Session 1:

HVDC as a bulk power transfer system

Carl Barker

Chief Engineer, Systems

Offshore Wind Training Seminar - March 2011

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Friends of the SuperGrid (FOSG)

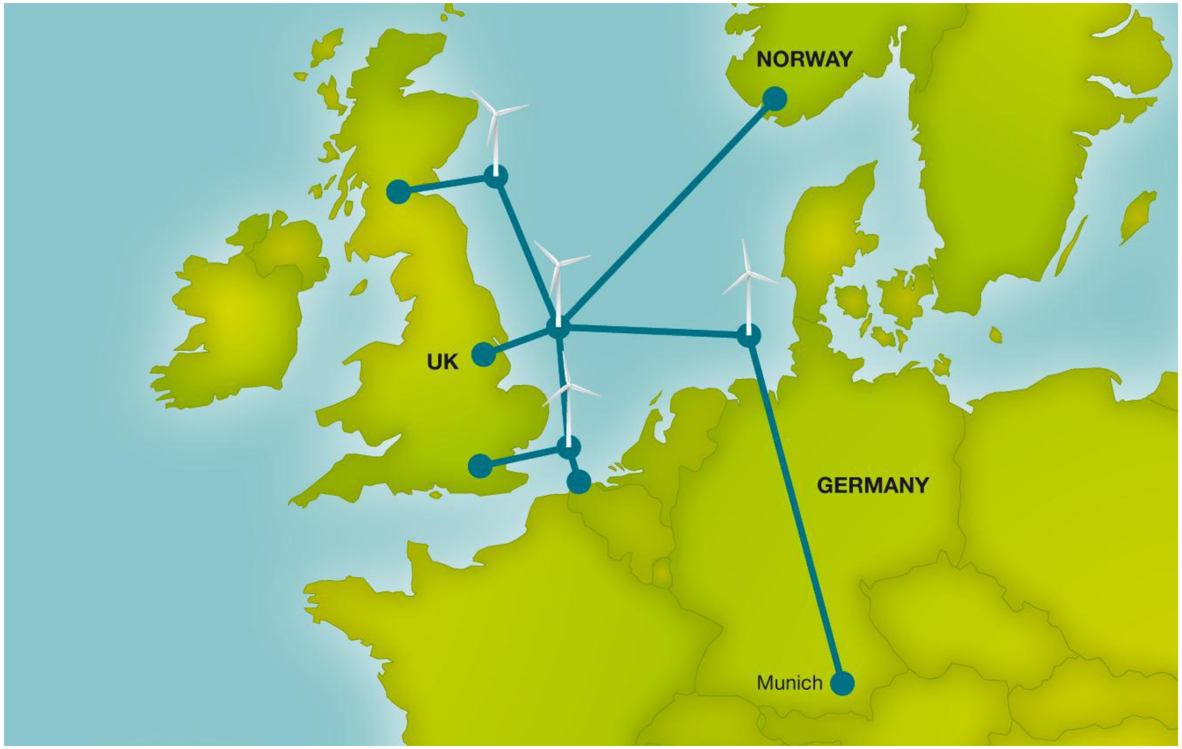

Figure 1: SuperGrid Phase 1

Connection	Capacity (GW)
Dogger – Germany Offshore	10
Dogger – Norfolk Bank	5
Dogger – Firth of Forth	5
Dogger – Norway	5
Germany Offshore - Munich	10
London – Norfolk Bank	5
Norfolk Bank – Belgium Offshore	2
SuperNode	
Belgium Offshore	2
Dogger - Hornsea	10
Germany Offshore	10
Norfolk Bank	5
Munich	10
Firth of Forth	5

Figure 2: Interconnection and SuperNode Cap

Source: FOSG Position paper on the EC Communication for a European Infrastructure Package, Dec 2010

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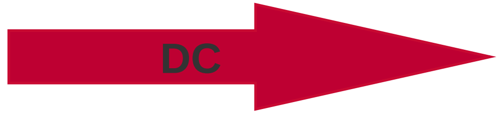
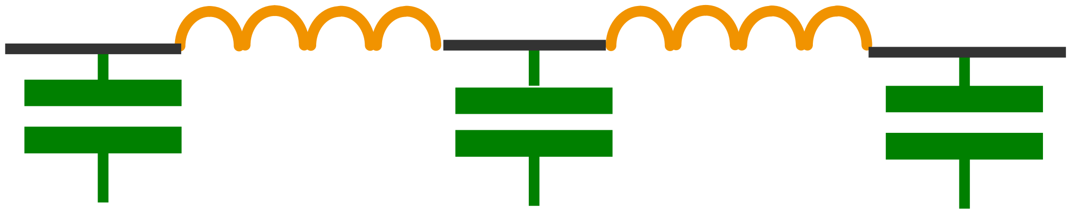
Why DC Transmission?

HVDC transmission is the correct technology for bulk submarine energy transfer.

Charges and Discharges
Every Half Cycle



Only Charges the Cable Once



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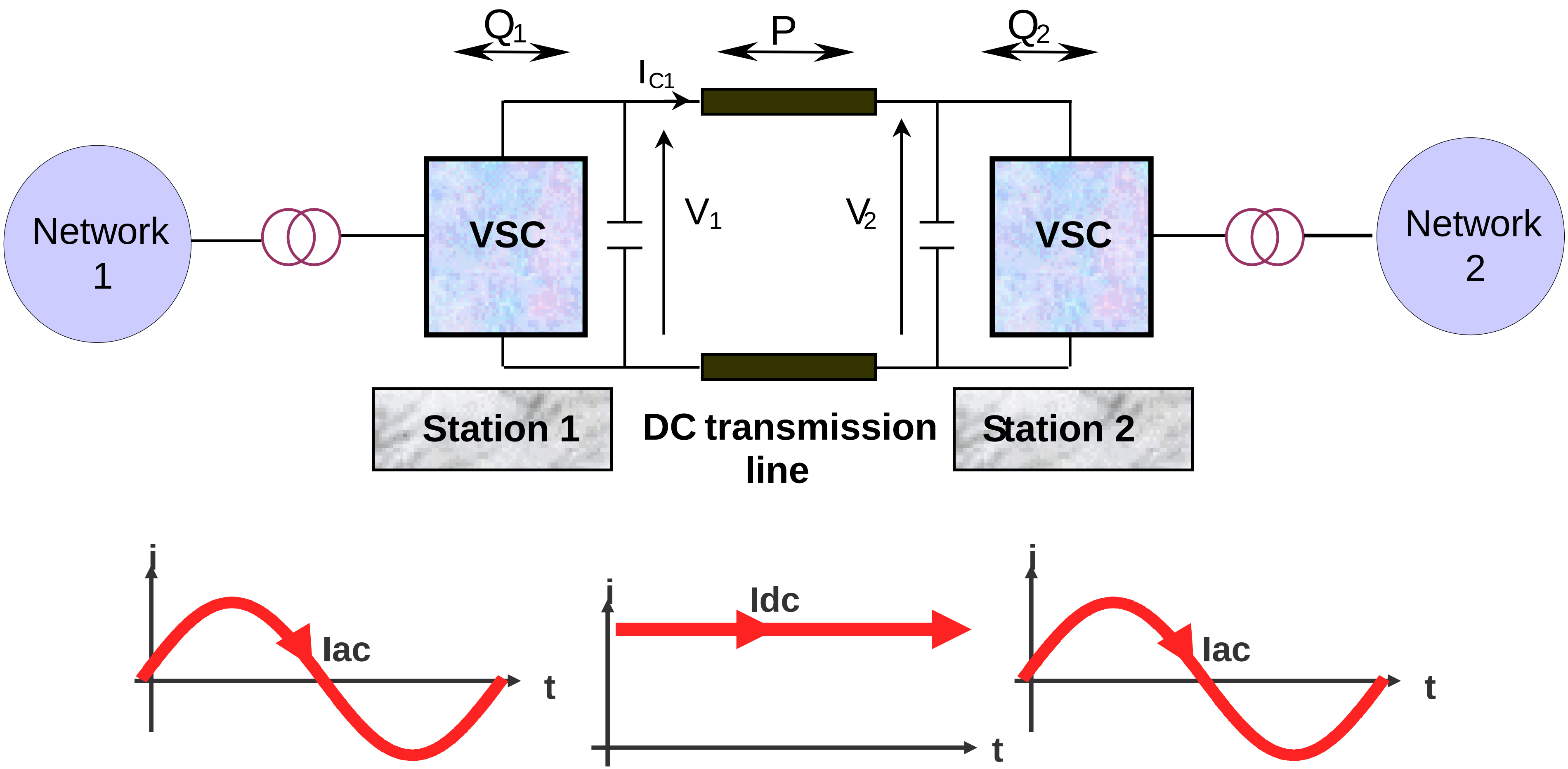
Why DC Transmission?



$$Idc = \frac{V1 - V2}{R}$$

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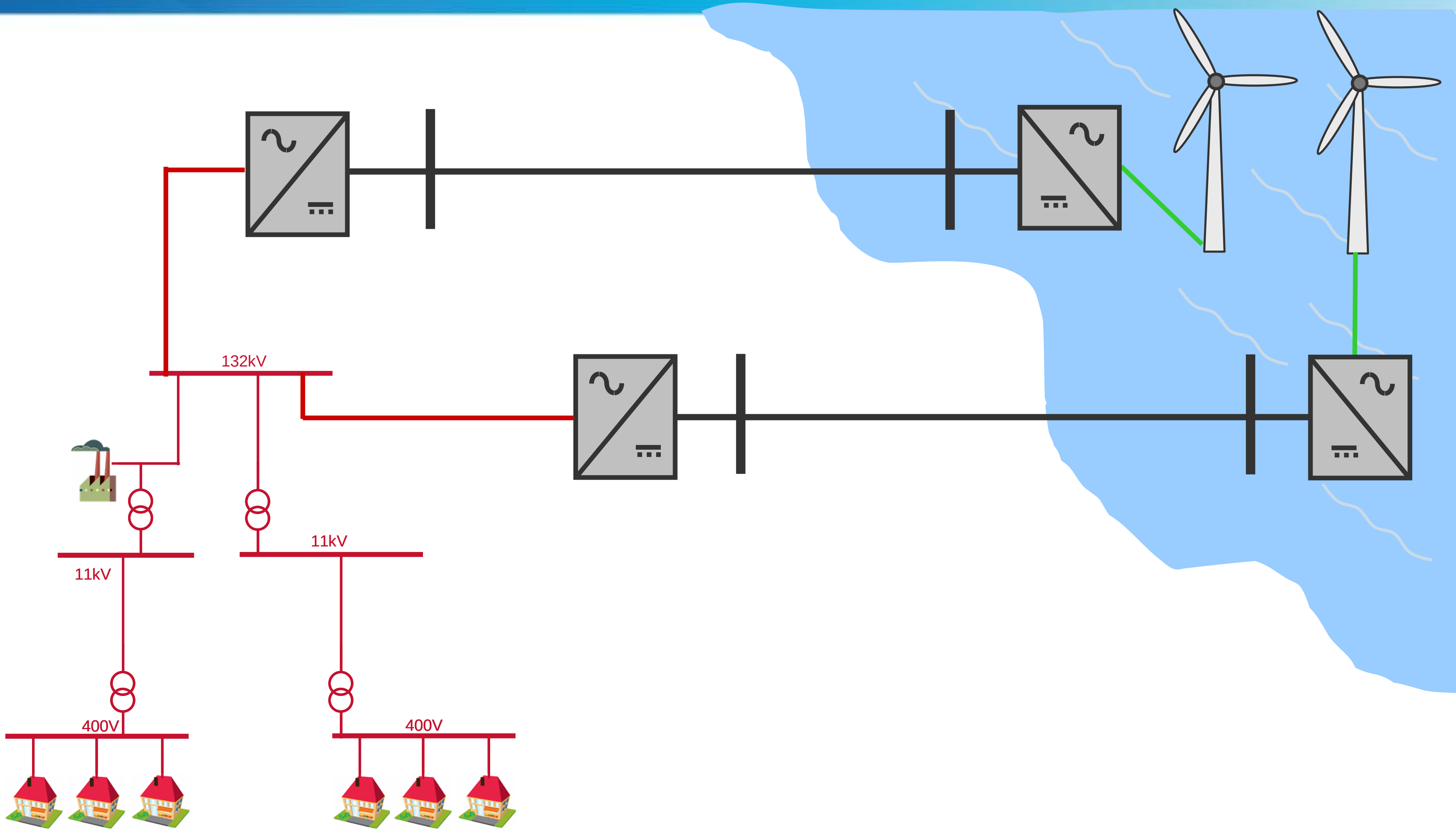
Offshore "DC Grids"

Definition:

- "DC Grids" – Multiple converters connecting AC power networks to a DC power network
- "DC Grids" – Permit the economic transfer of power over buried cables reducing environmental impact
- "DC Grids" – Permits economic bulk transfer over large distances
- "DC Grids" – Reduce the number of AC/DC Conversions therefore reduce losses

