Study Committee C1
Power System Development & Economics
Paper C1-ID11097-2022

German HVDC corridors as starting points for a pan-European HVDC overlay grid

Matthias MÜLLER-MIENACK
DNV Germany

Christian HEWICKER
DNV Germany

Karsten TREPTE
Germany

Cornelis A. PLET
DNV Canada

Motivation

- Many German HVDC projects are planned to transport offshore wind energy from the OWFs to the coast and further to the inland to load centres.
- Some are planned as multi-terminal configuration and may provide a starting point of a pan-European HVDC overlay grid. Others HVDCs will have to fulfil „multi-terminal readiness" criteria for later combination with further DC links.
- The paper discusses potential technical requirements and market benefits of using planned HVDC projects as nucleus of a future pan-European HVDC overlay grid

Method / Approach

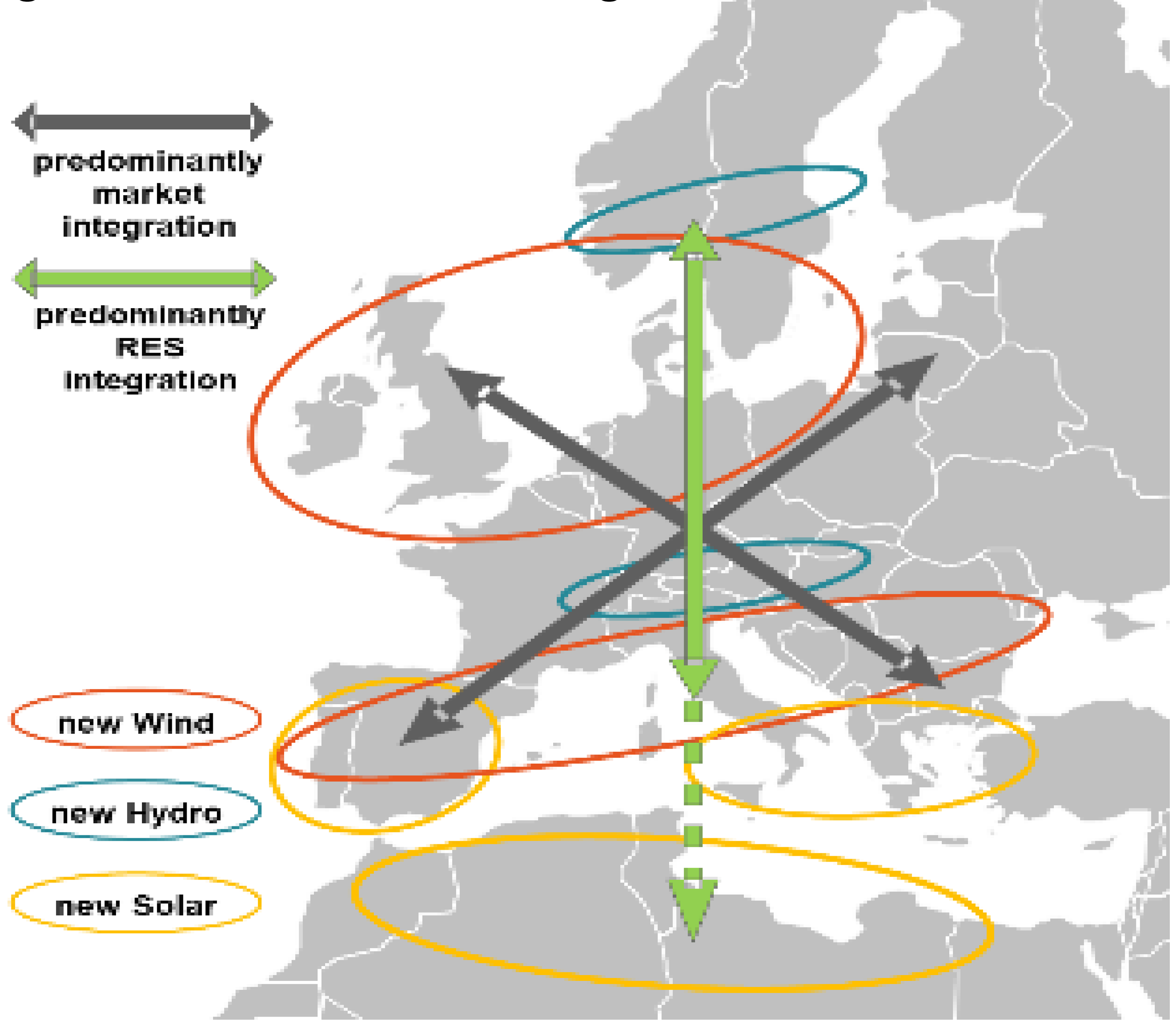
- Market integration & decarbonisation have been main triggers for establishing of HVDC lines and nowadays also triggering elements for HVDC grids.
- Pros and cons of HVDC topology options are discussed, focusing esp. on losses, availability, CapEx and lifetime OpEx.
- Structural 'corridors' such as the North-South axis between Scandinavia, Germany, the Alpine region and Italy are potential candidates for an HVDC start grid.

