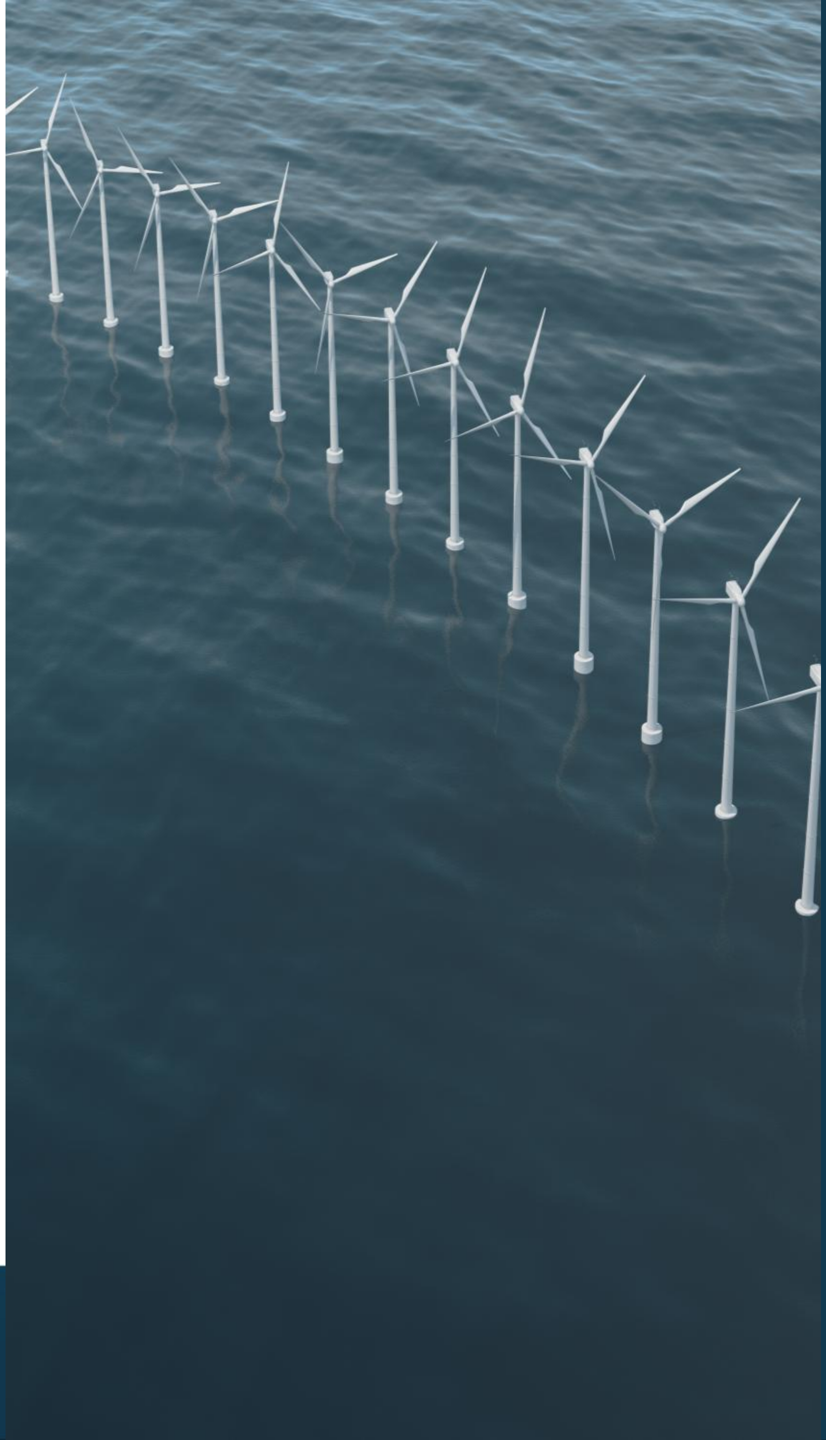


NORWEGIAN COLLABORATION GROUP ON OFFSHORE WIND

EXPERT GROUP
"GRID CONNECTION OF OFFSHORE FLOATING WIND"