DC Grid Configurations: Point-to-point System



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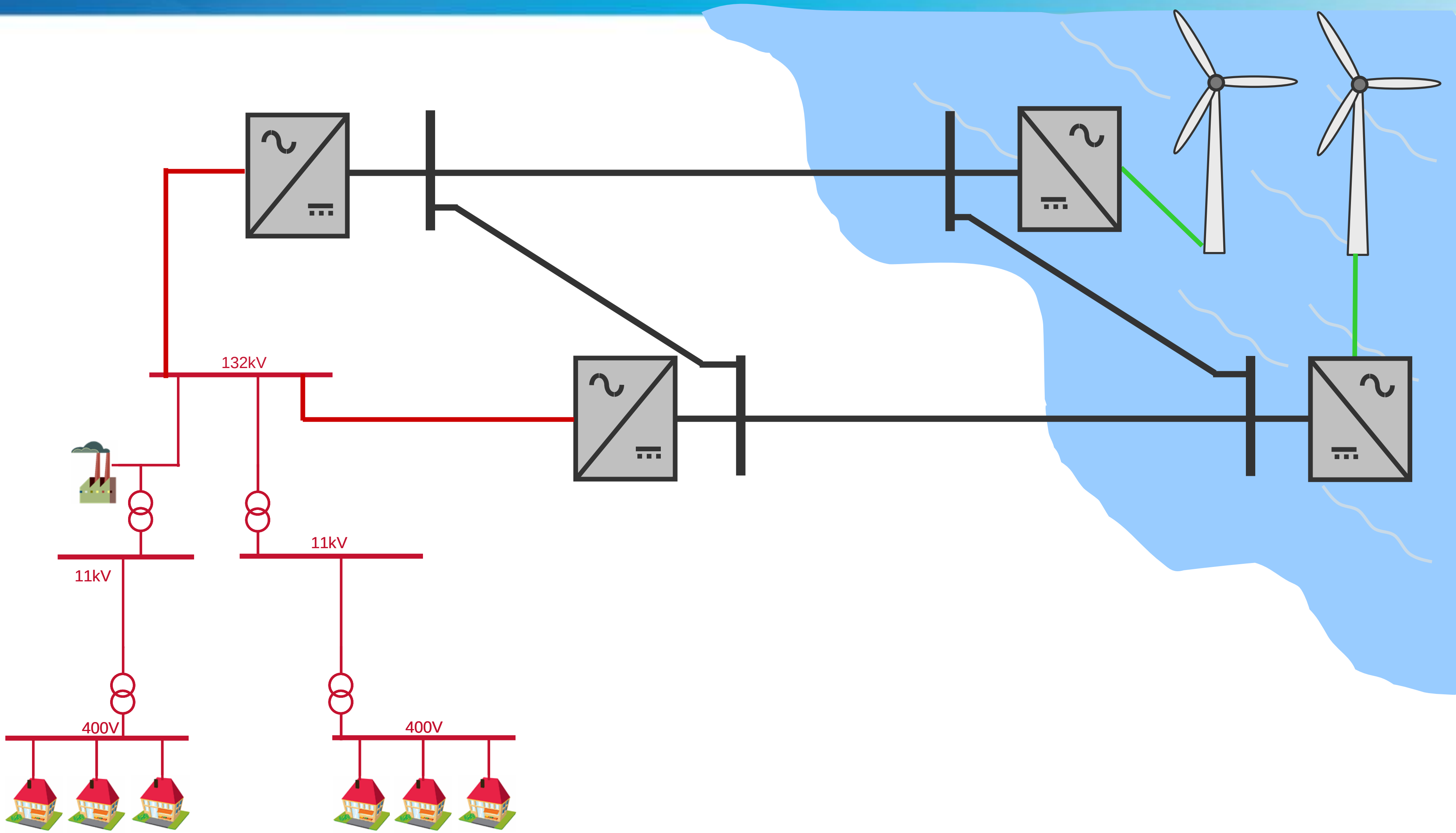
DC Grid Configurations: Meshed System



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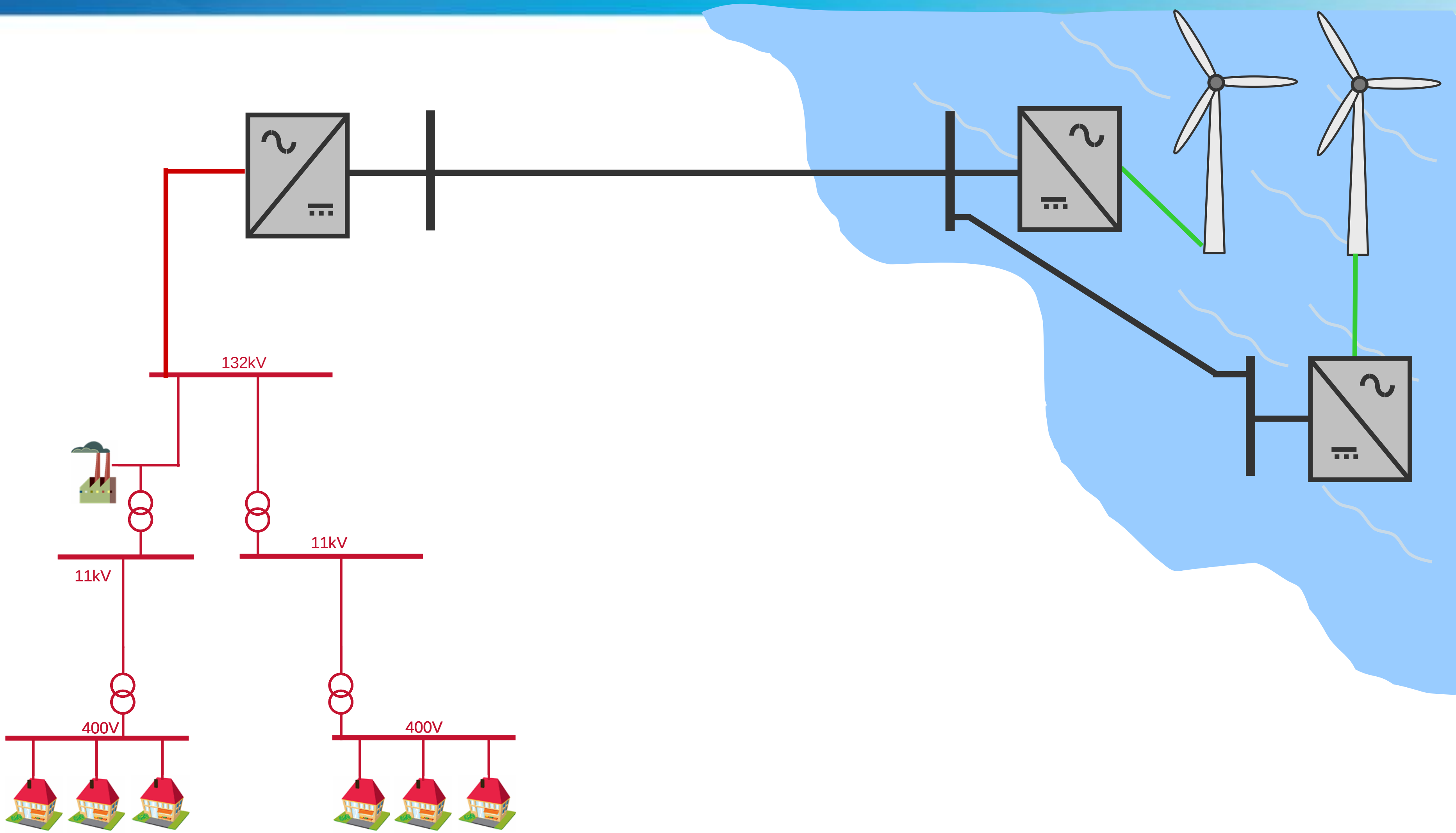
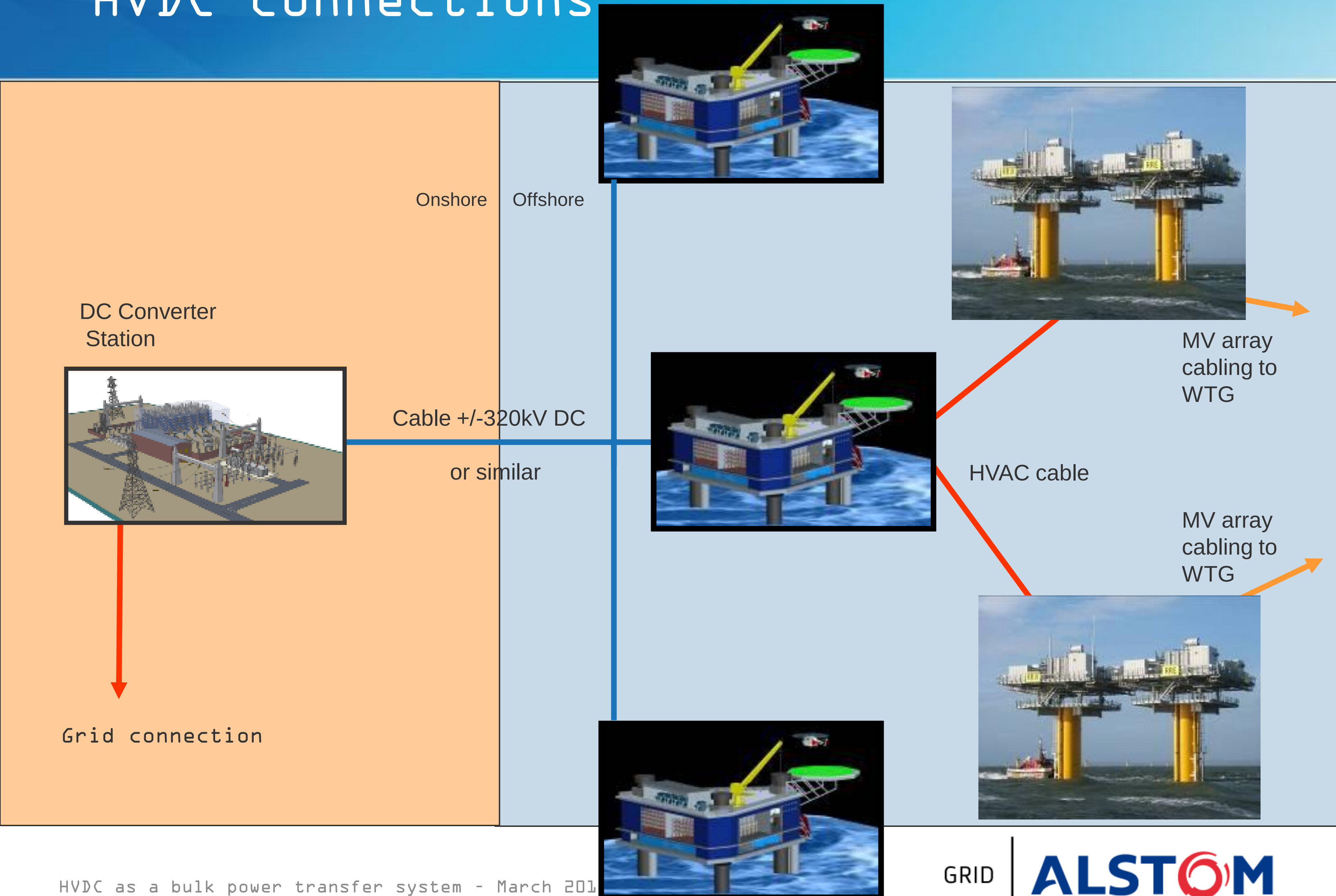
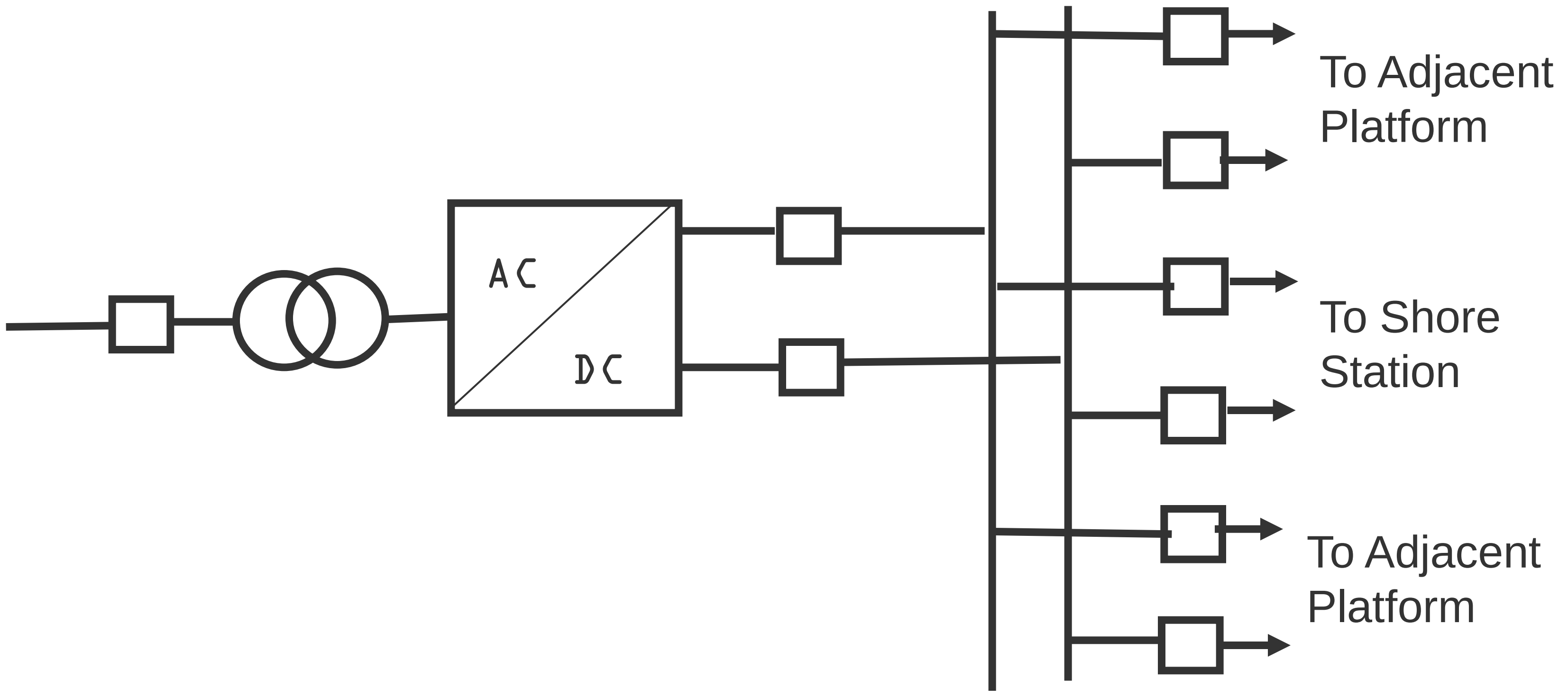
DC Grid Configurations: Radial System