Objects of investigation

- In China, converter and HVDC circuit breaker equipment incl. lower-level controllers of multi-terminal HVDC grids were supplied by multiple vendors, but system controller and upper-level controllers by a single vendor.
- European projects are usually procured on a turnkey basis from a single vendor. Projects are usually awarded on lifetime socio-economic benefit which does not include/value the benefit of technology demonstration.
- In Europe, various R&D projects have developed application guidelines, test requirements and test methods for key technologies necessary of meshed multi-terminal grids; but actual uptake remains slow and limited.
- While primary technical issues have been solved up to the DCCB, the main focus must now be on ensuring controller-related interoperability requirements, which need to be addressed in the tender specifications.

Experimental setup & test results

Figure based on ENTSO-E image



Discussion

- How to overcome the lack of standardization?
- How to assure multi-terminal readiness for HVDC projects?
- How to agree on embedding DC projects into a DC grid?

Conclusion

- Pressure to establish meshed HVDC grid structures towards a pan-European DC overlay grid is increasing; DC projects currently in planning can set the starting point for this.
- HVDC links should be planned and designed to be:
  - **Expandable** (include physical provisions such as a spare disconnector bay to make the DC connection),
  - **Compatible** (e.g. operating voltages, converter configuration and technology, system earthing, functional behaviour) and
  - **Interoperable** (compatible across organizational borders and integration with control rooms of different TSOs).
- A possible first multi-terminal multi-vendor structure in Europe could be an HVDC link from Sweden via Germany and Austria to Italy, involving the projects SouthWest Link, Hansa PowerBridge and the inner German HVDC project DC20.

