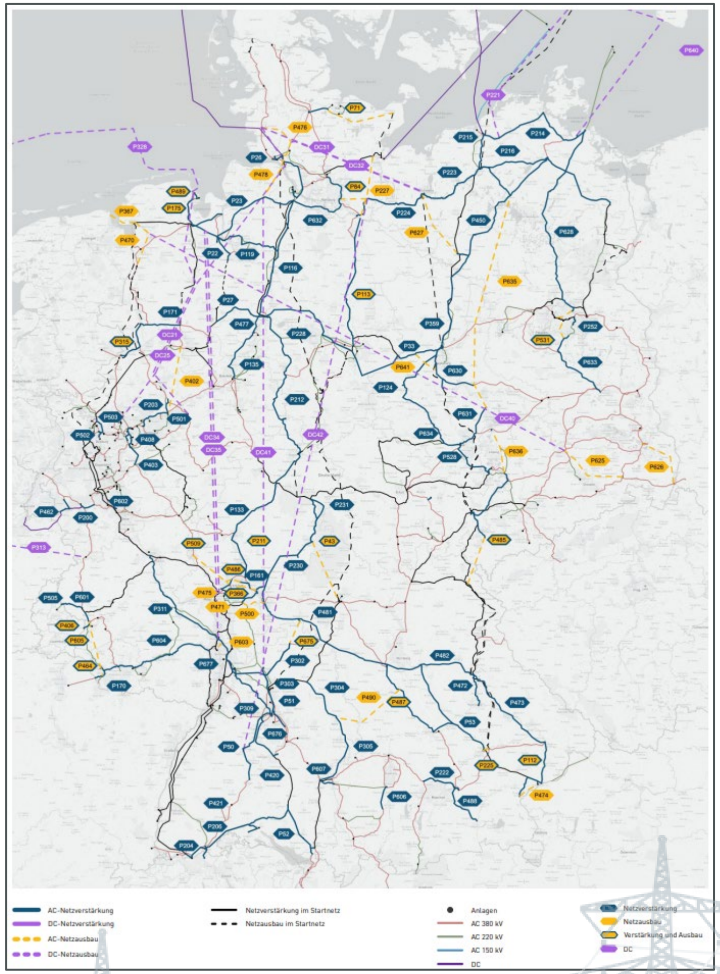
Onshore: AC grid

- Over **1,100 km** already realized
- Around **610 km** approved or under construction
- Around **2,870 km** in the approval process
- Around **380 km** of additional projects from BBP 2022 before the approval process
- Over **2,500 km** of new projects from NEP 2023

Onshore: DC grid

- Around **1500 km** approved or under construction
- Around **2000 km** of additional projects from BBP 2022 before the approval process
- Over **3000 km** of new projects from NEP 2023



NEP Scenario A / B / C 2037 Transmission only

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Achievement of Climate Target

Today → Innovations → Target Grid

- Decarbonization
- SF_6
- 2 GW Offshore
- DC-Overlay Grid
- Fault Separation Device
- Grid Booster
- E-STATCOM
- Grid Automatization
- Cable AC+DC
- HTSC-Systems
- Monitoring
- Health Index

Offshore 2 GW GCS

2 GW DC Connection 80 – 230 km Length

Grid Reliability
Full load hours 4500 h/a

Standard Design, TenneT offers to the market, Set European Standard, Accelerate Delivery

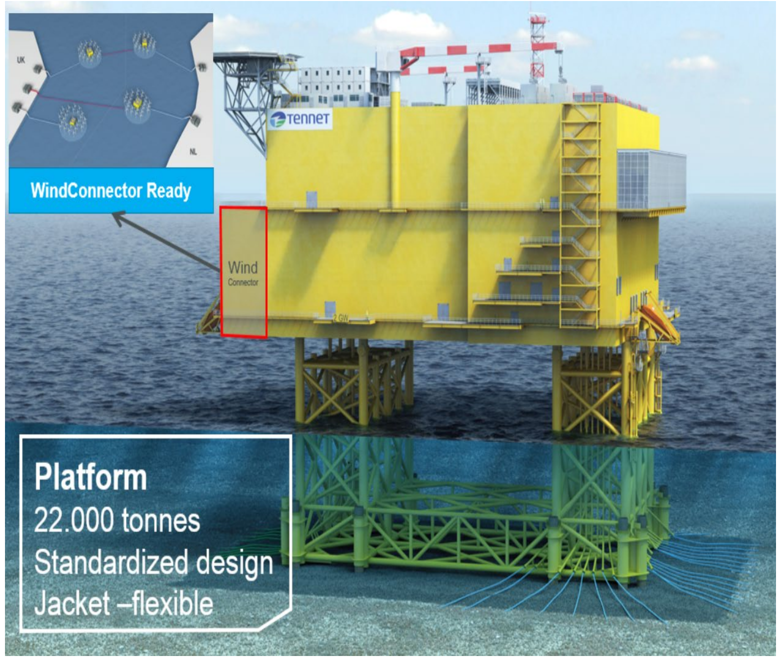
The approach:

Standardisation:
2 GW platforms from multiple providers

Cooperation:
Framework agreement of € 30 billion for 14 converter stations with 2 GW each