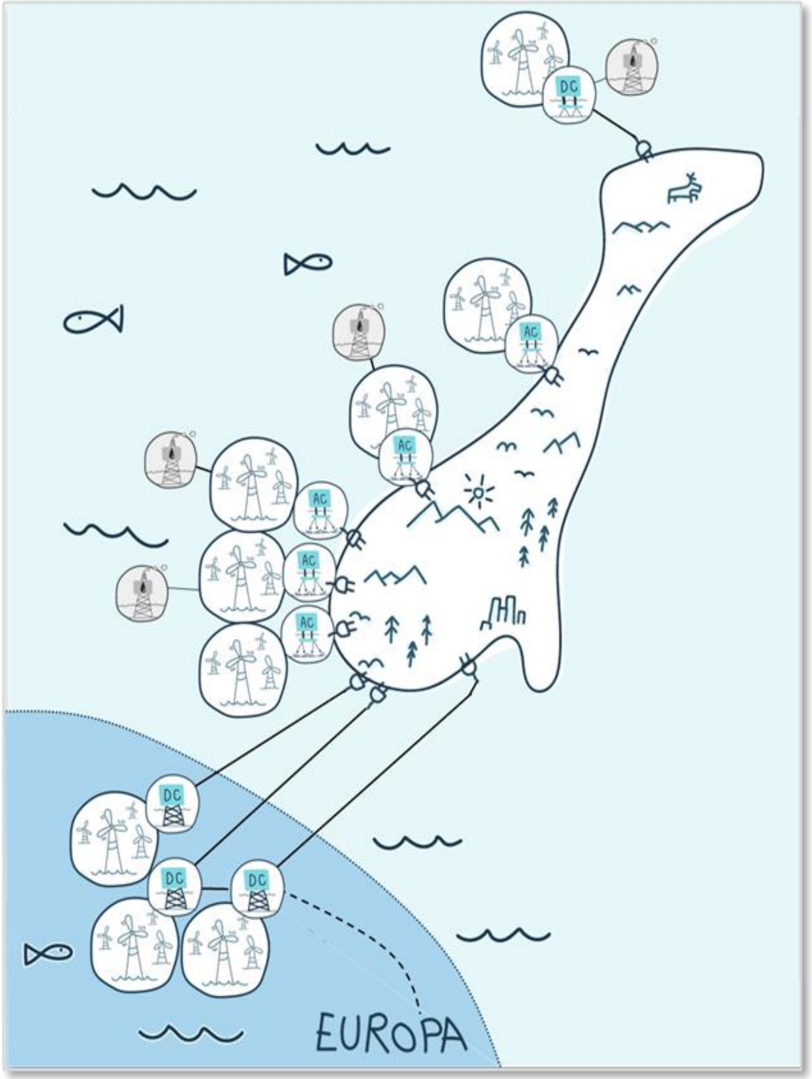
- The Expert Group and mandate
- Grid connection overview
- Technology gaps
- Closing of gaps
- Recommendations

Outlook North Conference 31. October 2024
On behalf of the Expert Group:
Hans Petter Rebo (Norsk Industri)
Jan Wigaard (Aibel)

