Engineering Specifications

Multi-terminal, Multi-vendor

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SSEN-Transmission Structure

HVDC

HVDC Operations

- Emergency response
- Project Support
- Daily operation

HVDC Engineering

- Technical support
- Project dev / execution
- Technical specification

HVDC Centre

- Simulation support / hosting
- Research & Development
- Industry support

- Transmission Business
  - not renewables or windfarms
- HVDC Engineering
  - Broad matrix functions
  - Integrated project teams
  - Technical policy, strategy, and specifications
  - Coordination with AC

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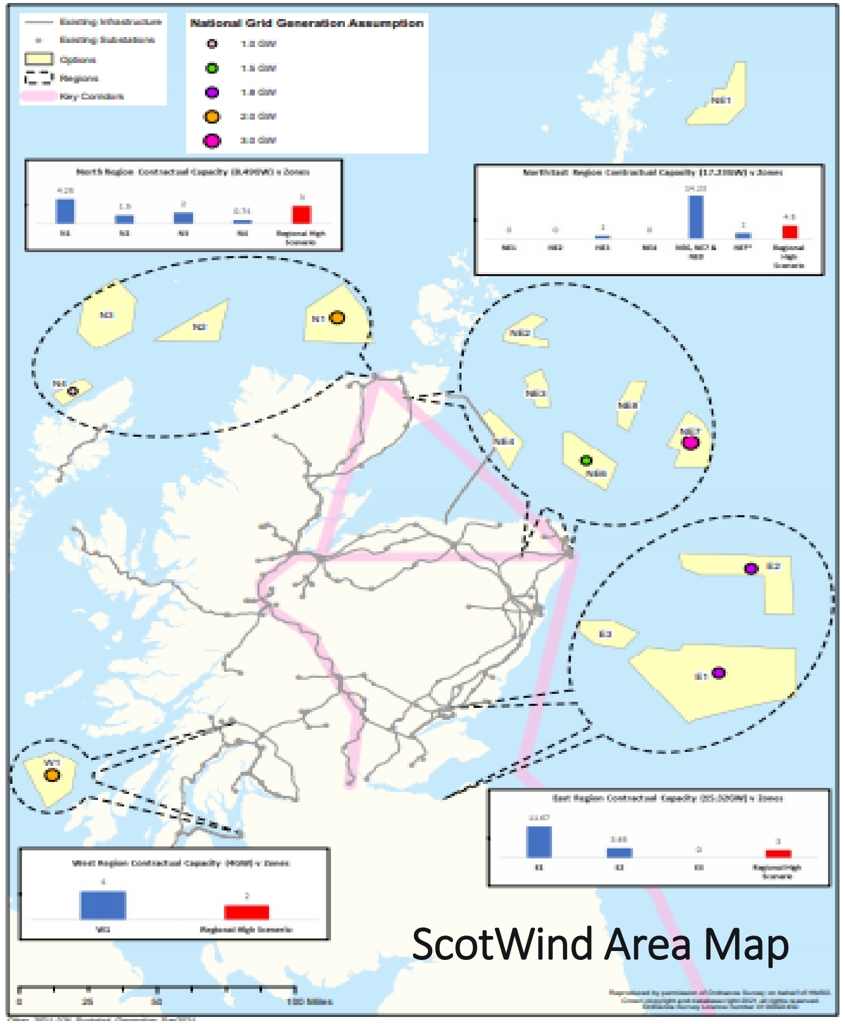
SSEN-T Network Development

HVDC

- Significant offshore wind in the north
- Load centres in the south
- SSEN-T responsible for embedded transmission
- Demonstrated need for HVDC grids
  - Capital cost reduction
  - Alleviate steady state stability