HVDC connections



Platform Switchgear Arrangement



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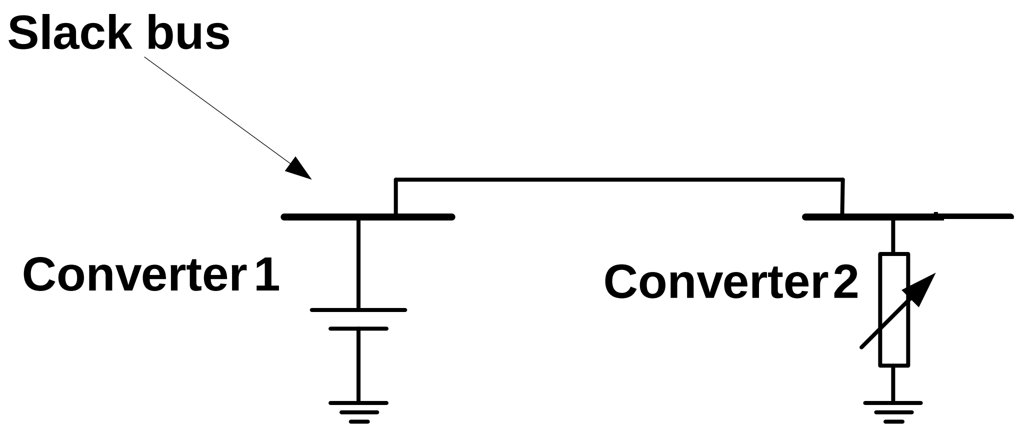
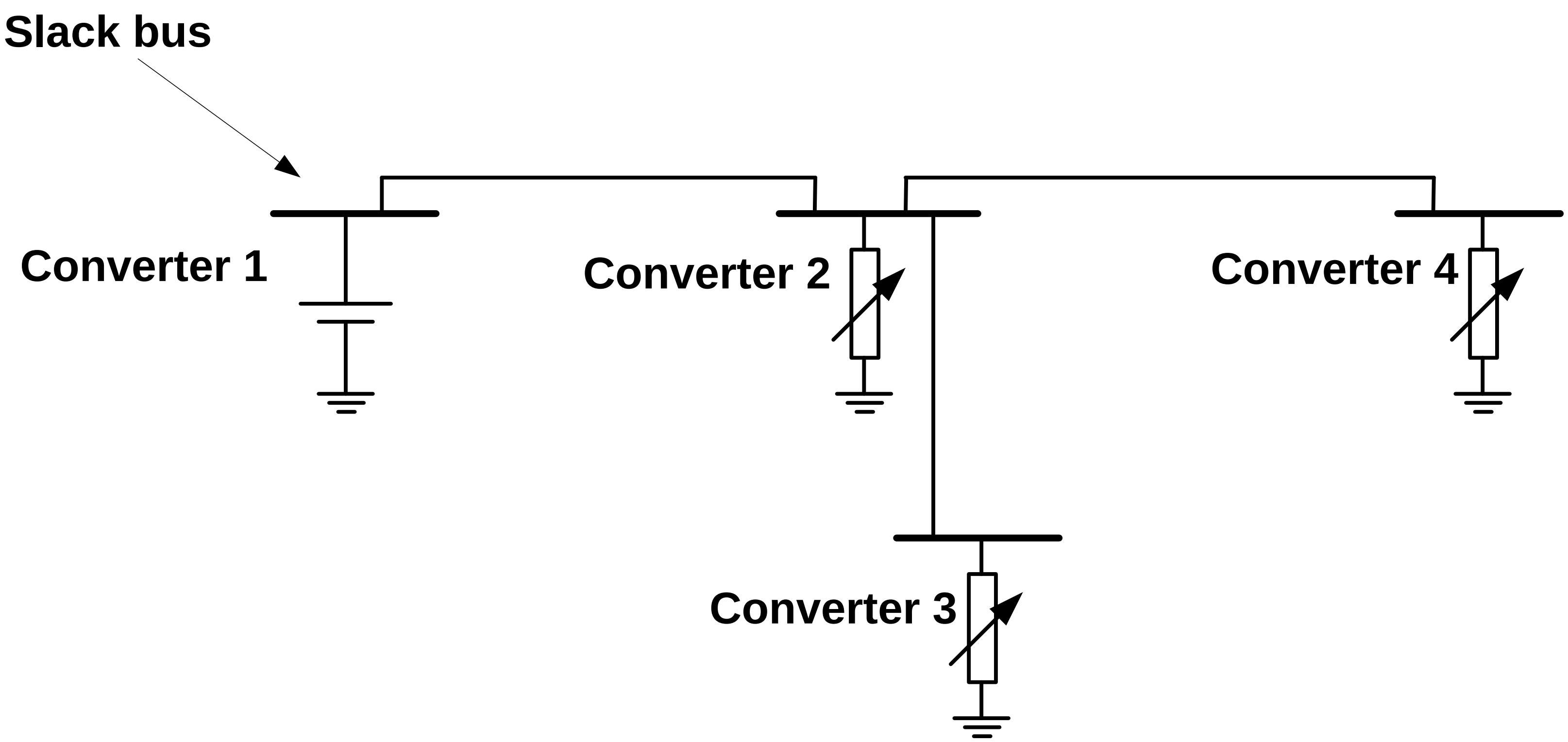
Two-terminal VSC Control



- Basic Converter control of a two-terminal VSC

DC Grid Control



- Will a single utility / system owner be prepared to act as the slack bus for all other interconnected systems?

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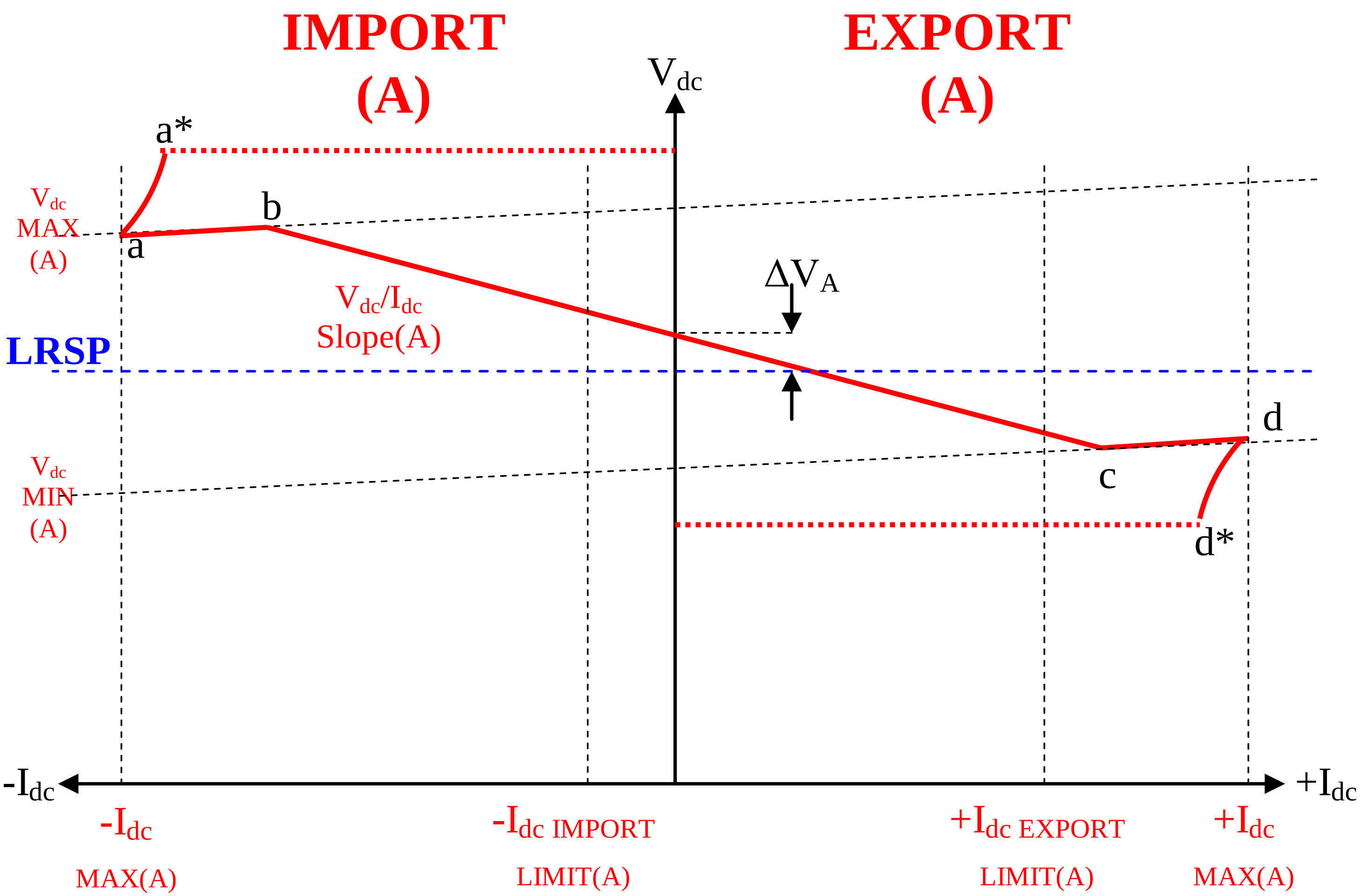
Comparison of AC and DC parameters

AC PARAMETER	DC PARAMETER
Frequency (ω)	Target DC Voltage (Vdc)
Voltage Change $(\mathrm{V}\cdot\sin(\delta))$	Voltage Change (ΔV)
Impedance of Connection (X)	Resistance of Connection (R)
Real Power $\dfrac{\mathrm{V}\cdot\mathrm{V}\cdot\sin(\delta)}{\mathrm{X}}$	Real Power $\dfrac{\mathrm{V}\cdot\Delta\mathrm{V}}{\mathrm{R}}$

