A Scaling method for a multi-terminal DC experimental test rig

6th HVDC Colloquium
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Modelling of HVDC systems

- *Simulation models:*
  - Not always accurate
  - Impractical simulation times in very complex systems

Alternatives

- *Experimental test rigs*
- *Real time simulators*
- *Hardware-in-the-loop (HIL):* Experimental test rig+ Real time simulator

Problem: Experimental test rig only for a limited number of configurations and specifications

Scaling a test system

- Experimental results are reliable if the test rig is a close representation of a test system
- What does it mean to scale a system?
  – Process to represent a test system with an experimental test rig

Test rig

Run experiments

Scale-up experimental results to represent test system

MEDOW MULTI-TERMINAL DC GRID FOR OFFSHORE WIND

CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD

Scaling a test system

HVDC system 1

Design to match HVDC system specifications

Test rig

HVDC system 2

HVDC system 3

Test rig is not designed to represent HVDC system 2 and 3

- 2 possible solutions:

Change configuration or specifications of test rig

Apply correction with VSC

PEOPLE

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MEDOW
MULTI-TERMINAL DC GRID FOR OFFSHORE WIND

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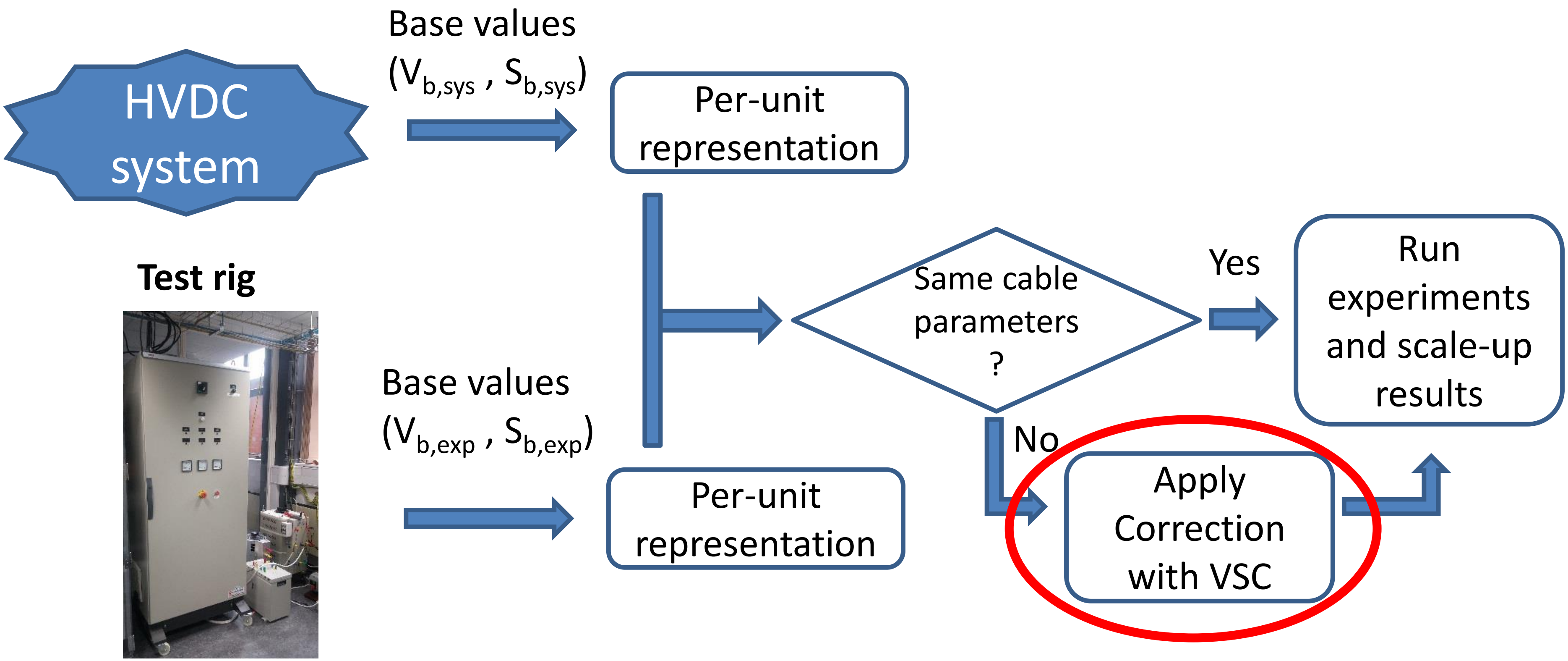
Proposed procedure



