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# Voltage Source HVDC - Overview

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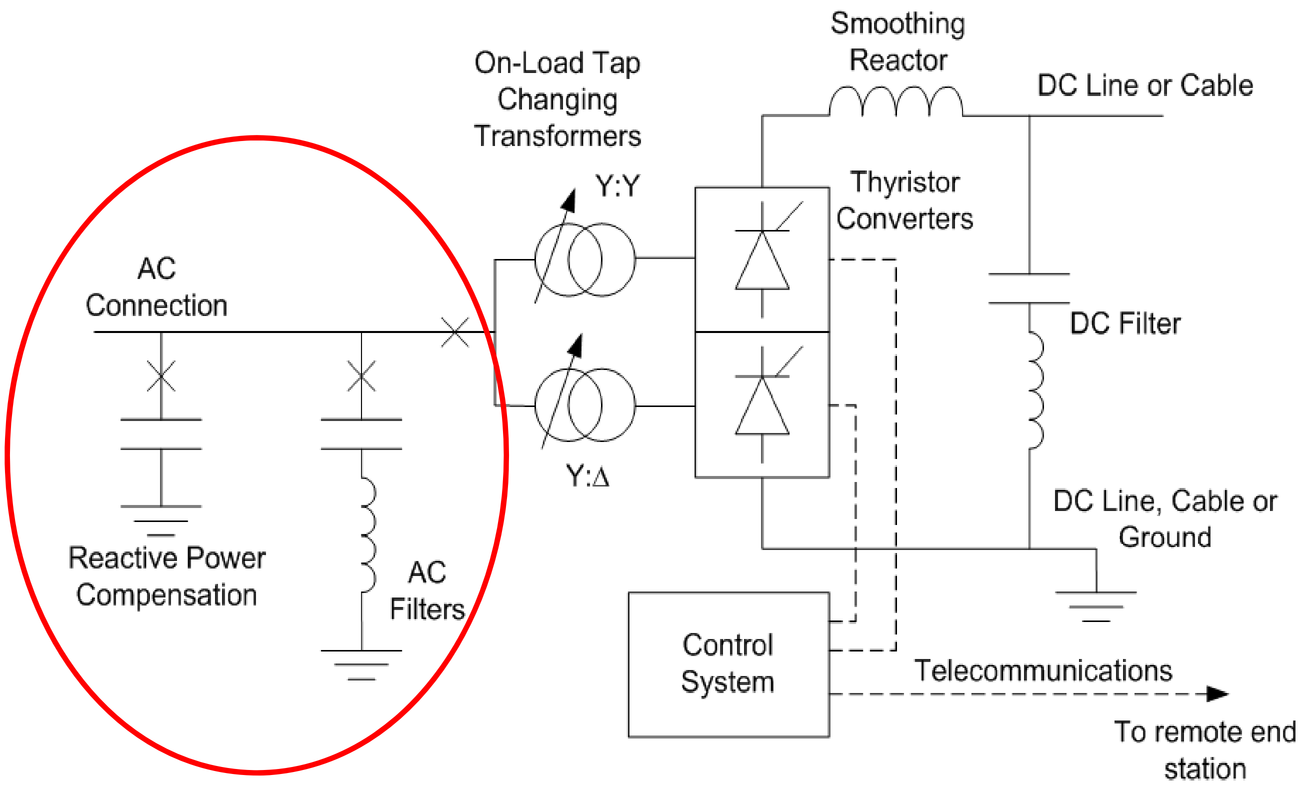
# AC vs DC

| Issue | AC | DC |
|---|---|---|
| Voltage conversion | Transformers | Power electronics |
| Protection | Current and voltage fall to zero twice per cycle | Breakers complex |
| Transmission distance | Limited by reactive power consumption | No Reactive power requirement (on DC side) |
| System cost | Cheap terminal cost<br>Line or cable more expensive per mile | Expensive terminal<br>Cheaper line or cable cost per mile |
| Space requirement | Lower terminal footprint<br>Greater line footprint | Greater terminal footprint<br>Lower line footprint |
| Interconnected systems | Must have same frequency and phase | Asynchronous connection |

In early 20$^{th}$ Century technology available meant AC was preferred for transmission

# Revival of DC High Voltage Transmission




- Initially Current Source (thyristor based)
  - Large station footprint
  - Strong AC system needed

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# Operation:

- Thyristor control delays current flow  with respect to input voltage

- Phase shift controls real power flow (P)
- Phase shift draws large amounts of reactive power (Q)

# Current-Source (CS) or Line-Commutated Converter (LCC) Examples

- Yunnan-Guangdong (2009)
  - 5000MW, +/-800kV Bipolar
  - 1418km
- Three Gorges (2004)
  - 3000MW, +/-500kV Bipolar
  - 940km
- Melo (2011)
  - 500MW, Back-to-Back

