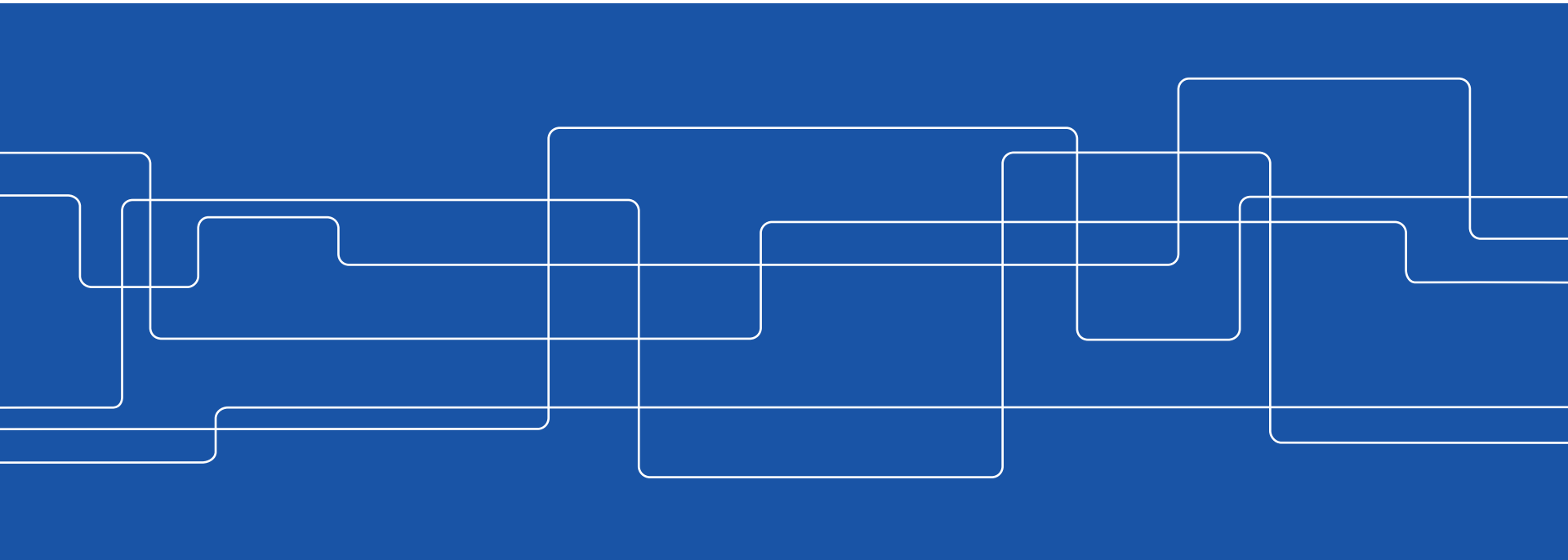
KTH ROYAL INSTITUTE
OF TECHNOLOGY

HVDC Grid Protection

Nordic Workshop on Power System Protection
2016-05-25



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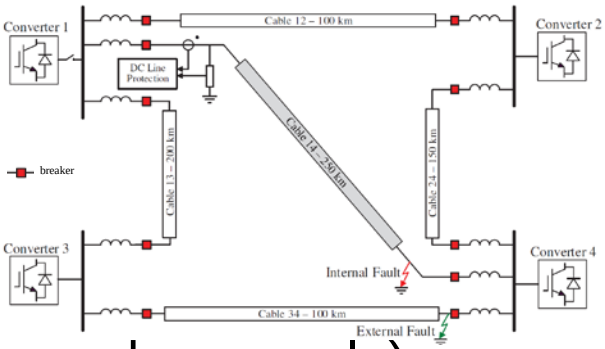
Motivation for MTDC Grids



- Point-to-point HVDC
  - Low transmission losses
  - VSC capabilities (voltage, frequency, phase angle)
  - Off-shore wind farms

- MTDC Grids
  - Additional flexibility, security and market access
  - Utilize off-shore wind potential
  - Electricity trading when less wind
  - **Need for selective fault detection and clearing**

Protection Requirements & Constraints

Constraints

- DC Side
  - SOA of IGBTs
  - Surge current capability of thyristors & diodes
  - Controllability & stability of the HVDC grid
- AC Side
  - Stability constraints of AC grid

