Sub-synchronous oscillations between FPC wind farms, VSC-HVDC links and nuclear power plants

Webinar: GINO Project Findings

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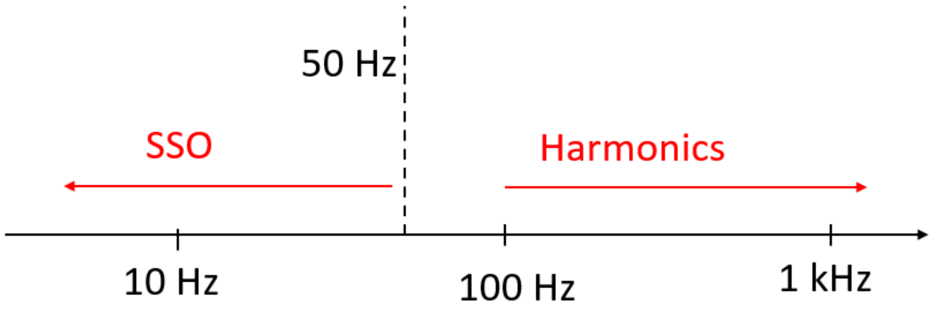
Definition of sub-synchronous oscillations, SSO

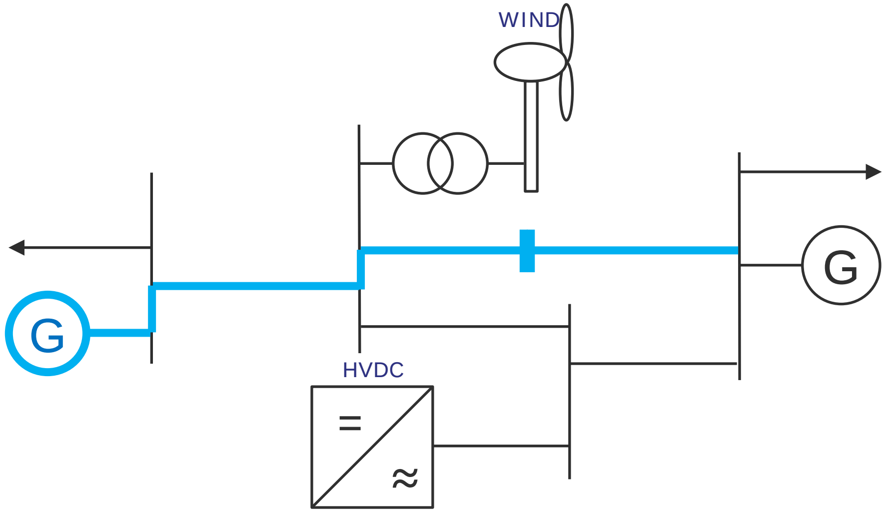
"Electro-mechanical interactions, either between a turbine-generator and passive system elements such as series capacitors, or between a turbine generator and active system elements at frequencies below the nominal frequency of the system (i.e. < 50 Hz)"

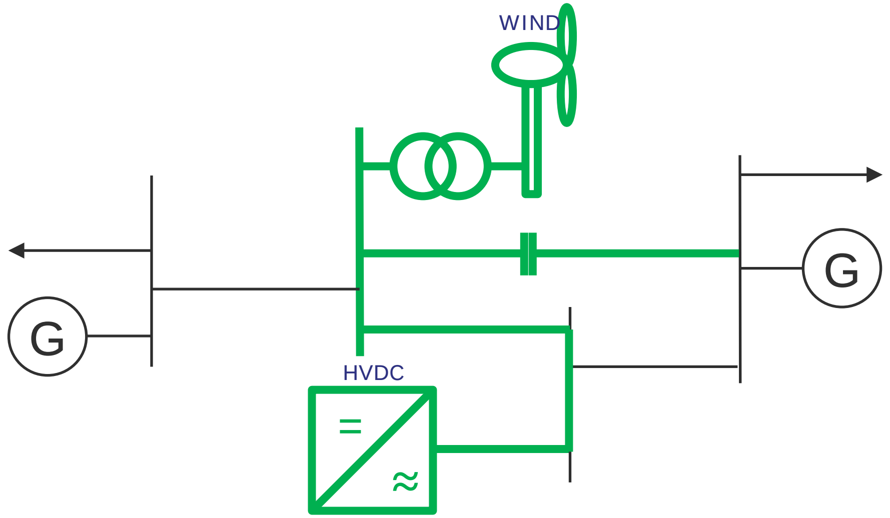


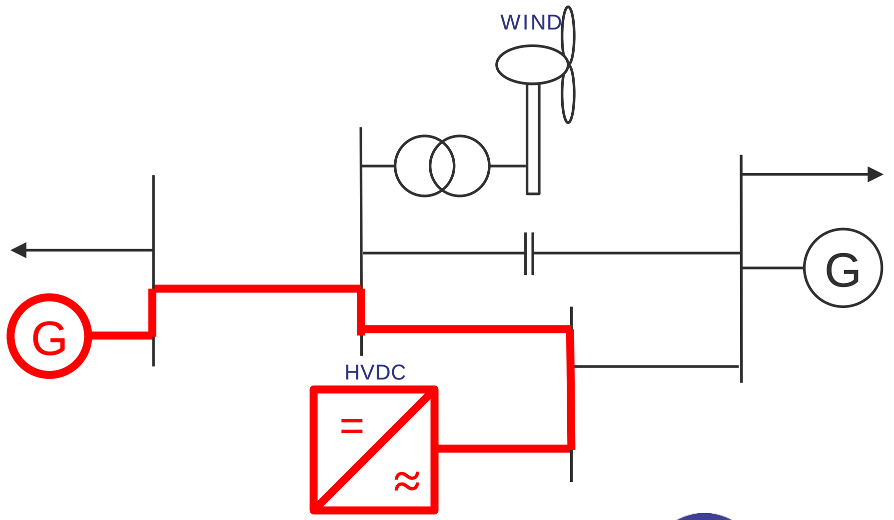
- First known occurrence in the Mohave project 1970 and 1971, including a plant and series compensated lines.
- Another incident in the Zorillo Gulf wind farm 2009, including a DFIG-based wind farm and a series compensated line.
- An increasing amount of large grid connected voltage source converters, VSC, increase the risk of experiencing SSO including these converters.

Different types of SSO

- Sub-synchronous resonance (SSR)
  Generator – Series compensation
- Sub-synchronous torsional interaction (SSTI)
  Generator – Power electronic device
- Sub-synchronous control instability (SSCI)
  Power electronic device – Other object







Aim of the project

The aim of the project is to gain a good general understanding of how VSC-HVDC links and FPC wind farms affect the existence of problematic sub-synchronous oscillation modes.

Content of the project:

- Identify and describe the different methods used for evaluating sub-synchronous oscillations.
- Evaluate the suitability of the different methods for investigating SSO between large synchronous generators and voltage source converters.
- Describe the physical construction and control for the grid connected voltage source converters.
- Implement the evaluation methods on a generic test system, focusing on oscillations between a large synchronous generator and a voltage source converter.

Evaluation of study methods

- Analytical calculations
  - Time domain analysis (eigenvalues)
  - Frequency domain analysis (transfer functions)

Requires equations for the system, gives exact answers.

Can't be used for black-box models.

- Frequency scanning
  - Complex torque method (electrical damping seen from a SG)
  - Impedance frequency scan (includes circuit parameters)
  - Impedance scanning by dynamic simulations (includes controls and black-box models)

Larger systems can be used since these methods are based on simulation models.

Using controls and black-box models requires a scanning using dynamic simulations.

- Time domain simulations (includes non-linearities)

Used to verify the results obtained from the other study methods.

Evaluation of study methods

- Limitations of the study methods – which methods are suitable for SG – VSC?