# However:

•Need to connect vast amounts of offshore wind

•Need to interconnect more networks, even those unsynchronised

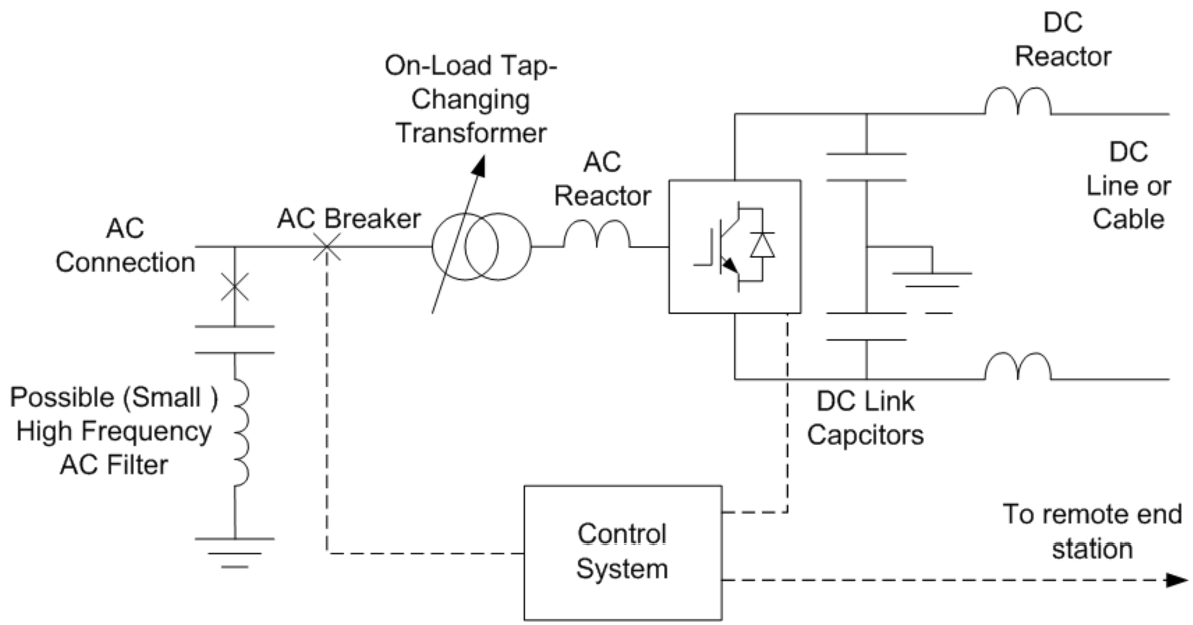
Issues with CS-HVDC:

• Station footprint

•Need for ‘strong’ AC network to connect to

•Needs to use mass-impregnated oil cable

# New Power Generation / New Solution - Voltage Source (VS) HVDC




- Main advantages of VSC over CS:
  - Smaller footprint (offshore platform cheaper)
  - Power direction in cable changed by current (keep same polarity V, use cheaper XLPE cable)
  - No need for reactive power generation to supply converter

# Evolution of VSC-HVDC Technology

| Technology | Year first scheme commissioned | Converter Type | Losses per converter (%) | Switching frequency (Hz) | Example Project |
|---|---|---|---|---|---|
| HVDC Light 1st Gen | 1997 | Two-Level | 3 | 1950 | Gotland |
| HVDC Light 2nd Gen | 2000 | Three-level Diode NPC | 2.2 | 1500 | Eagle Pass |
| | 2002 | Three-level Active NPC | 1.8 | 1350 | Murraylink |
| HVDC Light 3rd Gen | 2006 | Two-Level with OPWM | 1.4 | 1150 | Estlink |
| HVDC Plus | 2010 | MMC | 1 | <150* | Trans Bay Cable |
| HVDC MaxSine | 2014IP | MMC | 1 | <150* | SuperStation |
| HVDC Light 4th Gen | 2015IP | CTL | 1 | =>150* | Dolwin 2 |

*switching frequency is for a single module/cell.

# CS vs VSC HVDC

- Current Source – HVDC – Available since 1950's
  - Loss 0.8% per converter station
- Voltage Source Converter – HVDC
  - Loss 1.1% per converter station
  - Much smaller footprint
  - Newer technology (since 1997)

# First Offshore Installation

- Troll
  - 1&2 – 88MW (2005), 3&4 – 100MW (2015)
  - +/-60kV DC, 70km
  - 132kV AC on shore to 56kV or 66kV offshore

