HVDC Technology for Electric Highways

The Future Grid

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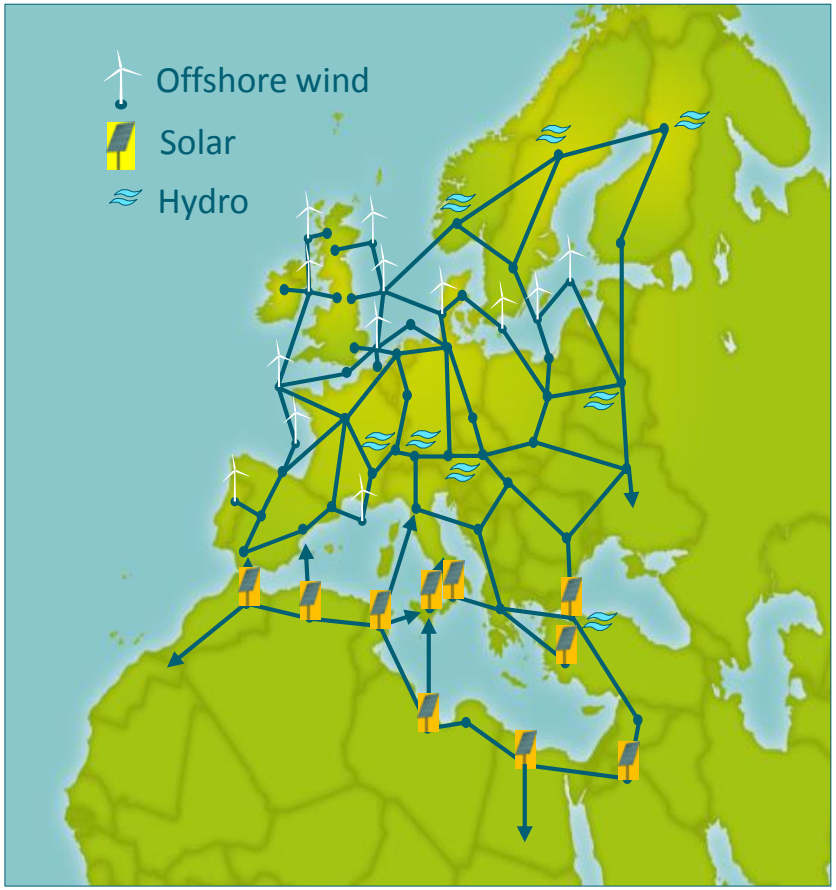
Supergrid Concepts

- A pan-continental grid interconnecting all unsynchronised regions, including off-shore systems
  - Large increase in energy trading capacity
  - Fast balancing of intermittant renewable power
  - Sharing of back-up power sources
  - Better security of supply
- Benefits over the existing AC Grids
  - Much larger interconnection capacity
  - Much longer distances between connection points
  - Agreements between more than two grid operators
  - Mainly using HVDC technology, principally Voltage Source Converter (VSC)

Roadmap Report 2016

- Review of the Technology Readiness Level of the components of a Supergrid
  - VSC technology
  - Cables and overhead lines
  - Off-shore platforms
  - Control systems
  - Protection systems
  - ICT and SCADA systems
  - Storage systems
- Assessment of the future development of technology and systems to 2025 and beyond



Preparation Phase; up to 2015

- Progressive shift from LCC to VSC technology
- HVDC links to off-shore wind farms in Germany
- Embedded HVDC links within synchronous grids up to 2000MW
- Interconnectors between asynchronous grids up to 500kV
- Multi-terminal HVDC schemes in China
  - Nan'ao 3 terminal scheme (with future 4th terminal)
  - Zhousan 5 terminal scheme
- 2-terminal schemes designed for future 3rd terminal
  - South – West link in Sweden
  - Caithness – Moray in UK
- Development of DC circuit breaker technology

