Offshore DC Grids
Studies in TWENTIES and ISLES

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TWENTIES – EU FP7 Project

University of Strathclyde Engineering

- **T**ransmission system operation with large penetration of **W**ind and other renewable **E**lectricity sources in **N**etworks by means of innovative **T**ools and **I**ntegrated **E**nergy **S**olutions
- 3-year study, 26 partners from across Europe
  - Transmission system operators, power plant manufacturers, research institutes, universities
  - "Allow for offshore wind development"
    - WP5 leading to demo 3: DC grid
    - WP6 leading to demo 4: storm management
  - Work Package 5 on DC Grids
    - WP5 led by RTE with Strathclyde, RSE, UCD and INESC
      - modelling continent-wide electrical energy resource and power flows
      - control of multi-terminal HVDC
      - impact of faults on AC or DC side

2020 2020 Twenties Transmitting wind

EUROPEAN COMMISION

SEVENTH FRAMEWORK PROGRAMME

http://www.twenties-project.eu/

Offshore grid dependencies

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Technology

Management of variable available power
Control of link interaction
Management of fault conditions
Voltage source converter technology
Cable technology

Investment feasibility

Electricity market benefit
Cross-border exchange of power

WP5

Twenties Transmitting wind

INESC PORTO LABORATÓRIO ASSOCIADO · RSE Ricerca Sistema Energetico · Rte Réseau de transport d'électricité · University of Strathclyde Engineering · UCD Dublin

What does the development of offshore grids depend on?

TWENTIES: key WP5 questions

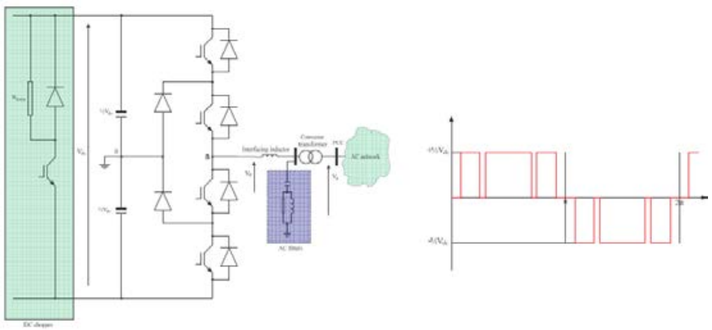
- What should be the specifications of the DC / AC interconnectors?
  - What minimum DC grid performance characteristics are required from the perspective of the AC system?
  - What services can a group of wind farms on a DC grid offer to the AC system?
- How should HVDC networks be controlled and protected?
  - How do different terminals of a DC grid interact?
  - What is the influence of
    - Faults on the DC side on the AC side?
    - Faults on the AC side on the DC side?
  - What is the requirement for a DC breaker?
    - What are is minimum capability required of a DC breaker?
- How much capacity should be built on an offshore DC grid in (northern) Europe anyway?
  - How strong are the drivers for a DC grid?

TWENTIES: converter topologies

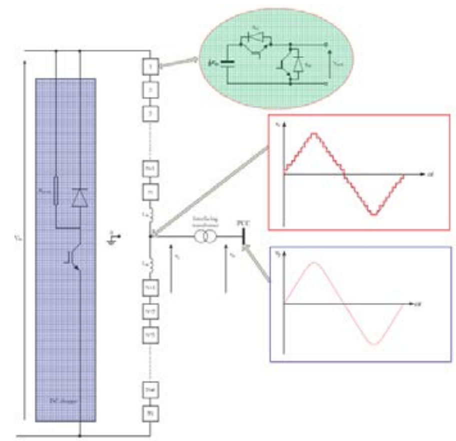
- Precise topology of voltage source converter determines
  - number of power electronic and conventional devices
    - size and weight
    - conduction and switching losses
  - issues with harmonics
    - requirement for filtering (size and weight)
  - dv/dt
  - risk of over-current during DC link energisation
  - capability to block fault current coming from AC side
  - audible noise
- Choices interact with
  - DC breaker capability/required capability
  - physical installation issues onshore and offshore
- Interoperability of different topologies?
- Different interactions with AC system under fault conditions?

TWENTIES: converter topologies

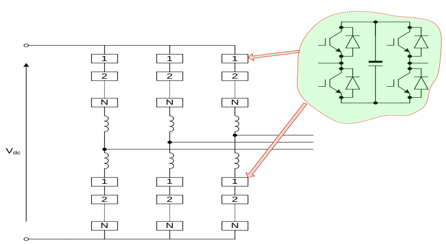
Neutralpoint clamped converter (NPC)



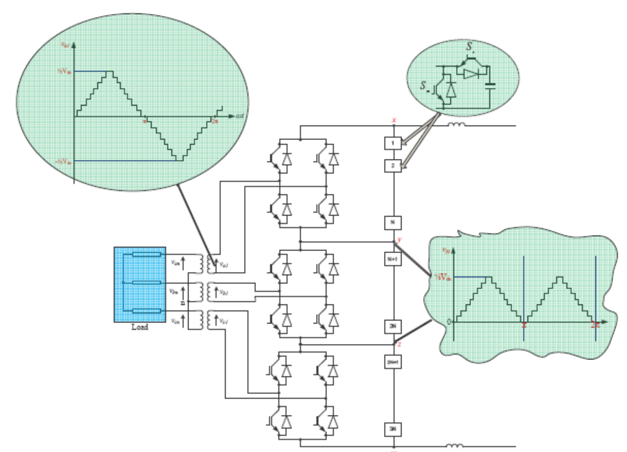
Two-switch modular multilevel converter (M2C)