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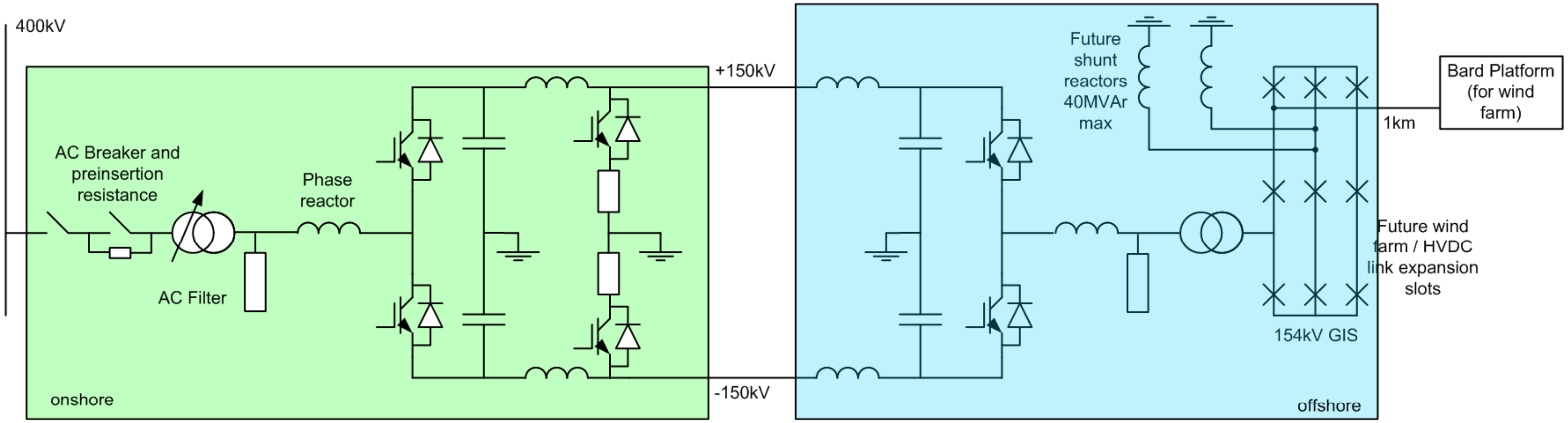
# First Offshore Windfarm: BorWin1 2009

-First wind farm installation: BorWin1=80x5MW turbines
-ABB 2-level converter
-Only existing offshore VSC-HVDC windfarm connection

**Cable data**

| | |
|---|---|
| Voltage | +/-150 kV DC |
| Power | 400 MW |
| Insulation | Polymeric HVDC Light |

# BorWin1 - Design




Design for maximising availability and minimising maintenance:

-DC choppers onshore

-No tap-changing transformer offshore

-Planned in service date 2009/10.

# First Multi-Level Converter

- Trans Bay Cable - 2010
  - First MMC Multilevel system

# Issues

- Many, but key issues include:
  - Multi-terminal control
  - Breakers
  - Availability
  - Cable Modelling

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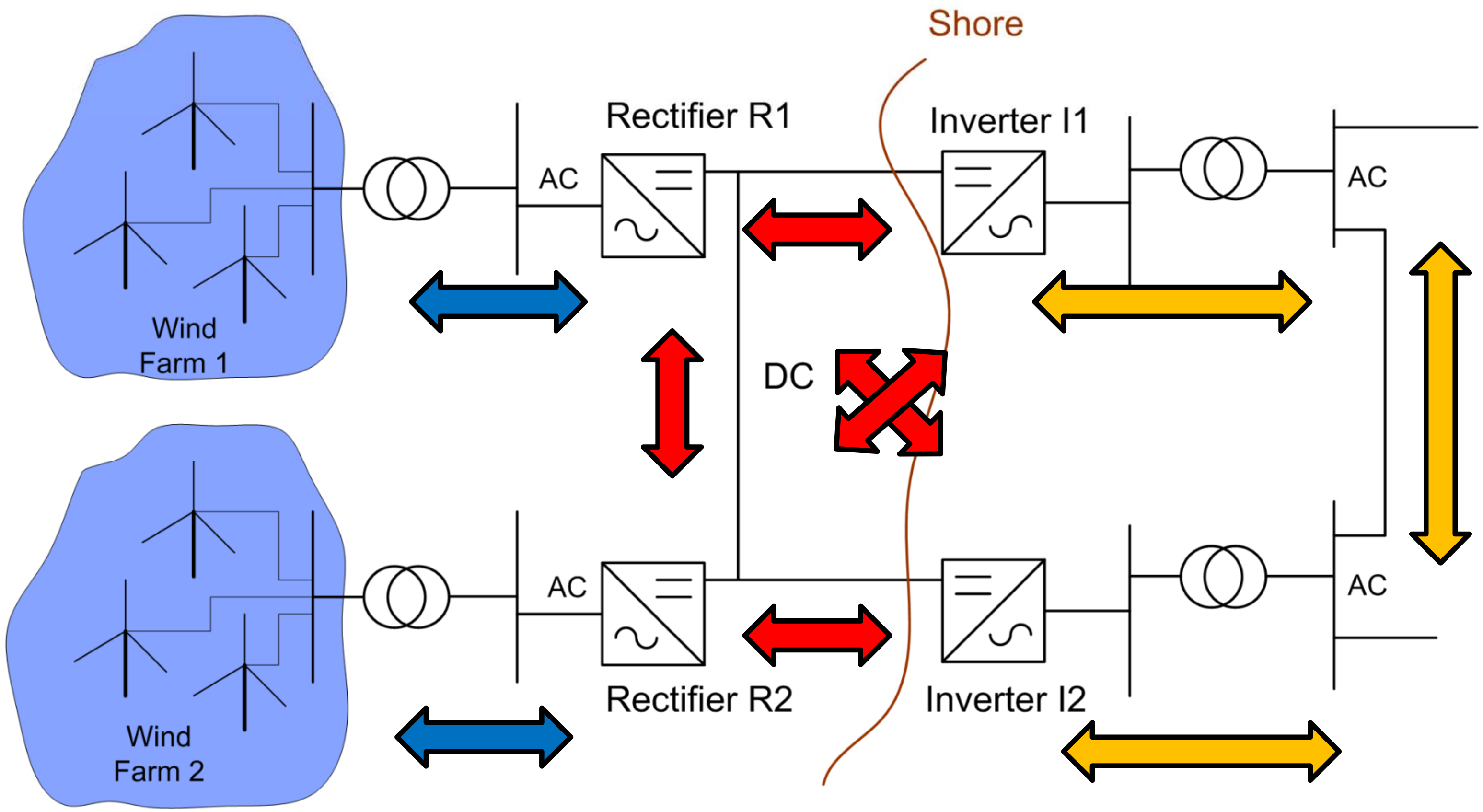
# 2. Multi-Terminal Control