Skagerrak Pole 4 : 700MW 500kV VSC Converter Station

Copyright : ABB

VSC valve hall

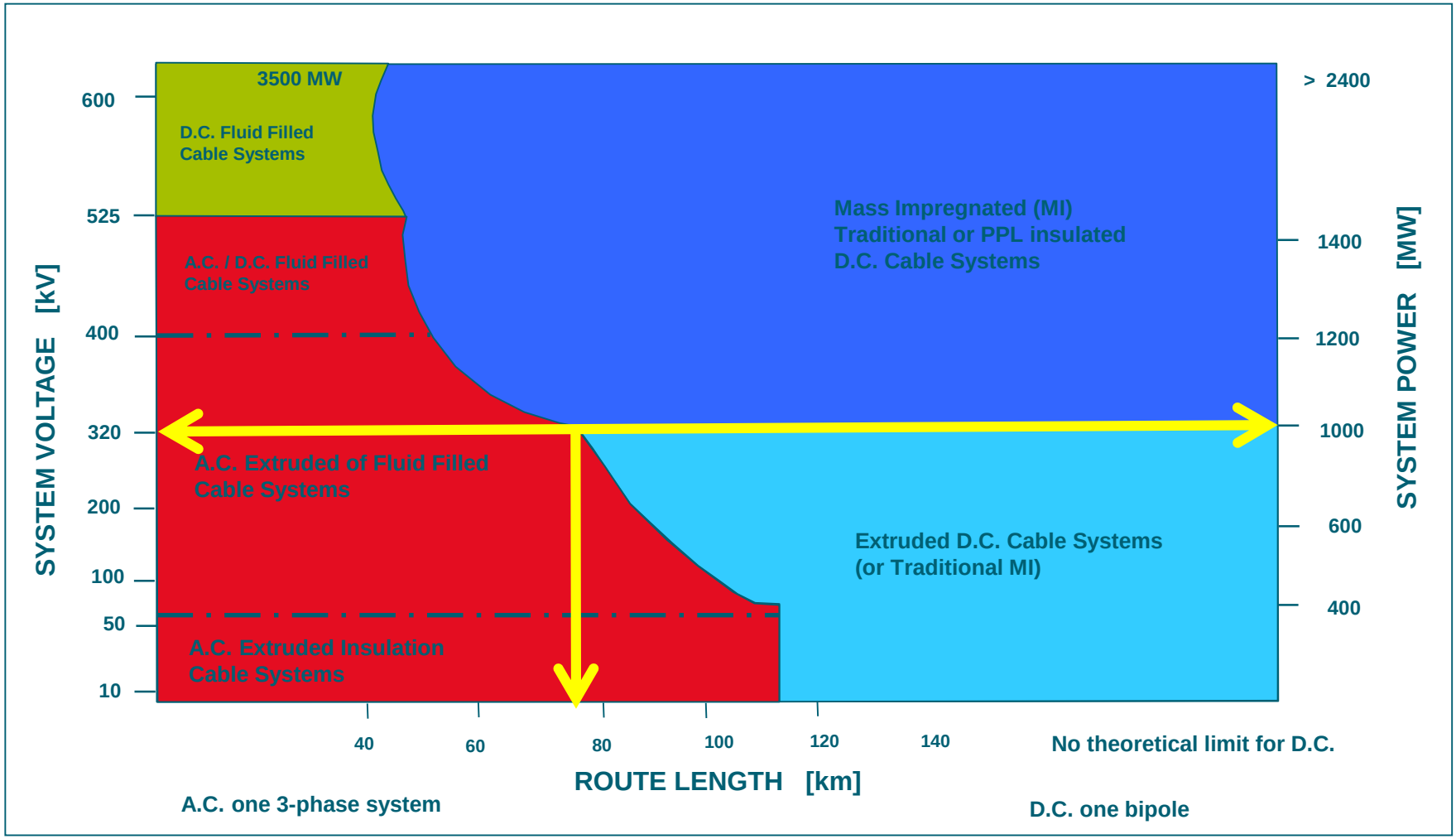
Source : GE (Alstom)

