Modelling grid connected VSCs for small-signal stability studies

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Content

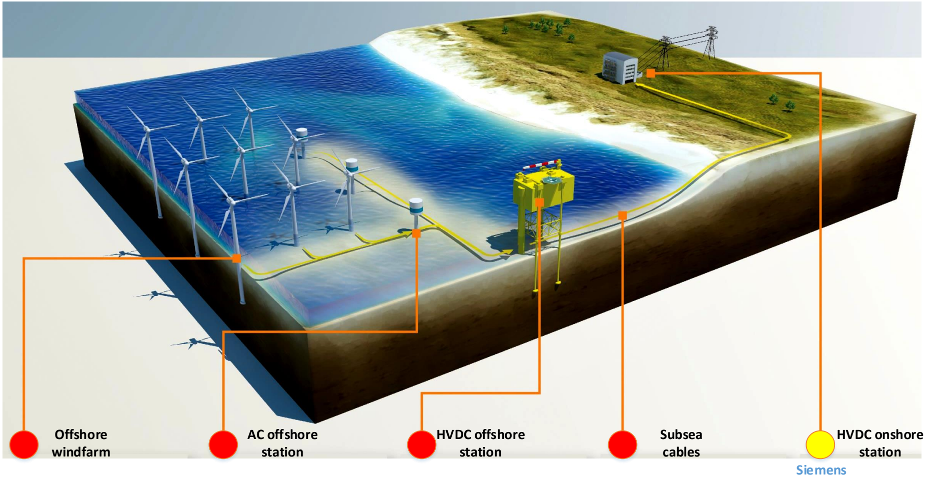
Introduction

- Widely use of power electronic converters on electrical grids.
- Interactions between the converters and electrical networks.
- Oscillations and instabilities might appear.

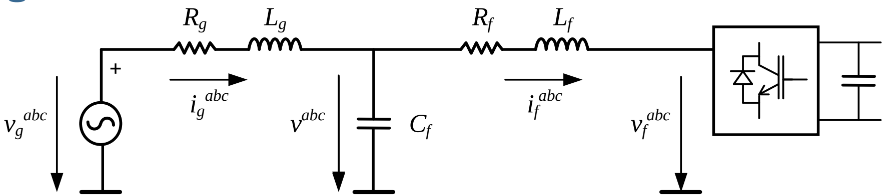
Objectives

- Stability assessment for grid connected VSCs.
- Small-signal state-space and impedance-based modelling.

Testing network



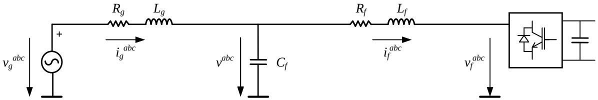
Modelling



Parameter	Symbol	Value	Units
Power	P	1	GW
Voltage	V	400	kVrms
Grid X/R ratio		10	
Resistance	R_f	0.2372	Ω
Inductance	L_f	0.0750	H
Capacitance	C_f	1	μF

Control Structure

- Grid-connected VSC
- Averaged two-level model



Control Structure

- Grid-connected VSC
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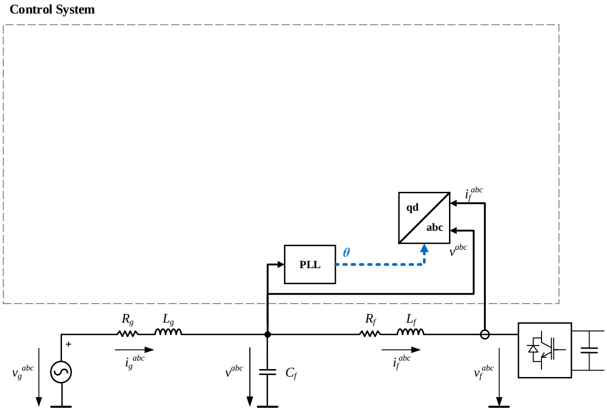
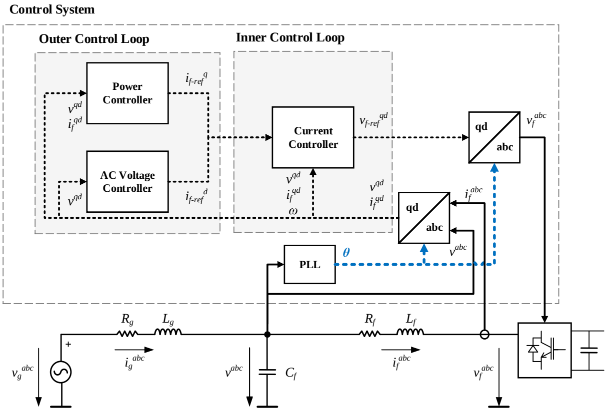
- Vector control strategy

