Coordinated Tuning of Converter Controls in Hybrid AC/DC Grids for System Frequency Support

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Outline

• Motivation for the study
• Frequency support from offshore wind farm
  – High Voltage DC (HVDC)
  – Multi Terminal DC (MTDC)
• Simulation model
• Study cases and proposed coordination of converter controllers
• Results
• Conclusion
Motivation for the study

• Increased number of HVDC connected offshore wind farms in the North Sea

• Growing interest in multi-terminal dc grids (MTDC) will lead to hybrid AC/DC power systems

• Several research has been conducted on primary frequency support from Offshore wind farm both through HVDC and MTDC

• Focus has been on frequency of the grid under study and does not consider the disturbances introduced in the other grids in the hybrid system
Frequency support from Offshore Wind through HVDC

- Onshore frequency signaling to OWF methods

Method #1

Onshore VSC

\[ f_{\text{grid}} \]  
\[ f_{\text{grid}} \]

\[ V_{\text{dc}} \]
\[ V_{\text{dc}} \]  
\[ V_{\text{dc, err}} \]
\[ V_{\text{dc}} \]
\[ V_{\text{dc}} \]

Offshore VSC

\[ f_{\text{grid}} \]
\[ f_{\text{grid}} \]

\[ f_{\text{grid}} \]
\[ f_{\text{grid}} \]

Method #2

Offshore VSC

\[ f_{\text{OWF}} \]
\[ f_{\text{OWF}} \]

\[ f_{\text{grid}} \]
\[ f_{\text{grid}} \]

Requires communication
Frequency support from Offshore Wind via MTDC (1)

- DC voltage droop control at all terminals
- Power imbalance is shared by all terminals
Frequency support from Offshore Wind via MTDC (2)

- Frequency support can be provided by adding frequency droop
- Frequency support from offshore wind farm
  - AC frequency change signaling through Vdc
  - auxiliary controllers both at onshore VSC and OWF VSC
- All terminals with DC droop controller participate in the frequency support
Study System

• Two multi-machine AC grids
  – Synchronous generators
  – Automatic voltage regulators, governors and Power System Stabilizers (PSS)

• Offshore Wind farm
  – No internal wind farm model
  – Stiff bus behind offshore converter

• DC grid
  – Symmetrical monopolar ±400kV three-terminals VSC-based MTDC
  – Π model cables with lumped parameters

• DIgSILENT PowerFactory

<table>
<thead>
<tr>
<th>Initial power flows</th>
<th>Terminal #1</th>
<th>Terminal #2</th>
<th>Terminal #3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>400 MW</td>
<td>200 MW</td>
<td>600 MW</td>
</tr>
<tr>
<td></td>
<td>Import</td>
<td>Import</td>
<td>Export</td>
</tr>
</tbody>
</table>
Study cases

- Loss of load in either of the grids is used to simulate frequency disturbance

<table>
<thead>
<tr>
<th>Case</th>
<th>Terminal #1</th>
<th>Terminal #2</th>
<th>Terminal #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Frequency + Vdc droop</td>
<td>Vdc droop</td>
<td>Vdc as freq. change signal</td>
</tr>
<tr>
<td>2</td>
<td>Frequency + Vdc droop</td>
<td>Vdc droop</td>
<td>Frequency signal via communication</td>
</tr>
<tr>
<td>3</td>
<td>Frequency + Vdc droop</td>
<td>Frequency + Vdc droop</td>
<td>Vdc as freq. change signal</td>
</tr>
<tr>
<td>4</td>
<td>Frequency + Vdc droop</td>
<td>Frequency + Vdc droop</td>
<td>Frequency signal via communication</td>
</tr>
</tbody>
</table>

Terms and Expressions:

- **Terminal #1 & #2 VSC**
  - $f_{grid}^*$
  - $\frac{1}{\rho_f}$
  - $v_{dc}$
  - $v_{dc}^*$
  - $P^*$
  - $V_{dc}$
  - $V_{dc}^*$
  - $I_d$

- **OWF Terminal #3 VSC**
  - $f_{grid}^*$
  - $\frac{1}{\rho_f}$
  - $v_{dc}$
  - $V_{dc}$
  - $P^*$
  - $I_d$

- Vdc as frequency change signal
- Frequency signal via communication
## Results (1)

- Loss of load in Grid 1

<table>
<thead>
<tr>
<th></th>
<th>Terminal #1</th>
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<th>Terminal #3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Case 1</strong></td>
<td>Frequency + Vdc droop</td>
<td>Vdc droop</td>
<td>Vdc as freq. change signal</td>
</tr>
<tr>
<td><strong>Case 2</strong></td>
<td>Frequency + Vdc droop</td>
<td>Vdc droop</td>
<td>Frequency signal via communication</td>
</tr>
</tbody>
</table>

### Diagrams

- **Case 1**
- **Case 2**
Results (2)

- Loss of load in Grid 2

<table>
<thead>
<tr>
<th>Terminal #1</th>
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<th>Terminal #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>Frequency + Vdc droop</td>
<td>Vdc droop</td>
</tr>
<tr>
<td>Case 2</td>
<td>Frequency + Vdc droop</td>
<td>Vdc droop</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vdc as freq. change signal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frequency signal via communication</td>
</tr>
</tbody>
</table>

Case 1
Case 2
Results (3)

• Loss of load in Grid 1

<table>
<thead>
<tr>
<th>Terminal #1</th>
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<th>Terminal #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 3</td>
<td>Frequency + Vdc droop</td>
<td>Frequency + Vdc droop Vdc as freq. change signal</td>
</tr>
<tr>
<td>Case 4</td>
<td>Frequency + Vdc droop</td>
<td>Frequency + Vdc droop Frequency signal via communication</td>
</tr>
</tbody>
</table>
Results (4)

- Loss of load in Grid 2

<table>
<thead>
<tr>
<th></th>
<th>Terminal #1</th>
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<th>Terminal #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 3</td>
<td>Frequency + Vdc droop</td>
<td>Frequency + Vdc droop</td>
<td>Vdc as freq. change signal</td>
</tr>
<tr>
<td>Case 4</td>
<td>Frequency + Vdc droop</td>
<td>Frequency + Vdc droop</td>
<td>Frequency signal via communication</td>
</tr>
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Conclusion

• By coordinating converter controllers at offshore wind farm and one ac grid, it is possible to avoid disturbance in other AC grids connected to the MTDC.

• However, the proposed method works when only one terminal is getting frequency support and the remaining AC grid connected MTDC terminals are operating in dc droop or constant power control mode.

• If more than one AC grids are going to receive frequency support through MTDC, then distributed dc voltage and frequency droop control is a better control method.
References