	Non-linear	Black-box	Includes controls	nv. Subsyst.	Time efficient
Analytical – time domain			X		
Analytical – frequency domain			X	X	
Complex torque method		X	X		
Impedance frequency scan					X
Impedance/admittance scan by dynamic simulations		X	X	X	
Time domain simulations	X	X	X		

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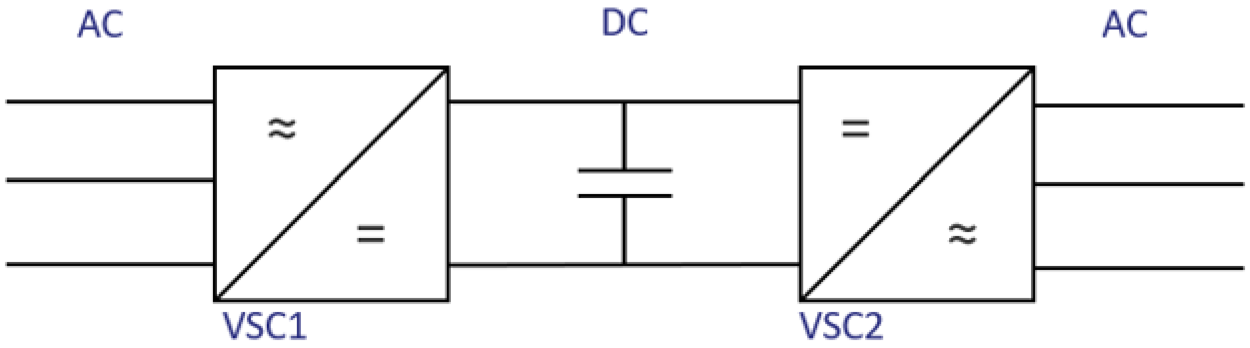
Voltage source converters, VSC

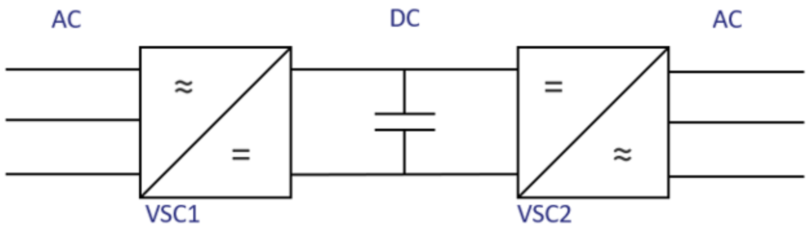
- Similar concept for VSC converters independent on the power level.

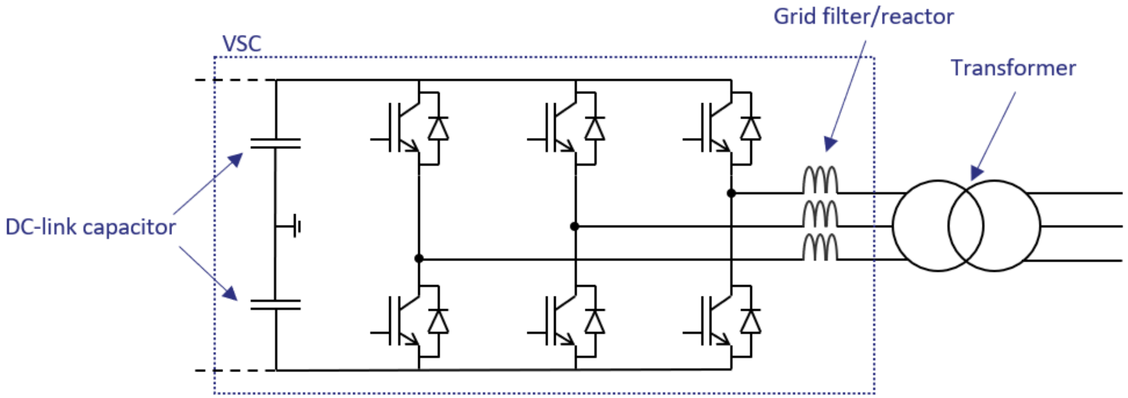


- A voltage source converter consists of force commutated valves and can operate independently of the AC grid.

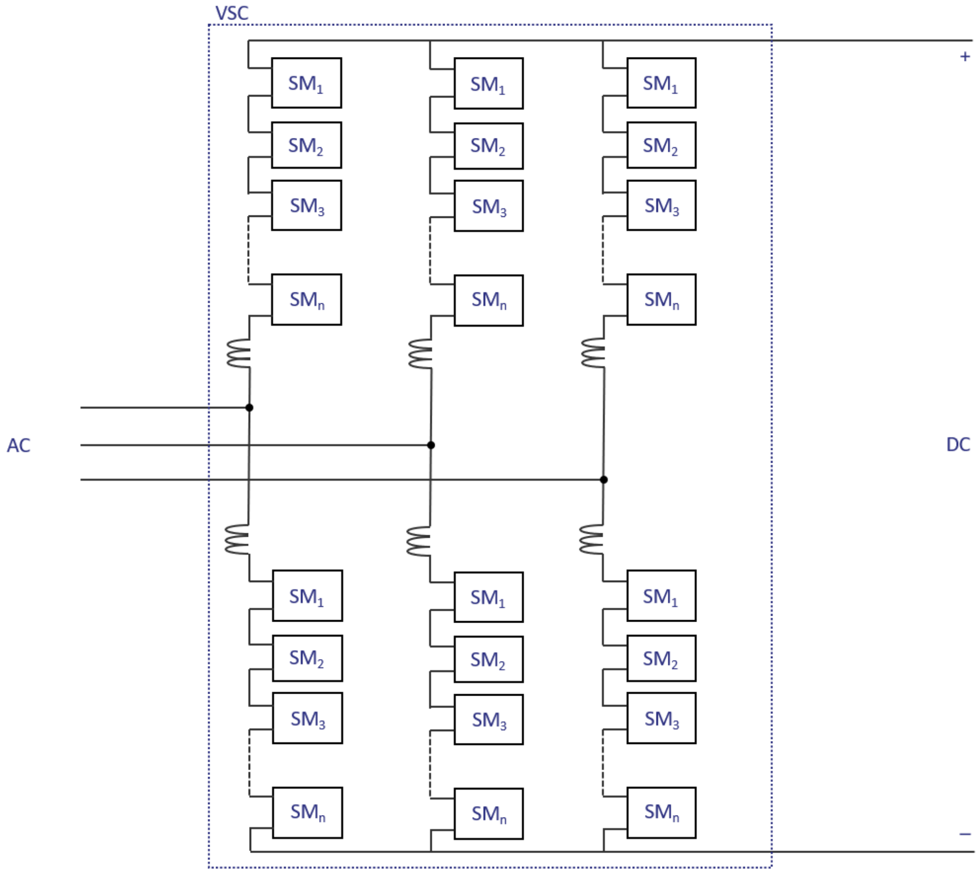
Voltage source converters, VSC

- Many possible topologies, two examples are the two-level converter and the modular multi-level converter.