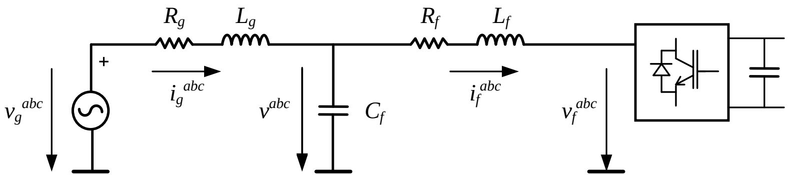


Control Structure

- Grid-connected VSC
- Averaged two-level model
- Vector control strategy
- Two-level cascaded controller
- Active power and AC voltage control



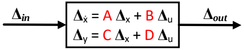
Modelling

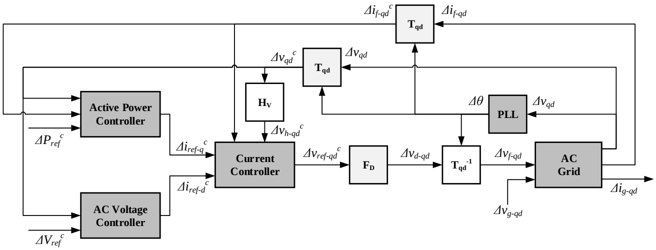


	Simulink	Impedance-based	State-space
Inner loop	✓	✓	✓
Feed-forward voltage filter	✓	✓	✓
PLL	✓	✓	✓
Outer loop	✓	✓	✓
Delay	✓	✓	✓

Modelling: State-space

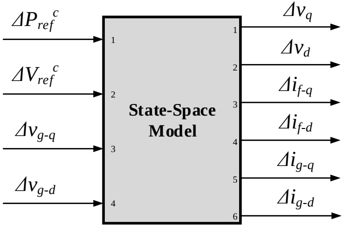
System of linear equations in the time-domain





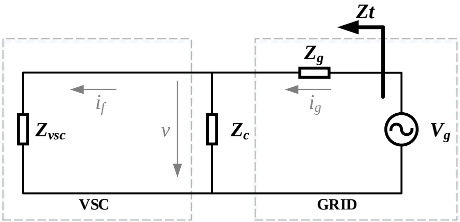
State-space matrix

- 4 inputs and 6 outputs
- 16 states



Modelling: Impedance-based

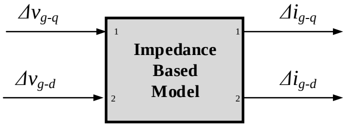
Impedance characterization of the system



$$\Delta V = \mathbf{Z_{vsc}} \Delta I_f$$
$$\Delta V = \mathbf{Z_c}(\Delta I_g - \Delta I_f)$$
$$\Delta V_g = \Delta V + \mathbf{Z_g} \Delta I_g$$

Transfer function in the *s*-domain

- 2 inputs and 2 outputs

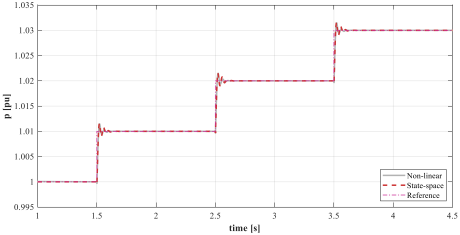


- A matrix of four 16th order transfer functions.

