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Impact of HVDC on the GB Network

Topic	Presenter	Affiliation	Duration
Transmission Stream Introduction		SHE Transmission	5
HVDC in the GB Context	John West	NGET – System Operator	5
Innovation in HVDC	Paul Coventry	NGET – Transmission Operator	10
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Close and Q&A	Paul Coventry	NGET – Transmission Operator	10

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HVDC in Great Britain

John West

21 October 2014

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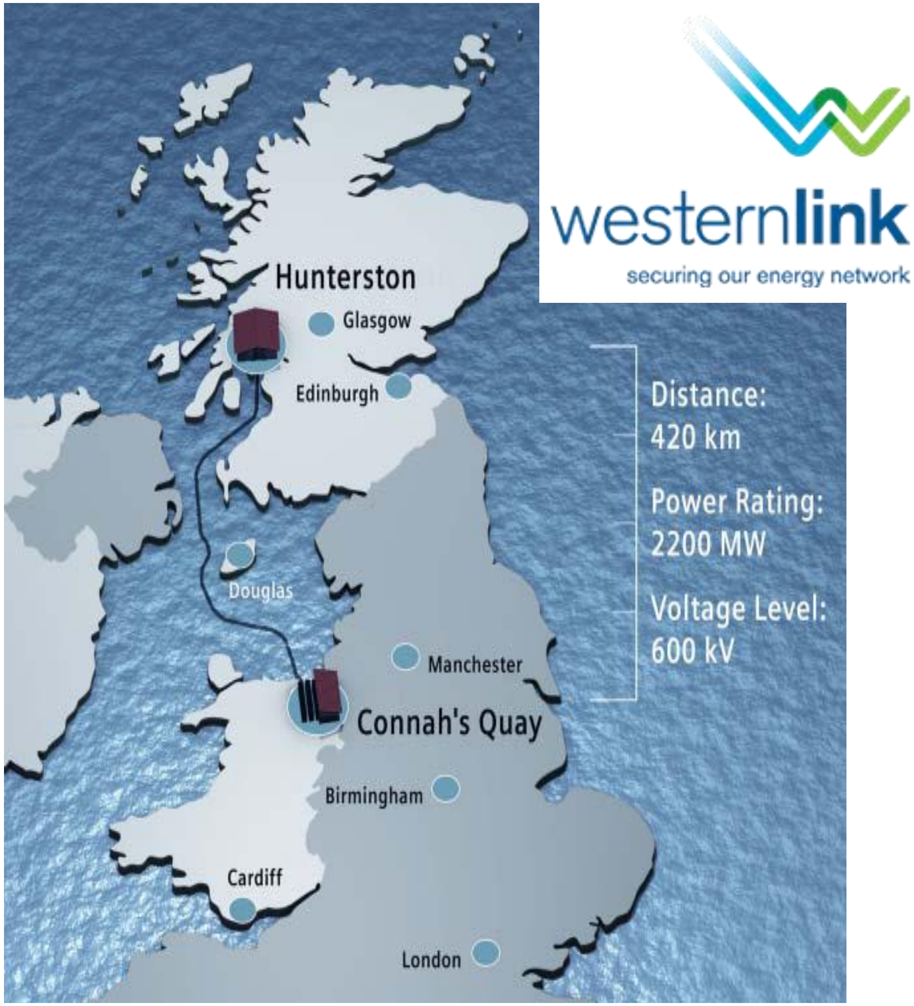
Use of HVDC Technology in GB

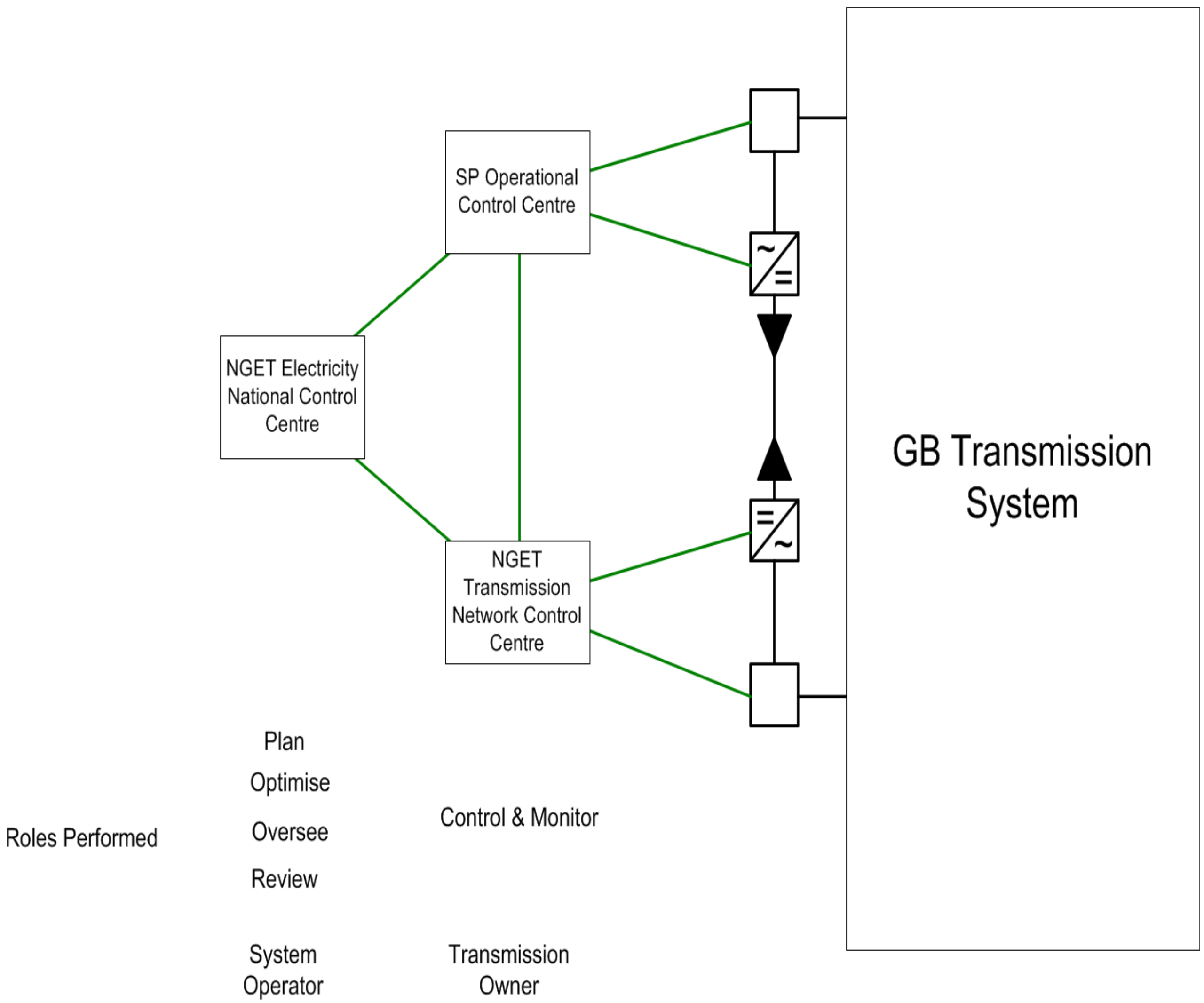
- Used for classic HVDC benefits of long distance transmission, power flow control and connecting synchronous networks
  - For example, the IFA & Britned interconnectors
- Going forward, we are also using HVDC technology for
  - Providing capacity within the GB network
  - To connect off-shore windfarms and to provide integrated offshore networks.

Western Link HVDC Circuit - Overview

- NG and SPT joint venture to increase North-South transmission capacity
  - Anglo-Scottish capacity > 6GW
- Less expensive, shorter lead-time & lower visual impact compared to AC
- Hunterston to Connah's Quay
- Line Commutated Current technology
- 2 cable bipole with no earth return, driven by Current Source Converters
  - losses & no black start favour CSC
- First 600kV DC Mass Impregnated (MI) Polypropylene Laminate (PPL) cable installation

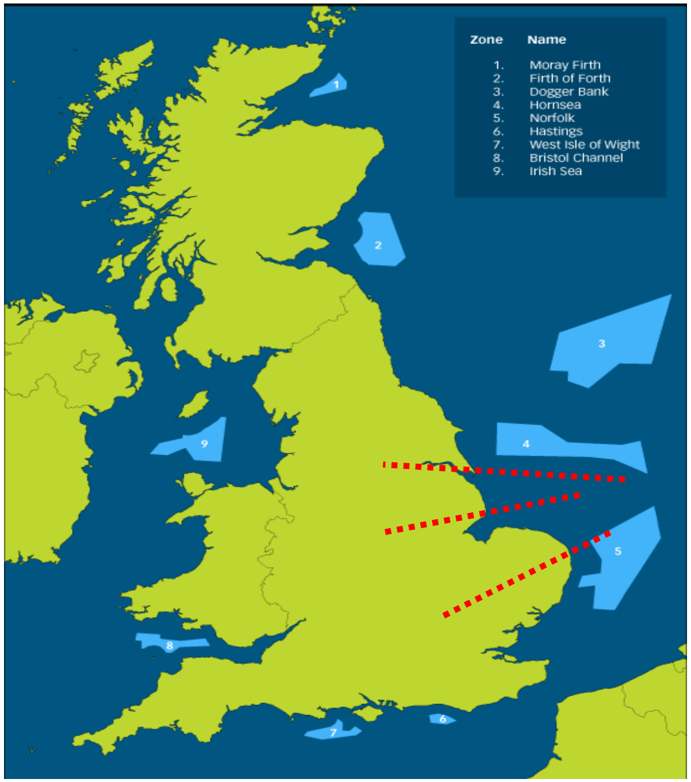


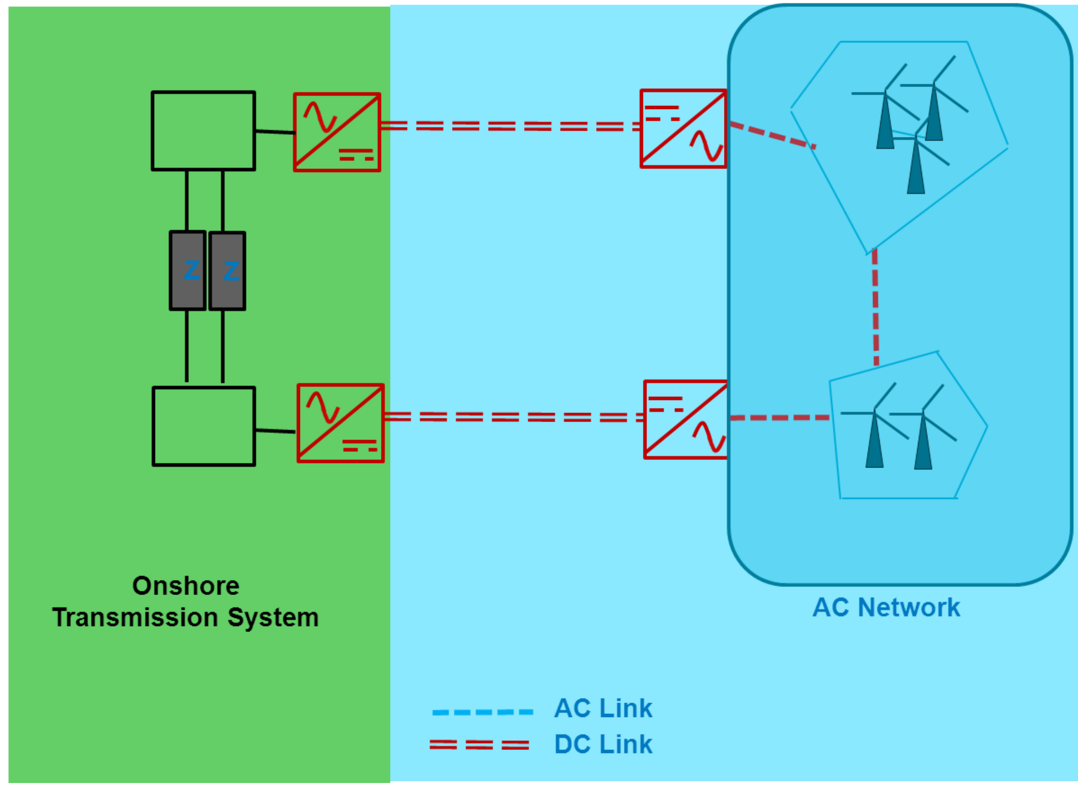
Western Link HVDC Circuit - Operation



- HVDC power flow will be determined by the System Operator & implemented by the Transmission Owners
- Network security will consider a trip of the Western Link as well as contingencies on the AC network.
- We are updating processes and systems and we are training staff to make best use of the asset

Integrated Offshore Windfarms





Given the size of the Round 3 windfarms, an integrated solution in comparison to radial offers 25% reduced overall Cost (including the onshore reinforcements required)

Fault detection
Fault Isolation
- Lack of DC Breakers
Converter control co-ordination
Power reversal

Innovation in HVDC

Paul Coventry

21 October 2014

Electricity Network Strategy Group (ENSG) Report

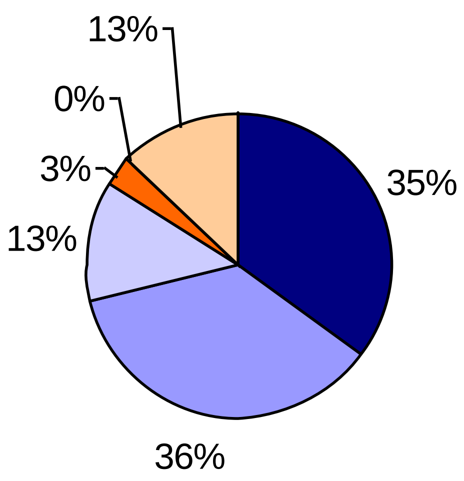
- July 2008: Following Government Consultation on UK Renewable Energy Strategy, the Electricity Networks Strategy Group, jointly chaired by DECC and Ofgem, requested the three GB transmission licence holders to:

1. Develop scenarios for electricity generation and demand consistent with the EU target for 15% of the UK's energy to be produced from renewable sources by 2020
2. Identify and evaluate potential electricity transmission network solutions required to accommodate the scenarios
3. March 2009: Report 'Our Electricity Transmission Network: A vision for 2020' published