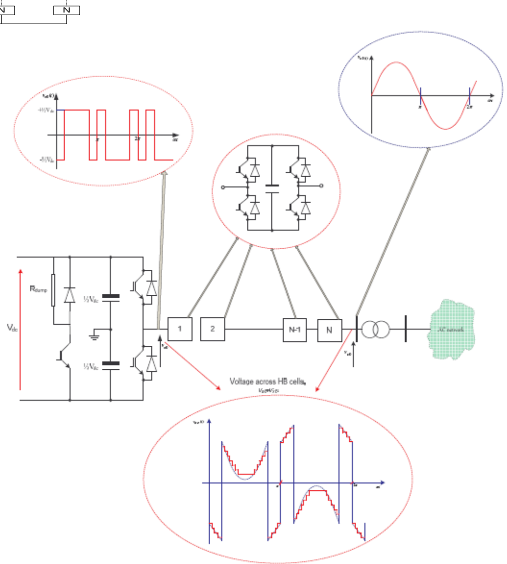
H-bridge M2C



Hybrid: M2C cells across DC link



Hybrid: series H bridge cells on AC side

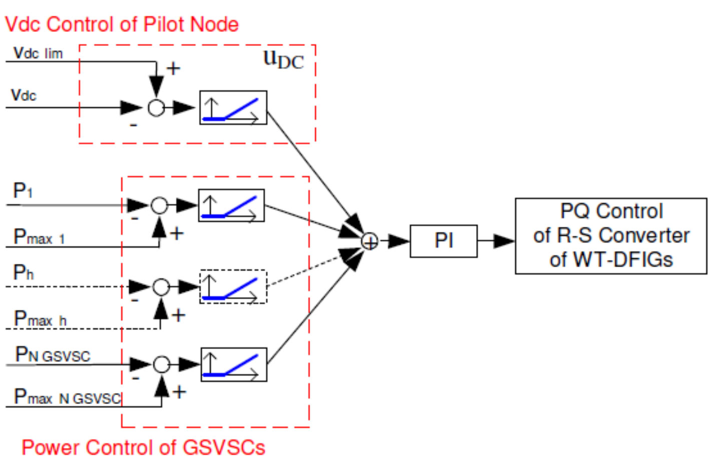


Controls on the DC grid

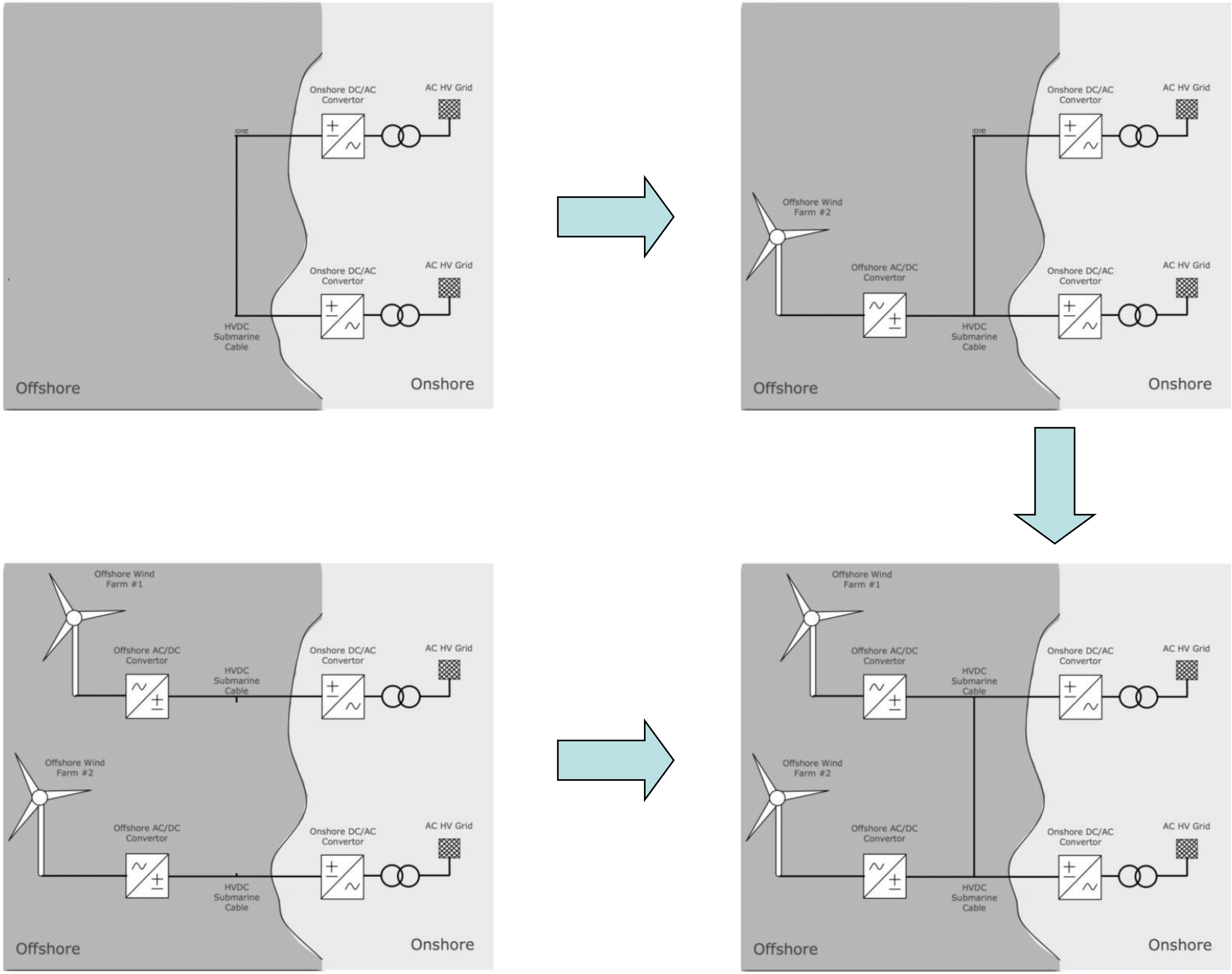
Need coordinated converter response to DC faults or loss of an inverter

- Try to avoid need for comms; use local droop controls
- Need for special protection schemes?

- DFIG
  - Grid-side WT converter: V_{dc} and Q_{PCC} control
  - Rotor-side WT converter:
    - Normal operation: P-Q control
    - In case of faults: reactive current control for voltage support
  - Protection:
    - V_{min}/V_{max}, $speed_{min}$/$speed_{max}$, crowbar
- Wind Farm-VSC:
  - V_{ac}-f_{WF} control
  - *Reactive current control*
  - *Current limitation*
- Grid side-VSC:
  - Vdc-Pdc droop control
  - Vac control
  - Current limitation
  - Reactive current control

