Automated Impedance Measurement Toolbox for Power System Stability Analysis

Heng Wu, Assistant Professor

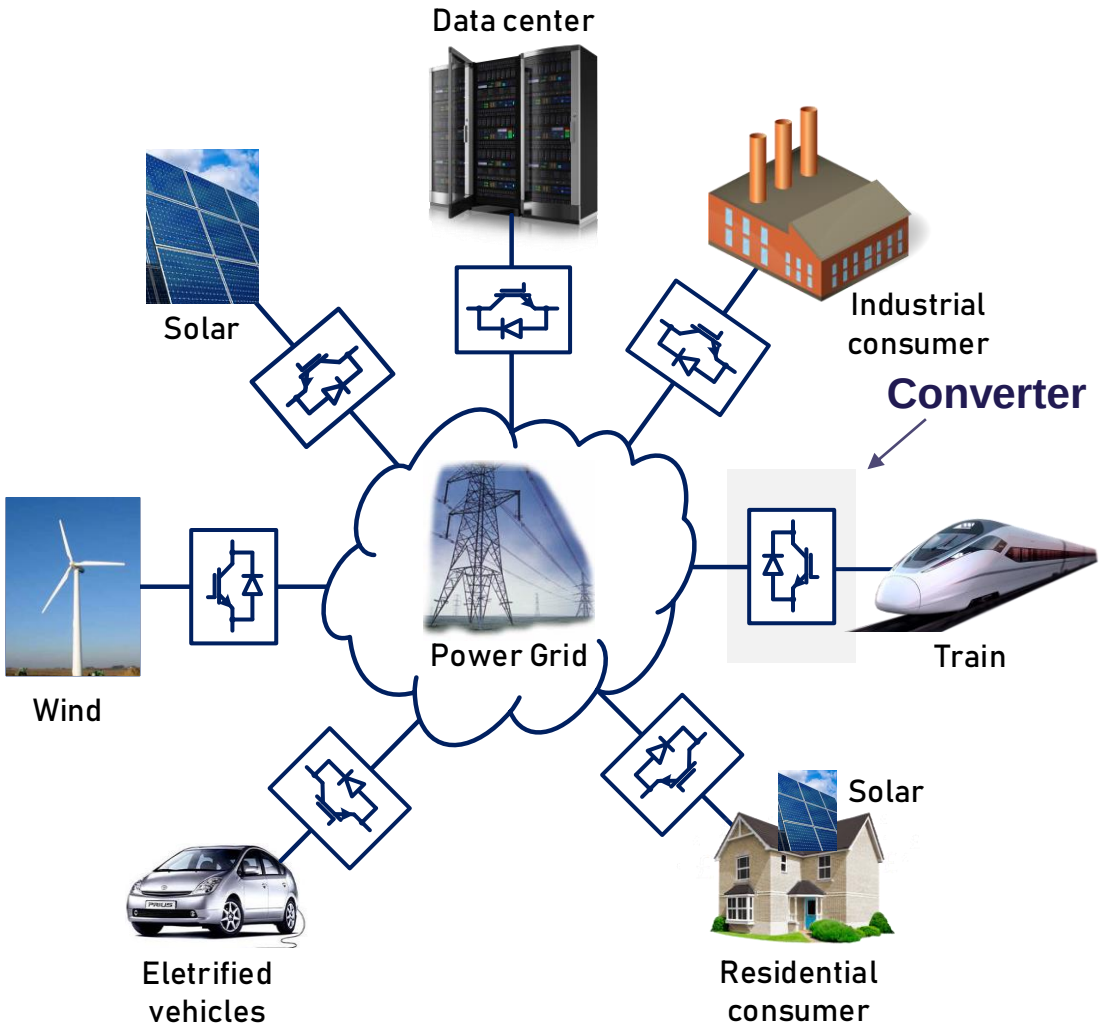
hew@energy.aau.dk

AAU Energy, Aalborg University, Denmark

eGRID ELECTRONIC POWER GRID

AAU ENERGY

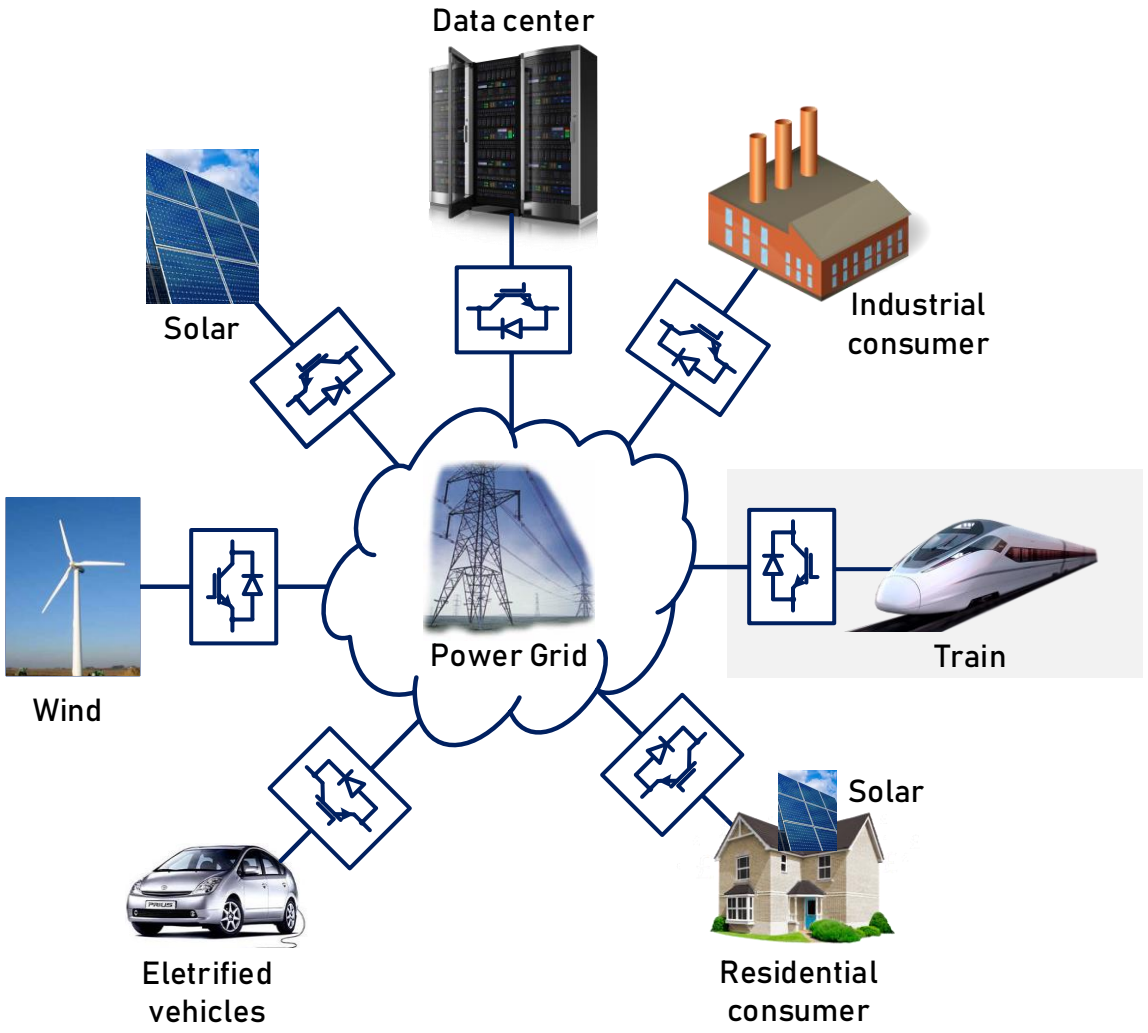
Converter-based power system



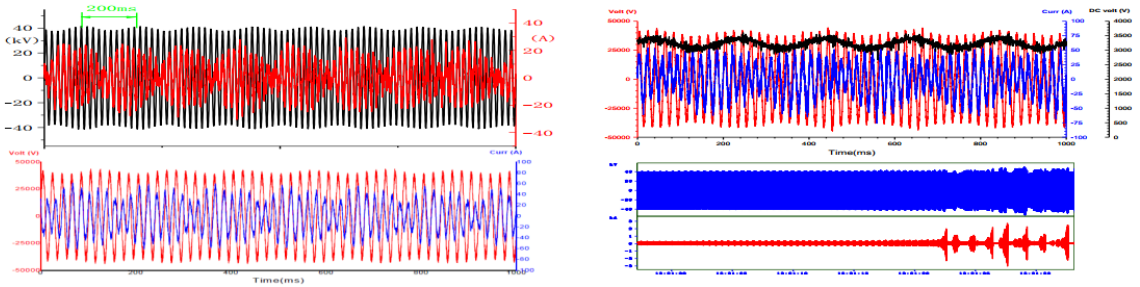
- Almost every electrical component is interfaced with power grid through **power converters**
- **Power converters can destabilize the power system**