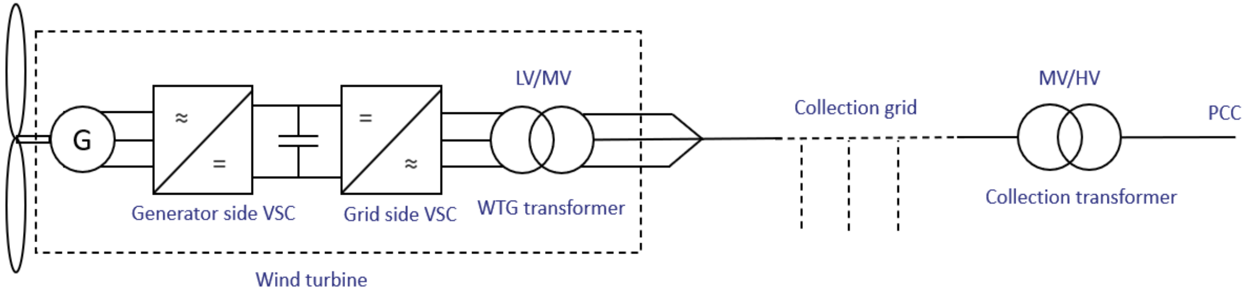
Two-level converter

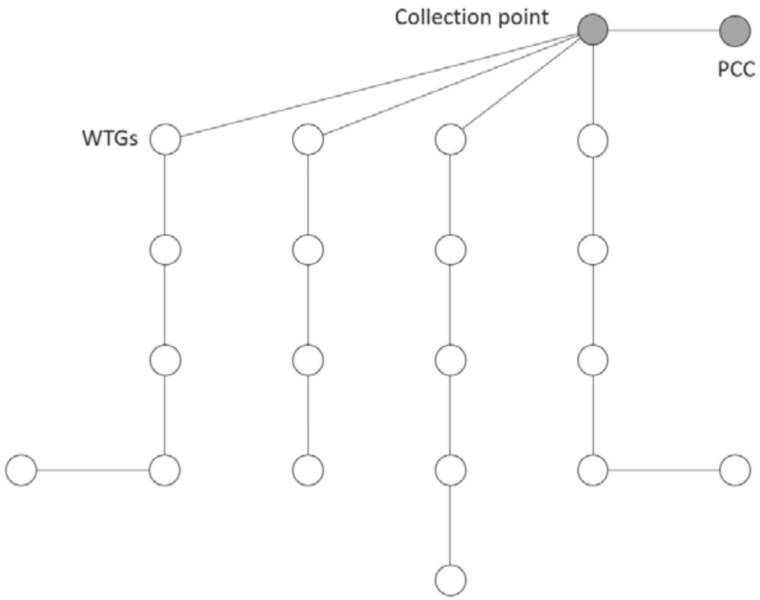


Modular multi-level converter

Wind park layout

- For a wind park there is one VSC in each converter

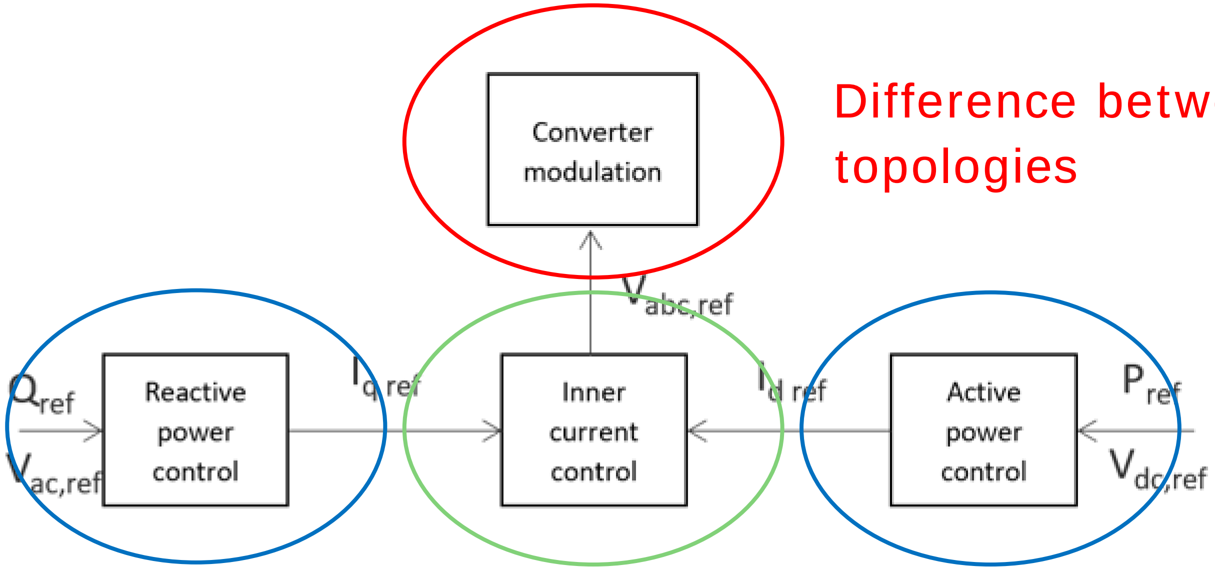




- The control of the generator is made in each turbine.
- The control of the park is made in the park controller.
- The park can be modelled as a large aggregated converter model.

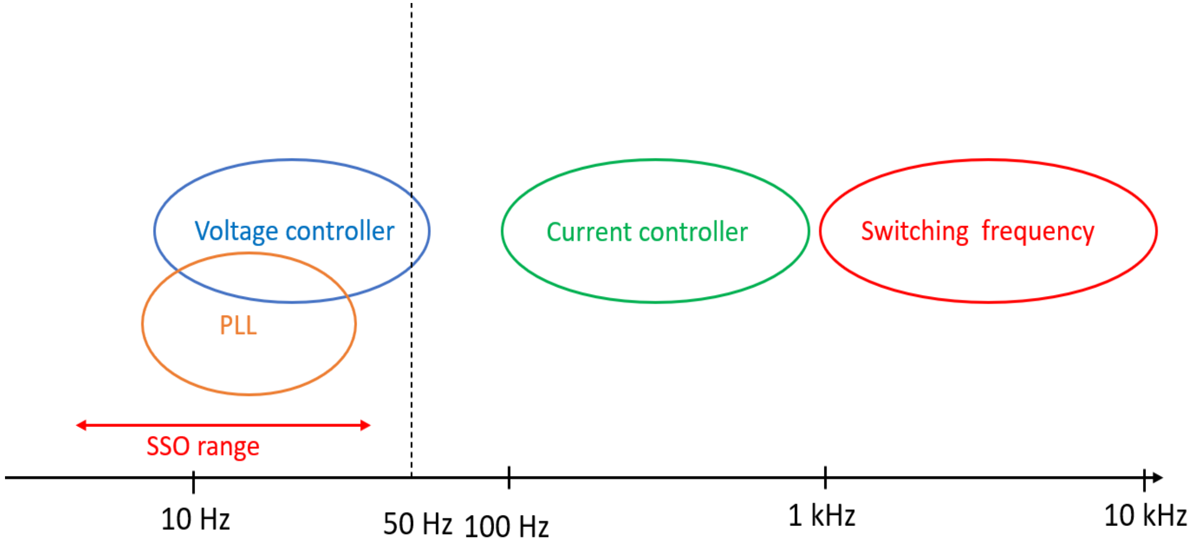
Converter dynamic operation

- Control principle:



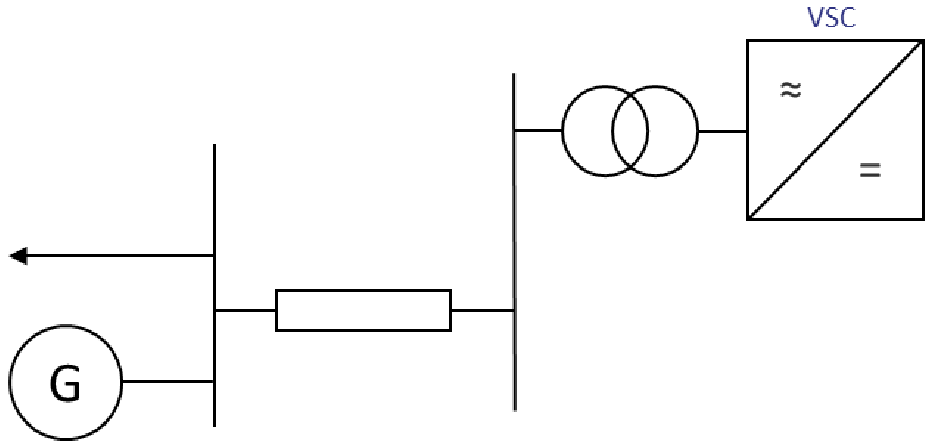
Difference between topologies

- Control bandwidths:



Evaluation of SSO using a generic test system

- Simple generic test system



- A large generator connected to an equivalent grid and the VSC is connected to the generator bus via an impedance.
- One transformer between the VSC and the transmission system, such as for HVDC.
- Known torsional modes for the generator at 16 Hz and 28 Hz.
- The purpose is to evaluate the test methods and illustrate possible results.