- How to control?
  - Levels / hierarchy / software algorithms
- Hardware to facilitate control

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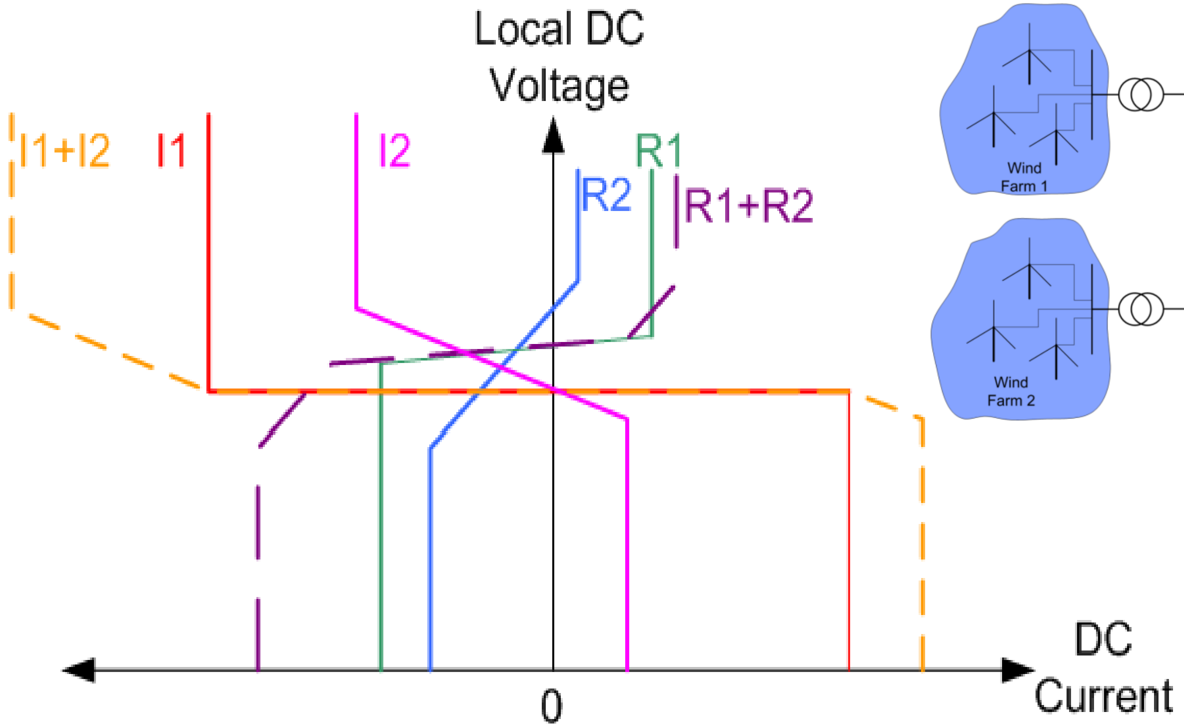
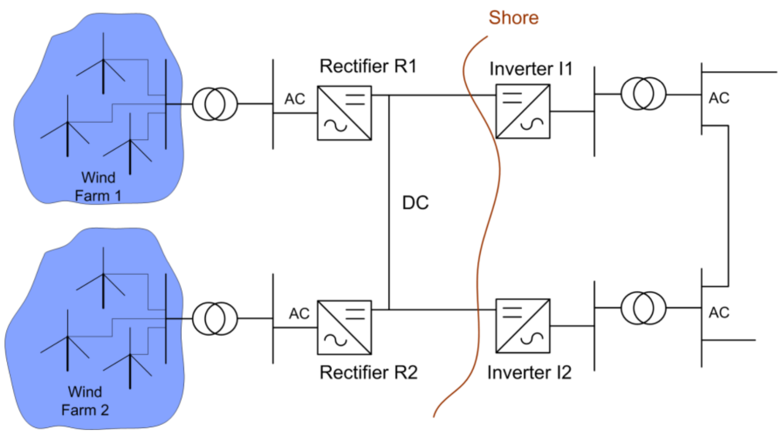
# Prior Art