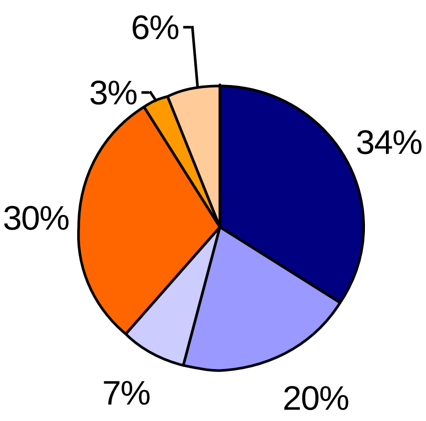
Electricity Network Strategy Group (ENSG) Report

- ‘Gone Green’ Scenario:
- One possible scenario for the 2020 generation mix
- UK renewable energy targets met
- Massive change in generation mix from existing position

Generation mix in 2010



Generation mix in 2020 Gone Green



Electricity Network Strategy Group (ENSG) Report

Electricity transmission network solutions:

- The transmission reinforcements needed to accommodate each scenario were considered
- Traditional solutions to transmission reinforcement likely to be subject to major difficulties in obtaining planning consents
- It was essential that new technologies and solutions that have not previously been used on the GB transmission system be investigated
  - Series compensation
  - HVDC technologies - VSC and multi-terminal applications
  - Sub-sea cables
- It was concluded that such technologies were well suited to playing a key role in the re-development of the GB transmission system

Voltage sourced converter (VSC) HVDC

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The ENSG report cited the following advantages of VSC HVDC over other converter types:

- External supply of reactive power not required; land requirement significantly smaller
- Independent control of active and reactive power, more flexible, fast acting control
- Can be sited almost anywhere within a network regardless of short circuit ratios
- Little or no need for ac harmonic filtering
- No minimum power operating limit; can provide active power to a network when active power is zero
- Well suited to offshore applications
- More easily used for large scale multi-terminal networks

Multi-terminal VSC HVDC

- The ENSG report proposed the optimisation of both onshore and offshore networks by integrating their design in order to capture significant cost savings
- This could be achieved by connection of wind farms by direct tee-connections into an HVDC link
- The report considered that *'…the potential for multi-terminal HVDC remains an unproven but attractive concept…'*

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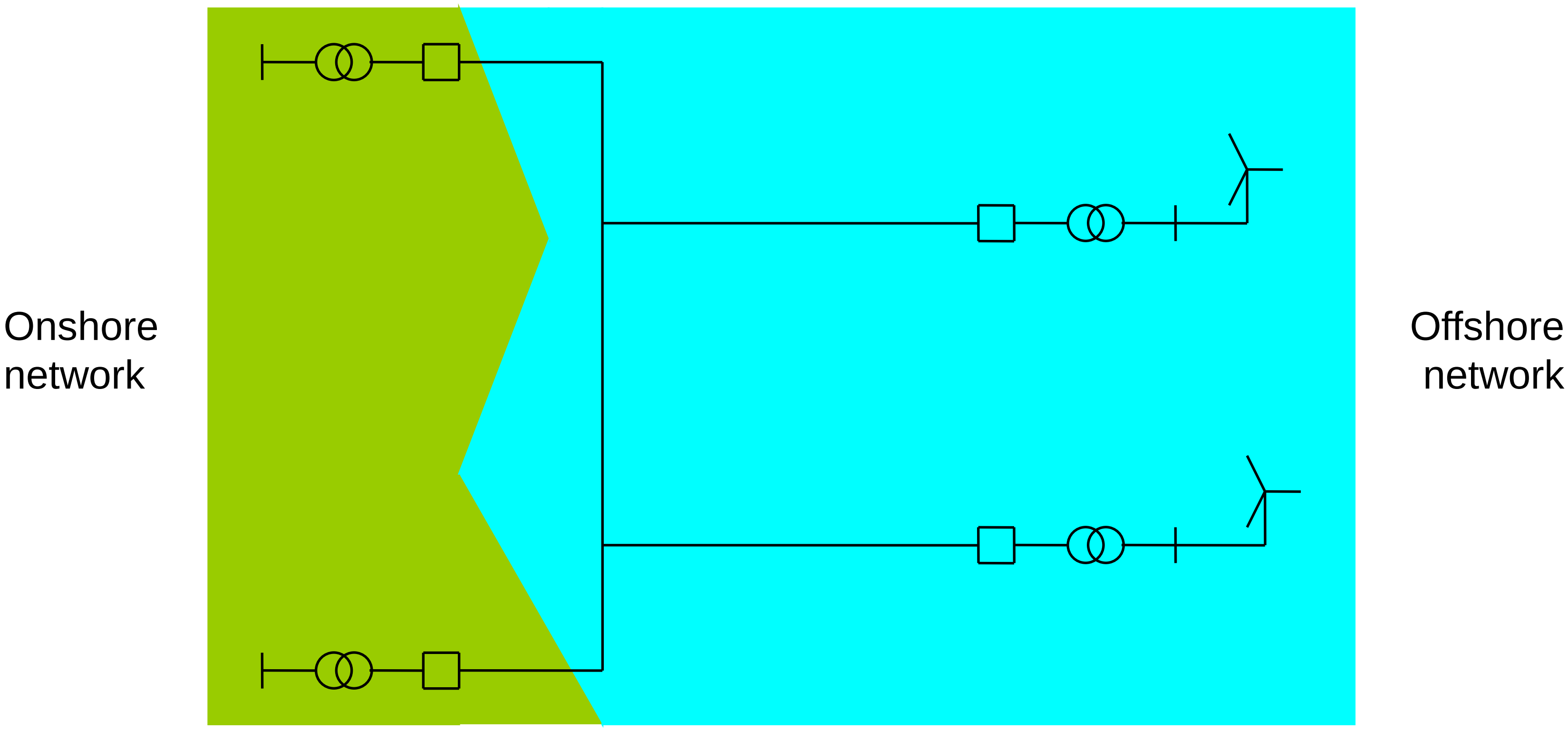
Multi-terminal VSC HVDC

Integrating the design of onshore and offshore networks by multi-terminal VSC HVDC link



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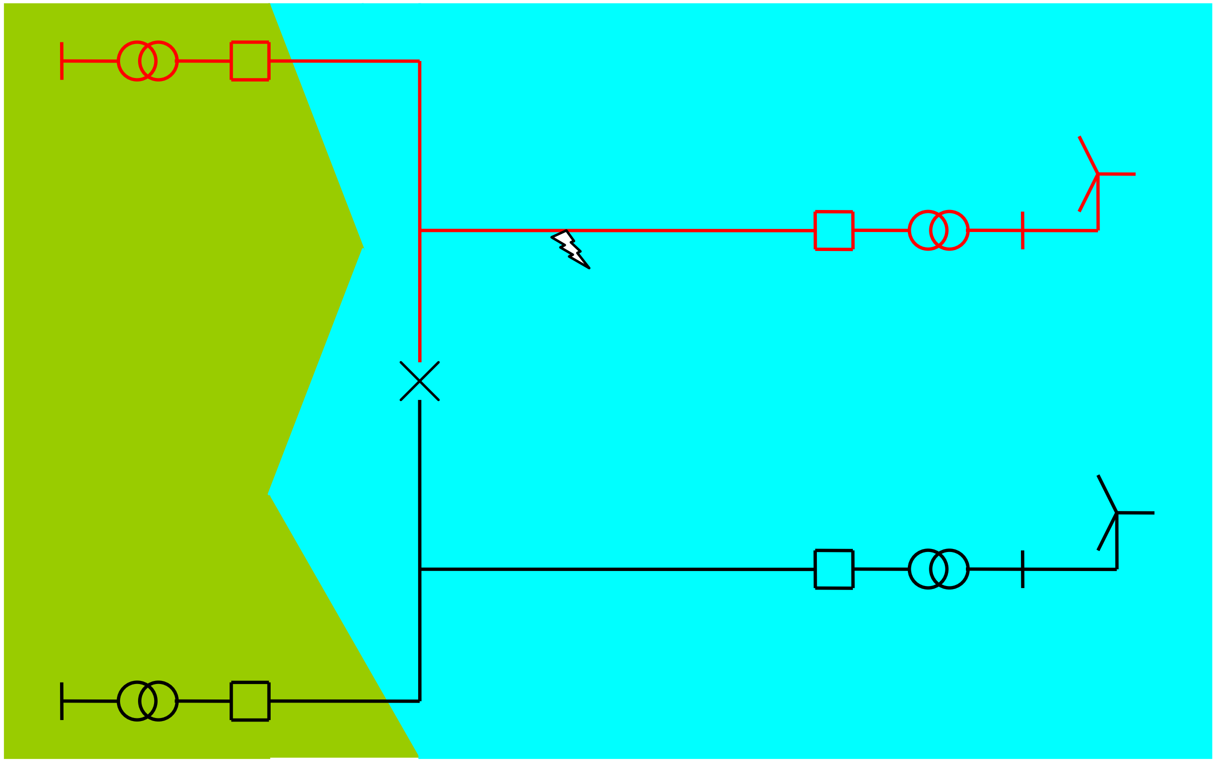
HVDC circuit-breaker

- Beyond the requirements of the ENSG report, the development of HVDC transmission presents a challenge …
- In the absence of a HVDC circuit-breaker, a dc fault causes an outage of the entire dc system until the circuits are reconfigured and the healthy part of the system restored to operation
- The volume of generation that can be connected is restricted by the limits on loss of infeed specified in planning standards
- In the event of a dc fault, a collapse of voltage spreads rapidly throughout the dc system (100 km in 700 μs)

Multi-terminal VSC HVDC

Fault clearance by HVDC circuit-breaker would allow the healthy part of the HVDC system to remain in service



The HVDC circuit-breaker is a key enabling technology for large-scale HVDC grids

Implementation of new technology

- VSC HVDC technology was a developing technology and not previously applied by National Grid
- No multi-terminal VSC HVDC system had been implemented anywhere
- No HVDC circuit-breaker has been applied in service
- National Grid adopts a risk managed approach to the introduction of new technology
- All issues associated with the technology must be understood before commitment to construct

Innovation programme

- An innovation programme was implemented:

1. To ensure that all issues associated with the new technology and its application were understood
2. To identify and mitigate risks
3. To inform Technical Specifications

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Innovation programme

The innovation programme comprised several strands including:

Cardiff University: 'Test of multi-terminal HVDC control strategies by means of an analogue test rig'

- To test and demonstrate control strategies for multi-terminal VSC HVDC systems using analogue 4-terminal VSC HVDC test rig
- To provide an early indication of feasibility of control strategies
- To identify potential problems with application of the technology

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Innovation programme

University of Manchester: 'Multi-terminal HVDC operation, control and ac system integration'

- To examine strategies to coordinate dc network controls for a multi-terminal VSC HVDC system
- To develop strategies to coordinate dc terminal operation and ac network control for a VSC HVDC system from slower system dynamics perspective
- To develop strategies to coordinate both the dc terminal and ac network operation from the fast dynamics perspective (electromagnetic transients, faults, switching …)

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Innovation programme

University of Manchester: ‘DC circuit-breaker technologies’

- Application of technology (testing, specification, identification of duties, possible tests and test circuits …)
- Detailed evaluation of concepts (detailed simulation to evaluate candidate new and potential concepts)
- Synthetic testing (validation by performing the proposed tests on candidate circuit breaker topologies)
- Fault current limiters (integration of fault current limiter technology to overcome limits on breaking capability)

A 4-terminal DC Analogue Test Rig

IFI Project Completed 2012

Jun Liang

21 October 2014

Testing of a control system for a 4-terminal HVDC link

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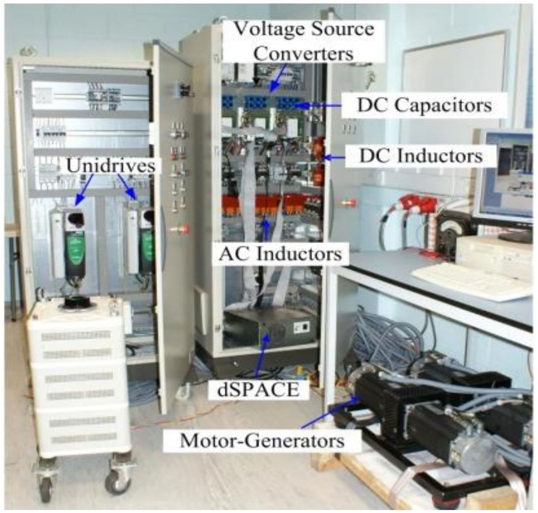
Objectives:

1. To test and demonstrate the performance of control strategies for multi-terminal VSC HVDC systems.

2. Give an indication of feasibility of the control strategies proposed for a 4-terminal VSC-HVDC link,

3. Identify potential problems with application of the technology and inform specifications and risk register.

Specifications of the test rig



- Four 10kW VSCs, two 5kW PMSMs, Power system simulator (PSS), and Real Time Digital Simulator (RTDS)
- Two configurations (1 WF+2 GSs, or 2 WFs+ 1 GS)
- VSCs are controlled through DSpace
- PMSMs are controlled through Unidrive
- PSS is used for transmission modelling and applying timed faults.
- RTDS is AC power system modelling, e.g. series compensation and SSR.