Unstable operation

High-speed train



Cases of low frequency oscillations in high-speed railway



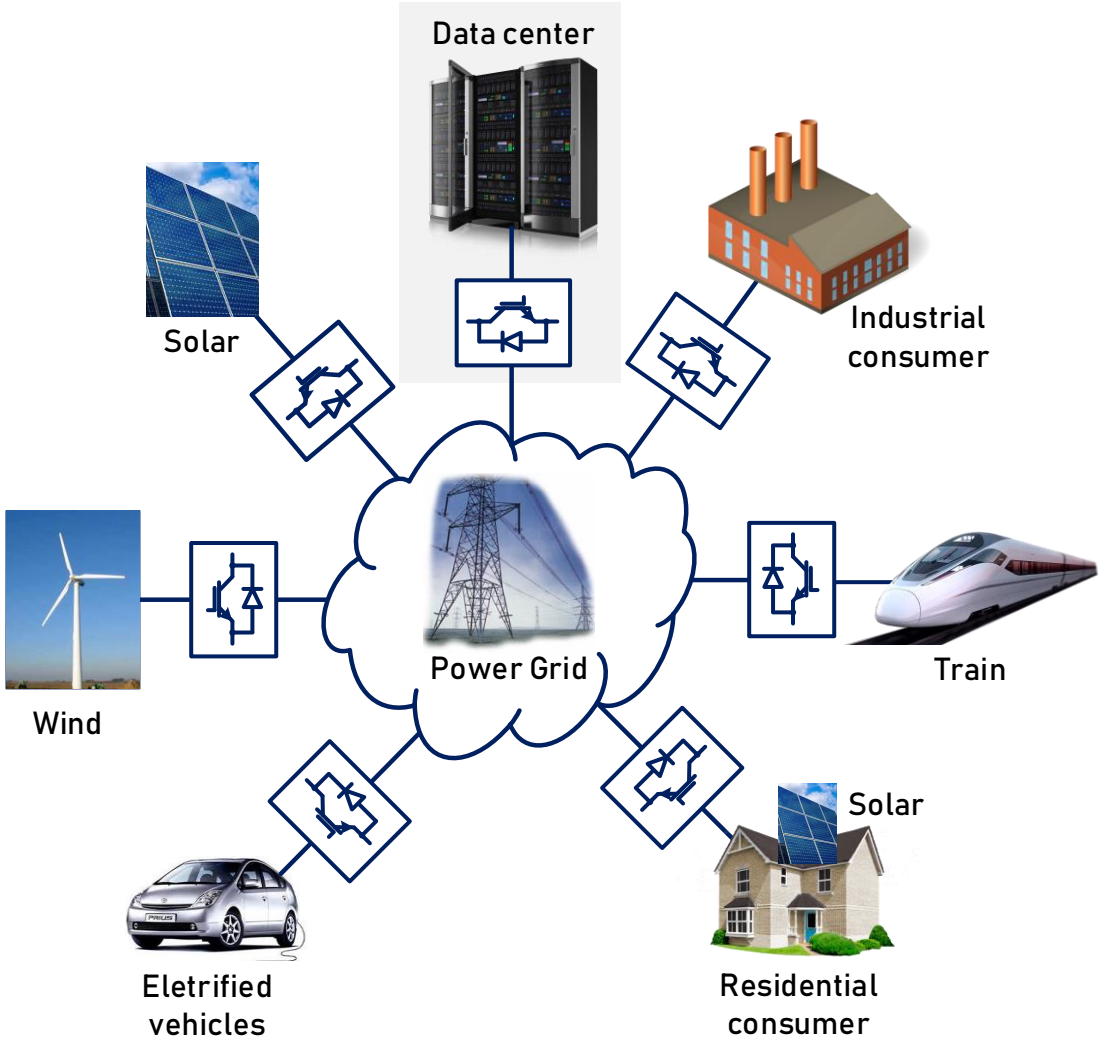
Cases of low-frequency oscillation

Vehicle type	Time	Place	Places overseas
HX_D1	2008.01	Hudong locomotive depot	Switzerland, France, the USA, Germany
CRH1	2010.01	Nanxiang station, Shanghai	
CRH5	2010.09	Qingdao	
HX_D2B	2011.06、2014.01	Xuzhou	
HX_D3B	2011.11	Shanhaiguan	

[1] Z. Liu and Y. Liao. “Stability and Protection of Vehicle-Grid Systems in High-speed Railway”. *IEEE et&d, 2017*

Unstable operation

Data center



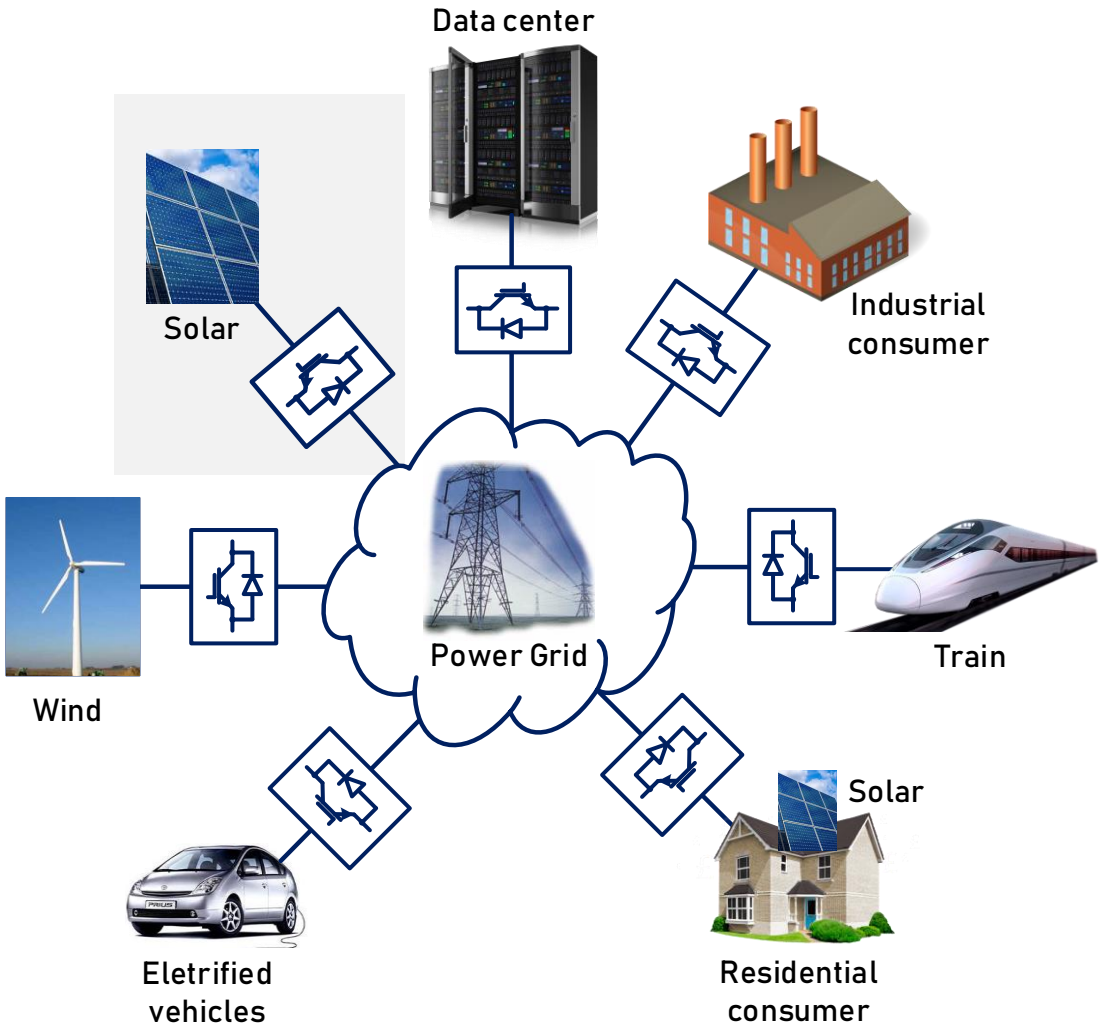
Incidents in Facebook

Fig. 1. Measured one PFC converter input current (upper) and voltage (lower) during a data center power system resonance.

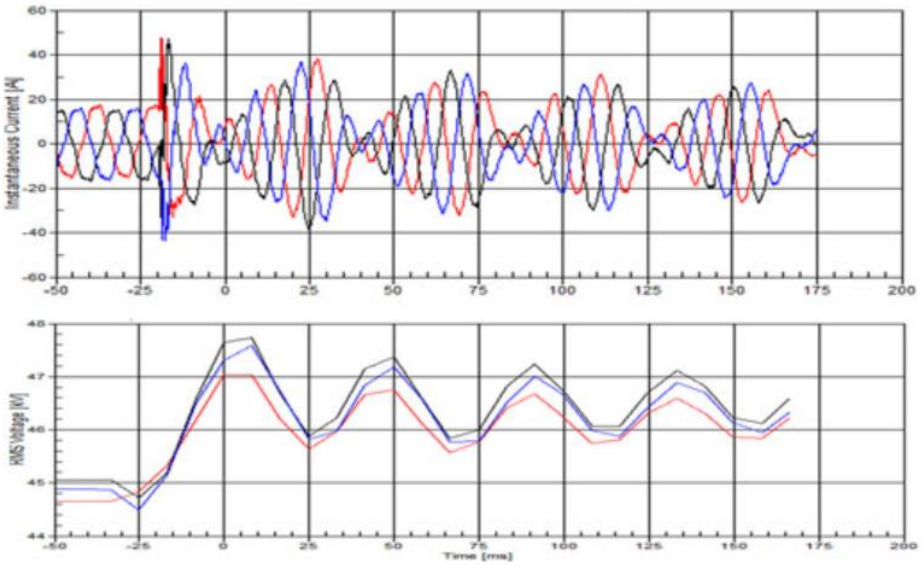
[1] J. Sun, M. Xu, M. Cespedes and M. Kauffman, "Low-Frequency Input Impedance Modeling of Single-Phase PFC Converters for Data Center Power System Stability Studies," 2019 IEEE Energy Conversion Congress and Exposition (ECCE), Baltimore, MD, USA, 2019, pp. 97-106, doi: 10.1109/ECCE.2019.8912862.

Unstable operation

Solar



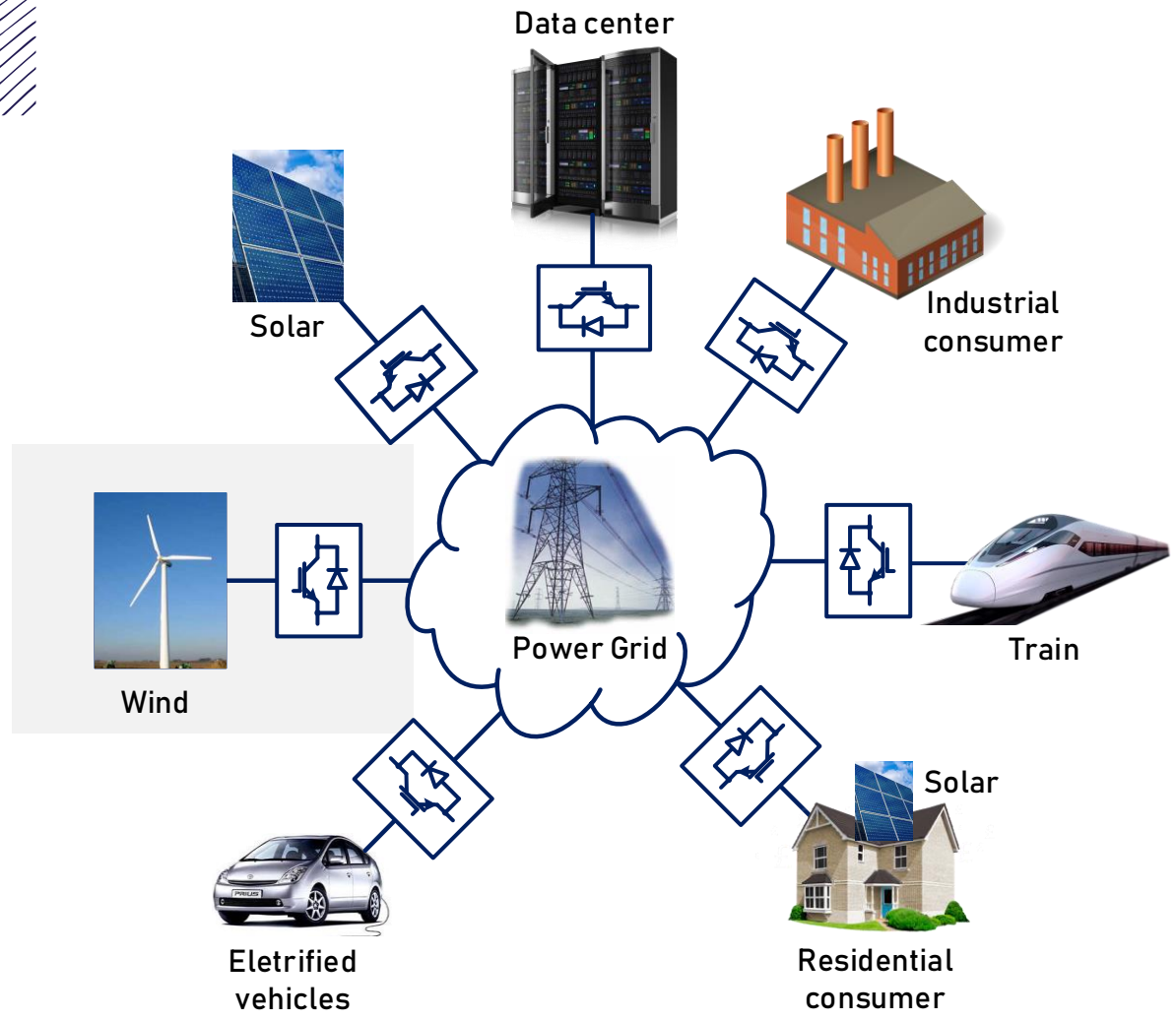
20Hz resonance occurs in a 1 MVA PV plant when a capacitor in the substation is energized [1]