Requirements

- Reliability
  - Dependability
  - Security
- Speed
- Selectivity
- Sensitivity
- Robustness

Fault occurrence

Fault detection

Fault localisation

Fault clearance

W. Leterme and D. van Hertem, “Classification of Fault Clearing Strategies for HVDC Grids," in *CIGRÉ Symposium*, Lund, 2015.
Haileselassie, T., “Control, Dynamics and Operation of Multi-Terminal VSC-HVDC Transmission Systems,” NTNU, Trondheim ,2012

Fault Detection & Localisation

- Single-Ended detection
  - No Communication, only local measurements
  - Protection zone has to be limited
    → Current Limiting Reactor
  - Need careful settings for triggering criteria
    → extensive simulations

- Double-Ended detection
  - Communication
  - Protection zone clearly defined
  - Asymmetric delay

Fault Detection, Single-Ended

- Voltage derivative $\Delta v \leq v_{ref}$
- Current derivative $\Delta i \geq i_{ref}$
- Transient-based $\Delta v \cdot \Delta i \leq -p_{ref}$
- Traveling wave $u^{m-} = Z_{surge} \cdot i^m - u^m$

- Undervoltage $v \leq v_{ref}$
- Overcurrent $i \geq i_{ref}$

Selectivity is difficult, backup

- Based on signal processing
  - Fourier
  - Wavelet

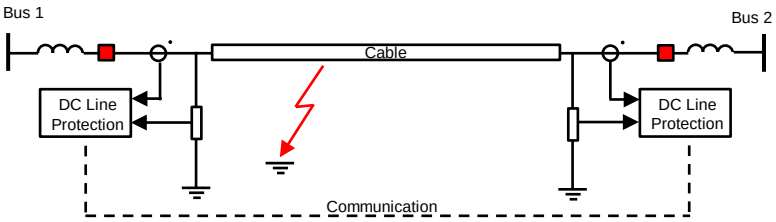
J. Marvik et al., “Communication-less fault detection in radial multi-terminal offshore HVDC grids,” in *11th IET International Conference on AC and DC Power Transmission*, Birmingham, 2015.

S. Pirooz Azad at al., “A DC Grid Primary Protection Algorithm Based on Current Measurements,” in *2015 17th European Conference on Power Electronics and Applications (EPE´15 ECCE-Europe)*, Geneva, 2015, pp. 1-10.

Fault Detection, Double-Ended

- Directional Comparison
  - Both sides detect forward fault
  - Both sides send message
  - Fault detected + message arrived → Breaker opens

- Longitudinal Current Differential
  - $|i_1 + i_2| \geq i_{d,ref}$
  - Pick-Up delay



N. Johannesson and S. Norrga, “Longitudinal Differential Protection Based on the Universal Line Model,” in *IECON 2015 - 41th Annual Conference of the IEEE Industrial Electronics Society*, Yokohama, Nov. 2015

Fault Current Interruption

- Today: Disconnect complete DC circuit
  - Open AC breakers

- Future: Selective fault clearing
  - Open DC breaker (PE, Hybrid, Mechanical)
  - Block converter (Full-bridge)
  - Combination

