SCAPP
Applications of Synchronous Condenser

SIEMENS
PowerLabDK
DTU

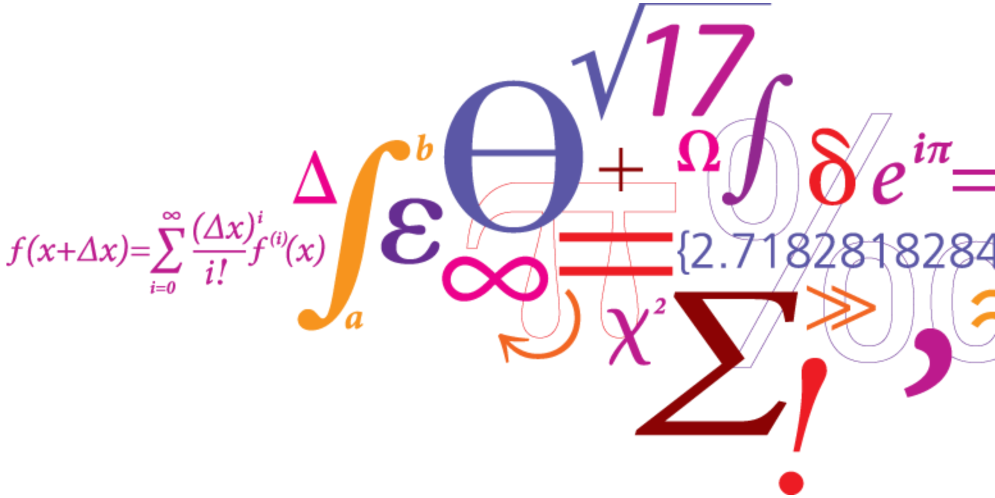
Presentation for the European RTDS User Group Meeting 11 Oct 2018

Studies on low inertia systems and application of synchronous condensers

Study in the Danish project SCAPP

Guangya Yang

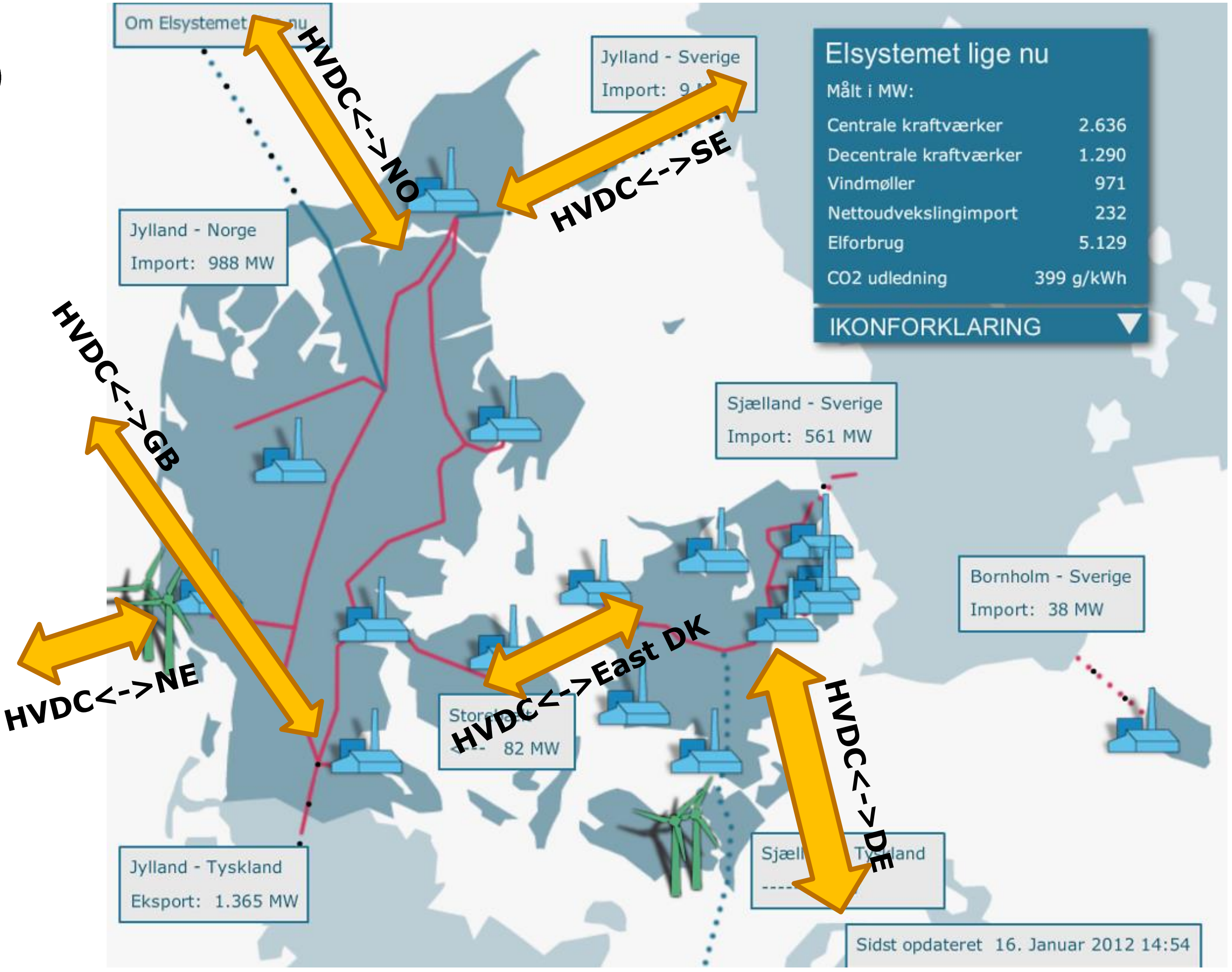
Center for Electric Power and Energy
Department of Electrical Engineering
Technical University of Denmark



Danish Power System

- Two synchronous areas
- High interconnection capacity
  - DK west 6 LCC poles (2300 MW), 1 VSC pole (700 MW)
  - DK East 2 LCCs (1200 MW)
- Need of synchronous machines
  - Short circuit power
    - Voltage variations during switching
    - HVDC load rejection
  - Dynamic voltage control
    - HVDC power ramping
    - High voltages in low load period
  - Reactive power demand from old wind turbines
  - Fault-ride-through capability
  - Must run is expensive

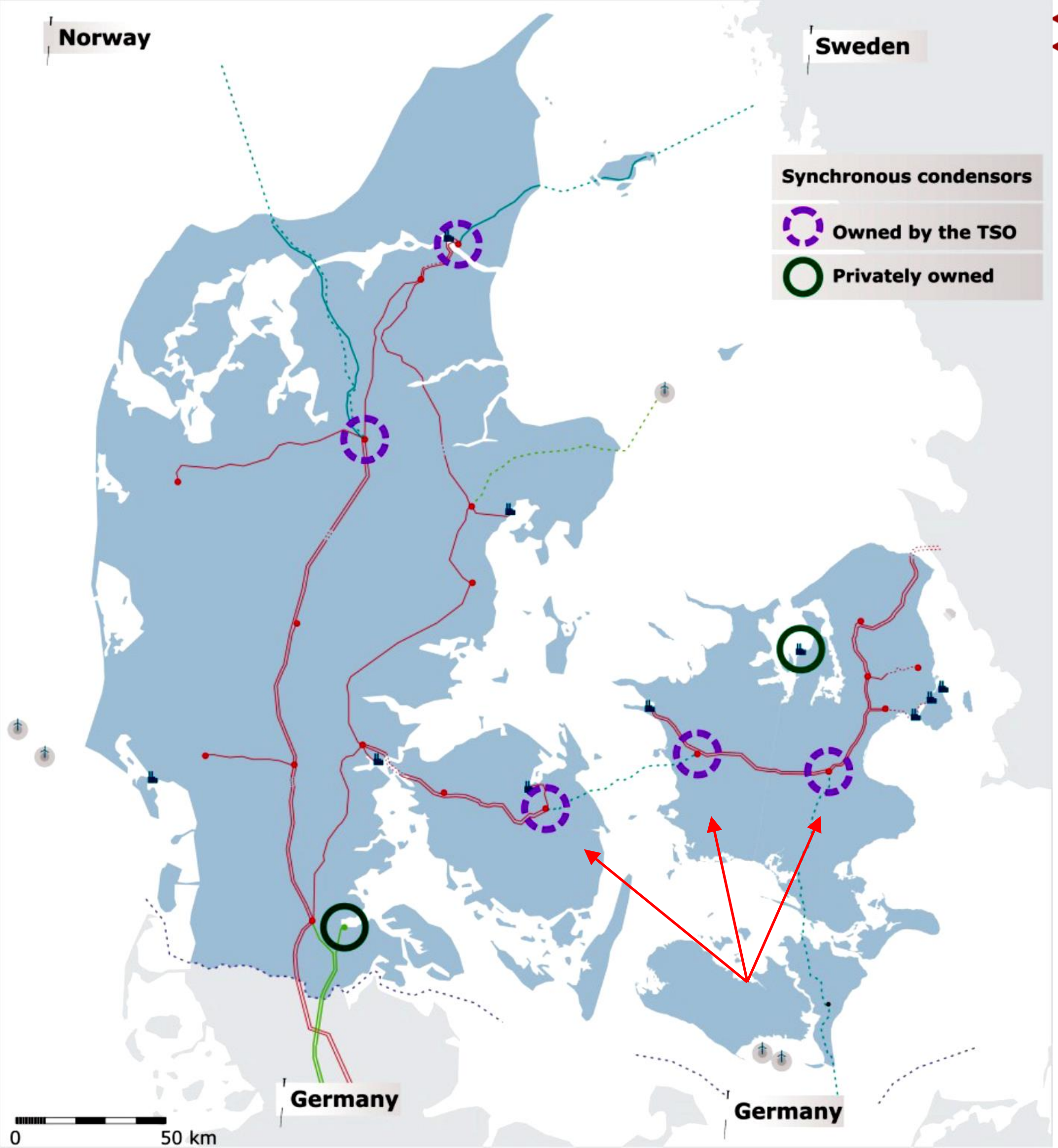
DK west	DK east
Central power plants 2250 MW	Central power plants 2900 MW
Local CHP plants 2000 MW	Local CHP plants 650 MW
Wind turbines 3700 MW	Wind turbines 1000 MW
Photovoltaic 450 MW	Photovoltaic 200 MW
Consumption 1400 - 3500 MW	Consumption 900 - 2500 MW