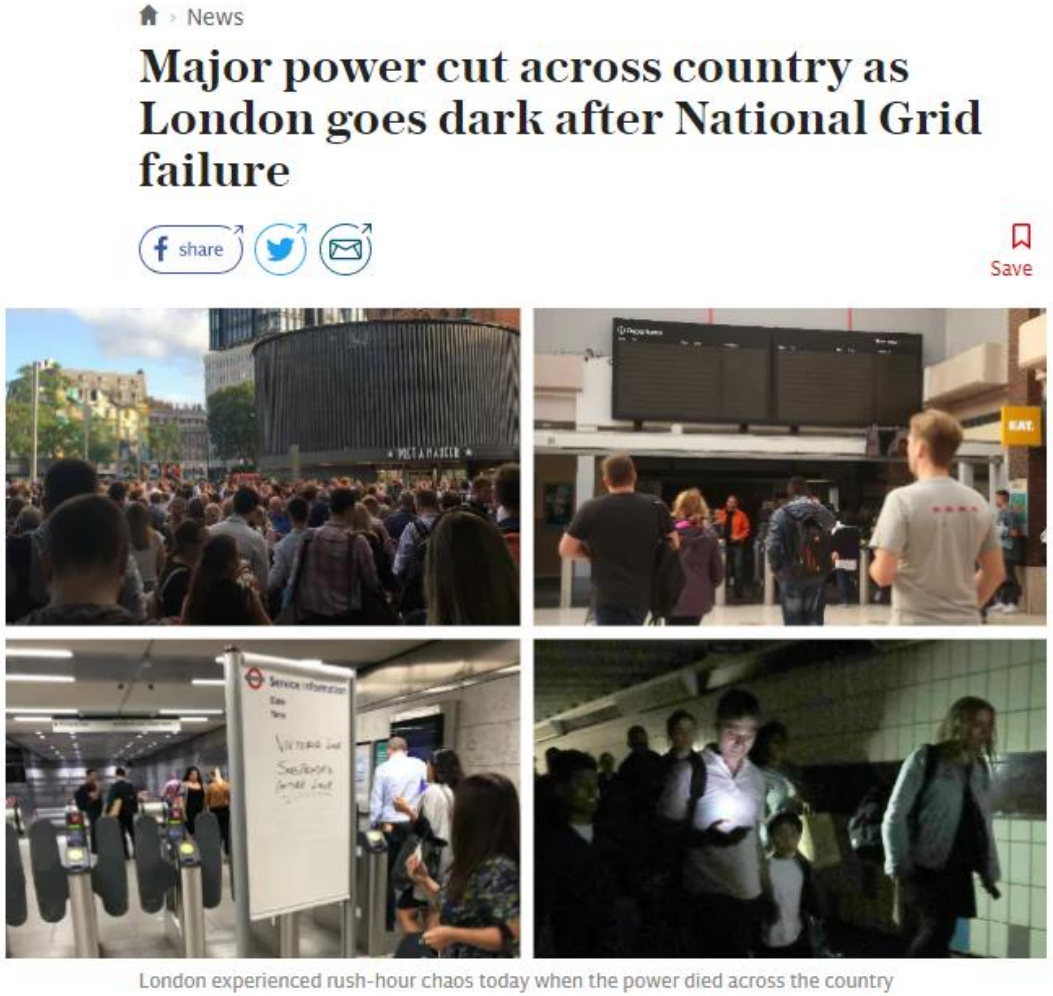
[1] C. Li. “Unstable Operation of Photovoltaic Inverter From Field Experiences ”. *IEEE Transactions on Power Delivery, 2018*

Unstable operation

Wind



In 2019, the Trip of 700MW wind power plant lead to 1 million customers lose power in London



News

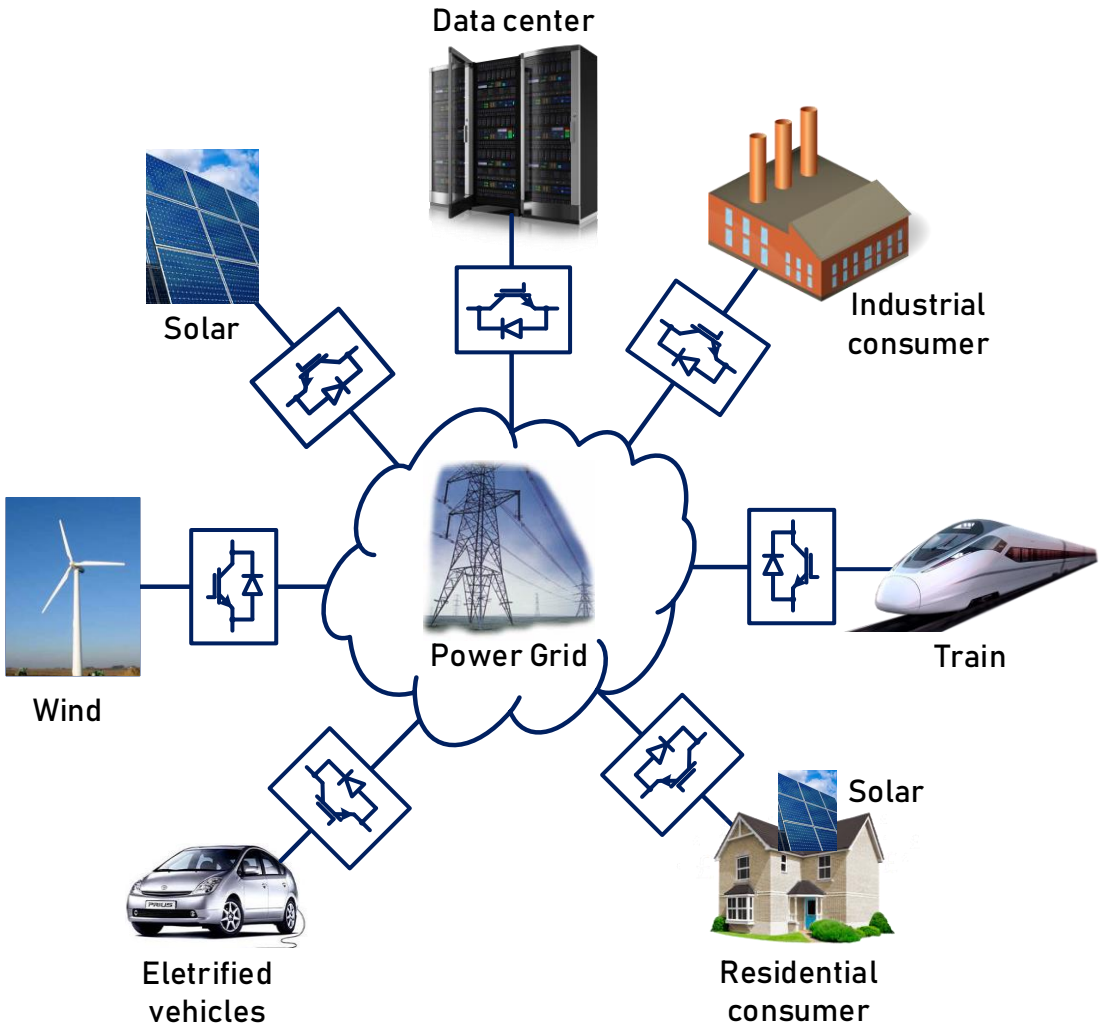
Major power cut across country as London goes dark after National Grid failure

share

Save

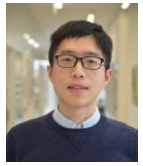
London experienced rush-hour chaos today when the power died across the country

Research topic



Stability analysis are mandatory of transmission system operator (TSO) before allowing converters to physically connect to the power system

Impedance-based stability analysis is most suitable for stability assessment for converter-dominated power system



Project: MTDC (2019~2021)