Multi-terminal VSC-HVDC test rig

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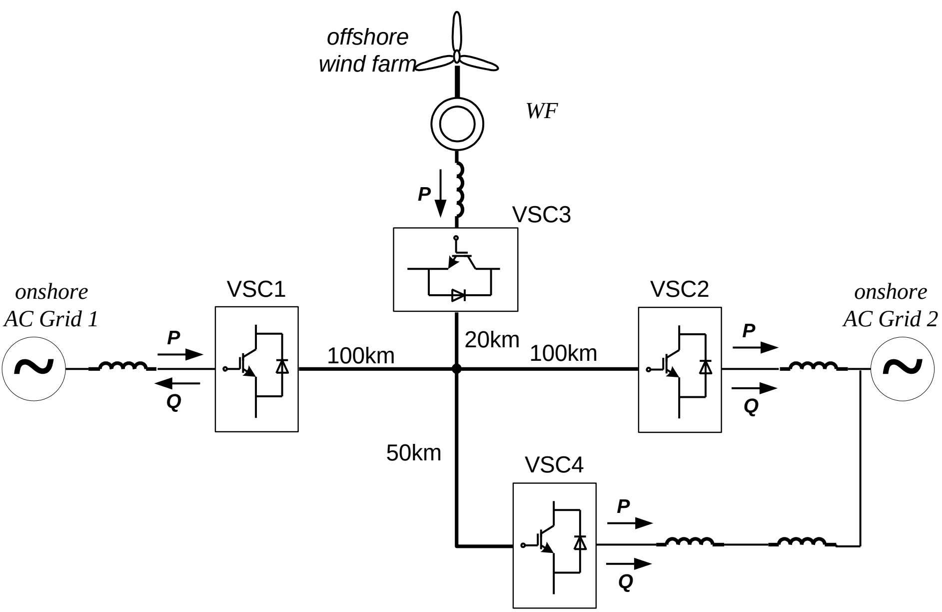
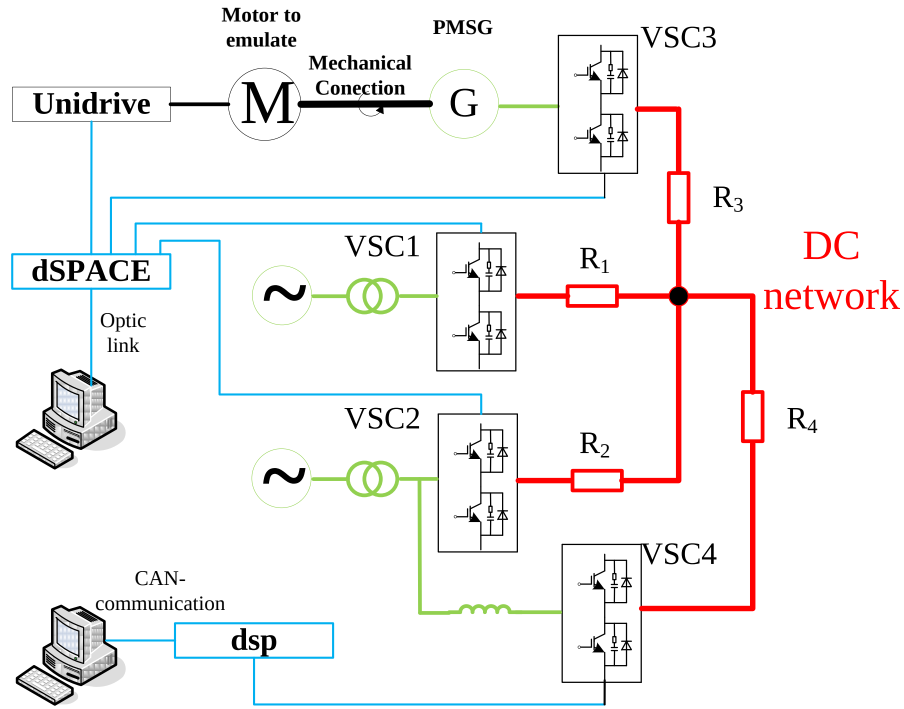
Multi-terminal VSC-HVDC test rig

Experiments using the test rig

4 Terminal Network Under Test





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Test Contents

1 Control system

- 1.1 Controller of the Wind farm side converter (VSC3)
- 1.2 Controller of the grid side converters (VSC1,2 and 4))

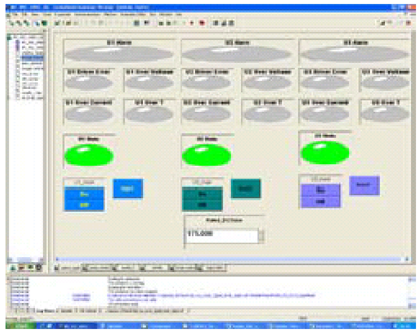
2 Tests of DC network under normal operation

- 2.1 Start-up test
- 2.2 Shut-down test
- 2.3 Test of power controller and voltage controller of VSC
- 2.4 Changing wind power and power to AC grids
- 2.5 Test of variable wind power generation, pre-defined wind power function
- 2.6 Test voltage droop controllers

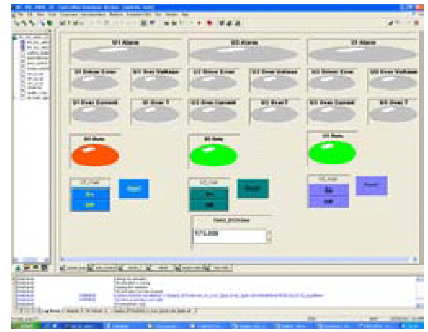
3 Abnormal Operation Tests

- 3.1 Disconnection of wind farm
- 3.2 Disconnection of a VSC in power control mode
- 3.3 Disconnection of a VSC in droop control mode
- 3.4 Transient short-circuit at an AC grid
- 3.5 Low voltage of an AC grid

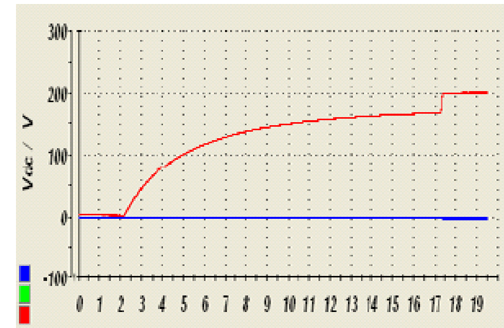
Results



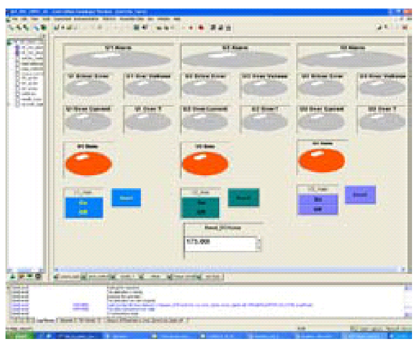
(a) VSC1,2,3 control and states



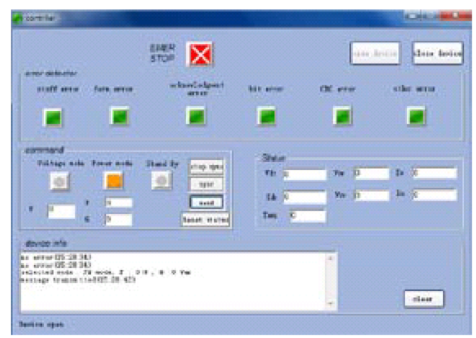
(b) Starting VSC1



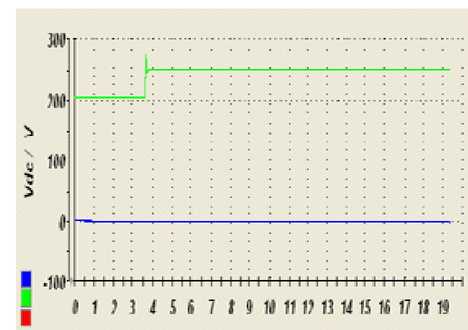
(c) DC voltage charge



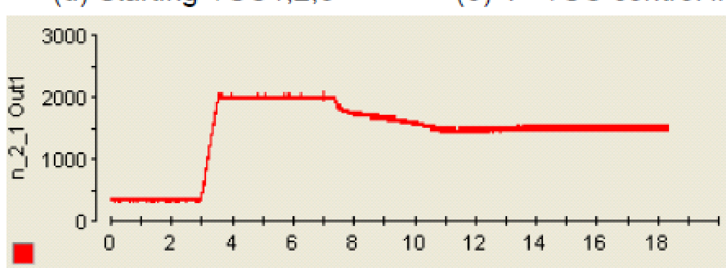
(d) Starting VSC1,2,3



(e) 4th VSC control interface



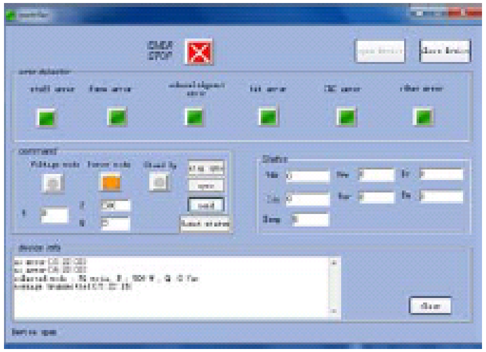
(f) DC voltage control



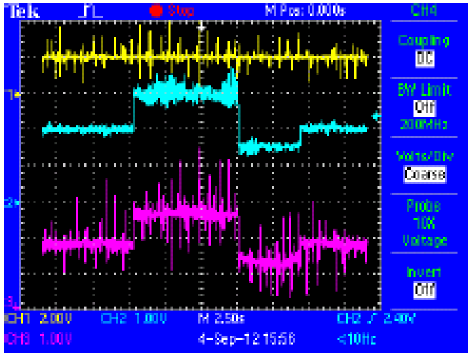
(e) start-up and speed control of the generator

Fig.4.1 Start-up of 4-terminal HVDC network

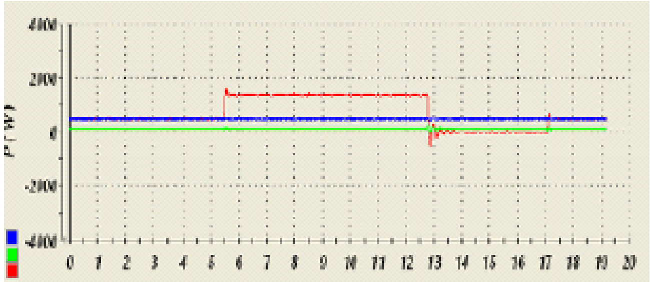
Results



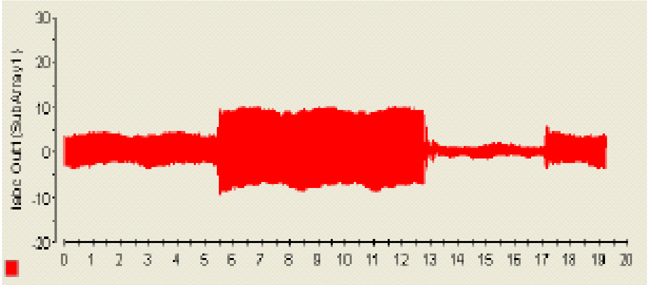
(a) Control interface of the 4th VSC



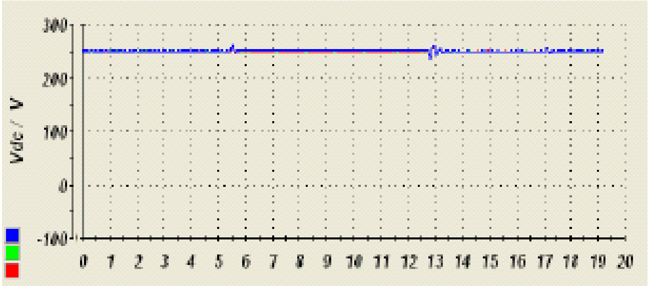
(b) DC voltage (yellow), power (blue) and current (pink) of VSC4



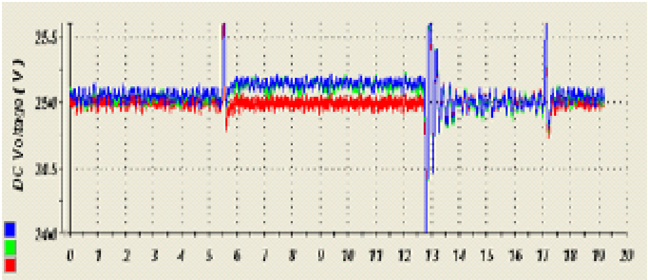
(c) Power of VSC1 (red), 2(green) and 3(blue)



(d) AC current of VSC1



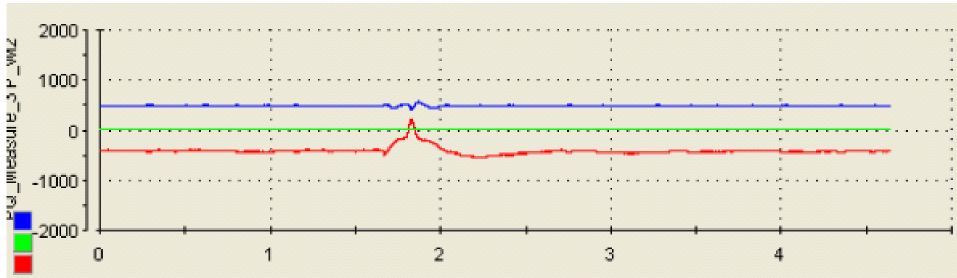
(e) DC voltages



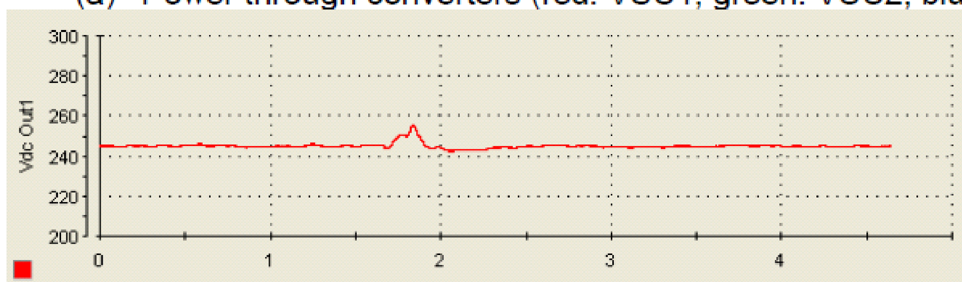
(f) DC voltage

Fig.4.4 Changes of power through the 4th VSC

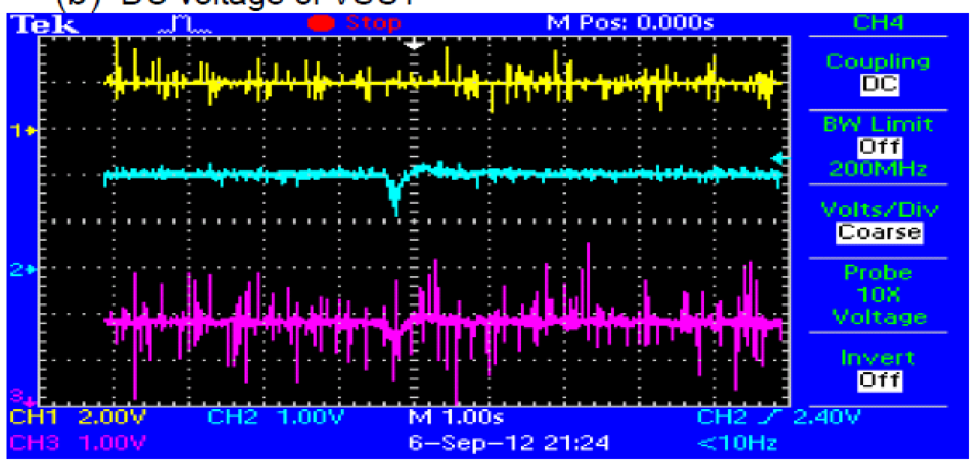
Results



(a) Power through converters (red: VSC1, green: VSC2, blue: VSC3)