- Shin-Shinano
  - 50MVAx3 back-to-back GTO VSC-HVDC
- SACOI CS-HVDC 3-terminal link
  - 200MW/50MW/200MW
- Hydro-Quebec
  - CS-HVDC
  - Planned at 5-terminal, installed as 3
  - Most usually run effectively as point-to-point

# Present proposed control




- Local droop-line control at each station
- Super-imposed master-slave central control (telecommunications)

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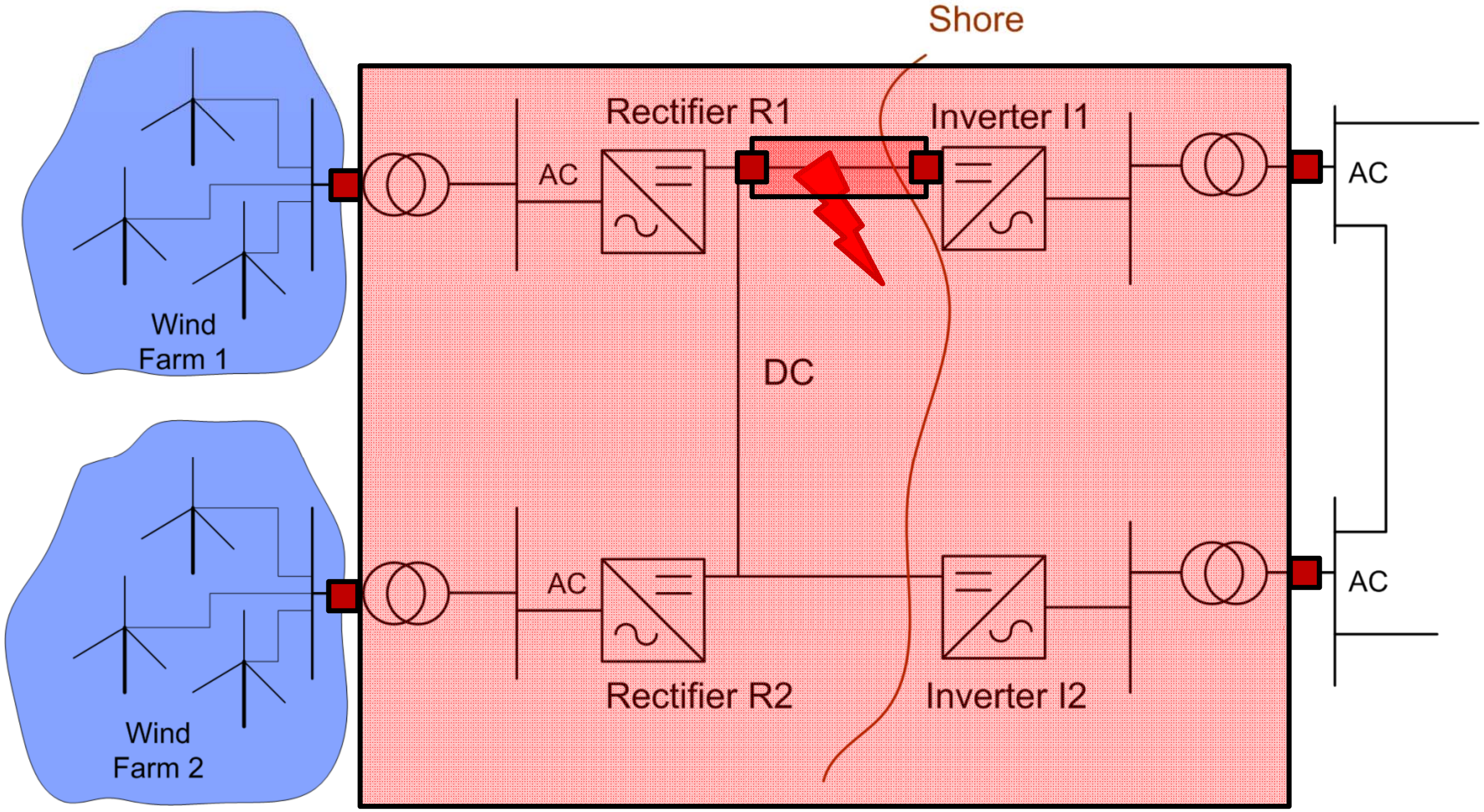
# However