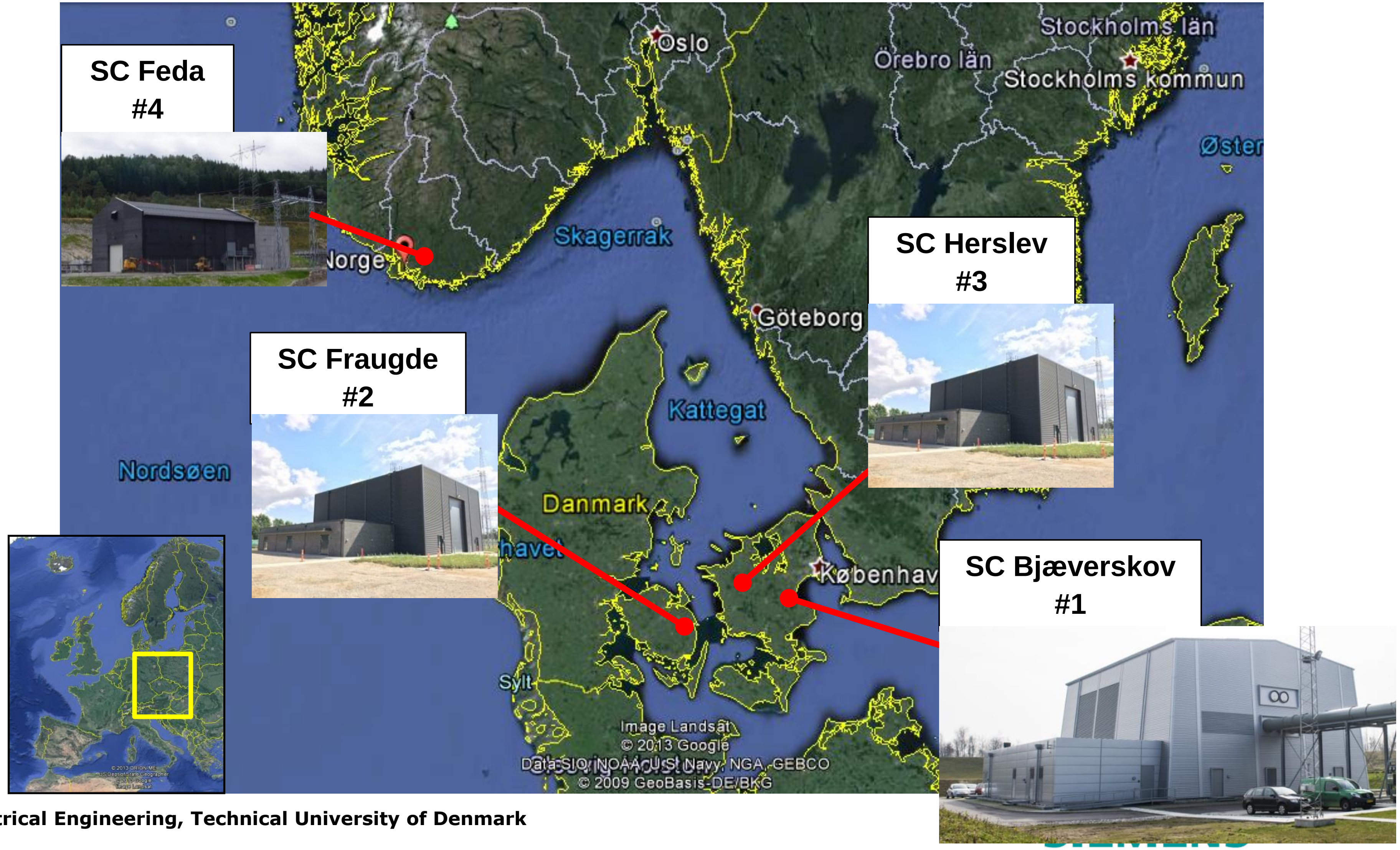
Synchronous condensers in DK

- 7 synchronous condensers in DK
- 3 recent synchronous condensers
- Short circuit power
  - BJS(2013) >800 MVA;
  - FGD/HKS (2014) > 1000 MVA;
- Reactive power compensation
  - -150/215 Mvar (BJS)
  - -120/180 Mvar (FGD/HKS)
- Installed at LCC HVDC converter stations

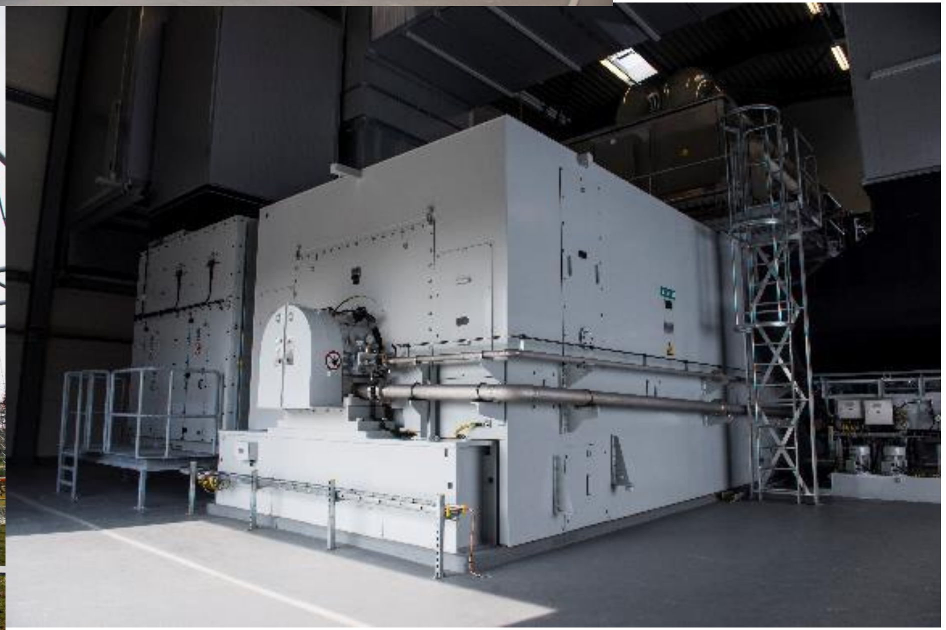
Station	Area	kV	Mvar	Year
Bjæverskov	DK2	400	270	2013
Herslev	DK2	400	200	2014
Fraugde	DK1	400	200	2014



Synchronous condensers in the Siemens portfolio was „re-invented“ in Denmark



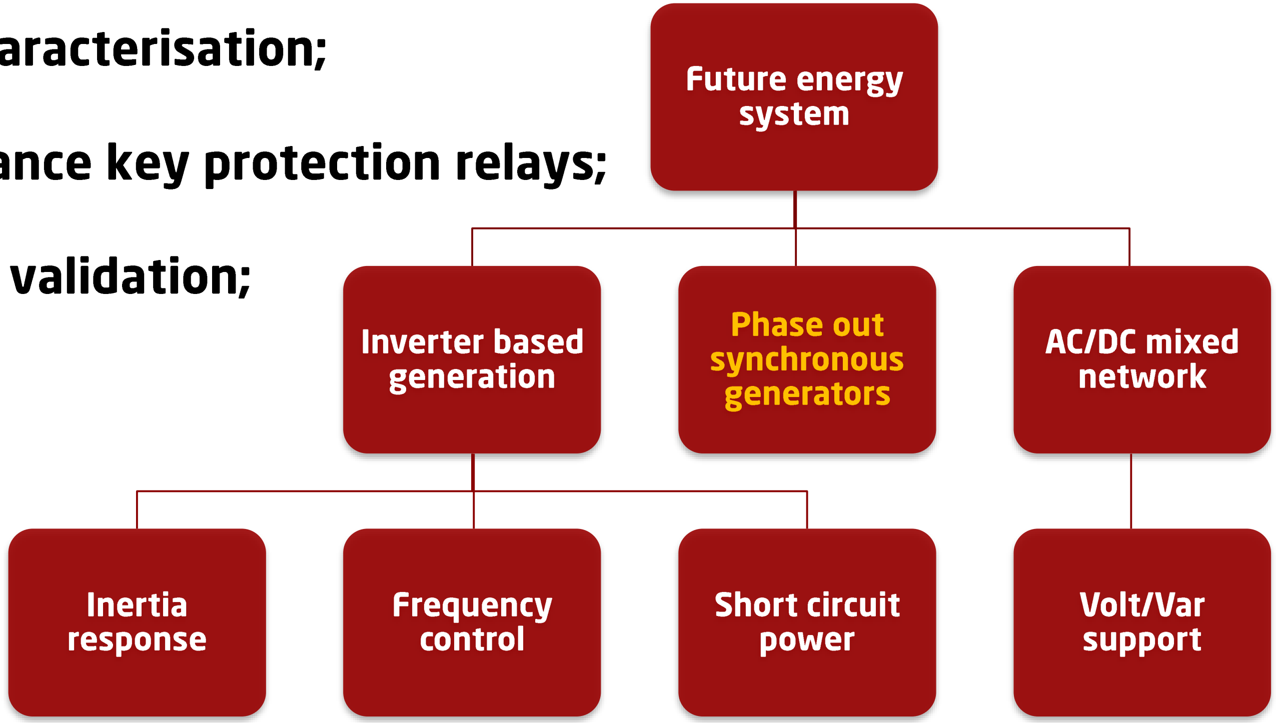
A condenser station



SCAPP Overview

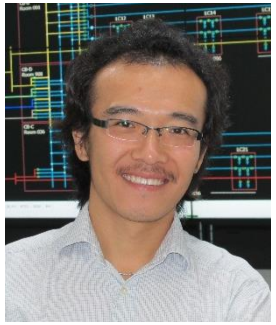
Synchronous condensers may play an important role during the transition.

- ❑ The project will look at the following issues with a focus on the application of synchronous condensers (SC)
  - ❑ **System frequency and inertia characterisation;**
  - ❑ **Short-circuit power and performance key protection relays;**
  - ❑ **Hardware-in-the-loop testing for validation;**
  - ❑ **Optimal properties of SC**;
- ❑ Use of RTDS for EMT simulations;
- ❑ Intensive R&D project;
- ❑ Close DTU-Siemens collaboration;



Project contributors

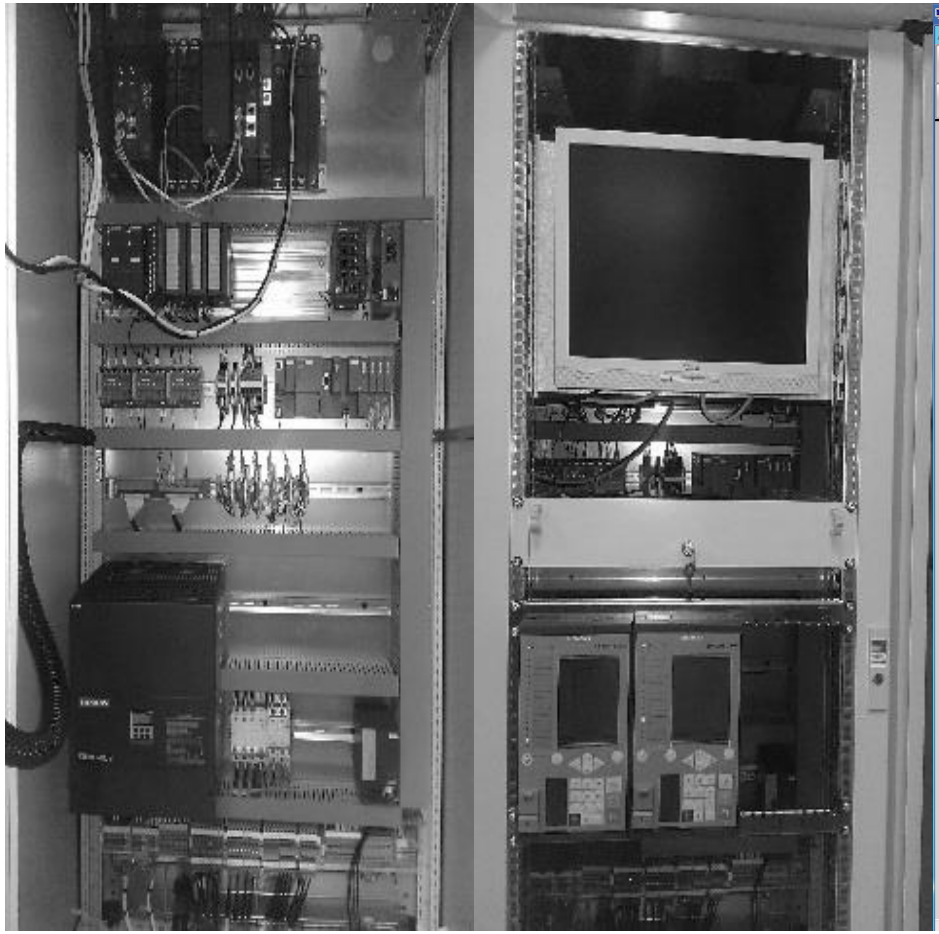
- Ha Thi Nguyen;
- Jundi Jia;
- Guangya Yang;
- Arne Hejde Nielsen;
- Peter Højgaard Jensen;
- Peter Rønne-Hansen
- Kenneth Soede;
- Bo Johansson;
- Peter Weinreich-Jensen;
- Martin Bo Sjoeberg;
- Matthew Lee Henriksen;
- Thomas Stampe Mogensen;
- Brian Willum Solberg;
- Jacob Østergaard