Predictability:
Framework agreement for 7,000 km of DC cable for € 5.5 billion

Platform dimensions:
approx. 106 x 77 x 41 m (top site)
approx. 20,000 t
approx. 90 x 40 m (jacket)
approx. 8,000 – 10,000 t

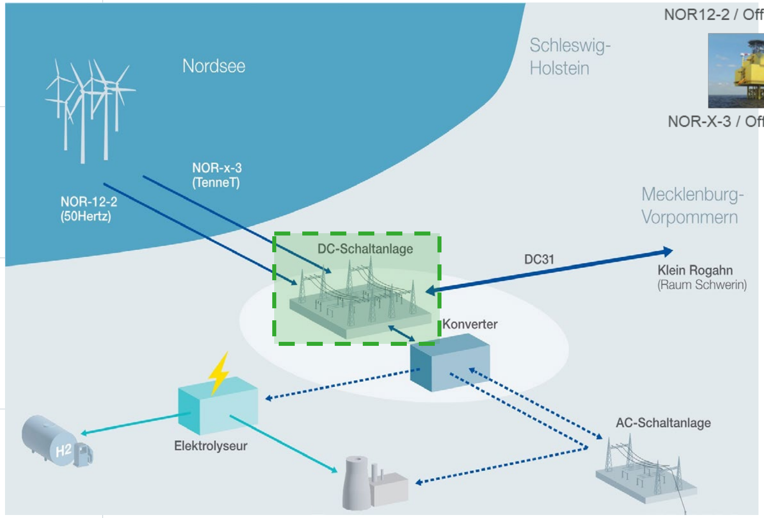


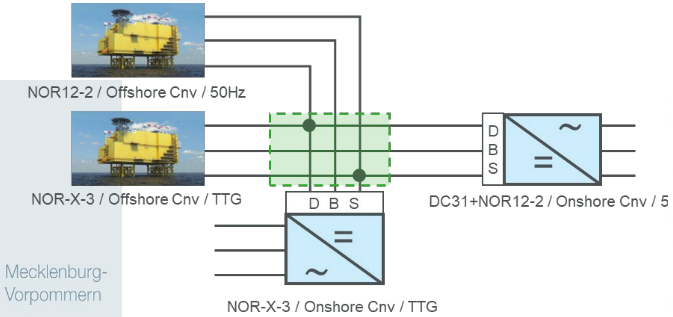
DC-Overlay Grid incl. DC-Substations

Meshed DC grid, hubs (connection points)

Reliability ensured also if failures occur

DC Switchyard
→ Connection of Hubs, **Development FSD** for selective disconnection necessary

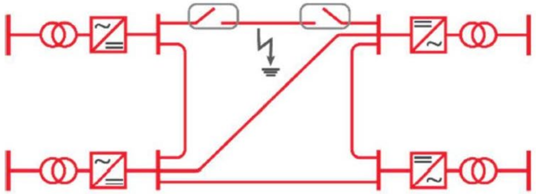




Fault Separation Device DC

- Enabler for Meshed HVDC grids
- In case of a fault, ensures that only affected part of the grid is disconnected
- Increasing availability and reliability of the system
- Conventional breakers are not suitable for DC grids
- To enable different protection zones in the DC grid

- **… through fast response, high reliability, low losses**



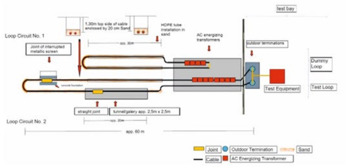
Cables

AC 380 kV + DC 525 kV

Quality Assurance (PQ), Laying Technology, Monitoring

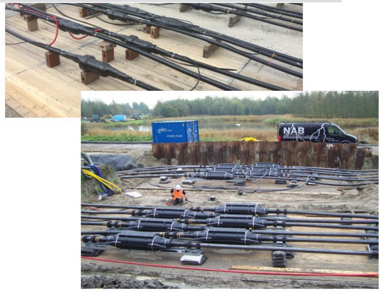
Monitoring
→ AC Extension with Thermal Rating (DTS), Failure Monitoring, Health Monitoring

Quality Assurance Arrangement of Test Loop
525 kV HVDC PQ Test



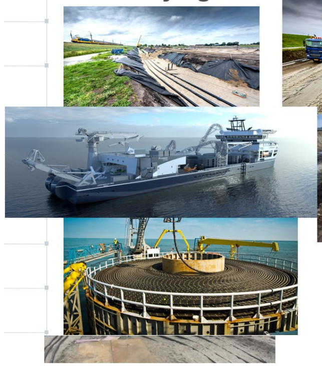
Test institute FGH Mannheim/DE
4 test loops
Test institute STRI Ludvika/SWE
1 test loop

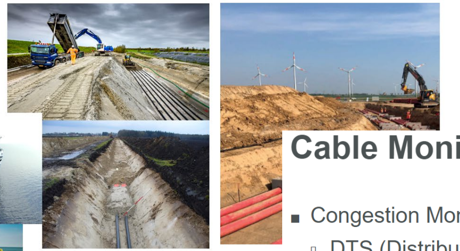
Layout of test loop
App.130 m cables per loop, 2 joints, 2 terminations
20 m inside a tunnel, 30 m inside cable pipes/ducts
Dummy loop for reference temperature measurement