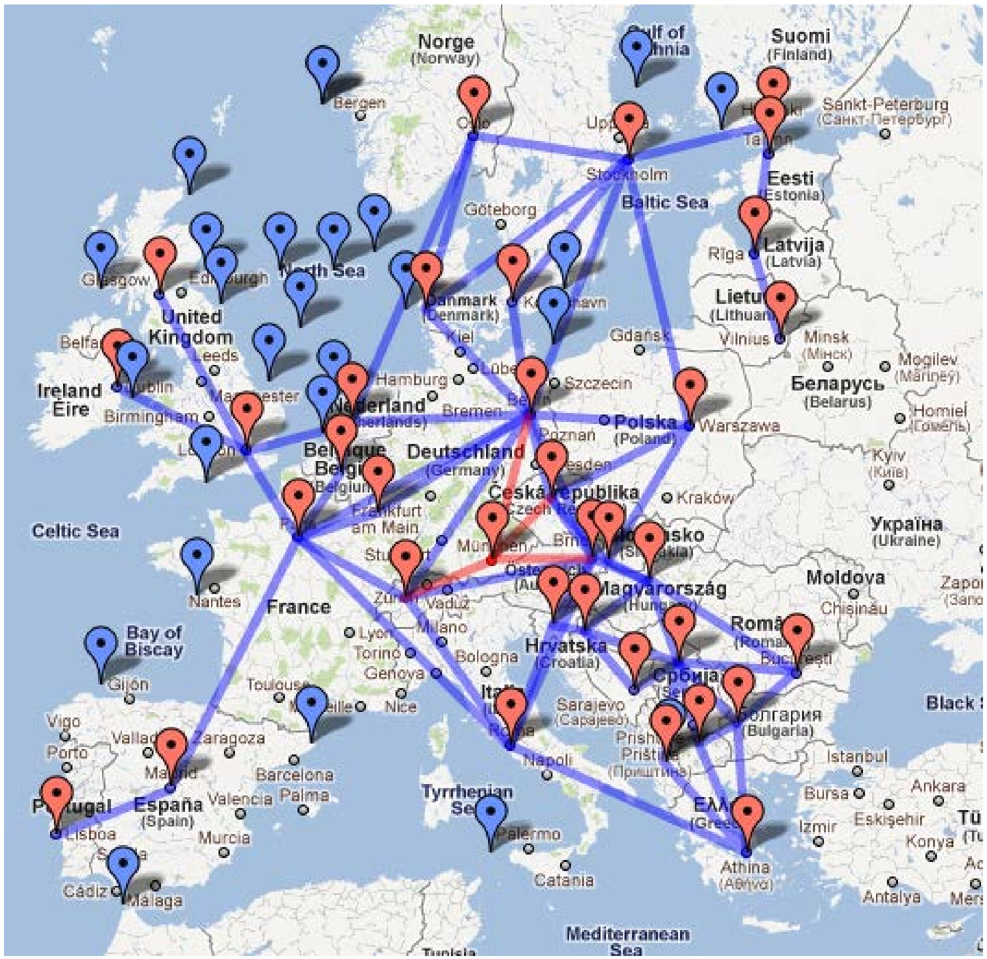


TWENTIES: ‘H’ test case



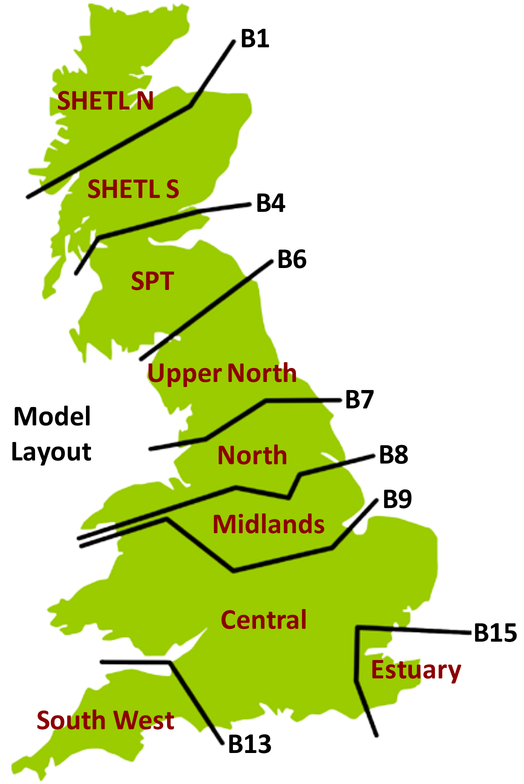
European transfer model

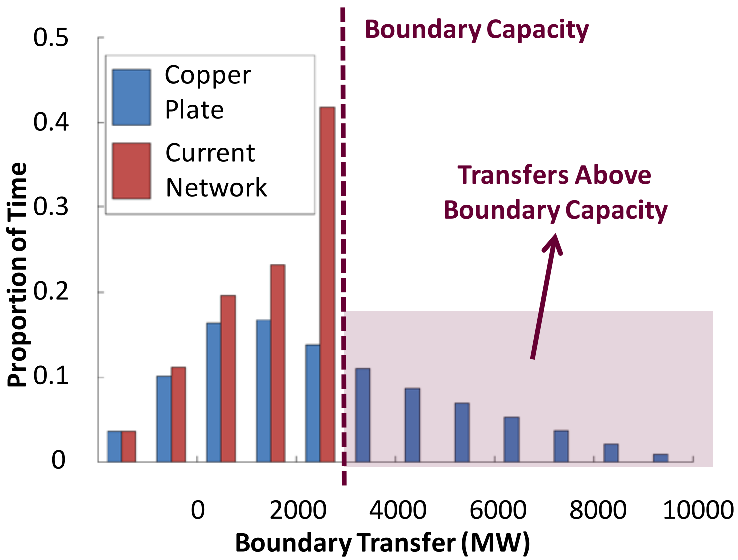
TWENTIES WP5 ‘drivers’ studies: how much offshore grid?

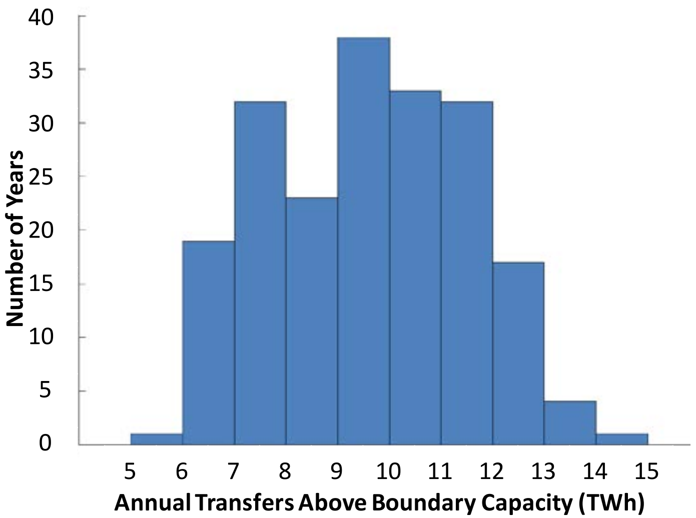


- Centre national generation portfolios and loads on single nodes
- Show international interconnections
- Add putative offshore wind sites
- Carry out hour-by-hour Europe-wide dispatch based on
  - nodal loads
  - available generation
  - assumed ‘merit order’
  - heuristic model of hydro
- Compare different network cases:
  - ‘copper plate’
  - Different levels of NTC for different offshore nets

Transfer uncertainty: GB example







Variation due to

- through the year variation in demand
- uncertain generation availability
- uncertain ‘merit order’

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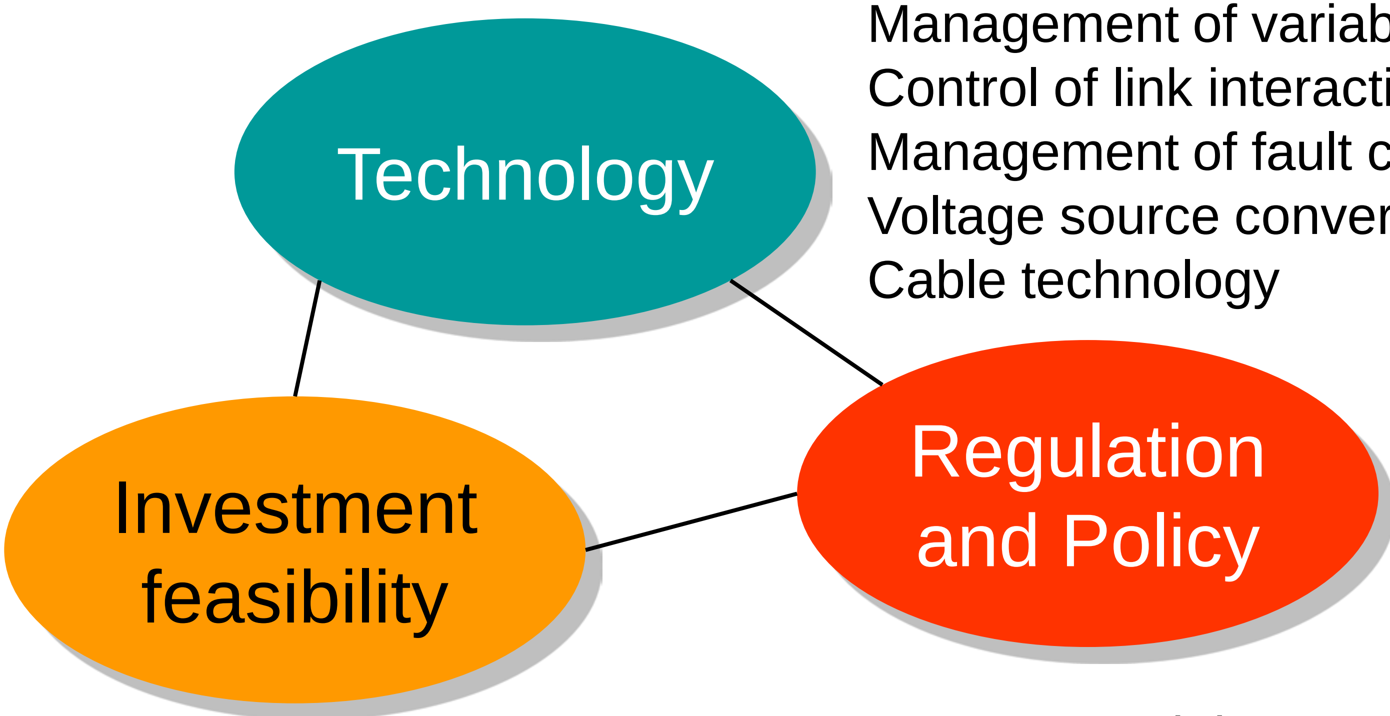

