LVRT Induced Frequency Stability in Offshore Wind Power System

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Outline

• Introduction
• OWF LVRT Requirements
• OWF Modelling
• OWF LVRT Capability
• Results and Discussion
• Conclusion
Statistics of Global Wind Power Installation

Global Cumulative Installed Wind Capacity 2001-2018

Global Cumulative Installed Offshore Wind Capacity 2008-2018

OWF LVRT Requirements


OWF Modelling
Full Converter based WTG and WF

WTG

Grid Side Converter

Offshore Wind Farm

HVDC Converter Control

S. Dennetière et al., “The CIGRE B4 DC Grid Test System,” CIGRE Electra Mag., 2013
Modified IEEE 39 bus

<table>
<thead>
<tr>
<th>Wind Farm no</th>
<th>Generator Replaced</th>
<th>No of WT</th>
<th>Total MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>G 4</td>
<td>469</td>
<td>703.5</td>
</tr>
<tr>
<td>2</td>
<td>G10</td>
<td>186</td>
<td>279</td>
</tr>
<tr>
<td>3</td>
<td>G 7</td>
<td>416</td>
<td>624</td>
</tr>
<tr>
<td>4</td>
<td>G 3</td>
<td>482</td>
<td>723</td>
</tr>
<tr>
<td>5</td>
<td>G 9</td>
<td>617</td>
<td>925.5</td>
</tr>
</tbody>
</table>

OWF LVRT Capability
Capability to satisfy LVRT
Conventional LVRT Strategy

\[ P_{\text{red}} = (V_{\text{ref}} - V_{\text{meas}}) \times K_v \quad (2) \]

\[ P_{\text{red}} = (f_{\text{ref}} - f_{\text{meas}}) \times K_f \quad (2)' \]

\[ P_{\text{ref}} = P_{\text{MPPT}} - P_{\text{red}} \quad (3) \]

\[ f_{\text{off}}^* = f_{\text{off}0} + K_v \left( V_{dccoef} - V_{dc0} \right) \quad (1) \]

\[ V_{\text{off}}^* = V_{\text{off}0} - K_v \left( V_{dccoef} - V_{dc0} \right) \quad (1)' \]

\[ I_{qREC}^* = \begin{cases} fIt = 1 & K_{LVRT} \left( V_{\text{ref}} - V_{\text{meas}} \right) \\ fIt = 0 & 0 \end{cases} \quad (4) \]
Active Power Recovery

(Without Ramp Rate)

(With Ramp Rate)
Modified Conventional LVRT Strategy

(With APR Ramp Rate)

\[
S_{ramp} = \begin{cases} 
1 & \text{for } \text{flt} = 0 \text{ and } i^*_d_{REC} < i^*_{d\text{ref}} \text{ and } t_{ramp} < \frac{1}{R_{up}} \\
0 & \text{for } \text{flt} = 1 \text{ or } i^*_{d\text{REC}} = i^*_{d\text{Ref}} 
\end{cases}
\]  

(1)

\[
di^*_d_{ramp} = \lim_{\Delta t \to 0} \left( \frac{i^*_{d\text{ref}} - i^*_d_{ramp}}{\Delta t} \right) = \frac{R_{down} - \frac{dV_{REC}}{dt} \cdot i^*_{ramp}}{V_{REC}} = \frac{R_{up} - \frac{dV_{REC}}{dt} \cdot i^*_{d_{ramp}}}{V_{REC}}
\]

(2)

\[
i^*_d = \begin{cases} 
i^*_{d_{ramp}} & S_{ramp} = 1 \\
i^*_{d\text{ref}} & S_{ramp} = 0
\end{cases}
\]

(3)

\[
i^*_{d\text{max}} = \begin{cases} 
i^*_{d_{max}} & V_{onshore} < 0.95 \\
max & V_{onshore} \geq 0.95
\end{cases}
\]

(4)

\[
i^*_d_{REC} = \begin{cases} 
i^*_{d\text{max}} & \text{flt} = 1 \\
i^*_{d\text{ref}} & \text{flt} = 0
\end{cases}
\]

(5)

\[
i^*_{q\text{REC}} = \begin{cases} 
K_{LVRT} (V_{ref} - V_{onshore}) & \text{flt} = 1 \\
0 & \text{flt} = 0
\end{cases}
\]

(6)
Results and Discussion
Results and Discussion

Test Case I
3-φ Fault with 70 % voltage dip for 500 milliseconds, and wind generation (penetration level of 33%)

<table>
<thead>
<tr>
<th>Ramp Rate</th>
<th>$f_{\text{Nadir}}$ (Hz)</th>
<th>RoCoF (Hz/s)</th>
<th>$\tau_{\text{Nadir}}$ (p.u)</th>
<th>RoCoT (p.u/s)</th>
<th>$\omega_{\text{turbine}}$ (p.u)</th>
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<tr>
<td>0.2 p.u /s</td>
<td>49.43</td>
<td>-0.88</td>
<td>0.46</td>
<td>0.27</td>
<td>1.075</td>
</tr>
<tr>
<td>0.5 p.u /s</td>
<td>49.69</td>
<td>-0.55</td>
<td>0.58</td>
<td>0.41</td>
<td>1.0378</td>
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<tr>
<td>1 p.u /s</td>
<td>49.87</td>
<td>-0.38</td>
<td>0.63</td>
<td>0.39</td>
<td>1.0275</td>
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<tr>
<td>2 p.u /s</td>
<td>49.92</td>
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Results and Discussion

Test Case II
3-φ Fault with 100 % voltage dip for 150 milliseconds, and wind generation (penetration level of 46%)

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<td>0.33</td>
<td>0.243</td>
<td>1.1</td>
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<td>0.5 p.u /s</td>
<td>49.4</td>
<td>-1.7</td>
<td>0.465</td>
<td>0.49</td>
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<td>1 p.u /s</td>
<td>49.7</td>
<td>-1.48</td>
<td>0.57</td>
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### Test Case I
*(70 % voltage dip for 500 milliseconds)*
*(penetration level of 33%)*

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### Test Case II
*(100 % voltage dip for 150 milliseconds)*
*(penetration level of 48%)*

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Conclusion

• The results suggest that the VDIF is significantly improved by increasing APR ramp rates.

• With increasing the APR ramp rate the RoCoT is increased, however the WTG rotational speed decreased.

• The WTG mechanical stress decreased slightly at high APR ramp rates.

• The wind generation penetration levels and grid fault severity may significantly impact frequency stability of onshore main grid.
Thank you