INELFE : 2 x 1000MW ±320kV VSC Converter Station, Spain

Source – REE/Siemens

SylWin Alpha HVDC Platform

AC and DC Cable Comparison

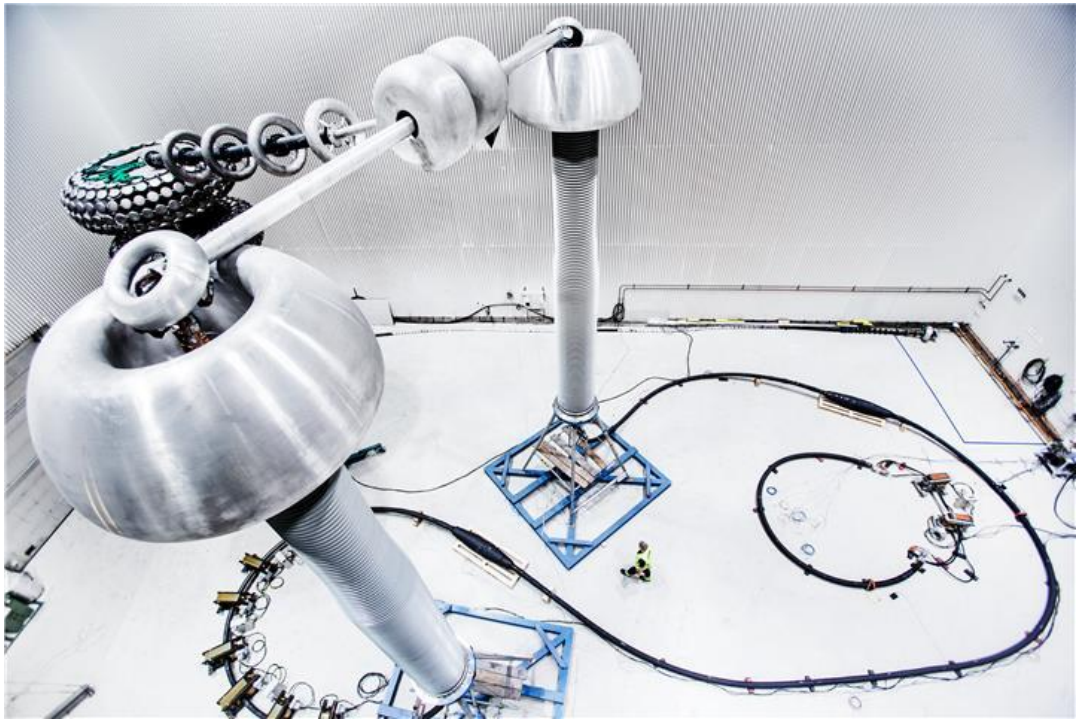


Phase 1: 2015 - 2020

- Rationale for scheme development
  - Evacuation of remote renewable energy sources
- MTDC enabled schemes enter service
  - South – West link, Sweden
  - Caithness – Moray, UK
- 1000MW @ ±320kV becomes a “de facto” standard
- Bi-pole VSC schemes up to 1600MW
- IGBT devices rated at 2000A from multiple vendors
- MI cables in service up to 600kV
- DC GIS/GIL available up to 500kV