PEOPLE

DC per-unit representation

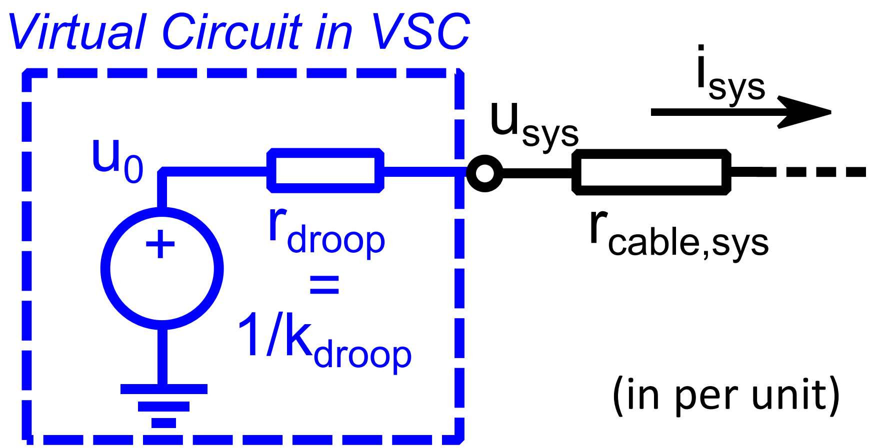
- In DC systems, L and C are not defined as impedances due to the lack of base frequency
- *Energy method [1]:* dynamic response represented with the energy stored in L and C

Quantity	Expression
Power	P_b
Voltage	U_b
Current	$I_b = {}^{P_b}/_{U_b}$
Impedance	$Z_b = {}^{U_b}/_{I_b} = {}^{U_b^2}/_{P_b}$
Resistance	$R_b = Z_b$
Inductance	$L_b = 2Z_b$
Capacitance	$C_b = 2/Z_b$

[1] T. M. Haileselassie. Control, Dynamics and Operation of Multi-terminal VSC-HVDC Transmission Systems. PhD thesis, Norwegian University of Science and Technology, 2012.

Droop control correction

- In this study only the **cable resistance** is modified→ **correction of steady state results**
- Droop control implemented in VSC represents:
  - Voltage source, u_0
  - Virtual resistance, r_{droop}

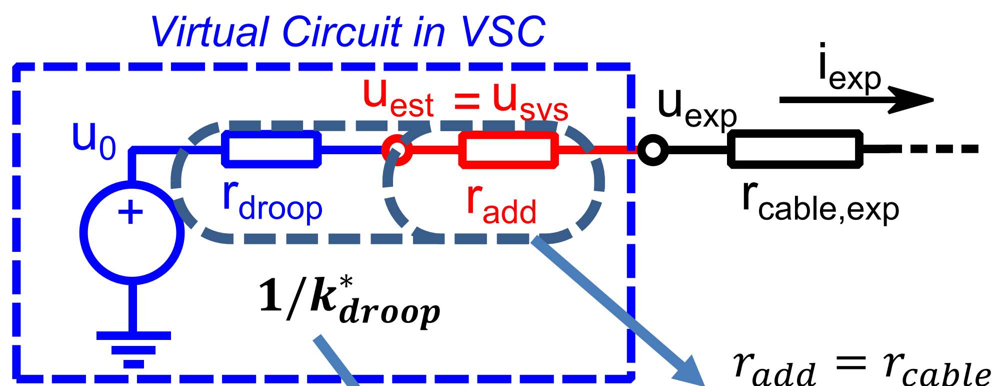


$$i_{sys} = k_{droop}(u_{sys} - u_0)$$

(in per unit)

Droop control correction

- In experimental test rig the virtual resistance compensates the difference with the HVDC test system:



$$i_{exp} = k^{*}_{droop}(u_{exp} - u_0)$$

(in per unit)

$$r_{add} = r_{cable,sys} - r_{cable,exp}$$

$$\frac{1}{k^{*}_{droop}} = \frac{1}{k_{droop}} + \frac{1}{k_{add}} = r_{droop} + r_{add}$$