A typical VSC converter slope characteristic



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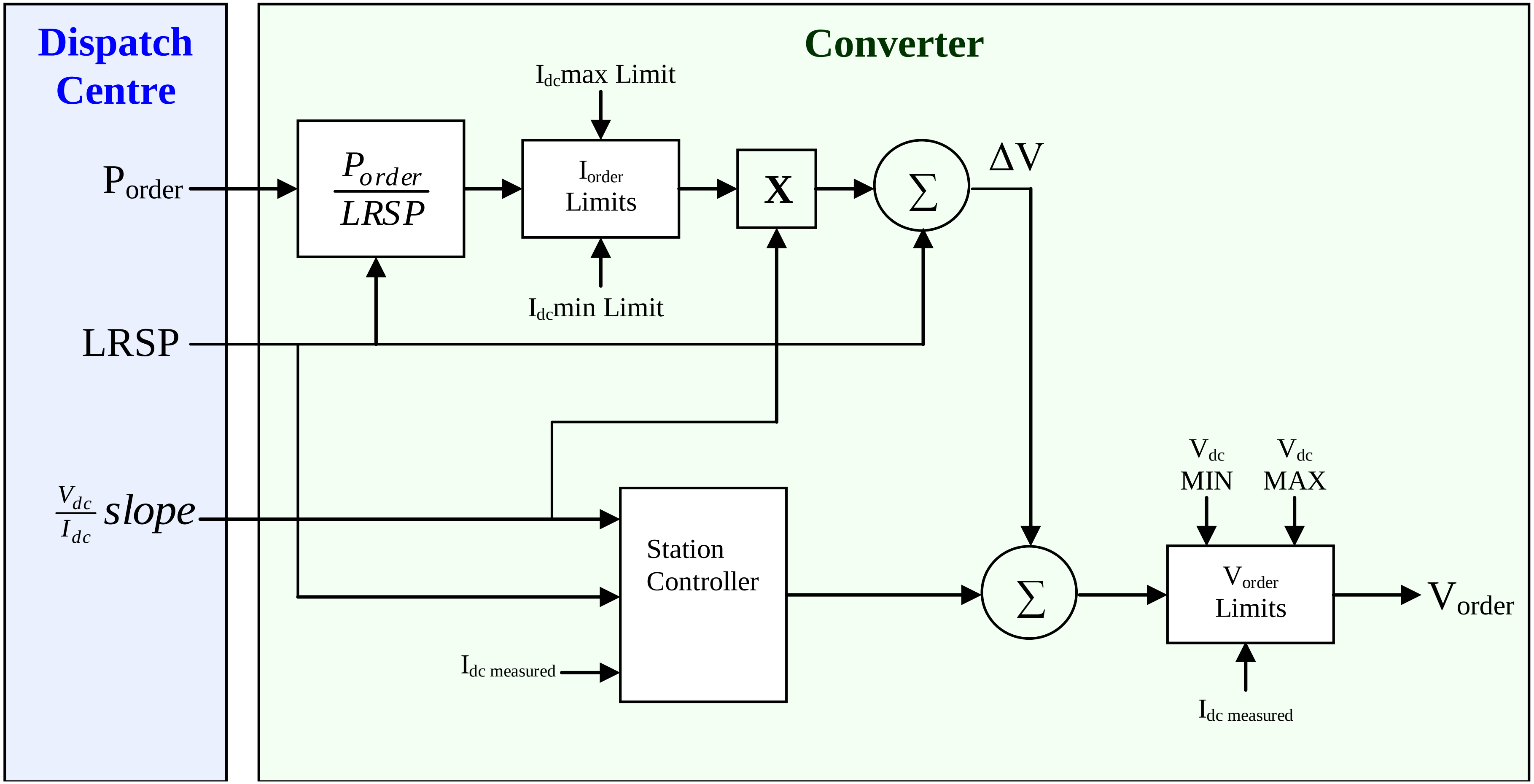
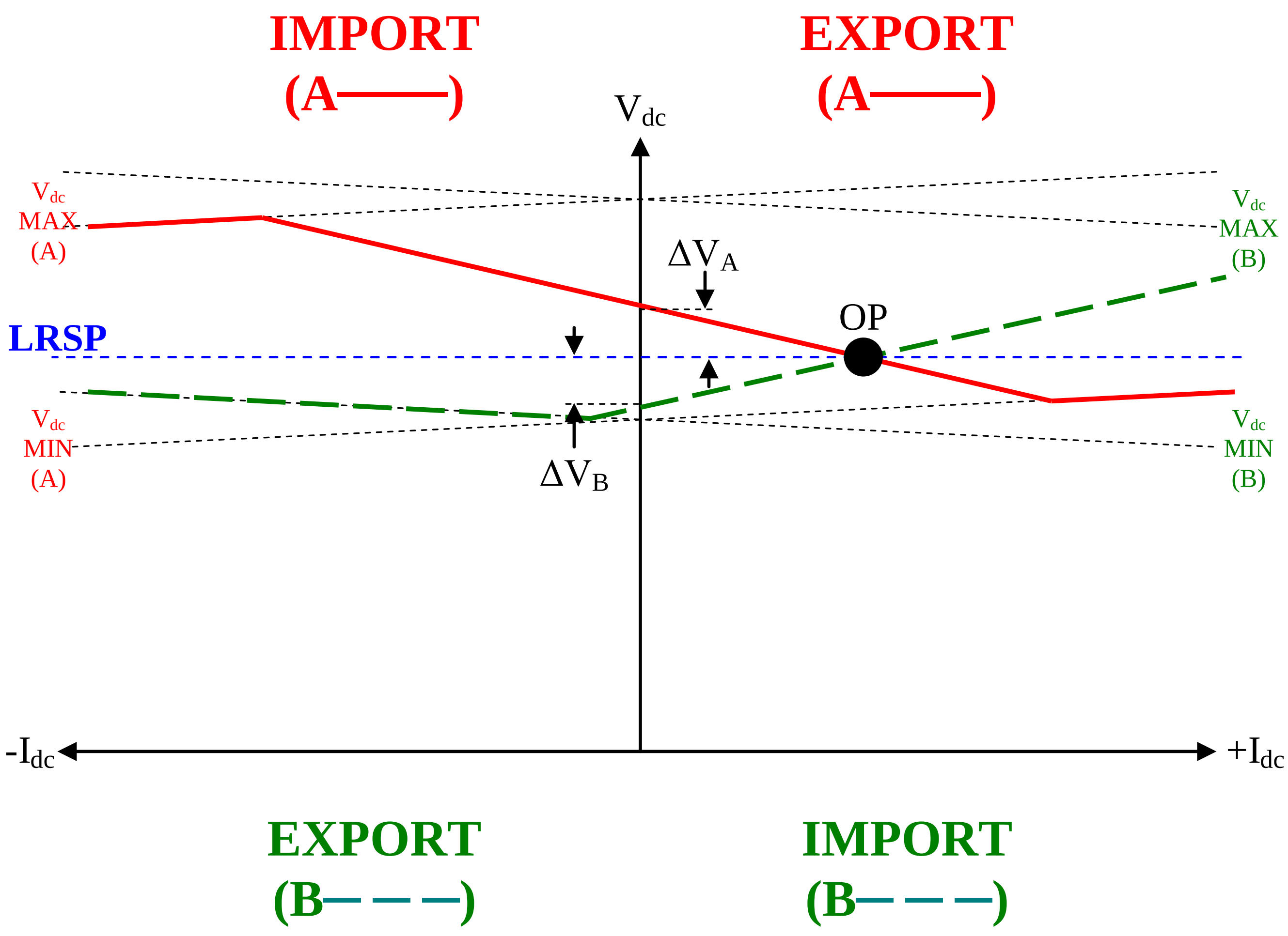
A basic controller for DC converter in a multi-terminal HVDC scheme



A two-terminal VSC Grid with power flow from terminal A to terminal B



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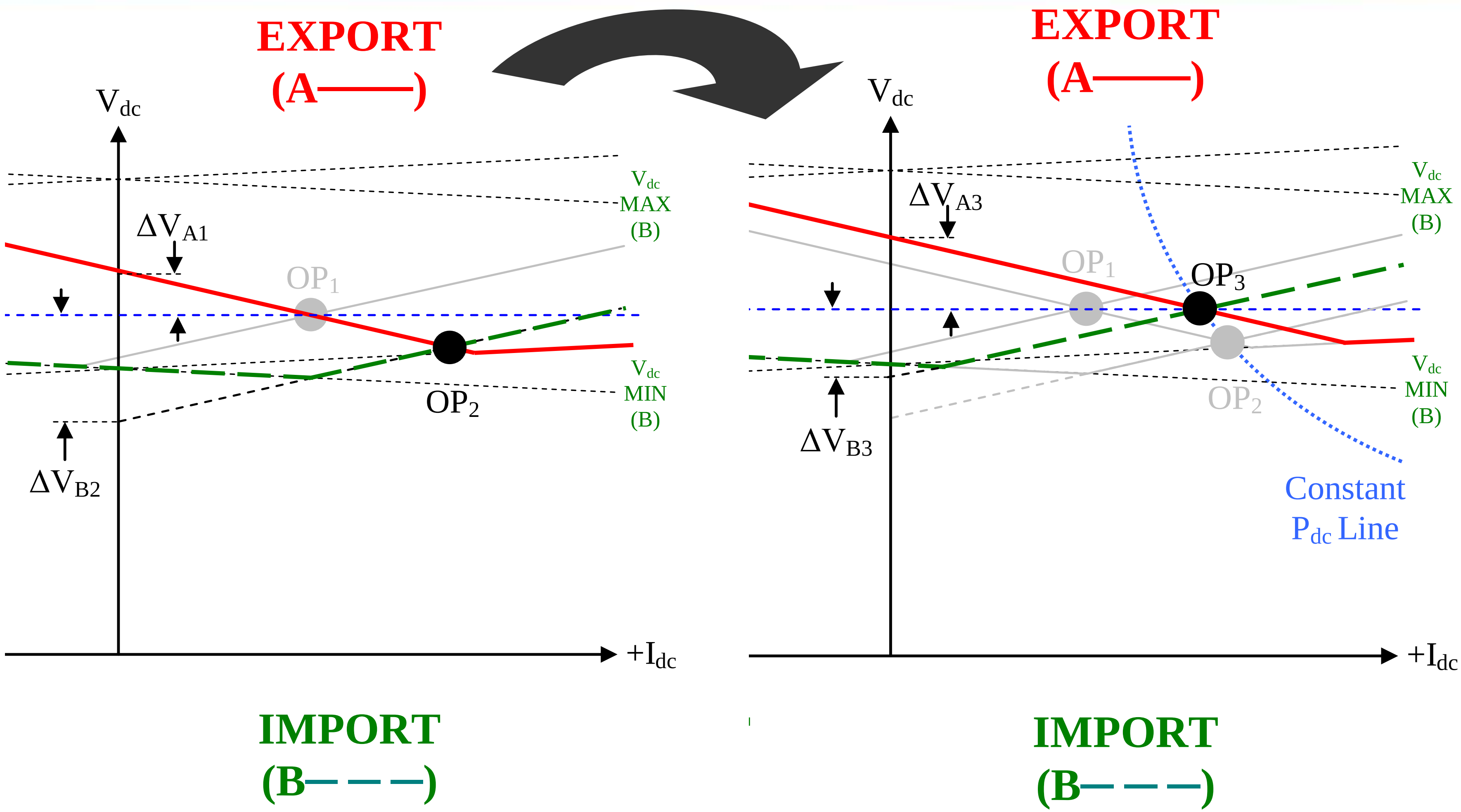
A change in power demand compensated by a new power dispatch



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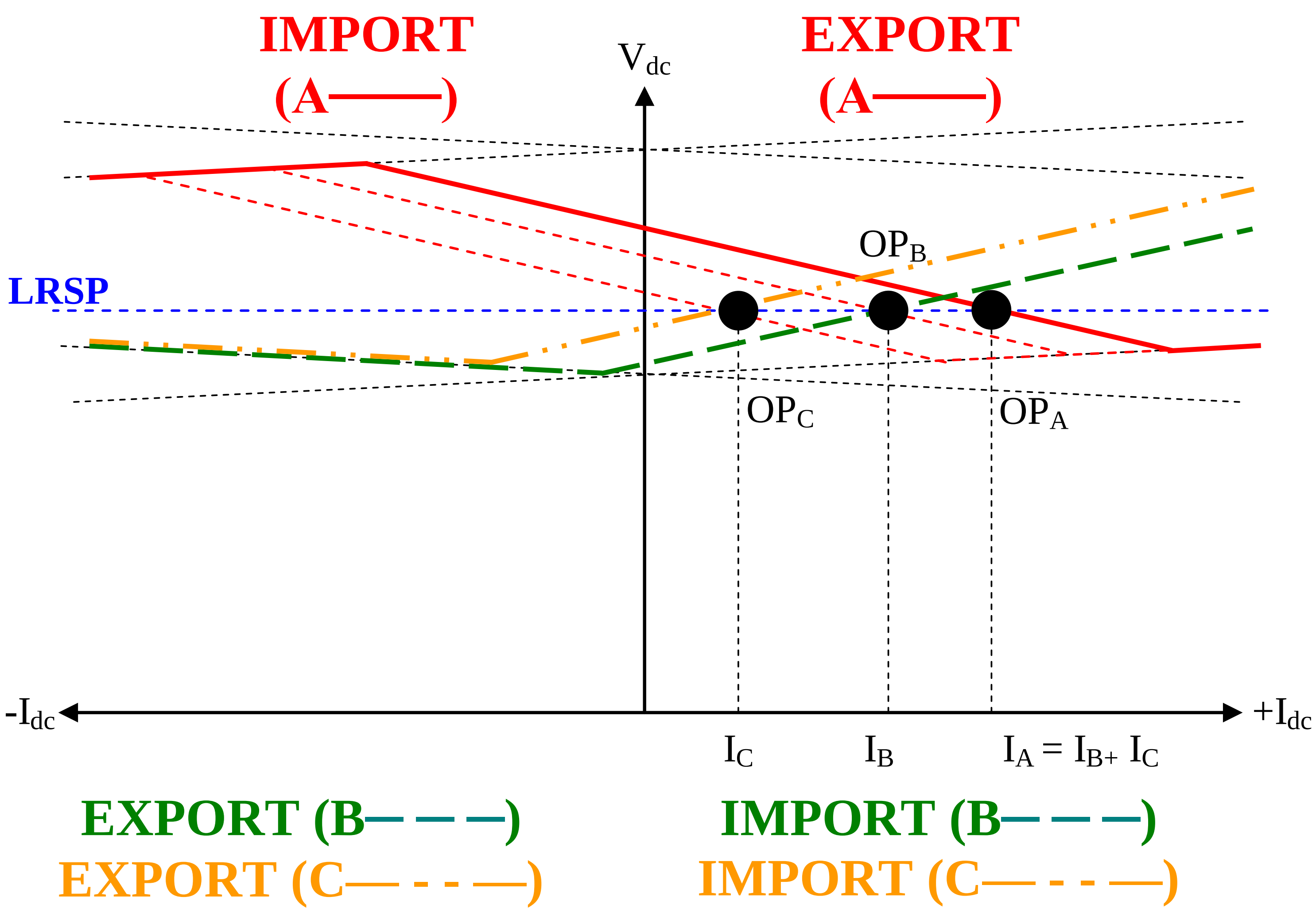
A three-terminal DC grid