$$\mathbf{Y_T} = \begin{bmatrix} Y_{qq} & Y_{qd} \\ Y_{dq} & Y_{dd} \end{bmatrix}$$

Validation: Non-linear vs state-space

- Non-linear Simulink and linearized state-space model have been compared.
- Time-domain simulation for a $SCR = \mathbf{3}$
- 0.01 pu step variation of active power up to 0.03 pu



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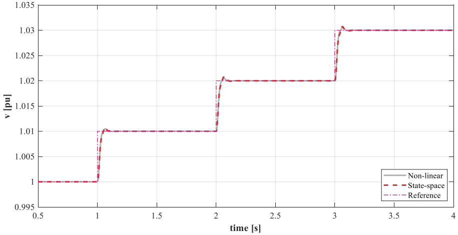
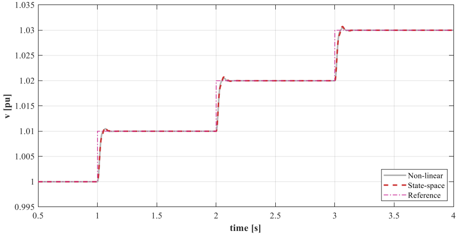
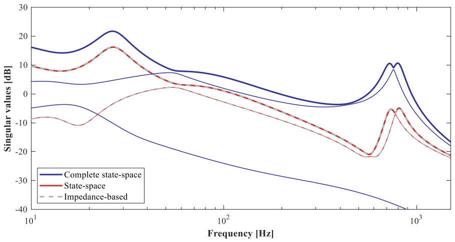
- 0.01 pu step variation of AC voltage up to 0.03 pu





Validation: Impedance-based vs state-space

- The impedance-based transfer function is given by the admittance seen from the grid side : $\frac{i_g}{v_g}$
- State-space model inputs and outputs have been selected for comparison purposes.



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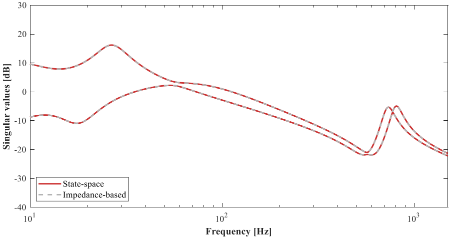

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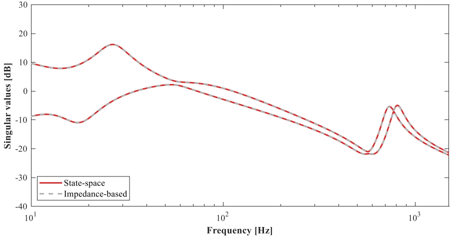
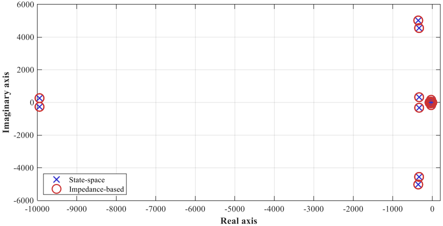
- The the singular values of the system frequency response and eigenvalues **match**.