Droop control correction

- Estimation of results from experiments (in per-unit)
  - DC current: $i_{sys} = i_{exp}$
  - DC voltage: $u_{sys} = u_0 - i_{exp} r_{droop}$
  - DC power: $p_{sys} = u_{sys} i_{exp}$
- Scale-up the results from base values of the HVDC system:

$$I_{sys} = I_{b,sys}\, i_{sys}$$

$$U_{sys} = U_{b,sys}\, u_{sys}$$

$$P_{sys} = P_{b,sys}\, p_{sys}$$

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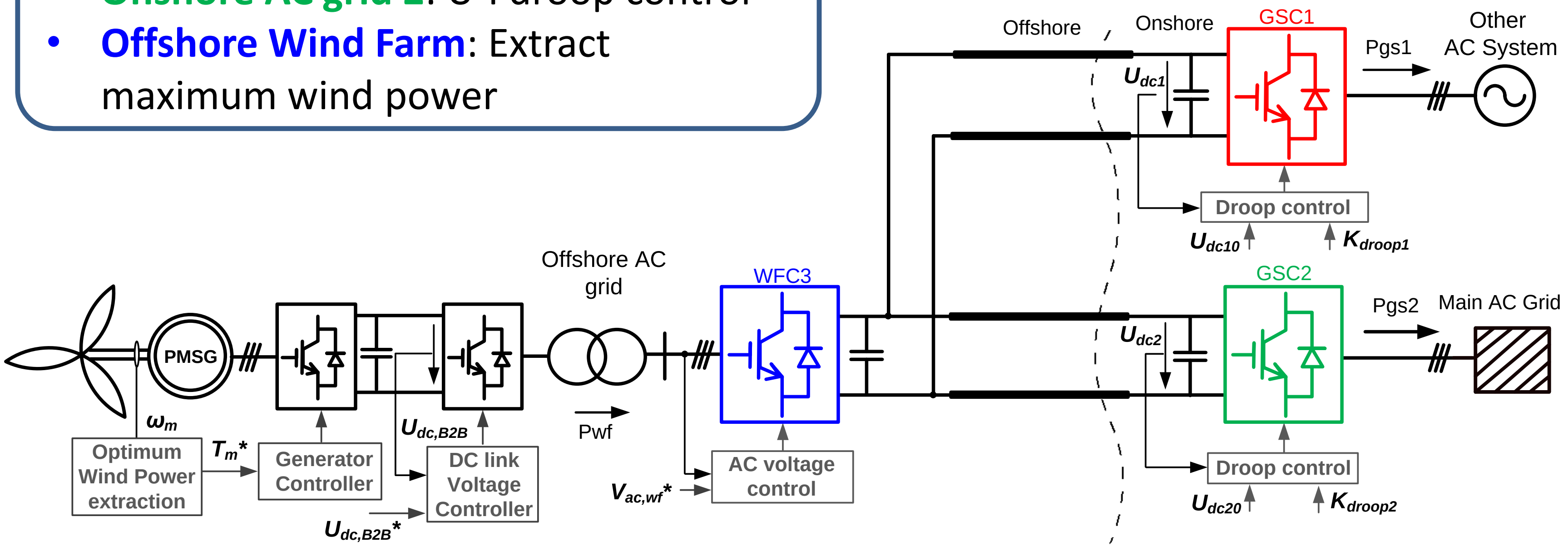
2. Scale-down procedure
3. Example
4. Conclusions