ScotWind Area Map

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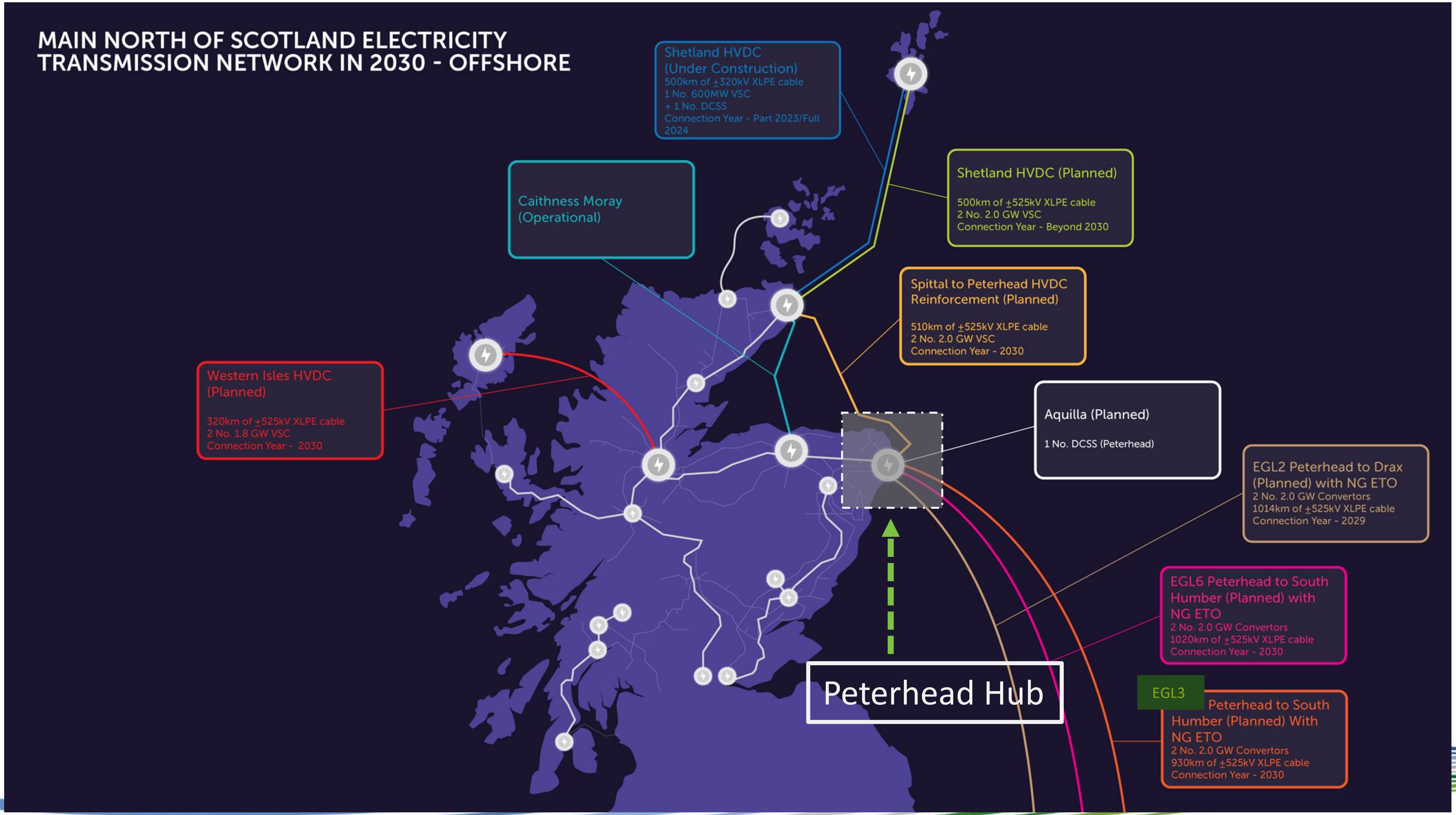
SSEN-T Network Development

HVDC



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SSEN-T Peterhead Hub

Why HVDC Multiterminal (Mt)?

- Transmission System Stability
- Enable future DC customer connections
- Reduce land use
- Reduce capital cost / market constraints

SSEN-T Peterhead Hub

Why Multi-vendor (Mv)?