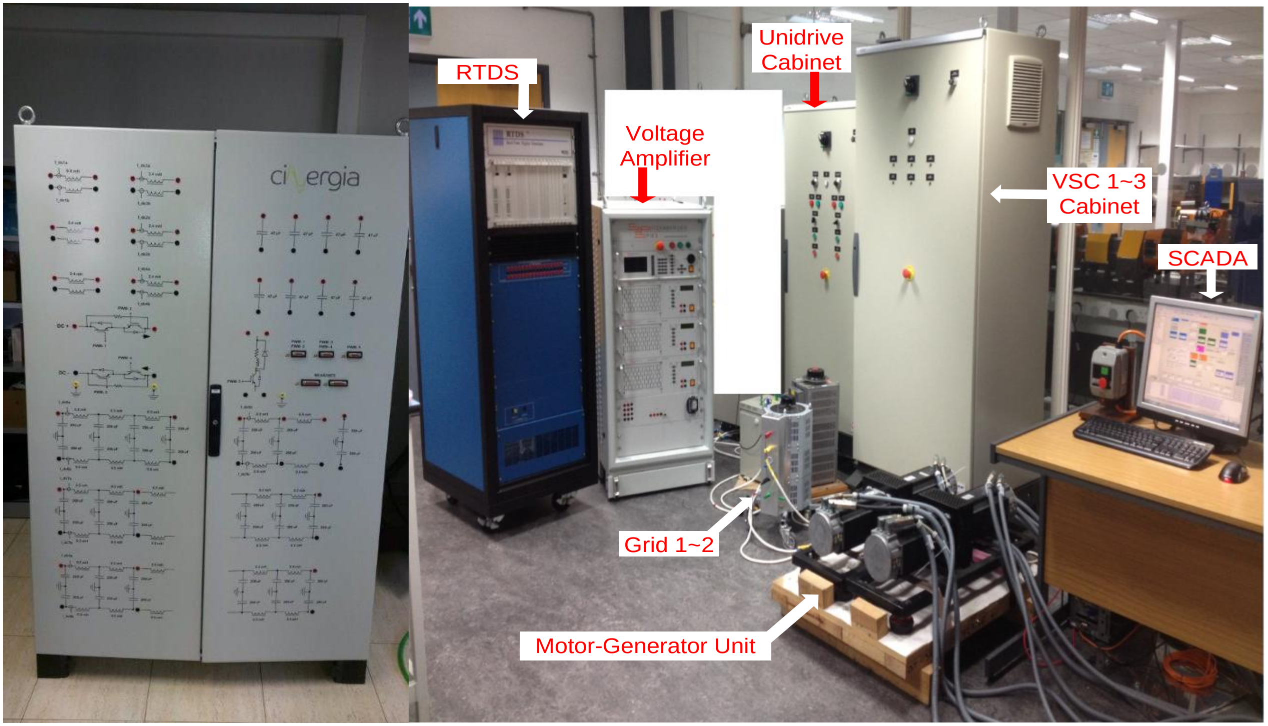
(b) DC voltage of VSC1



(c) States of VSC4 (yellow: DC voltage, blue: DC power, pink DC current)

Fig.5.6 Fault ride-through of DC network when VSC4 in droop control model

Expanding the test rig



For NGT tests:

- Meshed network;
- DC protections;
- Flexible power flow control ;
- AC frequency support from MTDC;
- AC stability control from MTDC.

Conclusions

- Tests completed successfully;
- Demonstrated the control strategies feasible;
- Identified potential problems and provided recommendations;
- Reduced risks of using MTDC;
- Provided increased confidence of NGET;
- The small scale test platform workable, and useful for various tests in future;
- Proved analogue test concept feasible.

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HVDC Operation & Standardisation

NGET0045, NGET0060

Oliver Cwikowski

Roger Shuttleworth, Mike Barnes

21 October 2014

MANCHESTER 1824

The University of Manchester

Multi-terminal VSC HVDC operation, control and AC system integration

NGET0045

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Project Overview

- **Aim**
  - Study the impact of integrating HVDC in the GB Network
- **Motivation**
  - Preliminary assessment of HVDC impact on AC grids
- **Method**
  - Modelling of the AC System (GB-like network)
  - Modelling of DC Components
  - Integration of these two models

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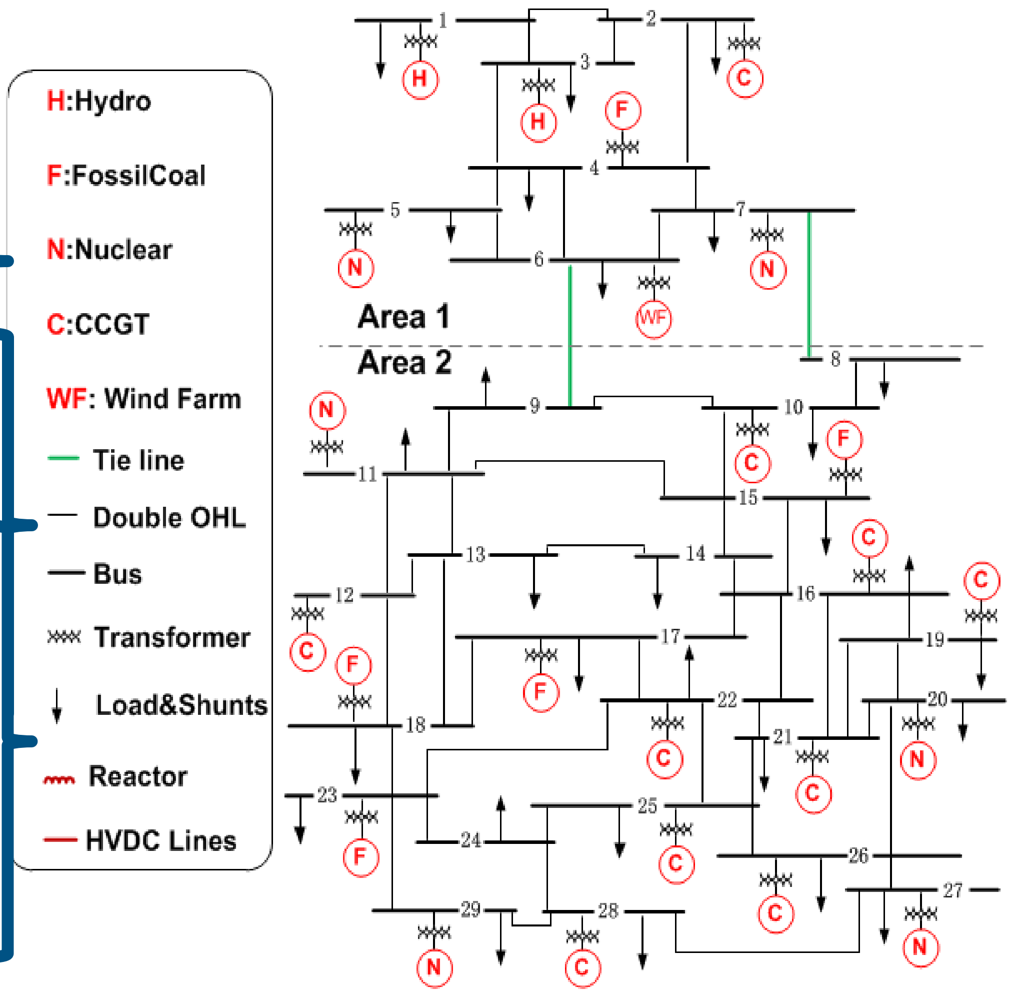
GB Network Model

HVDC Model Developed in DSPF
- Point-to-point applications.
- Multi-terminal applications.
- Structure of DC grid easily modified.
- Easily integrated with AC models.

double circuit lines and 1 single

Shunt Devices
- Mechanically switched capacitors and Static Var Compensators are represented in the model with appropriate reactive power capabilities at equivalent locations.



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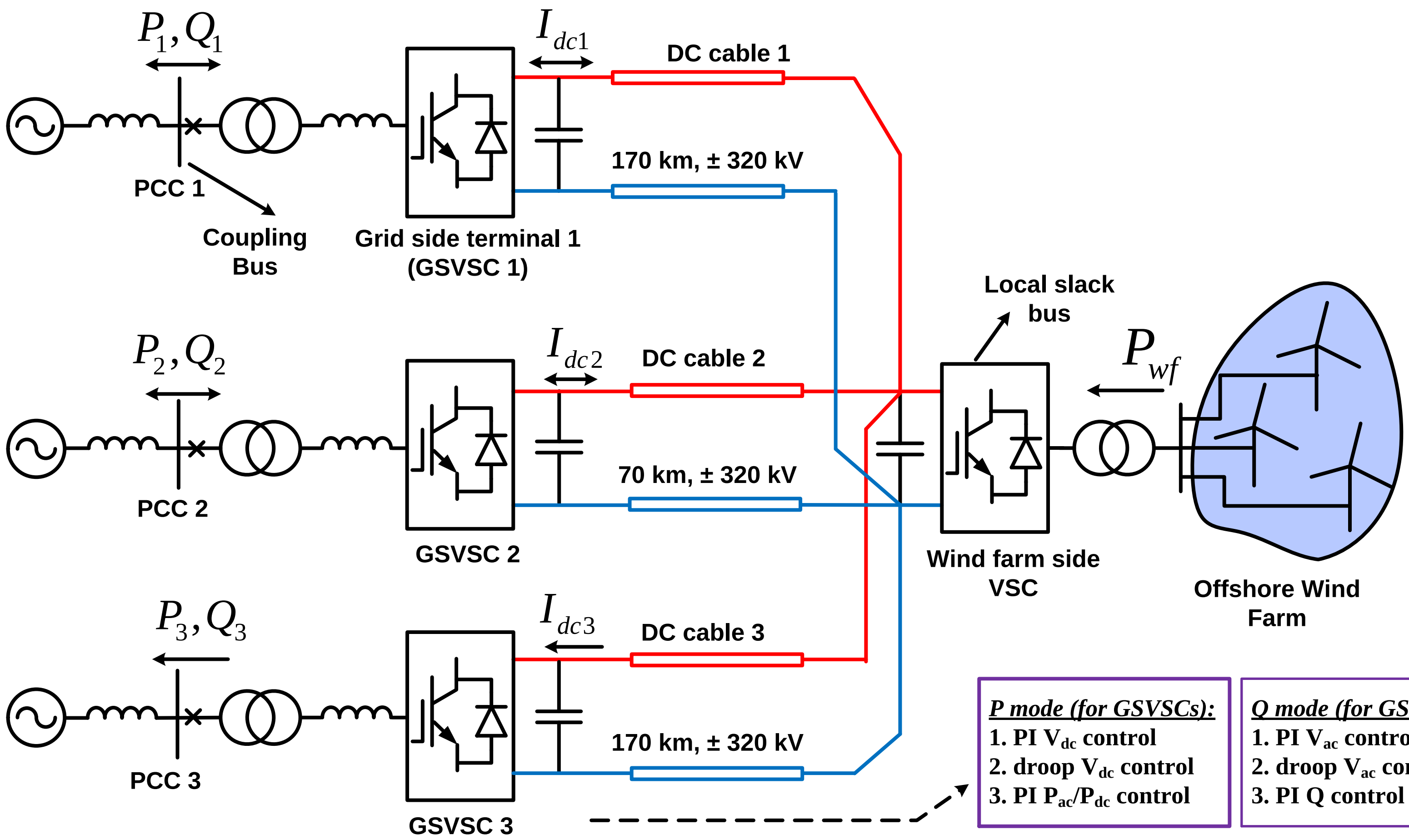
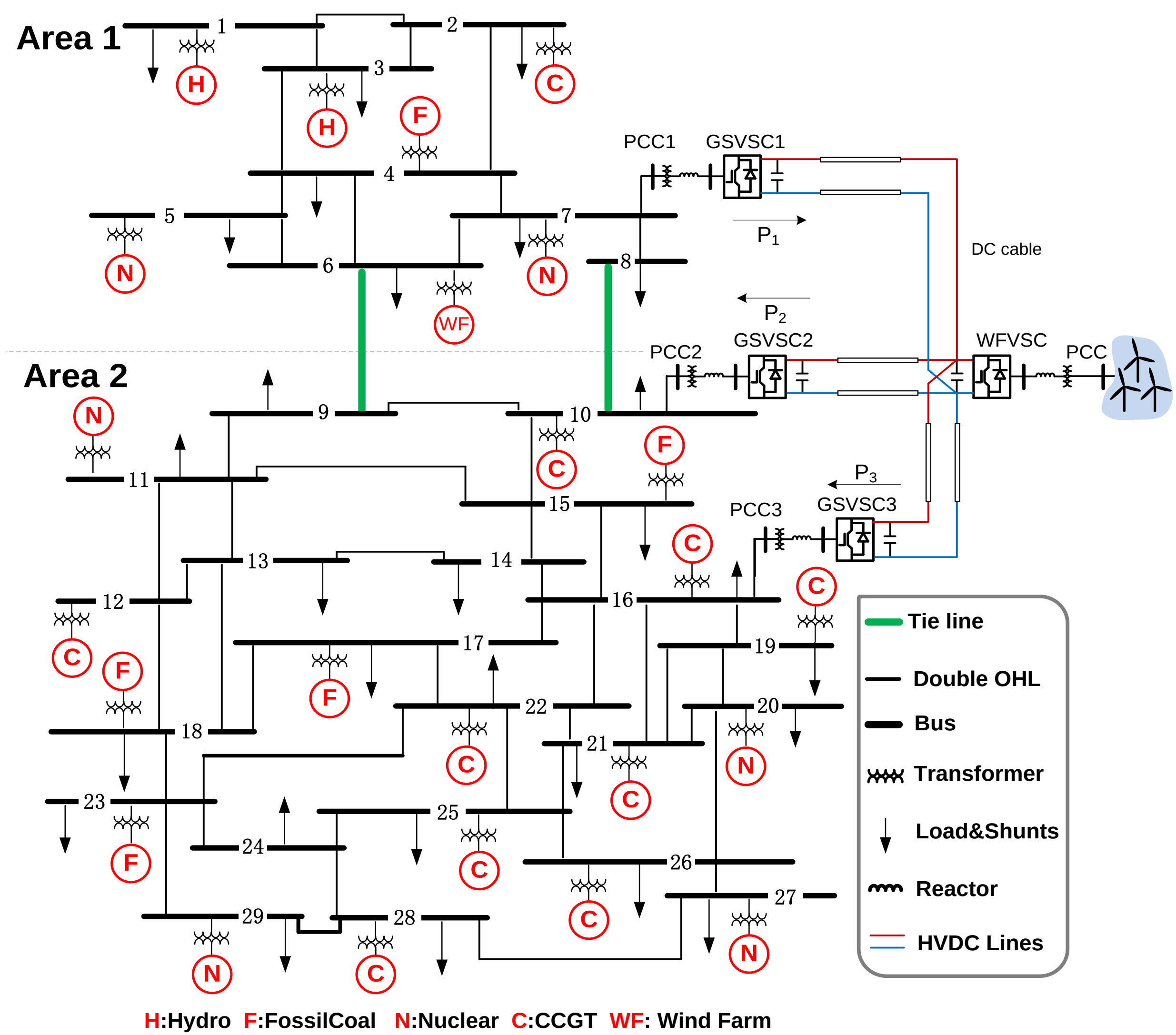
Example: 3 Terminal System