Assist. Prof. Heng Wu

MTDC = Multi-Terminal MMC-HVDC

AALBORG UNIVERSITY

TenneT Taking power further

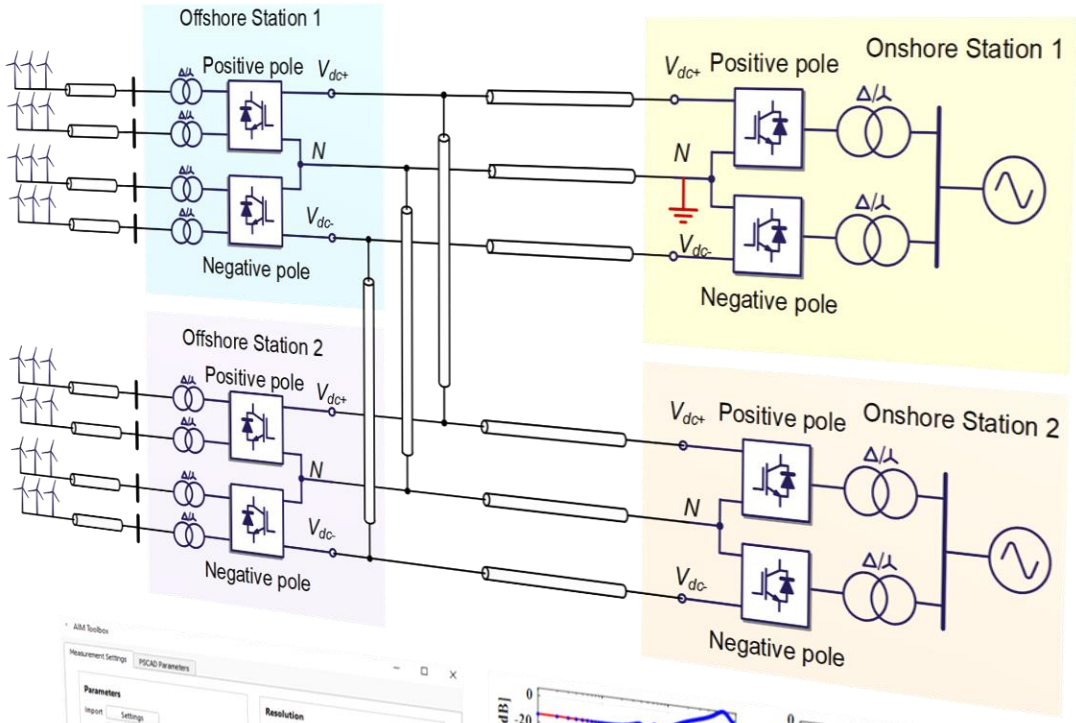
- **Objective**

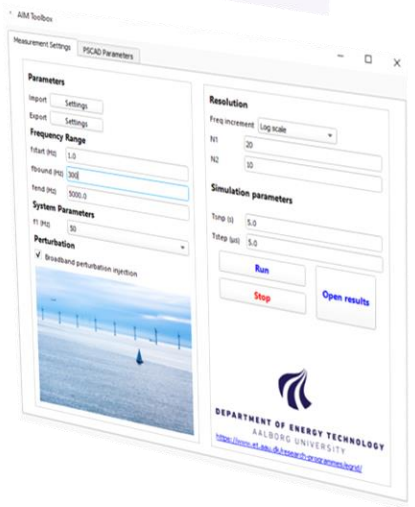
  Impedance-based modeling and stability analysis of multi-vendor, multi-terminal MMC-HVDC systems

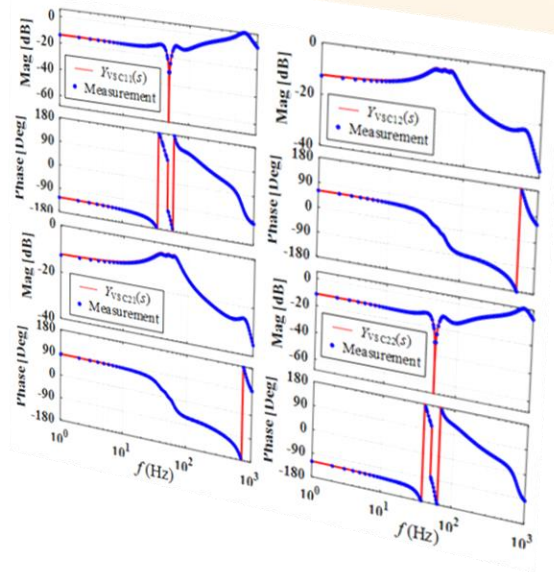
- **Deliverables**

  1. Theoretical model of ac/dc impedance matrix of the MMC.
  2. Impedance-based stability analysis of the MTDC system.
  3. Sensitivity analysis to identify the “trouble-maker” that destabilizing the system
  4. PSCAD-compatible toolbox for automated ac/dc impedance matrix measurement.

Commercialized





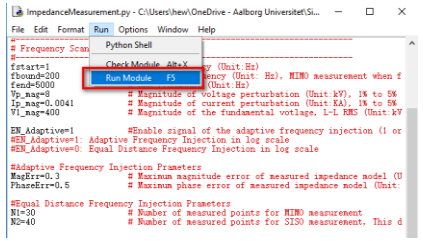


Development of the toolbox

2019

Start software development in corporation with German TSO TenneT

ImpedanceMeasurement



MathWorks

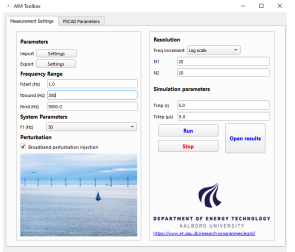
- ✓ Beta version of the software is developed
- ✓ Automatic impedance matrix measurement
- ✓ Tested by TenneT in the real HVDC project

- ✗ Matlab needed for data processing
- ✗ Open source python and matlab scripts, no graphical user interface
- ✗ No license system

2021. 01-2021.07

- AAU proof of concept (PoC) project is granted
- 1st commercial version

Imp_Tool box



- ✓ Get rid of matlab
- ✓ Convert python scripts to exe
- ✓ Graphical user interface development
- ✓ License system developement
- ✓ More funcitonalities
- ✓ Software robustness test in different comupter sytem environment
- ✓ **1st commercial version**