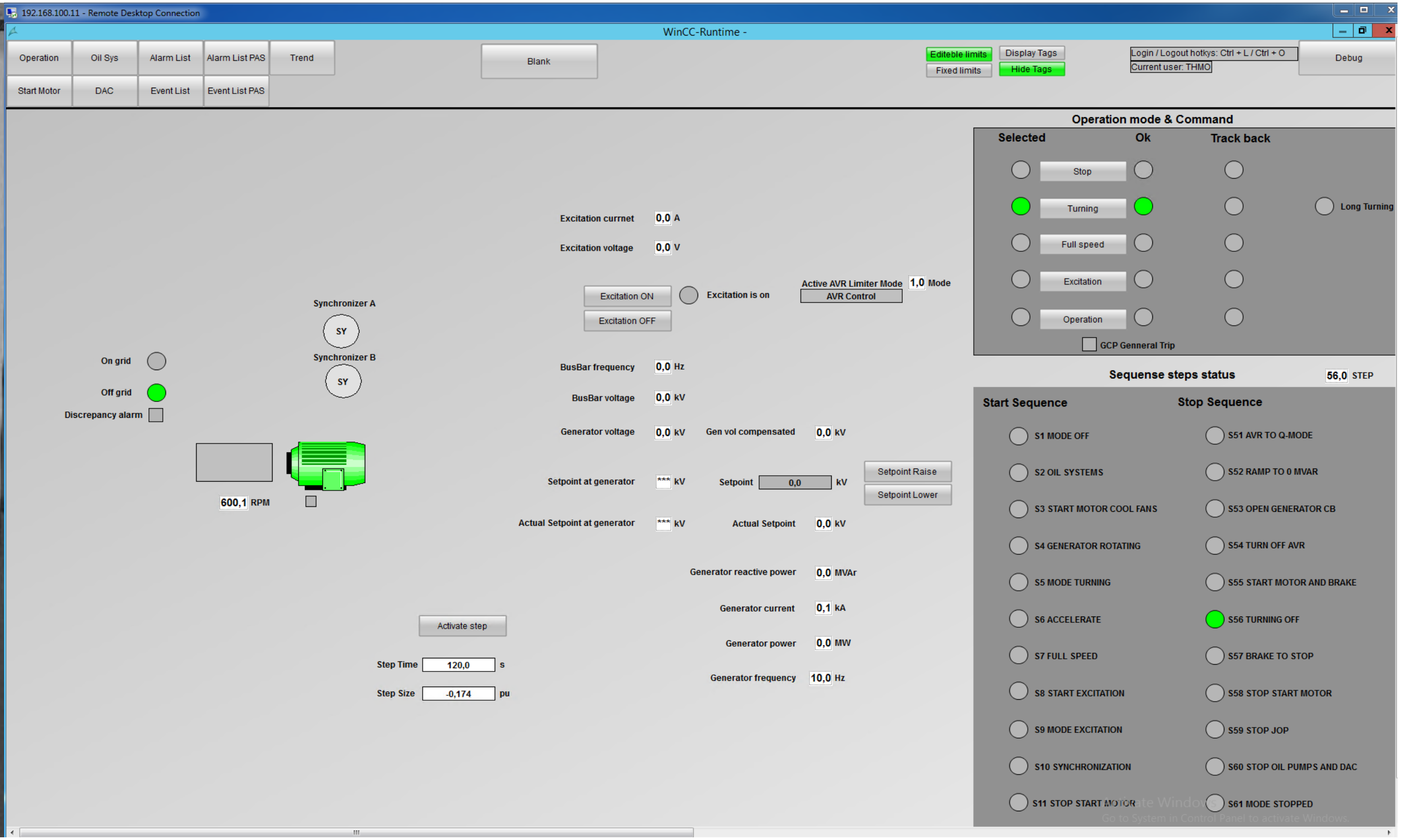




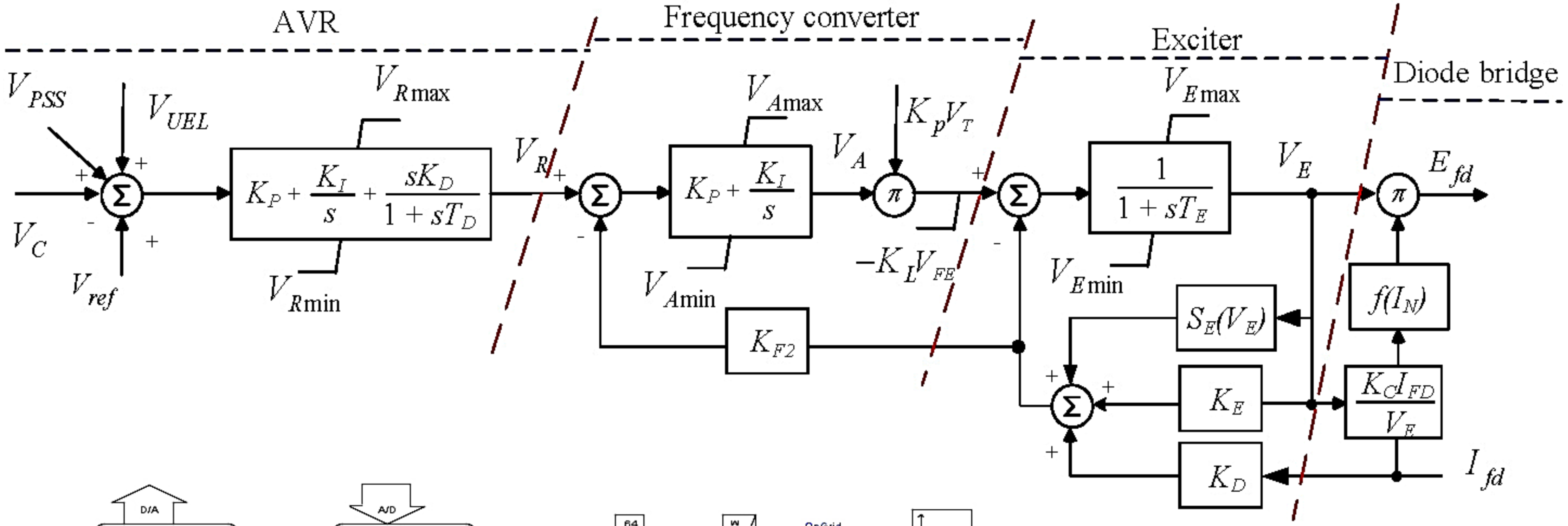


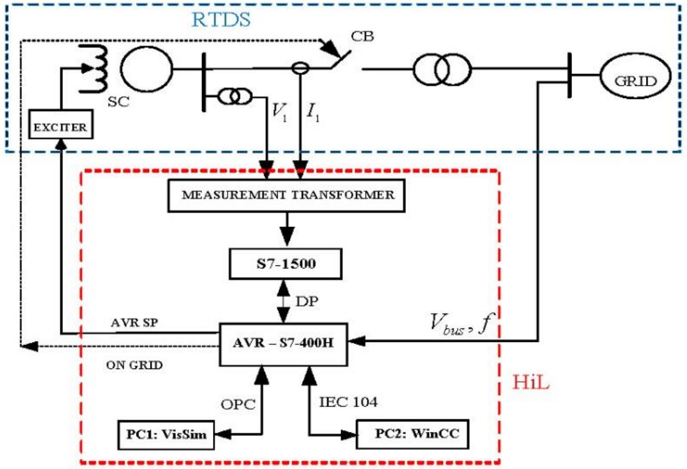

Pictures of the system



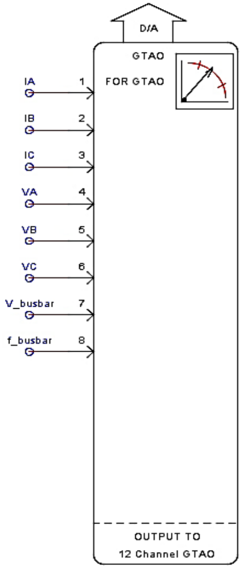


AVR configuration

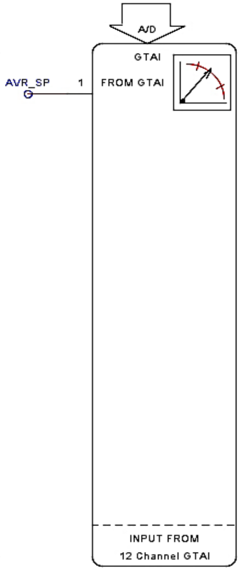




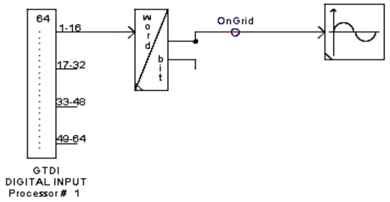
(a) The system diagram with AVR HiL.



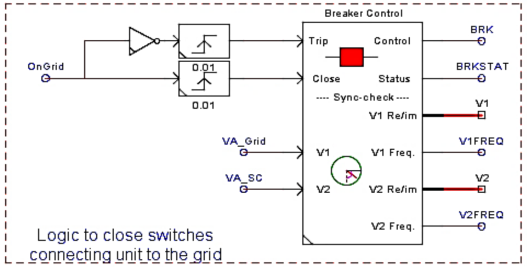
(a) GTAO card.



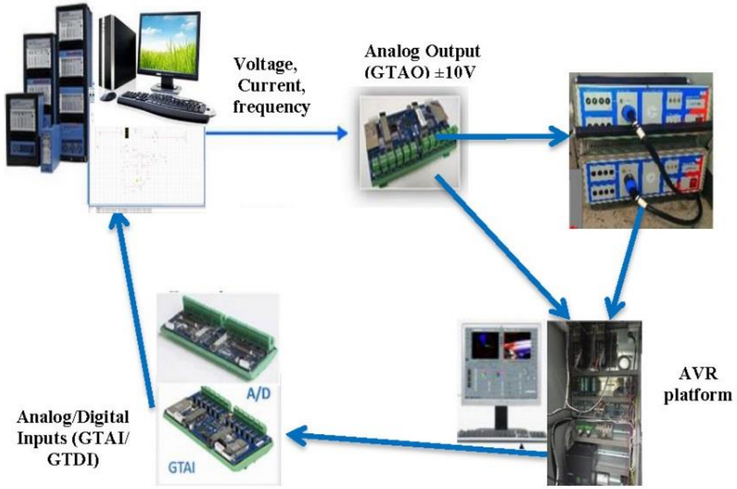
(b) GTAI card.



(c) GTDI card.



(d) Circuit Breaker logic.



(b) AVR hardware testing setup.