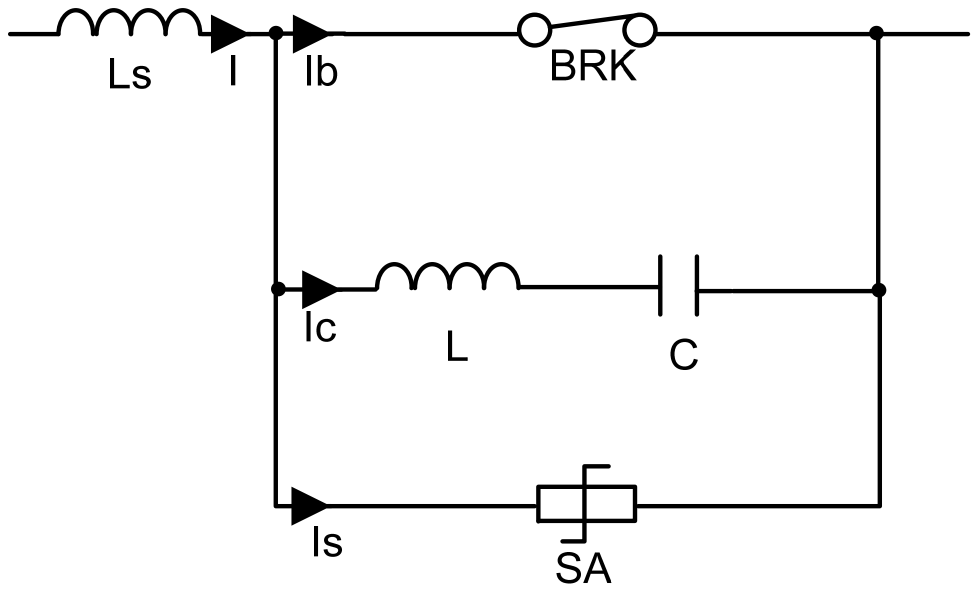
- No operational experience with VS-HVDC multi-terminal systems which are:
  - large scale
  - not co-located
- Planned systems:
  - Tres-Amigas – Texas
  - Scotland-Shetland Offshore
  - North Sea in Europe
  - Atlantic Offshore Wind Connection

# Circuit Breakers




- How to manage DC fault?
  - No DC circuit breakers
  - Faults cleared on AC side (at present)

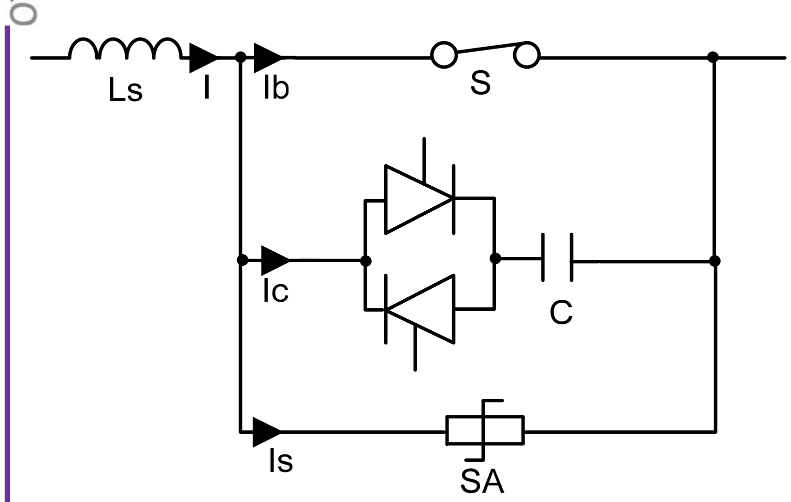
# 3. Breakers Available - Limited

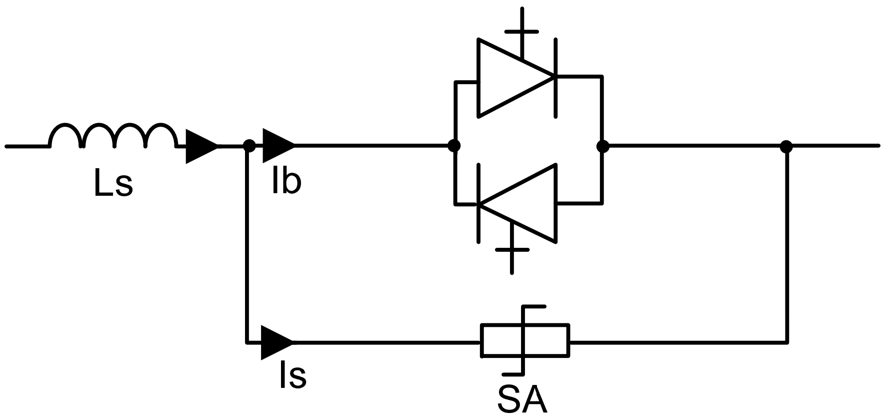



- Passive Resonance Breaker
  - Test designs constructed
  - Relatively low interruption speed
- Based on Metallic Return Transfer Breaker in CS-HVDC
  - Full Current, Limited Voltage