Electricity market benefit
Cross-border exchange of renewables support
Supply chain capability
Risk appraisal
Finance

Access rights
User charges
Ownership and licensing
Grid Code and Security Standards

What does the development of offshore grids depend on?

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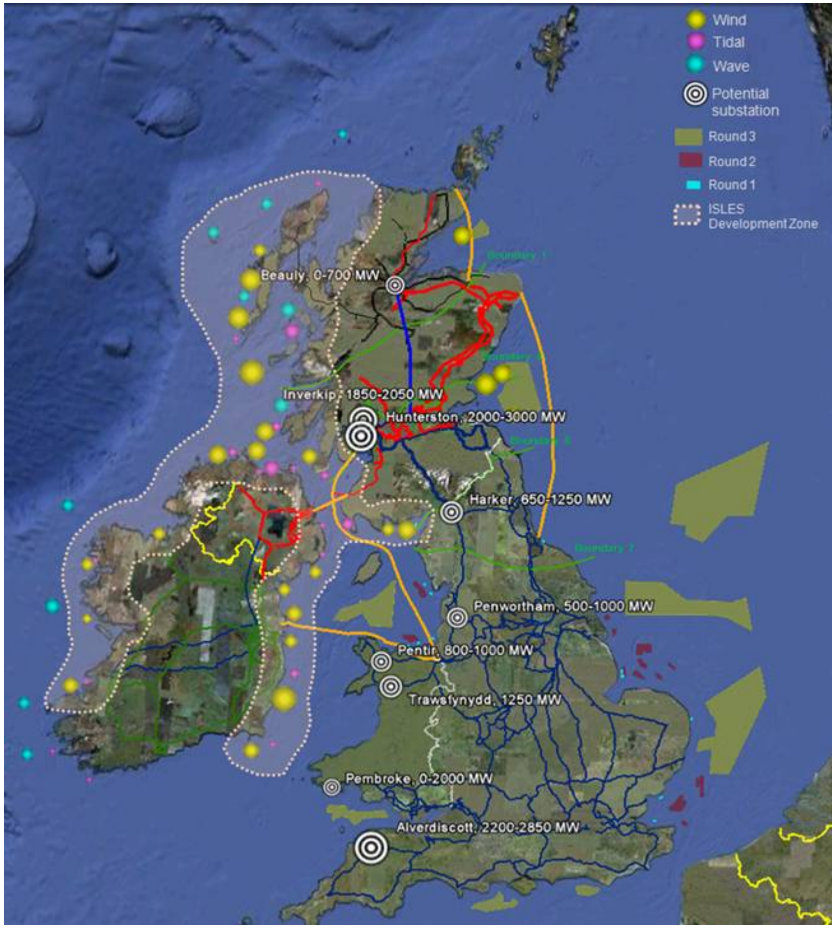
Ireland Scotland Links for Energy Study (ISLES)

- Develop concept and explore business case for an offshore transmission network off the west coast of Scotland and in the Irish Sea
  - What might the offshore network look like?
  - What might it cost?
  - What features would enhance its commercial viability?
  - What barriers might there be?
    - Technical
    - Legislative
    - Regulatory
    - Market compatibility



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Northern Ireland Executive

ISLES Workstreams

- Regulatory & Finance
- Technology & Infrastructure
- Environmental & Planning
- Construction & Deployment
- Cost Benefit analysis

Work overseen by a Steering Group comprising

- representatives of the three Governments
- a technical advisor

Full results published late November/early December 2011

ISLES observations on technology

- Capacity and distance dictate a predominantly HVDC solution
- VSC HVDC required due to offshore wind generation islands
- VSC HVDC viable up to at least 1000MW
  - Ability to install converters >1000MW on platforms? (up to ~10,000 tons)
- Multi-terminal VSC HVDC currently not proven, but likely to be viable
  - HVDC circuit-breakers are not currently available

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ISLES technology observations

- Due to the far-offshore nature of some of the ISLES generation, network resilience is essential
- Key technology issues include the prime equipment such as HVDC converters and subsea cables
- Other important considerations are the installation capability vessels for the platforms and cables
  - High sea state and deep waters

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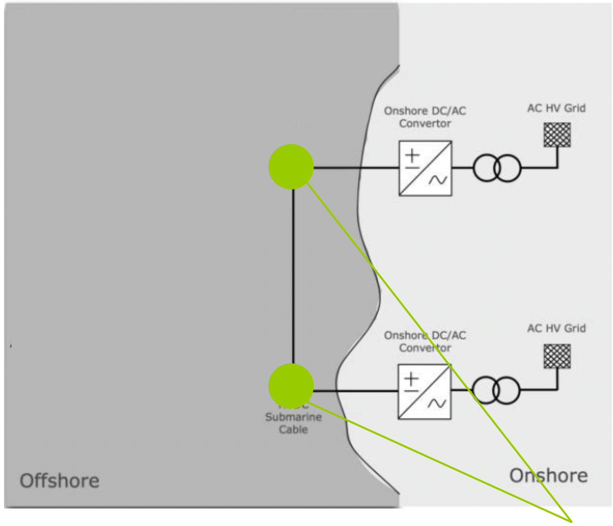
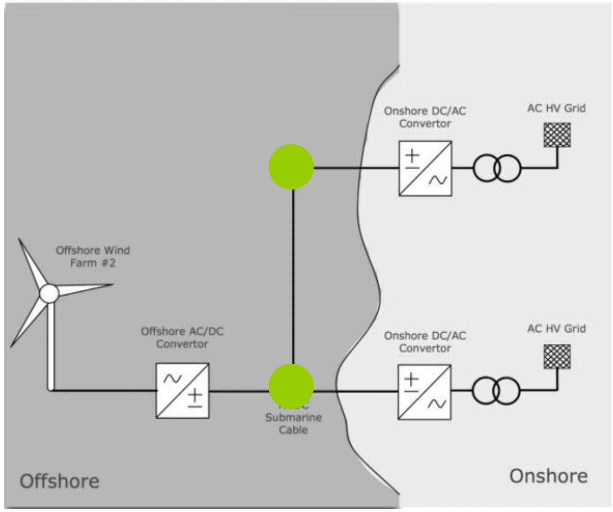
ISLES North 'Concept'