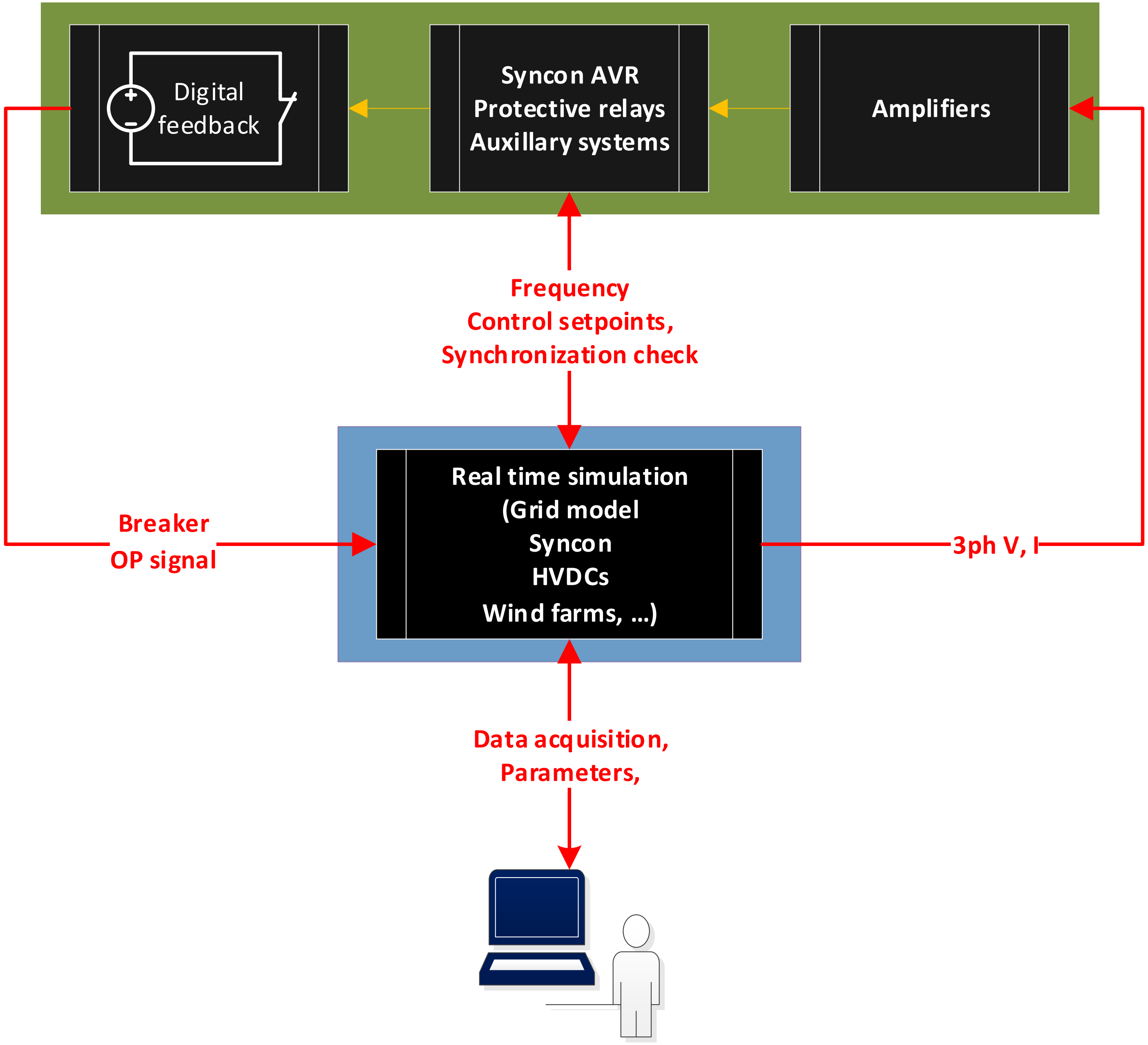
Real time test platform in laboratory

Platform capabillity

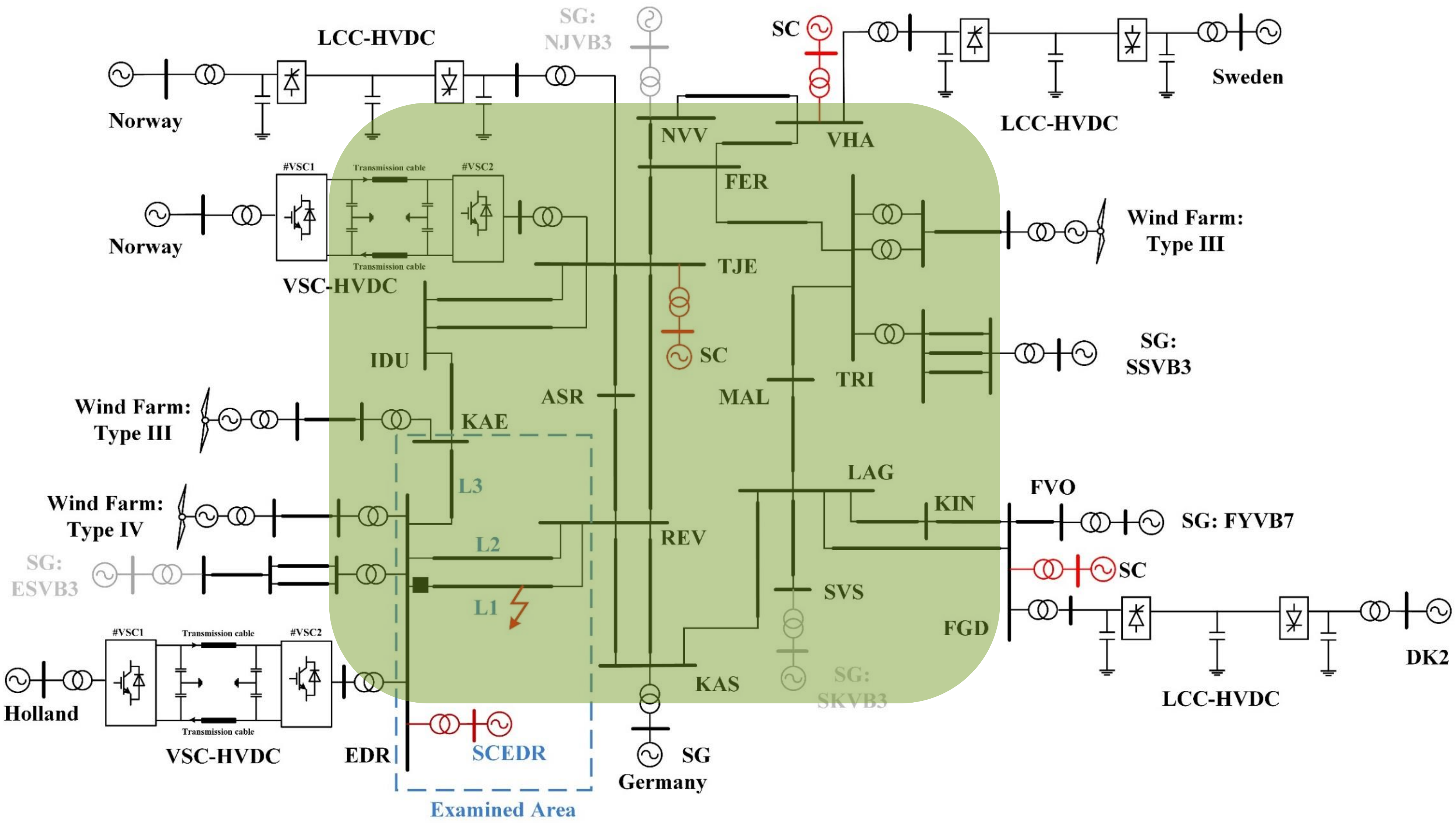
- ✓ SC startup and shut down process
- ✓ SC model validation and verification
- ✓ SC plant auxillary system monitoring
- ✓ SC control design and parameterization
- ✓ SC protection test
- ✓ Grid protection test
- ✓ Converter tests

Simulation control

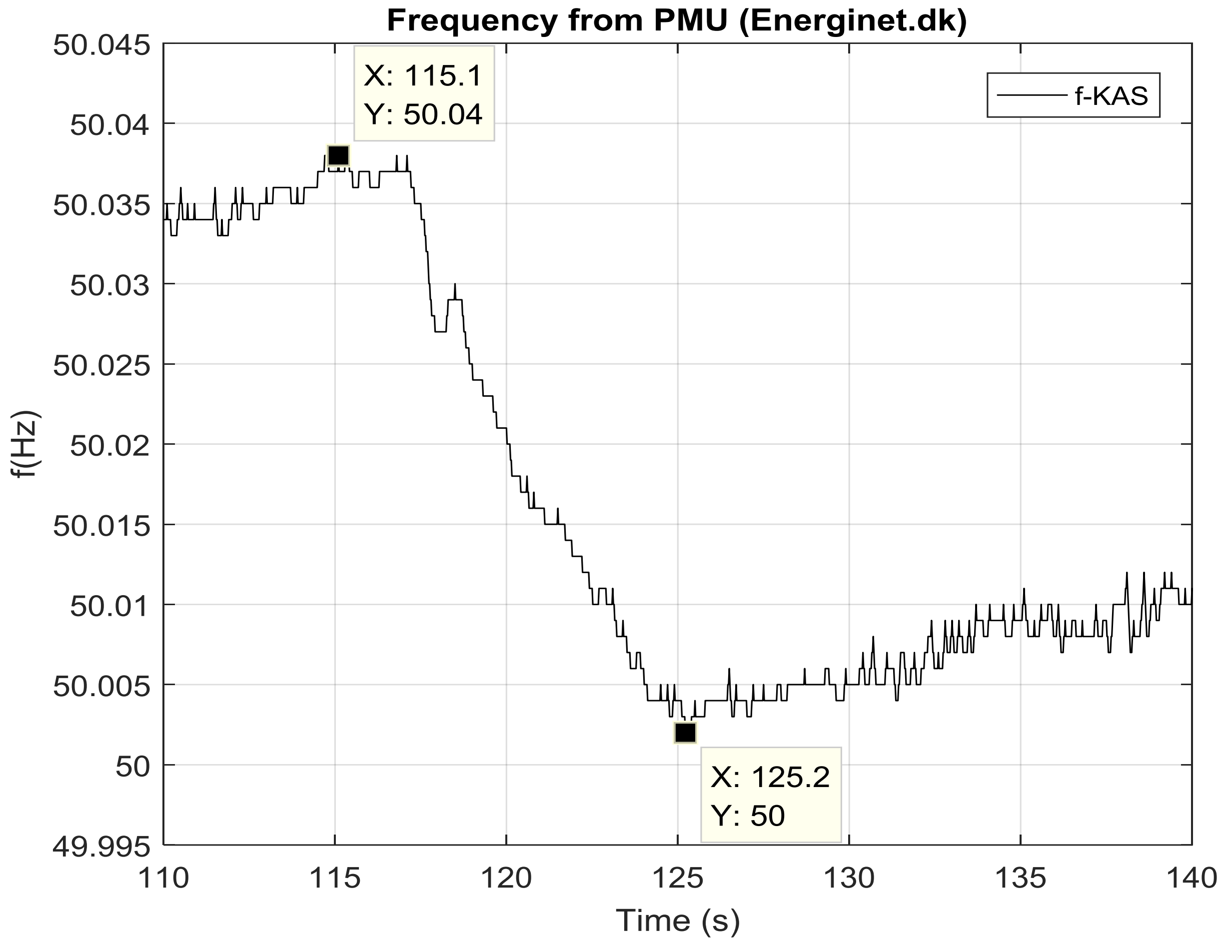
- ✓ OPC for data acquisition from simulation
- ✓ Remote control of simulation through Matlab
- ✓ Incorporation of nonlinear optimization tool for modelling/ control parameterization
- ✓ Scenario control for relay testing