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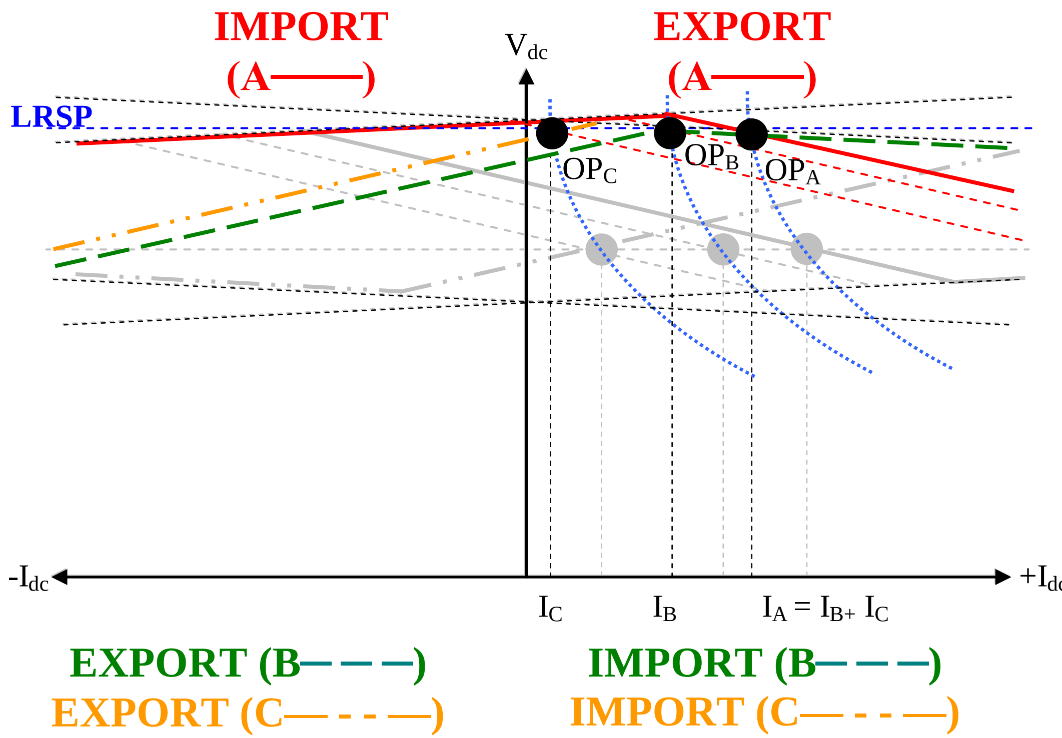
Voltage Optimiser

- Steady-state transmission loss minimisation
- One converter terminal determines the new, higher, LRSP
- LRSP ramp can be stopped at any time



"Autonomous Converter Control in a Multi-Terminal HVDC System"
Authors: Carl Barker Robert Whitehouse, Alstom Grid, UK
8th International Conference on AC and DC Power Transmission, IET, London, 2010

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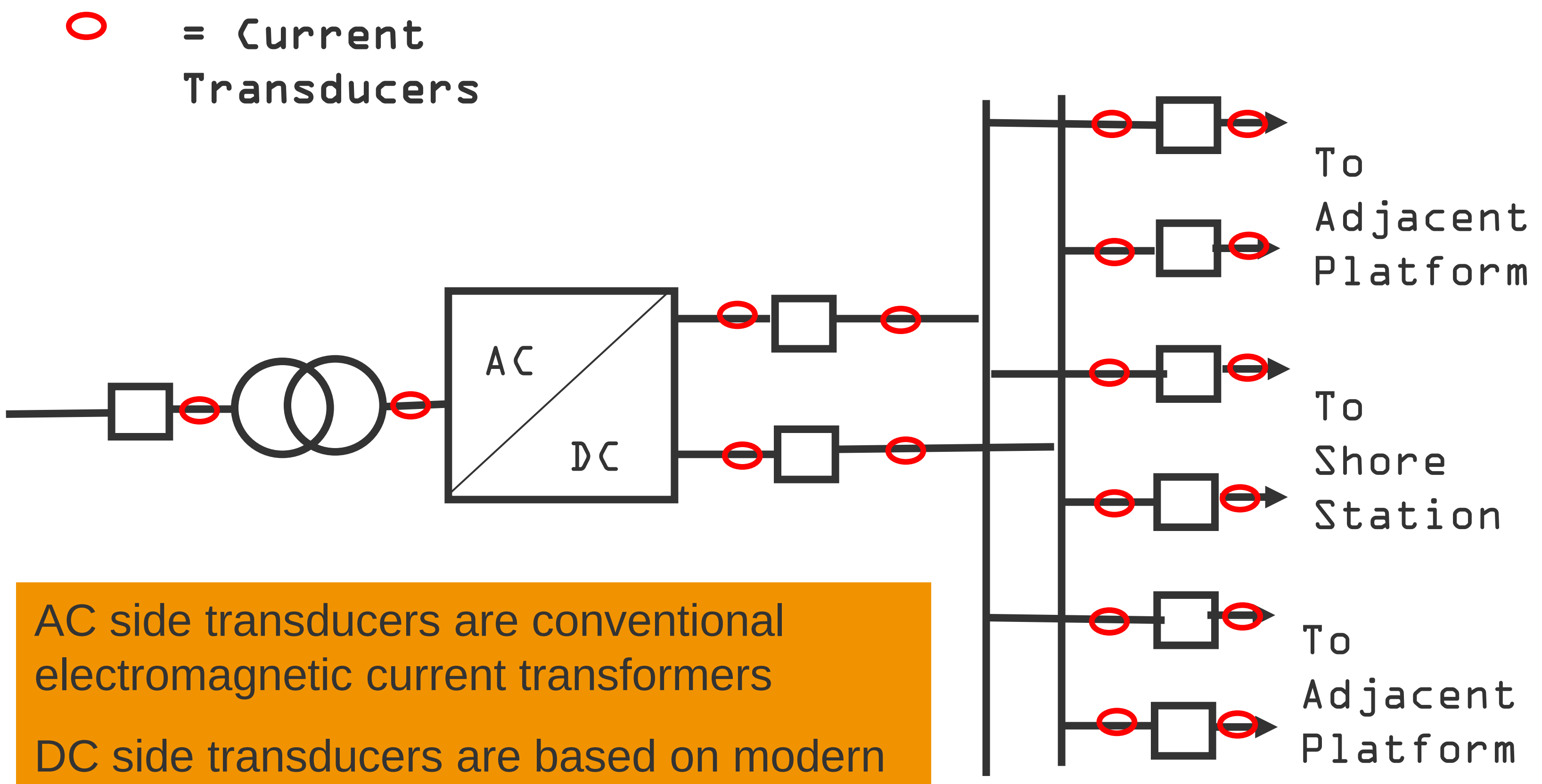
DC Grid protection

Key issues

- Multi-terminal DC cable systems are “low inertia” systems
- A DC fault (voltage on one pole goes to zero) is experienced simultaneously throughout the system
- Protection system must discriminate the faulted cable section to allow rapid isolation by switchgear action
- Multi-terminal system should return to stable operation, in minimum time with minimum loss of infrastructure

Protection systems



AC side transducers are conventional electromagnetic current transformers

DC side transducers are based on modern fibre optic current measurement techniques

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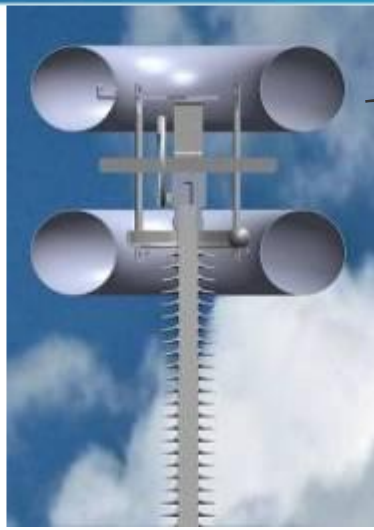
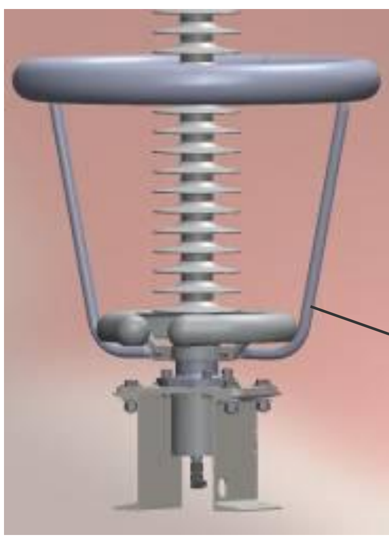
Current Transducer - Nxt Phase



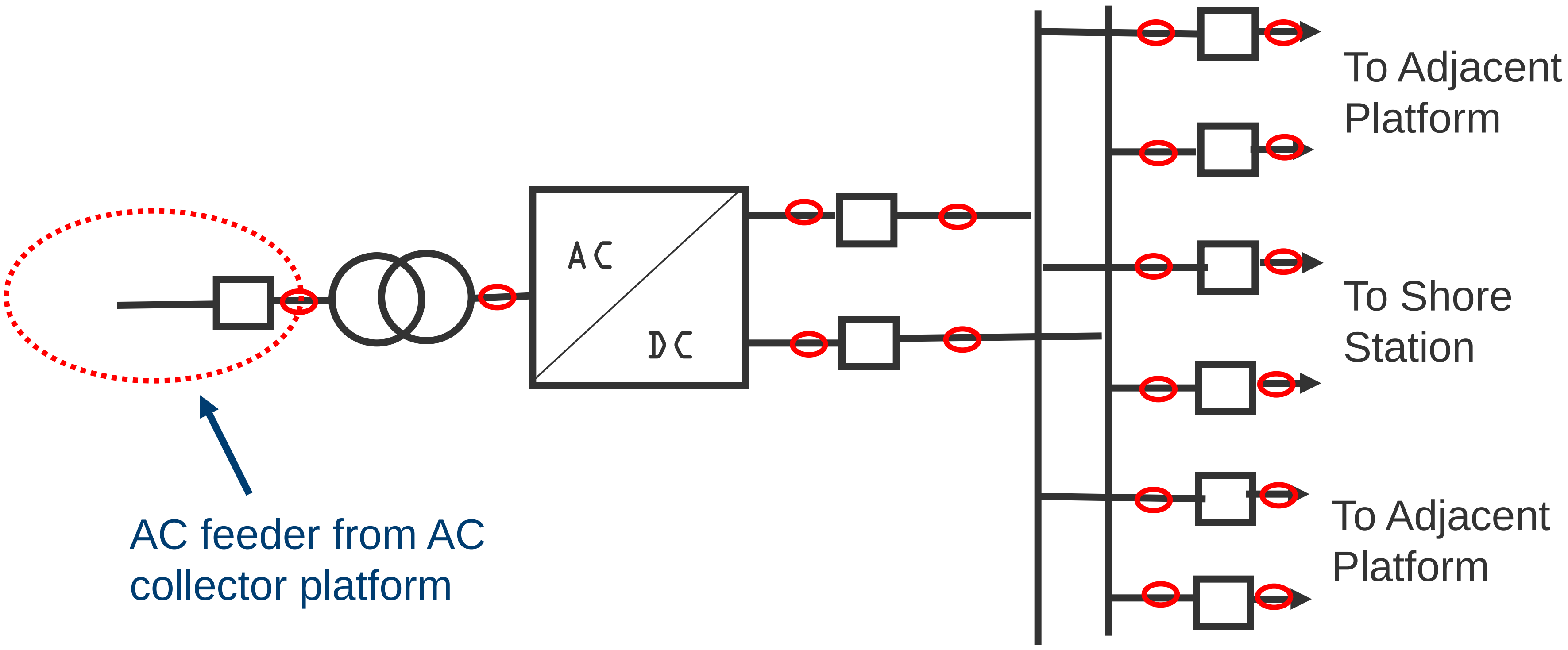


Fibre optic measurement head

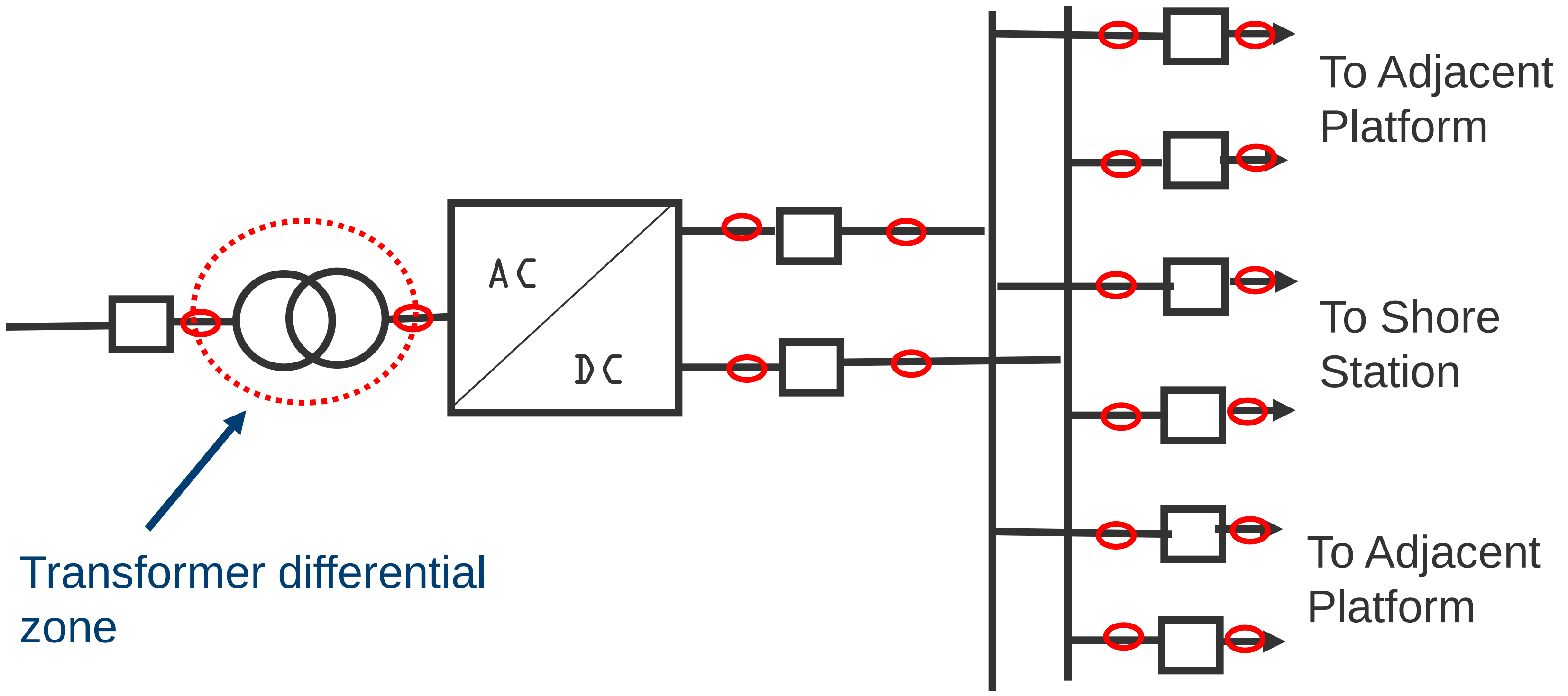
Polymeric insulators to protect fibre optic cables