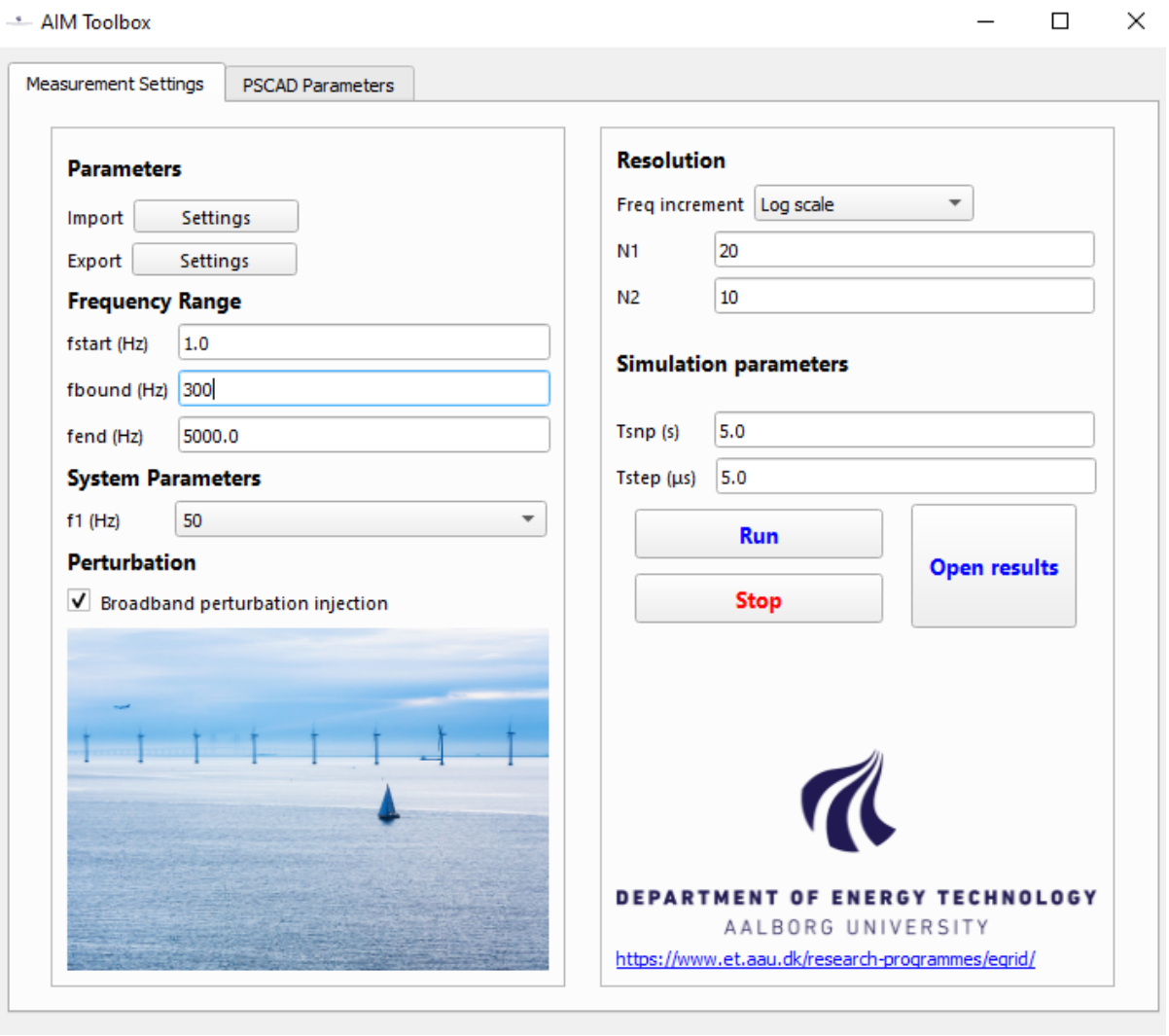
2021.07-2022.12

- Innoexploreer is granted
- Version 2 is excepted

Innovation Fund Denmark

- ✓ Using AI to make the toolbox more intelligent

GUI of the toolbox

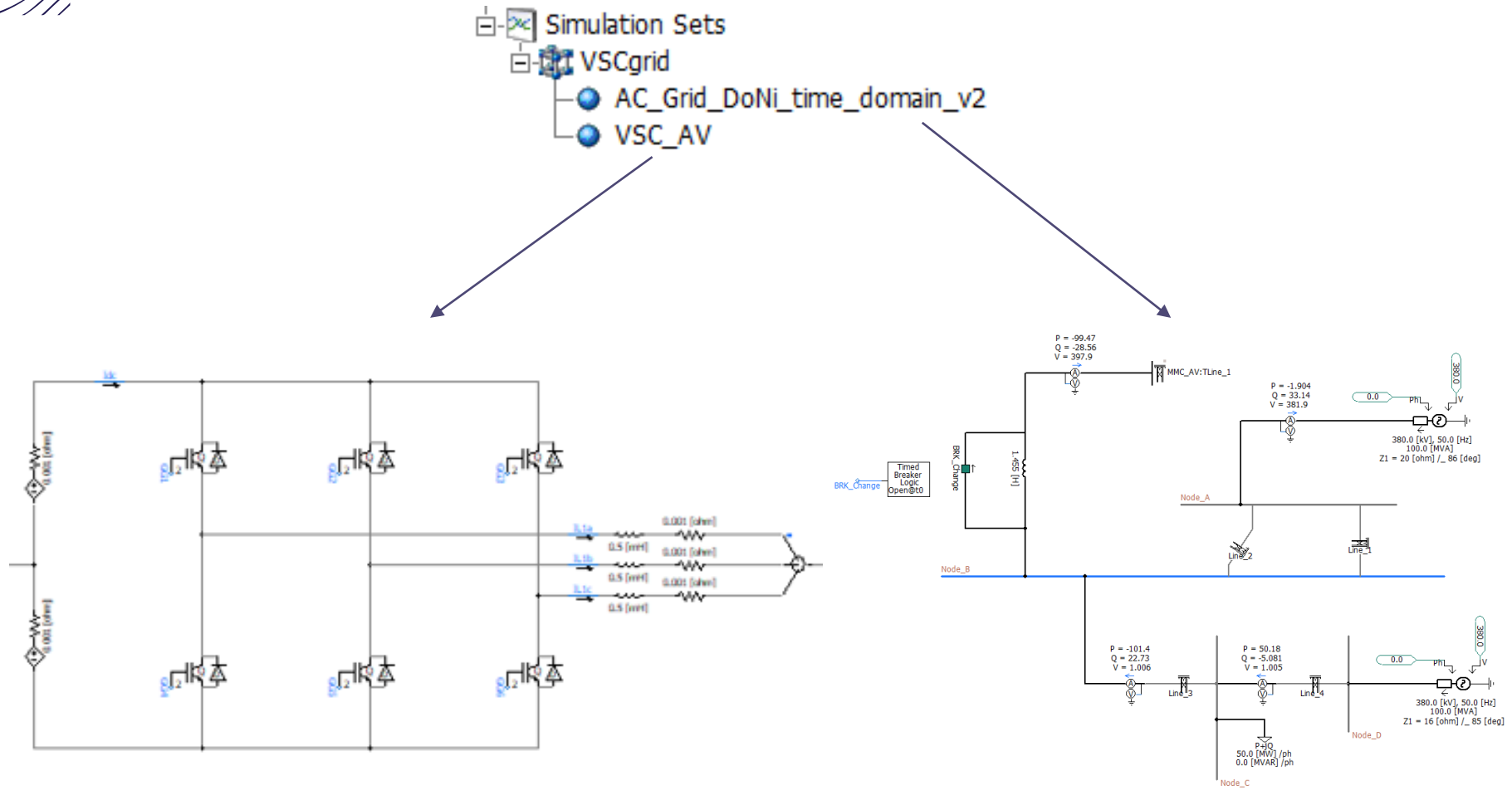


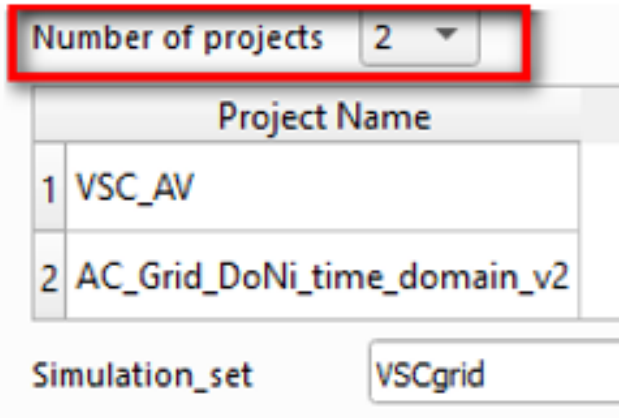
Features

- Fully compatible with PSCAD simulation environment
- Fully automated, one click and the results are automatically generated
- Able to measure all elements in the impedance (admittance) matrix in both dq and αβ frame
- Has already be used by TenneT in the real MMC-HVDC projects and the measurement results show high accuracy

Features

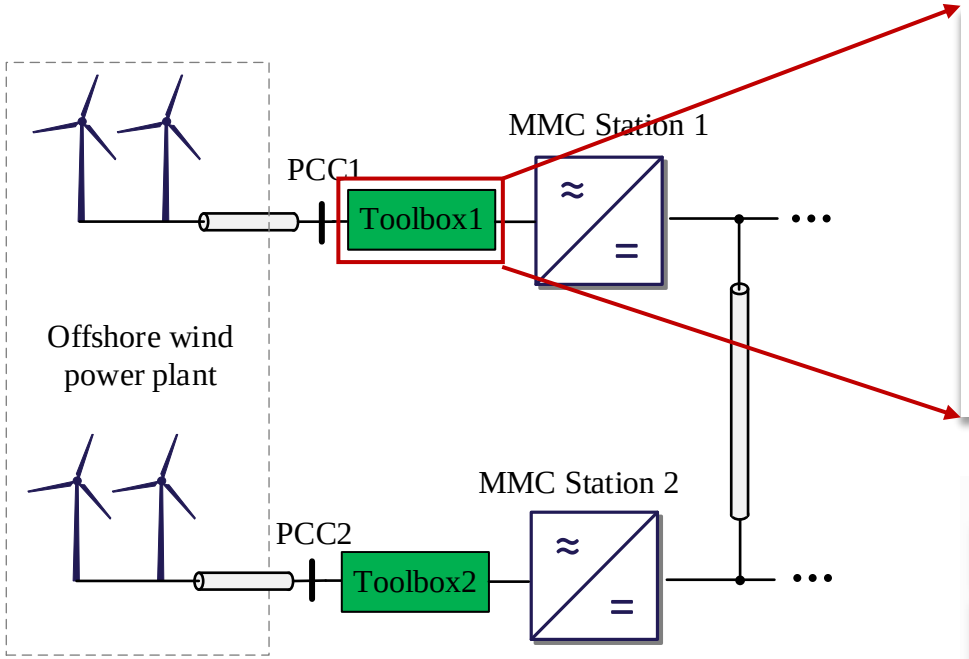
- Compatible if parallel simulation is used in PSCAD

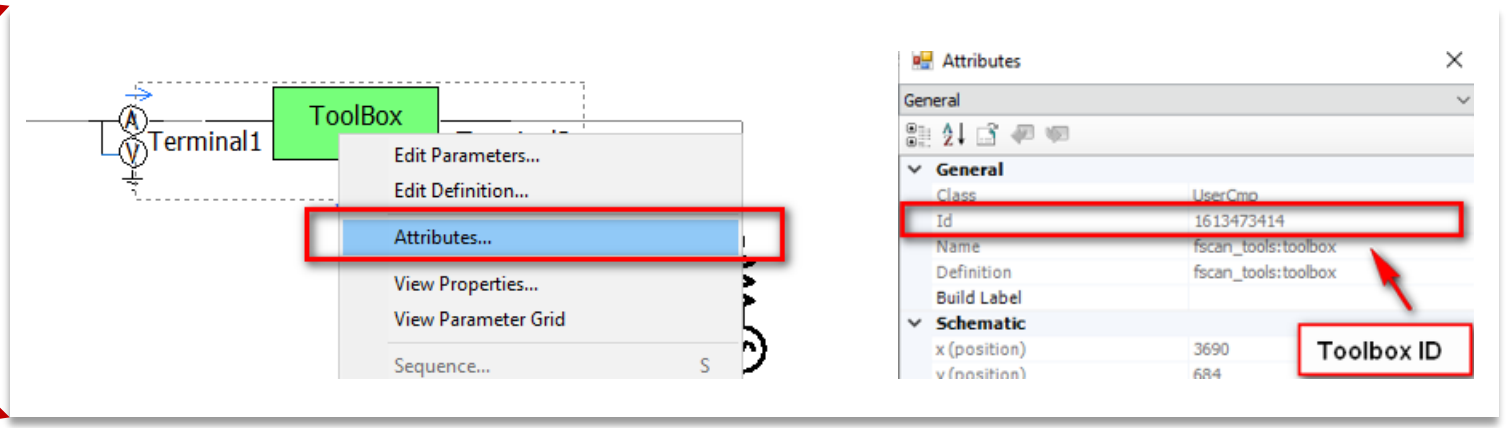




Features

- Impedance measurement of multiple converters within one simulation





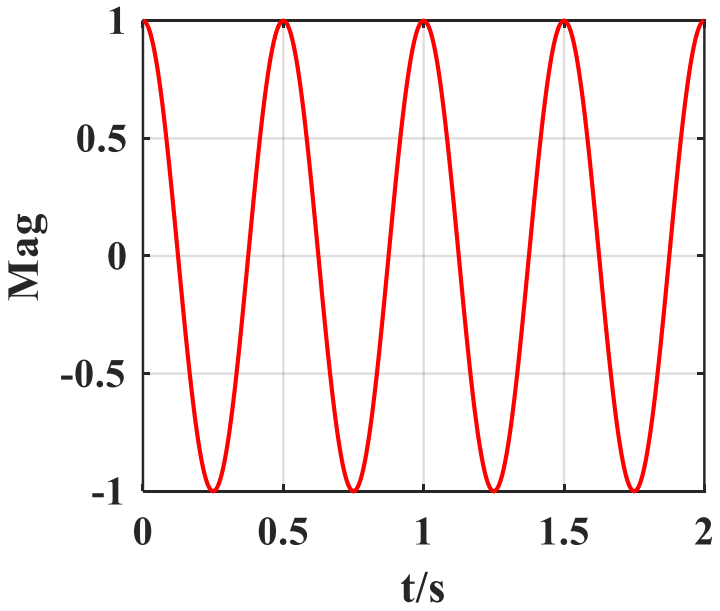
Toolbox settings

Number of toolboxes: 2

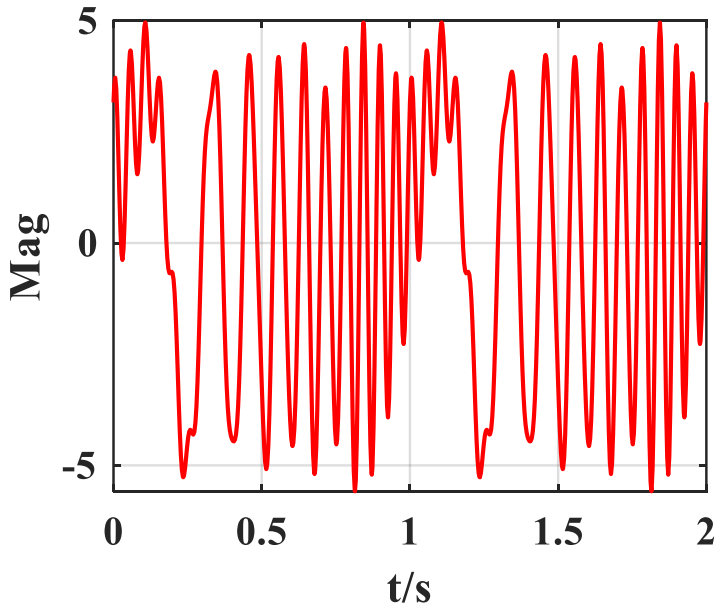
	Toolbox ID	Vp_mag (kV)	Ip_mag (kA)	Project number
1	1613473414	0.003	0	1
2	1015356345	0	0.002	1