# HVDC Breaker Review

- Preferred topologies



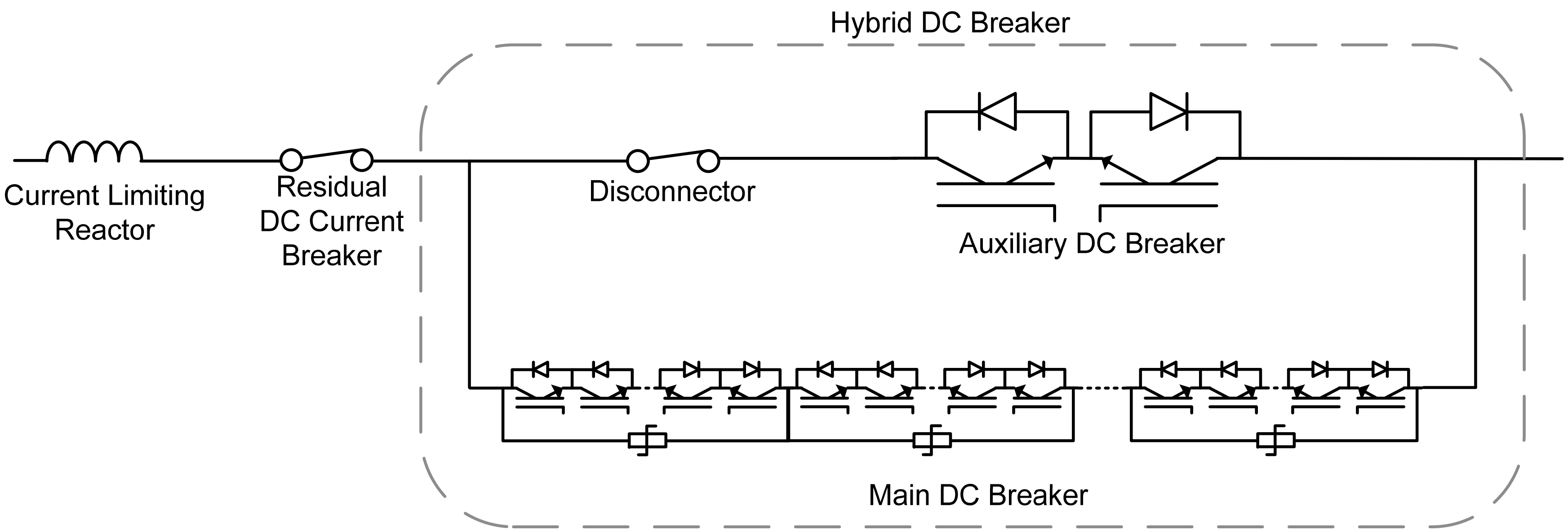

## Hybrid Circuit Breaker

- Low on-state losses
- Relatively slow interruption speed

## Solid-state Circuit Breaker

- High on-state losses
- Fast Interruption speed

# ABB Patent




- Medium Voltage Prototype Built

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# 4. HVDC Cable Modelling

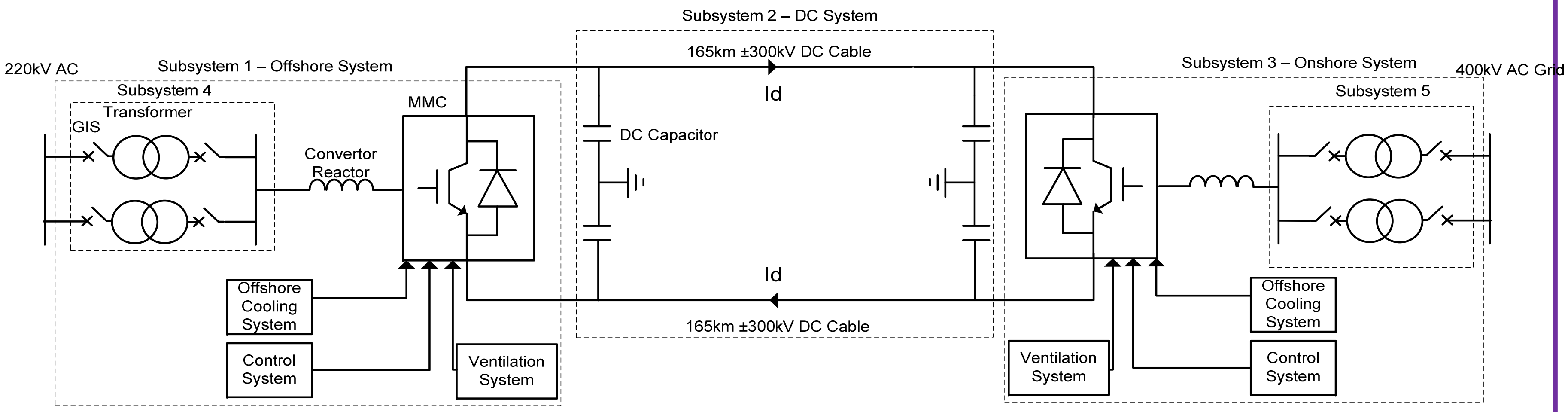
- No standard model
- What models are commercially available?
  - Differences between the models
  - Background theory
  - Implementation

