CENTRE FOR RENEWABLE AND SUSTAINABLE ENERGY STUDIES

9th RENEWABLE ENERGY POSTGRADUATE SYMPOSIUM

13 – 14 September 2018,
Faculty of Engineering, Stellenbosch University

University of Cape Town • iYunivesithi yaseKapa • Universiteit van Kaapstad

SPES BONA

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

By

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Advanced Machines and Energy Systems (AMES) Research Group

14th September 2018

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

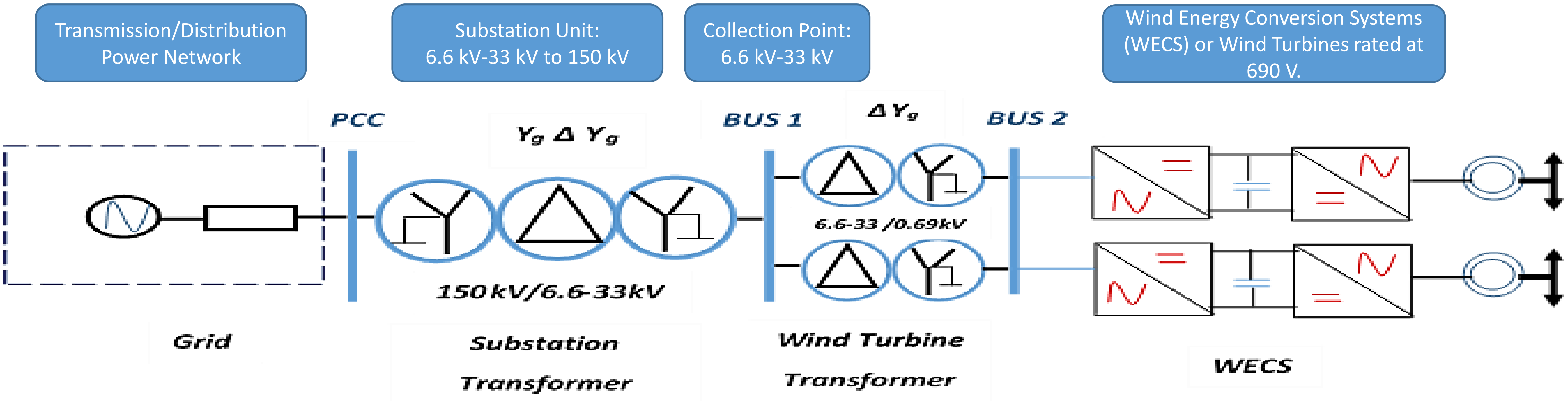

Fig. 1: A Conventional Wind Power Plant

Purpose of a Transformer in 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.

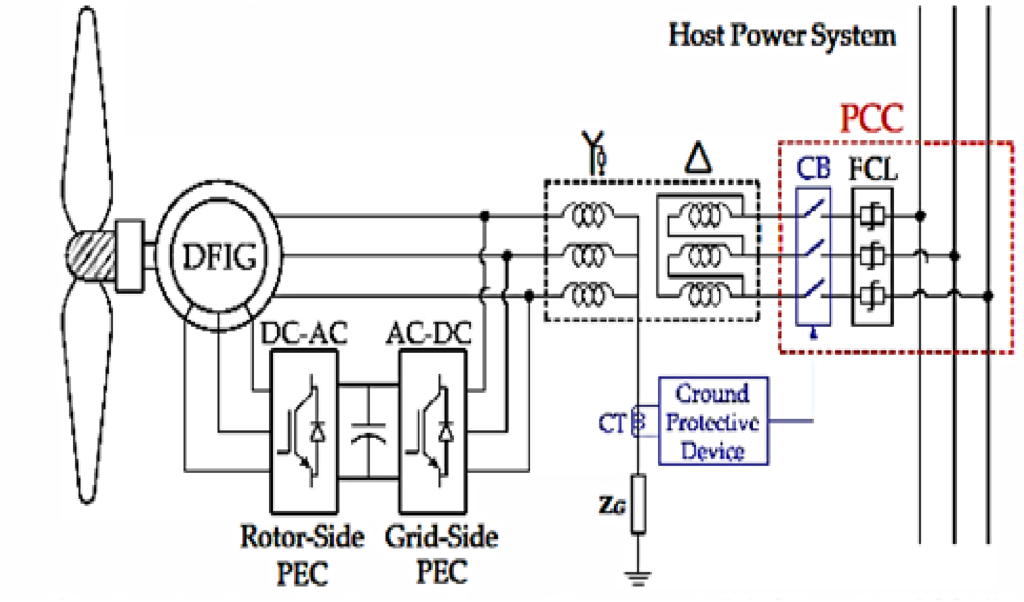

Fig. 2: A grid-connected DFIG-based WECS with its grounded-wye/delta transformer winding connection and protective device.

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Purpose of a Transformer in a Conventional Wind Power Plant