Application of scaling method

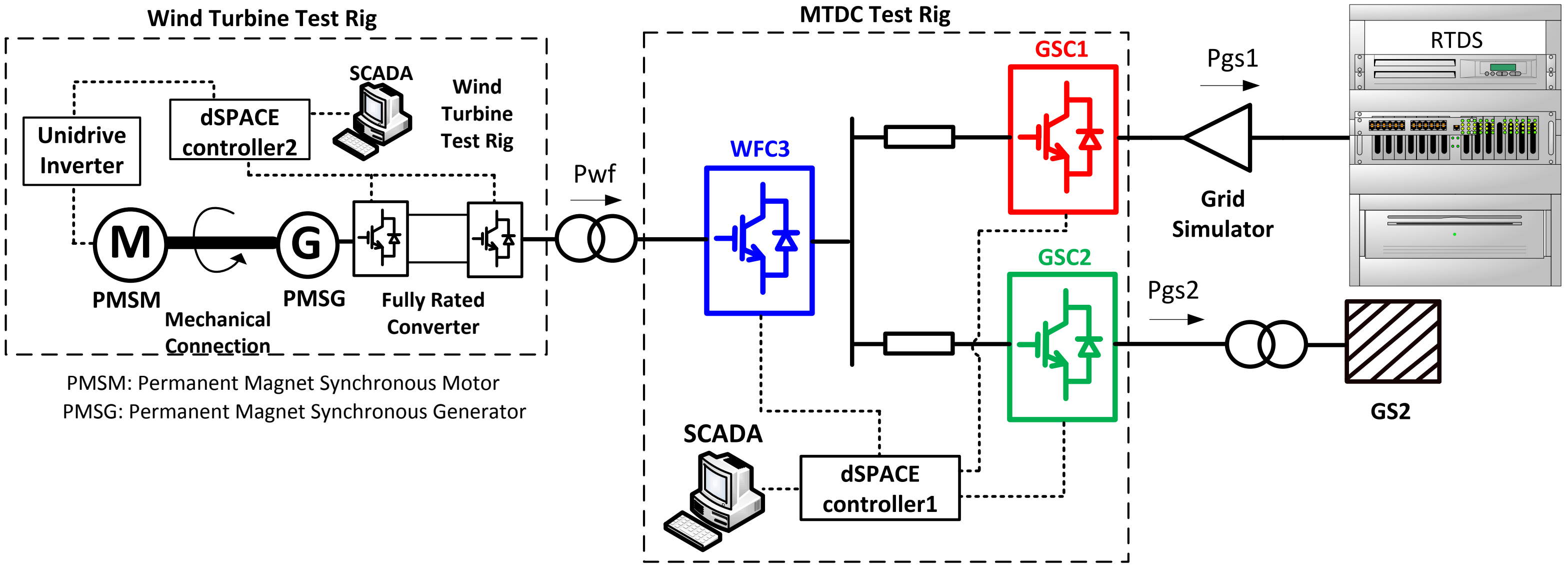
- *Test system*: 3-terminal VSC-HVDC scheme

- **Onshore AC grid 1**: U-I droop control
- **Onshore AC grid 2**: U-I droop control
- **Offshore Wind Farm**: Extract maximum wind power