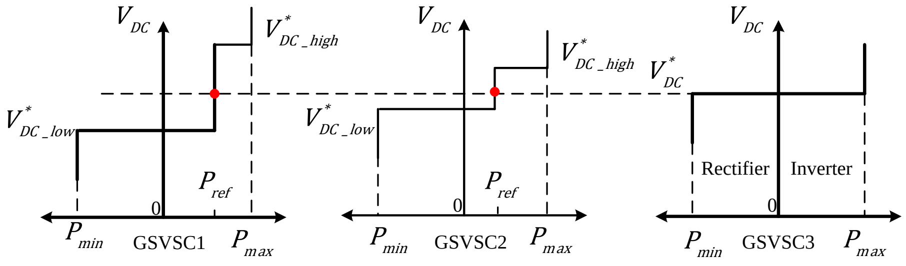
P mode (for GSVSCs):
1. PI V_{dc} control
2. droop V_{dc} control
3. PI P_{ac}/P_{dc} control

Q mode (for GSVSCs):
1. PI V_{ac} control
2. droop V_{ac} control
3. PI Q control

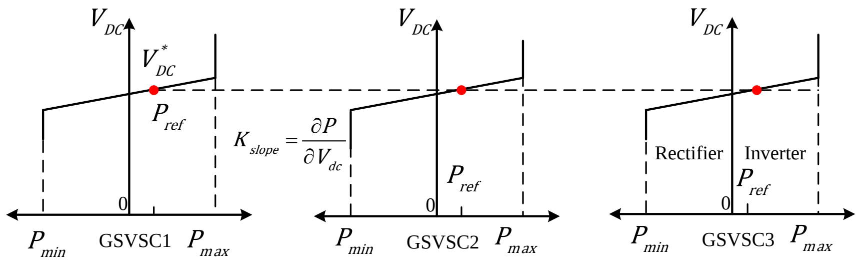
Integrated GB & MTDC



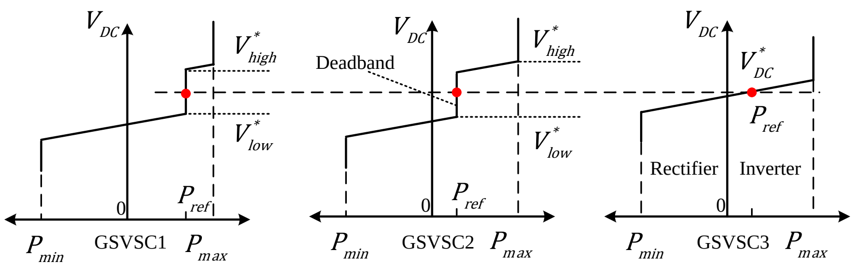
Example Simulation Results



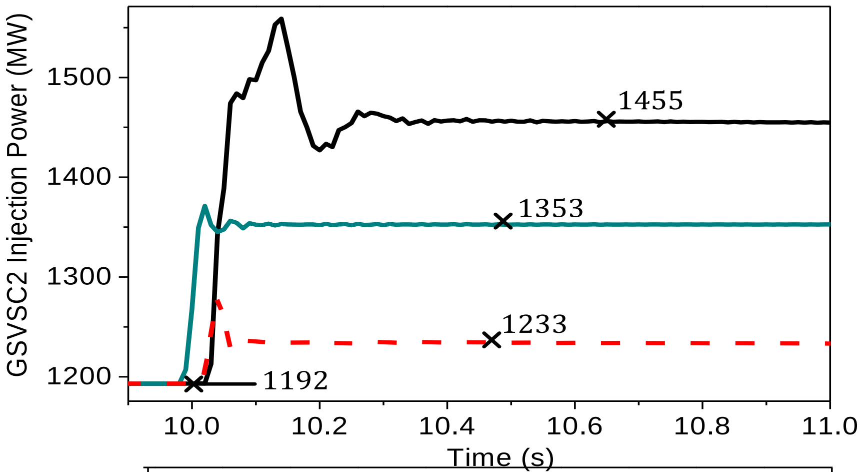
Control Scheme 1: Voltage Margin Control

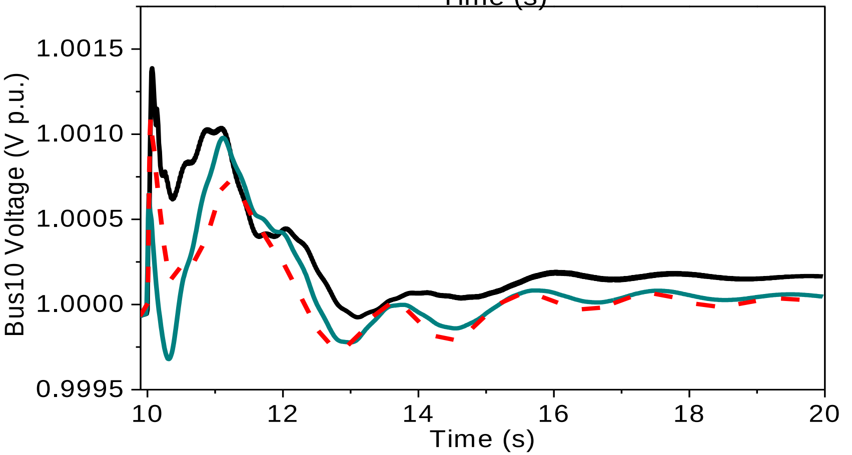


Control Scheme 2: Droop Control



Control Scheme 3: Droop Control with Dead-band





Impact of Work

Allows National Grid to:

- Assess existing VSC-HVDC models
  - Effects on ‘realistic’ system
  - Against detailed PSCAD benchmark
- Investigate improved models
- Assess the potential impact of HVDC systems
  - De-risk HVDC development
  - Assess potential problems and mitigation strategies

Application of DC Circuit Breakers in DC Grids

NGET0060

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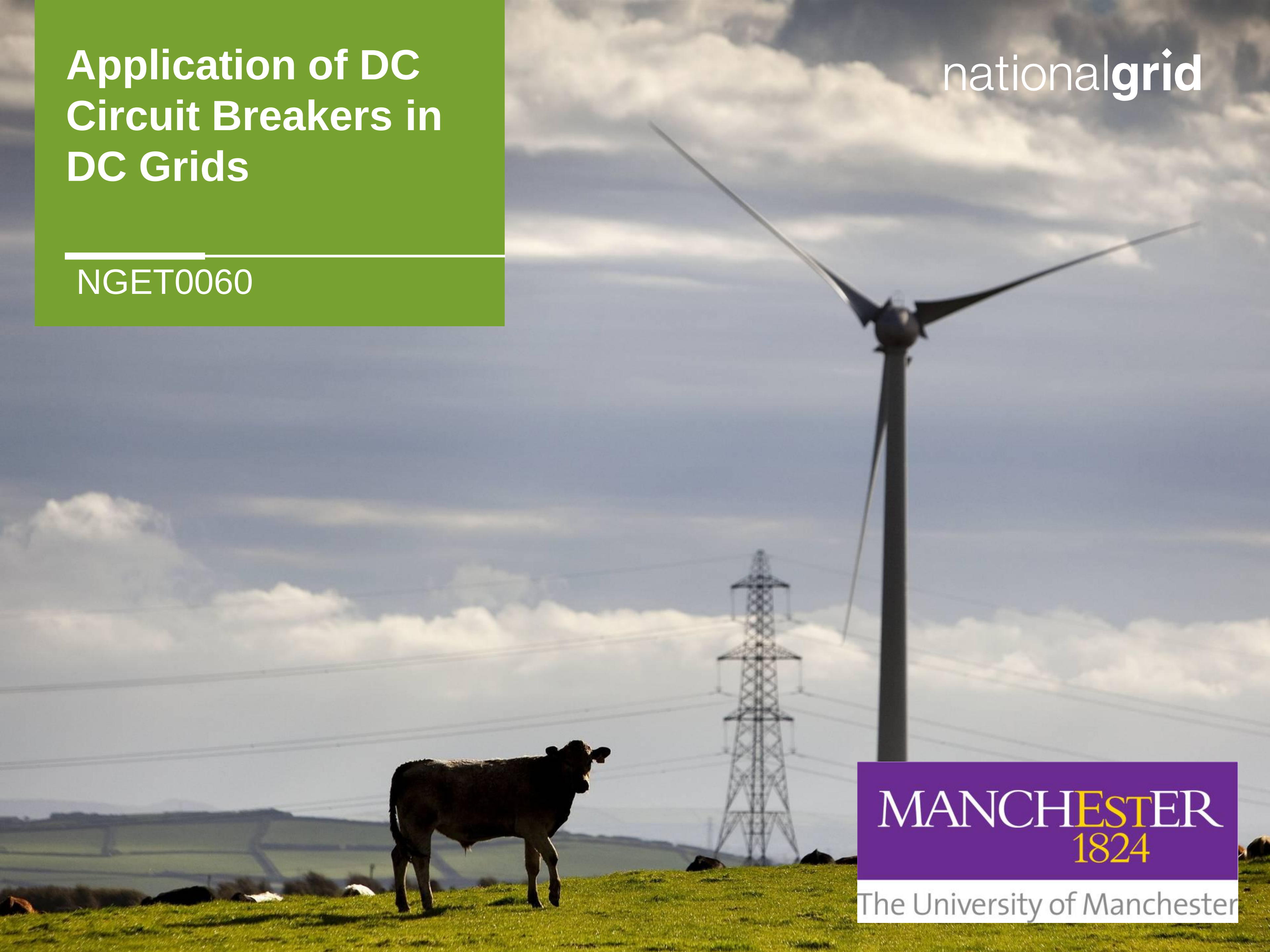

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Presentation contents

Aim

- To aid in the development of a performance specifications for HVDC circuit breakers

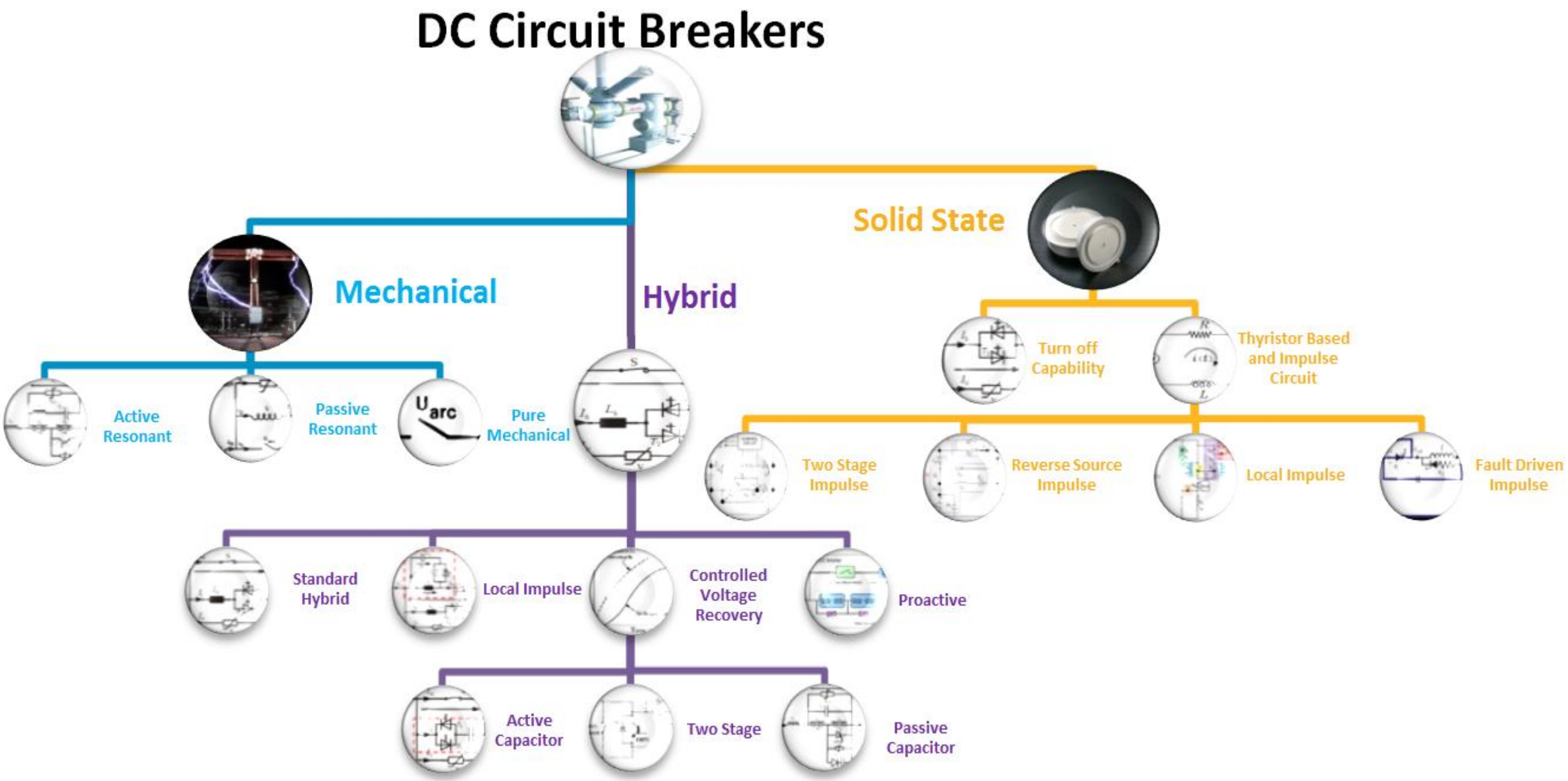
Motivation

- Short circuit protection is required to isolated sections of grid and the use of circuit breakers is one possible solution