# HVDC Cable Models

- **Pi-Section**
  - Lumps cable's RLC parameters
  - Adequate for steady state simulations with short lengths of cable
  - Computational intensive if many pi-sections are required
- **Bergeron Model**
  - Represents distributed nature of LC with R lumped
  - Does not account for frequency dependent nature of parameters
- **Frequency dependent models**
  - Distributed RLC model frequency dependency of all parameters
  - Mode model does not account for frequency dependent transformation matrix.
  - Phase model said to be the most robust and numerically accurate cable model commercially available

# 5. VSC-HVDC Availability Analysis

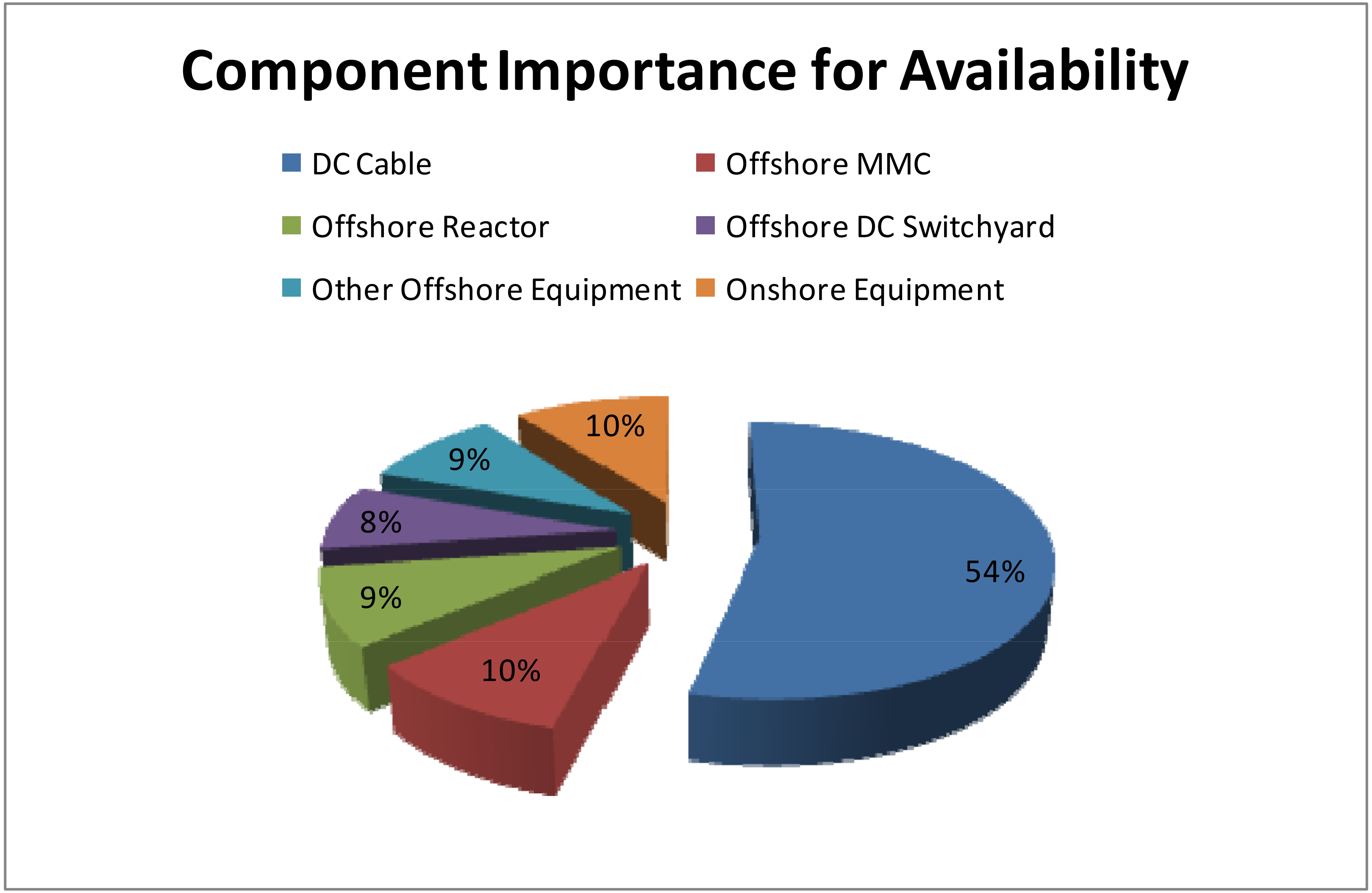
- Typical Radial Scheme for an UK Round 3 Windfarm:
  - Determine overall availability of scheme
  - Identify key components which effect the scheme
- Availability statistics are next to non-existent




Radial VSC-HVDC Scheme

# Results

Overall energy availability of 96.5%



# 6. In Conclusion

- Absence of history, data and experience with voltage-source HVDC
  - Offshore/ MMC
- No defined standards
  - Hardware or Control
- Intra-operability issue (for multi-manufacturer systems)
- Developing technology

- Unavailability: cables, instrumentation and software, transformers
- Reliability: Big question is how to manage multi-terminal

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