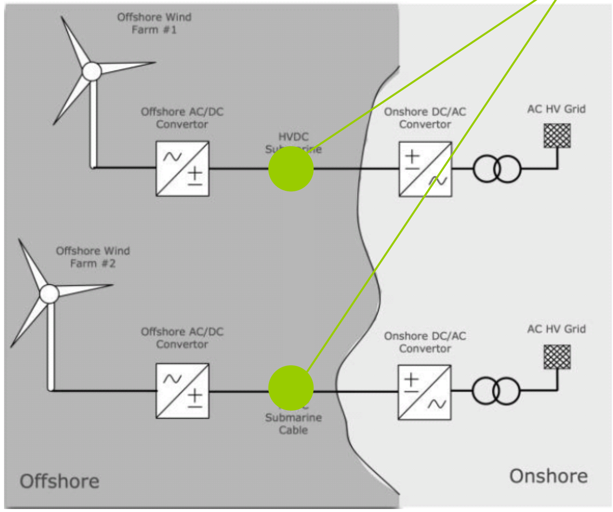
- Circa 7.8 GW of potential marine resources
- 2.5 – 3.0 GW represents ambitious scale for North Concept with 'available' connection capacity
- Incorporates 500 MW of potential Interconnection capacity to test market benefit
- Technology requirements at this level are non-trivial

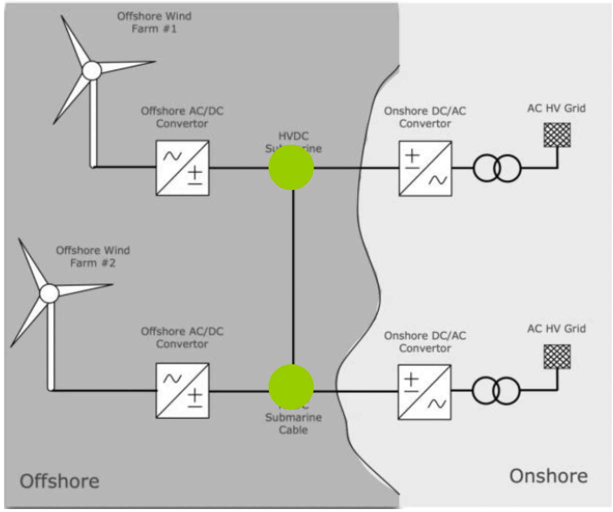
‘H’ grid development





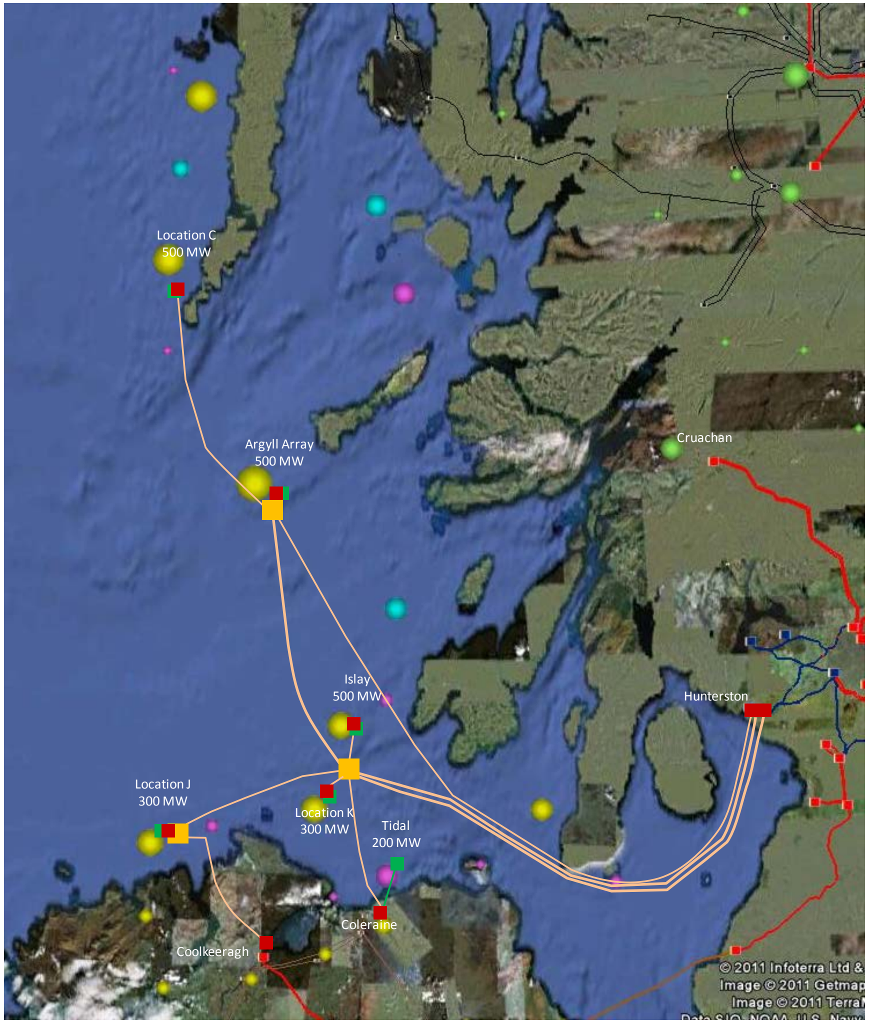
Need for hubs to be constructed in anticipation?
How much cable capacity to put in place?





ISLES network design philosophy

- Network design needs to consider the phasing, constructability, maintainability aspects
- Network availability and resilience is also critical from a bankability perspective
- Northern ISLES Generation resources comprise of:
  - 4 x ~500MW OWF blocks
  - 500MW of Interconnection
  - One primary grid export point
- Phased development and common routes provides integration options