Joint arrangement

Cable Laying





Reduce the impact by:
- Horizontal Directional
- Cable Ploughing

→ Stimulate and use ne

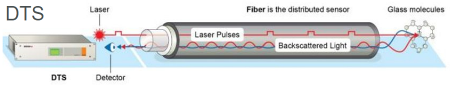
New developed XB-boxes / Randstad

Cable Monitoring

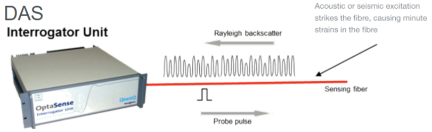
- Congestion Monitoring and higher cable utilization
  - DTS (Distributed Temperature Sensing)
- Health Monitoring
  - DTS
  - DAS (Distributed Accoustic Sensing) / Vibration Monitoring
  - Seabed Laying Depth Evaluation
- Failure Monitoring
  - On-Offline Monitoring (HiMON)
  - DAS

Monitoring is an essential / crucial part for security of supply

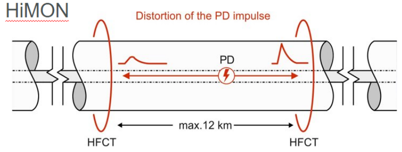
DTS



DAS



HiMON



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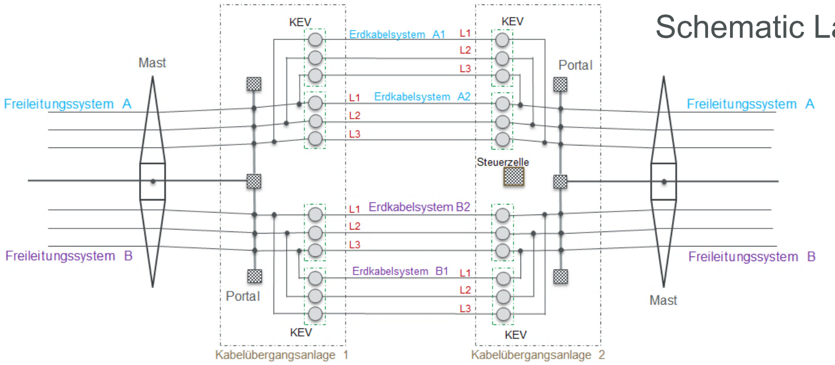
Onshore 380kV AC with Cable Sections

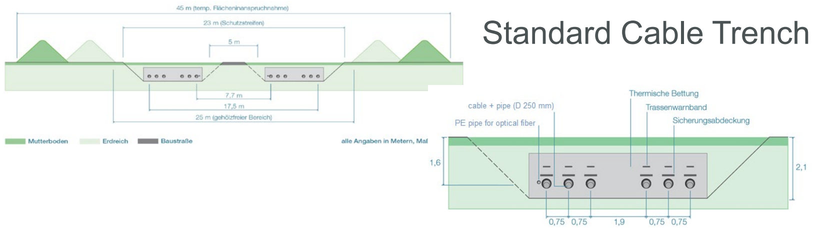
Onshore Grid Extension
Overheadlines + Cable Section

Political Preference and
Acceptance

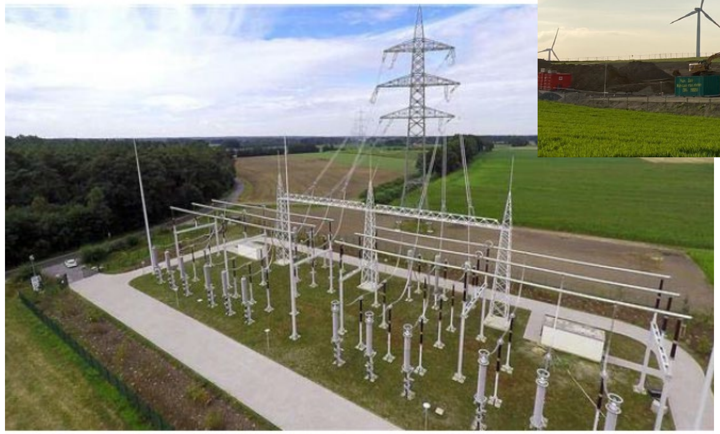
Technical Challenges with transients, missing zero crossings, failure monitoring, DistributedTemperatureSensor (DTS/RTTR), reactive power compensation



Schematic Layout CSS



Standard Cable Trench



Cable Section Station (CSS)
w/wo compensation

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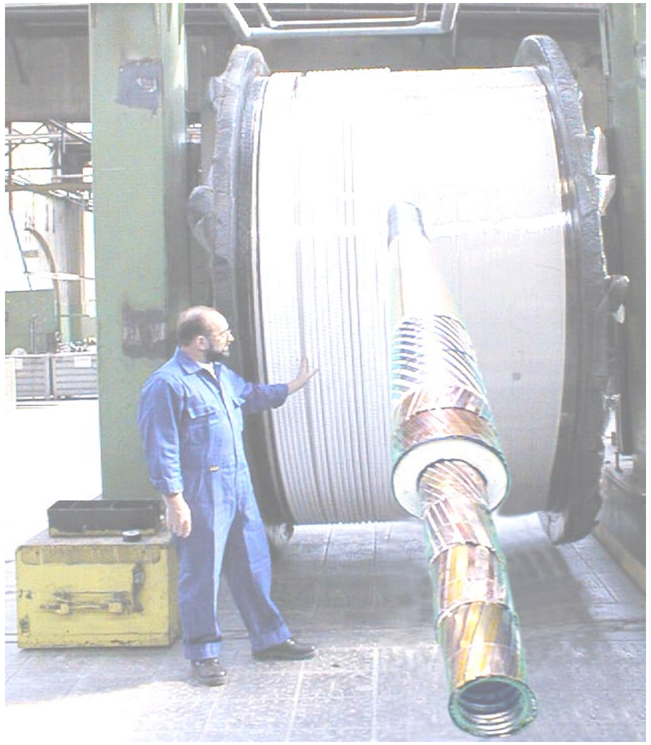
Possible Applications for HTSC Cable Systems

