Impact of Voltage Sags on a Transformer-less Wind Energy System

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Presentation Outline

• Purpose of a Transformer in a Conventional Wind Power Plant

• Why Transformer-less?

• Impact of Voltage Sags on a Conventional Wind Power Plants

• Impact of Voltage Sags on a Transformer-less Wind Energy Conversion Systems

• Conclusions
Purpose of a Transformer in a Conventional Wind Power Plant

A. Voltage Step-up

Fig. 1: A Conventional Wind Power Plant
B. Grounding

• The primary wye winding connection of this transformer provides the low impedance path between the wind energy conversion system (WECS) and the wind power plant ground.

• Allows the transmission of excess current to the ground during faulty conditions.

Fig. 2: A grid-connected DFIG-based WECS with its grounded-wye/delta transformer winding connection and protective device.
Purpose of a Transformer in a Conventional Wind Power Plant

C. Voltage Sag Transformation

Fig. 3: A Conventional Wind Power Plant model with a short circuit fault at PCC.
Purpose of a Transformer in a Conventional Wind Power Plant

C. Voltage Sag Transformation

Type A
- Voltage drop in all three phases symmetrical.
  - $V_a = V$
  - $V_b = \frac{1}{2}V - \frac{1}{2}jV\sqrt{3}$
  - $V_c = \frac{1}{2}V + \frac{1}{2}jV\sqrt{3}$

Type B
- Voltage drop in one phase.
  - $V_a = V$
  - $V_b = -\frac{1}{2} - \frac{1}{2}jV\sqrt{3}$
  - $V_c = -\frac{1}{2} + \frac{1}{2}jV\sqrt{3}$

Type C
- Voltage drop and phase angle shift in two phases.
  - $V_a = 1$
  - $V_b = -\frac{1}{2} - \frac{1}{2}jV\sqrt{3}$
  - $V_c = -\frac{1}{2} + \frac{1}{2}jV\sqrt{3}$

Type E
- Voltage drop in two phases.
  - $V_a = 1$
  - $V_b = -\frac{1}{2}V - \frac{1}{2}jV\sqrt{3}$
  - $V_c = -\frac{1}{2}V + \frac{1}{2}jV\sqrt{3}$
C. Voltage Sag Transformation

**Type D**
- Voltage drop in one phase and phase angle shift in two phases.
- $\overset{\rightarrow}{V}_a = V$
- $\overset{\rightarrow}{V}_b = -\frac{1}{2}V - \frac{1}{2}j\sqrt{3}$
- $\overset{\rightarrow}{V}_c = -\frac{1}{2}V + \frac{1}{2}j\sqrt{3}$

**Type F**
- Voltage drop in all three phases and phase angle shift in two phases.
- $\overset{\rightarrow}{V}_a = V$
- $\overset{\rightarrow}{V}_b = \frac{1}{2}V - \frac{1}{3}\left(\frac{2}{3} + \frac{1}{3}V\right)j\sqrt{3}$
- $\overset{\rightarrow}{V}_c = -\frac{1}{2}V + \frac{1}{3}\left(\frac{2}{3} + \frac{1}{3}V\right)j\sqrt{3}$

**Type G**
- Voltage drop in all three phases and phase angle shift in two phases.
- $\overset{\rightarrow}{V}_a = \frac{2}{3} + \frac{1}{3}V$
- $\overset{\rightarrow}{V}_b = -\frac{1}{2}\left(\frac{2}{3} + \frac{1}{3}V\right) - \frac{1}{2}jV\sqrt{3}$
- $\overset{\rightarrow}{V}_c = \frac{1}{2}\left(\frac{2}{3} + \frac{1}{3}V\right) + \frac{1}{2}jV\sqrt{3}$
Why Transformer-less?

Study A: 1500 Wind Turbines operated for 15 years

Study B: 3700 Wind Turbines operated for 5 years

Study C: 6000 Wind Turbines operated for 11 years

Fig. 4: Percentage Distribution of the Number of Failures for Onshore Swedish Wind Power Plants

Fig. 5: Breakdown of the Failure Rates and Downtimes of Electrical Subsystem Components of Direct Drive WECS
Why Transformer-less?

