MEDOW
MULTI-TERMINAL DC GRID FOR OFFSHORE WIND

Subsynchronous Resonance testing and damping in an AC/DC network using real-time hardware in-the-loop framework

Tibin Joseph
Marie Curie Early Stage Researcher
Institute of Energy
Cardiff University, Wales, UK

Email: josepht@cardiff.ac.uk

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www.medow.engineering.cf.ac.uk

Outline

- **Introduction to the transmission system now and in 2020**

Planned reinforcements by the national transmission grid operator

- Grid Code requirements and the UK transmission system

- **Test system model**

- Generic GB adapted model

- **Control of Subsynchronous interaction and damping using VSC converter**

- Real time test setup
- HIL test set up

- **Conclusion and Future Tests**

Planned Network Reinforcement for 2020

Major reinforcement include series compensation of transmission routes and two additional HVDC links between Scotland and England

Increase boundary capacity by 1100 MW to 4400 MW by series compensation

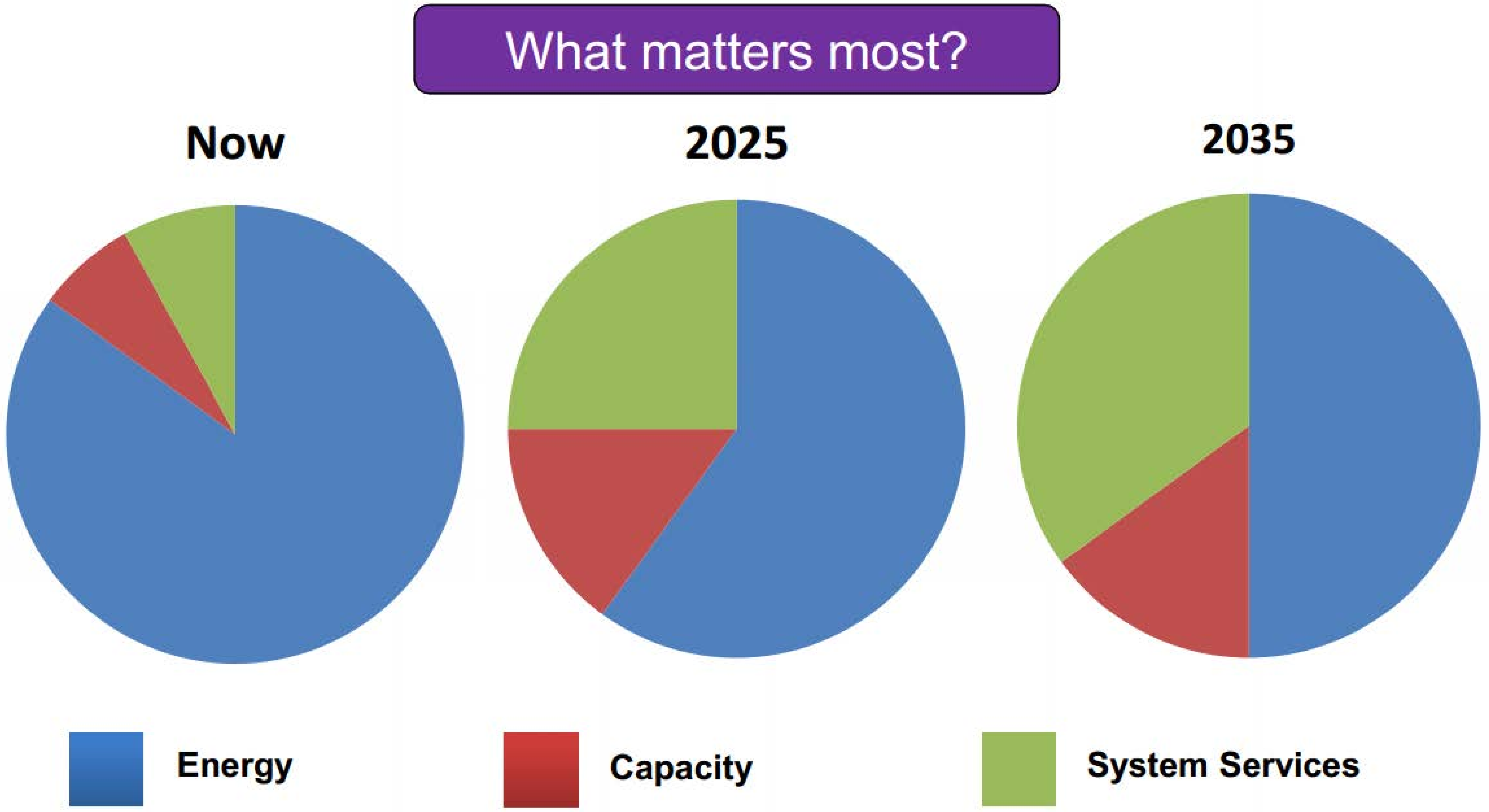
Increase transmission capacity to England to 6.6 GW (now 2.8 GW) by HVDC links

Connect a further 2.5 GW of wind generation (total of 4.4GW) to align with Gone Green scenario

ENSG 'Our Electricity Transmission Network: A Vision for 2020', Full report, July 2013

GB System Operability Framework 2015

Impact on System Services



National Grid '**System Operability Framework October 2015**',

GB System Operability Framework 2015

New Technologies and Services

- New technologies, especially those associated with series compensation and HVDC assets, bring on the risk of SSR.

- The Thyristor Controlled Series Capacitor (TCSC) installation at Hutton;
- Scottish Power Transmission (SPT) installation of Fixed Series Compensation at Moffat, Gretna and Eccles with passive SSR filters ;
- Western HVDC link project between Hunterston (Scotland) and Flintshire Bridge (North Wales) to be commissioned in October 2016;

National Grid '**System Operability Framework October 2015**',

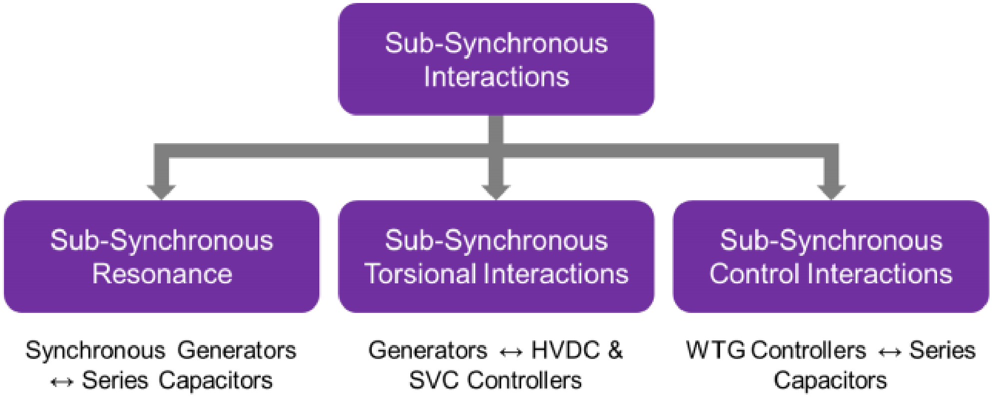
New Technologies and Services

- Some key areas that will see an increase in the connection of highly sophisticated control systems have been identified as:

■ South East: connection of NEMO HVDC, Eleclink HVDC, and new SVCs, along with existing wind farm HVDC links;

■ North Wales: large number of new wind farm connections in proximity of East West HVDC Interconnector, Western HVDC link, series capacitor and new HVDC Links;

■ East Coast: interaction between new multi-GW wind farms connected via VSC-HVDC;