Northern ISLES Configuration

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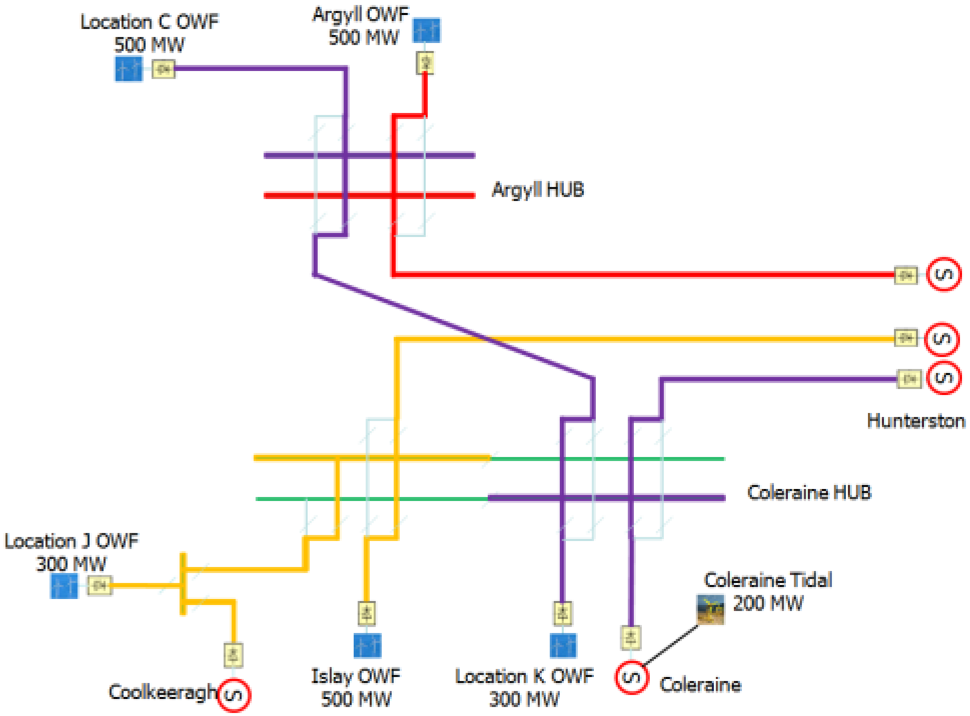
- Proposed Northern ISLES concept is a network of three non-interconnected three-ended multi-terminal VSC HVDC links
- HVDC Hub with off-load switching provides network resilience in the event of cable faults
- Parallel cable paths provides the opportunity for phased network developments



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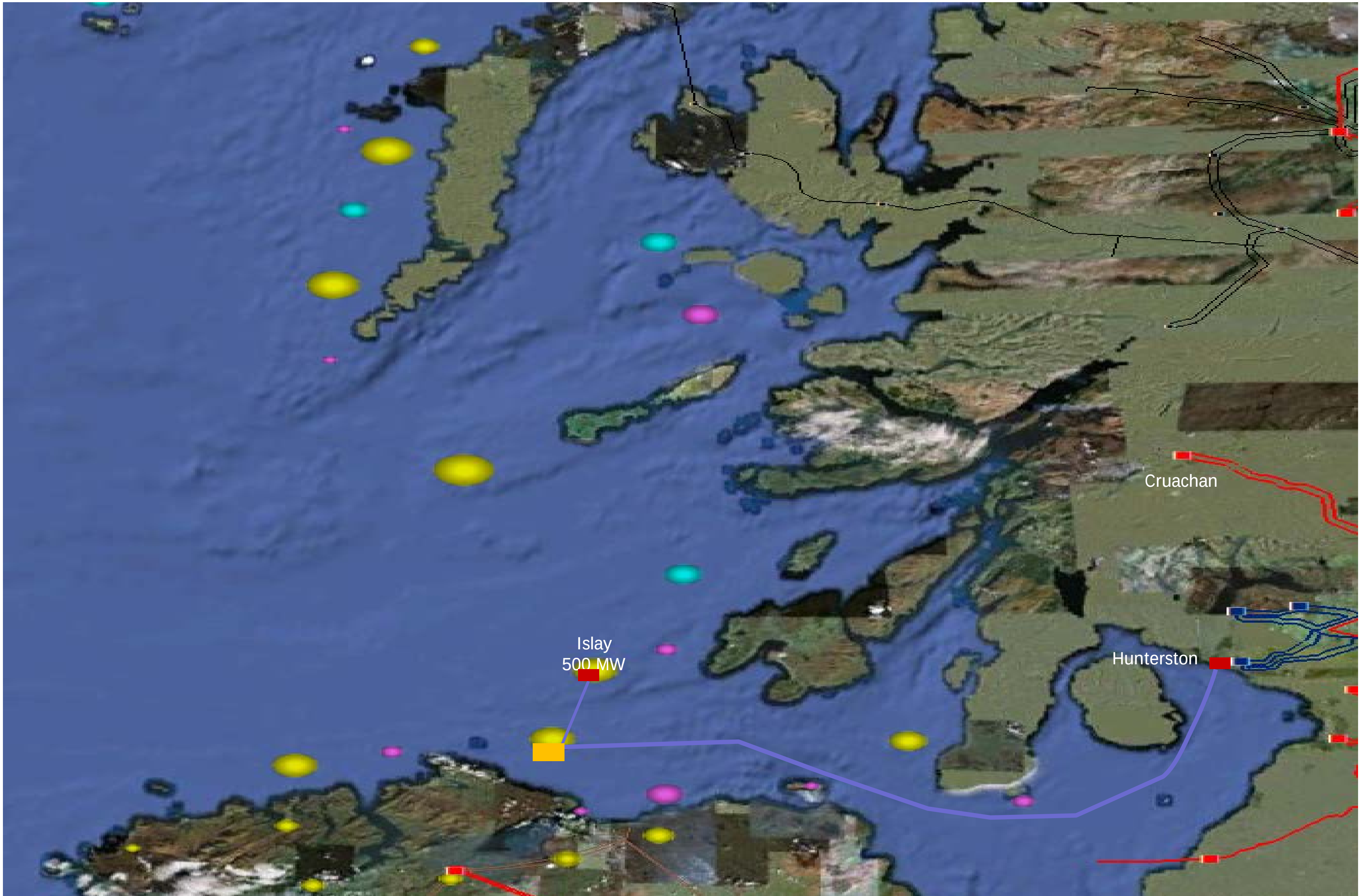
Cruachan
Islay
500 MW
Hunterston

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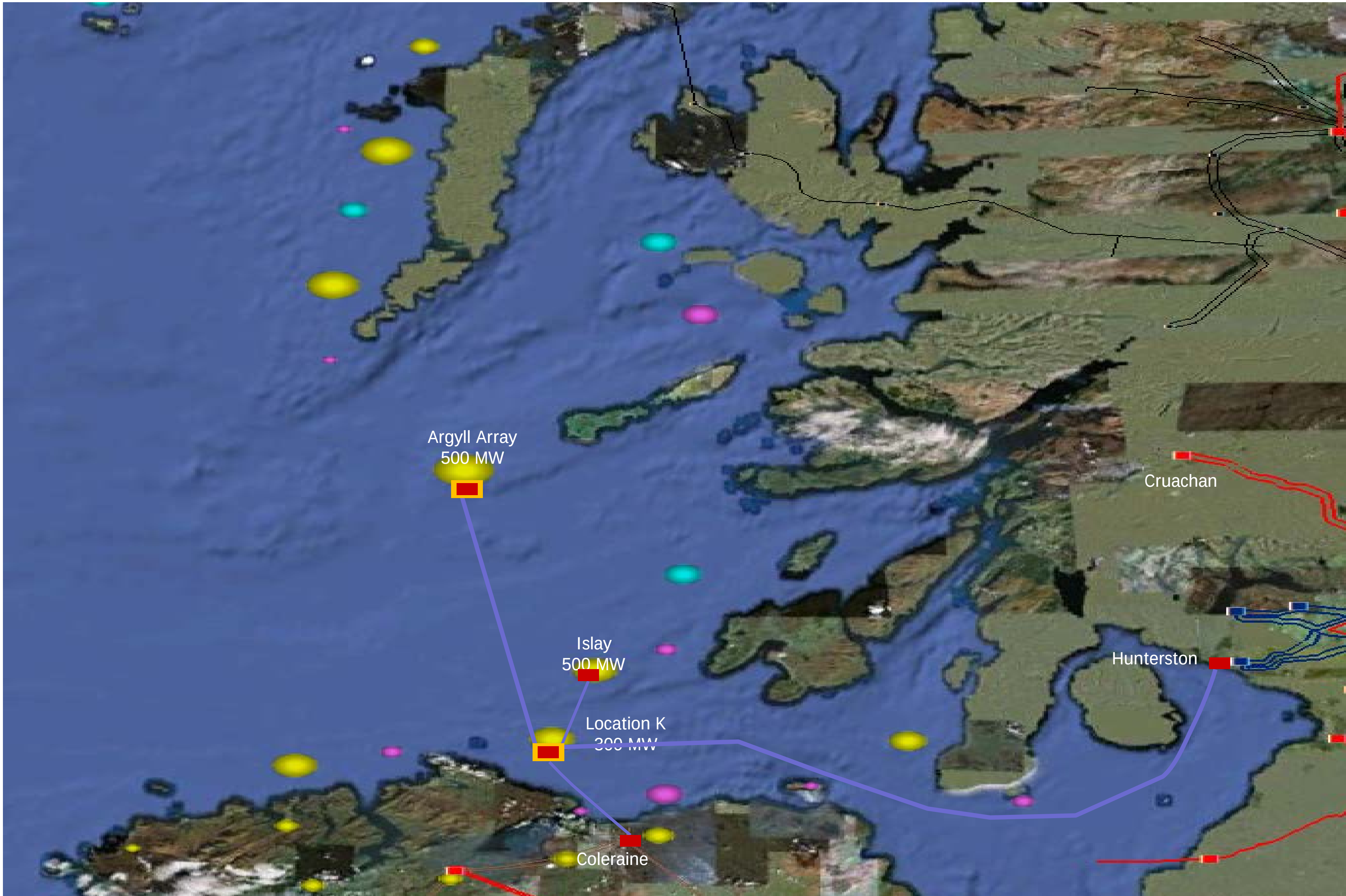

