HVDC Grid Protection Design Considerations

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Protection design is trade-off between cost and desired reliability

- Minimize fault impact on the system operation
- Minimize stresses to components
- Ensure human safety

- What is the optimum for HVDC grid protection?
VSC HVDC: from point-to-point to multi-terminal and grids

• VSC HVDC technology has matured for point-to-point links
  • Voltages have increased towards +/-300 and +/-500 kV

• First multi-terminal schemes have been built in China recently and are considered within Europe
  • Mainly as extension to the AC system, protected as “1” in N-1

• HVDC grids are considered as a fundamental upgrade for the existing AC system
  • Large grids can no longer be considered as “1”
  • Several challenges to be addressed => ProMOTION
Promotion project overview

- Cost effective and reliable converter technology
- **Grid protection**
- Financial framework for infrastructure development
- Regulation for deployment and operation
- Agreement between manufacturers, developers and operators of the grid
PROMOTioN WP 4 looks into different options for HVDC grid protection

• Develop functional requirements for HVDC grid protection for various grids

• Benchmark different fault clearing strategies

• Analyze selected fault clearing strategies in off- and on-line simulations

• Development of multi-purpose protection IEDS

• Investigate influencing parameters of protection in cost-benefit analysis
Presentation outline

• Fault clearing strategies in HVDC grids

• Constraints for protection operation

• Trade-offs in HVDC grid protection design
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Fault currents within a DC grid: example pole-to-pole fault

- Fault current:
  - No zero crossings
  - High rate-of-rise
  - High steady-state value
Different technologies exist to interrupt a DC fault current

- Converter ac breakers
  - As used in existing projects
  - No additional cost
  - Slow (40-60 ms opening time)

- Fault-current blocking converters
  - Full-bridge (commercially available)
  - Other concepts also exist
  - Higher losses compared with half-bridge
  - Fast (response within few ms)
Different technologies exist to interrupt a DC fault current

- **DC Circuit Breakers**

- **Hybrid HVDC breakers**
  - Prototypes tested
  - Power electronic component within main path generates losses
  - Operation times of 2-3 ms

- **Active resonant DC breakers**
  - Prototypes tested
  - No power electronic components in main path
  - Operation times of 5-10 ms
The use of different technologies leads to various fault clearing strategies.

- **Selective (a,b)**: using DC breakers in every line
- **Open Grid (c)**: alternative breaker sequence
- **Partially selective (d)**: split DC grid in sub-grids
- **Non-selective (e)**: shut down the whole DC grid
Presentation outline

• Fault clearing strategies in HVDC grids

• **Constraints for protection operation**

• Trade-offs in HVDC grid protection design
Constraints are imposed at either the AC side or the DC side.

- **DC side constraints**
  - **Component limits**
    - IGBT Safe Operating Area (converters, breakers)
    - Thyristor limiting load integral \( (i^2t) \)
    - Breaker energy absorption capability
    - ...
  - **System limits**
    - Ensure a stable DC voltage

- **AC side constraints**
  - **System limits**
    - Limit loss of infeed towards AC system
    - Transient stability issues
Strategies focusing on protecting the DC side must be an order of magnitude faster compared with those focusing on the AC side.
Additional AC side constraints might be imposed in future AC grid codes

• Current AC grid code:
  • Only defines maximum allowed permanent loss
  • E.g. Continental Europe: 3000 MW

• Possible future AC grid code:
  • Transient loss $P_1$: $< t_1$ (e.g. one cycle)
  • Temporary loss $P_2$: $< t_2$ (e.g. hundreds ms)
  • Permanent loss $P_3$
Possible future AC grid code lead to minimum requirements on DC grid protection

• Non-selective (AC circuit breaker)
  • Permanent loss $\sum_{i=1}^{n} PCi < P_3$

• Non-selective (converter with fault blocking capability)
  • Temporary loss $\sum_{i=1}^{n} PCi < P_2$

• Partially selective
  • Permanent loss $\sum_{i=1}^{l} PCi < P_3$, $l < n$
  • Temporary loss $\sum_{i=1}^{l} PCi < P_2$, $l < n$

• Fully selective (DC circuit breaker)
  • Transient loss $\sum_{i=1}^{n} PCi < P_1$

Presentation outline

- Fault clearing strategies in HVDC grids
- Constraints for protection operation
- Trade-offs in HVDC grid protection design
Different types of faults require different countermeasures

<table>
<thead>
<tr>
<th>Fault type</th>
<th>Line type</th>
<th>Probability</th>
<th>Symmetric monopole (high impedance ground)</th>
<th>Bipole (low impedance ground)</th>
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</thead>
<tbody>
<tr>
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- Depends on type of transmission line
- Depends on type of fault and grounding
- Depends on probability of occurrence
Desired impact decides which action to take

- **Zone 1**: out of norm
  - Highly unlikely
  - No particular protection design to address them
- **Zone 2**: unacceptable consequences
  - High impact, high probability
  - Reduce probability or impact (e.g., by adapting system design or protections)
- **Zone 3**: unacceptable risk
  - Medium impact, med-high probability
  - Adapting protections needed
- **Zone 4**: acceptable risk
  - Low impact, med-high probability
  - No actions necessary
Desired impact also influences the ratings of protective components

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- **Cable systems:** limited currents if pole-to-ground faults are considered in symmetric monopole
  - Might result in lower breaking capabilities
  - Might be combined with slower protection
    - Cost reduction in protection
  - Higher voltages in the system
  - Pole-to-pole faults require shut-down of the entire system
Multi-vendor interoperability requires transition from project-specific design towards generic protection concepts

- Standardization needed
  - Converter control and protection during/post-fault
  - Breaker classes (operation time, current interruption capability)
  - Current/overvoltage levels in the system
  - Relay inputs/outputs
Summary

• Fault clearing strategies in HVDC grids
  • Different options exist depending on technology and objective of protection

• Constraints for protection operation
  • Protecting the DC side itself requires much faster actions compared with protecting the AC side

• Trade-offs in HVDC grid protection design
  • Fault type and impact determine required protection and components
  • Multi-vendor interoperability must be considered
HVDC Grid Protection Design Considerations

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The opinions in this presentation are those of the author and do not commit in any way the European Commission.

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