National Grid '**System Operability Framework October 2015**',

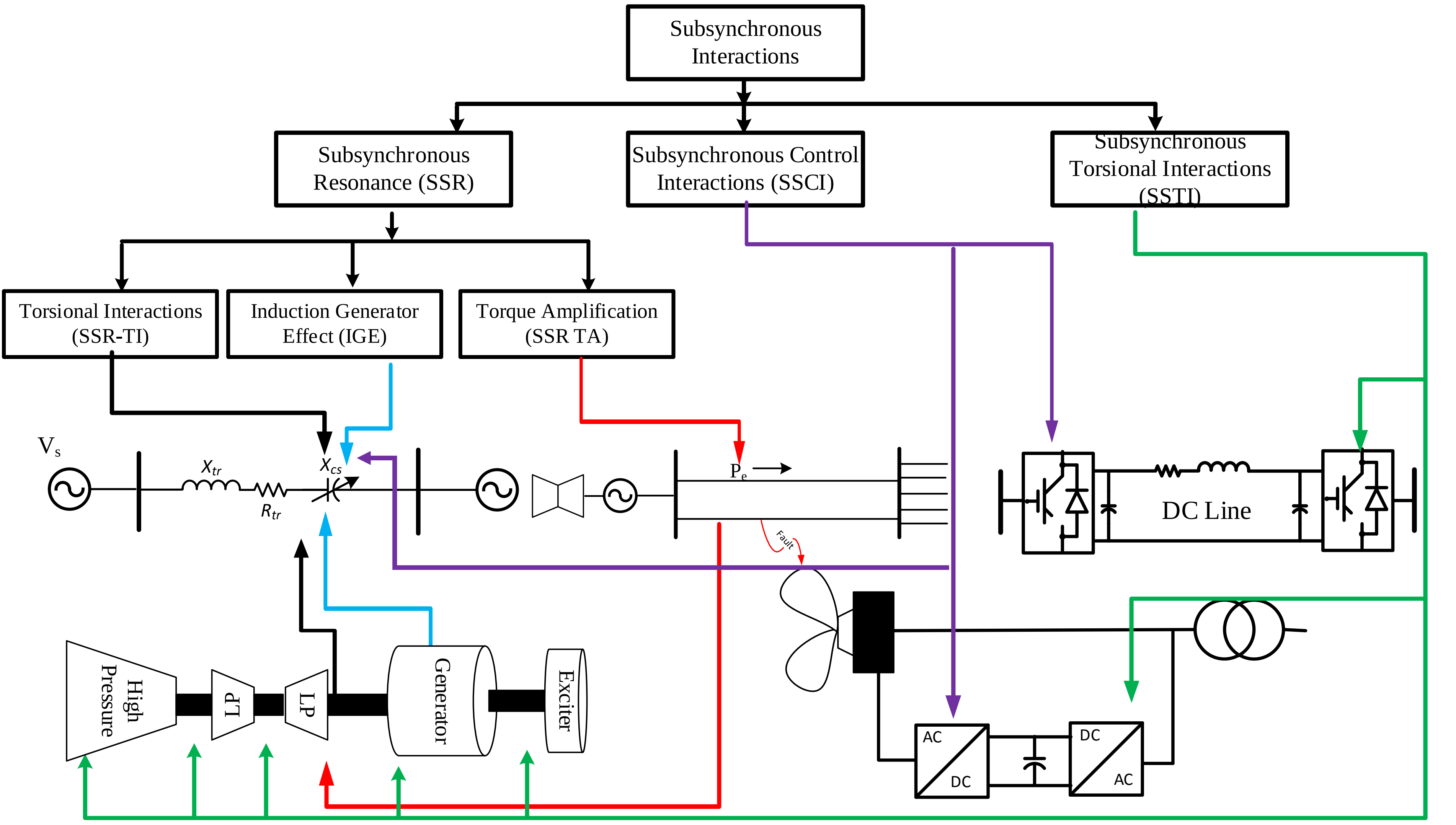
Grid Code Requirements

- The grid code requirements by the National Grid Electricity operator of UK in relation to SSR are outlined here with:

Grid Code	Requirements	Summary
GC0077	Suppression Of Sub-Synchronous Resonance From Series Compensators	➢ *Transmission Owners should mitigate Sub-synchronous Oscillation risks when installing new plant and apparatus*
GC0040	Information Required To Evaluate Sub-Synchronous Resonance	➢ *DC Converter owners must ensure that any of their Onshore or offshore DC Converters will not cause a subsynchronous resonance problem on the Total System* ➢ *Each DC Converter or OTSDUW DC Converter is required to be provided with subsynchronous resonance damping control facilities*

www.nationalgrid.com/UK/Industry-information/Electricity-codes/Grid-code

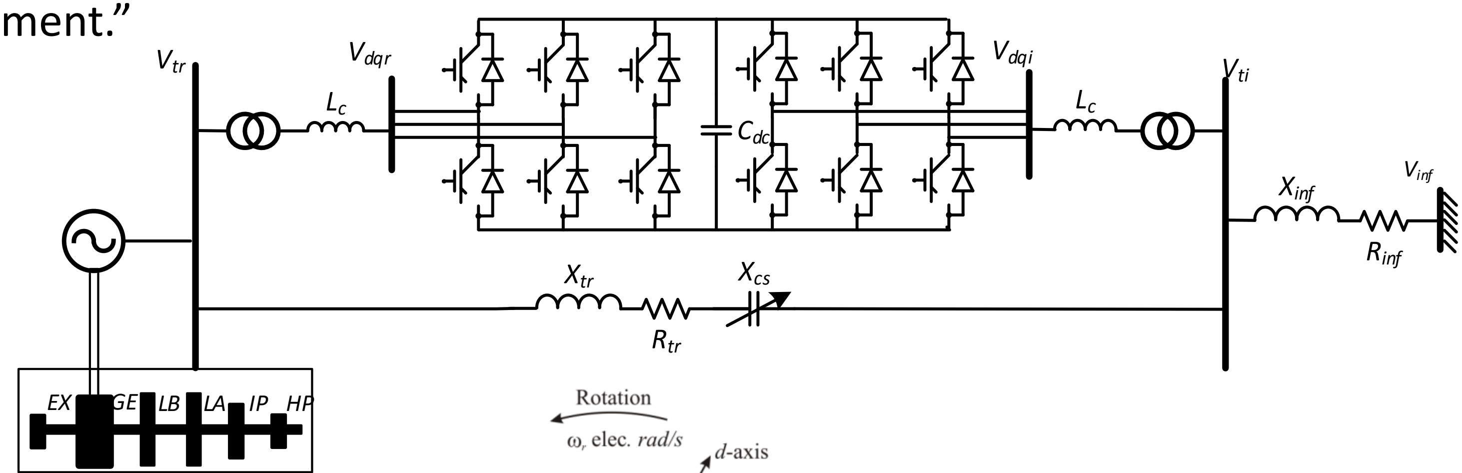
Forms of Subsynchronous Interactions



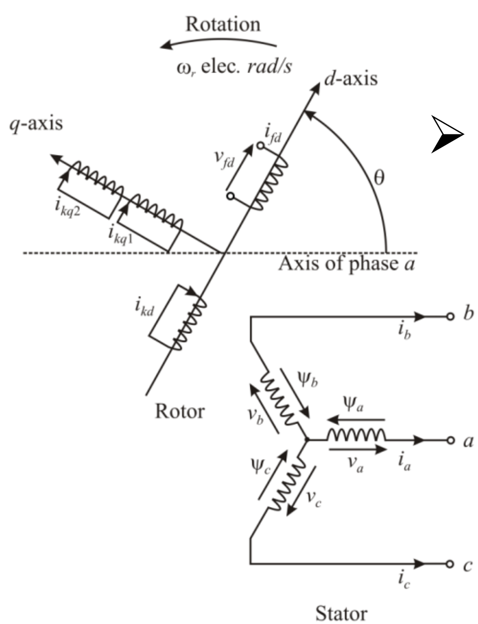
Modified IEEE First Bench Mark Model

- **Origins**

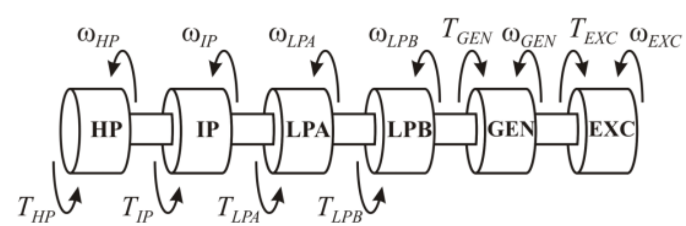
The **IEEE First Benchmark Model (FBM)** was created by the IEEE Working Group on Subsynchronous Resonance in 1977 for use in “computer program comparison and development.”