C. Voltage Sag Transformation

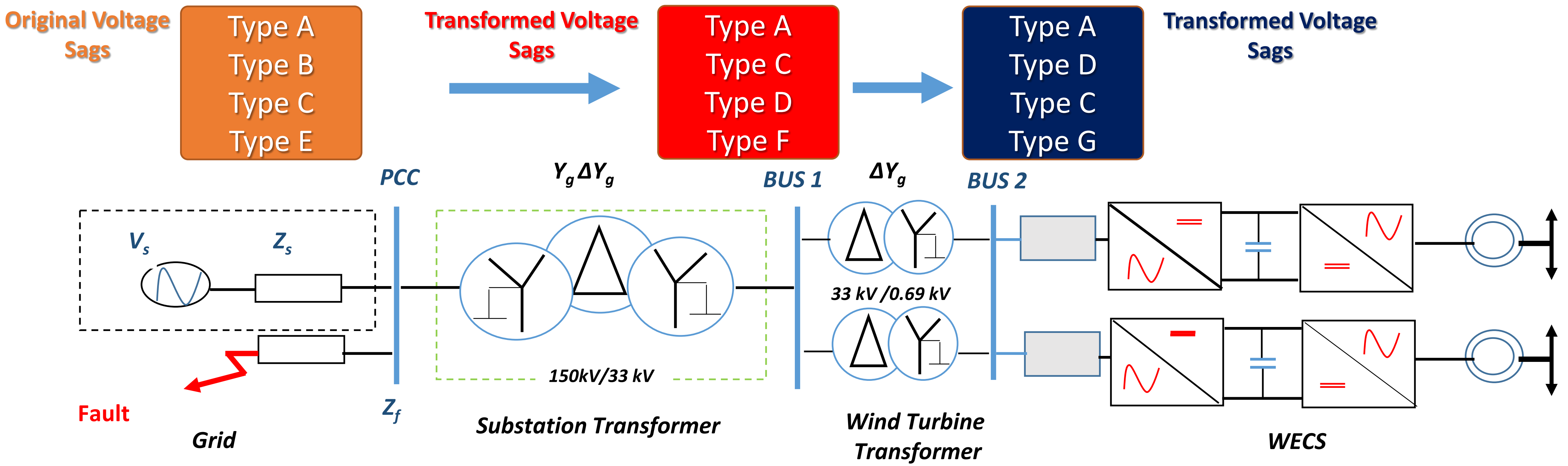

Fig. 3: A Conventional Wind Power Plant model with a short circuit fault at PCC.

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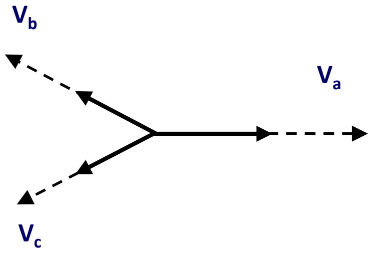
Purpose of a Transformer in a Conventional Wind Power Plant

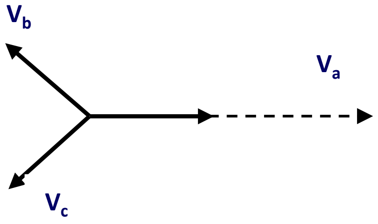
C. Voltage Sag Transformation

Type A



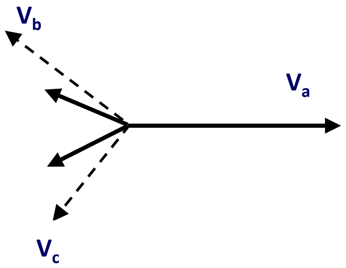
Type A
- Voltage drop in all three phases symmetrical.
- $\overline{V}_a = \mathrm{V}$
- $\overline{V}_b = -\frac{1}{2}\mathrm{V} - \frac{1}{2}\mathrm{jV}\sqrt{3}$
- $\overline{V}_c = -\frac{1}{2}\mathrm{V} + \frac{1}{2}\mathrm{jV}\sqrt{3}$

Type B



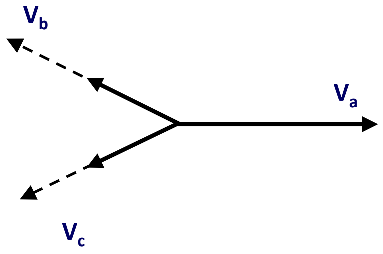
Type B
- Voltage drop in one phase.
- $\overline{V}_a = \mathrm{V}$
- $\overline{V}_b = -\frac{1}{2} - \frac{1}{2}\mathrm{j}\sqrt{3}$
- $\overline{V}_c = -\frac{1}{2} + \frac{1}{2}\mathrm{j}\sqrt{3}$

Type C



Type C
- Voltage drop and phase angle shift in two phases.
- $\overline{V}_a = 1$
- $\overline{V}_b = -\frac{1}{2} - \frac{1}{2}\mathrm{jV}\sqrt{3}$
- $\overline{V}_c = -\frac{1}{2} + \frac{1}{2}\mathrm{jV}\sqrt{3}$

Type E



Type E
- Voltage drop in two phases.
- $\overline{V}_a = 1$
- $\overline{V}_b = -\frac{1}{2}\mathrm{V} - \frac{1}{2}\mathrm{jV}\sqrt{3}$
- $\overline{V}_c = -\frac{1}{2}V + \frac{1}{2}\mathrm{j}V\sqrt{3}$

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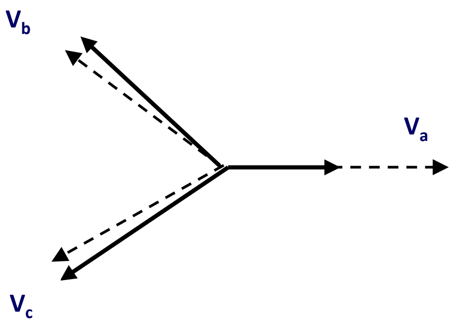
Purpose of a Transformer in a Conventional Wind Power Plant

C. Voltage Sag Transformation

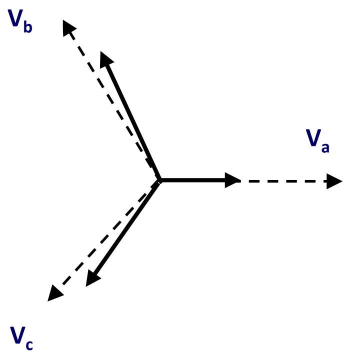
Type D



Type D

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

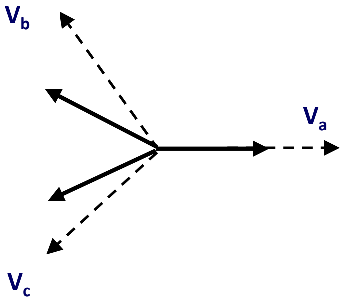
Type F



Type F

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

Type G



Type G

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

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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