- Expand market capability
  - Avoid vendor lock-in
  - De-risk future DC customer connections
  - Develop confidence in multiple vendors
- Encourage innovation
  - Progress HVDC maturity through standardisation
  - Improve project execution and delivery over long-term
- If not now, then when?
  - Optimal location with "safe-to-fail" delivery strategy

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Mt-Mv Specification

Guiding Principles

- Adopt existing industry resources where practical
  - CIGRE TB 657 Connection agreements for Mt
  - CIGRE TB 699 Vdc / power flow control in Meshed HVDC
  - IEC 63291 HVDC Grids Functional Specifications
- Absorb / participate in industry working groups
  - ProMotion, Interopera, Ready4DC, etc.
- Safe to fail delivery strategy
  - Avoid compounding risks through technology dependencies (i.e., DCCB, DCGIS, full-bridge, etc.)
  - Plan for future DCCB expansion
- Scope of Delivery
  - SSEN civil work
  - Manageable interface boundaries
- Account for "known un-knowns"
  - Busbar ratings, DC voltage tolerance, operations strategy
  - Project risk allowance for "development" aspects
- Pragmatic
  - Challenge industry norms /standards (i.e., maximum infeed loss, fault tolerance, etc.)
  - "Don't let the perfect be the enemy of the good"
  - Take partial responsibility and ownership of design – don't leave everything to suppliers
- Protect IP
  - Don't re-invent the wheel
  - Aquila Interoperability Project

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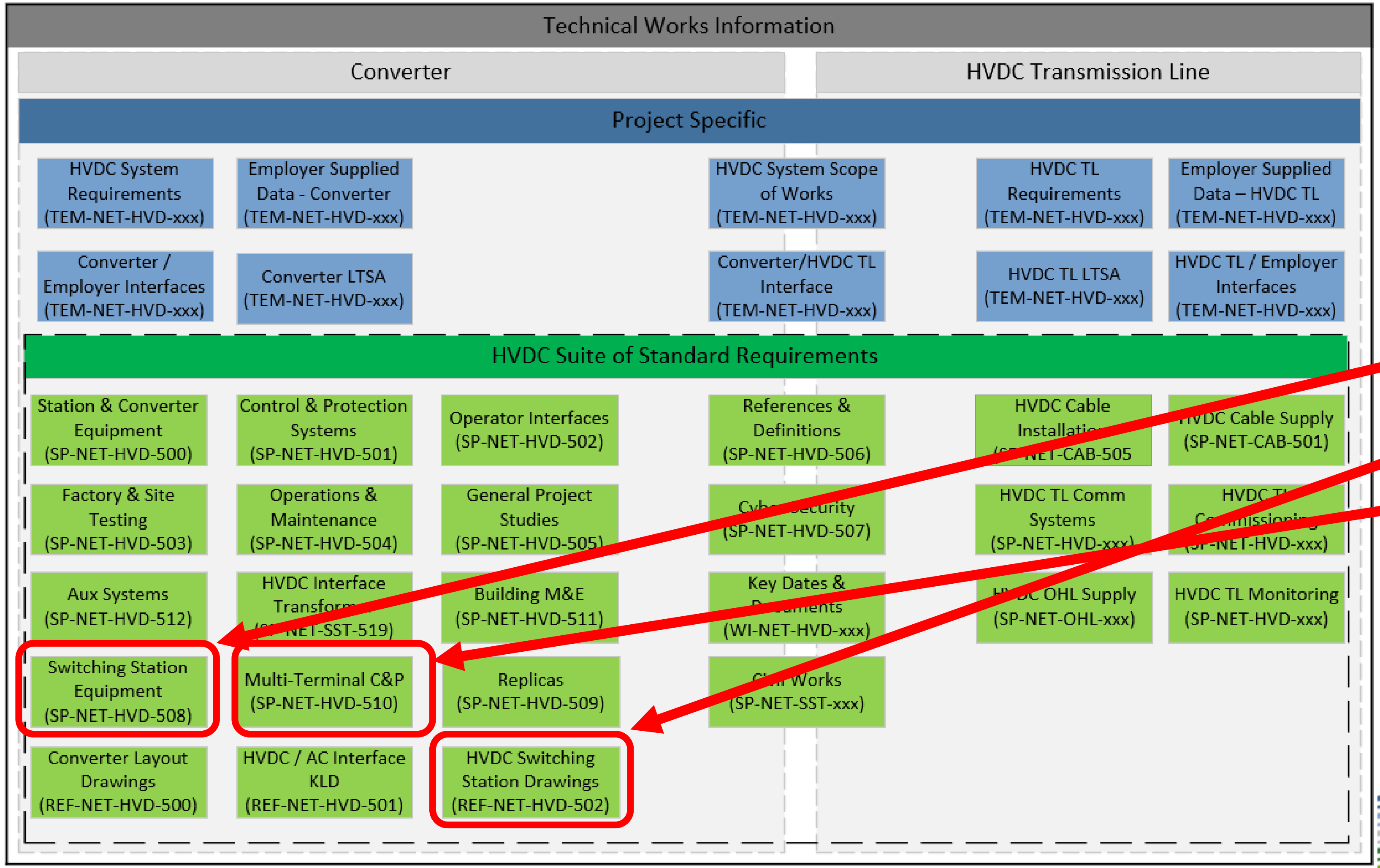
Mt-Mv Technical Specification

