Multi-terminal HVDC grids:

Technology, topologies and applications for renewable energy integration

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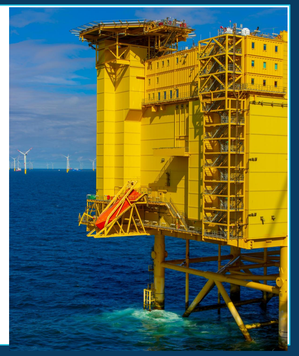
F. SALEHI[1] and C.A.PLET[2]
[1]DNV Power System Advisory, Dallas, USA
[2]DNV Power System Advisory, Toronto, Canada

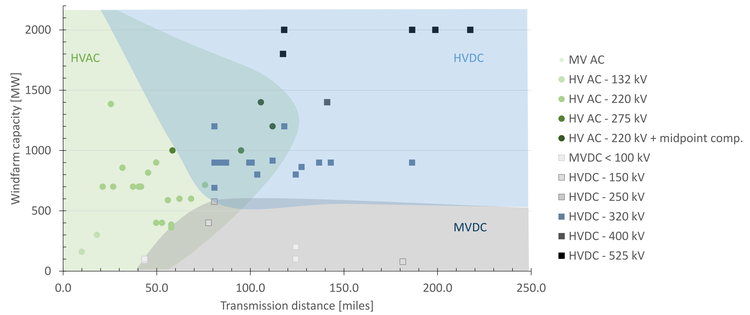
DNV

WHAT IS HVDC?

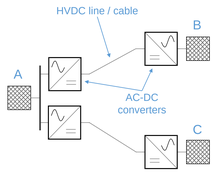
- High voltage direct current
- Cost-effective and low-impact technology for high capacity and long-distance transmission
- Fully controllable
- Grid integration of remote large-scale renewables
  - Hydro
  - Offshore wind
  - Solar
- Energy trade between countries / continents
- Reinforcement of existing onshore grids



WHEN DOES IT MAKE SENSE TO USE HVDC?

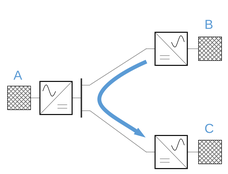


HOW CAN HVDC SYSTEMS BE USED?



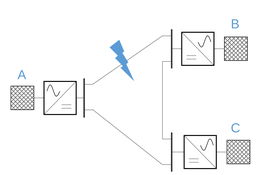
Point-point systems

- Bespoke projects
- Easier project development
  - Single vendor procurement
  - Single purpose
- Mature and widely applied



<u>Radial</u> multi-terminal system

- Multi-purpose
- Fewer converters
  - Lower cost
  - Lower footprint
  - Lower losses
- Requires compatibility



<u>Meshed</u> multi-terminal system

- Redundant paths
  - Increased availability
  - Reduced impact on AC grids
- Requires DC protection system

WHAT IS THE DIFFERENCE?

Multiple point-point links

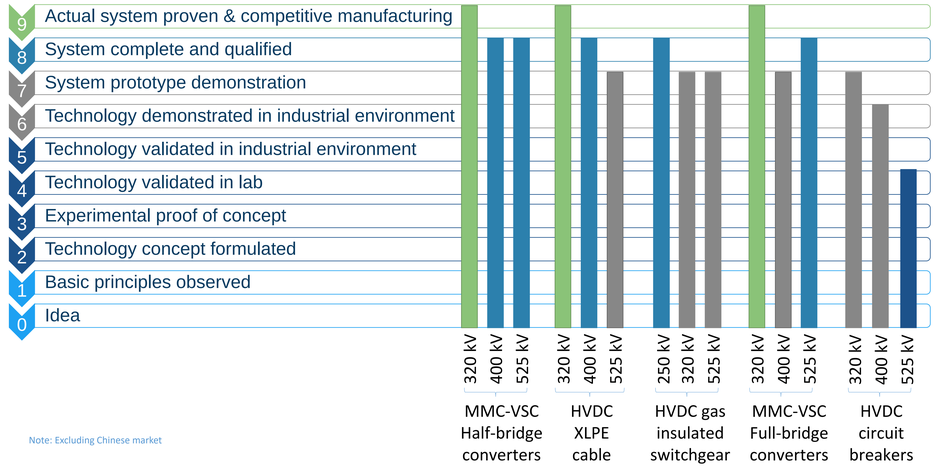
- *Allows different technologies and voltage levels for each link*
  - *Optimize design & operation of each link*
- *Avoids project dependencies*
  - *Schedule*
  - *Terminal locations*
  - *Anticipatory investments for expandability*
- *Simplifies multi-vendor interoperability*
  - *Systems from different vendors coupled at AC side guided by AC grid codes*
- *Proven, accepted technology*

VS

Multi-terminal grid

- *Fewer converters*
  - *Lower losses*
  - *Lower footprint*
    - *Lower socio-environmental impact*
    - *Lower permitting burden*
  - *Higher availability*
- *Better utilization*
  - *Multi-purpose use*
- *Fewer cables (for meshed systems)*
  - *Use redundant paths to satisfy most severe single contingency constraints*

IS MULTI-TERMINAL HVDC TECHNOLOGY READY?

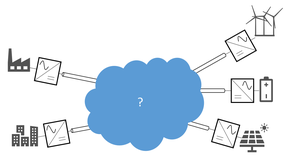


Note: Excluding Chinese market

WHY ARE MULTI-TERMINAL HVDC GRIDS APPEARING?

The increasing density of HVDC transmission links creates opportunities to realize multi-terminal synergies

Offshore wind export | Onshore grid reinforcements | Onshore inter-regional links | Onshore renewable lead lines



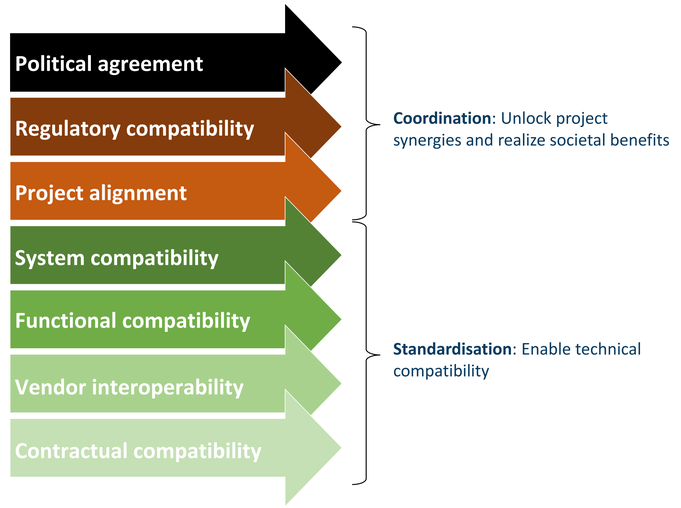
New HVDC projects often use Voltage Sourced Converter technology whose superior control capabilities make it naturally suitable for multi-terminal connections

Changes current polarity to change power flow direction, but keeps voltage constant | Suitable for large, complex multi-terminal HVDC networks

Development of DC fault current clearing technologies enables large HVDC grids without jeopardizing AC grid frequency stability

Full bridge converters | HVDC circuit breakers | Superconducting fault current limiters

WHAT NEEDS TO HAPPEN?



CONTACT INFORMATION

Dr. F.Salehi, farshid.Salehi@dnv.com