Method

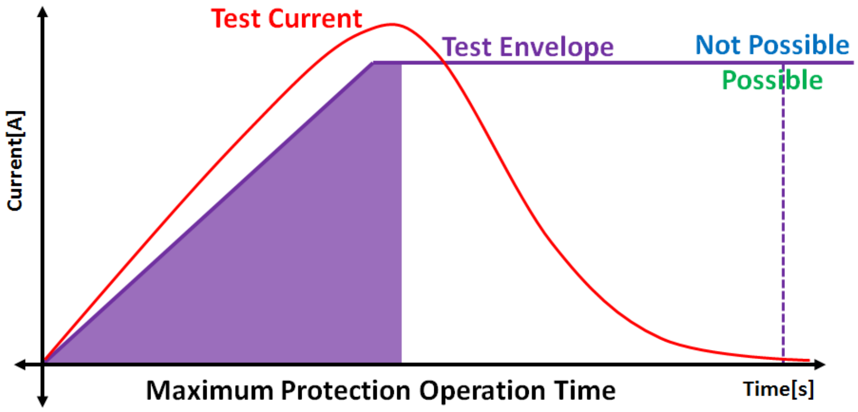
- Assess the suitability of present standards
- Develop criteria and tests
- Design and build test circuit
- Perform tests on different topologies
- Review procedure

DC Circuit Breakers

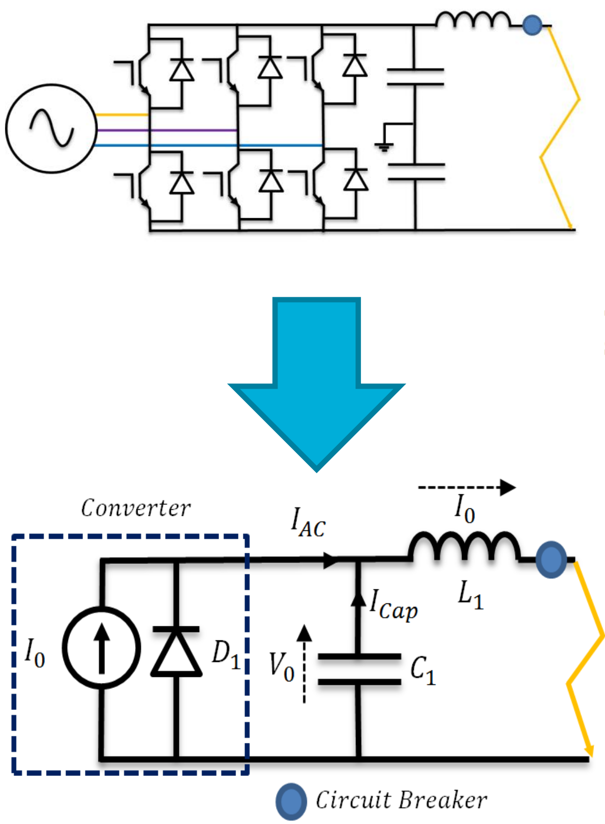


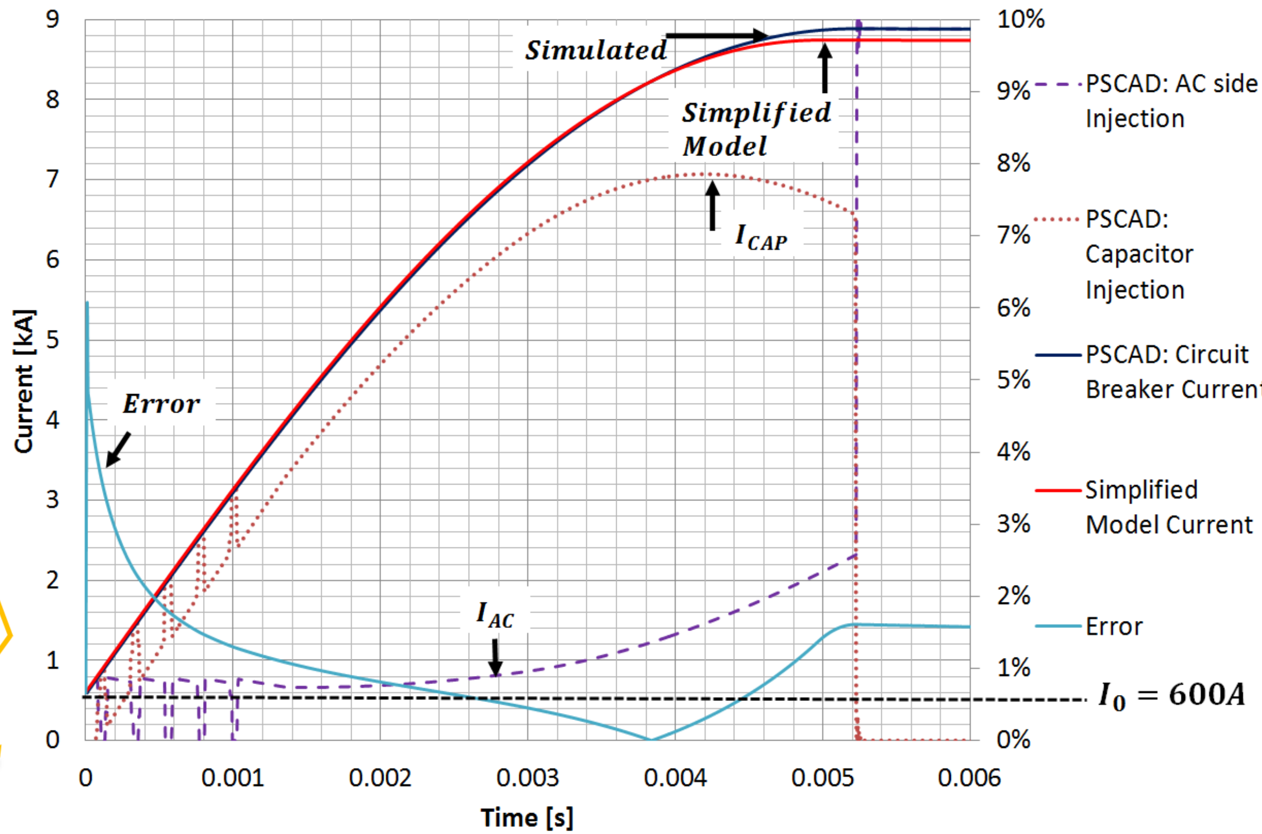
How to test them

- Direct Testing
  - Not Achievable
- Synthetic testing
  - Must cover all breaker types
  - Cover all transients (Fault and operational)
  - Be more sever than real system
- No Operational Experience
- No Standards