- **Generator model**



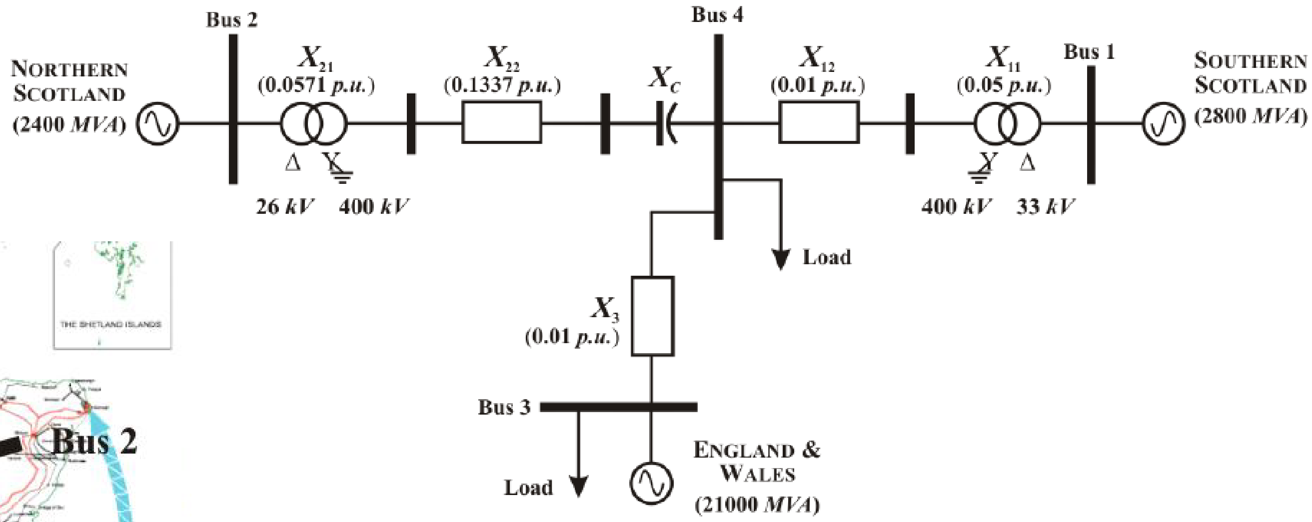
- **Turbine Generator Shaft model**

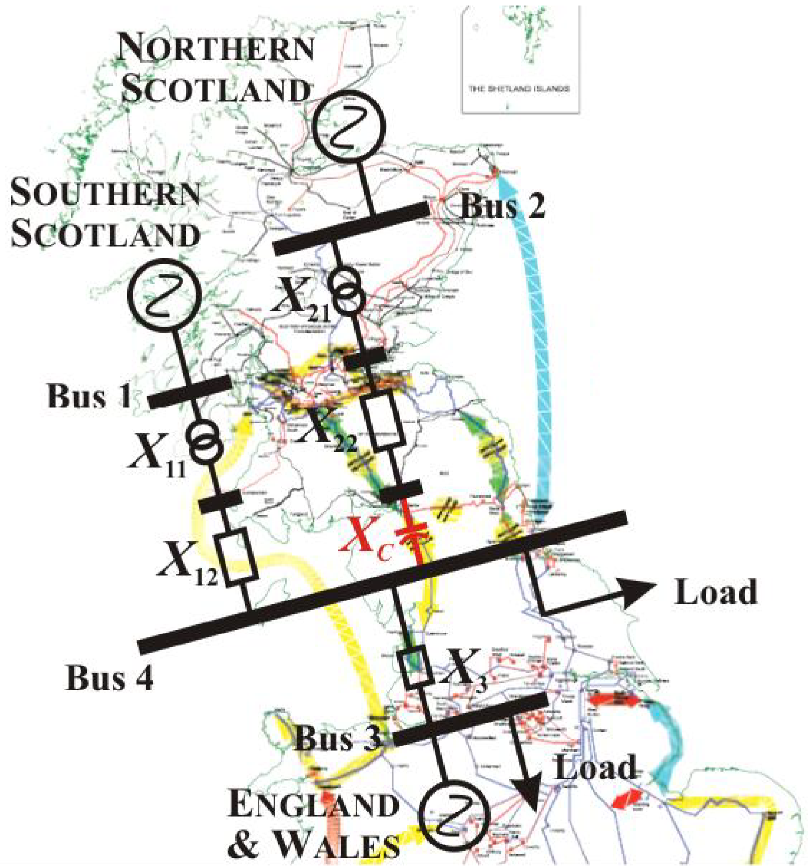


Subsynchronous Resonance

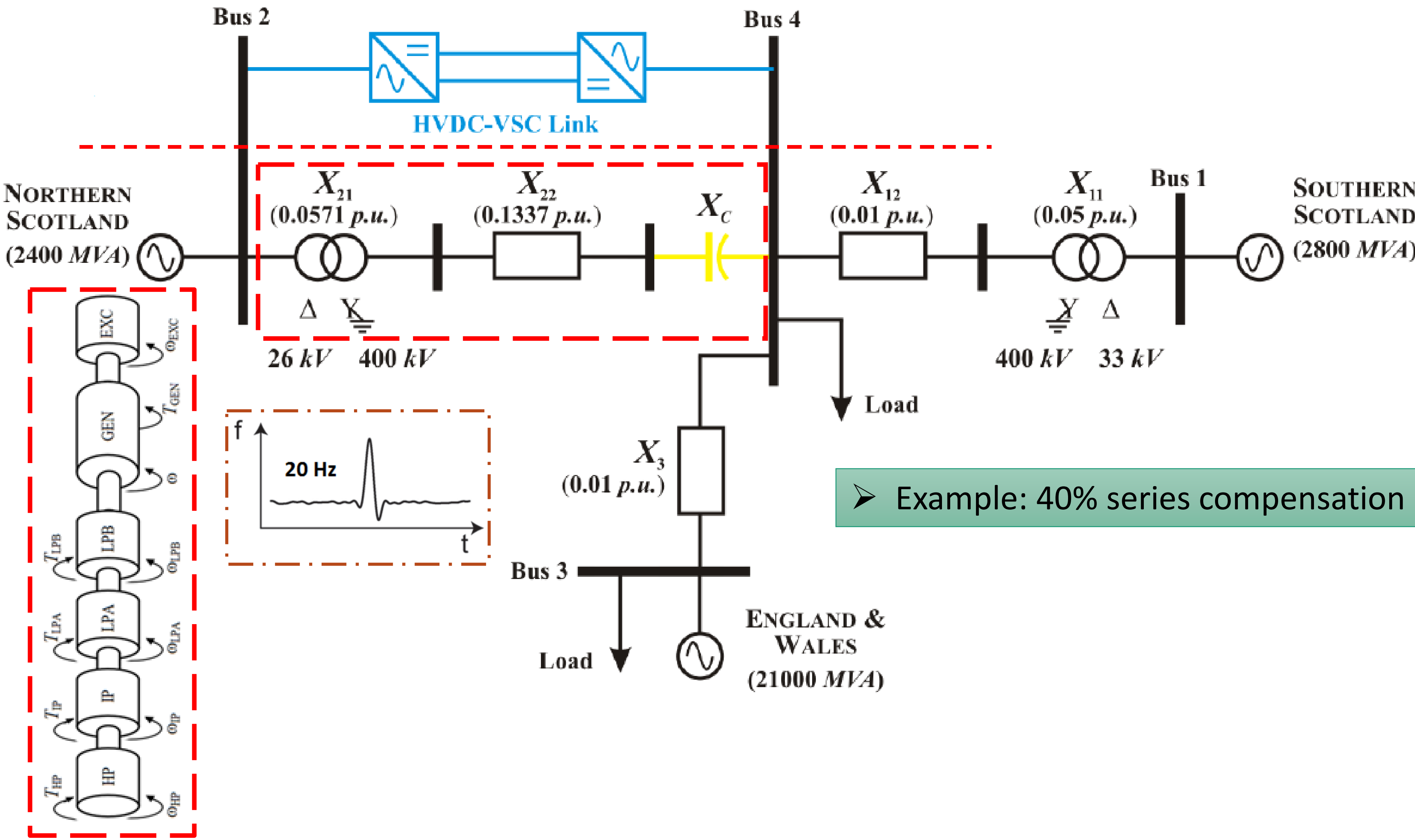
- **shaft stress & fatigue**
- **possible damage**
- **failure**