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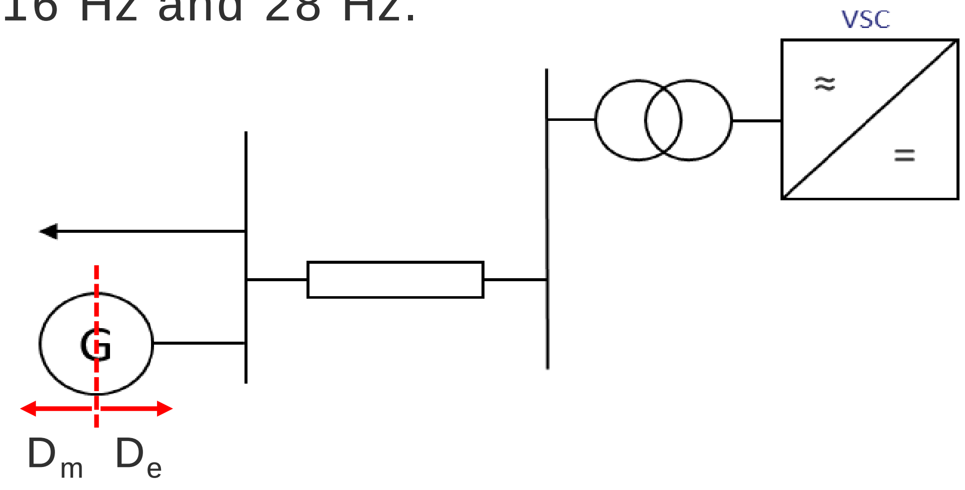
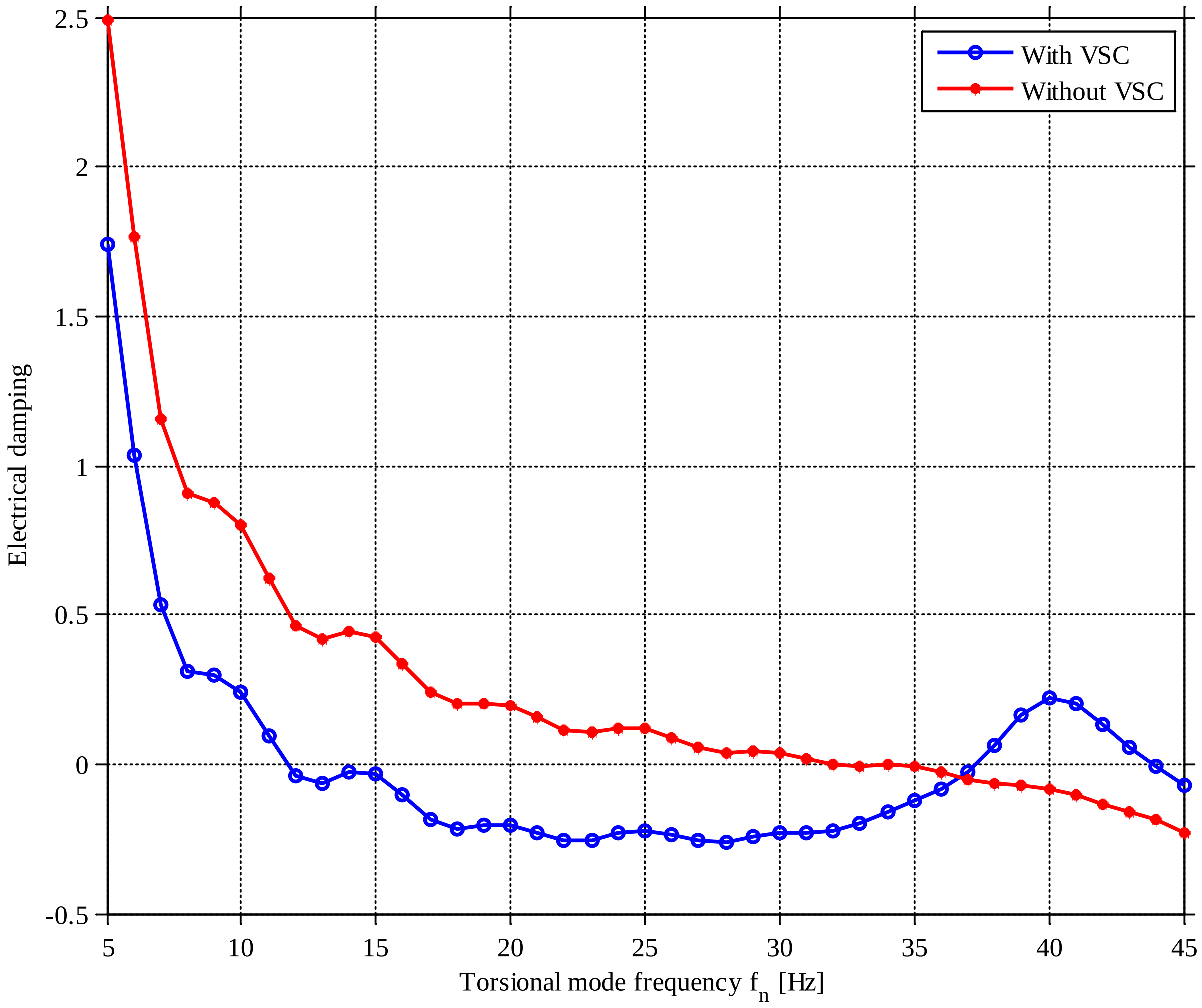
Evaluation using complex torque method

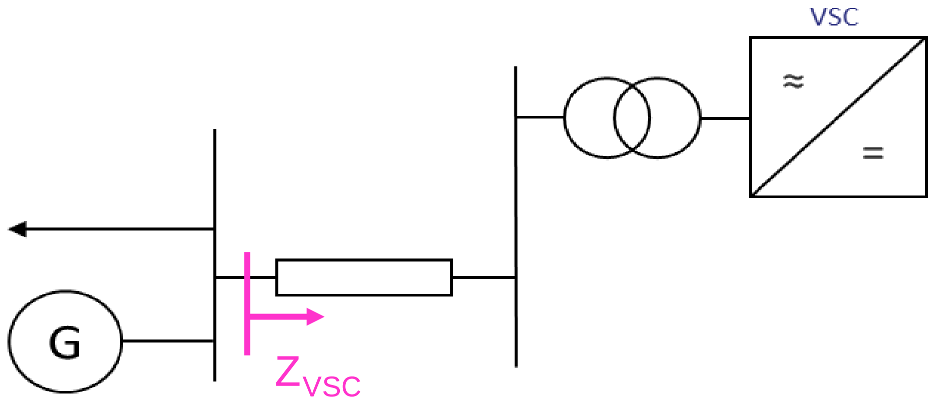
- Complex torque gives the electrical damping D_e seen from the generator.
- Shows the impact of the VSC on the electrical damping.
- With the VSC connected there is a negative electrical damping at the torsional modes 16 Hz and 28 Hz.

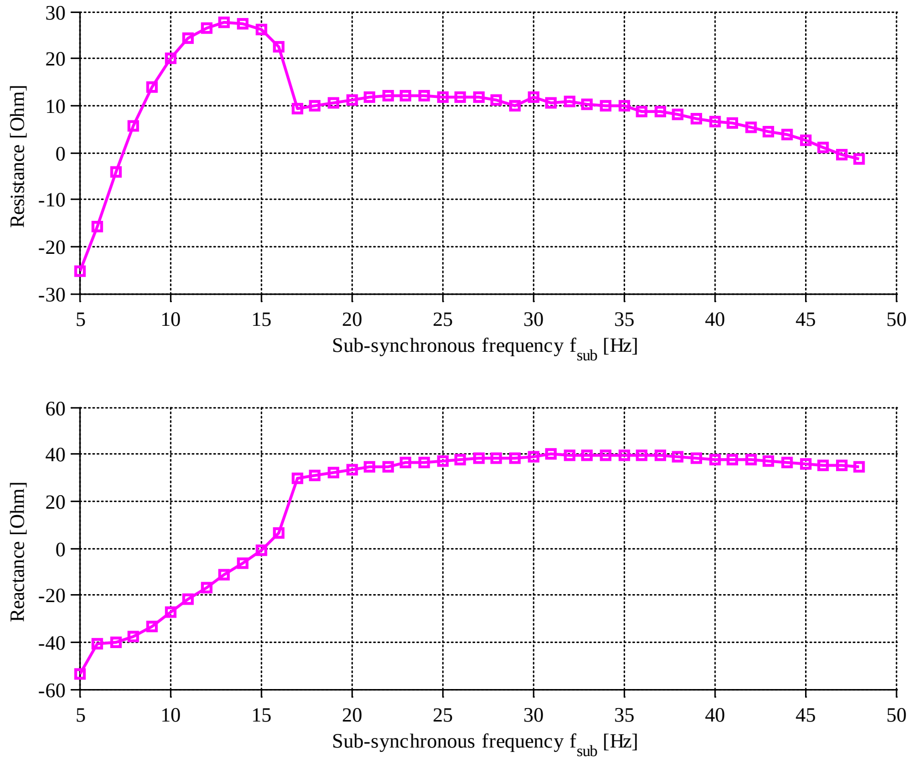




Evaluation using impedance scanning

- The impedance scanning is made from the generator bus towards the VSC.
- Small positive resistance at sub-synchronous frequencies.
- The sub-synchronous resistance for the generator is not included.