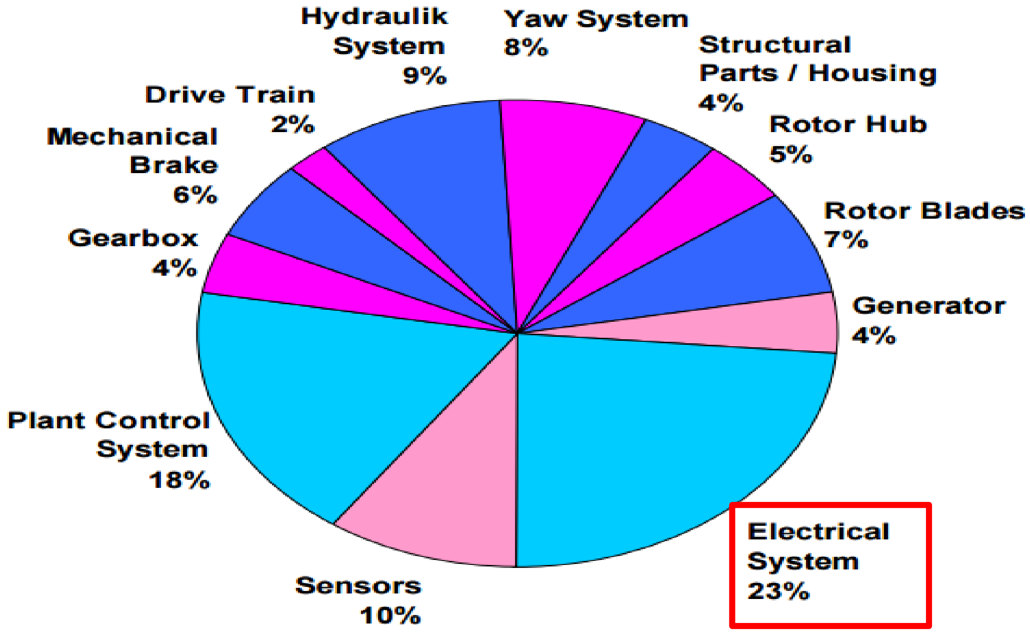

Fig. 4: Percentage Distribution of the Number of Failures for Onshore Swedish Wind Power Plants

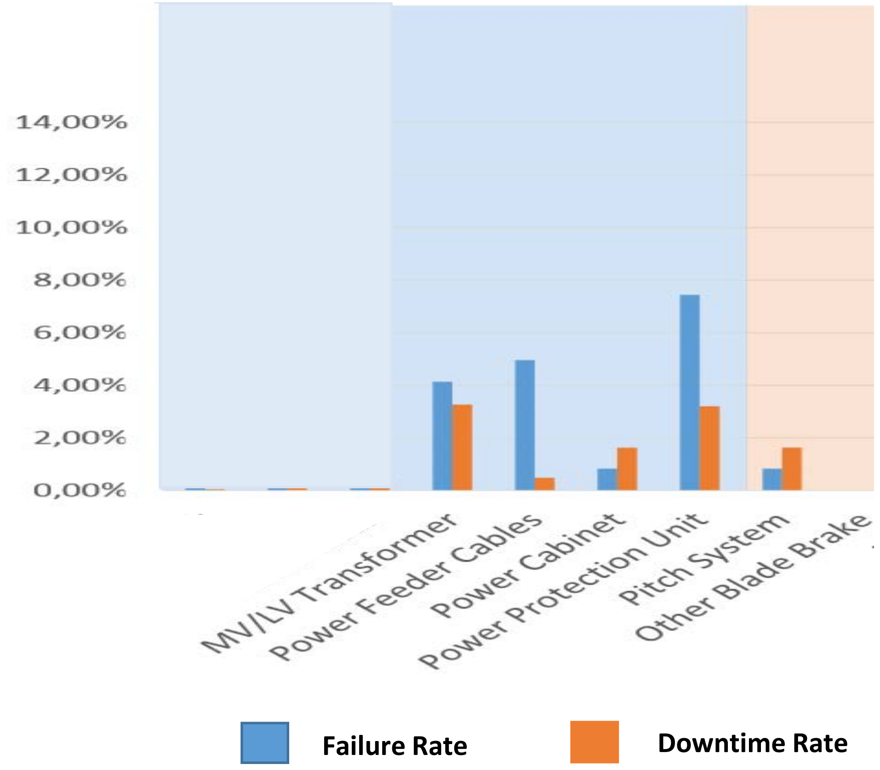

Fig. 5: Breakdown of the Failure Rates and Downtimes of Electrical Subsystem Components of Direct Drive WECS

Why Transformer-less?