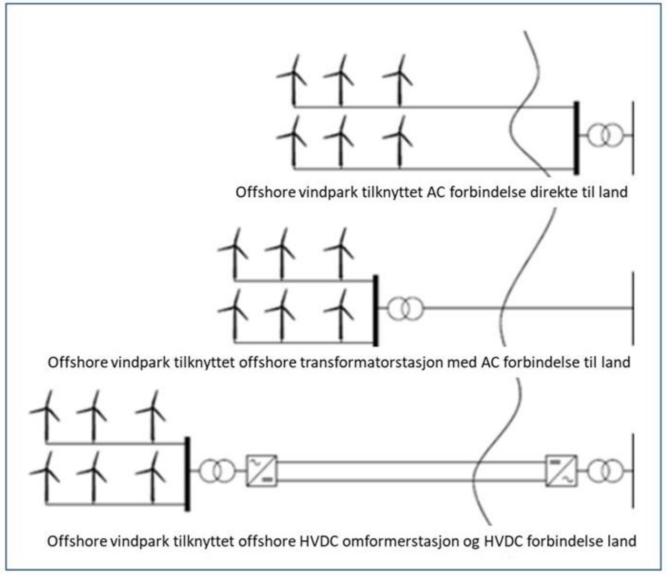
Aker Solutions
aibel
HITACHI Inspire the Next
Hitachi Energy
SIEMENS energy
Nexans
NKT
Statnett
Norsk Industri

Mandate for Expert Group "Grid Connection of Floating Offshore Wind"

- Working Group 2 and 3 under the Minister of Energy's Cooperation Forum established an Expert Group for "Grid Connection of Floating Offshore Wind" in December 2023.
- The Expert Group has assessed:
    - Technology and concepts for grid connection of offshore wind for deep water (floating technology) so that grid connection can be realized in line with the authorities' goal of 30 GW announced by 2040 and upcoming allocation rounds.
    - Identified technology gaps and looked at opportunities to close these gaps.
    - Identified what can lead to significant cost reductions



Configurations of grid connection



Offshore wind farm directly to shore (AC)

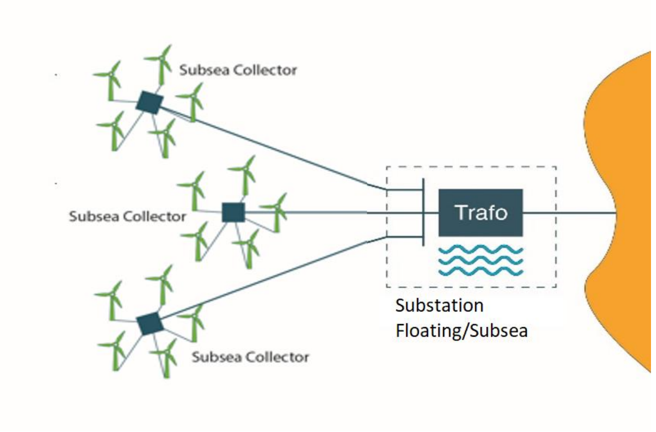
- Typically, less than 100 km from shore/connection point

Offshore wind farm connected to offshore transformer station

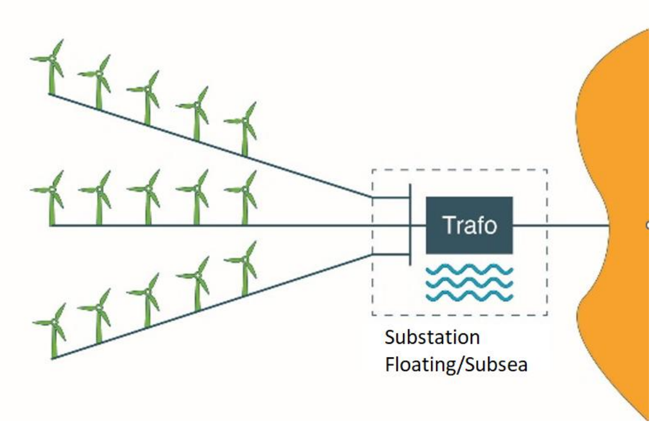
- Typically, less than 100 km from shore/connection point
- (Normal configuration for bottom fixed wind farms)