Fig. 6: A Wind Power Plant with Transformer-less Wind Energy Conversion System (WECS).
Impact of Voltage Sags on a Conventional Wind Power Plants.

Based on a MATLAB/Simulink Model of a Wind Power Plant with five Permanent Magnet Synchronous Generator (PMSG) using the following parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Power Rating of PMSG</td>
<td>2 MW</td>
</tr>
<tr>
<td>Terminal Voltage Rating of PMSG</td>
<td>690 V</td>
</tr>
<tr>
<td>Fundamental Frequency</td>
<td>60 Hz</td>
</tr>
<tr>
<td>Power Rating of Transformer</td>
<td>2.5 MVA</td>
</tr>
<tr>
<td>DC-Link Voltage</td>
<td>1100 V</td>
</tr>
<tr>
<td>DC-Link Voltage Controller Proportional Gain (Kp)</td>
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</tr>
<tr>
<td>DC-Link Voltage Controller Integral Gain (Ki)</td>
<td>27.5</td>
</tr>
</tbody>
</table>

Fig. 7: (a) Wind Turbine Output Voltage; (b) DC-Link Voltage Transient.
Impact of Voltage Sags on a Conventional Wind Power Plants.

Asymmetrical Sag

Type A
- Consist of positive sequence component.
- Overshoot of dc-link voltage is directly proportional to the amplitude of positive sequence in the grid voltage
- Largest overshoot in the dc-link voltage in the type A sag.

Transient overshoot in the dc-link voltage increase by 83% and it lasts for about 1 minute.
Impact of Voltage Sags on a Conventional Wind Power Plants.

**Symmetrical Sag**

**Type C**

- Consist of positive sequence and negative sequence components.
- Overshoot of dc-link voltage is between 10%-30%.
- Largest overshoot in the fault current is observed.

**Transient overshoot in the dc-link voltage increase by 13.6% and it lasts for about 2 minutes.**
**Symmetrical Sag**

**Type G**
- Consist of positive sequence, negative sequence, and zero sequence components.
- Overshoot of dc-link voltage is between 10%-30%.

Transient overshoot in the dc-link voltage increase by 18.2% and it lasts for about 2 minutes.
Impact of Voltage Sags on a Transformer-less Wind Energy Conversion Systems.

Based on a MATLAB/Simulink Model of a Wind Power Plant with five Permanent Magnet Synchronous Generator (PMSG) using the following parameters:

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<tr>
<td>Terminal Voltage Rating of PMSG</td>
<td>11000 V</td>
</tr>
<tr>
<td>Fundamental Frequency</td>
<td>60 Hz</td>
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<tr>
<td>DC-Link Voltage</td>
<td>17000 V</td>
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<tr>
<td>DC-Link Voltage Controller</td>
<td></td>
</tr>
<tr>
<td>Proportional Gain (Kp)</td>
<td>1.1</td>
</tr>
<tr>
<td>Integral Gain (Ki)</td>
<td>27.5</td>
</tr>
</tbody>
</table>

Fig. 8: Wind Turbine Output Voltage
Impact of Voltage Sags on a Transformer-less Wind Energy Conversion Systems.

**Type A**

Transient overshoot in the dc-link voltage increase by 11.2% and it lasts for more than 10 minutes.

**Type C**

Transient overshoot in the dc-link voltage increase by 7.06% and it lasts for more than 10 minutes.

**Type F**

Transient overshoot in the dc-link voltage increase by 7.65% and it lasts for more than 10 minutes.
Impact of Voltage Sags on a Transformer-less Wind Energy Conversion Systems.

Major Impact of Voltage Sags on Wind Energy Conversion System.

- Grid Code under Fault Ride-Through
- Thermal Loading of semiconductor devices
- Dynamics of the Voltage and Current Controllers
- Combined control algorithm (using both PI control and Predictive control)
Conclusions

• A transformer-less WECS will be operated at the medium voltage range between 6.6 kV to 33 kV, and high power megawatt range (1MW to 10MW).

• Therefore, the PMSG will be more suitable for the transformer-less WECS and will require a full-scale converter.

• A multilevel converter topology will be required at the grid-side converter of the WECS.

• The current controller of the grid-side converter must provide fast response to the severe grid faults.
Thank you very much !!!!!!