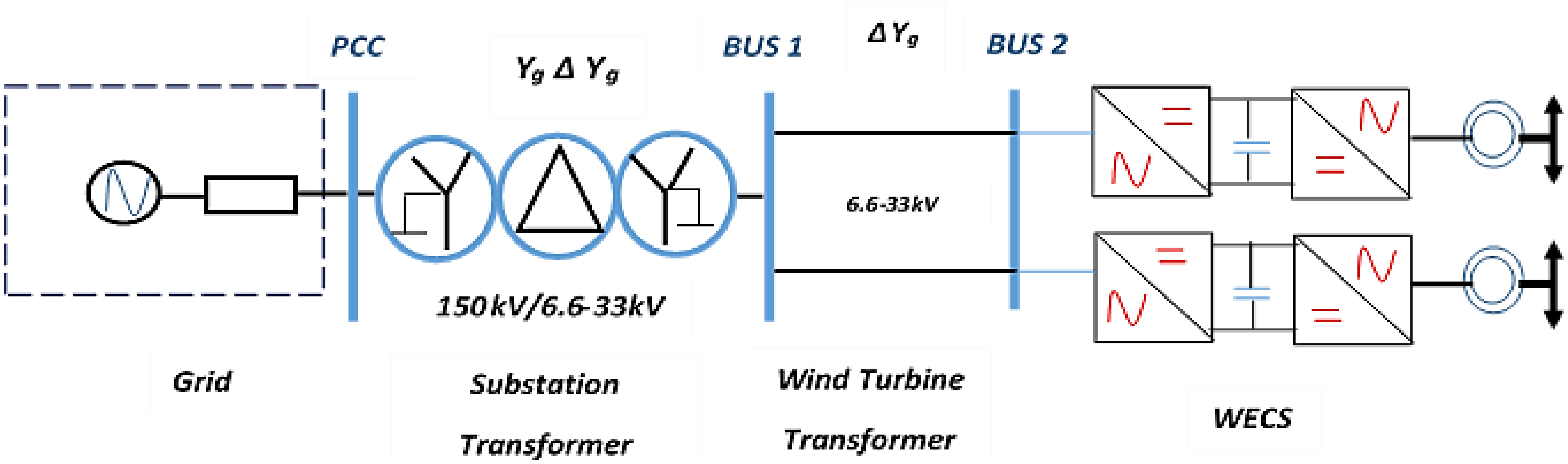

Fig. 6: A Wind Power Plant with Transformer-less Wind Energy Conversion System (WECS).

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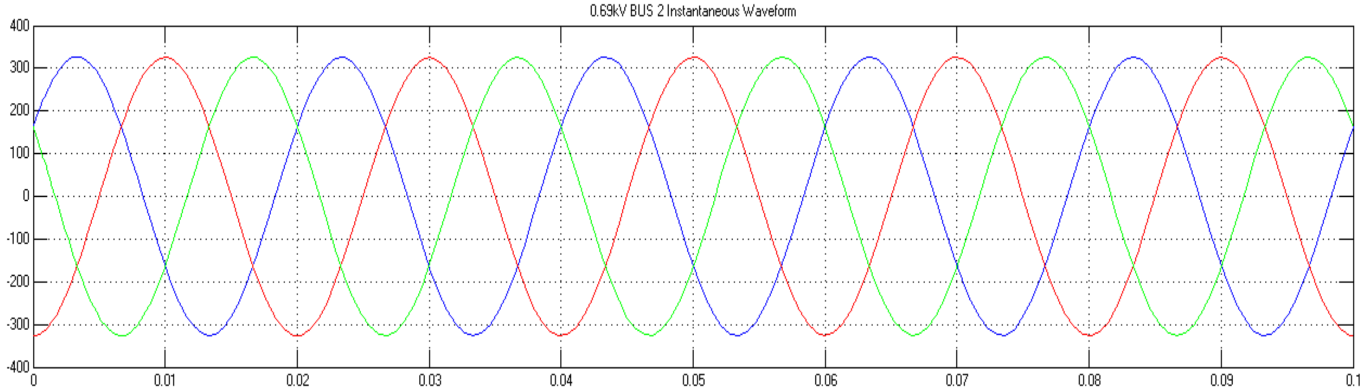
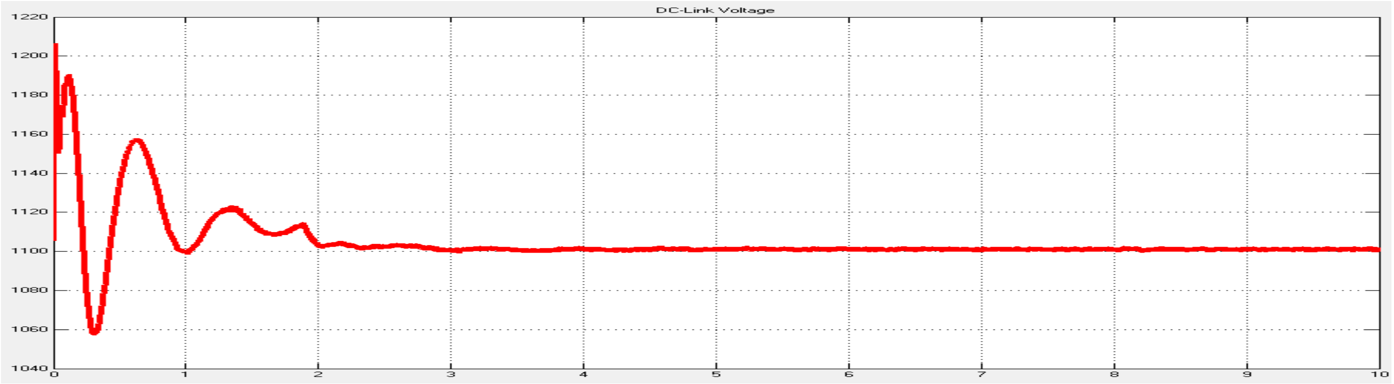
Impact of Voltage Sags on a Conventional Wind Power Plants.

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

Parameter	Value
Nominal Power Rating of PMSG	2 MW
Terminal Voltage Rating of PMSG	690 V
Fundamental Frequency	60 Hz
Power Rating of Transformer	2.5 MVA
DC-Link Voltage	1100 V
DC-Link Voltage Controller Proportional Gain (Kp)	1.1
DC-Link Voltage Controller Integral Gain (Ki)	27.5



(a)



(b)

Fig. 7: (a) Wind Turbine Output Voltage; (b) DC-Link Voltage Transient.