Offshore wind farm connected to offshore HVDC converter

- Typically, more than 100 km from shore/connection point



Wind park
Collector grid

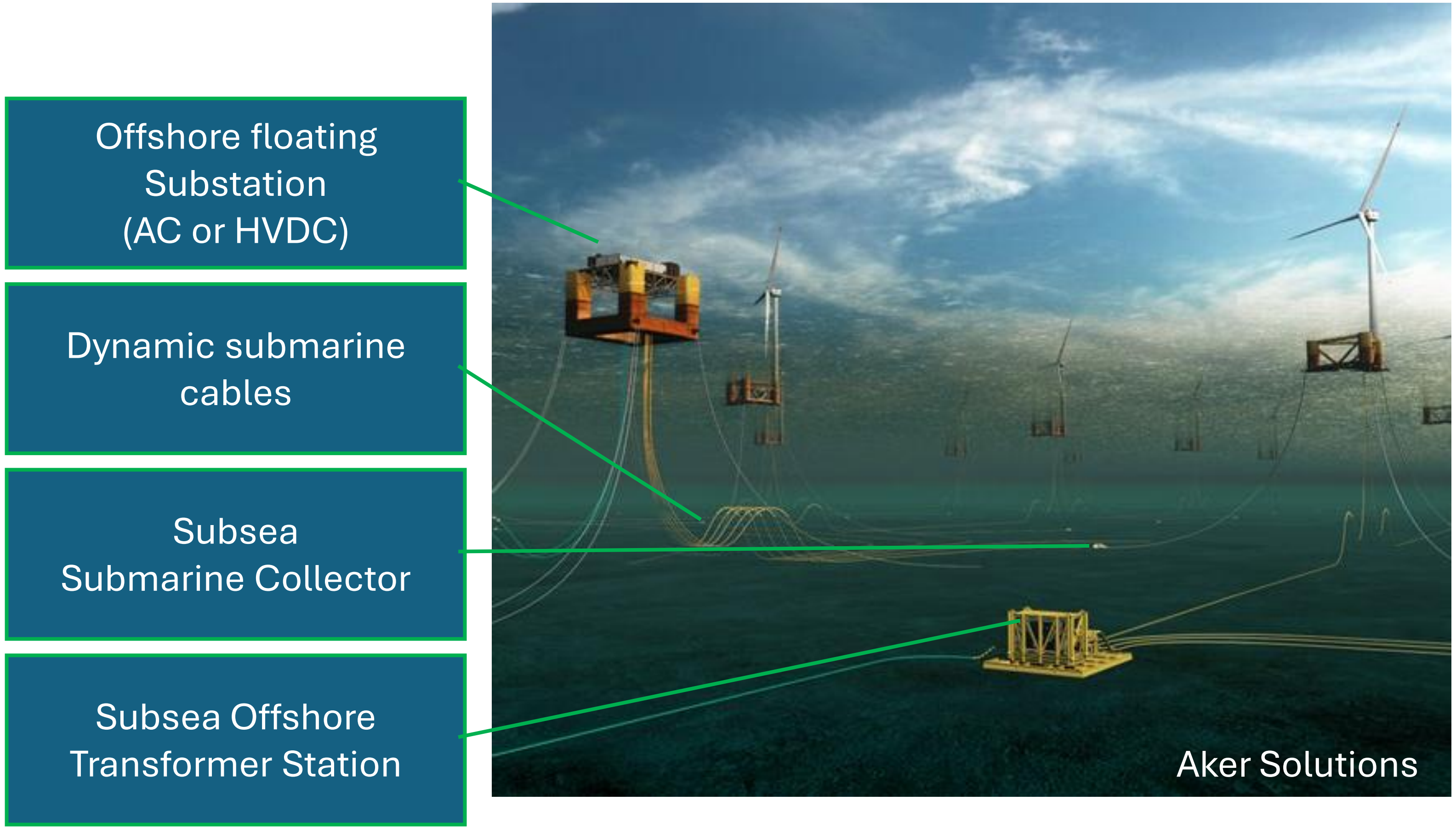


Wind Park
Daisy Chain grid

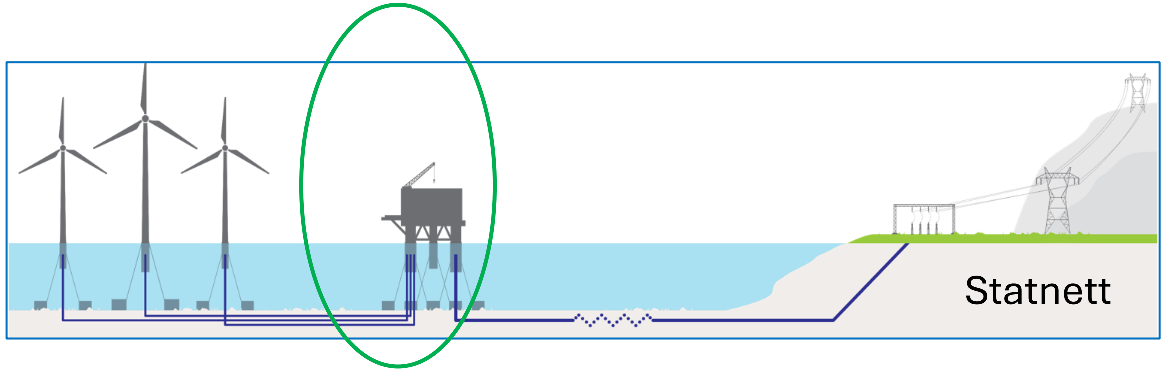
Technologies for floating wind parks

The difference between bottom fixed and floating wind parks is the water depth

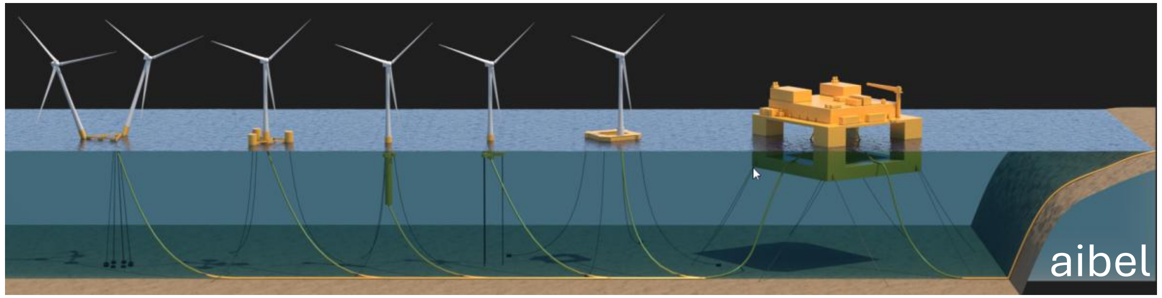
- At a certain depth, it will be less costly with floating or subsea solutions than a huge bottomfixed structure
- When introducing Floating bodies, the motions will be different
- Equipment and cables then need to be designed to tolerate the floater motions