Features

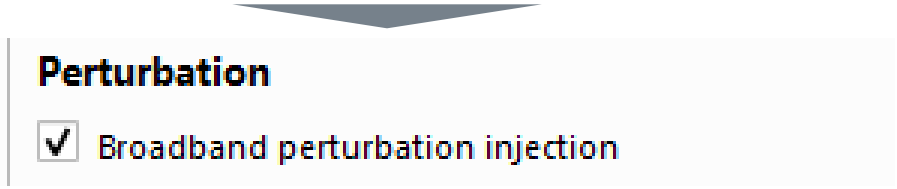
- Broadband perturbation injection to speed up the simulation



Single frequency perturbation injection



Broadband perturbation injection

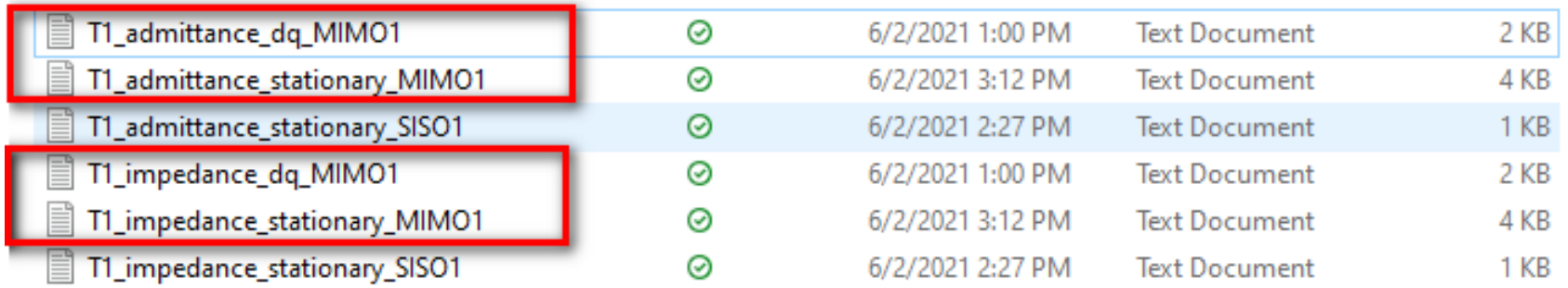


eGRID ELECTRONIC POWER GRID

AAU ENERGY

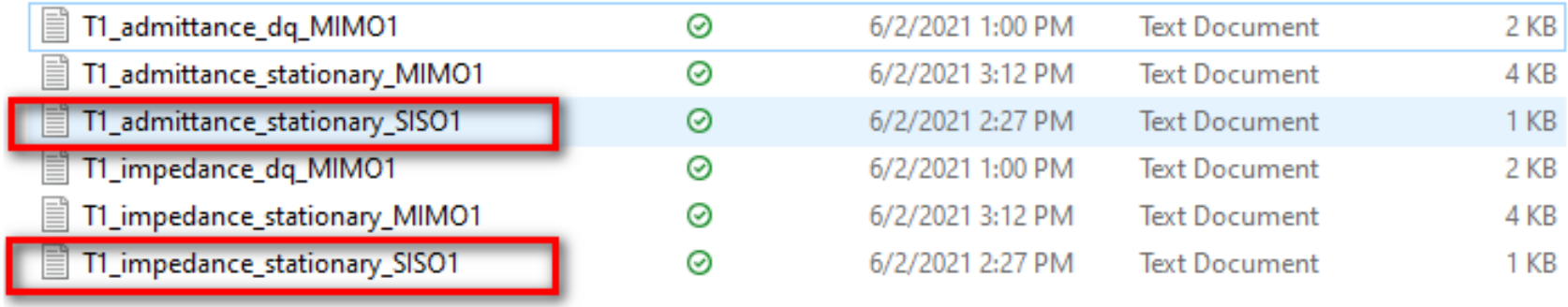
Measurement results

Format of generated files



T1_admittance_dq_MIMO1	6/2/2021 1:00 PM	Text Document	2 KB
T1_admittance_stationary_MIMO1	6/2/2021 3:12 PM	Text Document	4 KB
T1_admittance_stationary_SISO1	6/2/2021 2:27 PM	Text Document	1 KB
T1_impedance_dq_MIMO1	6/2/2021 1:00 PM	Text Document	2 KB
T1_impedance_stationary_MIMO1	6/2/2021 3:12 PM	Text Document	4 KB
T1_impedance_stationary_SISO1	6/2/2021 2:27 PM	Text Document	1 KB

MIMO measurement results, impedance/admittance matrix in dq/αβ frame



T1_admittance_dq_MIMO1	6/2/2021 1:00 PM	Text Document	2 KB
T1_admittance_stationary_MIMO1	6/2/2021 3:12 PM	Text Document	4 KB
T1_admittance_stationary_SISO1	6/2/2021 2:27 PM	Text Document	1 KB
T1_impedance_dq_MIMO1	6/2/2021 1:00 PM	Text Document	2 KB
T1_impedance_stationary_MIMO1	6/2/2021 3:12 PM	Text Document	4 KB
T1_impedance_stationary_SISO1	6/2/2021 2:27 PM	Text Document	1 KB

SISO measurement results, impedance/admittance in αβ frame

Cross-validation

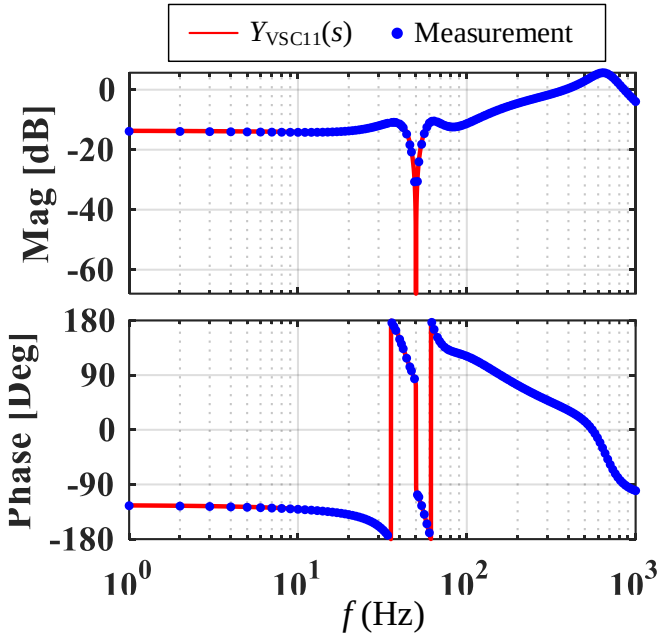
AC impedance matrix

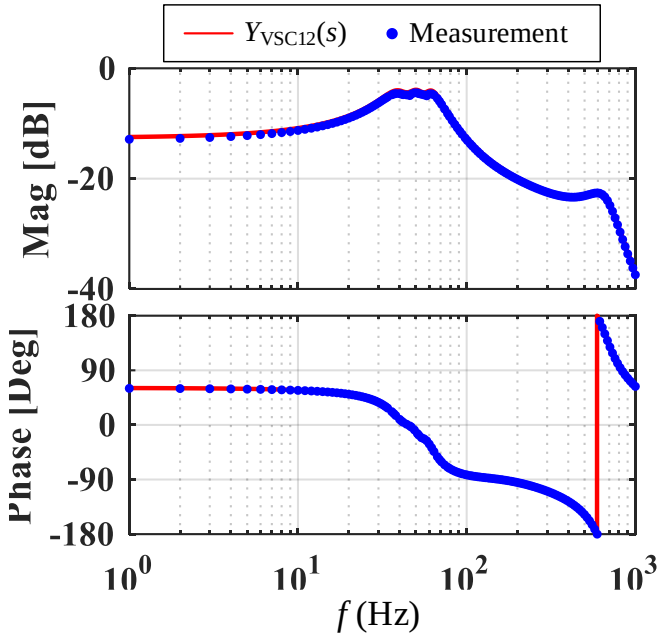
Mag error < 1dB

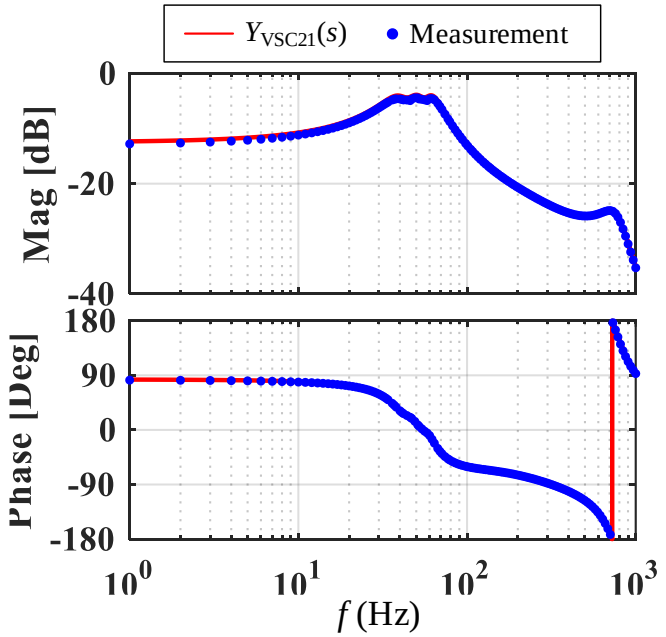
Phase error < 1°

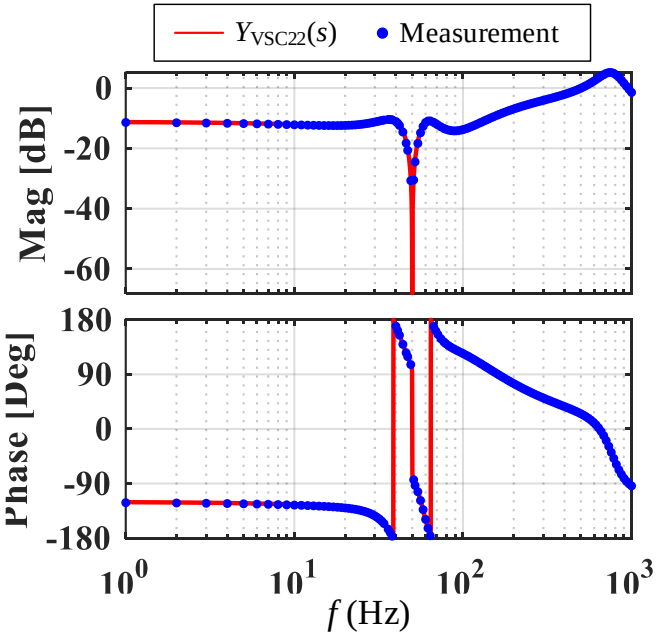
$$\begin{bmatrix} i_{\alpha\beta}(\omega_p) \\ i_{\alpha\beta}(2\omega_1 - \omega_p) \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \begin{bmatrix} v_{\alpha\beta}(\omega_p) \\ v_{\alpha\beta}(2\omega_1 - \omega_p) \end{bmatrix}$$