Application of scaling method

- Experimental set-up

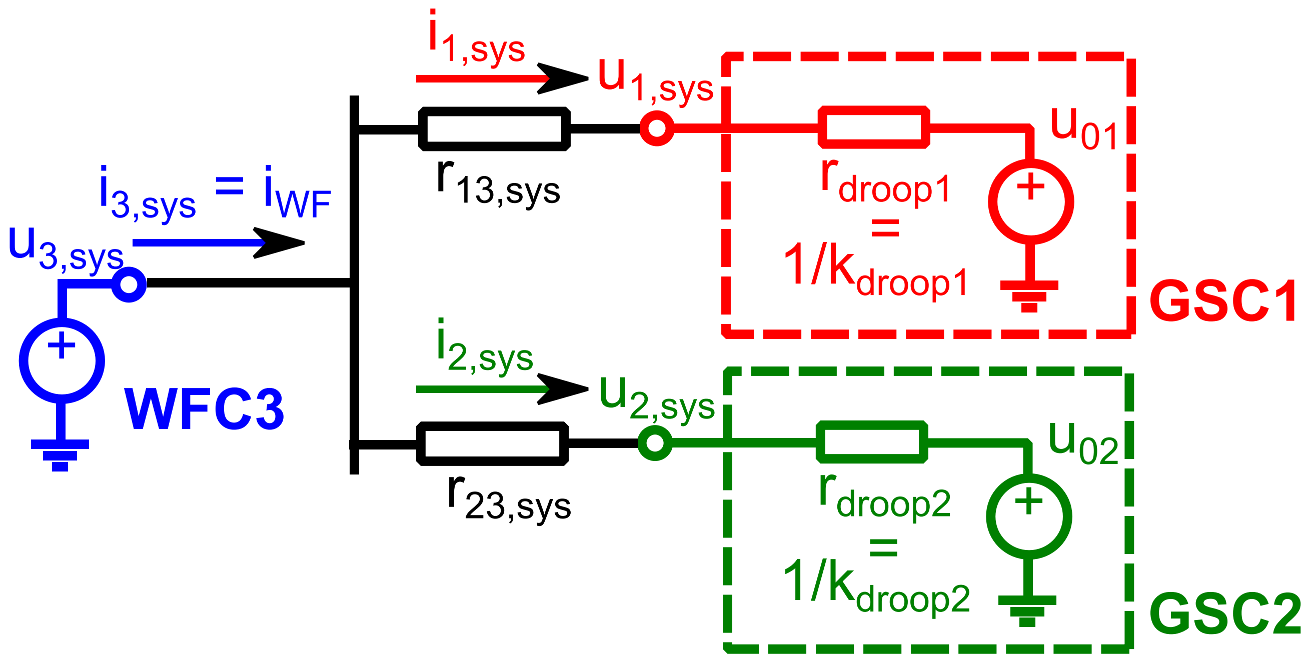


PMSM: Permanent Magnet Synchronous Motor
PMSG: Permanent Magnet Synchronous Generator

Specifications of VSCs	Operation rating
Rated power	2 kW
DC voltage	250 V
AC voltage	140 V