AC 380 kV + DC

Technology Development

Applications
→ Retrofit, OHL replacement, Generator Supply

- Increasing the transmission capacity of existing conventional point-to-point cable trays (Retrofit)
- Relocation of high-voltage overhead lines underground (as with conventional cable systems)
- Generator supply systems
- Relocation of industrial customer connections to HV grid substations
- High-performance HVDC energy transmission over long distances (future)



Design of 380kV HTSC-Cable

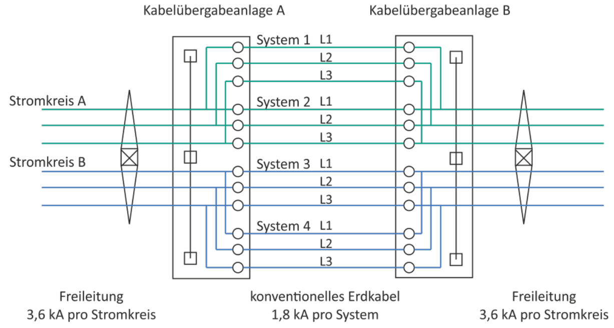
Design of 380kV HTSC-Cable

Feasibility Study
KIT, Prof. Noe et.al.

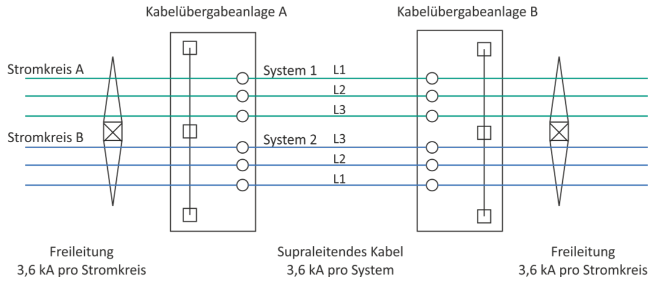
Example Intermediate Cable Sections for 380kV-OHL

- XLPE-Cable
  - Two parallel cables required per circuit per phase
  - 12 cables in total
  - Heat emission into the environment, sufficient cable spacing required
- HTSC-Cable
  - One cable required per circuit per phase
  - 6 cables in total
  - **No** heat emission into the environment, very close cable laying possible

Option 1 - Teilerdverkabelung durch konventionelle Erdkabel mit 4 Systemen je 1,8 kA



Option 2 - Teilerdverkabelung durch supraleitende Kabel mit 2 Systemen je 3,6 kA



380kV AC Cable Sections with HTSC Technology

Design of 380kV HTSC-Cable

Feasibility Study
KIT, Prof. Noe et.al.

Prequalification test is mandatory to achieve higher TRL level

- Advantages:
  - No System doubling necessary
  - Some kms transmission lengths possible with single sided cooling system
  - No thermal problems expected which is advantageous with regard to crossings
- Disadvantages:
  - High Invest
  - Limited black start capability
  - High OPEX
  - Behaviour in short circuits
  - Longer repair duration compared to XLPE cables

Substation System Optimisations

AC Load Flow Optimization

PST: Phase Shifting Transformers
TCSC: Thyristor-controlled series capacitors

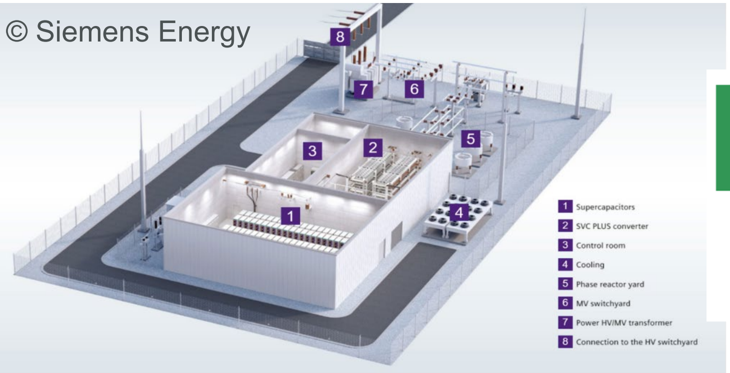
Reduction of conventional Power Plants means loss of inertia

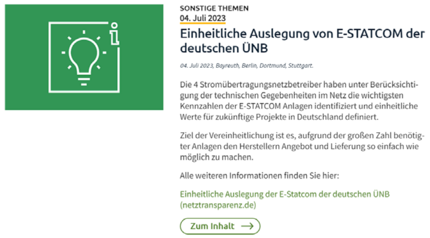
E-STATCOM will contribute to Reactive Power infeed and grid forming

