Protection coordination aspects of AC/DC hybrid line corridors

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New Transmission Corridors in Germany

• Transmission capacity from North to South is needed

• Optimization and network development lead to hybrid transmission corridors:
  – Usage of existing support structures where possible
  – Minimization of new buildings
  – Better utilization of existing corridors

• Additionally hybrid transmission lines solve acceptance problems
ULTRANET

• AC and DC in near vicinity

• ULTRANET:
  – 2 GW bipole MMC (+ - N)
  – Osterath to Philippsburg
  – Commissioning 2019

• Different impacts:
  – Ion current, inter-system faults, etc.

[1] BBPIG 2013, Germany
Hybrid Transmission Line

- Steady-state and transient influences

- Protection systems may be influenced adversely

- Most challenging issues:
  - DC-protection and failure clearing
  - Transient influences
  - Inter-system faults
Inter-System Faults

- Arc faults should be cleared just by DC auto-reclosing
- Permanent faults need coordination of AC and DC protection
Inter-System Faults

• **First step:** Fault detection and clearing on DC-side

• **Detection:**
  - Fundamental frequency component in DC-system
  - 40-60 ms needed to detect properly
  - Inter-system fault detection if threshold is exceeded

• **Clearing:**
  - Circuit breaker for half bridge (HB) modules
  - Signal blocking for full bridge (FB) modules (5-10 ms)
  - Current ramping possible
Inter-System Faults

- DC-fault current in case of HB modules
Inter-System Faults

- DC-fault current in case of HB modules
Inter-System Faults

• DC-fault current in case of HB modules
  – Module capacitors are bypassed
  – Six-pulse diode bridge rectifier
  – Typical short circuit current on the DC-side
Inter-System Faults

• DC-fault current in case of FB modules
Inter-System Faults

- DC-fault current in case of FB modules
Inter-System Faults

• DC-fault current in case of FB modules
  – Module capacitors are **not** bypassed
  – Capacitors block the current through the modules
  – In consequence short circuit current is blocked

• Current ramping possible in the future
  – FB modules have the possibility to inverse output voltage
  – Module output between positive and negative polarity
  – Circular currents inside the converter
  – Complex controller => higher effort
Inter-System Faults

• **Second step:** Fault clearing on AC-side

• **Problems related to AC-fault clearing:**
  – Different protection systems (distance and differential protection)
  – After DC-clearing a open circuit is connected to AC-system via fault branch
  – Additional capacitance in the faulted AC-phase
  – Line charging current flows through the fault
  – Possible over-voltages at the ends of the open circuit (Ferranti)
  – No proper fault detection possible
Inter-System Faults

• Numerical example:
  – AC-busbars: 50 GVA and $R/X=0.1$
  – Transmission angle: 20°
  – Double circuit line 400 kV AC
  – Line length: 50 km for AC, 350 km for DC (with 50 mH reactors)
  – Typical data:

<table>
<thead>
<tr>
<th></th>
<th>400 kV double-circuit overhead line</th>
</tr>
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<tbody>
<tr>
<td>$R'_{(1)}$</td>
<td>35 mΩ/km</td>
</tr>
<tr>
<td>$R'_{(0)}$</td>
<td>124 mΩ/km</td>
</tr>
<tr>
<td>$L'_{(0)}$</td>
<td>2.84 mH/km</td>
</tr>
<tr>
<td>$L'_{(1)}$</td>
<td>0.98 mH/km</td>
</tr>
<tr>
<td>$C'_{(1)}$</td>
<td>12.3 nF/km</td>
</tr>
<tr>
<td>$C'_{(0)}$</td>
<td>6.9 nF/km</td>
</tr>
</tbody>
</table>
Inter-System Faults

- Situation after DC fault clearing
- “Single phase to ground fault” including a capacitor
Inter-System Faults

• In symmetrical components

\[ \omega C_{DC} \frac{U_N}{\sqrt{3}} = 175 \text{ A} \]
Inter-System Faults

- Variation of AC-fault location
- Influence on distance protection negligible
- No pickup for ground and phase elements
- Marginal variation and far away form distance zones
- Almost resistive load
Inter-System Faults

• Converters provide short circuit
• Other pole blocks AC-current (worst case)
Inter-System Faults

• In symmetrical components
• Variation of AC- and DC-fault location => fault tuple $T(x,y)$
Inter-System Faults

- Variation of AC- and DC- fault location
- Ground element of faulted phase generates pickup
- Not all tuples are inside the zones
- approx. 60% are not detected
Inter-System Faults

• Converters provide short circuit

**Problems:**
- Line length DC >> AC
- Impedance of converter in short circuit mode?
- Value of short circuit current
- Only one star point earthed of DC-system

**Consequences:**
- No pickup in case of low currents
- Not all fault locations are detected
- Delayed or no trip
- Differential current too low
Inter-System Faults

- Converters provide short circuit + Surge arrester

**Possibility:**
- Surge arrester alloys in DC neutral point (short circuit)
- Minimum voltage of 69 kV at neutral point for fault tuples
- Marginal effect on distance protection (reactors)
Inter-System Faults

• Earthing switches at dedicated locations
Inter-System Faults

• Earthing switches at dedicated locations

**Problems:**
- Line length DC >> AC
- Find proper locations to provide instantaneous tripping (optimization)
- Communication and malfunction (interlock!)

**Consequences:**
- More than two needed
- Secured pickup and tripping
- Save communication
- Blocking during normal operation
Conclusion

• Hybrid transmission corridors:
  – Possible way to increase transmission capacity
  – Solve acceptance problems among the people

• Different challenges have to be mastered:
  – Steady-state and transient influences
  – Inter-system faults are most challenging for primary and secondary equipment (protection coordination)
  – Performance of AC-protection has to be checked

• Concepts for fault clearing and restoration are needed
Thank you for your attention!