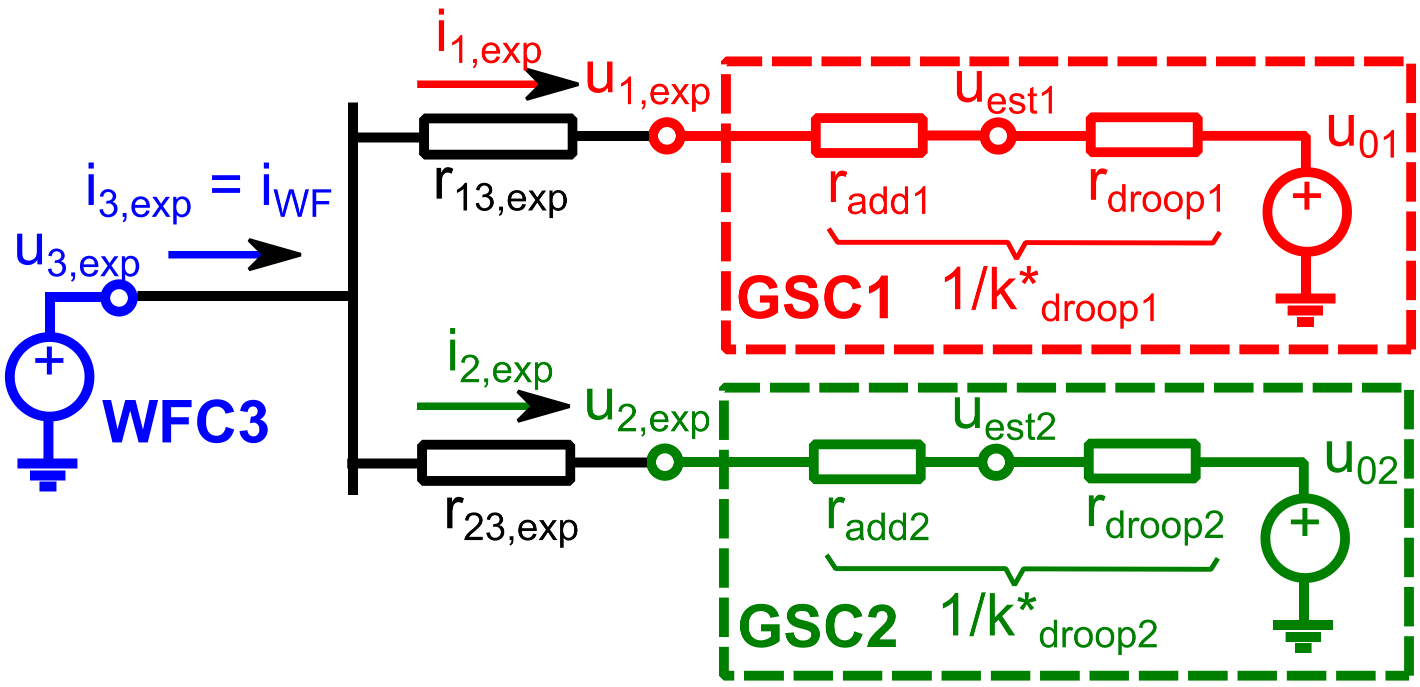
Application of scaling method

- Virtual circuits in the 3-terminal system



Application of scaling method

- Droop correction in the experimental set-up



Application of scaling method

- 3 case studies are considered to validate the method

Parameter	Case 1	Case 2	Case 3
Rated power of VSCs	800 MW		400 MW
MTDC rated voltage	±200 kV		
Cable length 1-3	200 km	100 km	200 km
Cable length 2-3	400 km	500 km	400 km

- Base values and DC cable resistances in per-unit for each case study and the experimental test rig

Quantity	Case 1	Case 2	Case 3	Test rig
Base power, P_b	800 MVA		400 MVA	700 VA
Base voltage, V_b	400 kV			250 V
Resistance 1-3, r_{13}	0,0096	0,0048	0,0048	0,0005
Resistance 2-3, r_{23}	0,0192	0,0240	0,0096	0,0026

Results

- Comparison simulation in PSCAD with experimental results with and without the droop correction

- Initial injection of 0,3 pu from OWF.
- Increase of power to 0,6 pu.
- Droop control in GSC1 and GSC2 designed to share the same power