Admittance matrix in αβ frame



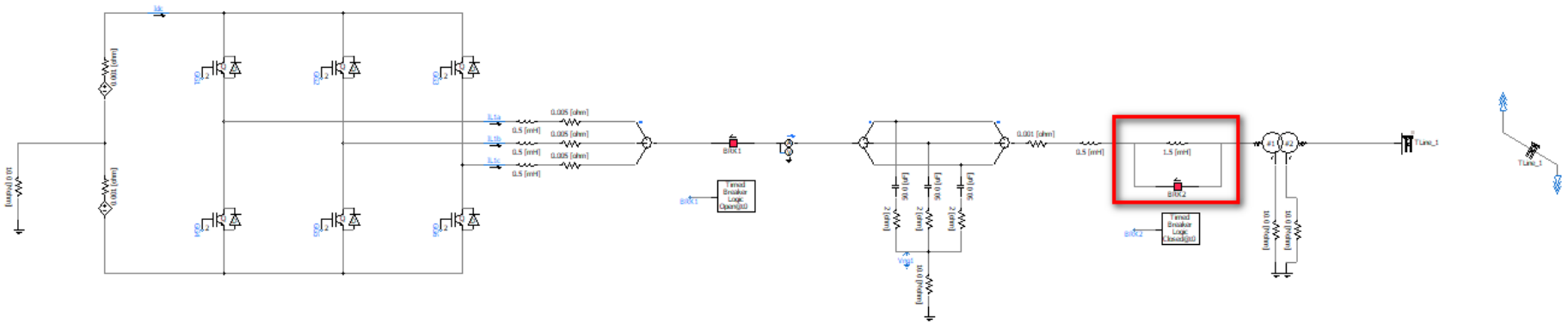


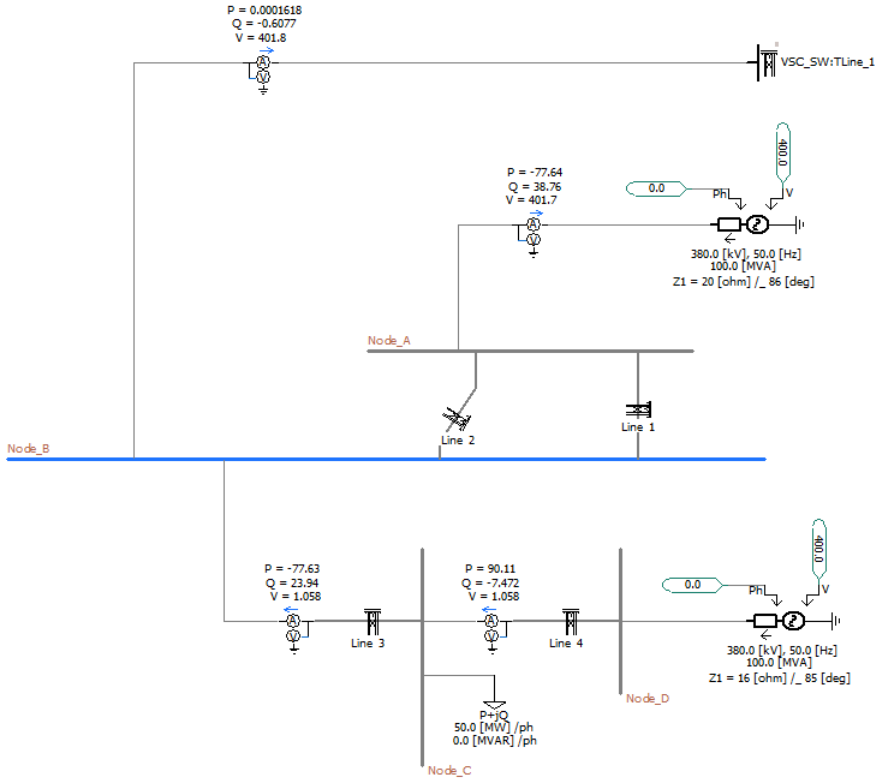




H. Wu, X. Wang, Y. Liao, M. Ndreko, R. Dimitrovski and W.Winter, "Development of an AC/DC impedance matrix measurement Toolbox for MTDC System", in 20th *Proc. Wind Integr. Workshop*, 2021.

Case studies with AIM toolbox



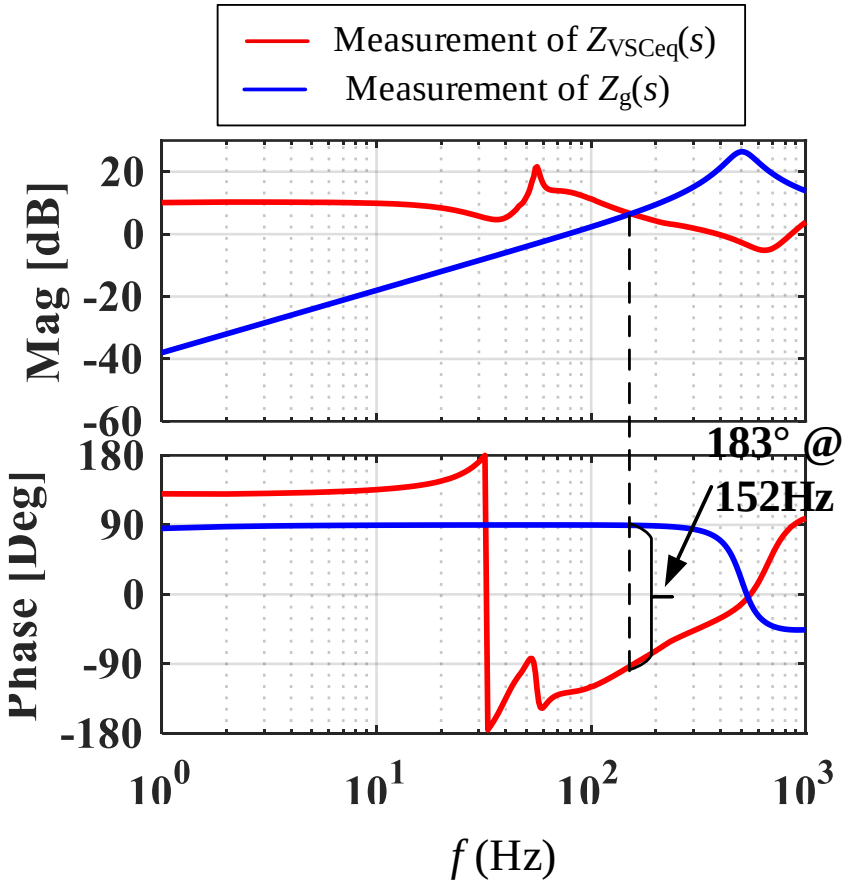


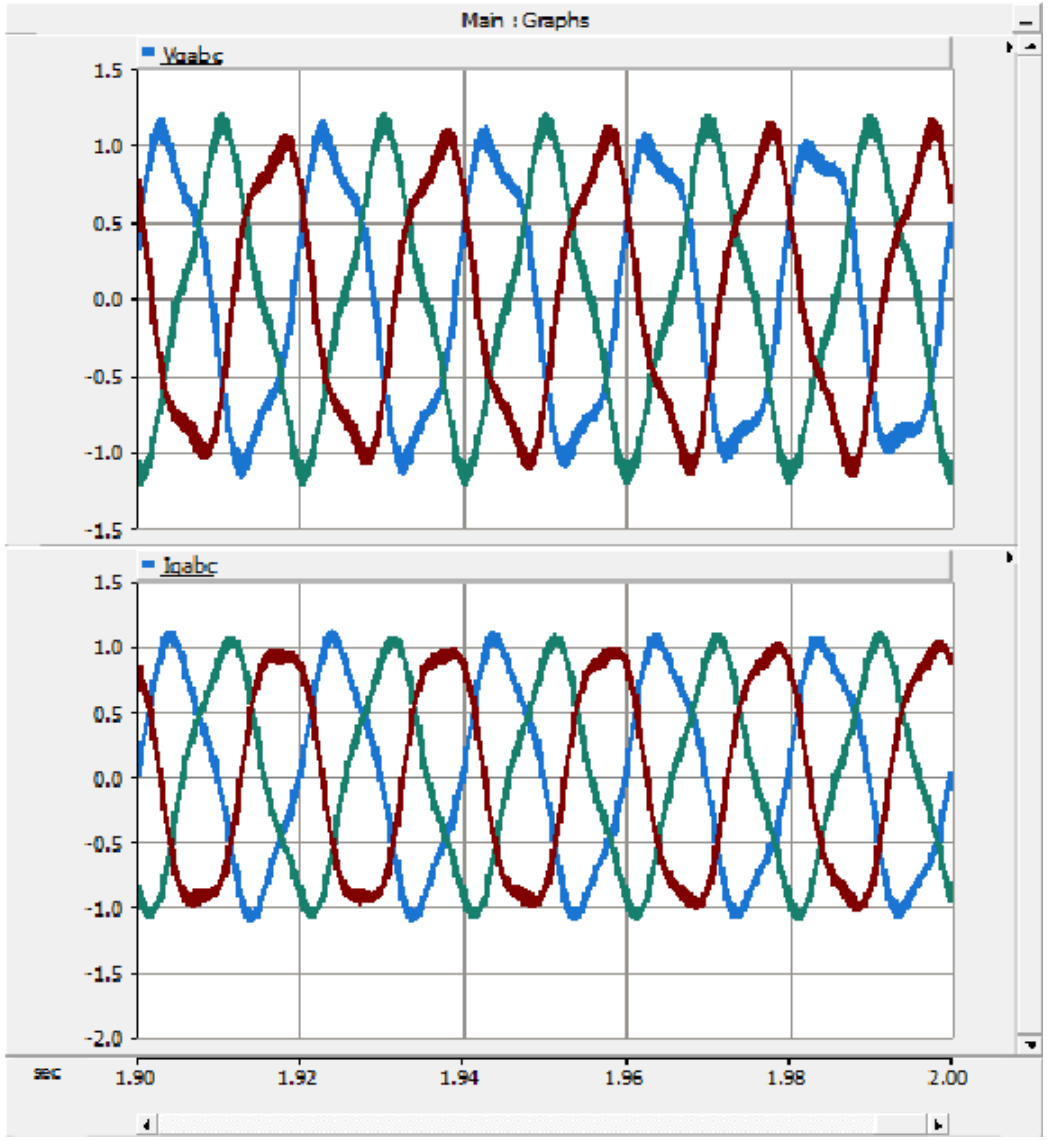
- BRK opens, weak grid
- BRK closes, strong grid