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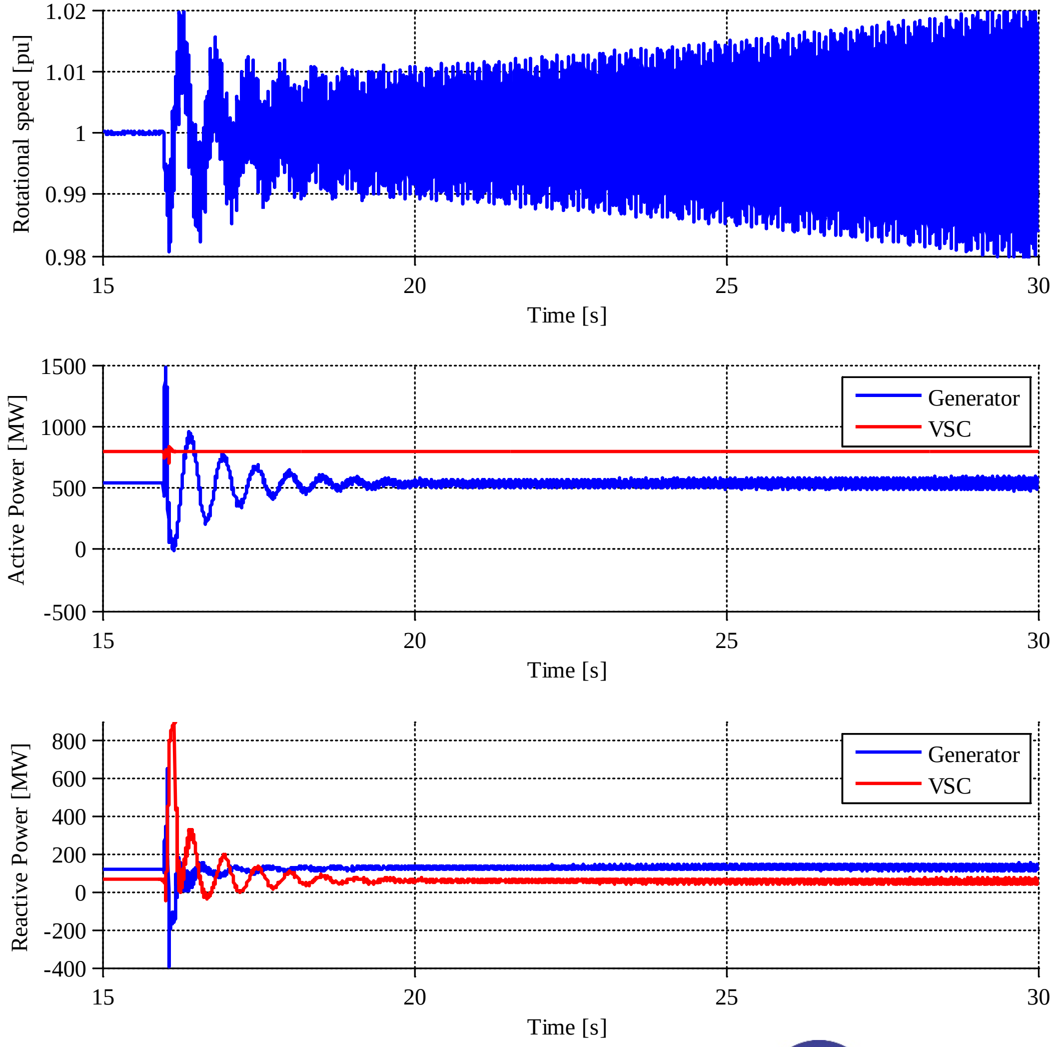
Evaluation using time domain simulations

- A short high-impedance fault is made to trigger the oscillations.
- Amplified oscillations occur at about 28 Hz, which is one of the torsional frequencies of the generator.
- For the VSC, there are oscillations in the reactive power but not in the active power.
- This indicates that the AC voltage controller can be a reason for the oscillations.



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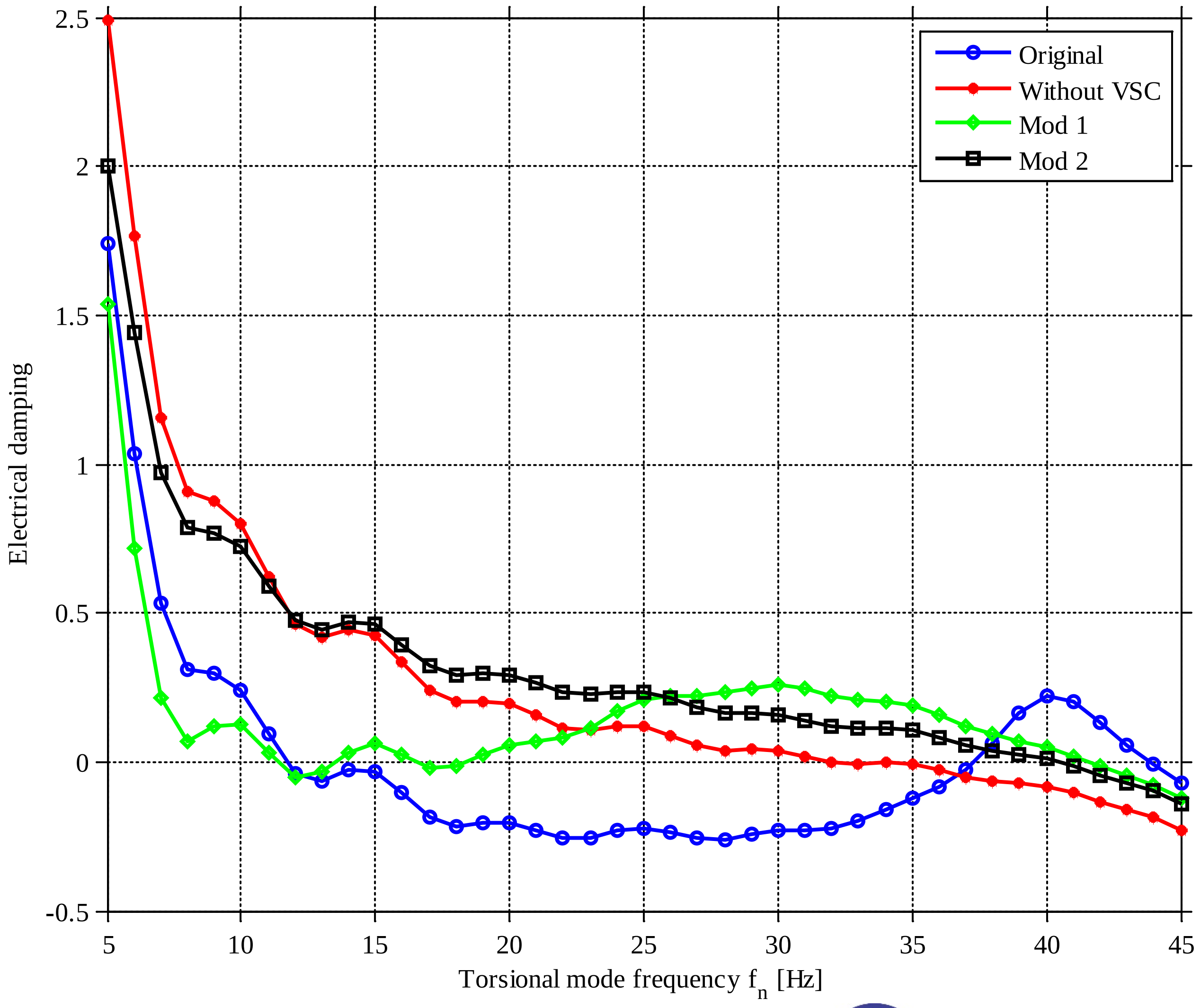
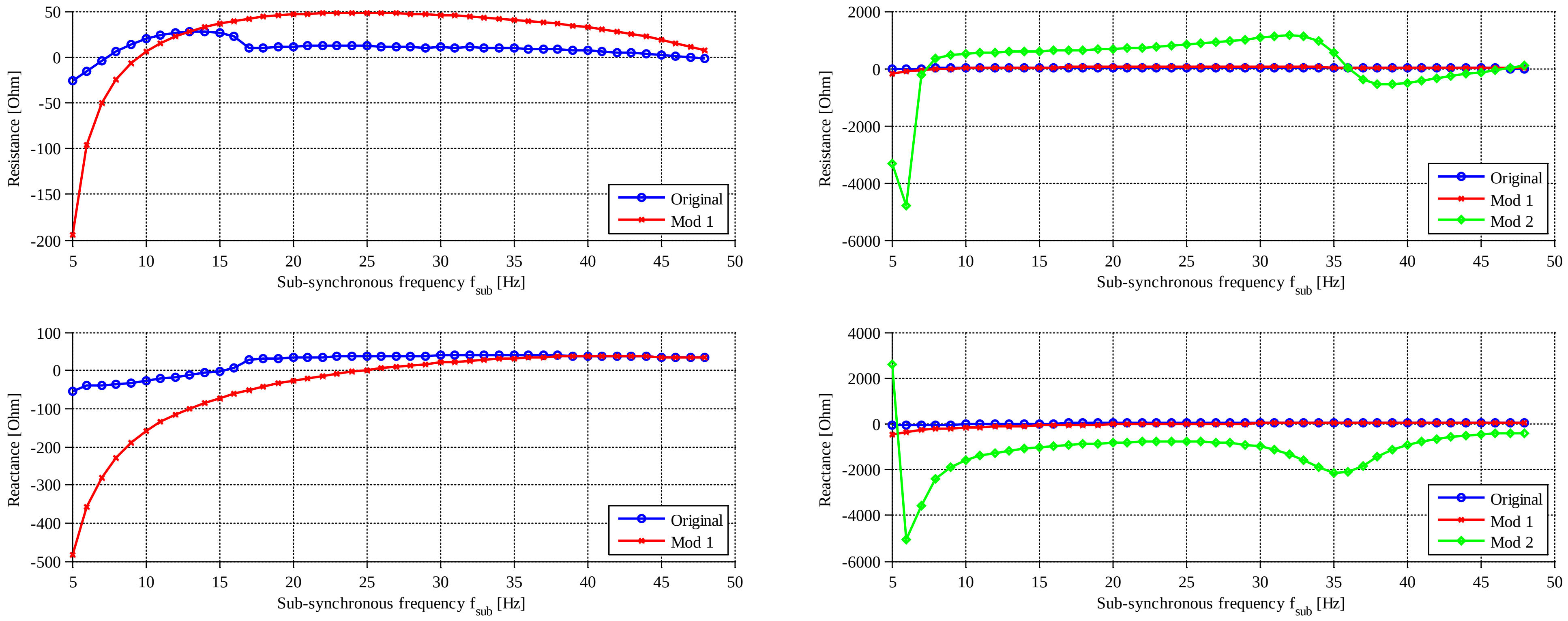
Control parameter variations