SSEN HVDC Suite: Structure



- Use existing Converter Station requirement specs as basis
  - Equipment, C&P, studies, O&M, testing, etc.
- Augment with critical items
  - Additional Equipment / operating requirements
  - Concept SLD / building layout
  - Multi-terminal C&P requirements

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Mt-Mv Technical Specification

Equipment Requirements (SP-NET-HVD-508)

- DCSS Design
  - General concepts / philosophy
  - Fire protection & Control
  - Interlocking
  - Spare parts
- Major Equipment
  - Ratings
  - DC Switching
  - Bushings & busbars
  - Measurement transducers
  - Surge arrestors
- Structural Requirements
  - Support and foundation interfaces (SSEN responsible for civil scope)
- Facilities
  - Bus Halls, Bay Halls, Neutral Bus Hall, Neutral Bay Halls
- Auxiliary Supplies

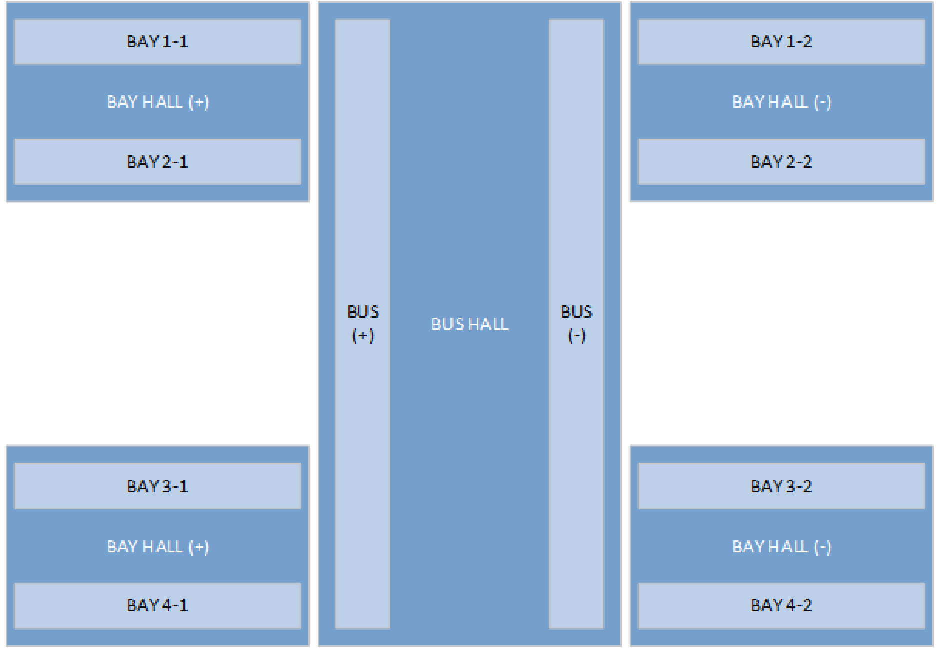

Figure 6-1 - Typical Bus Hall and Bay Hall Arrangement

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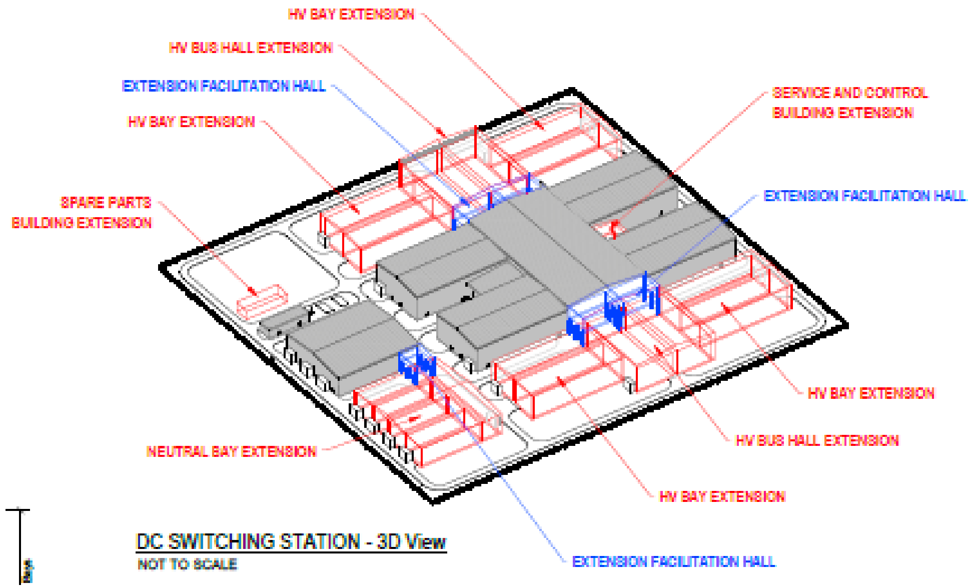
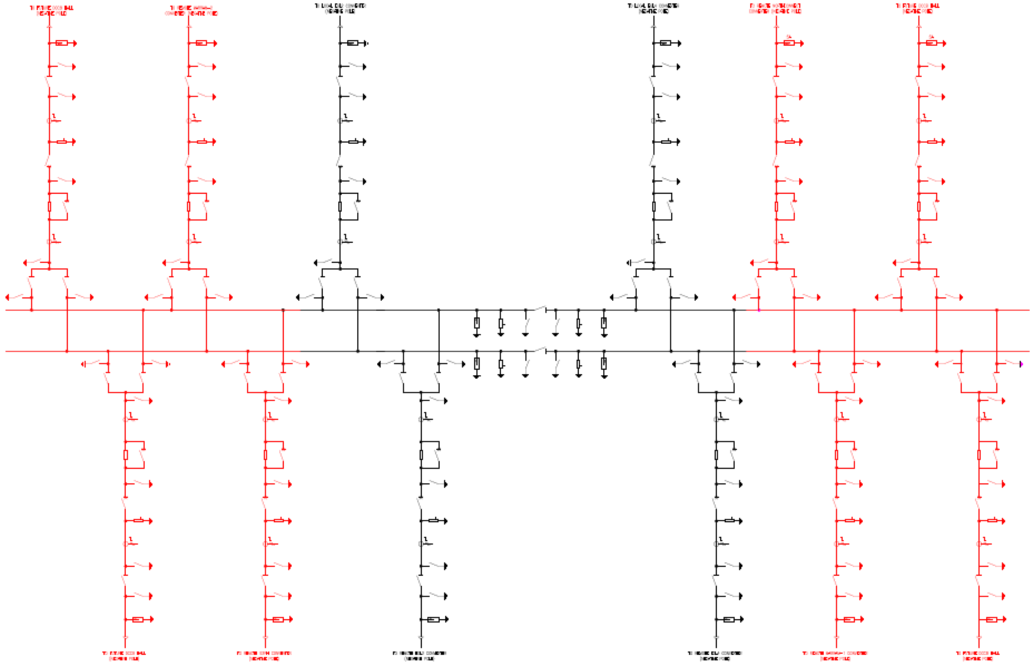
Mt-Mv Technical Specification