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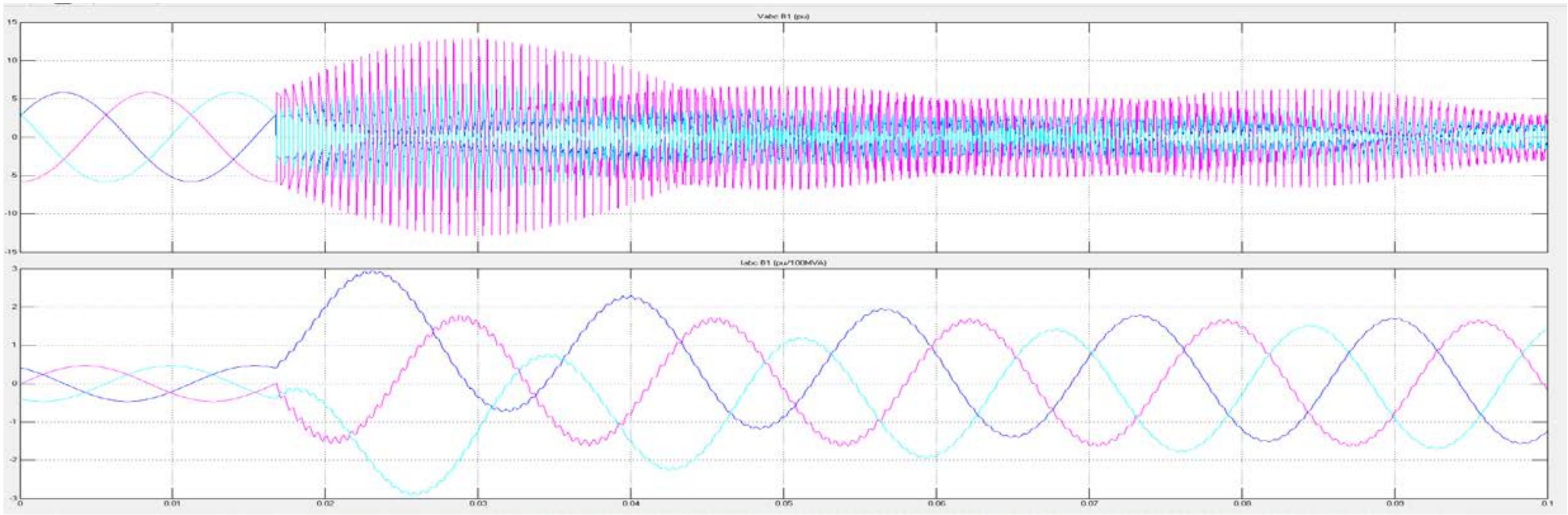
Impact of Voltage Sags on a Conventional Wind Power Plants.

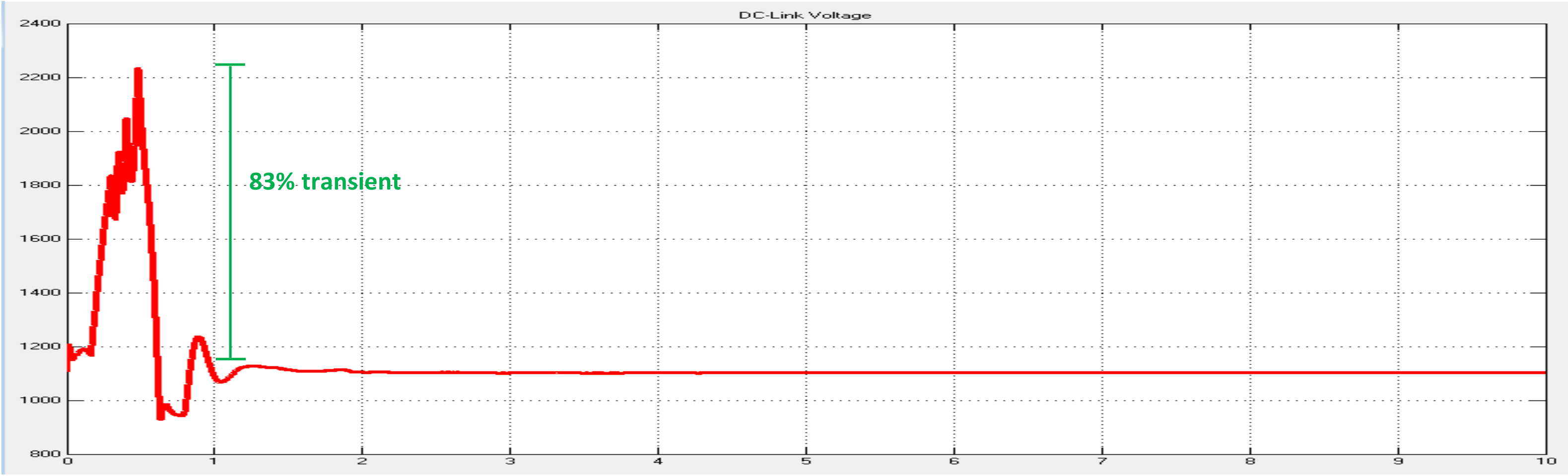
Asymmetrical Sag

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.