- To study the impact of the controller, two modifications are made:
  - Mod 1: Decrease the AC voltage gain to 20% of the original value.
  - Mod 2: Change to reactive power controller.
- Changing the control parameters has a large impact on the electrical damping.



Control parameter variations

- Changing the control parameters has a large impact on the sub-synchronous impedance of the VSC.



Control parameter variations

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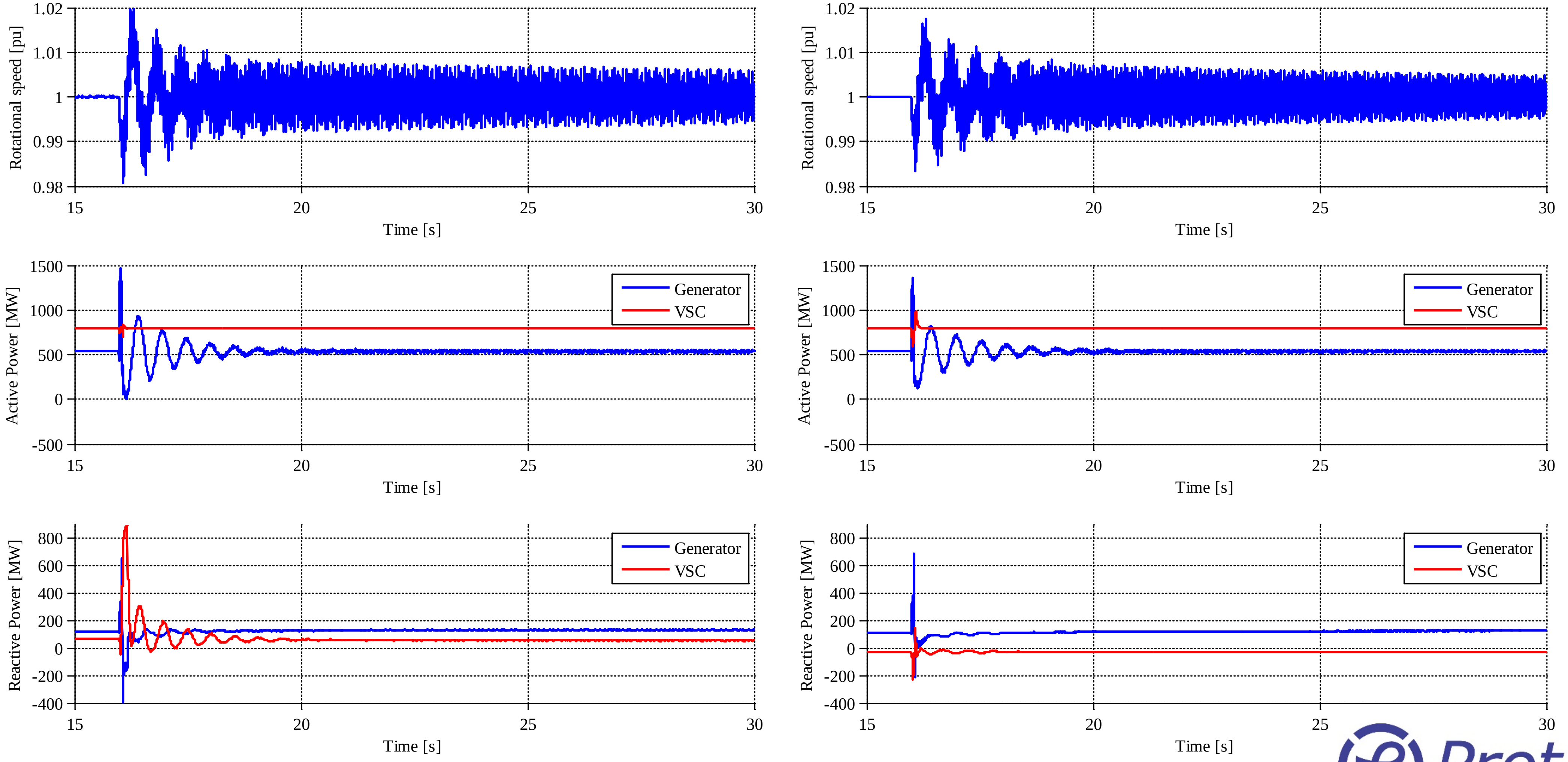