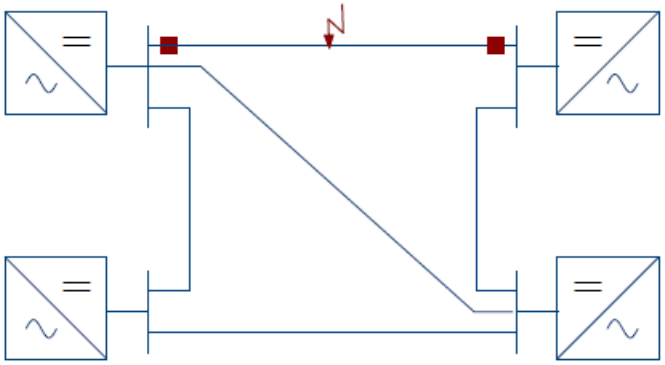
Fault Clearing Strategies

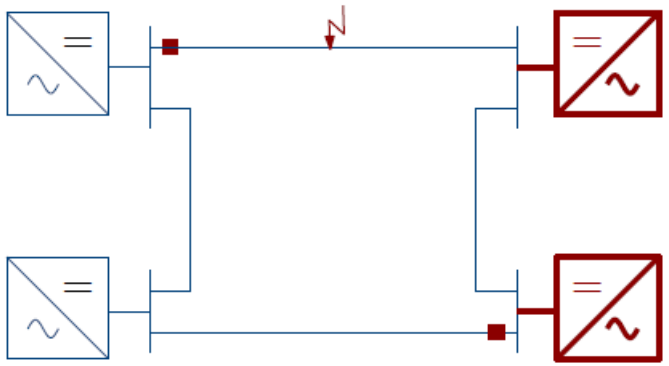
Line Protection

- Highly selective protection
- DC breakers at each line end
- Fast fault detection & localisation needed
- Least impact on grid

Grid Splitting

- Protection zone larger than one line
- Isolation of faulted zone
- Then, isolation of faulted line





W. Leterme and D. van Hertem, “Classification of Fault Clearing Strategies for HVDC Grids," in *CIGRÉ Symposium*, Lund, 2015.

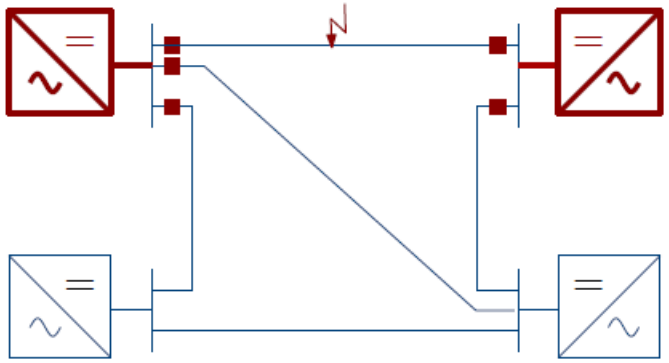
Fault Clearing

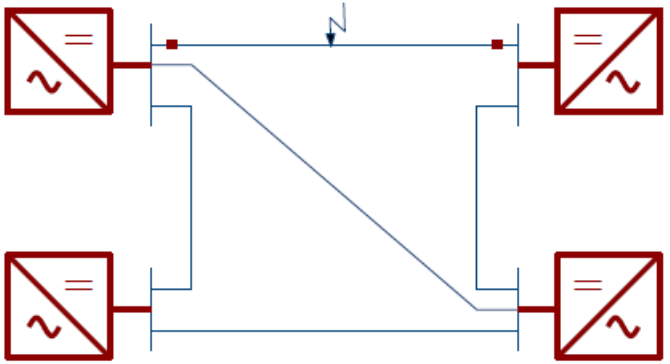
Open Grid

- All breakers at bus operate
- Fast DC breakers at each line end, reclosure capability
- Fast fault detection, slower fault localisation

Low-Speed Protection

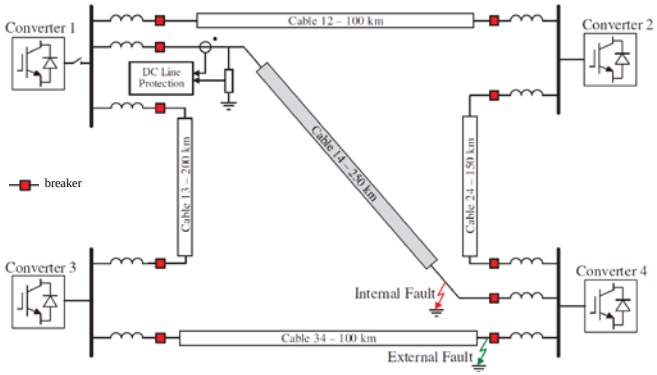
- All elements affected by fault
- AC breakers or converter blocking
- Low-speed DC disconnectors or residual current breakers





W. Leterme and D. van Hertem, “Classification of Fault Clearing Strategies for HVDC Grids," in *CIGRÉ Symposium*, Lund, 2015.
C. Petino, M. Heidemann, D. Eichhoff, M. Stumpe, E. Spahic, F. Schettler, “Application of multilevel full bridge converters in HVDC multiterminal systems,” in IET Power Electron., 2016, Vol. 9, Iss. 2, pp. 297-304

Summary



- Motivation for MTDC grid
- Protection requirements

- Fault detection
  - Single-Ended, no communication
  - Double-Ended, communication

- Fault clearing strategies

- Line protection
- Grid splitting
- Open grid
- Low-speed protection

Future plan & Collaboration

- Focus on fault clearing strategies
  - Building different models for realtime simulation
  - Full-bridge vs. half-bridge; bipol vs. monopol; low vs. high impedance grounding

- Developing a prototype of protection IED, TRL 5-6
  - Model-based design approach
  - Embedded systems, FPGA, DSPs
  - Communication

Future plan – contd.