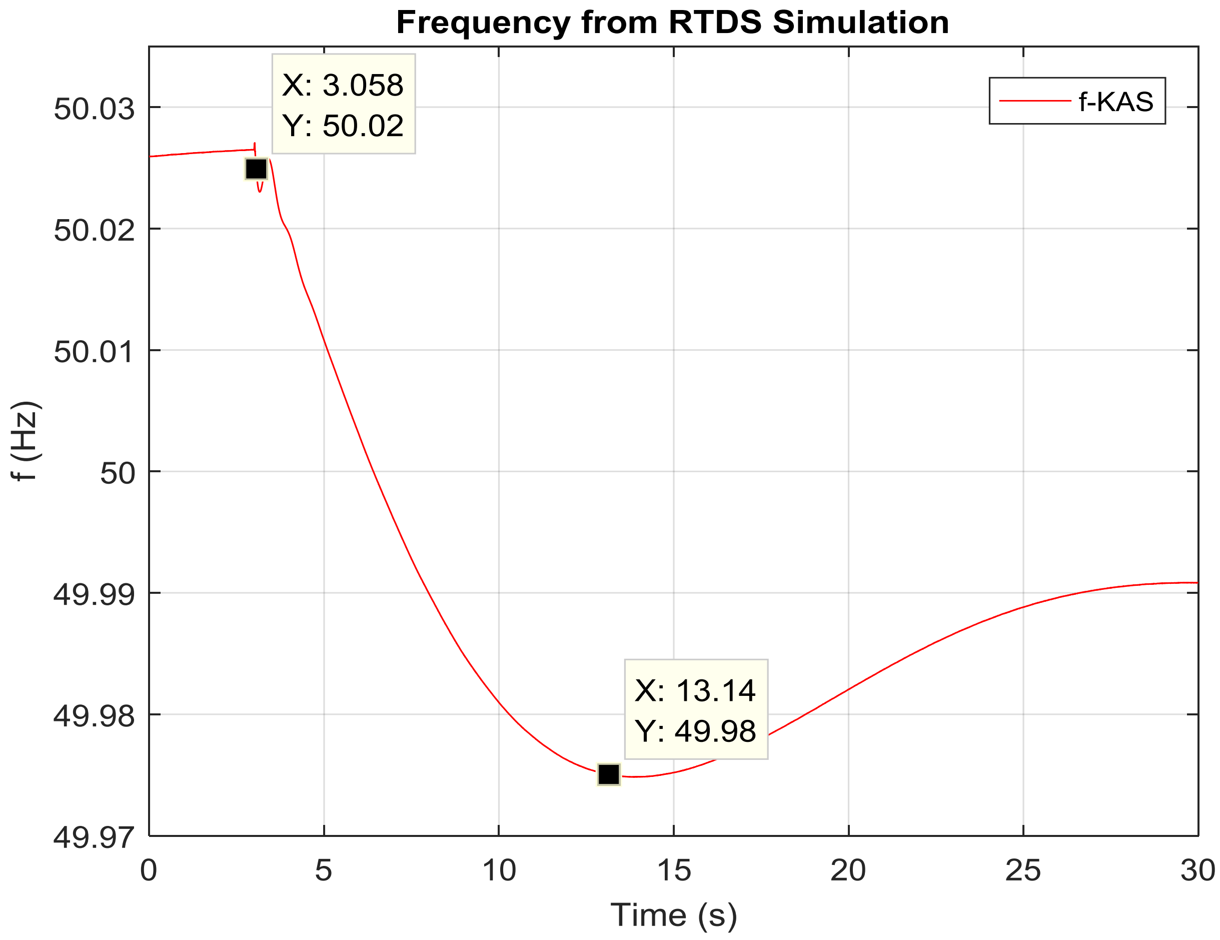


DK1 system modelling and validation



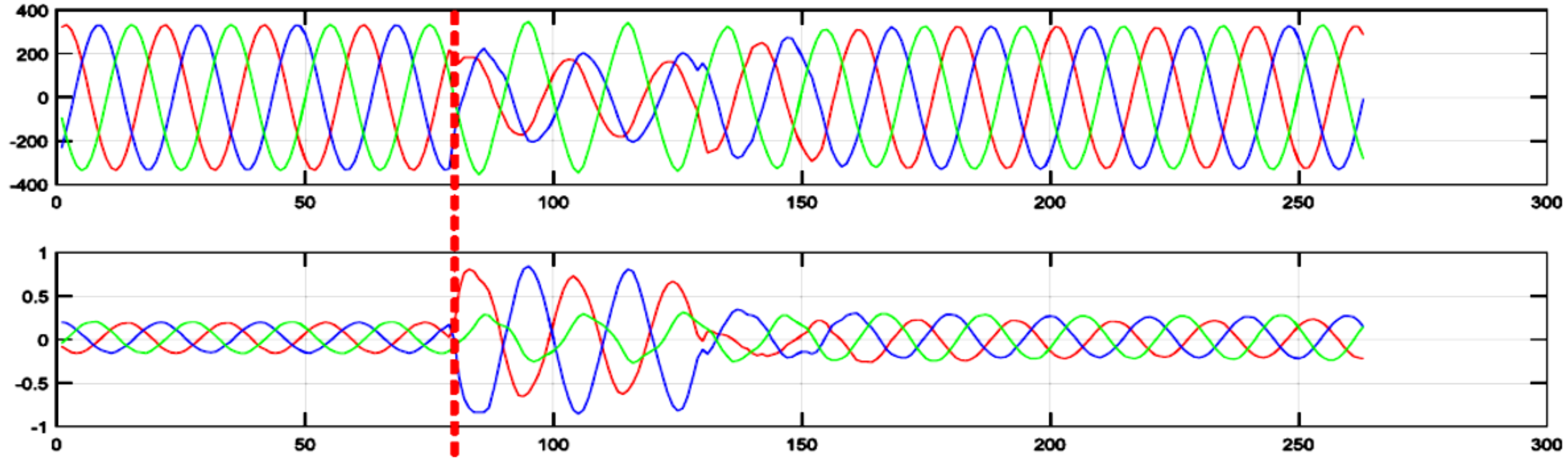
Frequency response validation



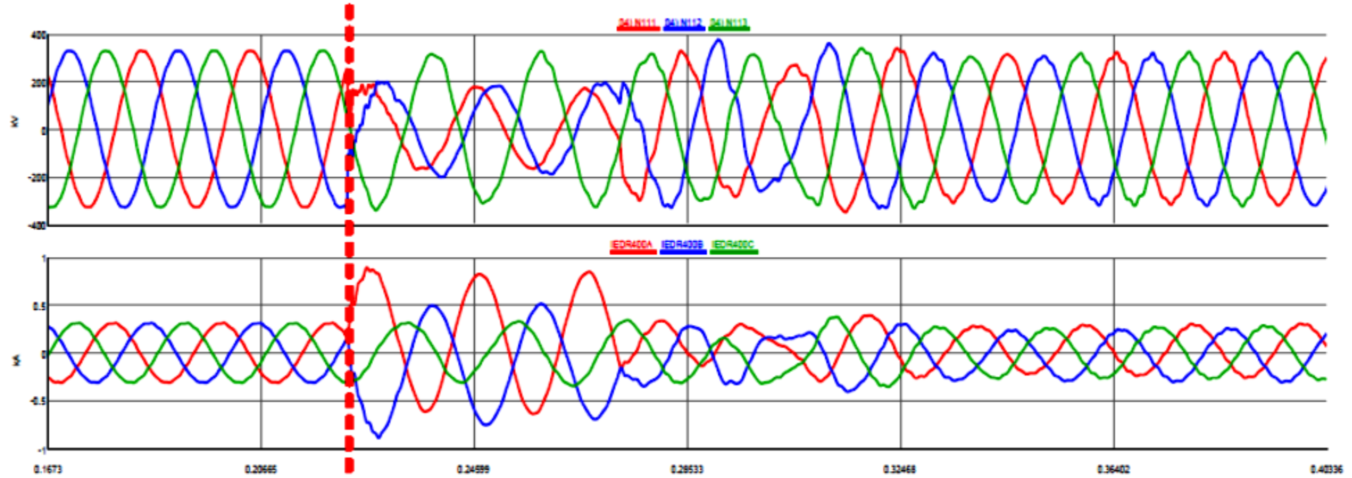


Short circuit current validation

Data provided by Energinet

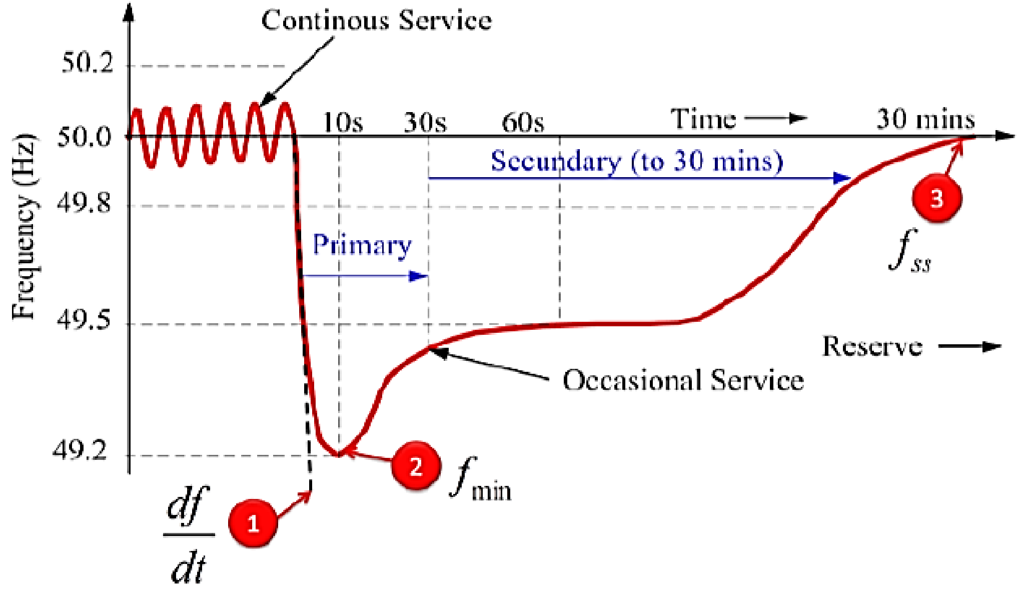


RTDS Simulation



Frequency studies

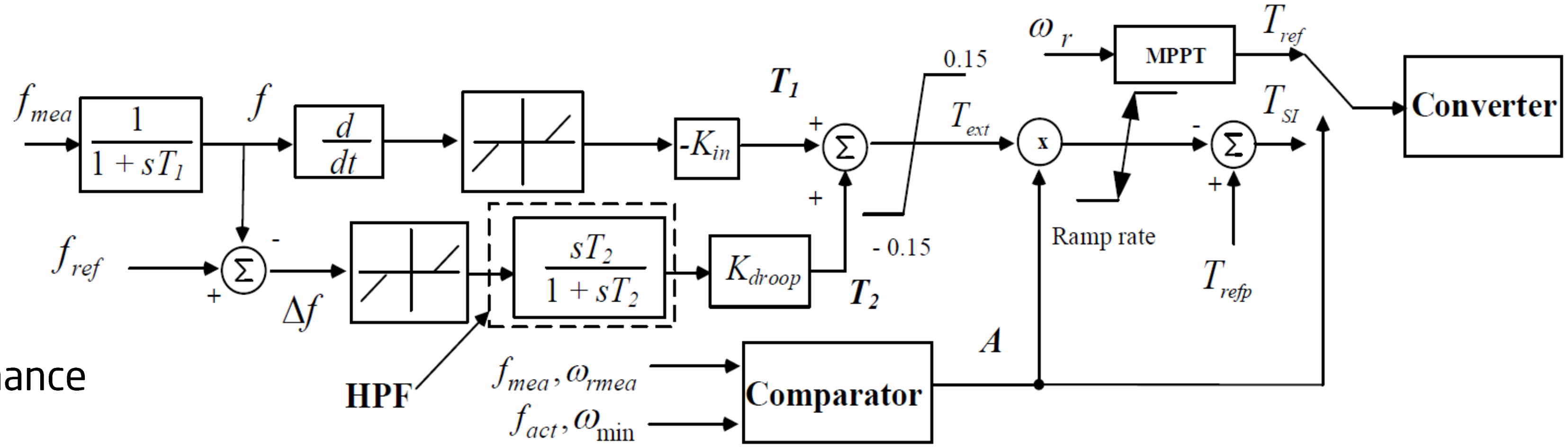
- Modelling efforts
  - Synthetic inertia from wind
  - Frequency dependent load
  - Synchronous condenser (HiL)
- Qualification
  - Intrinsic inertia
  - Synthetic inertia
- Identify frequency issues
  - Three measures
- Innovative controls from SCs
  - Improve the system performance