Three machine test systems adapted for GB





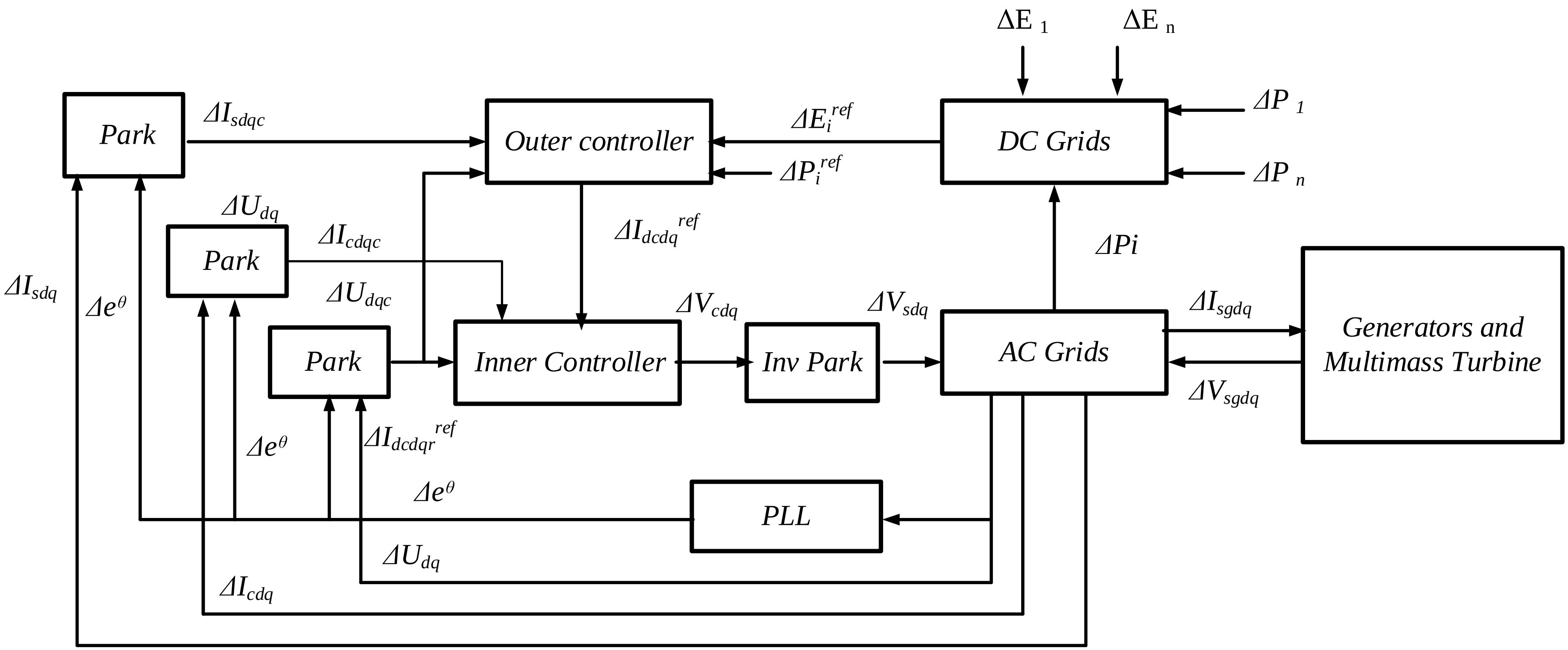
Three machine test systems adapted for GB



- Example: 40% series compensation

AC/VSC-HVDC State-Space Representation

- A state space representation of the AC/DC system under investigation was constructed
- The torsional modes, of the AC/DC system have been identified using linearized models.
- These modes have been used to design the controller for SSR damping



Stability of the Torsional Modes

The system is characterised by:

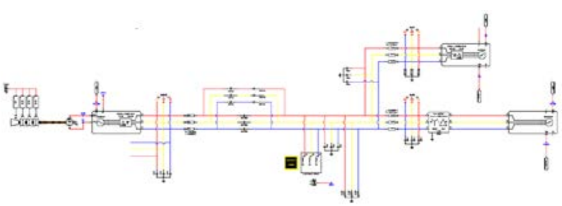
- Five unstable torsional modes (TM1-TM5)
- The torsional interaction occurs whenever a subsynchronous mode frequency (SUB) coincides with a torsional mode frequency (TMx)

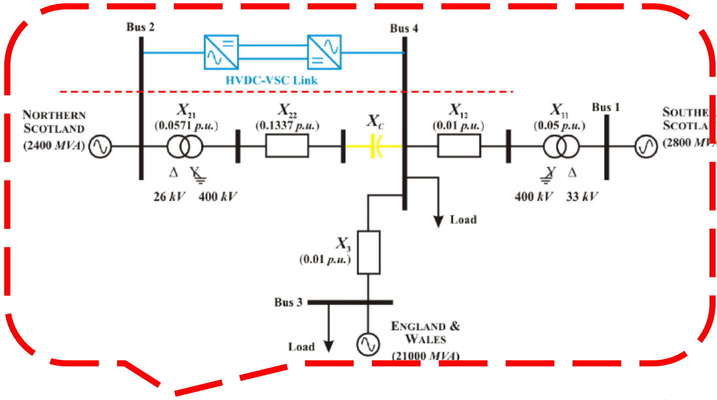
Natural Shaft Frequencies		
Torsional Modes	**Frequency (*rad/s*)**	**Frequency (*Hz*)**
TM 1	**90.62**	**14.42**
TM 2	**115.97**	**18.45**
TM 3	**146.69**	**23.34**
TM 4	**185.71**	**29.55**
TM 5	**272.19**	**43.32**
SUB	**190.21**	**30.12**

Development of real-time simulation for DC/AC grids

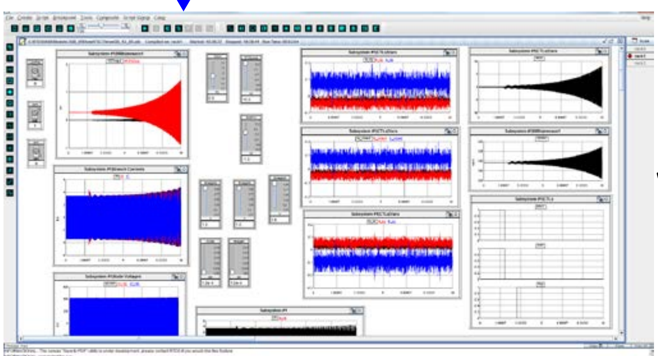
- **Objective:** To validate the offline PSCAD/EMTDC simulation results with RSCAD/RTDS real time simulation platform