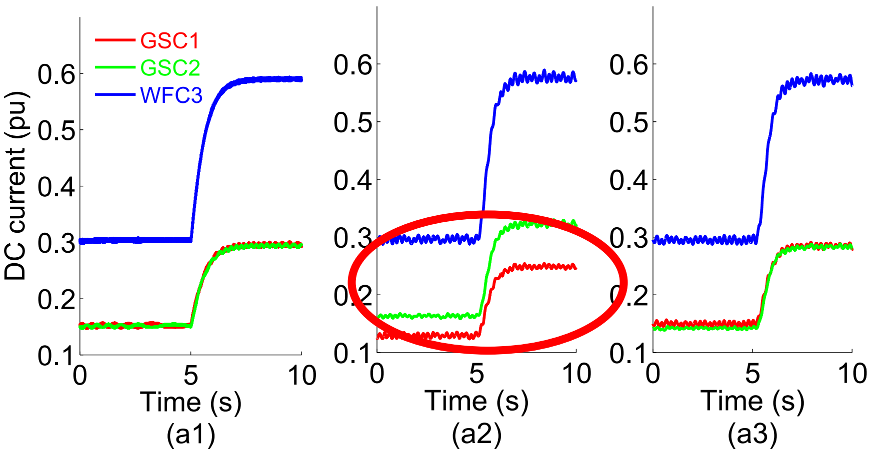
- DC current and voltage results

Results

- Case 1: 800 MW, l13=200 km, l23=400 km

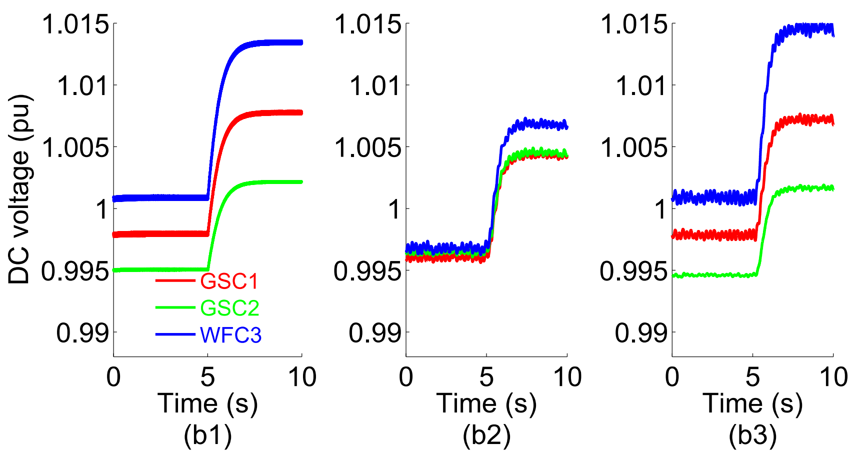
DC currents

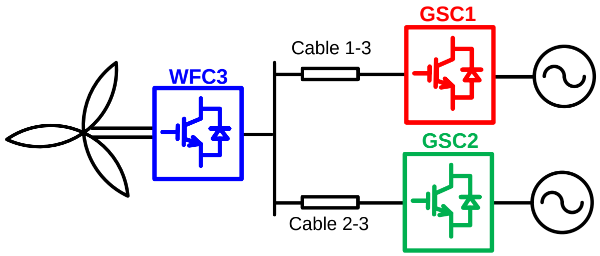
Simulation | Experiments without correction | ***Experiments with correction***



DC voltages

Simulation | Experiments without correction | ***Experiments with correction***

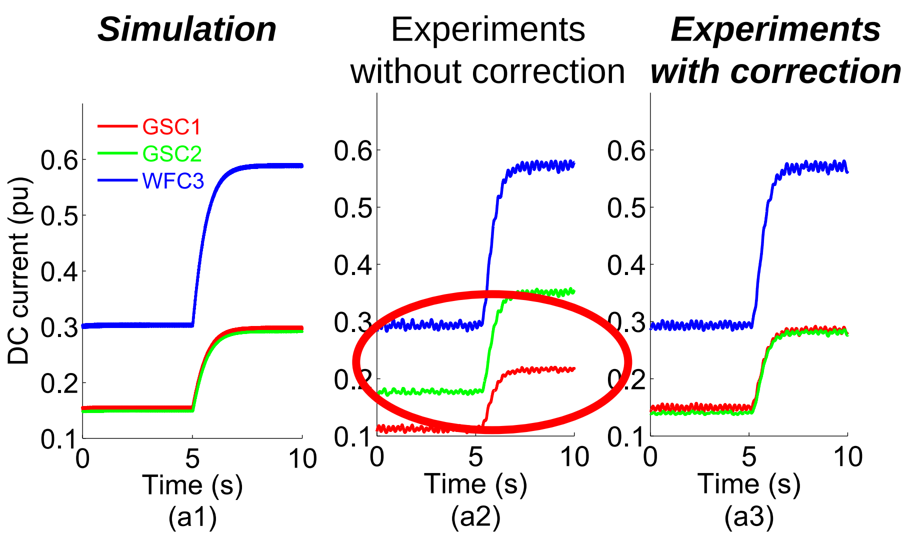




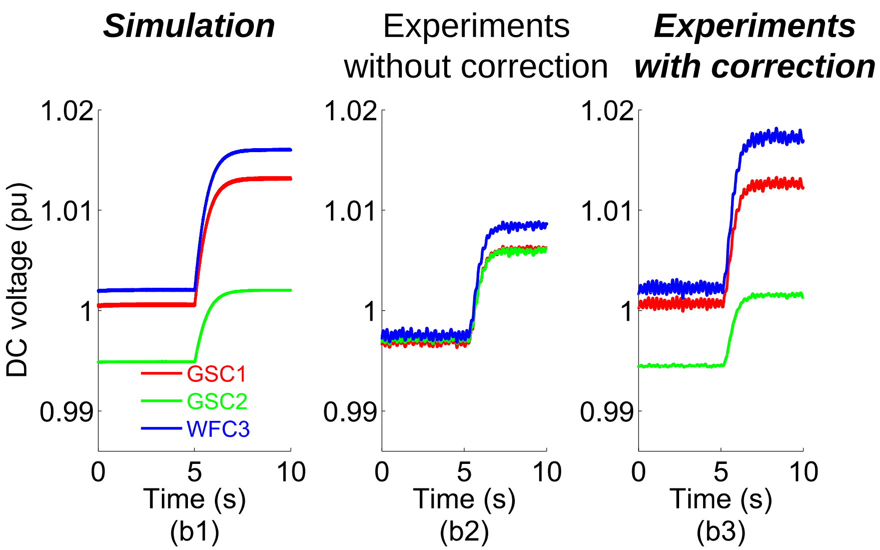
Results

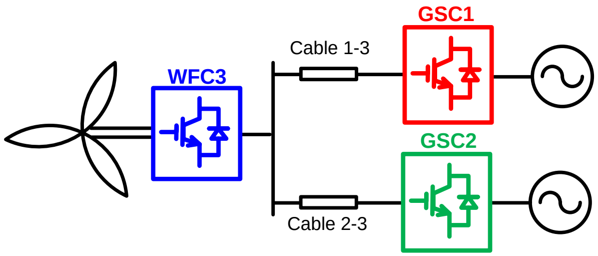
- Case 2: 800 MW, ***l13=100 km, l23=500 km***