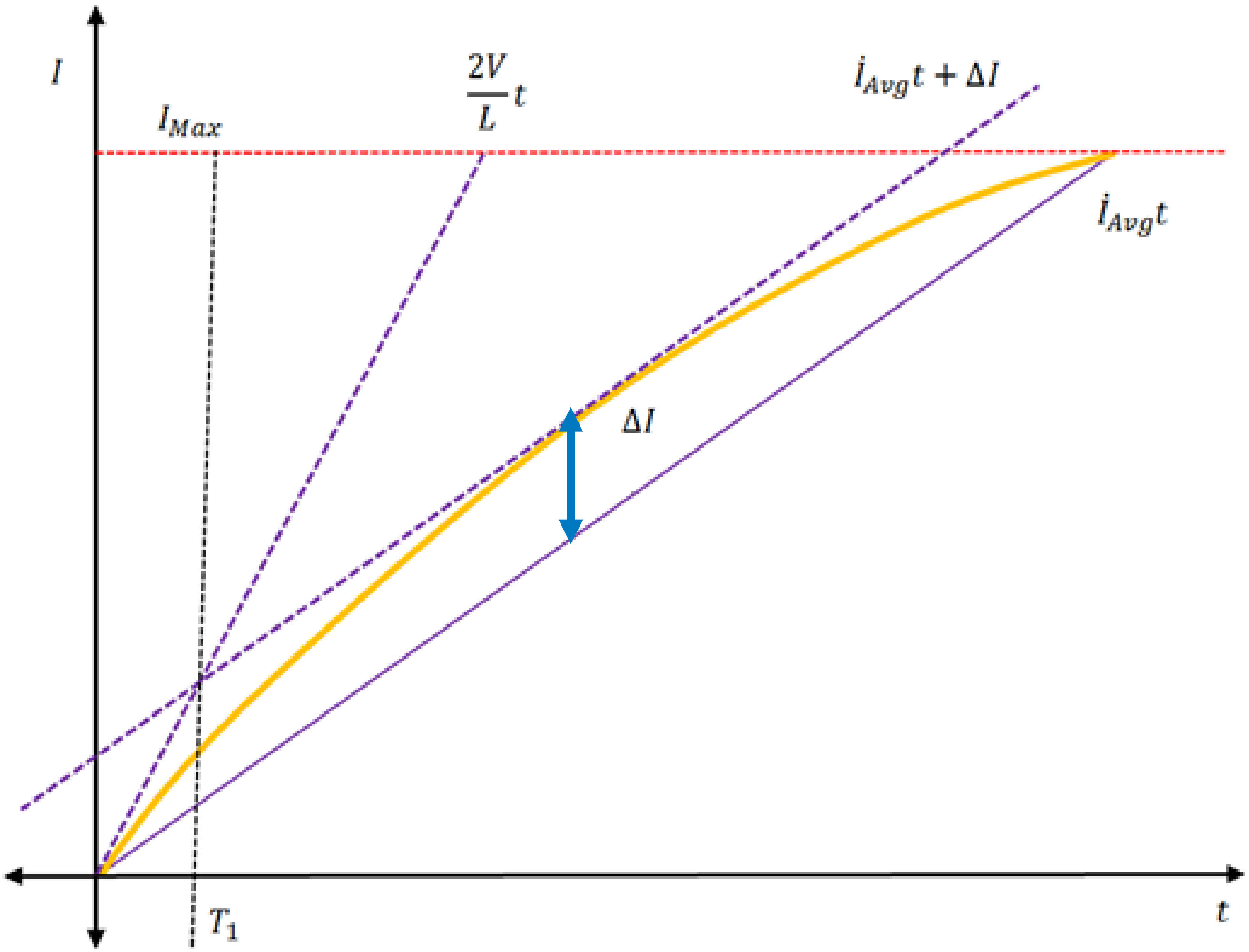


Equivalent Model

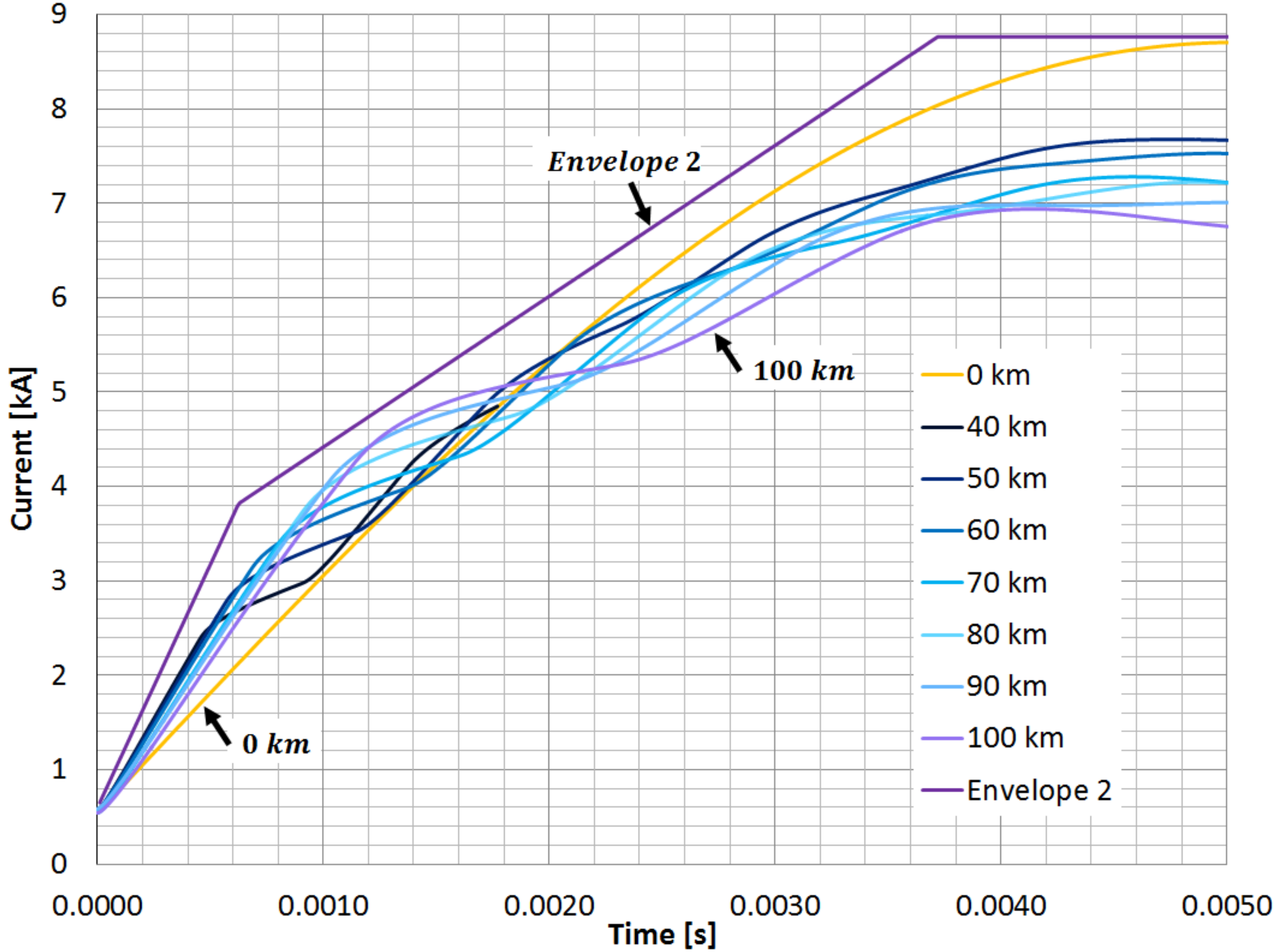




Fault Current Envelope



Pole to Ground Faults



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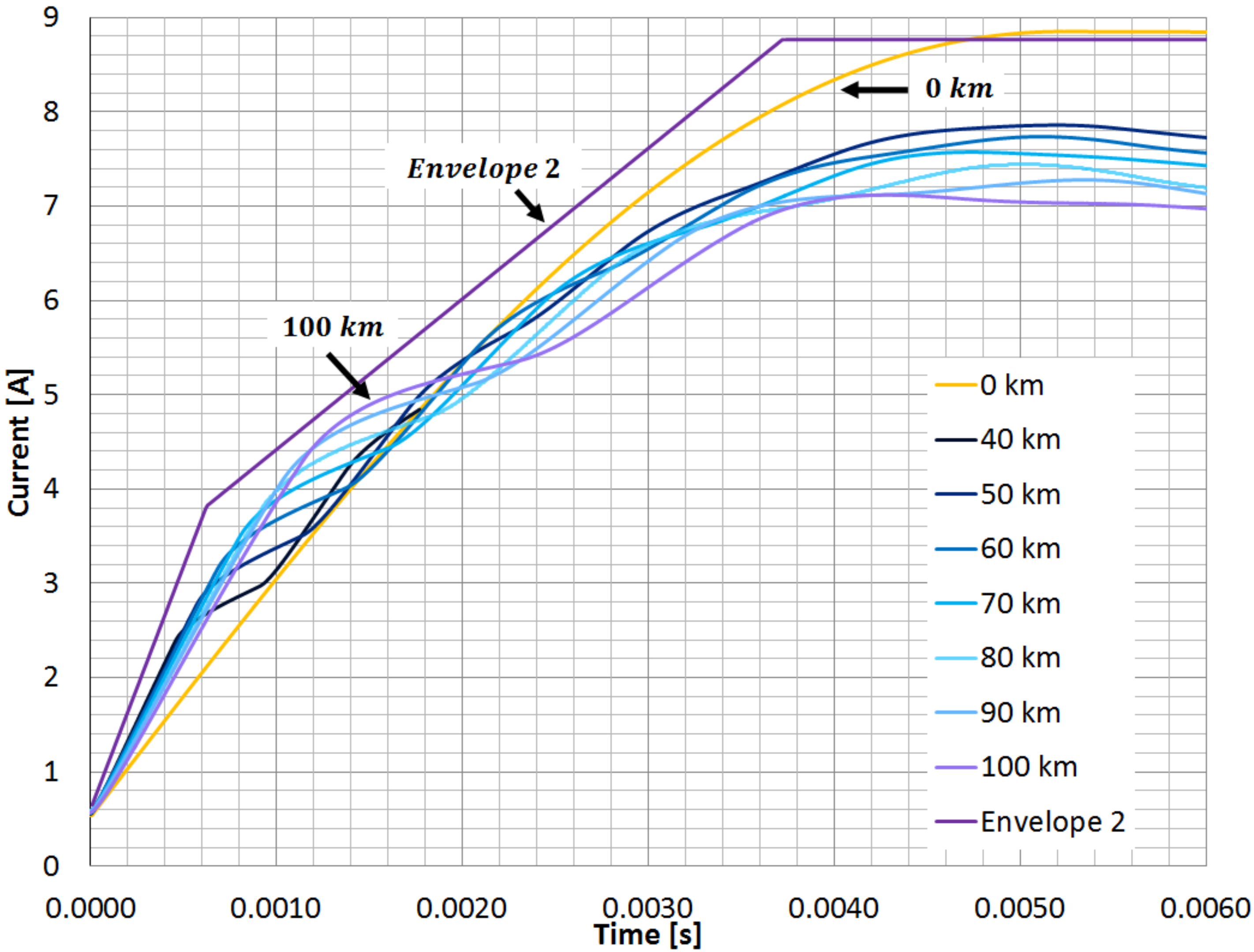
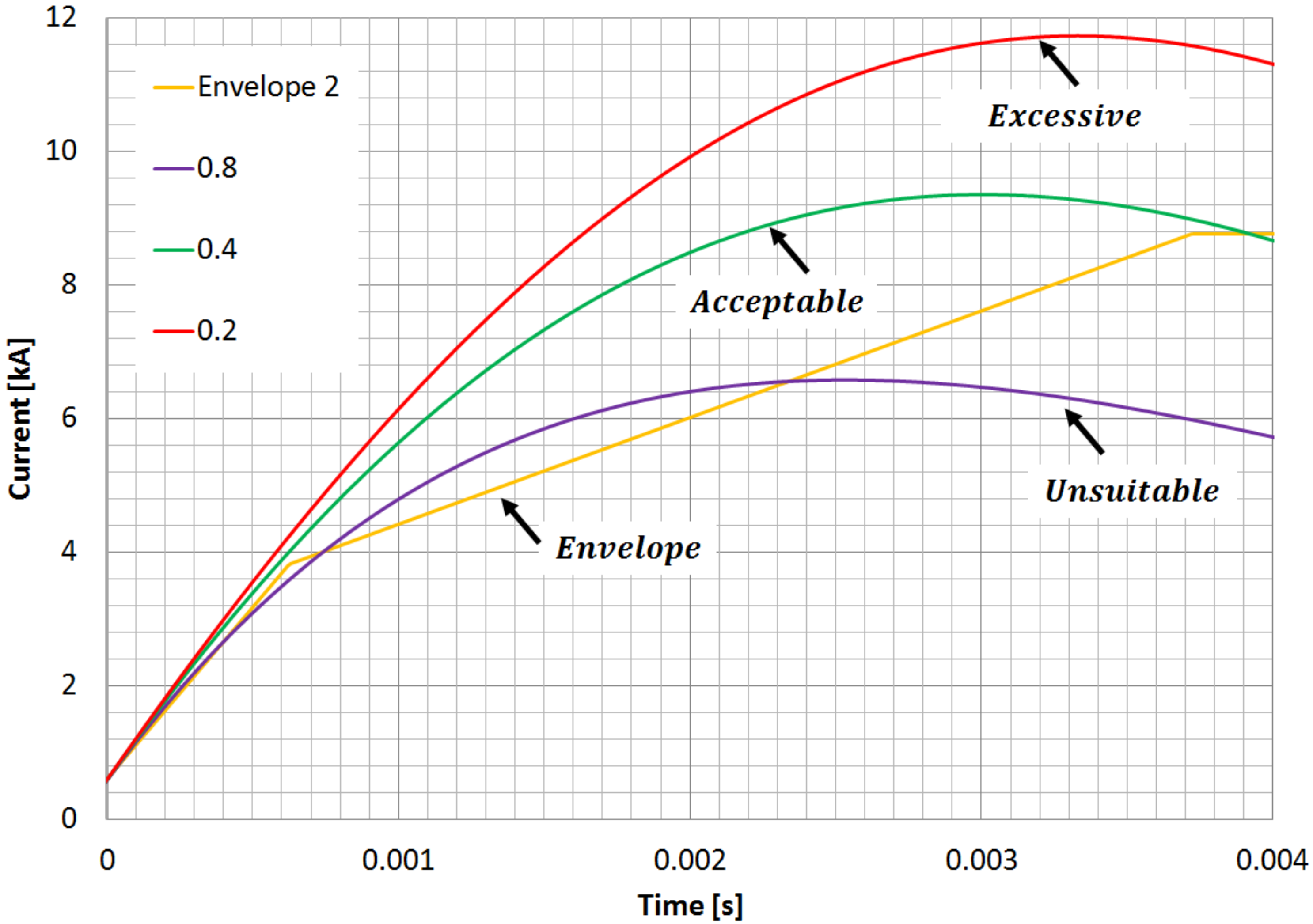
Pole to Pole Faults



Test Circuit Suitability



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Impact of Work

Allows National Grid to:

- Assess foundations for HVDC CB standards to be developed.
- Establishes benchmark for test circuit currents
- Provide background to development of HVDC CB testing methods
- Define additional criteria and tests to cover all elements of circuit breaker operation.

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Cable Decommissioning

Richard W Attwell

21 October 2014

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AC Cable Innovation Strategy

Ratings and Installation	Monitoring	Decommissioning
NGET 47 Dynamic Ratings (DROP)	NGET 15 Dinorwig Monitoring	NGET 90 Cable Extraction
NGET 82 Rating Impact (RINGS)	NGET 36 XLPE Cables	NGET 115 Cable Stripping Truck
NGET 87 Cable Installation Design	NGET 48 Long Electrical Sections	
	NGET 92 PD in Cables	
	NGET 93 Gas-in-Oil Analysis	
	NGET 103 Tape Corrosion	
	NGET 116 Combustible Gases	

NGET 150 EPRI Underground Transmission

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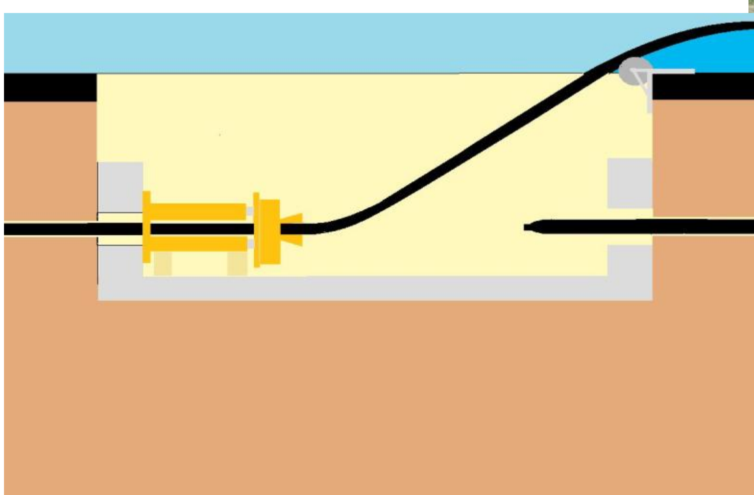
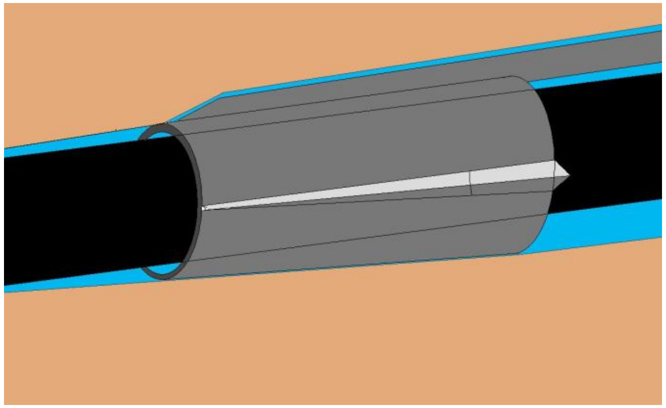
Cable Extraction: the aim

- Reduced Direct Costs e.g. through reduced planned capital expenditure on cable removal and system monitoring
- Reduce our environmental impact from legacy assets



Cable Extraction: how it works

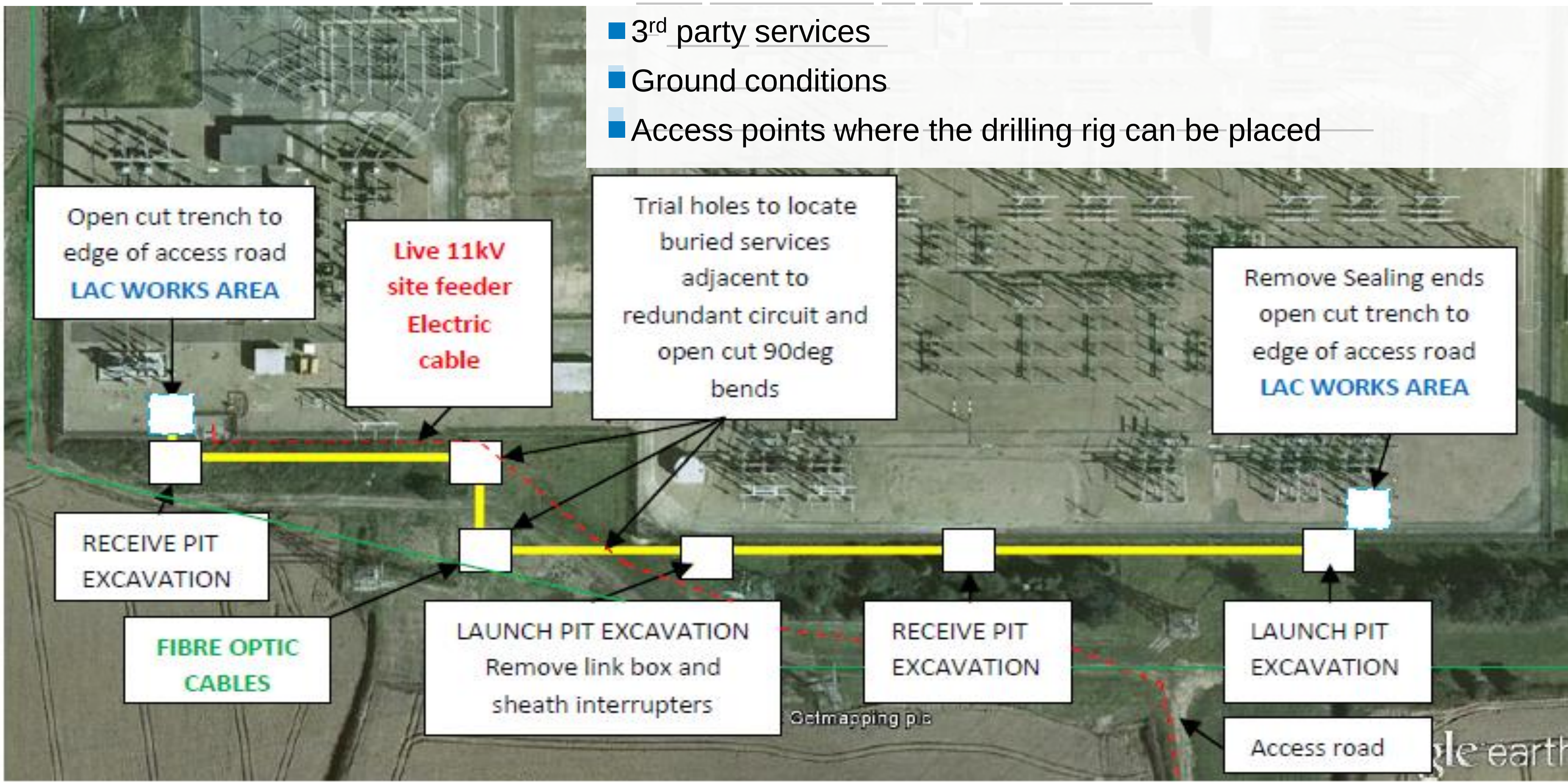
- Cable extraction utilises the directional drilling technique. A specially designed head loosens the backfill material around the cable allowing the cable to be extracted by winch or pulling device similar but opposite to cable installation