DRAFT





GTNET CARD



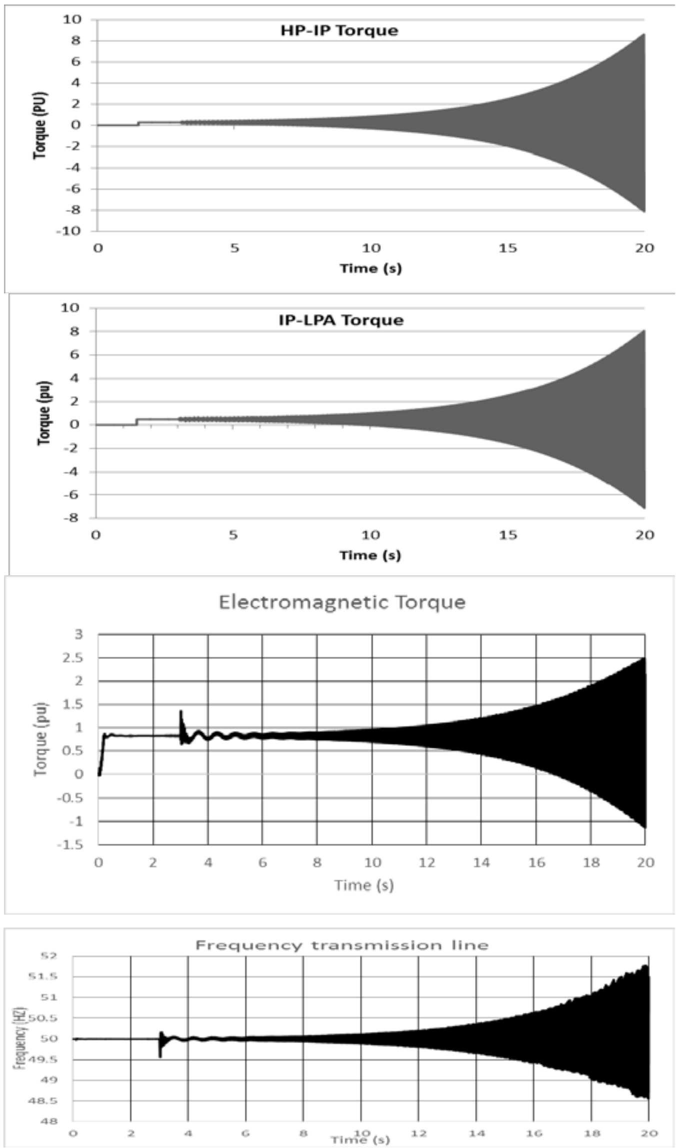
WORK STATION: RSCAD/INTERFACE

RUNTIME

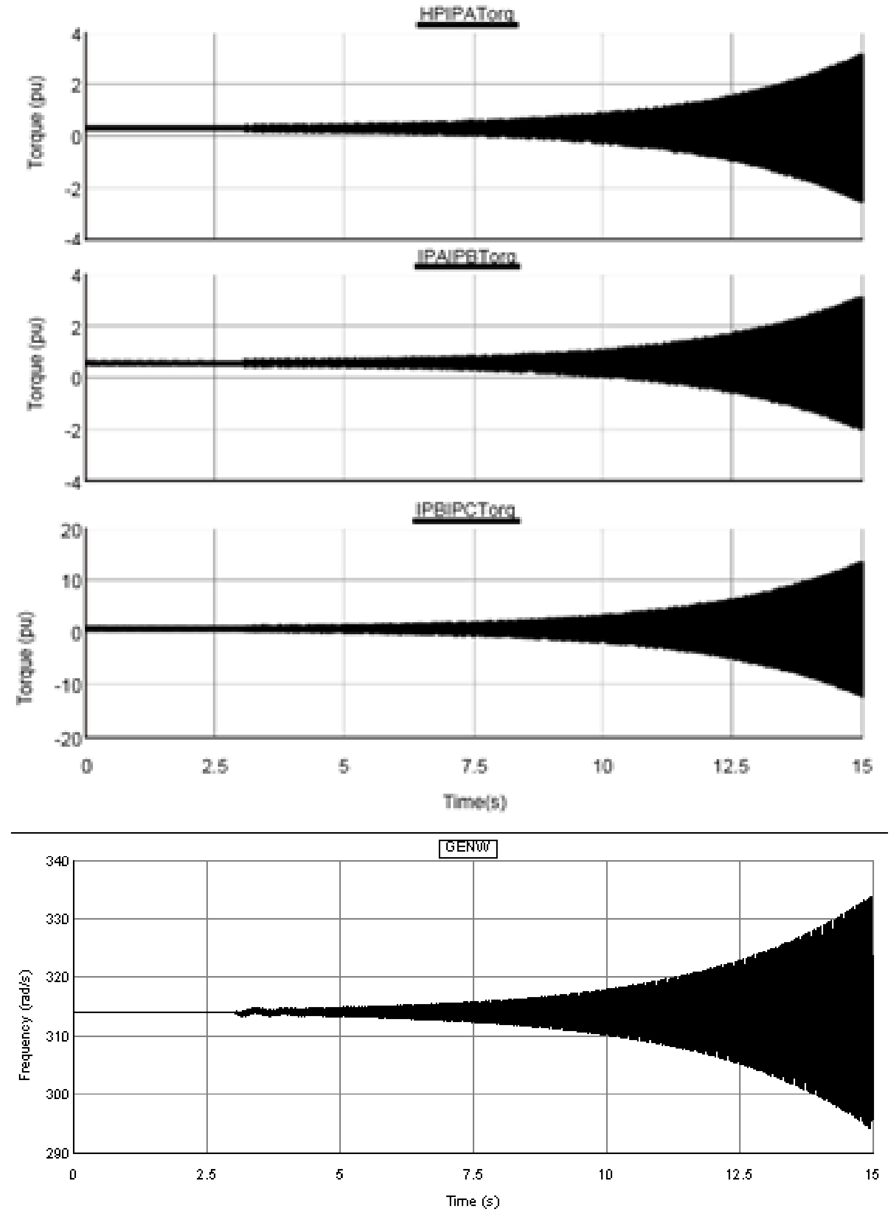
Software in the loop results

- 30 to 40% series compensation @ 3 s

PSCAD Platform

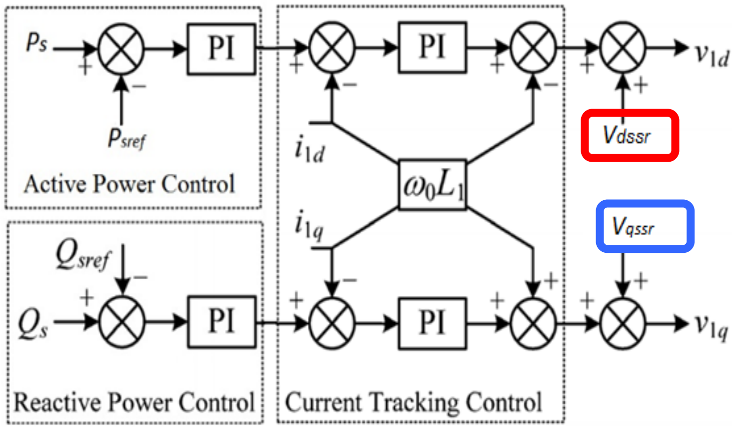


RSCAD Platform

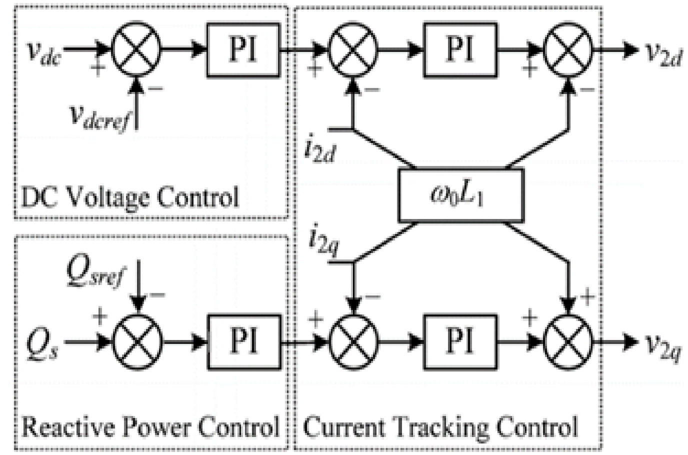


SSR damping controller development

- Rectifier side converter control

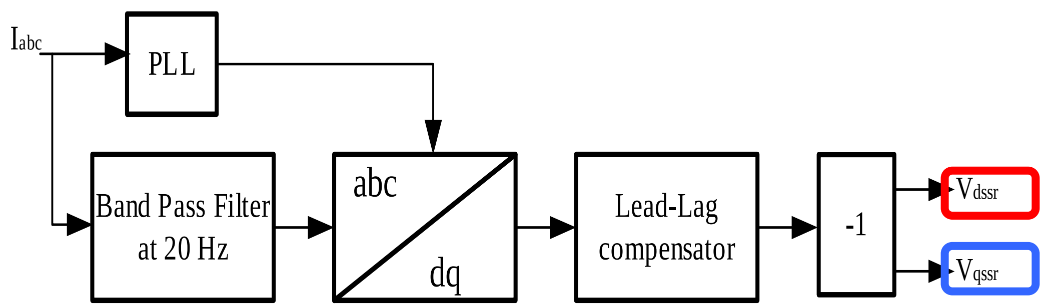


- Inverter side converter control



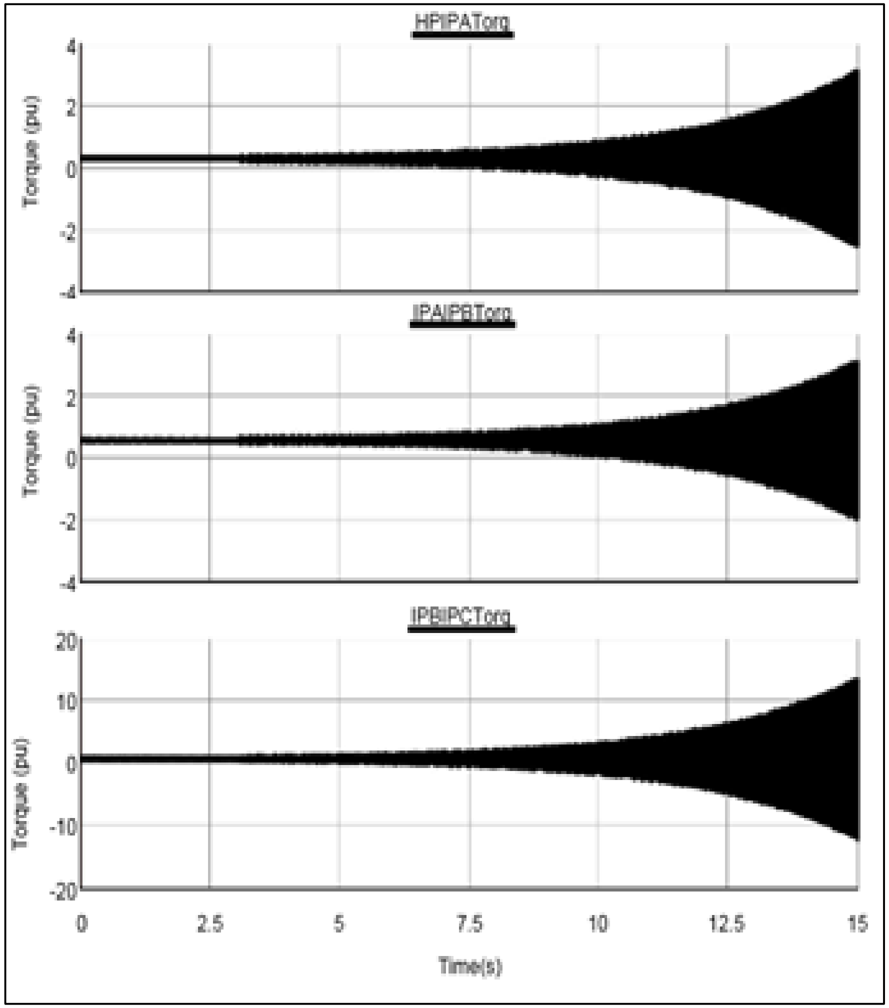
SSR Damping Scheme:

Classical PSS-SSR damping scheme

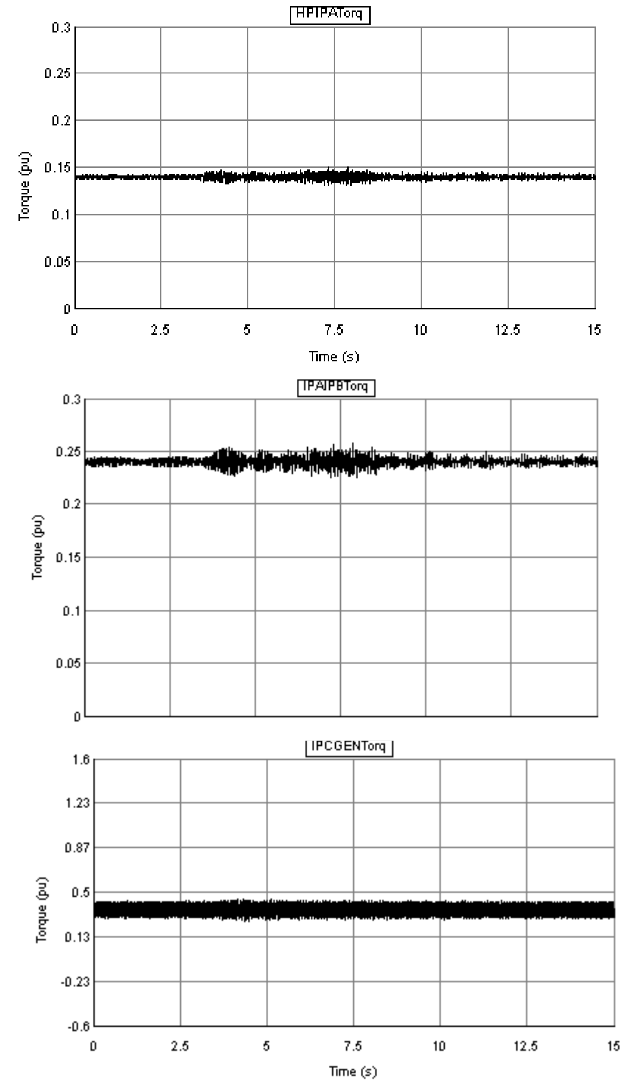


Real time test results with controller

➢ Without the Controller

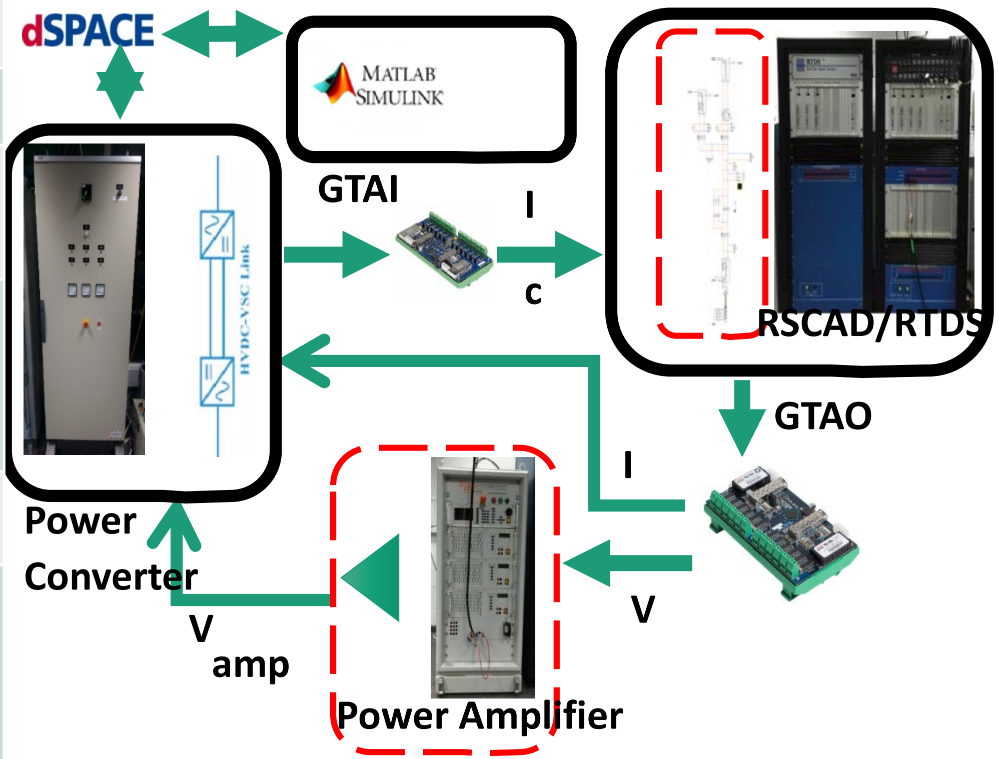


➢ With the Controller



AC/DC grid operation using experimental test rig

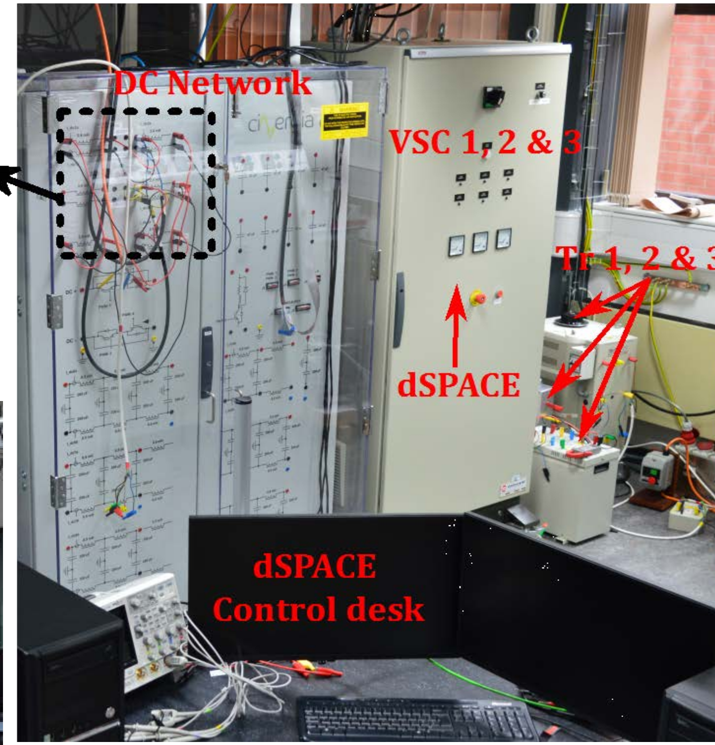
Equipment	Specs	Rating	Operating range
Voltage Source Converter	Rated Power	10 kW	2 kW
	DC Voltage	800 V	250 V
	AC Voltage	415 V	140 V
	DC capacitors	1020 μF	
	AC inductors of DC Test Rig	3.5 mH	
dSPACE	DS1005		
Real Time Simulator	RTDS. 2 Rack. Cards: 2 GTWIF. 2 PB5, 4 GPC (2 IBM PPC750GX 1 GHz), 1 GTIRC, 1 GTDI, 1 GTDO, 2 GTAI, 2 GTAO, 1 GTNET. *Lead-Lag compensator:* T_{lead}*=16ms,* T_{lag}*=0.8ms,* K_{L-L}*= 0.75*		



PHIL Test Set UP

- Start-up and shutdown sequence of converters in a hybrid AC/DC network
- Development of real-time models suitable for testing AC/DC circuits
- Real time simulation using the RTDS platform for implementing SSR damping schemes
- Testing of the HVDC link integration with the AC circuits using analogue DC test rig