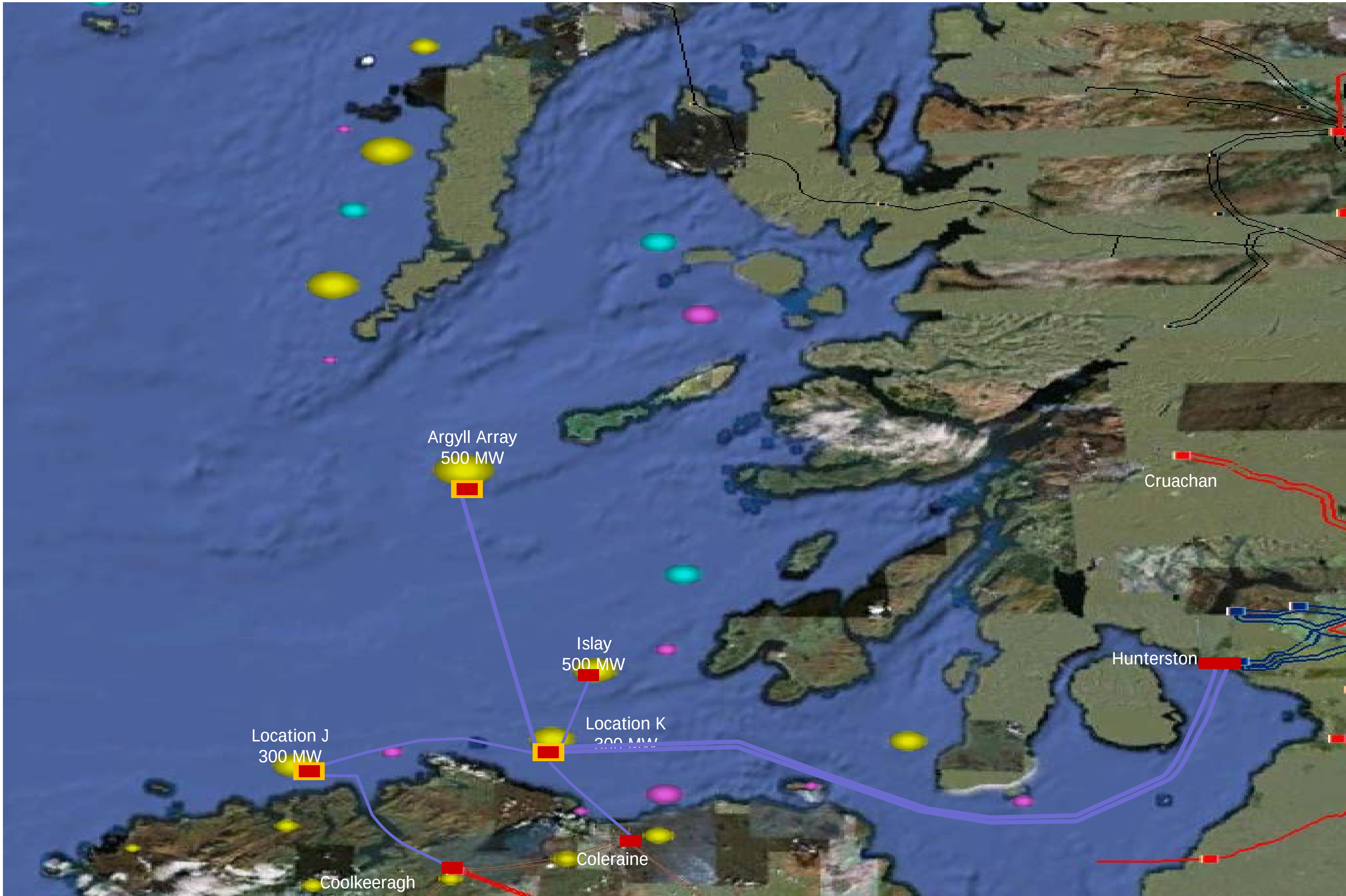
Argyll Array
500 MW
Cruachan
Islay
500 MW
Hunterston
Location K
Location J
300 MW
Coleraine
Coolkeeragh