DC currents



DC voltages



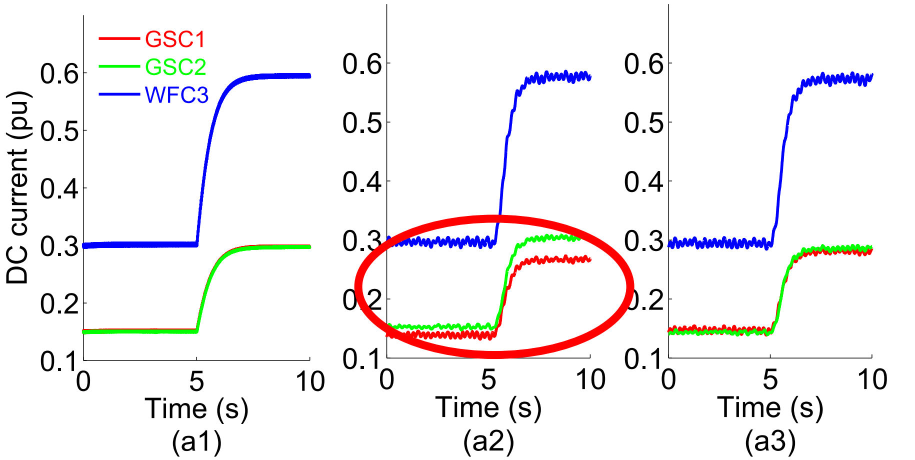


Results

- Case 3: ***400 MW***, l13=200 km, l23=400 km

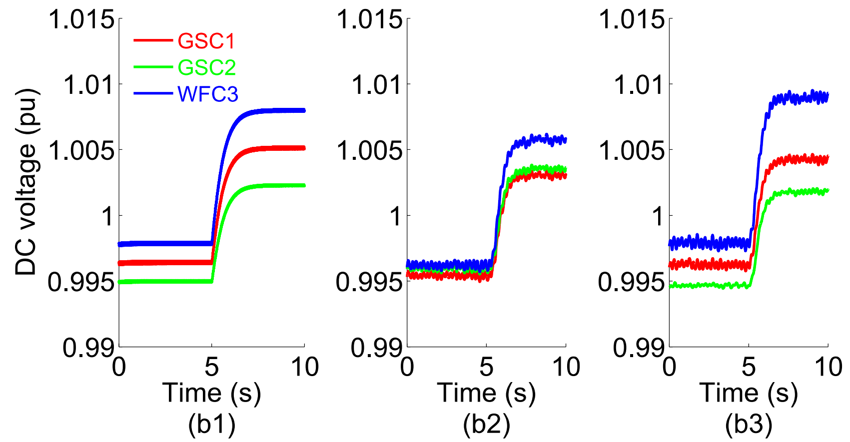
<u>DC currents</u>

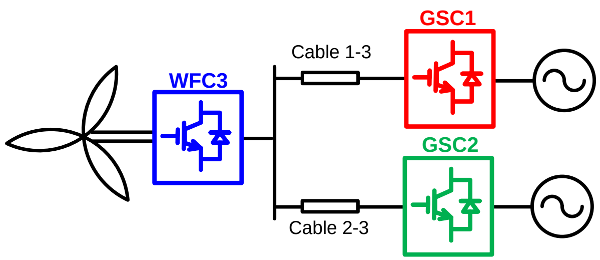
Simulation | Experiments without correction | ***Experiments with correction***



<u>DC voltages</u>

Simulation | Experiments without correction | ***Experiments with correction***





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Conclusions

- A scaling method was demonstrated to obtain uniform steady state responses between an MTDC experimental rig and three different HVDC systems
- The droop control correction allows representing many equivalent DC cables without using different physical elements→ Increase flexibility of experimental set-up.

Any question?