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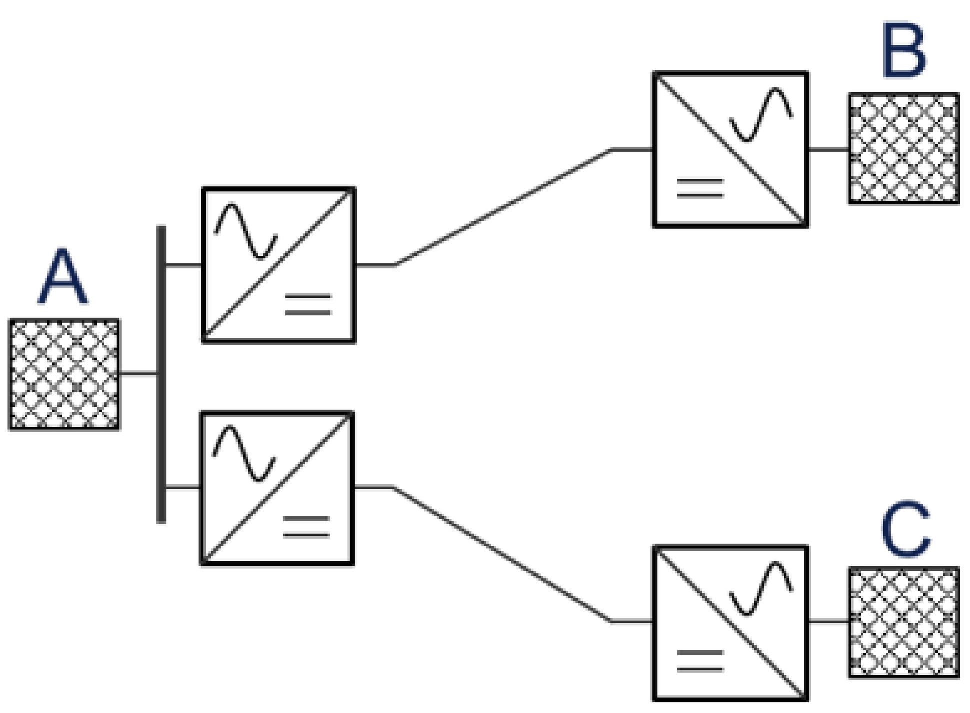
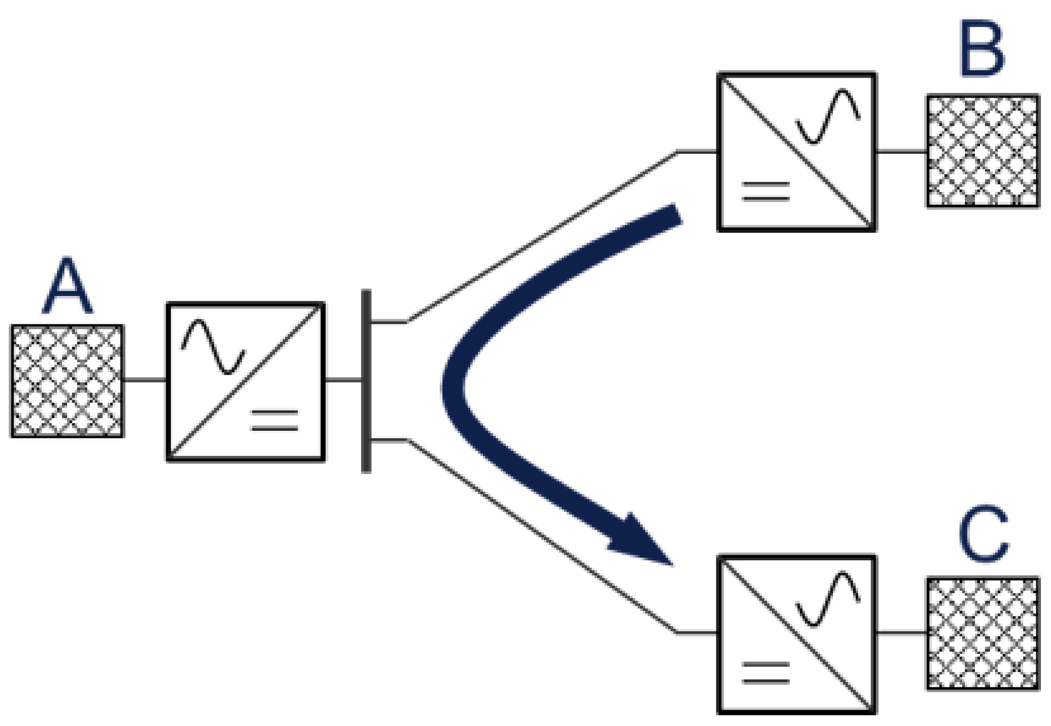
More insights: Pros and cons of HVDC