Fibre optic connection to matching unit

Protection Zones



Protection Zones



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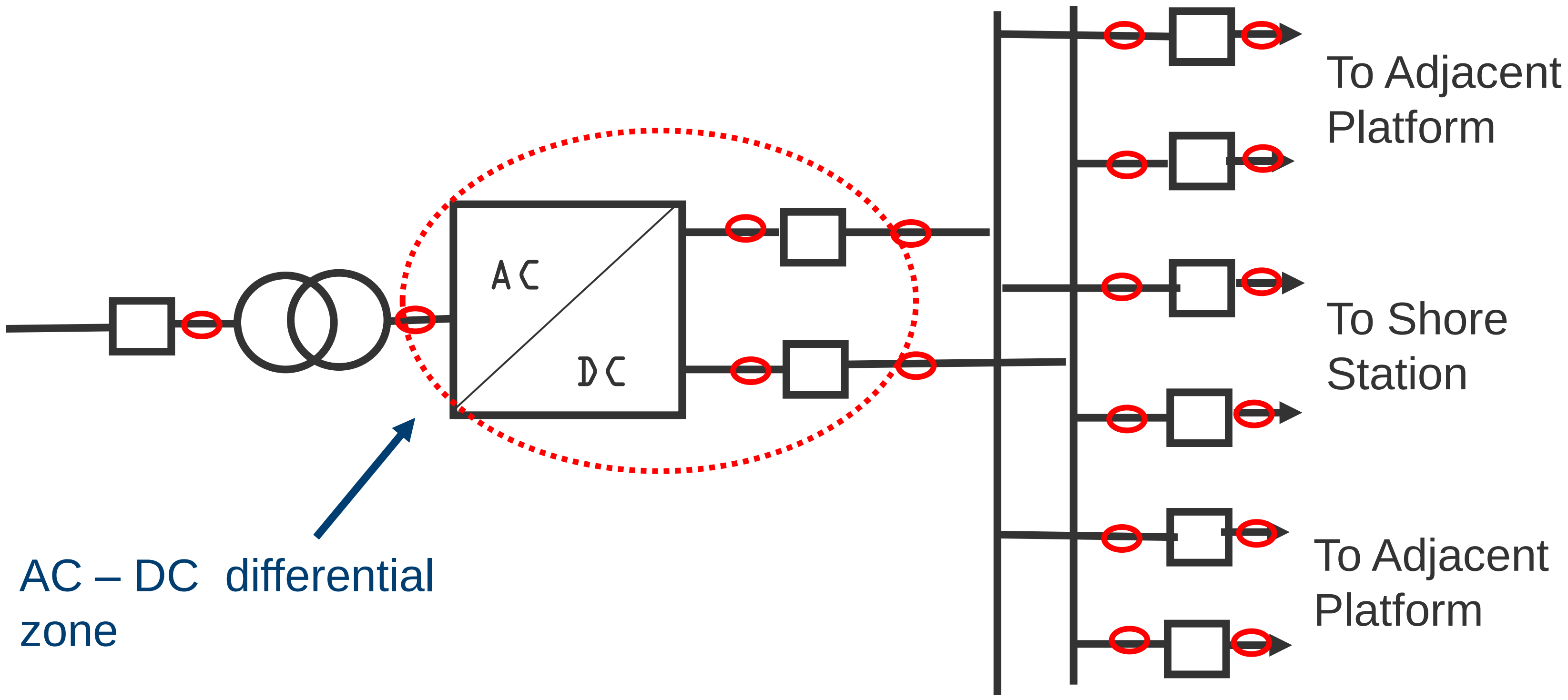
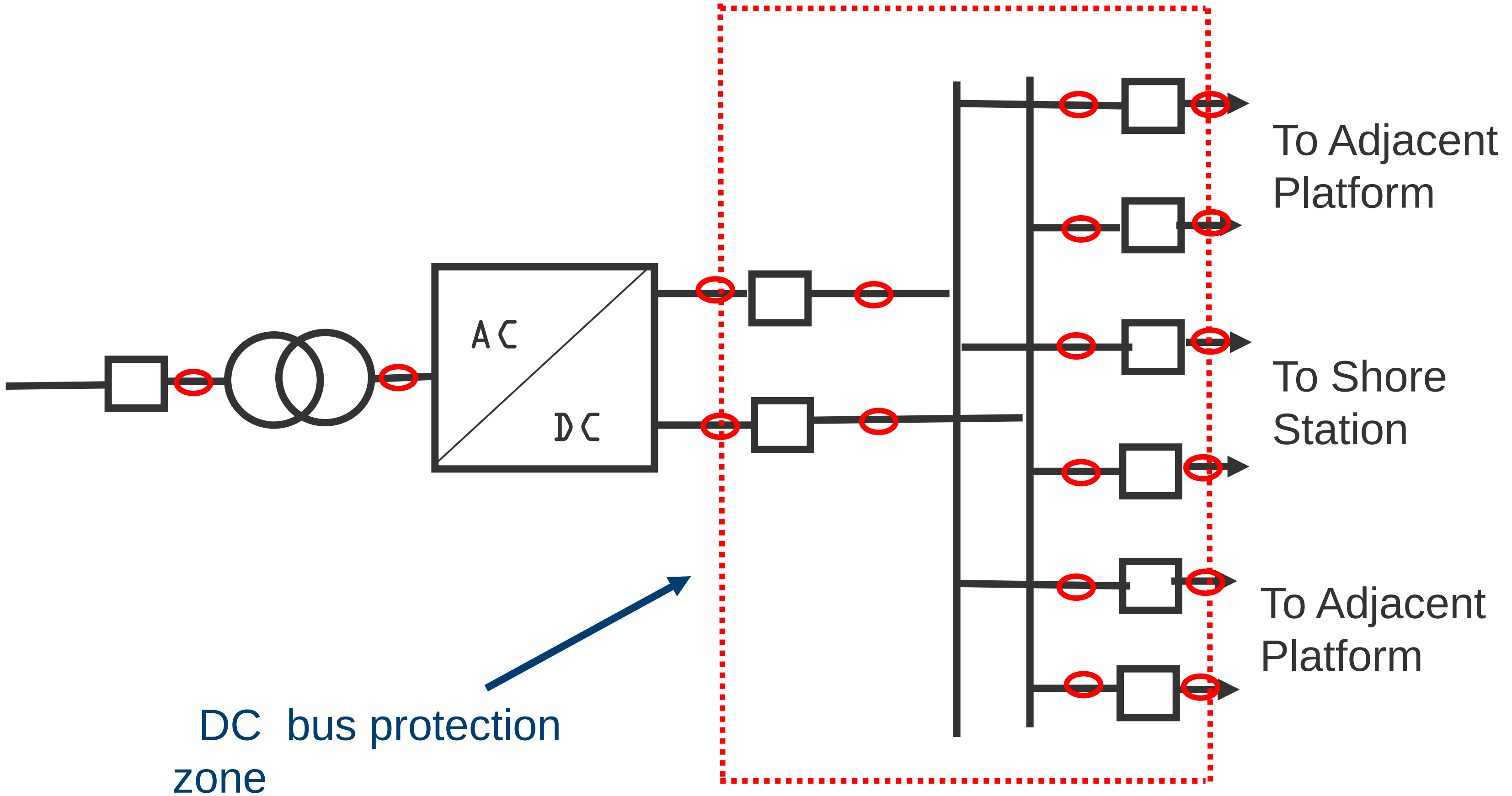
Protection Zones



Protection Zones



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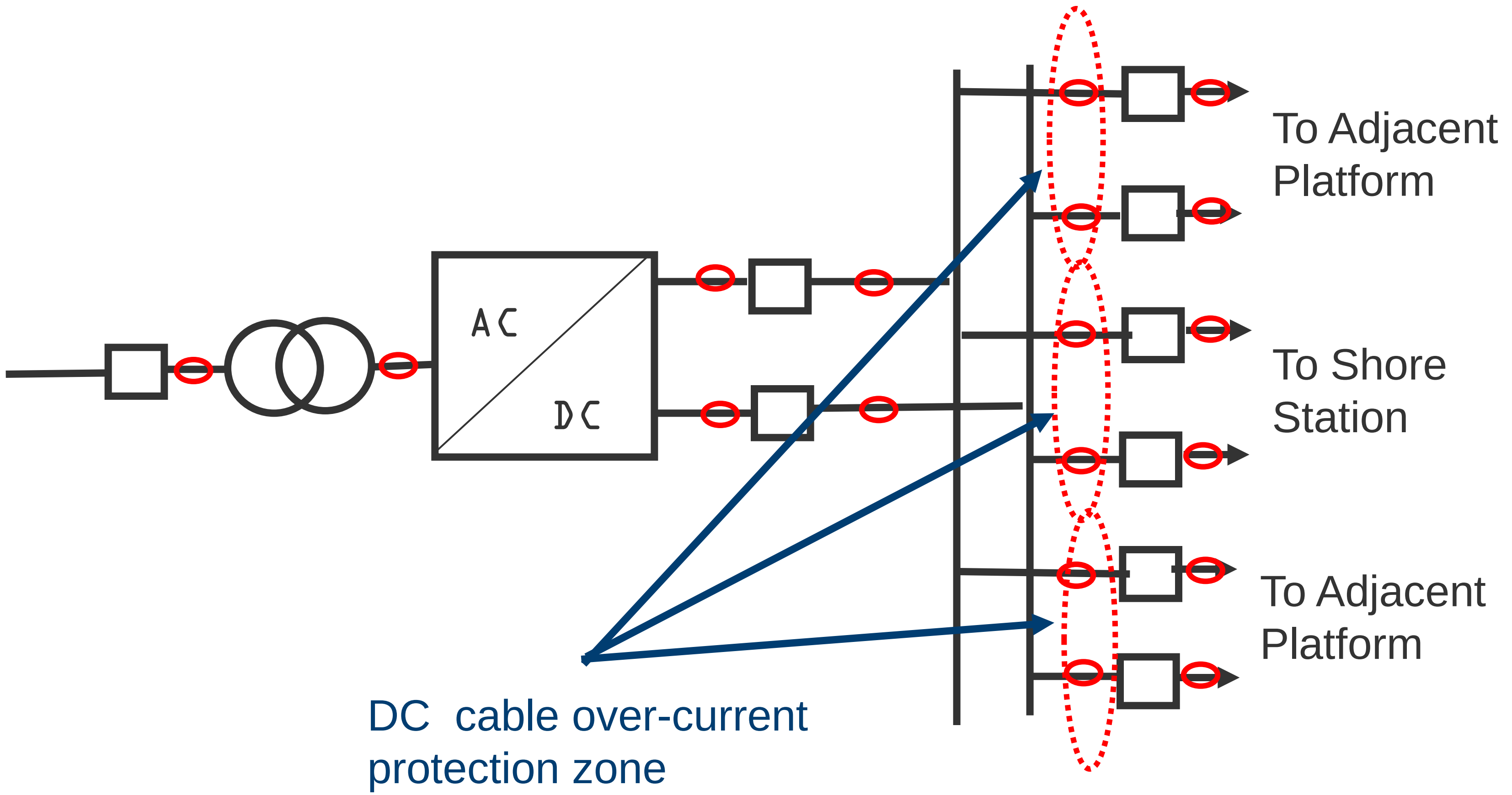
Protection Zones