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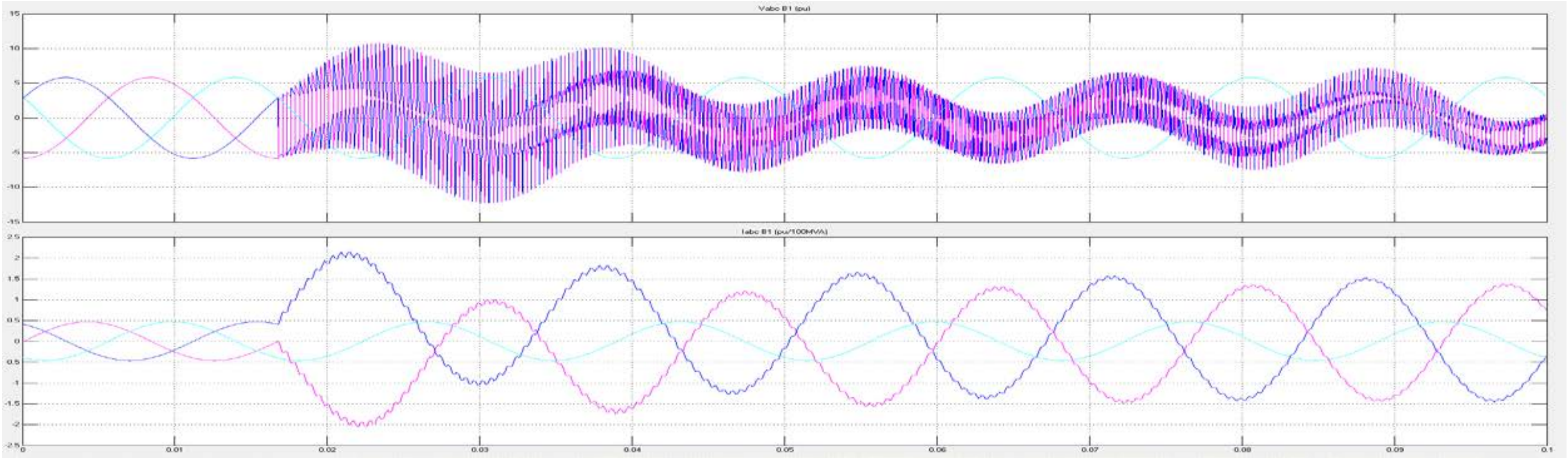
Impact of Voltage Sags on a Conventional Wind Power Plants.

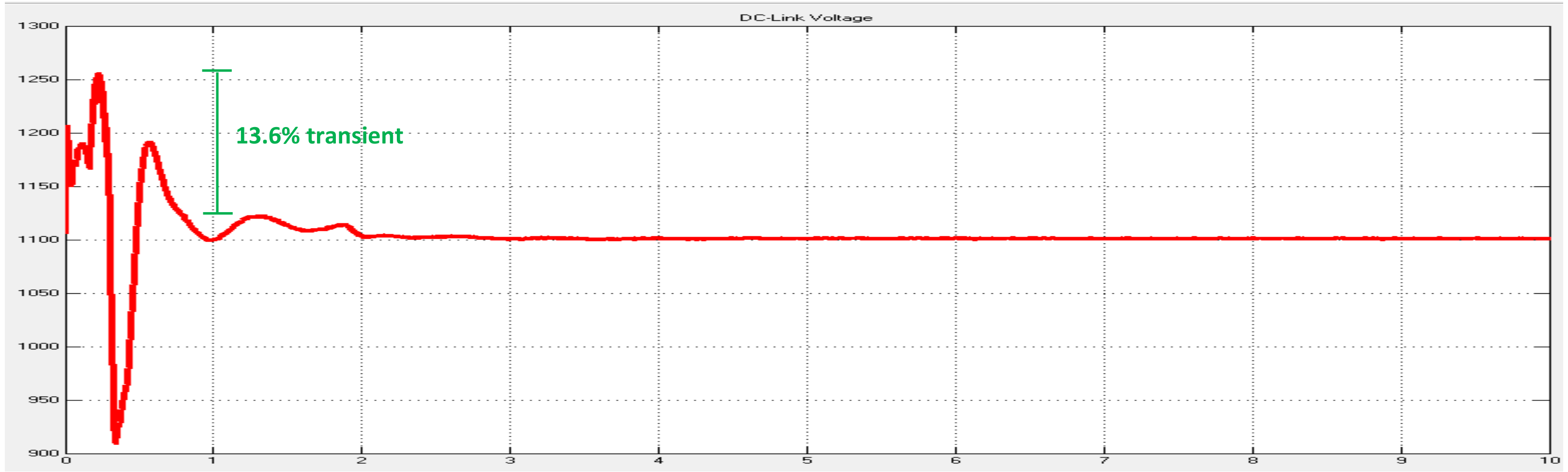
Symmetrical Sag

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.