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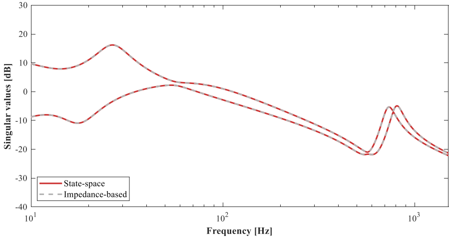
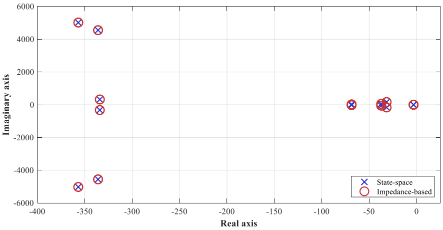
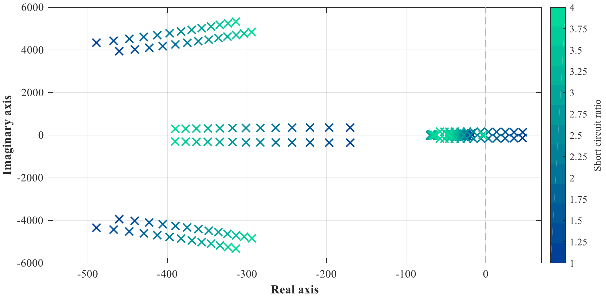




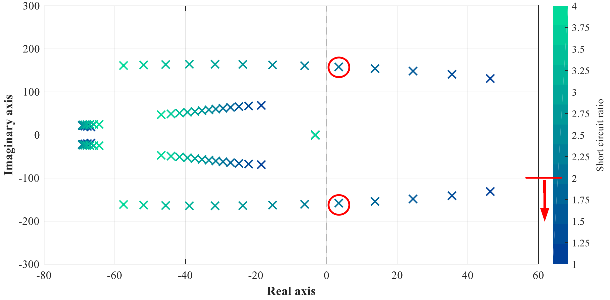
Sensibility analysis of the strength of the grid

- Eigenvalues and singular values for different SCRs.



Stability assessment: Eigenvalues

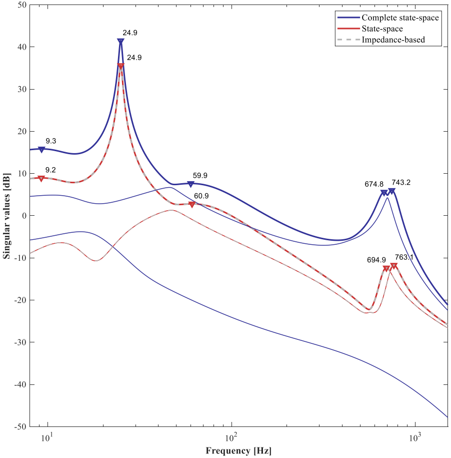
- Eigenvalues and singular values for different SCRs.
- The system becomes unstable for:
  - $SCR = \mathbf{2}$



Stability assessment: Singular values

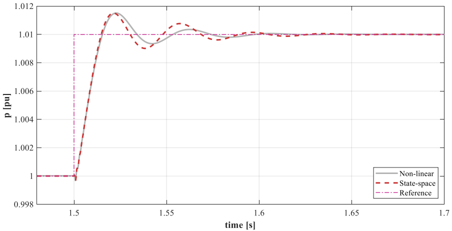
- Oscillations in the sub-synchronous and harmonic range.

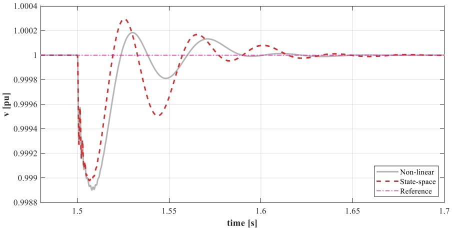
Mode	Real	Imaginary	Damping	Frequency [Hz]
9	**3,49**	**156,65**	**-0,022**	**24,93**
10	**3,49**	**-156,65**	**-0,022**	**24,93**
3	**-410,67**	**4691,06**	**0,087**	**746,61**
4	**-410,67**	**-4691,06**	**0,087**	**746,61**
5	-392,36	4256,68	0,092	677,47
6	-392,36	-4256,68	0,092	677,47
13	-28,99	62,18	0,423	9,90
14	-28,99	-62,18	0,423	9,90
7	-264,28	345,50	0,608	54,99
8	-264,28	-345,50	0,608	54,99
11	-69,14	21,97	0,953	3,50
12	-69,14	-21,97	0,953	3,50
1	-9949,47	265,92	1,000	42,32
2	-9949,47	-265,92	1,000	42,32
15	-3,16	0,00	1,000	0,00
16	-3,16	0,00	1,000	0,00