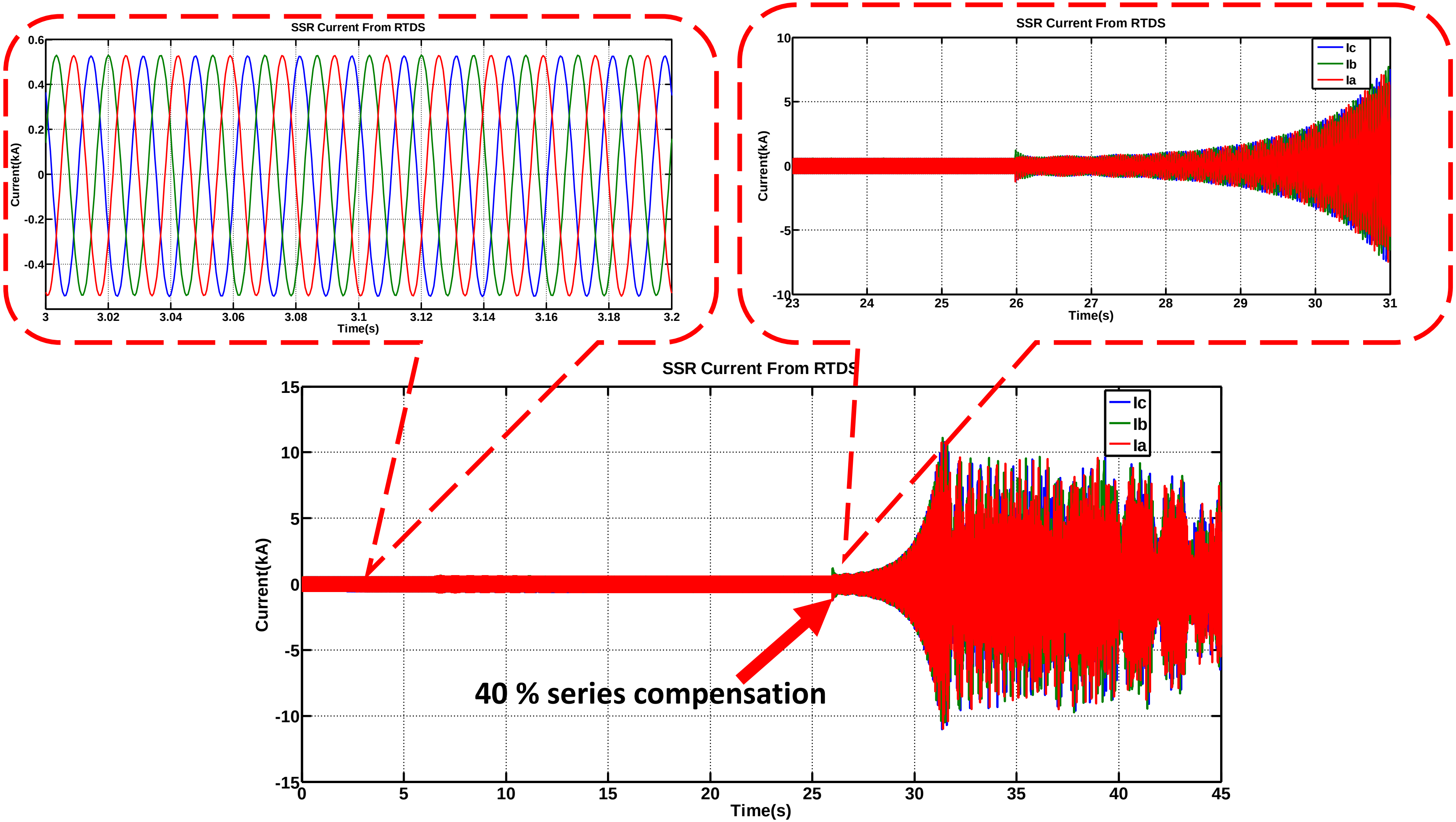
DC Lines



Parameters	Value
AC transformer	400 V/140 V
Nominal power P_{rig}	2 kW
Phase inductance L_{rig}	2.2 mH
Phase resistance R_{rig}	-
DC capacitance C_{rig}	2040 μF
Converter f_{sw_rig}	4 kHz
AC frequency	50 Hz
DC voltage V_{DCrig}	250 V

Results: Line current measurement from dSPACE

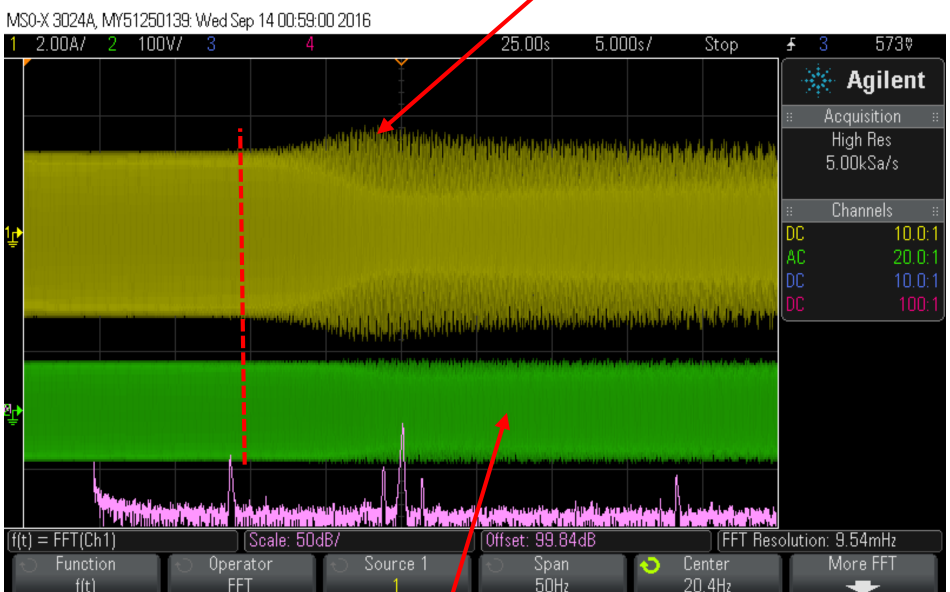
- The scaled AC current with SSR component from the RTDS measured at the converter terminals