- Subsea solutions require specialized products and equipment
  - need special qualification
  - no access means design for replacement



Offshore floating substation



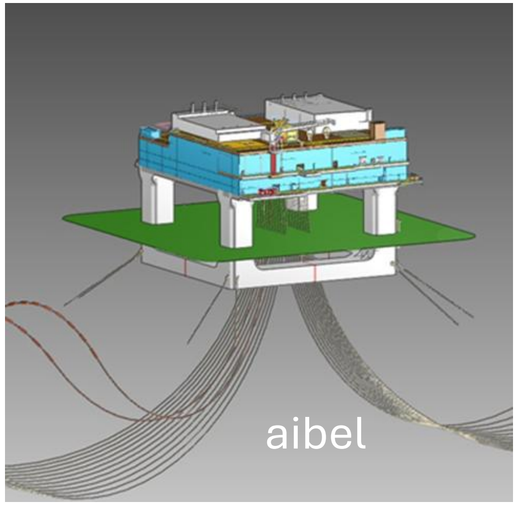
Technology
- Well known from oil and gas
- Topside is well known from bottom fixed AC and HVDC platforms
- Land based AC and HVDC equipment available and used for bottom fixed platforms



Status
- Lack of reference projects
- Relevant projects in pipeline

Gaps
- Verification of AC and HVDC equipment to withstand motions from waves
- Dynamic cables 220 kV AC or larger and 320 kV HVDC (or 525 kV)
- Rules and regulations under development at both Norwegian Ocean Industry Authority and DNV.