Main Data Würgau / Krempermarsch

Übersetzung: 410 / 410 kV
Bemessungsstrom: 2000 A
Leistung: 1420 MVA
Durch die direkte Parallelschaltung von 2 PST ergeben sich 4000 A bzw. 2840 MVA
Leerlaufwinkel: + / - 24°
Lastwinkel: + 16° / - 32° (der „Bremswinkel" wird bei Last größer)
Anzahl der Stufen: +/- 32
Gesamtschallleistungspegel je PST: Ca. 103 dB(A)
Leerlaufverluste: ca. 145 bis 280 kW je nach Stufe
Lastverluste bei Bemessungsstrom: 1200 bis 2450 kW je nach Stufe
Gesamtgewicht je PST: Ca. 950 t, davon ca. 230 m³ Öl

TCSC Würgau





SONSTIGE THEMEN
04. Juli 2023

Einheitliche Auslegung von E-STATCOM der deutschen ÜNB

04. Juli 2023, Bayreuth, Berlin, Dortmund, Stuttgart.

Die 4 Stromübertragungsnetzbetreiber haben unter Berücksichtigung der technischen Gegebenheiten im Netz die wichtigsten Kennzahlen der E-STATCOM Anlagen identifiziert und einheitliche Werte für zukünftige Projekte in Deutschland definiert.

Ziel der Vereinheitlichung ist es, aufgrund der großen Zahl benötigter Anlagen den Herstellern Angebot und Lieferung so einfach wie möglich zu machen.

Alle weiteren Informationen finden Sie hier:

Einheitliche Auslegung der E-Statcom der deutschen ÜNB (netztransparenz.de)

Zum Inhalt →

S_{Nom} /. S_{Max}	level of simultaneous provision (minimum requirement)		storage in MWs @P_2	$RoCoF_2$ in Hz/s	P_1 in MW @ 1Hz/s	P_2 in MW @2 Hz/s	Q_n in Mvar	$T_{A,P}$ in s	Inertia contribution in GWs
	P_{sp} in MW	Q_{sp} in Mvar							
300	75	290	375*	2	75	150	300	50 relative to 75 MW	1,875

*For operation within the frequency limits 47,5 Hz to 52,5 Hz

Standard ratings for E-STATCOM of the German 4 TSO

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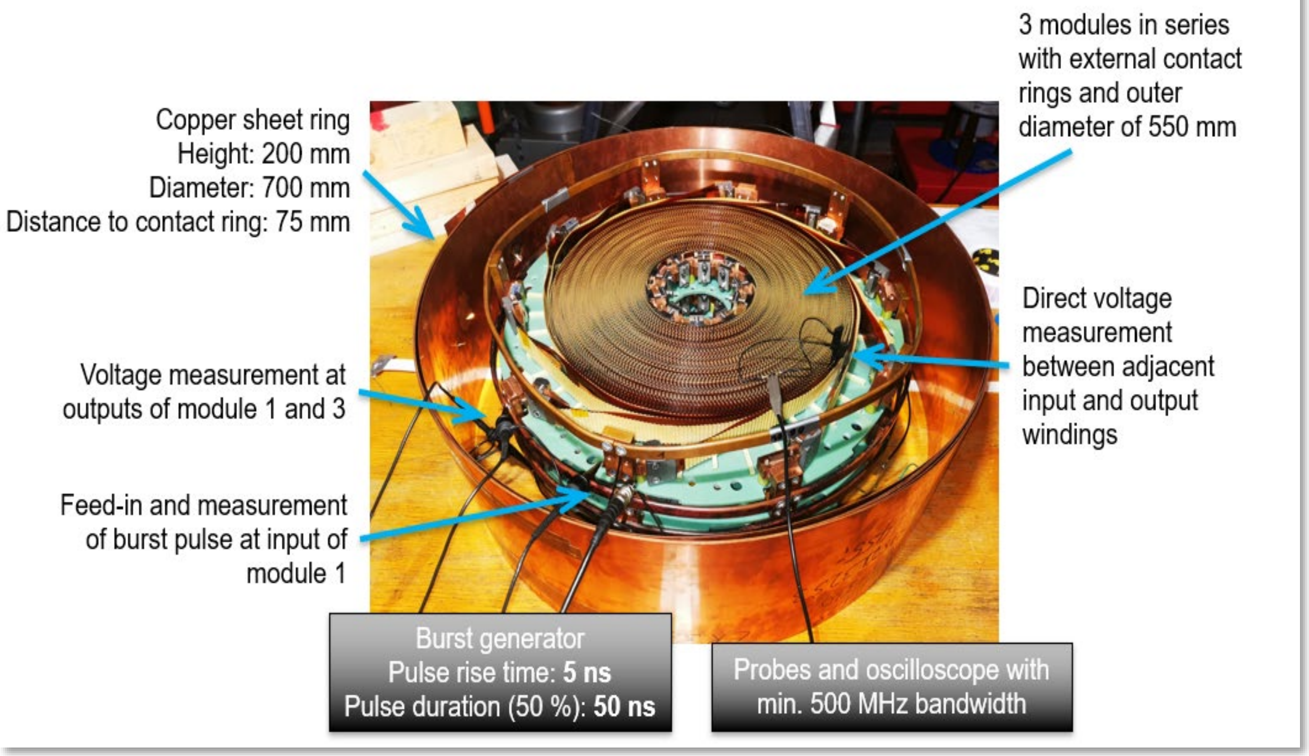
High Temperature Superconducting Fault Current Limiter