SLD / Station Layout Concept (REF-NET-HVD-502)





- Expandable / ultimate design
- Proposed SLD
- De-risk cable routings / crossings
- Operations / maintenance access
- Enable informed discussion with suppliers

Mt-Mv Technical Specification

C&P Requirements (SP-NET-HVD-510)

- Studies
  - Steady State, harmonic, transient, DPS
  - Frequency scans
- MTDC C&P System
  - Scope
- MTDC Control System
  - Control & Operating Modes
  - Voltage control
  - Coordinated active power control
  - Neutral current balancing
  - Asymmetric operating control

- DCSS Protection System
  - Interlocking and bay control
  - Main-busbar protections
- HVDC Protection System
  - Converter Bay protections
- C&P Testing
  - Additional FPT / DPT requirements and interfaces

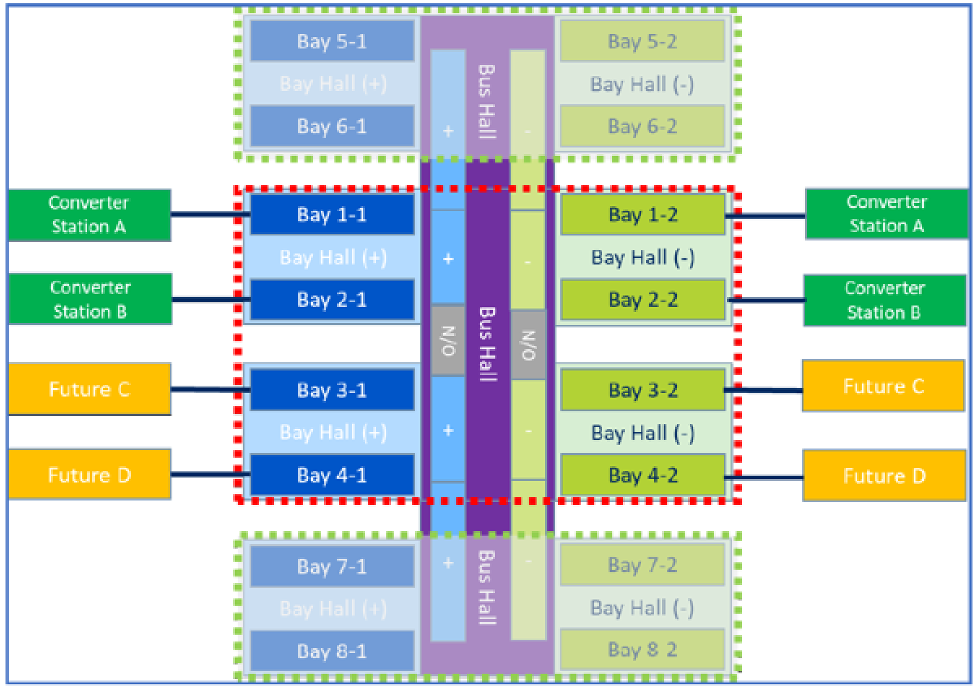


Figure 4-1: DCSS Conceptual Scope division

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C&P Requirements (SP-NET-HVD-510)