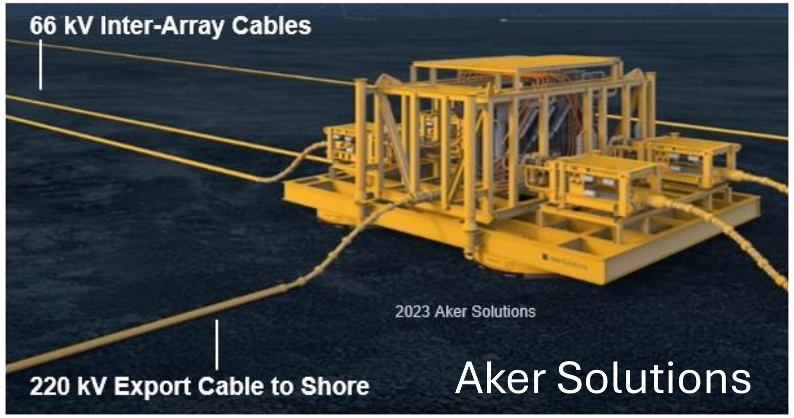
Close Gaps
- Platform design and AC and HVDC equipment regarding motions
- Simplifications, less volume/weight, etc
- Data simulations and lab/factory testing
- Full scale testing
- Cost optimization



Industry anticipate offshore floating substation technology to be ready for start project development:
- Floating AC substation with high power/voltage by ~2025
- Floating HVDC substation with high power/voltage by ~2028

Subsea AC transformer station

Technology description
- Subsea AC transformer (66 kV / 220 kV and high capacity
- Dynamic Inter array cables with wet mate connector
- Static Export cables
- Current developments without breakers (disconnector and circuit breaker)



Status
- Smaller subsea transformers been in operation for more the 40 years.
- Subsea transformers 20 MVA and 132/22 kV in service since 2015
- Ocean Grid R&D project; Technology development66 kV / 220 kV subsea transformer station
- Goliat wind (North of Norway) plan to commission 75 MW floating wind farm in 2028. Subsea transformer is an option.

Gaps
- Complex installation
- Repair challenges (maintenance is anticipated to be minor)
- Inspection and Monitoring
- High-capacity cooling system
- Wet mate connector 66 kV.
- Subsea breakers

Close gaps
- Full scale testing

Industry anticipate technology for subsea AC transformer 66/220 kV with higher capacity to be ready for start project development by ~2025

Subsea Collector

Technology description

- Subsea submarine collector
- Dynamic Inter array cables with wet mate connector
- Static Export cables
- Current developments without breakers (disconnector and circuit breaker)

Status

- Design study ongoing related to a 66 kV subsea test installation at the Norwegian offshore test scenter (METCentere - outside Karmøy in Norway)
- Ocean Grid R&D project; Technology development 66 kV / 220 kV subsea collector

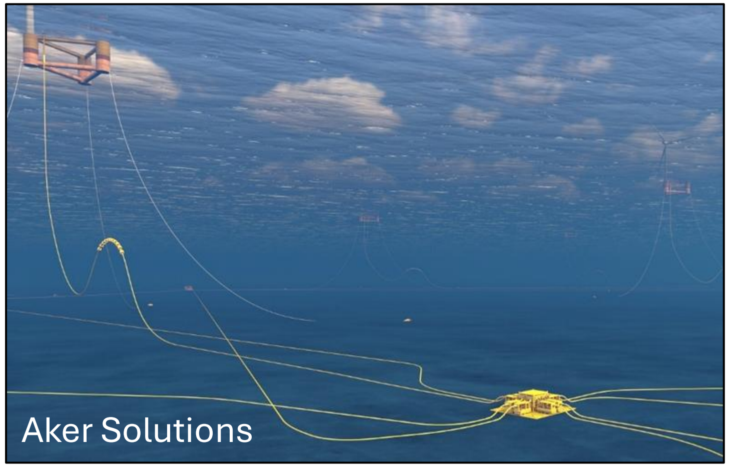
Gaps

- Complex installation
- Repair challenges (maintenance is anticipated to be minor)
- Inspection and Monitoring needs
- Wet mate connector 66 kV.
- Subsea breakers