ROCOF

Frequency nadir

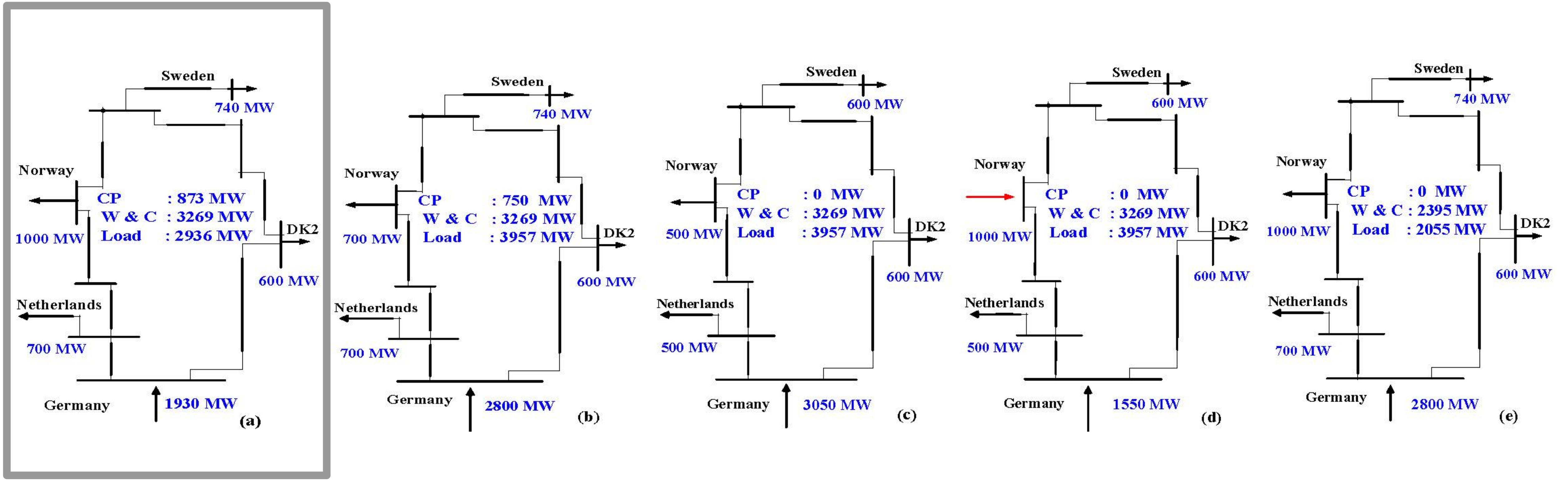
Settling time



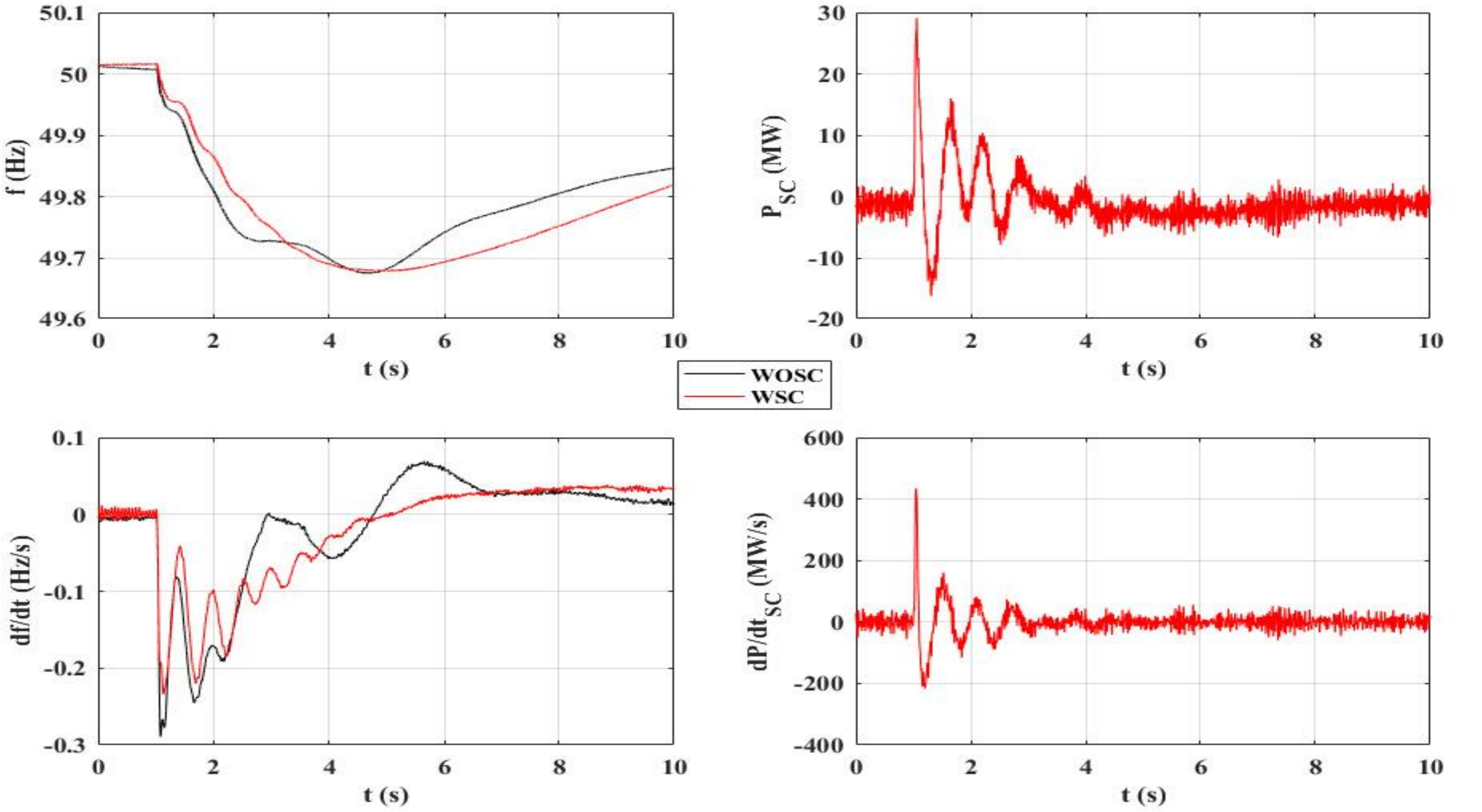
Frequency analysis example

- Effect of synchronous condensers
  - What is the difference between condenser's contribution and inertia response from wind
  - What can condenser bring to the system in terms of frequency stability

Frequency study results - base case

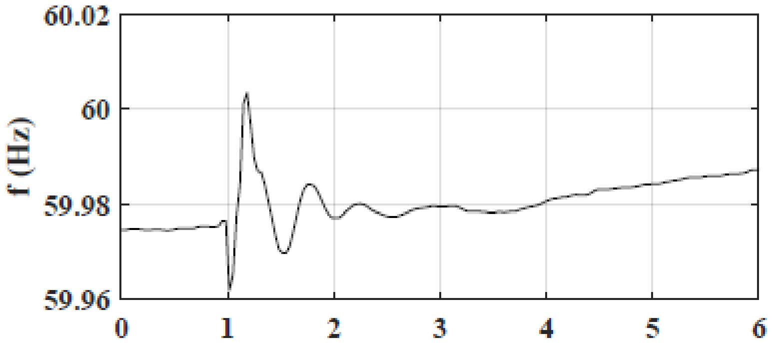


Frequency results – base case

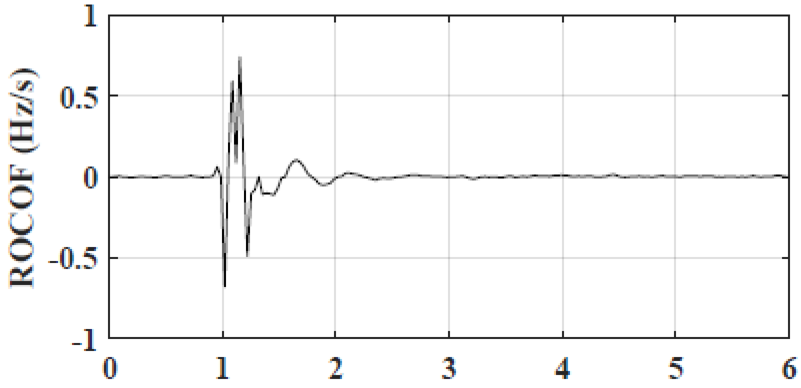


System response during a 200 MW load increase.