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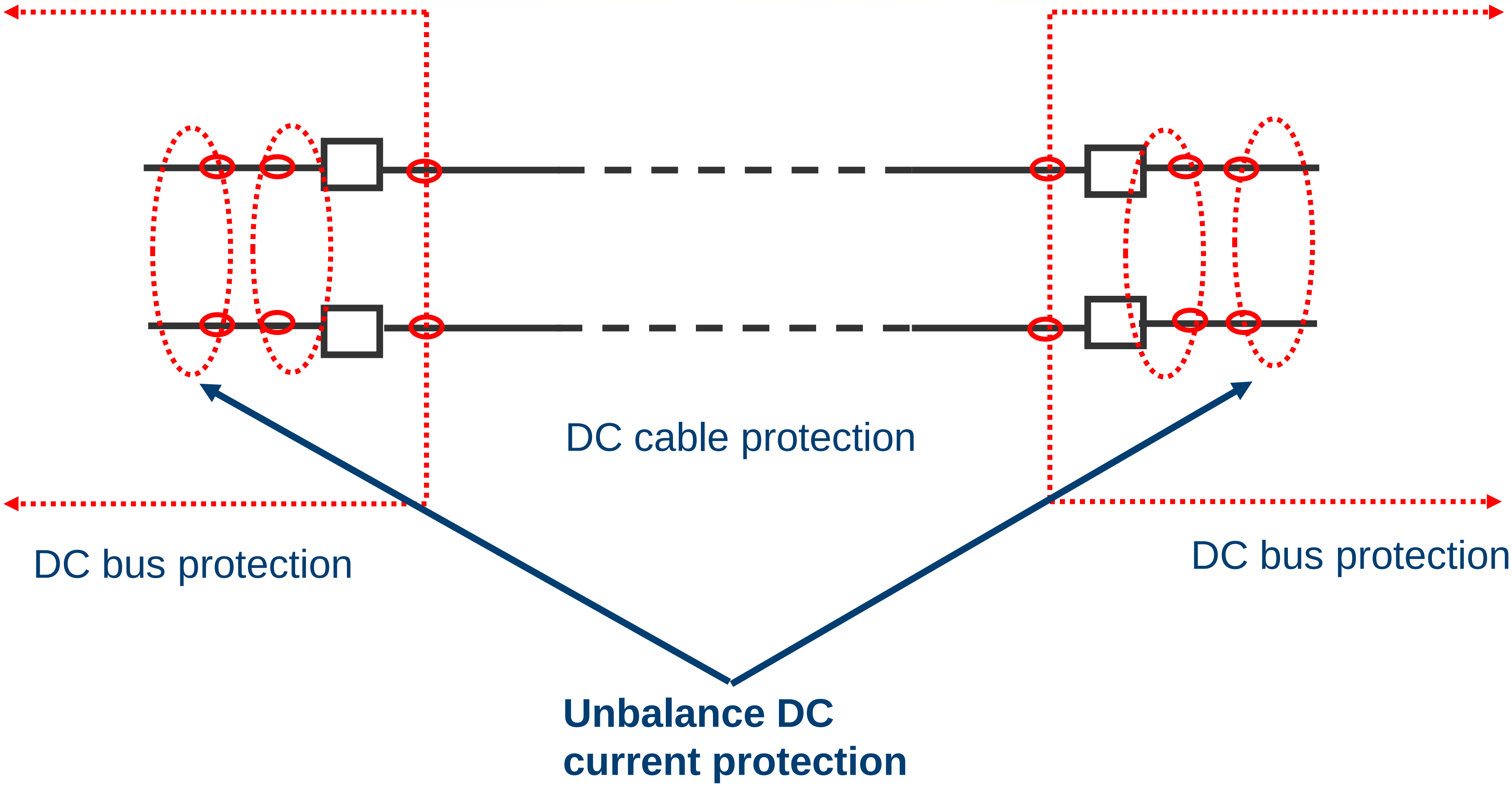
DC cable fault protection



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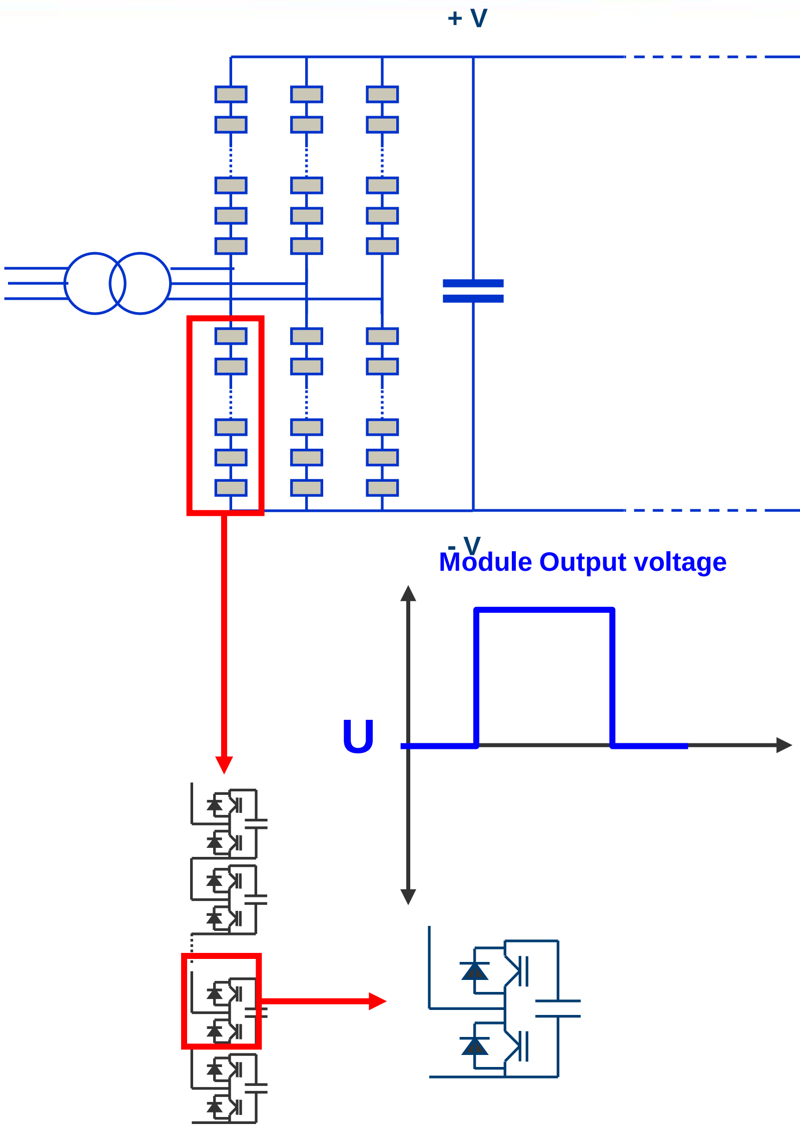
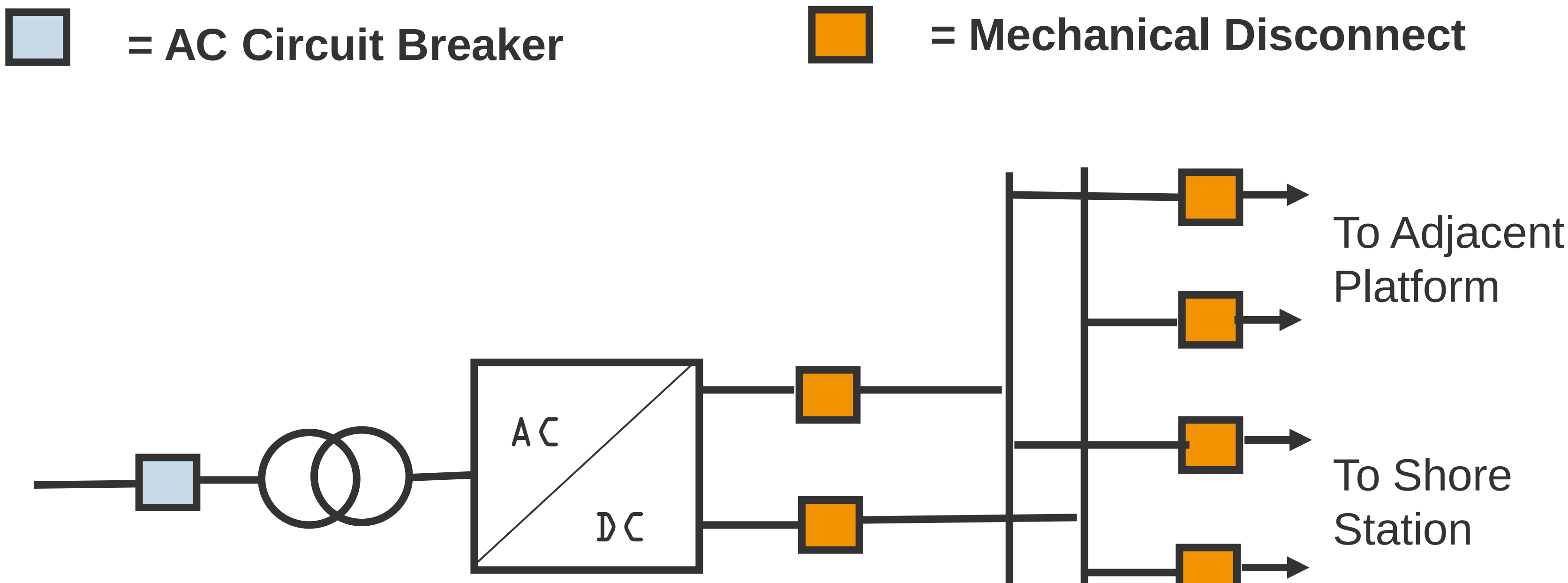
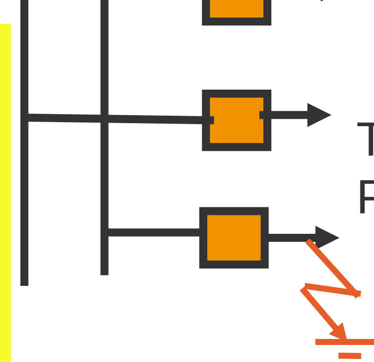
Modular Multi-level Converter : Half link



- Lowest component count
- Only one possibility of output voltage polarity
- No capability of suppressing DC-side faults

Option 1 "Half-bridge converters + Disconnects





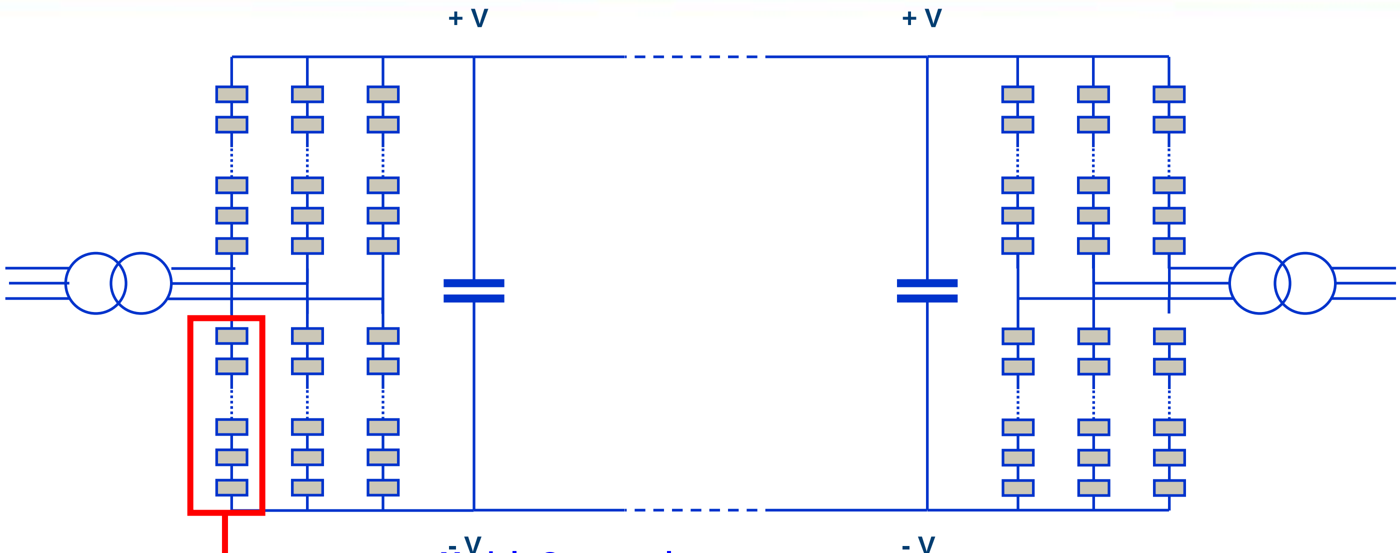
DC cable fault can not be cleared by "half – bridge" AC/DC converter

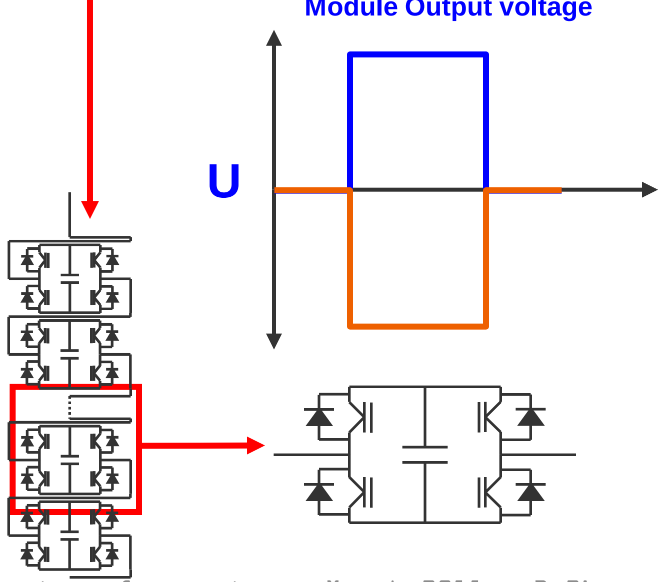
AC circuit breakers on all platforms open to clear the fault