Close gaps

- Full scale testing

Industry anticipate technology for connector to be ready for start project development by ~2025



"Daisy chain" configuration

"Subsea collector" configuration

Dynamic cables

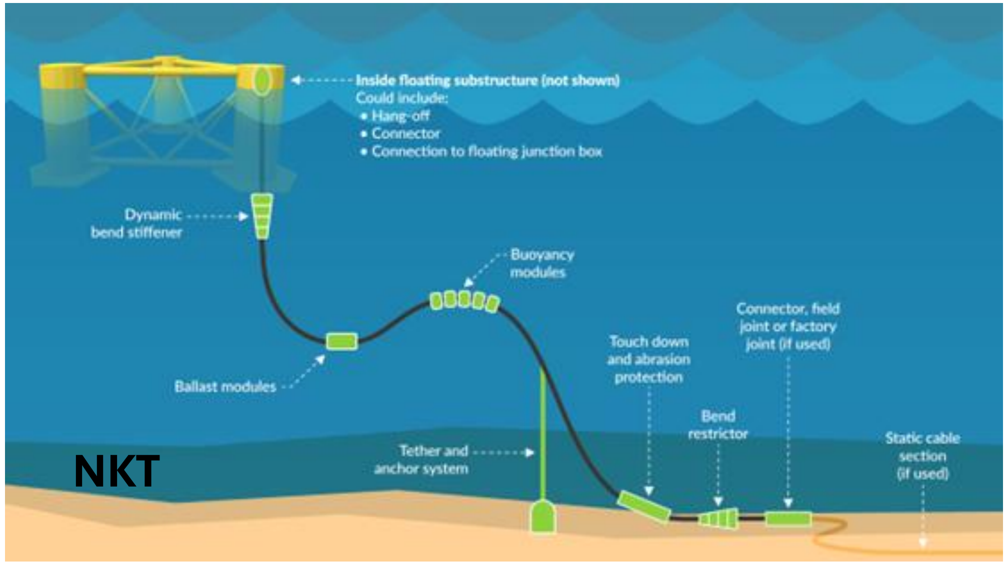
Technology description
- Withstand the constant motion of floating structures.
- Current wind turbine voltage is up to 66 kV.
- 132 kV is anticipated to be the new standard for inter array cables.

Status:
- 132 kV is current state of the art for dynamic AC cables
- Qualification220kV dynamic cables ongoing
- Qualification alternative water barrier to substitute use of lead ongoing

Gaps:
- Need for higher voltage for AC floating substation, 220 kV and above
- Need for 320 kV (525 kV) for HVDC floating substation
- Aluminium instead of copper for the conductor
- Monitoring of operation and possible fault conditions
- Optimise installation methodology

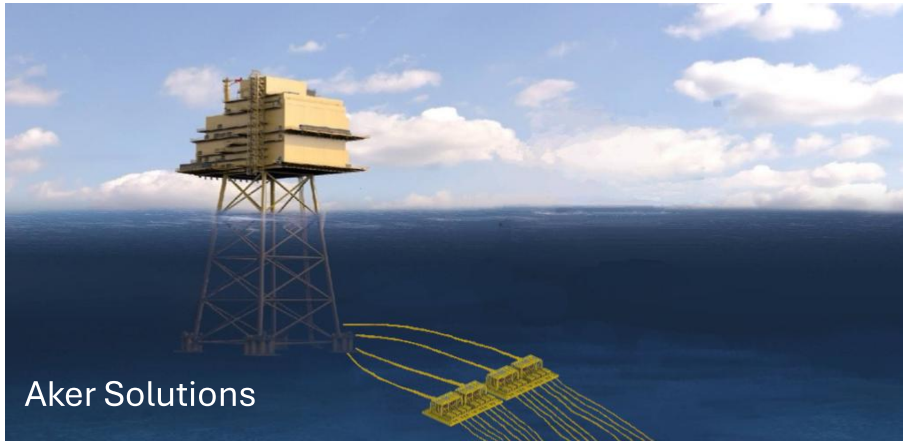
Close Gaps:
- Research and development projects
- Full scale testing