HTSC-FCL

Feasibility Study KIT, Prof. Noe & TH Cologne, Prof. Humpert

Bifilar HTSC Coils in measurement set-up

- Reasoning
  - In view of increasing short circuit currents (SCC) in our grid, the performance of AC circuit breakers come to a physical limit
- Mitigation
  - Substation Layout
  - Switching position (busbar connection)
  - HTSC-FCL



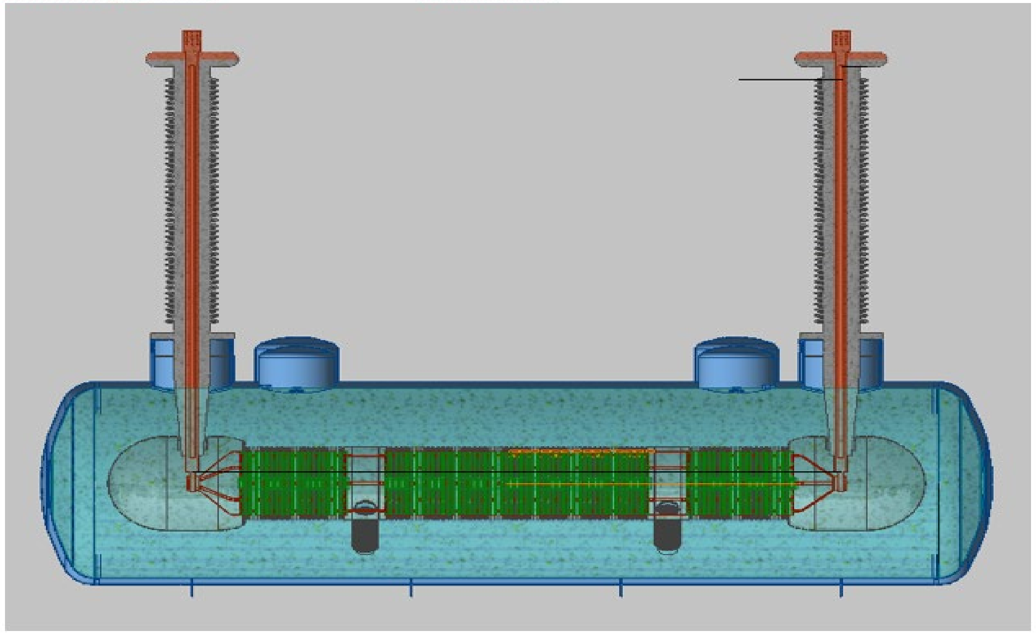
Preliminary Design Proposal 380kV

HTSC-FCL

Feasibility Study KIT, Prof. Noe & TH Cologne, Prof. Humpert

Pilot installation in preparation together with Siemens Energy, HSP and all four German TSO (Amprion, TransnetBW, 50Hertz and TenneT)

- Advantages:
  - Reduces short circuit currents of substations if SSC value exceeds 63 and 80 kA, respectively
  - HTSC FCL will be connected in series to short circuit breaker with no changes to substation
- Disadvantages:
  - High Invest / high OPEX
  - Limited black start capability
  - Longer repair time compared to conventional switchgear