Appropriate disconnects opened to isolate faulted cable section

Complete multi-terminal scheme is re-started

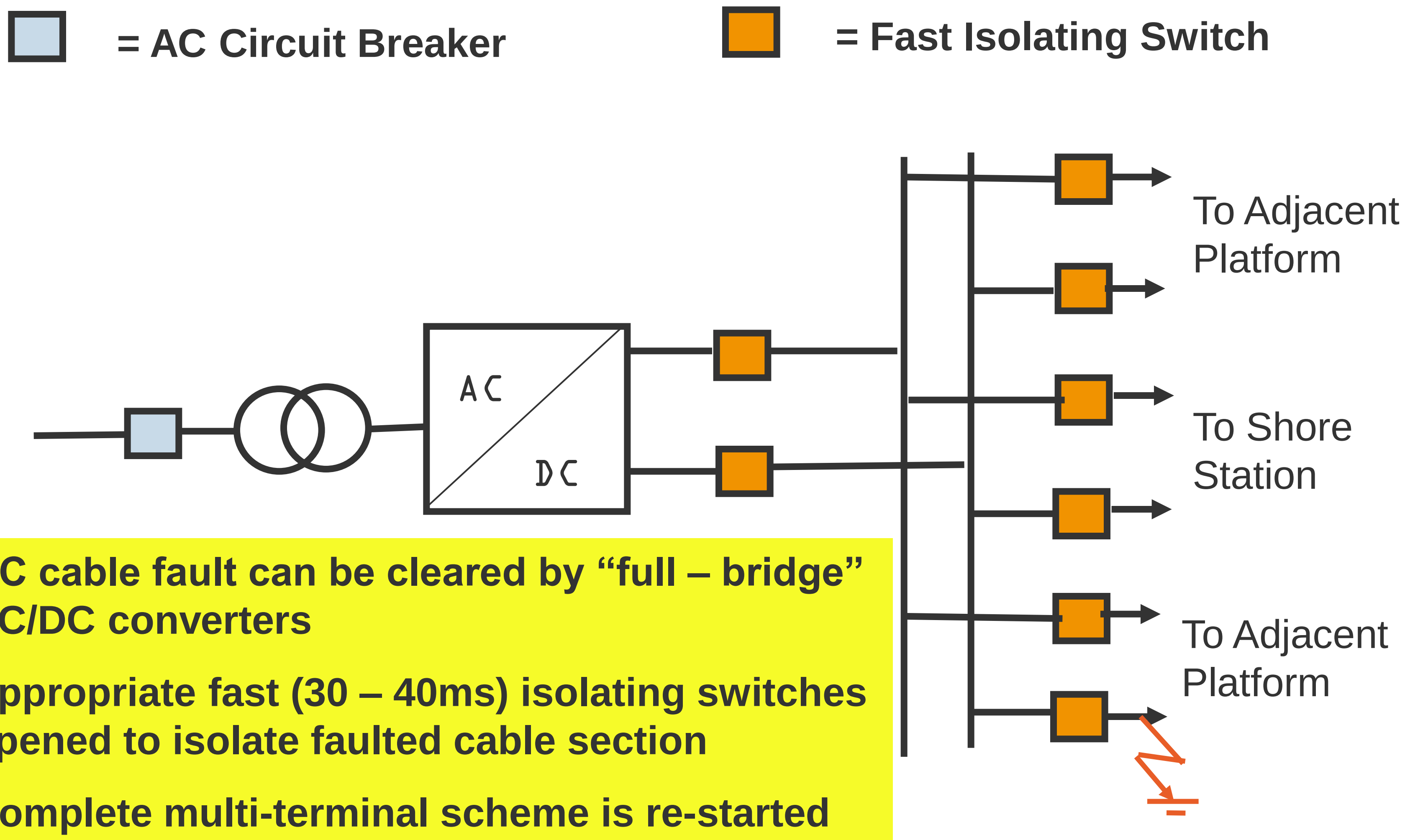
Modular Multi-level Converter : Full link





- Same circuit as ALSTOM STATCOM chain circuit
- Output DC voltage can be either polarity
- Hence can connect as tap to LCC-HVDC link
- Can also suppress DC side faults

Option 2 "Full-bridge" converters + Fast Switches

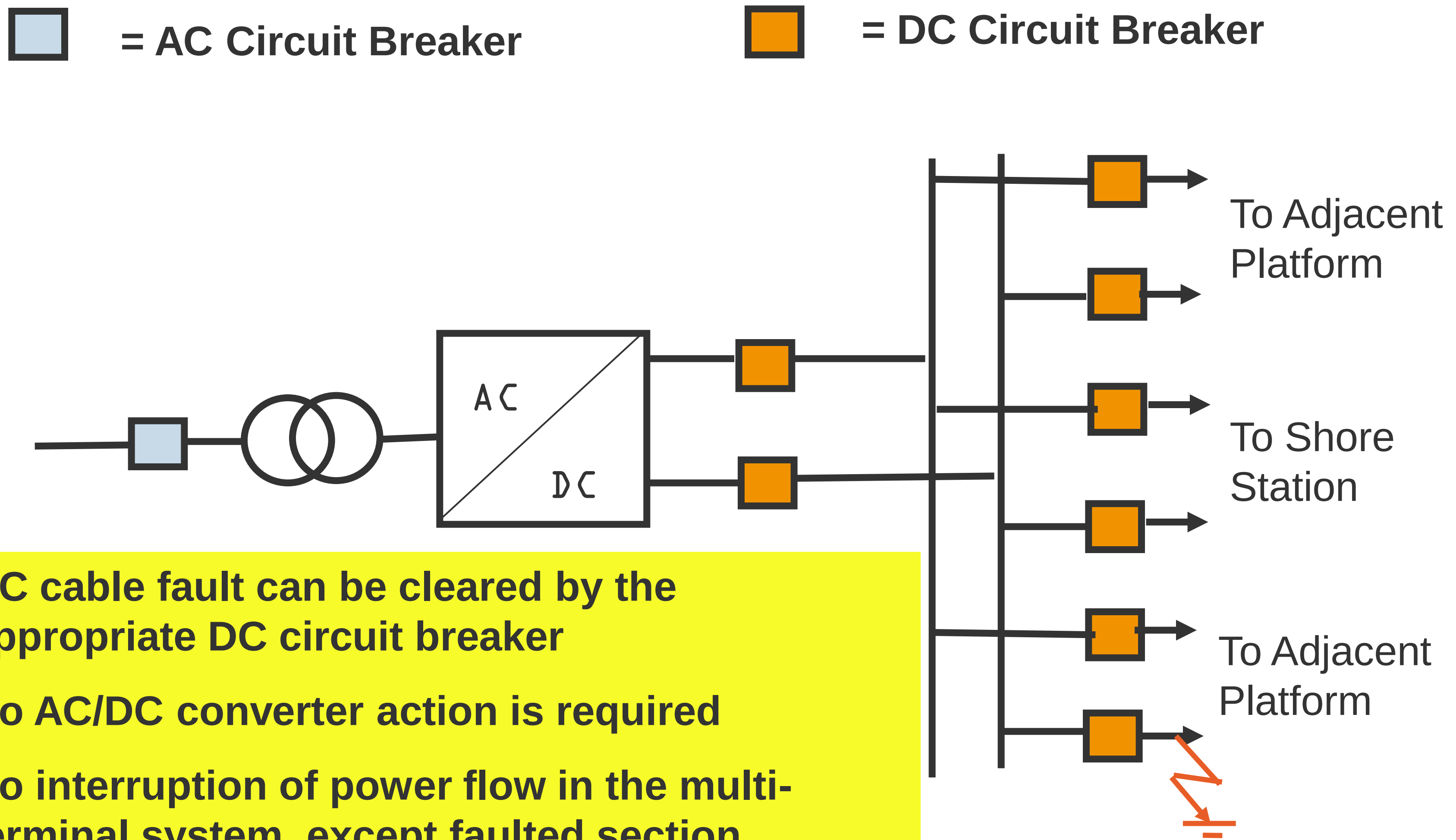


DC cable fault can be cleared by "full – bridge" AC/DC converters

Appropriate fast (30 – 40ms) isolating switches opened to isolate faulted cable section

Complete multi-terminal scheme is re-started in 300 – 400ms

Option 3 "Half-bridge" converters + Circuit Breakers

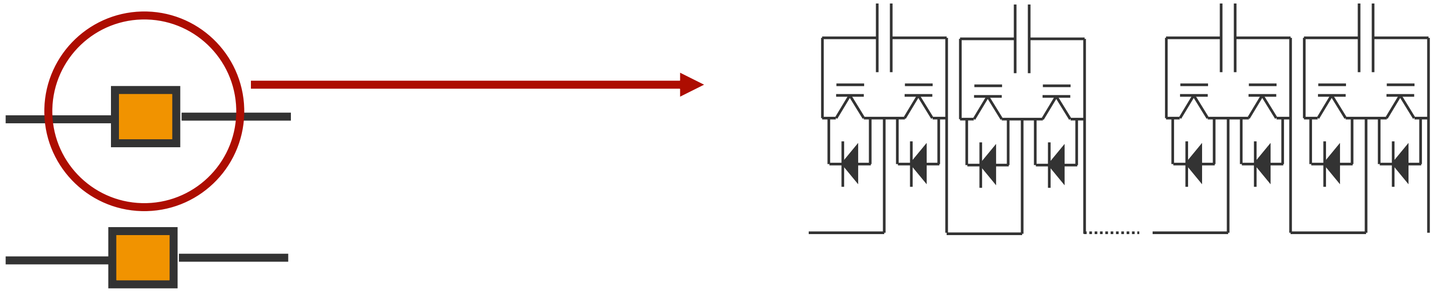


DC cable fault can be cleared by the appropriate DC circuit breaker

No AC/DC converter action is required

No interruption of power flow in the multi-terminal system, except faulted section

DC Circuit Breaker



- Half Bridge power electronic converter
- Each pole is equivalent to 1/6th of the main AC/DC converter
- Full DC fault current interruption capability
- Full DC voltage withstand capability
- Operating losses = 0.11% of station power per pole
- Coordination is required between the over-current capability of the AC – DC converter and the time required for the “Breaker” to detect and interrupt the fault current

DC Circuit Breaker - Possibilities

There are no commercially available DC circuit breakers at this time, although R&D work is in progress. Possibilities include,

- Vacuum
- Plasma
- Power electronic
- Magnetic
- Super-conducting
- Hybrid of technologies

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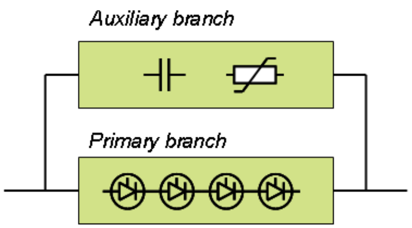
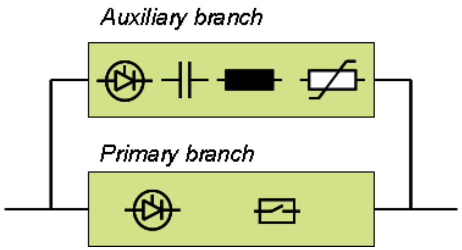
Collaborative Activities

TWENTIES project – DC Breaker WP

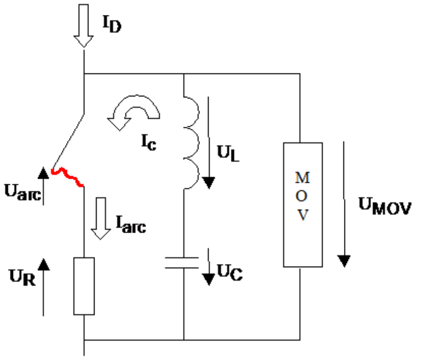
- Work package goal: specify and demonstrate the critical component for multi-terminal grids, the DC breaker
- Candidate technologies:



Power electronic switch



Hybrid switch



Mechanical switch

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Do We Need to Standardise?

Purpose of Standards

- Support interoperability
- Allowing interconnected systems to be built incrementally and by different equipment suppliers, thus support incremental investment plans and avoid “stranded assets”
- Allow separation of cable and converter procurement thus allowing buyers to take advantage of the increasing number of HVDC cable manufacturers

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Functional Specifications

Equipment that should have a common functional specification

- AC/DC Converters
- HVDC Cables
- DC Breakers
- DC-DC Converters
- Dump Resistor

Design Specification

Equipment that should be defined at the initial design stage

- Topology?
  - Symmetric Monopole
  - Monopole
  - Bipole
- DC Voltage (nominal, steady-state and transient range)
- Fault Current Contribution
- Multi-terminal DC Protection
- Multi-terminal DC control

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DC Grid Standardisation Activities

- International recommendations being created;
  - CENELEC - Four, five, six terminal grids
  - Cigrè B4-52 - Large pan-European grids

- Cigrè have just approved five further DC grid working groups;
  - B4-56 Guidelines for the preparation of "connection agreements" or "Grid Codes" for HVDC grids
  - B4-57 Guide for the development of models for HVDC converters in a HVDC grid
  - B4-58 Devices for load flow control and methodologies for direct voltage control in a meshed HVDC Grid
  - B4-59 Devices for load flow control and methodologies for direct voltage control in a meshed HVDC Grid
  - B4-60 Designing HVDC Grids for Optimal Reliability and Availability performance

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