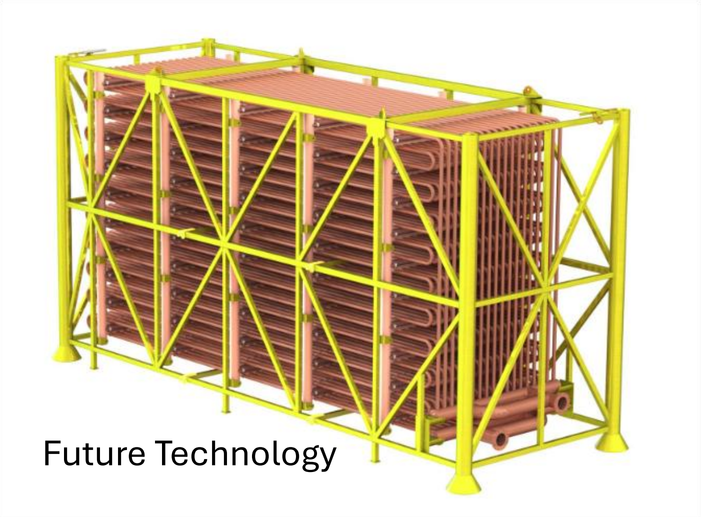
Industry anticipate technology for 220 kV AC to be ready for start project development by~2025
Industry anticipate technology for 320 kV HVDC to be ready for start project development by ~2028




Nexans

OTHER TECHNOLOGY DEVELOPMENTS THAT MAY CONTRIBUTE TO COST REDUCTIONS





Subsea HVDC Transformer

- TenneT has invited the industry to quote a possibility study related to development of a VSC-HVDC subsea transformer (related to a 2GW offshore converter station, 525 kV)
- Higher complexity than AC transformer
- Low technology readiness level
- No reference projects

- Note: Subsea HVDC transformer can also be an advantage for bottom fixed offshore wind farms

Subsea cooling of platform AC transformer, converter and other equipments

- To reduce space and weight on offshore AC transformer and HVDC platforms, cooling systems can be moved from platform to the seabed.
- No reference projects in scale

- Note: Subsea cooling system can also be an advantage for bottom fixed offshore wind farms

IDENTIFIED GAPS - SUMMARISED

- Technology maturity in general
- Adaption to marine environment and motions
- Need for technology development and testing
- Need for standardisation, rules and standards
- Needs and Opportunities for cost reduction (Capex and Opex)
- Better sustainability solution

How to close the gaps?
How can floating offshore wind become profitable ?

Technology for grid connection of floating offshore wind has generally high technological maturit

- Floating platforms is known from oil&gas. Simplification and standardization needed.
- Electrical equipment for AC and HVDC are commercially available. Must be adapted for floating applications.
- Subsea transformers well known from oil&gas applications. Voltage and capacity must be higher.
- AC dynamic cables for 132 kV are available today. AC dynamic cables for 220 kV must be qualified.

- Ongoing activities within Research and Development
- Real projects is next, will not get more ready with more R&D
- No clear winner among technologies, should develop and qualify several
- One can and should use the first projects to develop the technologies
  - Not consider lowest cost for e.g. Utsira only, but use the project for pilots within both Floating and Subsea substations and dynamic cables
- Oil&Gas experience is good, however not sufficient, special competence and experience within Offshore wind is required
- Other countries has more powerful support regimes and foreign contractors are gaining head vs Norwegian contractors