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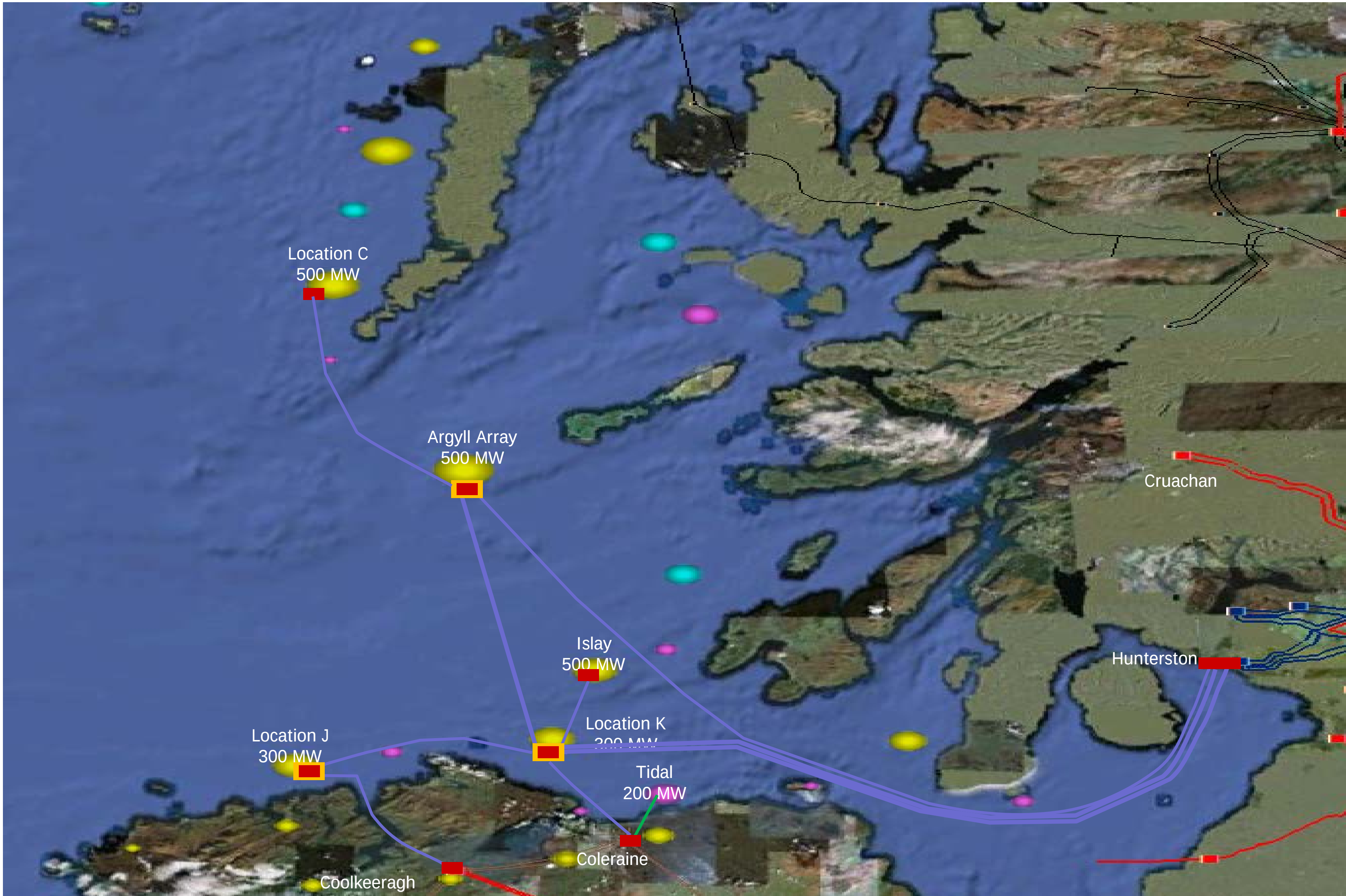
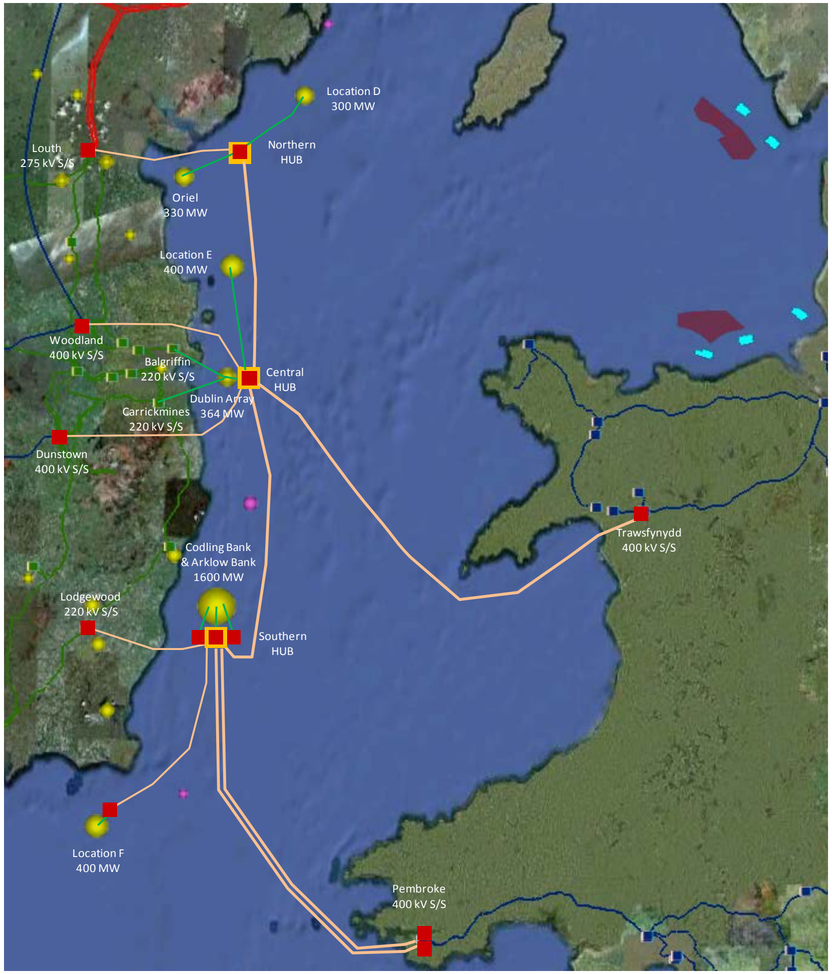


Southern ISLES Concept

- Circa 3.4 GW
  - similar scale to North Concept
- Incorporates 3000 MW of potential Interconnection capacity
- Enhanced transfer capacity and reinforcement across all Ireland
- DC and AC mix
- 3 x 1000 MW links to Wales
- Phased development



Technology issues

- Modular/phased build-out possible (necessary?)
- Technology and design selections need to be ‘bankable’
  - Large investments will be sensitive to technology risks
- Standardisation of key equipment parameters needed
  - E.g. HVDC voltage – 300kV?
  - May need some push from outwith the manufacturers
- DC breakers: a necessity or not?
- On-going supply chain pressures, particularly on subsea cable supply and installation capability

Issues

- Licensing, ownership and charging mechanisms
  - Merchant, in style of GB OFTO regime or some other?
  - Who is the ‘design authority’? What design principles applied?
- Support for investment in renewables
  - REFIT in Ireland, ROCs in UK now; electricity market reform (EMR) bringing about change in UK
  - sharing contributions to renewables targets and access to support mechanisms across national borders?
- Technical
  - supply-chain, multi-terminal HVDC, onshore grid constraints
- Cost (“Green Giant”): multi-billion £/€
- Sources of funding?
  - private, state or EU investment? (Or combination?)
- Need for high-level coordination if implementation is to happen?

Some design questions

- What is the value of having redundancy in network paths versus the very high cost of cables and converters?
  - Depends on distance to main interconnected network
  - Depends on how lack of market access is priced
- To what extent is it useful for more than one offshore wind farm to share a long connection to shore?
  - Depends on WF sizes & diversity compared with cable capacities
- What is the value of multiple connections to shore that would enable transfer of power between onshore locations as well as simply from offshore to onshore?
  - Onshore locations could be within same synchronous area
  - Depends on diversity of need for power transfer
- Given that not all wind farms will be built at the same time, what is the 'option cost' of overspecifying an initial network development?
  - Enable cheaper accommodation of a later farm
  - Risk of stranded assets if later wind farm not actually developed?