Weak Grid

f_{PLL}=25Hz, unstable

Accurate stability prediction based on the impedance measurement data

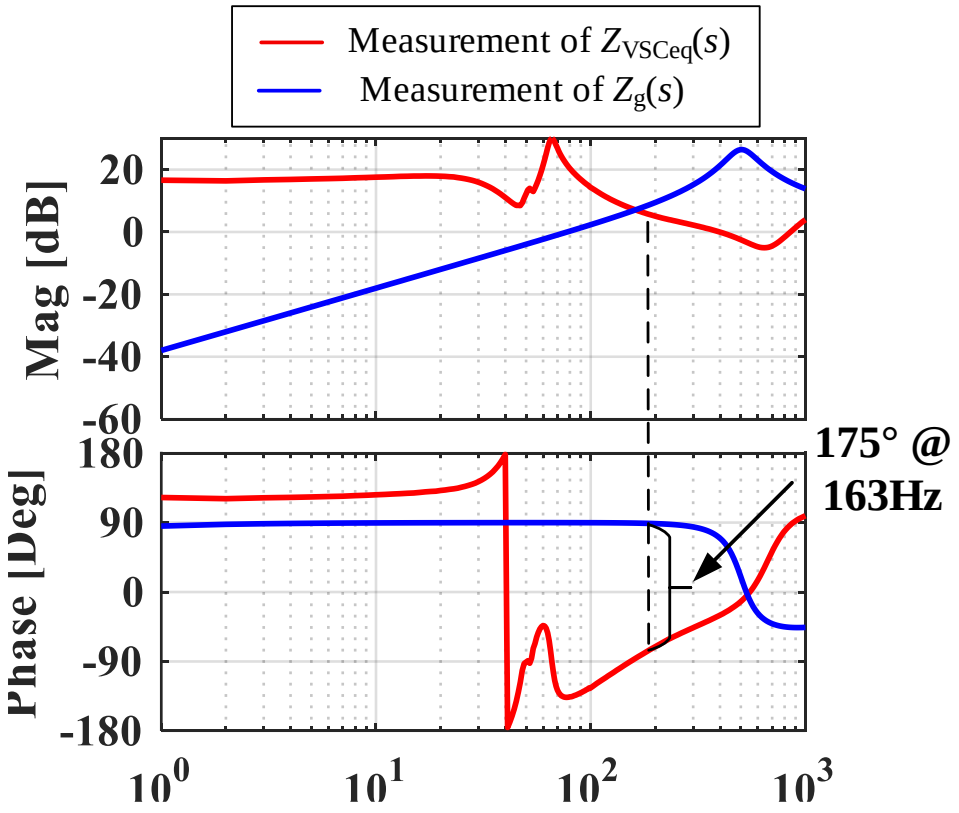


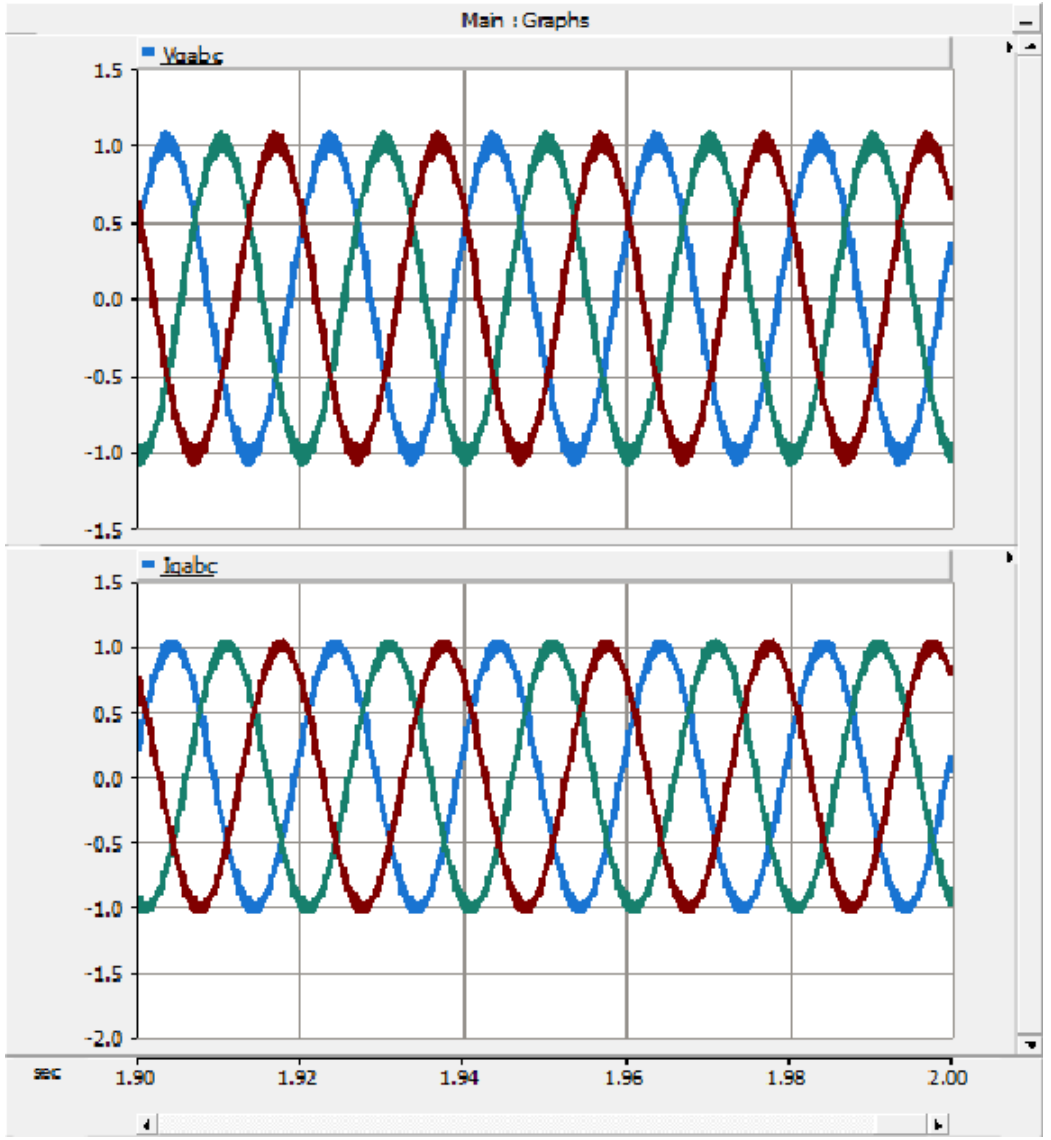


Weak Grid

f_{PLL}=5Hz, stable

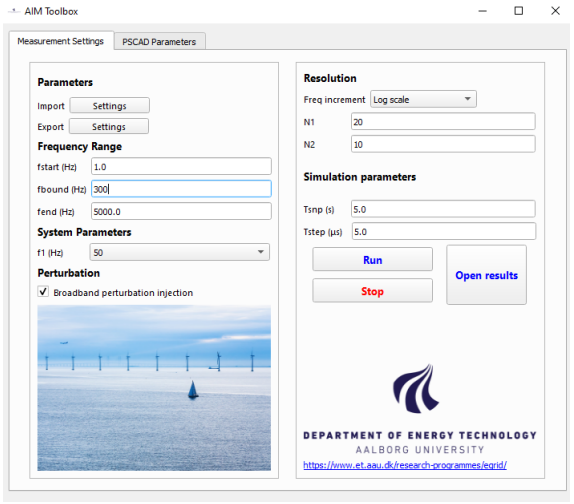
Accurate stability prediction based on the impedance measurement data





Commercialized software toolbox for power system stability analysis

Impedance measurement toolbox



User's manual

PDF

Cross-validation

PSCAD

Generic EMT model of two-level voltage source converter

MathWorks

Theoretical calculated impedance of two-level voltage source converter

TenneT Taking power further

TRANSNET BW

YONSEI UNIVERSITY

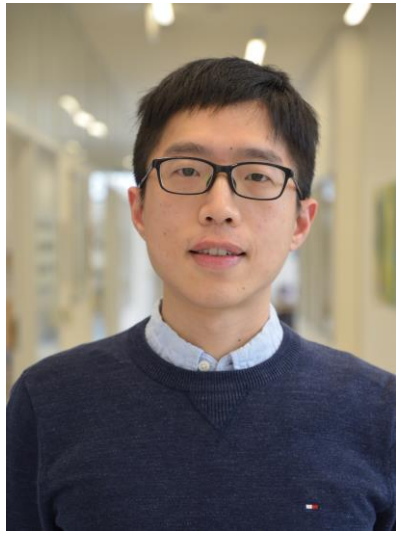
상명대학교 SANGMYUNG UNIVERSITY

For more information

https://www.energy.aau.dk/research-groups/egrid/Research/AIM-Toolbox

https://www.en.patent.aau.dk/technologies/impedance-measurement/

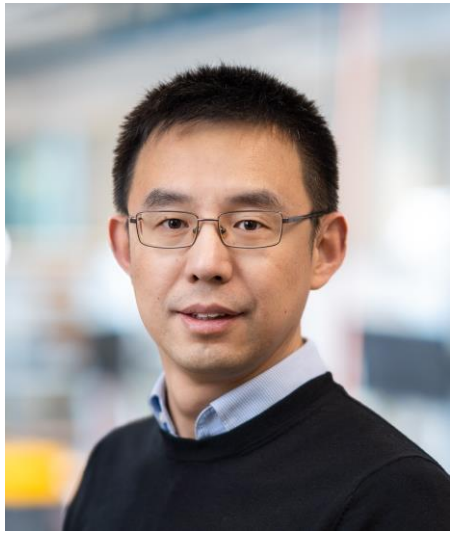
Spin-out on the way….



Heng Wu

PhD, Assistant Professor
AAU Energy, Aalborg University

hew@energy.aau.dk



Xiongfei Wang

PhD, Professor
AAU Energy, Aalborg University

xwa@energy.aau.dk

Emil Krog Kruse

PhD, CEO
Leap Solutions ApS

ekk@leap-solutions.dk