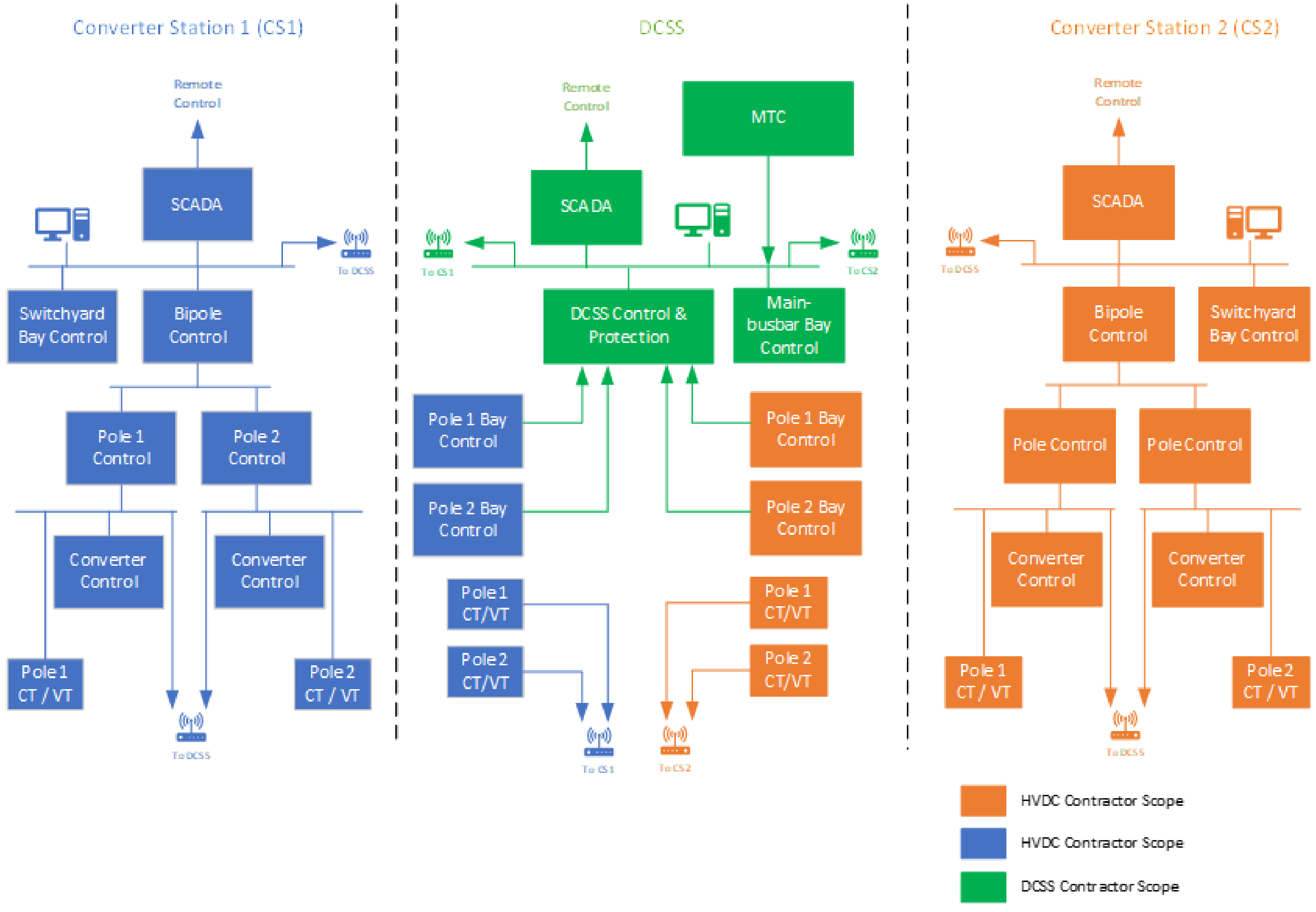

Figure 4-2: Concept for MTDC Control & Protection System

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Mt-Mv Technical Specification

Future Proofing for DCCB

- Mesh corner arrangement
- Engineering Analysis on multiple options
  - Integrated DCCB
  - DCCB connected main-busbar via cable
  - DCCB connected to Converter Bay
  - Second DCSS with integrated DCCBs