One-phase HTSC-FCL vessel with bushings, length app. 15m

Future System Automation

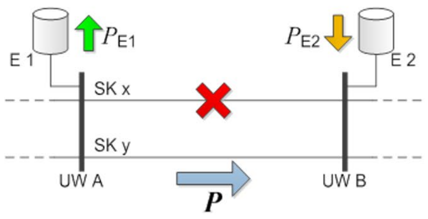
Optimisation Load Flow
Active n-1

System Automation Emergency Power Control,
Special Protection Scheme

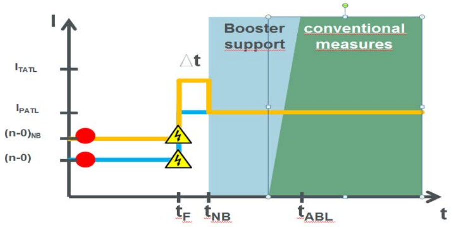
Grid Booster ~ Virtual HVDC

Growing Asset Base and complexity of the new Assets Base needs System Automation

Grid Booster

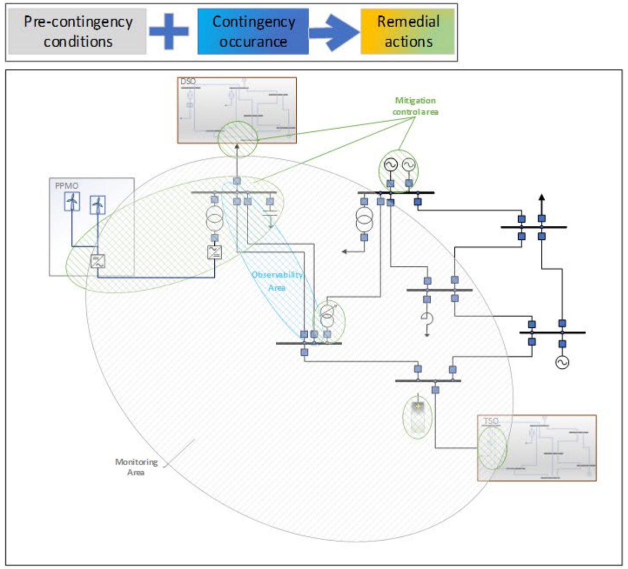


Principle of n-1 situation

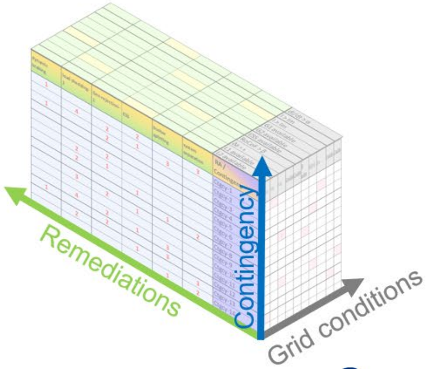


Line current vs. time

System Automation
Generic concept



- **Monitoring area**: pre-contingency grid conditions (load flow, topology, generation level,…)
- **Observation area**: all contingency elements (CB status, line outages,…)
- **Mitigation control area**: action of system automatics (generation rejection, trigger EPCs, grid booster activation, load shedding, CB switching,…)



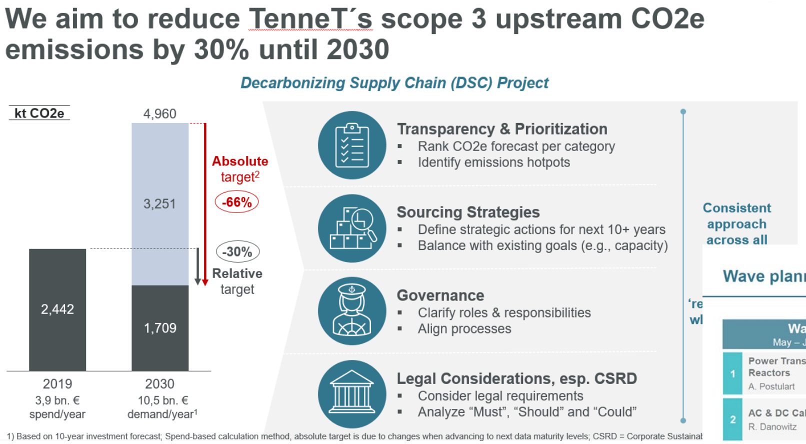
TenneT

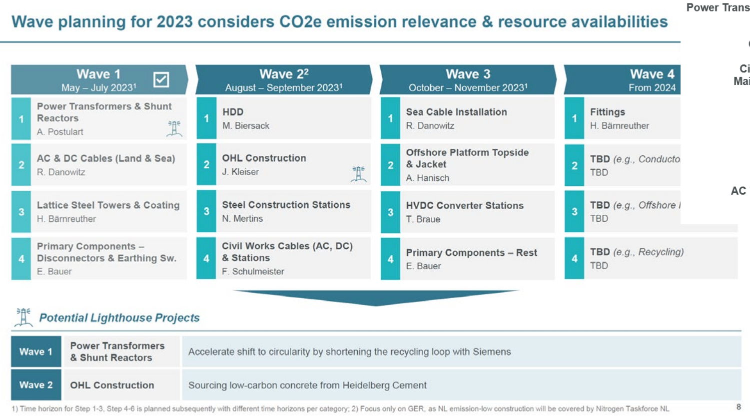
Decarbonization / Circularity

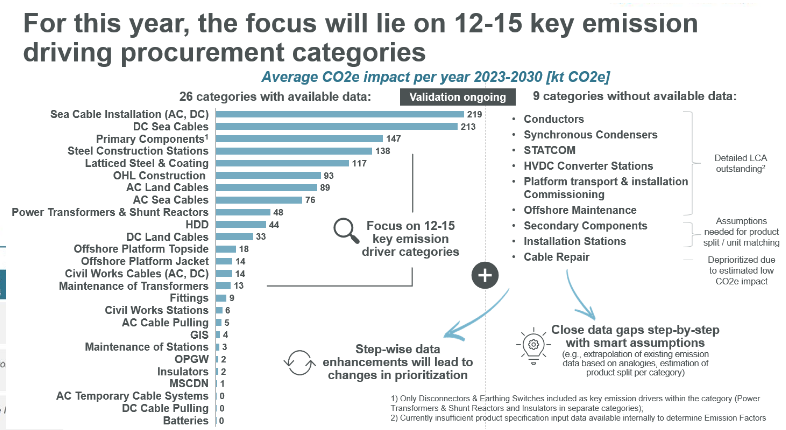
Reduce CO_2 emissions

Invest in whole supply chain

Challenging targets to keep pace with climate protection







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SF_6

Avoidance of Insulation Gas SF_6 Long-term goal GWP ≤ 1!

Worlds 1st SF_6-free 380kV Gas-Insulated Switchgear (Erzhausen)

Components

Pilot Installations for Current and Voltage Transformers, Circuit Breaker -> Standard

From Lagging to Leading
TenneT's new leading SF_6-KPI until 2030

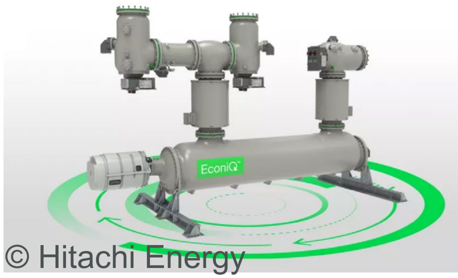
- The share of SF_6 free assets shall at least be 2/3 in new assets by 2030.