Stability assessment

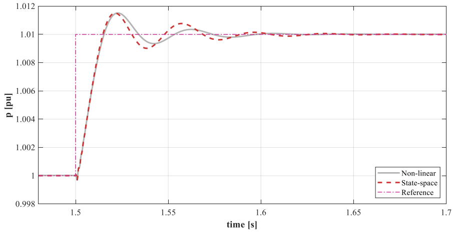
- 0.01 pu step in active power at 1.5 sec. for:
  - $SCR = \mathbf{3}$
- AC voltage oscillations

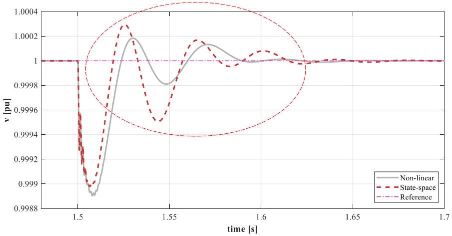




Stability assessment: Sub-synchronous and harmonic oscillations

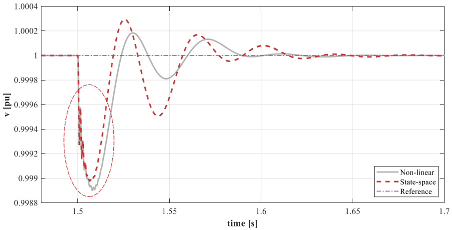
- 0.01 pu step in active power at 1.5 sec. for:
  - *SCR* =**3**
- AC voltage oscillations
  - Sub-synchronous

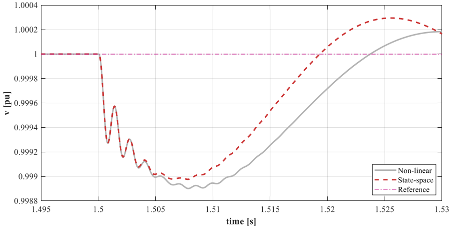




Stability assessment: Sub-synchronous and harmonic oscillations

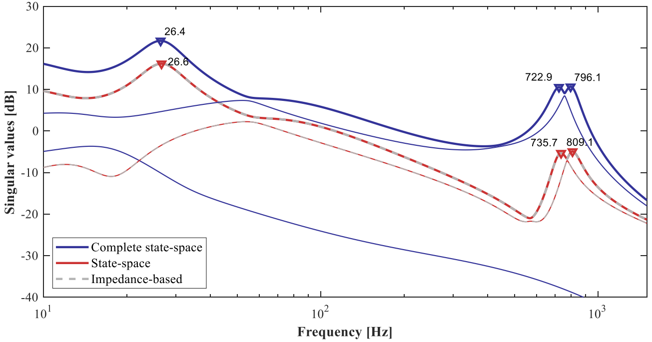
- 0.01 pu step in active power at 1.5 sec. for:
  - $SCR = \mathbf{3}$
- AC voltage oscillations
  - Sub-synchronous
  - Harmonic





Stability assessment: Sub-synchronous and harmonic oscillations

- 0.01 pu step in active power at 1.5 sec. for:
  - $SCR = \mathbf{3}$
- AC voltage oscillations
  - Sub-synchronous: 26 Hz
  - Harmonic: 722-809 Hz



Conclusion

- Both methodologies can determine the oscillatory phenomena of a system.
- The linearized state-space model closely reproduces the dynamics of a non-linear Simulink model.
- The oscillation frequency of **unstable poles** matches for the complete state-space and impedance-based models.
- The oscillation frequency of **stable** poles has proved to be challenging. There is a slight variation in the oscillation frequency between the complete state-space and the impedance-based models.

Thanks for your attention!

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