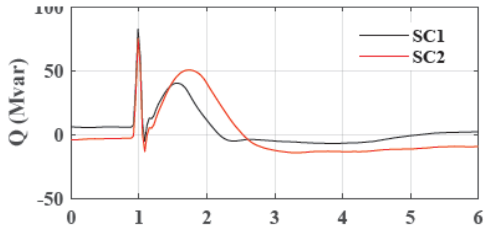
Frequency results – From the field



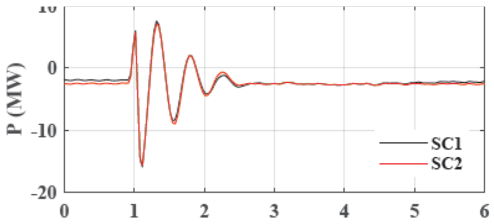
(a) Frequency response



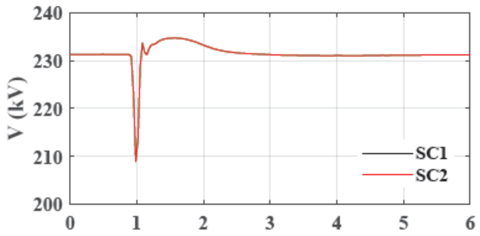
(b) ROCOF



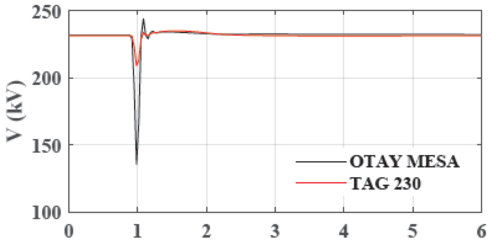
(a) Reactive power of SCs



(b) Active power of SCs

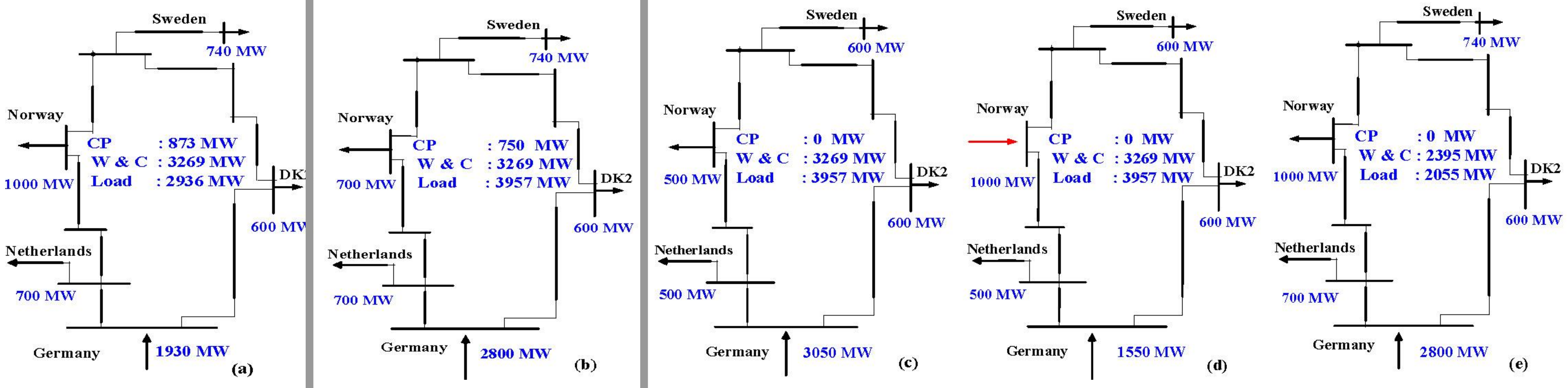


(c) Terminal voltage of SCs

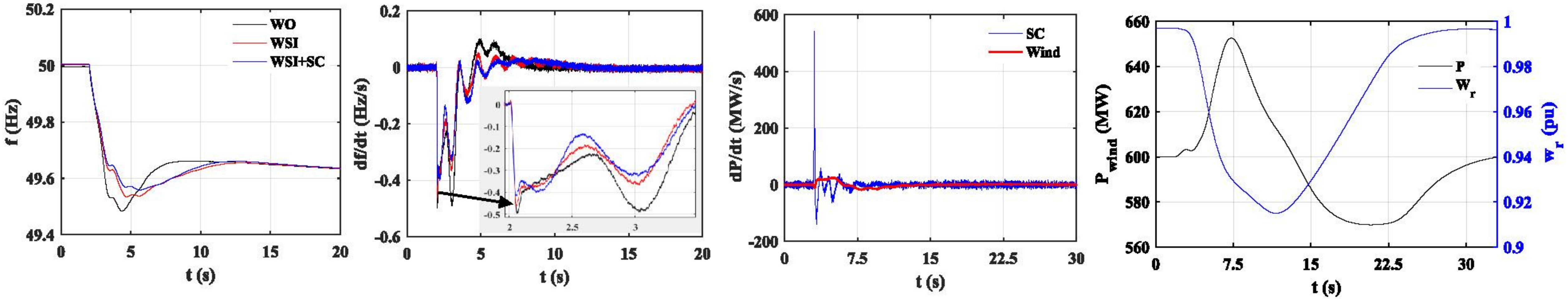


(d) The voltage of the busbar

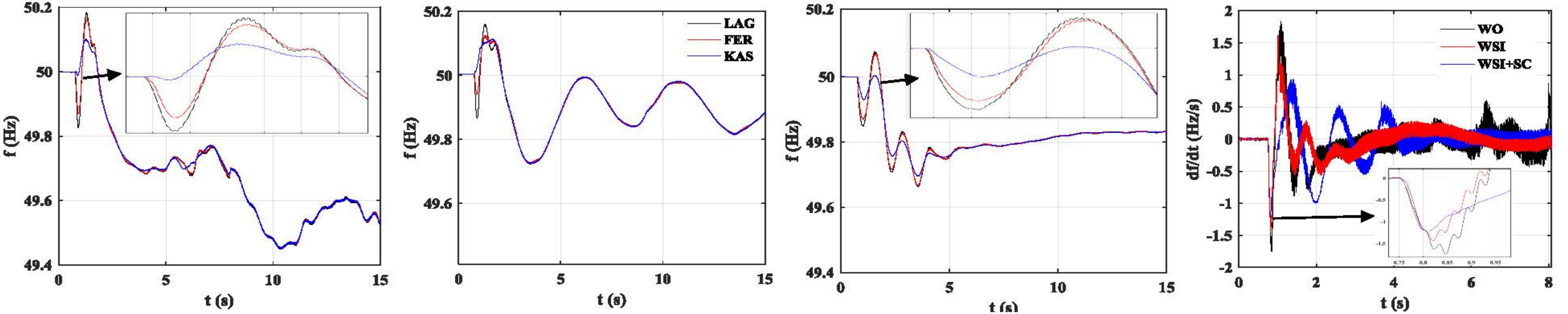
Frequency study results - HWHL



Frequency study results - HWHL



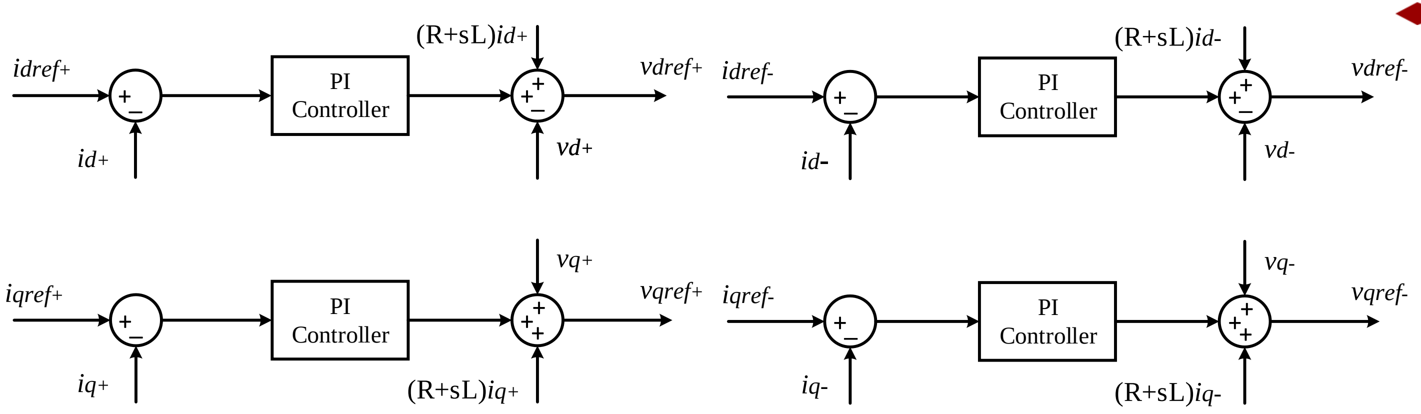
Frequency response at 1 substation during a 10% load increase disturbance of HWHL (3 SGs in operation).

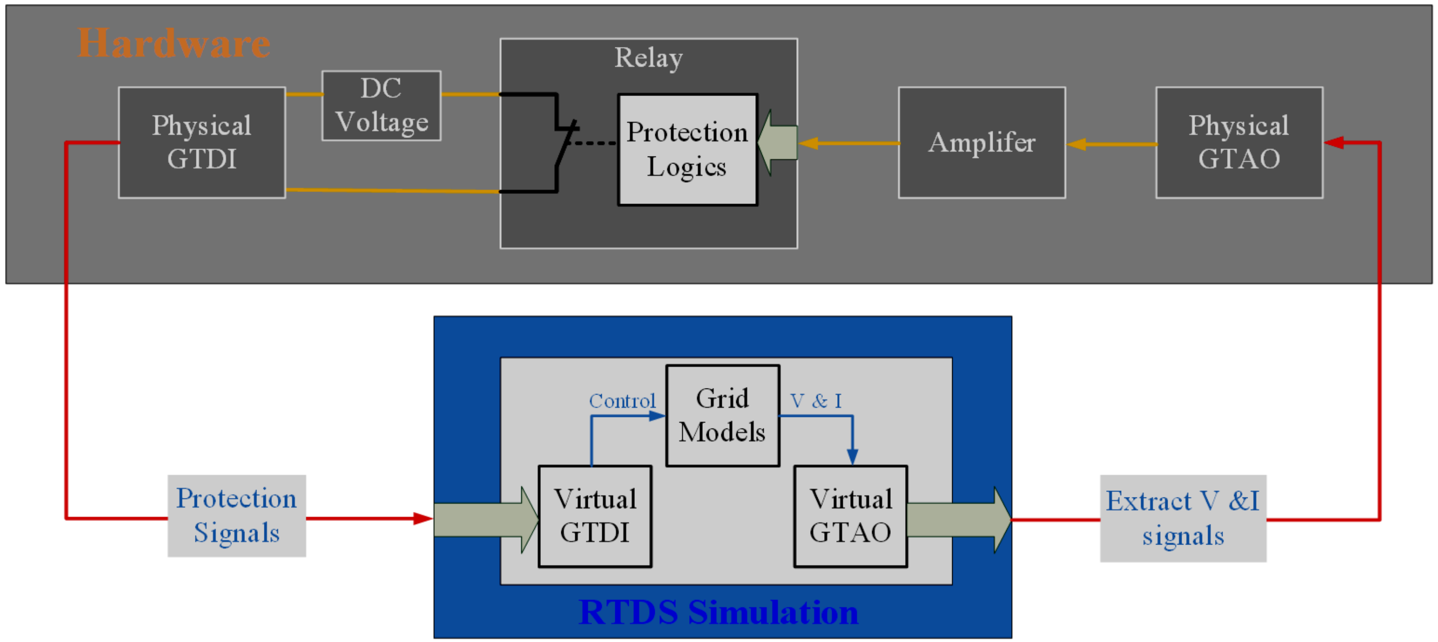


Frequency response in 3 substations during a 10% load increase disturbance of HWHL (no SGs in operation) WO, WSI, and WSI+SC

Short circuit studies

- Modelling efforts
  - Synchronous condenser
  - HVDCs and wind
  - Incorporation of converter control methods
- Short circuit power assessment
  - Effect of converter controls
  - Interaction with SCs
- Static fault analysis algorithm
  - VSC equivalent
  - SC planning and grid codes
- HiL testing
  - Distance and generator relays





Converter control strategies during fault

- **Synchronous reference frame (SRF) vector control**
  - Positive sequence current only with current limit;
- **Flexible positive/negative sequence power control**
  - Sequence power can be controlled separately.
  - Considering positive and negative sequences on both directions
  - Current reference can be separated into active and reactive component

$$\boldsymbol{i}^{ref} = \boldsymbol{i}_p^{ref} + \boldsymbol{i}_q^{ref}$$

  - Active power control

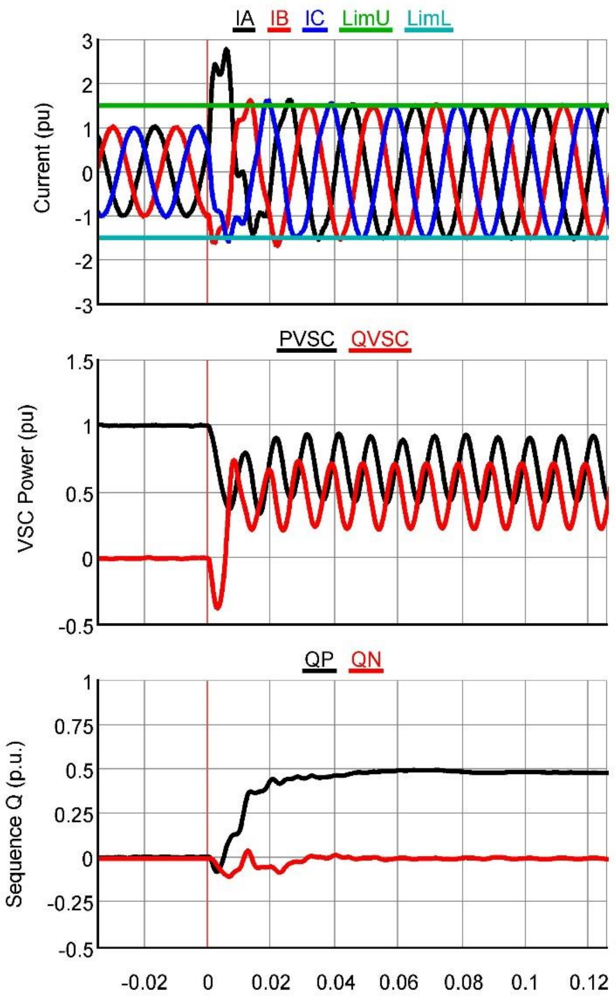
$$\boldsymbol{i}_p^{ref} = k_p \frac{P^{ref}}{|\boldsymbol{V}^{+}|^2}\boldsymbol{v}^{+} + (1 - k_p)\frac{P^{ref}}{|\boldsymbol{V}^{-}|^2}\boldsymbol{v}^{-}$$

  - Reactive power control

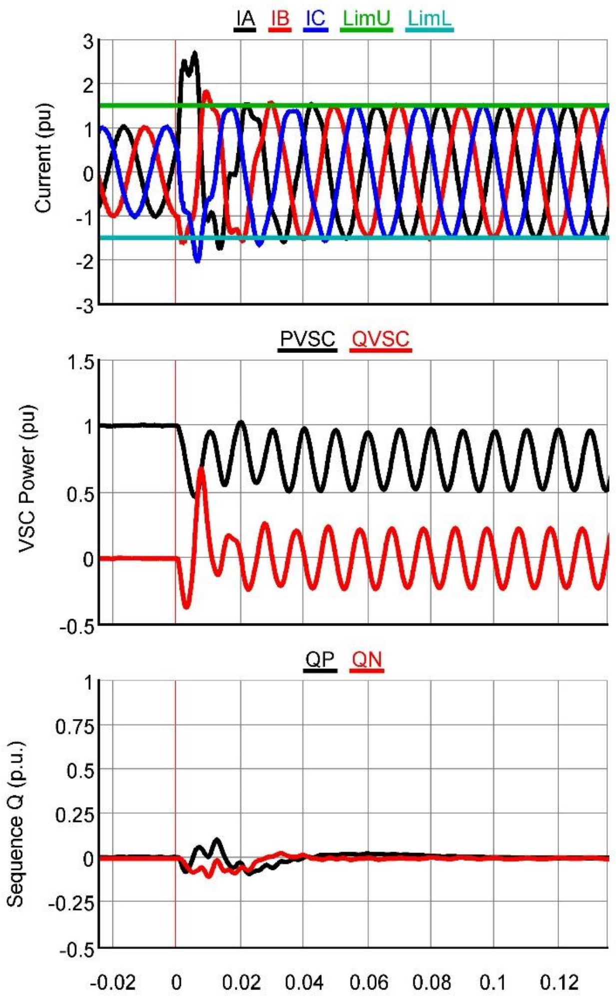
$$\boldsymbol{i}_q^{ref} = k_q \frac{Q^{ref}}{|\boldsymbol{V}^{+}|^2}\boldsymbol{v}_{\perp}^{+} + (1 - k_q)\frac{Q^{ref}}{|\boldsymbol{V}^{-}|^2}\boldsymbol{v}_{\perp}^{-}$$