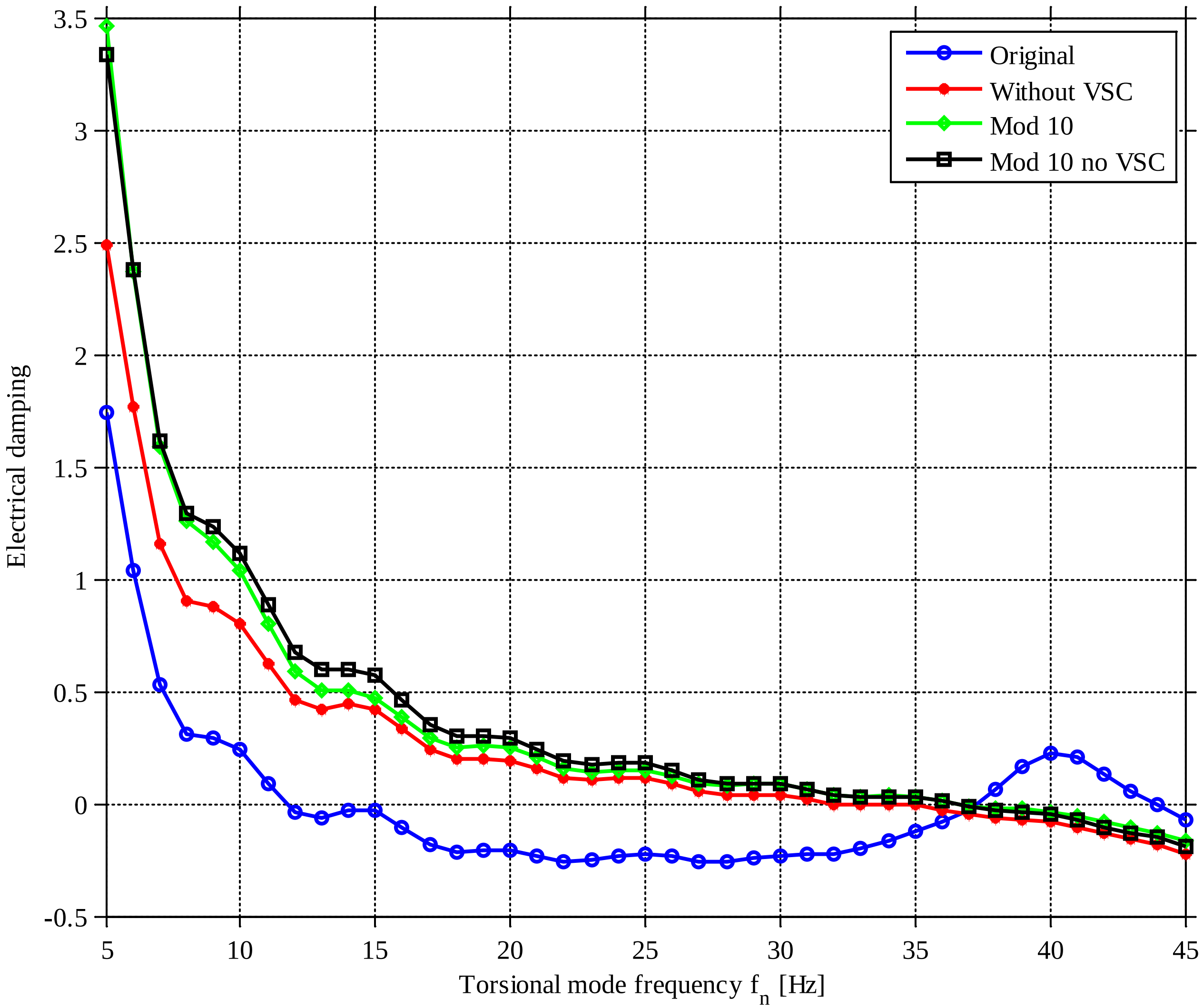
Mod 1

Mod 2

Impact of the grid strength

- To study the impact of the grid strength, one modification is made:
  - Mod 10: Increase the short circuit power for the grid to 10 times the original value.

- In case of a strong grid connection, the VSC has a very small impact on the electrical damping seen from the generator.



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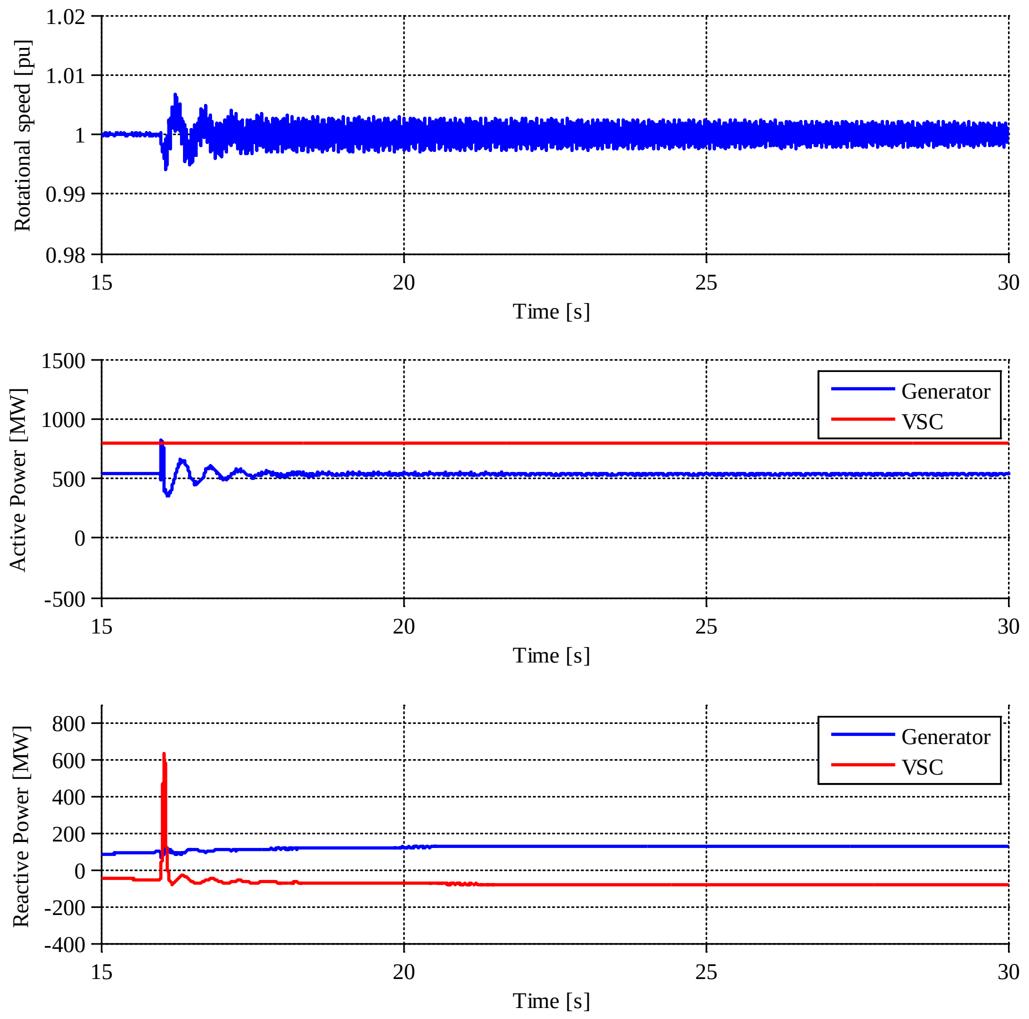
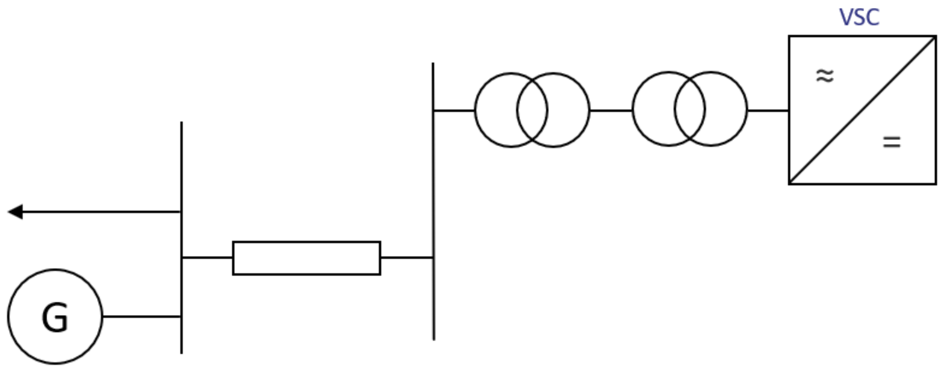
Impact of the grid strength