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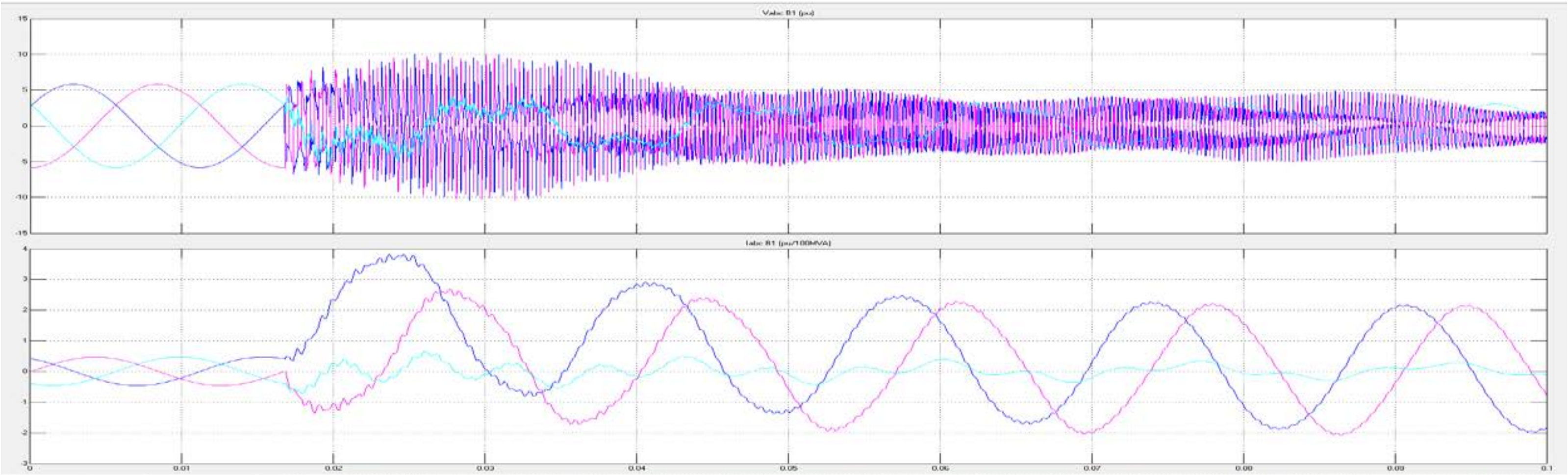
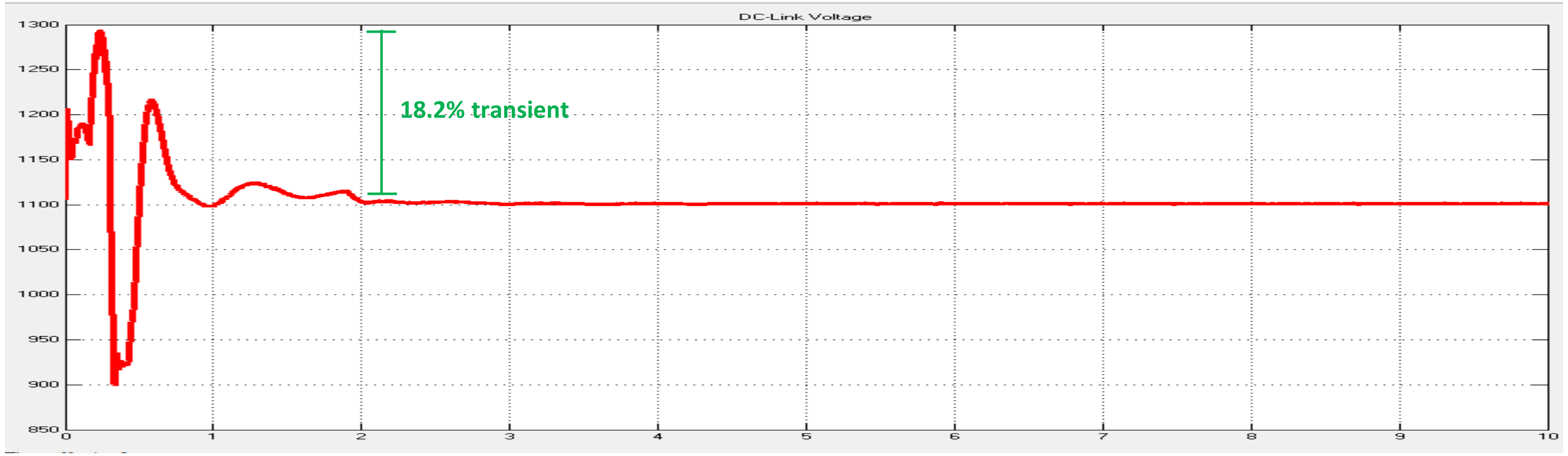
Impact of Voltage Sags on a Conventional Wind Power Plants.

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.

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

Parameter	Value
Nominal Power Rating of PMSG	2 MW
Terminal Voltage Rating of PMSG	11000 V
Fundamental Frequency	60 Hz
DC-Link Voltage	17000 V
DC-Link Voltage Controller Proportional Gain (Kp)	1.1
DC-Link Voltage Controller Integral Gain (Ki)	27.5