Process

1. A complete site survey is carried out on the cable route identifying

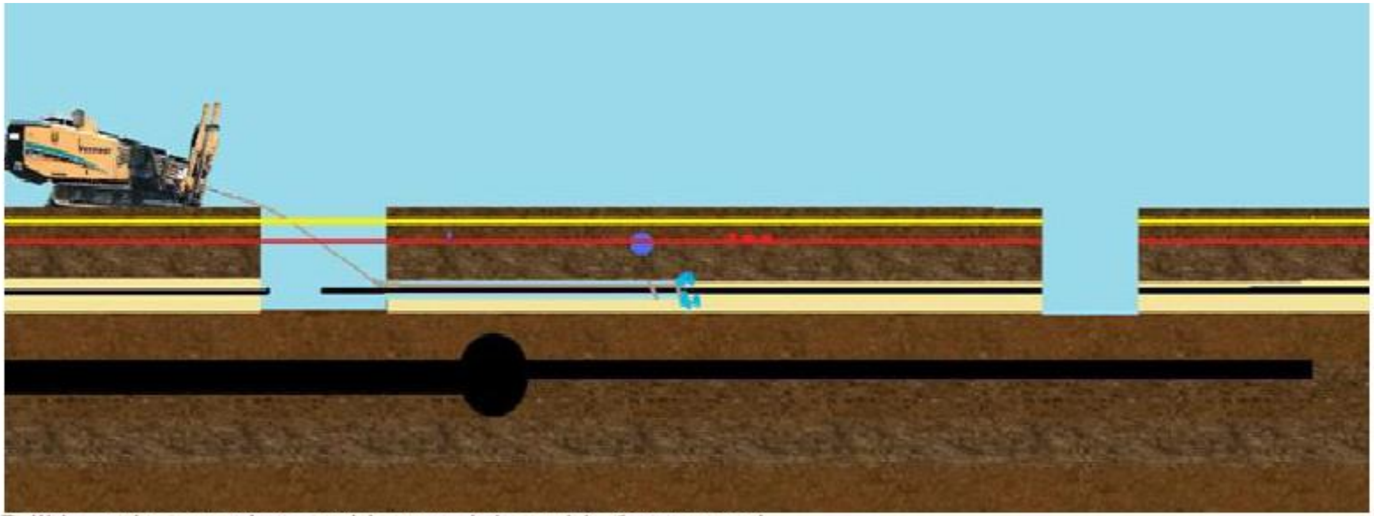
- Joint positions
- Sharp deviations in the cable route
- 3rd party services
- Ground conditions
- Access points where the drilling rig can be placed



Estimated 1200m of 275kV 1.750 Sq in cable

Cable Extraction Process

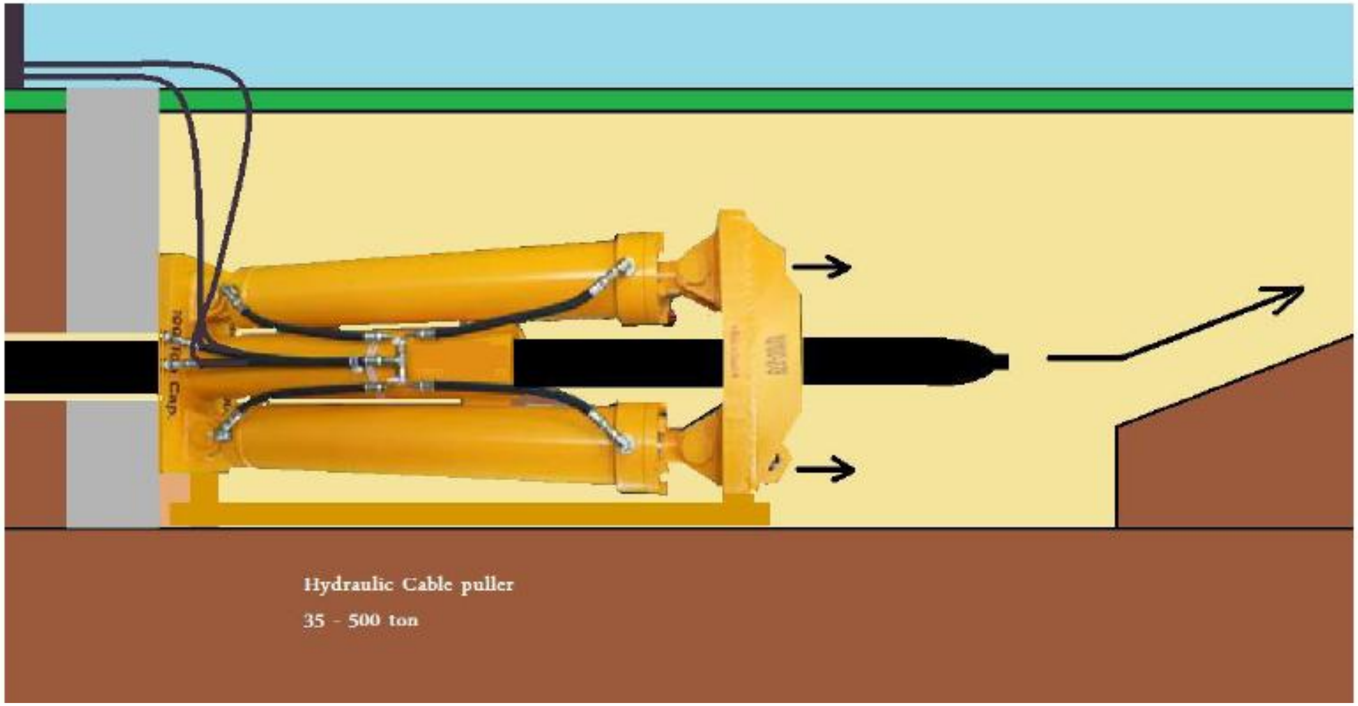
The drilling rig is placed at one of the joint position and the drilling processes carried out between joint bays or to the next excavated point where the cable changes direction



Drill in action creating a void around the cable for removal

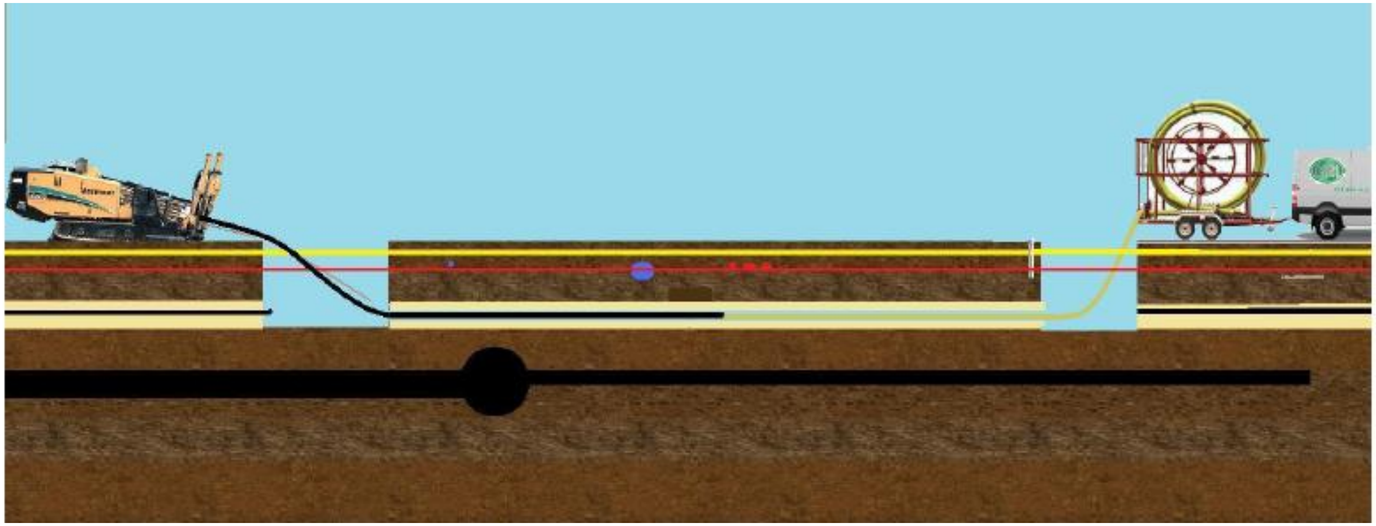
Cable Pulling Process

Once the length of cable has been freed, it will be pulled out using a 250ton hydraulically powered casing puller as used in the piling industry which incorporates a unique collet gripper system as shown below.



Back fill

- On completion of the cable extraction the void in the trench can be filled with grout or a spare duct which could be utilised for other services.
- Considerations have been made for the installation of the new cable into this void



- This has been used twice on two schemes and estimated saved £15m etc.

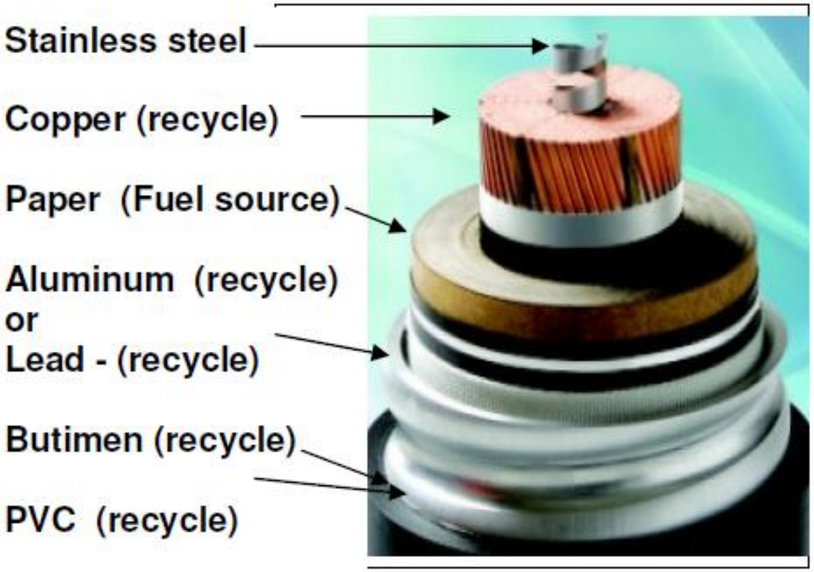
Cable Recycling

CABLE RECYCLING

When National Grid removes cable and accessories from the ground a credit is requested from the contractor for the scrap value of the materials. The value of this material or asset can never be accurately evaluated and therefore is always in favor of the contractor and the scrap metal merchant.

It is proposed that National Grid invest in developing the technology that will provide a workable design for a mobile cable stripping plant that will have the full on site capability to strip down the cable into the various components

Segregating the different cable components will all allow the metallic components to be sold at a better value with the PVC and other parts recycled or used as fuel.



Fluid Filled cable

- Copper
- Fluid Impregnated Paper
- Aluminium
- Dielectric Fluid
- Lead
- Aluminium Foil
- Tinned Copper
- Stainless Steel
- Stainless Steel
- Hessian
- Copper stranded Hessian
- Hessian with Copper Strand
- Bitumen
- PVC
- PE
- Copper Tape

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Why this Innovation

- The bulk metal components are normally universally recycled
- There are few environmental advantages to be achieved with these materials
- The key to achieving successful outcome, when recycling these cables, is to control the movement of the materials
- separation of the materials, should be carried out as close to source as possible.

The process to Value

- The separation process essentially turns the cable from a scrap item into a collection of commodities,
- These commodities can enter the open marketplace.
- The freedom to market commodities allows control over the route taken and the commercial price.
- Price for commodity materials are published on the London Metal Exchange (LME) and normally negotiated prices are quoted as a percentage or discount from the LME.

What do we do with the components

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- The copper conductors can be used in place of newly mined cathode copper by the UK's largest manufacturer of copper tubing, Mueller Europe based in the West Midlands.
- The lead material is treated similarly by companies producing lead sheet and casting materials such as Midland Lead in Derbyshire.
- Aluminium is readily accepted by Alcoa of Birmingham.
- In all of the cases above the separated material is used in place of raw material without any additional processing.
- The oil impregnated paper is currently landfilled or incinerated . It is proposed that this element is briquetted and marketed as a fuel source, this fuel can be used in Bio mass generators however some additional testing and evaluation needs to take place regarding emissions.

What do we do with the components

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- The Briquetting process liberates free dielectric fluid, which can be used directly by companies such as EOS in Cheshire
- The thermoplastics used would require further processing prior to their use as raw material alternative.
- The quantities and consistent nature of the material lend themselves to single stage granulation for blending into injection moulding alongside raw material,
- in the case of PE, PP and PVC it is expected to be In excess of 50% recycled granulate to raw material in certain cases.