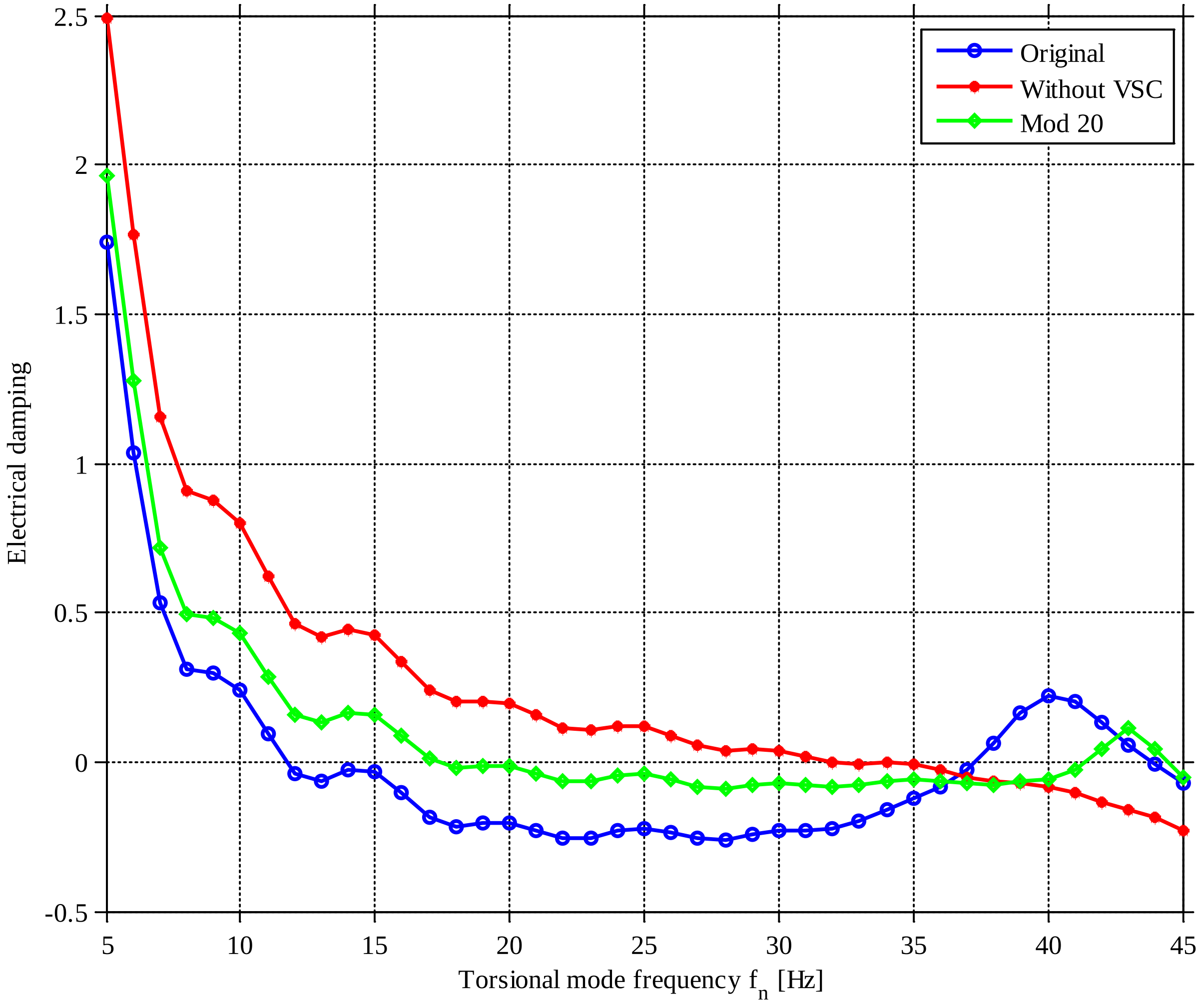
- Time domain simulations verify that there will not be any amplified sub-synchronous oscillations in case of a strong grid connection.



Impact of an additional transformer

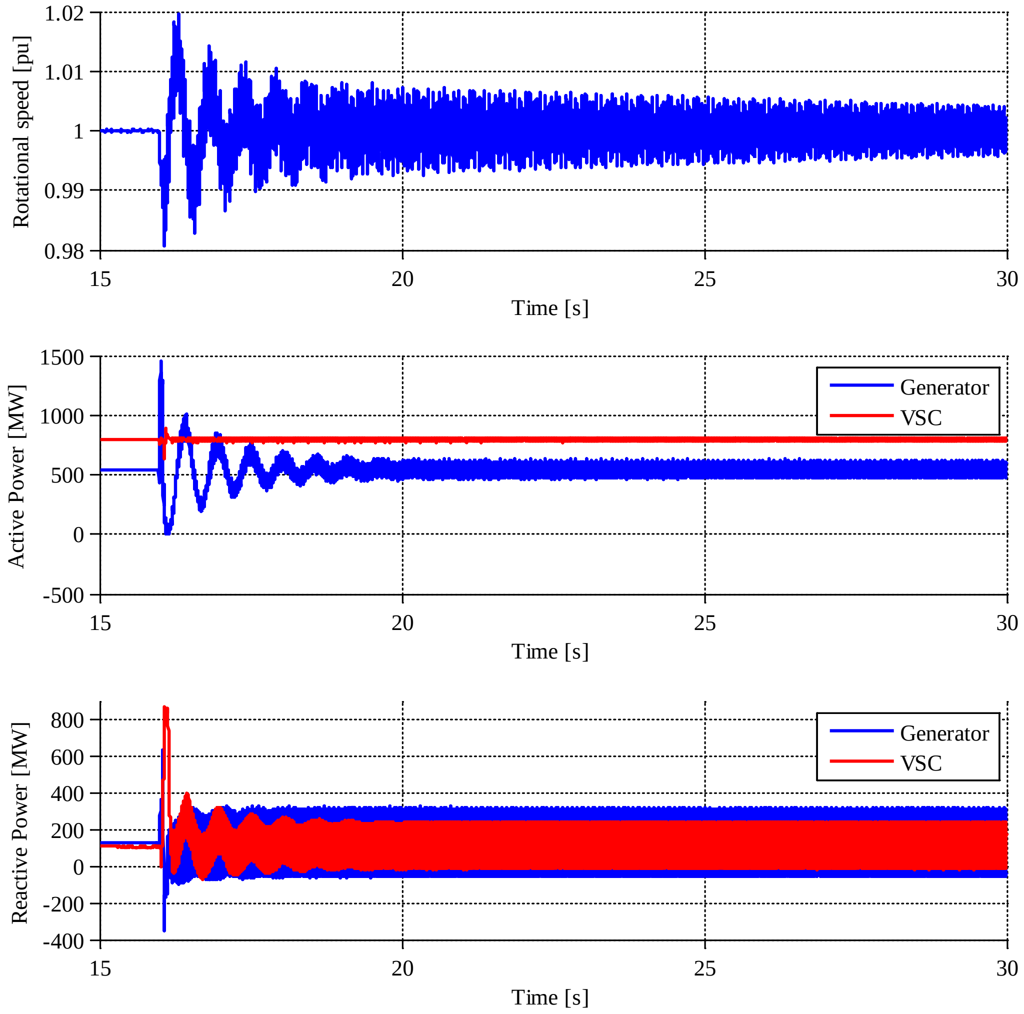
- An additional transformer is added study the impact of wind turbine converters that are located at a lower voltage level:
  - Mod 20: Add one additional transformer with ratio 1:1 between the VSC transformer and the VSC bus.
- An additional transformer increases the electrical damping.





Impact of an additional transformer

- Impact of an additional transformer.
  - The fast AC voltage controller has an unacceptable performance in case of a weaker grid.
  - There are no amplified oscillations including the torsional modes in the generator.



Summary for risk of SSO

- A strong grid connection will reduce the risk of SSO.

- A larger impedance between the generator and the VSC will reduce the risk of SSO.

- The controller of the VSC has a very large impact of SSO.

NOTE: The results shown here are for this specific illustration. The converter characteristics can vary significantly between different converters and therefore each converter must be studied individually.

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Summary about the study methods

- Complex torque method:
  - Gives the electrical damping seen from the generator.
  - Can show the impact of a VSC but not the characteristics of the VSC itself.
  - Suitable method for oscillations including a synchronous generator.
- Impedance scanning by dynamic simulations:
  - Gives the sub-synchronous impedance of an object.
  - Can give the characteristics of any chosen system, such as the VSC itself.
  - Suitable method if no synchronous generator is included
- Time domain simulations:
  - Used to verify the results.
  - Include non-linear characteristics.

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Thank you

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