- Investigating IEC 61850 possibilities in HVDC stations
  - Configuration Language (SCL, IEC 61850-6)
  - Information models (IEC 61850-7-3 & IEC 61850-7-4)
  - Mapping on communication stacks (Part -8-1 & -9-2)

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Approved May 2016
IEC 61869-9 provides new formats, beyond IEC 61850-9-2LE

Sample rates [Hz]	Nr. of ASDUs per frame	Publishing rate [frames/s]	Remarks
96 000	**1**	**96 000**	**Preferred rate for instrument transformers for high bandwidth d.c. control applications.**

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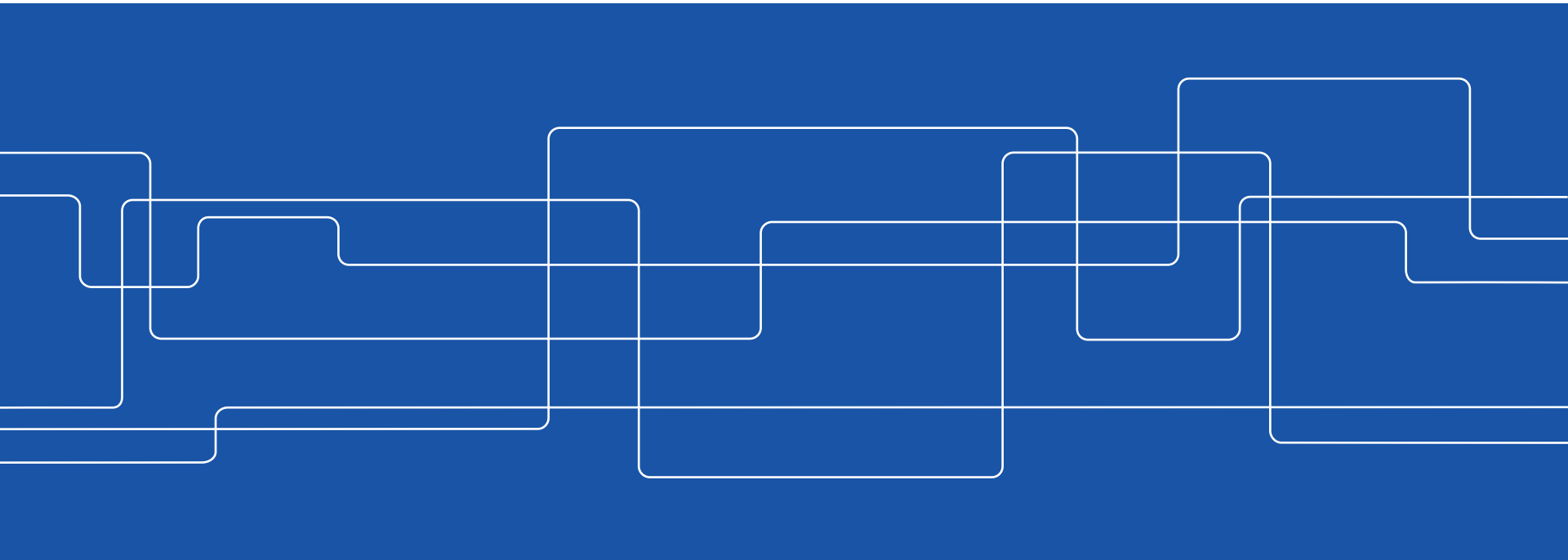
Thank you for your attention!



PROMOTioN

- Progress on Meshed HVDC Offshore Transmission Networks (H2020 European Project)

- 35 partners

- Goals:

  1) Diode Rectifier offshore converter

  2) Multi-Vendor protection IED

  3) DC breaker demonstration

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