Voltage level	Year 2022	2025	2028	2030
110/150 kV	40 %*	50 %*	67 %*	90 %*
220/380 kV	5 %*	33 %*	40 %*	67 %*

* % of the new to build assets that will be with alternative gases. Percentage from the knowledge of current share of IT, CB and GIS in our installed asset base.

- The SF_6-leakage rate for all installed assets shall be ≤ **0.28** %.

The targets will yearly be reviewed based on market and project developments.



© Hitachi Energy

145 kV Circuit synthetic air breaker

245 kV Current Transformer

Pilotinstallations@TenneT

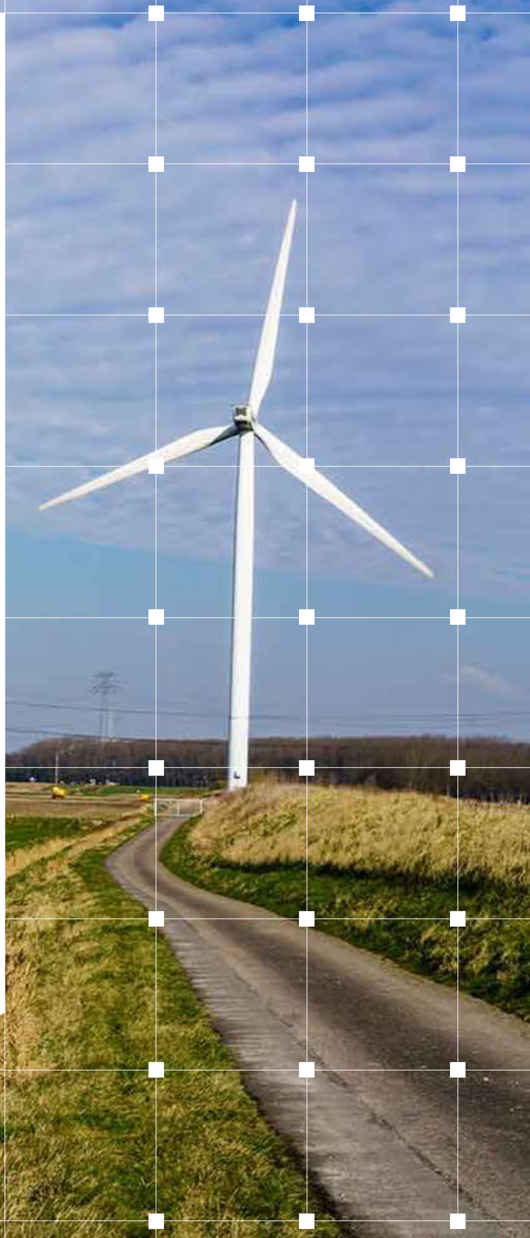
Gas Mixture used	U_m	Application	Number of Equipment / bays	In service since or planed
Synthetic Air	245 kV	Voltage Transformer	3 pcs.	2019
Synthetic Air	420 kV	Voltage Transformer	6 pcs.	2021
Synthetic Air	420 kV	Voltage Transformer	12 pcs.	2022
Novec 4710 gas mixture	245 kV	Current Transformer	6 pcs.	2016
N_2	320 kV	RC-Voltage Divider in HVDC	4 pcs.	2008
N_2	320 kV	RC-Voltage Divider in HVDC	4 pcs.	2011
N_2	320 kV	RC-Voltage Divider in HVDC	4 pcs.	2013
Synthetic Air	145 kV	GIS; Offshore Grid connection System; 72,5 kV system	19 bays	2026
Novec 4710 gas mixture	420 kV	GIS bus duct (GIL)	1 bay	2022
Synthetic Air	145 kV	Circuit Breaker; 30 kV system	1 bay	2019
CO_2	145 kV	Circuit Breaker	1 bay	2021

Summary

- Offshore:
  - In operation 2023 (10 GW): 9 Offshore HVDC’s, 5 Offshore AC’s NL, 3 direct AC’s
  - New built till 2031 (> 34 GW): numerous Off- and Onshore HVDC’s, 4 Offshore HVAC’s
- Onshore
  - Grid Enforcement requires a bundle of measures to catch up with future demands
- Evolution of the Transmission Grid must take benefit of proven and new technologies especially with regard to development of a DC Multiterminal Grid and innovative HTSC technology
- Strong partnership with scientific entities and reputable suppliers is highly appreciated to cope with future demands

TenneT is a leading European grid operator. We are committed to providing a secure and reliable supply of electricity 24 hours a day, 365 days a year, while helping to drive the energy transition in our pursuit of a brighter energy future – more sustainable, reliable and affordable than ever before. In our role as the first cross-border Transmission System Operator (TSO) we design, build, maintain and operate 23,900 km of high-voltage electricity grid in the Netherlands and large parts of Germany, and facilitate the European energy market through our 16 interconnectors to neighbouring countries. We are one of the largest investors in national and international onshore and offshore electricity grids, with a turnover of EUR 4.5 billion and a total asset value of EUR 27 billion. Every day our 5,700 employees take ownership, show courage and make and maintain connections to ensure that the supply and demand of electricity is balanced for over 42 million people.

Lighting the way ahead together.



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