Control effects

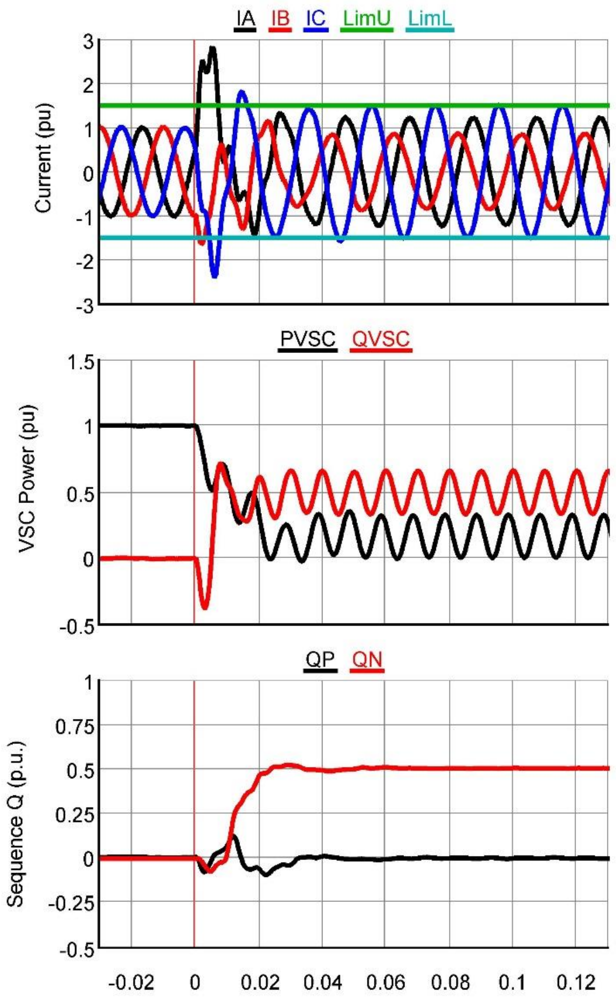
Method 1: k_q=1, Q_{ref}=0.5



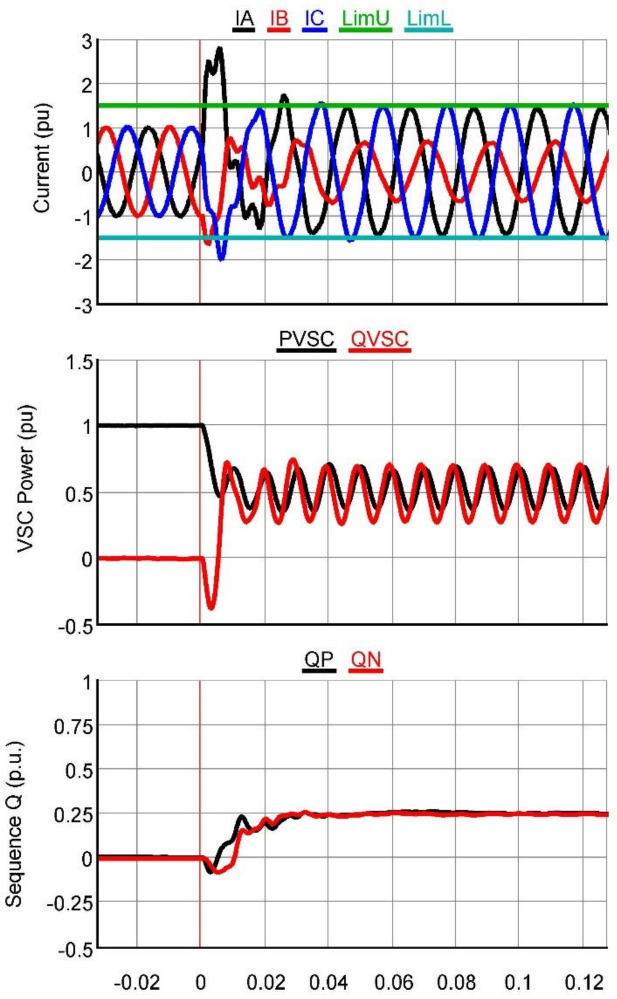
Method 2: k_p=1, Q_{ref}=0



Method 3: k_q=0, Q_{ref}=0.5

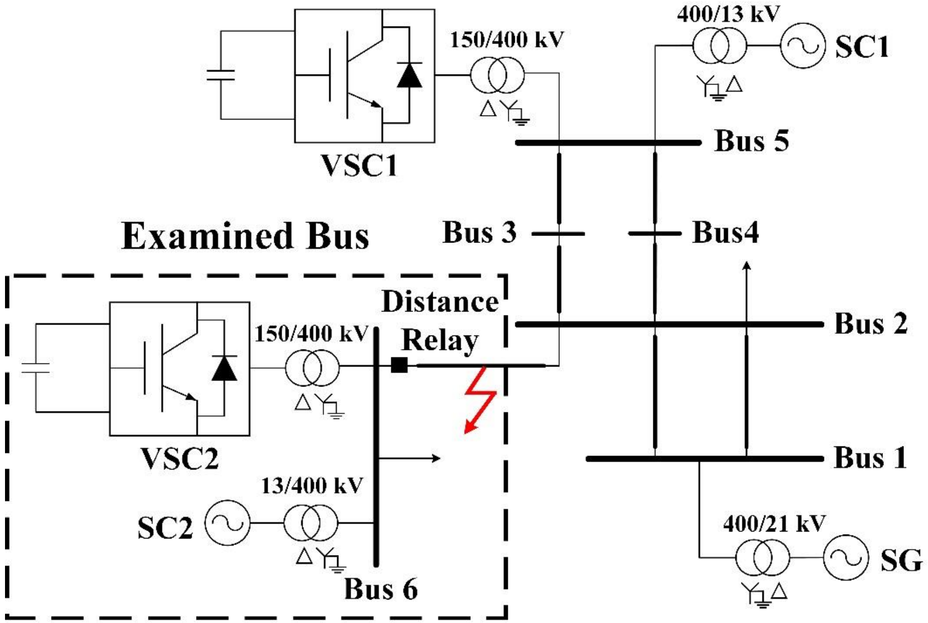


Method 4: k_q=0.5, Q_{ref}=0.5



Relay testing results

- Real relay is used for test
- Relay performance is adversely affected by converters
- Generally more SC capacity, better relay performance



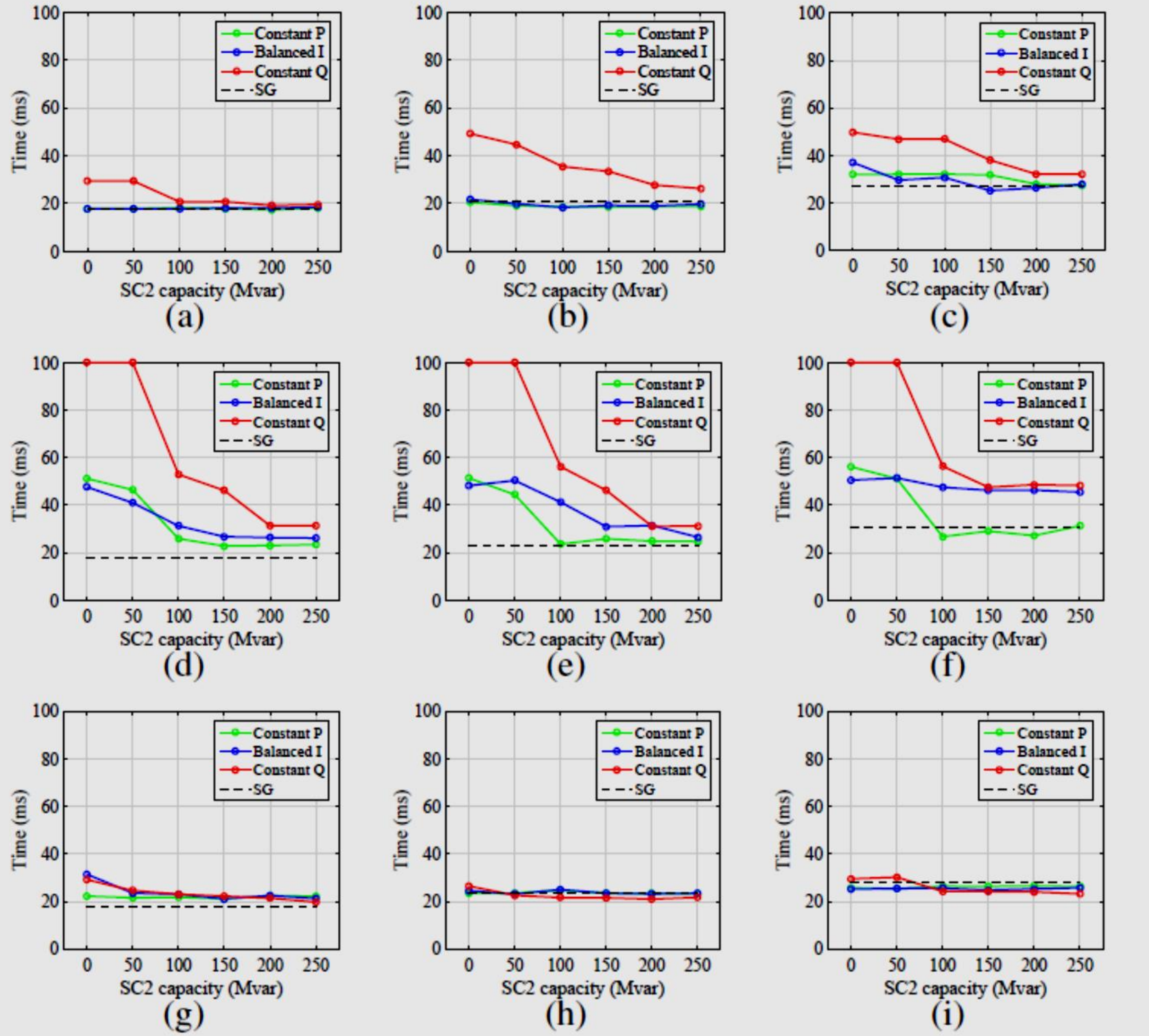


Fig. 12. Average response time for Case 1, 2 and 3: (a) A–g fault at 25%. (b) A–g fault at 50%. (c) A–g fault at 75%. (d) A–B fault at 25%. (e) A–B fault at 50%. (f) A–B fault at 75%. (g) A–B–g fault at 25%. (h) A–B–g fault at 50%. (i) A–B–g fault at 75%. (100 ms in (d)–(f) represents refuse-to-trip failure)

Short circuit power from converters

- Control methods suffer from the current limits given by the power electronic elements, unless with oversized systems, but cost increases;
- There is an interaction between converter and synchronous generators during faults.
- The impact on the relays is from both the current magnitude and phase;
- Problems can occur either due to less fault current level, or relay cannot detect the fault after filtering;
- Due to lack of requirements in general in this field (esp. unbalanced faults), there are needs for more specifications and innovation.
- There is potential for innovative converter controls;

Thank you for your attention!