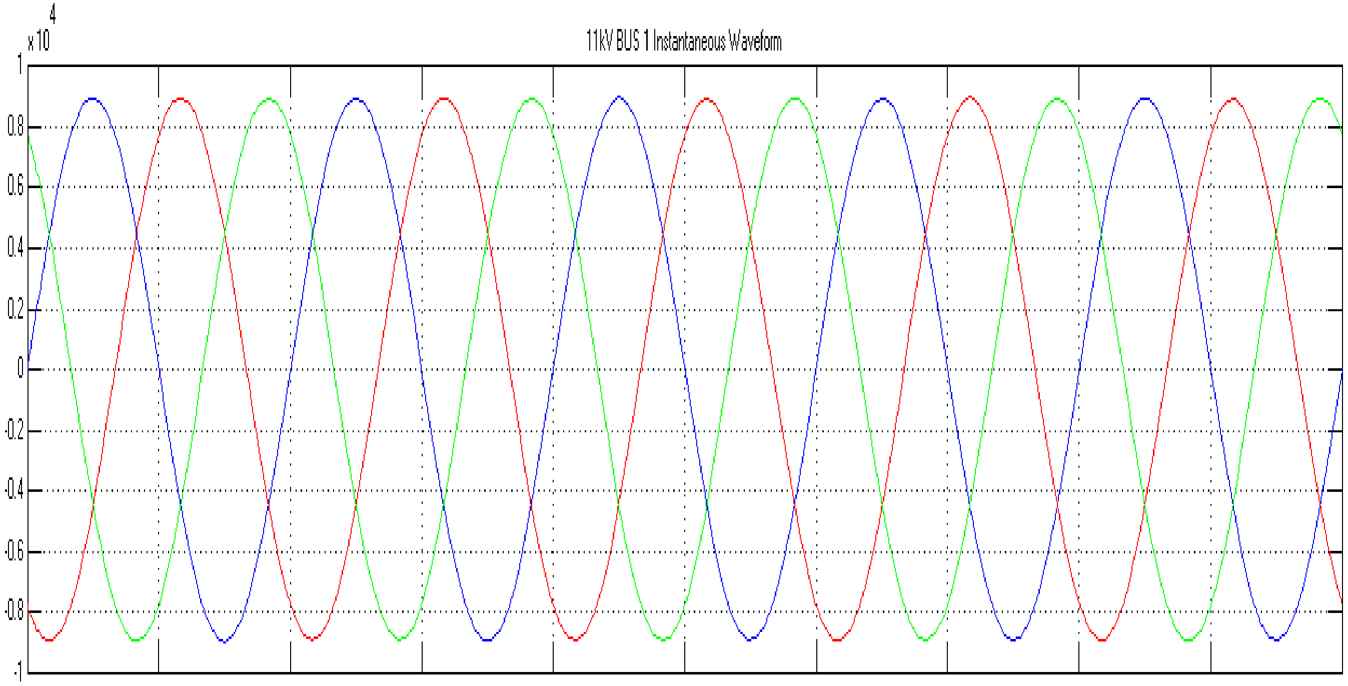

Fig. 8: Wind Turbine Output Voltage

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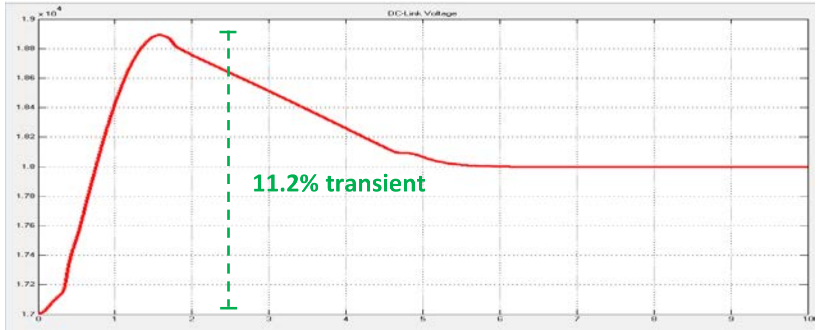
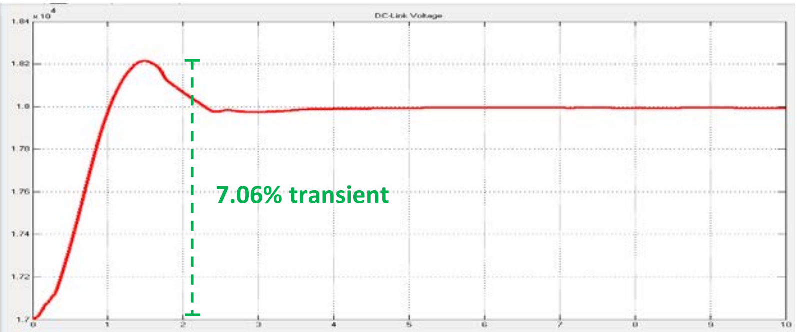
Impact of Voltage Sags on a Transformer-less Wind Energy Conversion Systems.

Type A



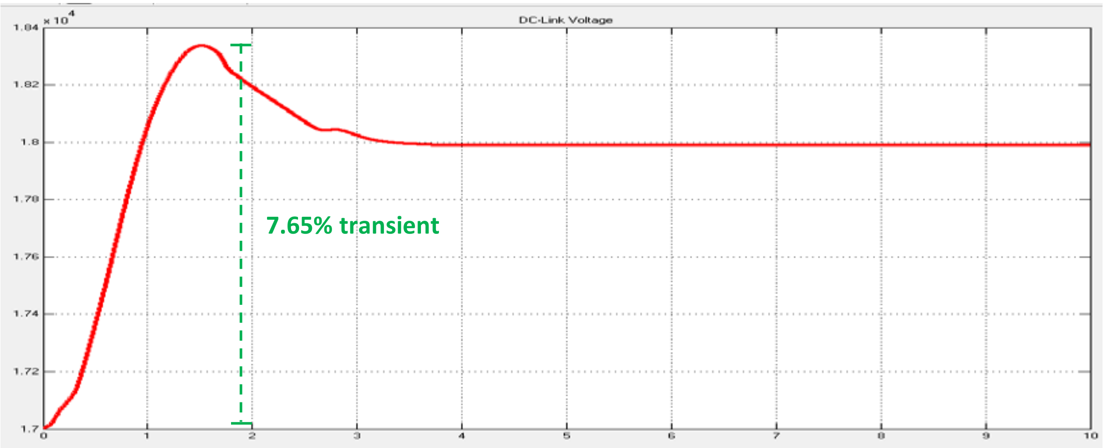
Transient overshoot in the dc-link voltage increase by 11.2% and it lasts for more than 10 minutes.

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.

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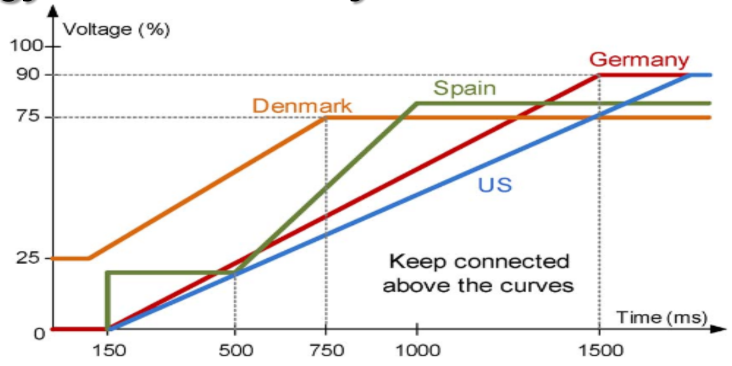
Impact of Voltage Sags on a Transformer-less Wind Energy Conversion Systems.

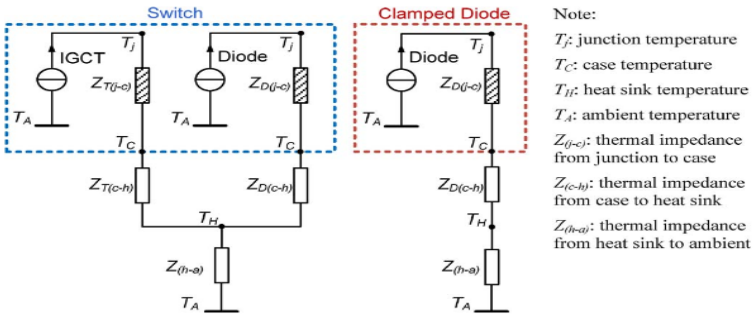
Major Impact of Voltage Sags on Wind Energy Conversion System.

Fault Ride-Through Requirement

- 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.

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Thank you very much !!!!!!