525kV XLPE DC Cable

Cable cross-section



Cable Test Circuit

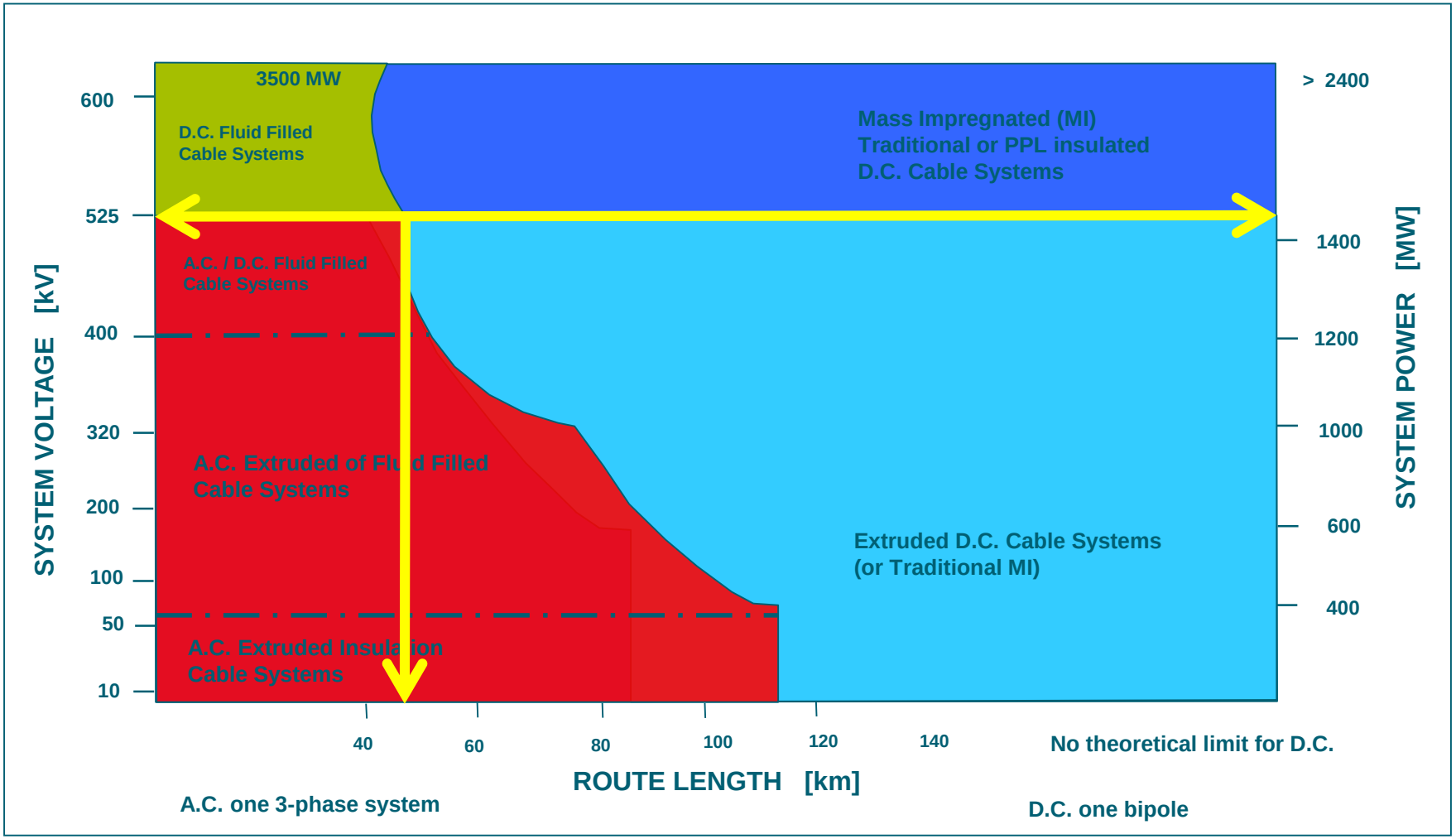
DC Gas Insulated Switchgear (GIS)

Source: Siemens

Phase 2; 2020 - 2025

- Rationale for scheme development
  - Increased interconnectivity in line with EU target of 10% of generation capacity
- Bi-polar schemes at ±600kV and 2500MW in design and construction
- Use of parallel converters to achieve higher power levels with limited power loss during a pole trip
- Cable technology becomes a key factor
  - MI cable experience at 600kV
  - XPLE in construction at 525kV
- Overhead line schemes in operation at ±500kV

AC and DC Cable Comparison



Phase 3: After 2025

- Rationale for the evolution of the Supergrid
  - Aggregation of the disparate HVDC schemes
  - Coordination by ENTSO-E and ACER
- Cable technology moves to higher voltages
  - MI-PPLP to >600kV
  - XLPE to >525kV
- Control and protection techniques evolve from MTDC systems to grid systems
- DC – DC converters; developed in Phase 1, demonstrated in Phase 2 and deployed in Phase 3

Route to the Supergrid

- Key benefits of interconnecting HVDC schemes
  - Higher operational flexibility
  - Greater security of supply
  - Higher utilisation of transmission corridors
- Challenges include
  - Cooperation between multiple TSOs
  - Cooperation between multiple vendors
  - Coordination of system design and operation
- Organisations working to resolve these issues
  - ENTSO-E; Network Code for HVDC
  - CENELEC: working group on DC grids
  - CIGRE: working groups on DC grids

Conclusions

- The roadmap report presents a vision of the Supergrid technologies and their anticipated timeline
- The Supergrid is a significant technological challenge, but **there are no insuperable problems**
- **Interoperability** of multi-vendor systems is a key requirement
- Regulatory and economic challenges are still to be resolved

- FOSG Roadmap report (191 pages) available at http://www.friendsofthesupergrid.eu

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