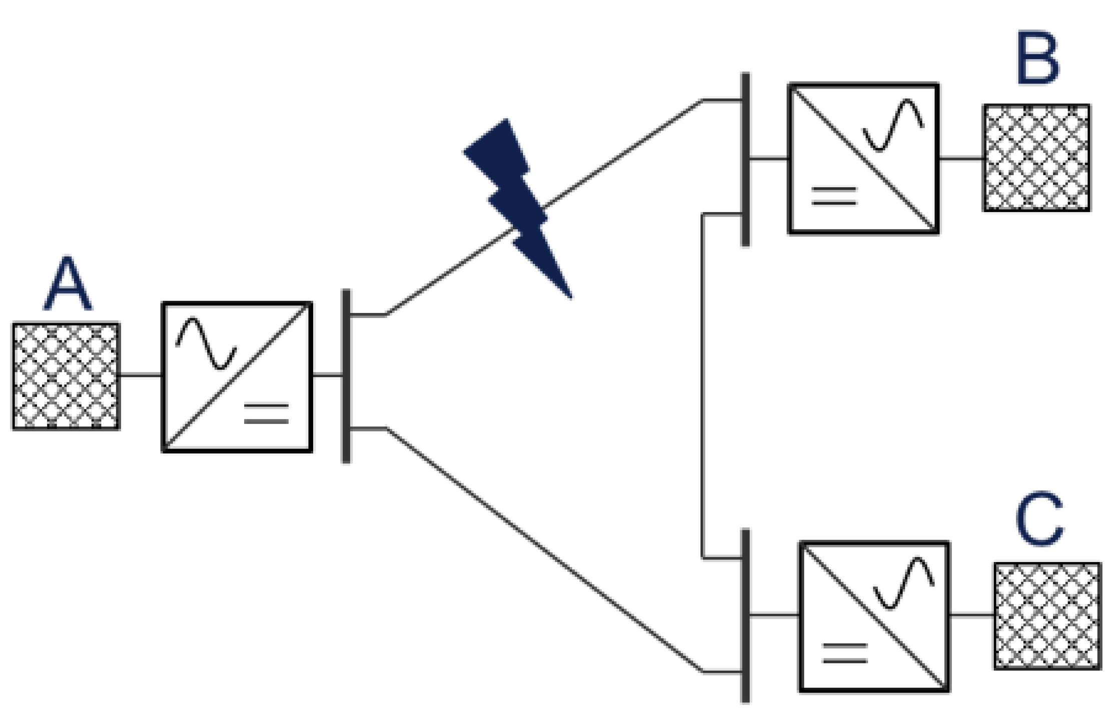
- HVDC systems can connect multiple energy markets, AC transmission grids and/or renewable energy sources in different ways, as shown in Figures bwlow which illustrates the three main HVDC system topologies (source: DNV):



a) Point-to-point systems



b) Radial multi-terminal system



c) Meshed multi-terminal system

- The figures show a power system consisting of multiple point-to-point HVDC links, which reflects today's HVDC system building paradigm in Europe.
- Each link serves a different distinct purpose, can be tailored for the application in terms of technology, voltage rating and capacity, and can be procured on a turn-key basis from a single vendor or consortium.
- In such a power system, power flows which traverse multiple HVDC links, e.g. from grid B to grid C, have to pass through multiple converters at each AC connection point.
- Each converter incurs a 1% loss and is associated with significant CAPEX and lifetime OPEX. To avoid this, a radial multi-terminal HVDC system can be realized as shown in Figure 2 b).
- This topology minimizes the number of converters and therefore minimizes cost and impact on the environment and local communities and increases efficiency and availability.
- However, in case of an outage on one of the radial links, there is no redundant path. This means that any generation or scheduled power flow is lost instantaneously and completely for as long as the link repair takes.
- In the immediate moment after the fault, this outage jeopardizes the connected AC grids' frequency stability due to the sudden loss of infeed.
- In the long term, the outage leads to a potentially significant loss of revenue for the parties connected by the HVDC link.
- An additional transmission link, creating a so-called meshed grid as shown in Figure 2 c), can provide redundant transmission capacity during the outage limiting the loss of revenue.
- When fitted with a (partially) selective HVDC fault clearing system, such a redundant transmission link can also limit the instantaneous loss of infeed and thereby limit operational costs associated with procuring additional frequency containment reserves.

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More insights:
HVDC projects in Northern Europe

- A large number of VSC based point-point HVDC links are currently in operation or in development in Europe today, as illustrated with the HVDC projects map below (source_ DNV).
- These links serve one of four purposes: Energy trade between countries, export of offshore wind energy, supply of energy to offshore oil & gas facilities or the reinforcement of incumbent AC transmission system.
- It is possible to see that the end points of different HVDC links are geographically located close to another, and that power flows are likely to pass from one link into the other.
- At these locations a DC connection, indicated by the orange dots, would make sense for the reasons mentioned above, creating a multi-terminal HVDC system.
- Many links have (slightly) different operating voltages and different converter configurations (symmetric monopole vs rigid bipole vs bipole with dedicate metallic return), which complicate such a DC connection.
- But when considering that most of the operating voltages are actually quite similar and could be grouped into voltage classes, it is possible to start seeing how different existing and planned links could be interconnected on the DC side into multi-terminal HVDC grid topologies.
- The multi-terminal readiness will require a significant coordination and standardization effort on all stakeholder levels ranging from suppliers, system operators to national governments and EU bodies such as ENTSO-E.