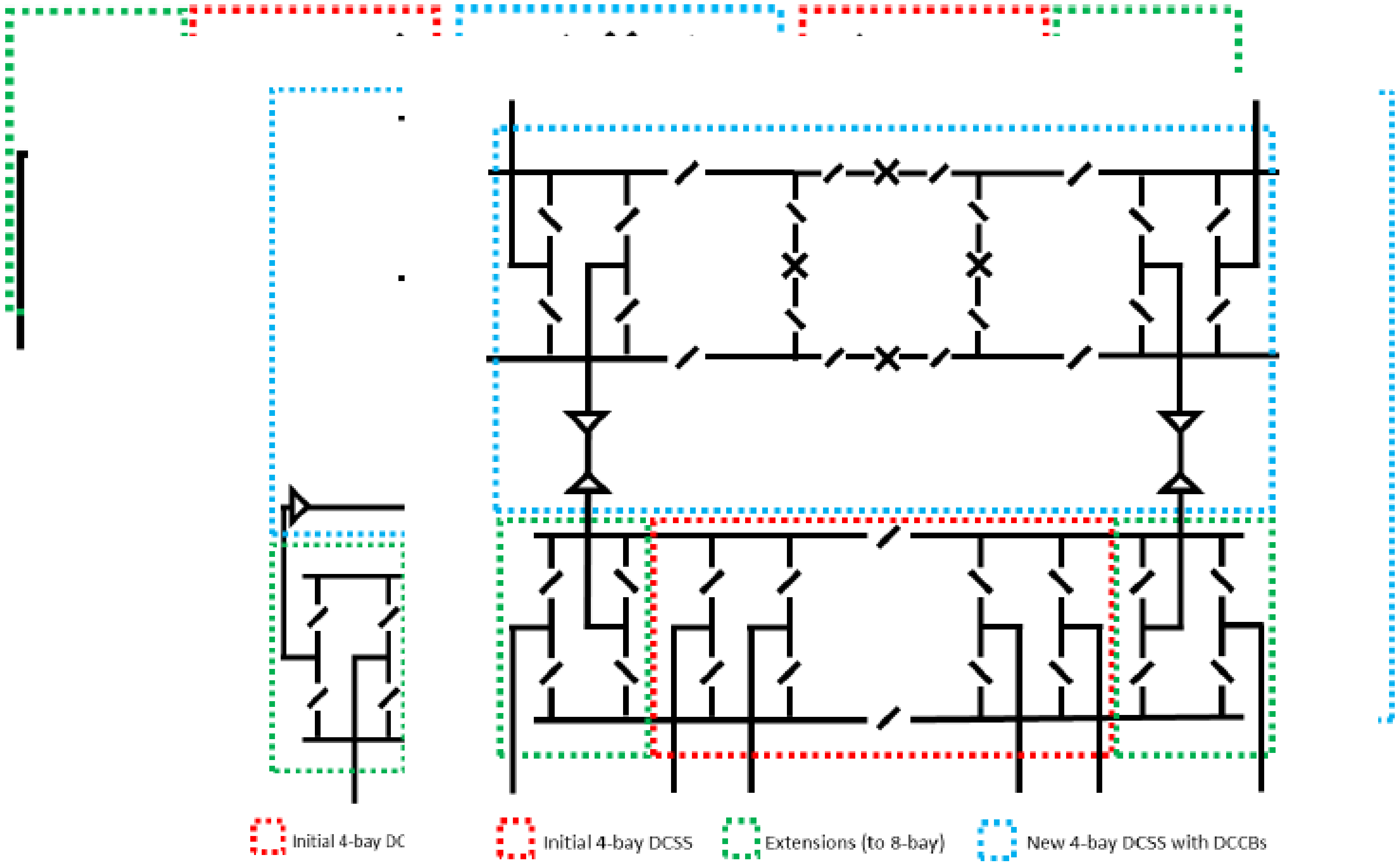

Figure 6.3 - Option C connects Figure 6.4 - Option D connects the standard 8-bay DCSS to a DCSS with integrated DCCBs

Multiterminal / Multivendor

Commercial Considerations

- Boundaries of performance guarantees
- Criteria for performance guarantees

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HVDC Systems Introduction

Questions?