Experiment Results

- PCC bus voltage and current without damping controller

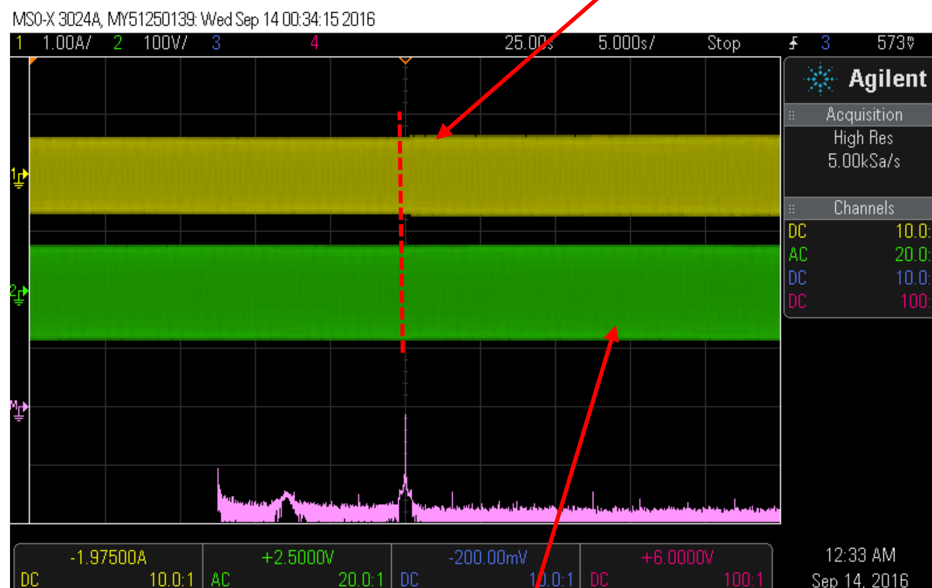
PCC Bus Voltage



Line Current measured at PCC

- PCC bus voltage and current with damping controller

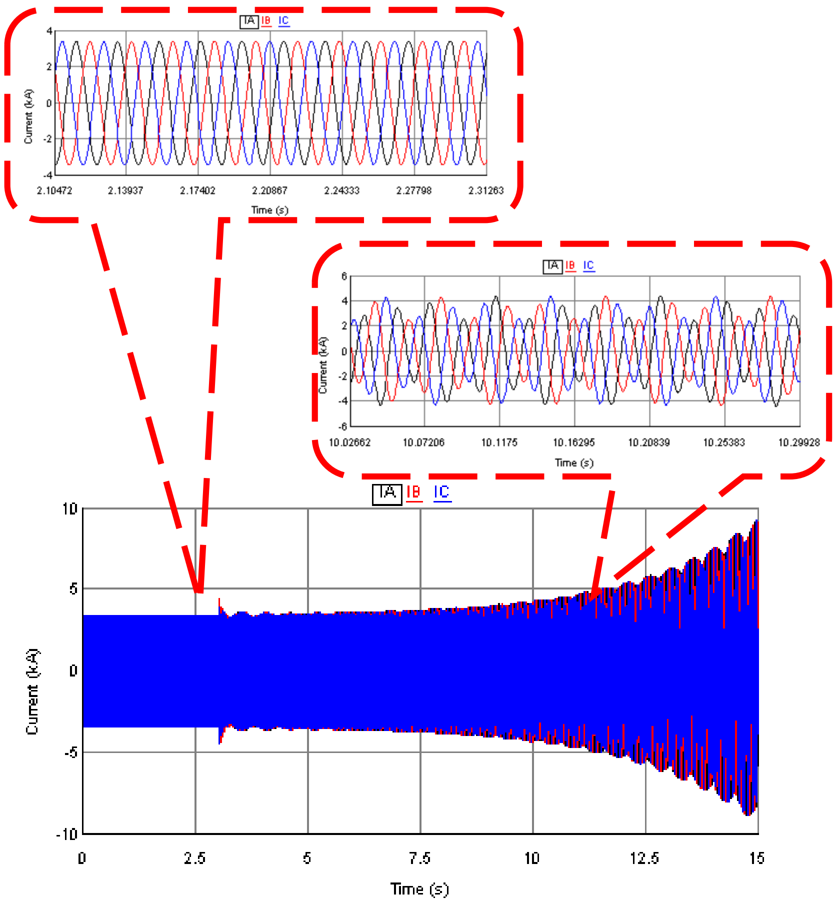
PCC Bus Voltage

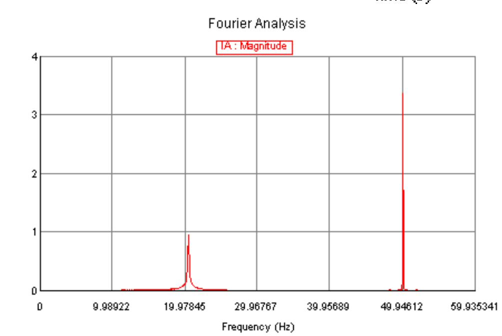


Line Current measured at PCC

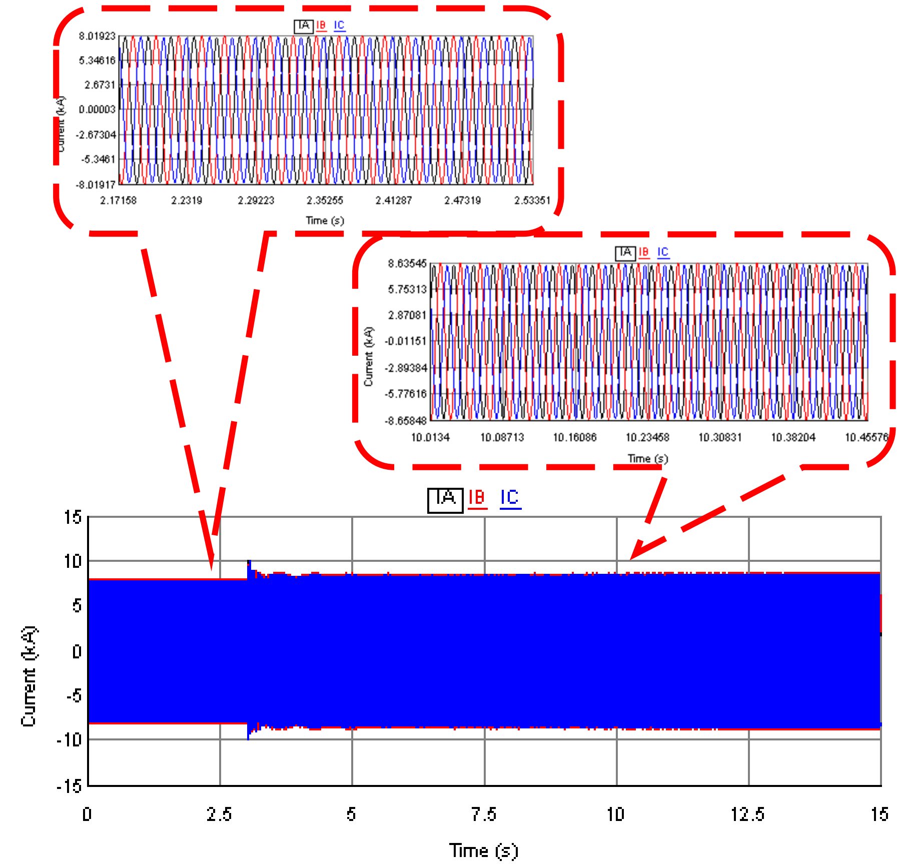
Closed loop results from RSCAD

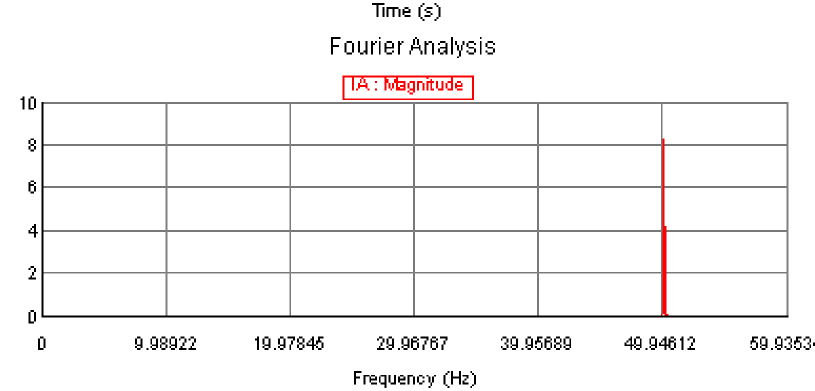
Line Current at PCC without damping controller





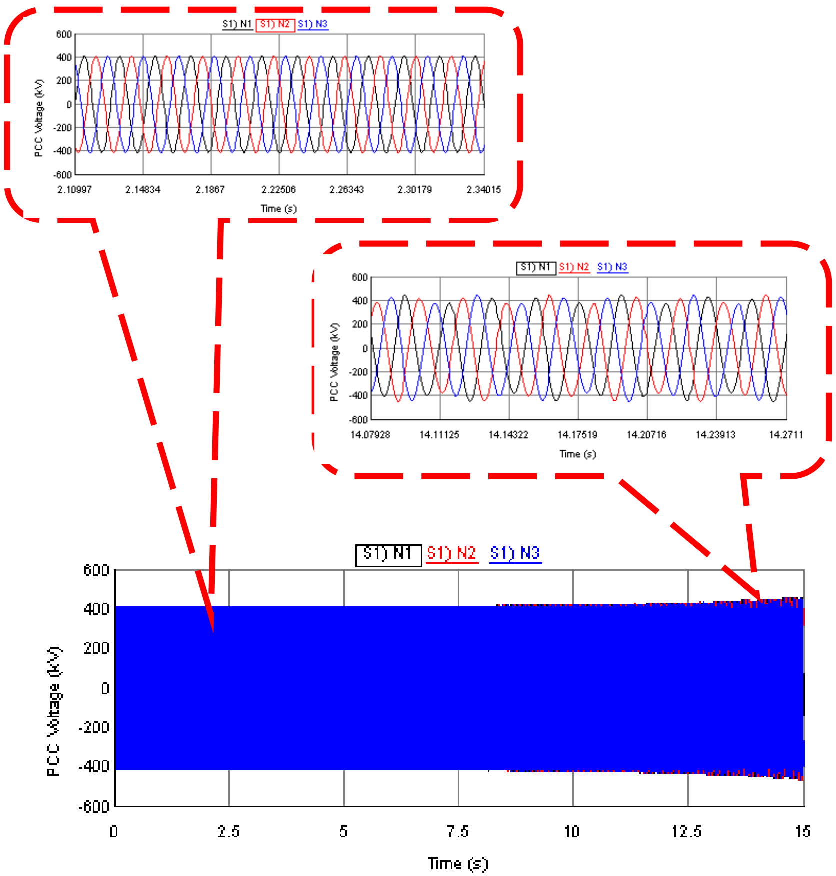
Line Current at PCC with damping controller

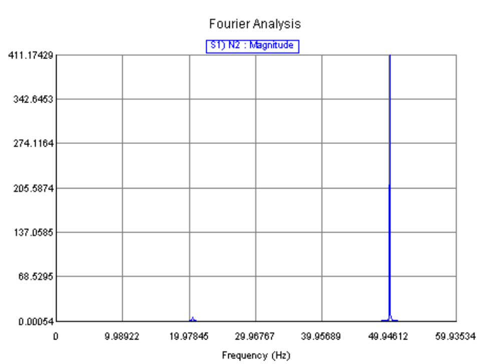




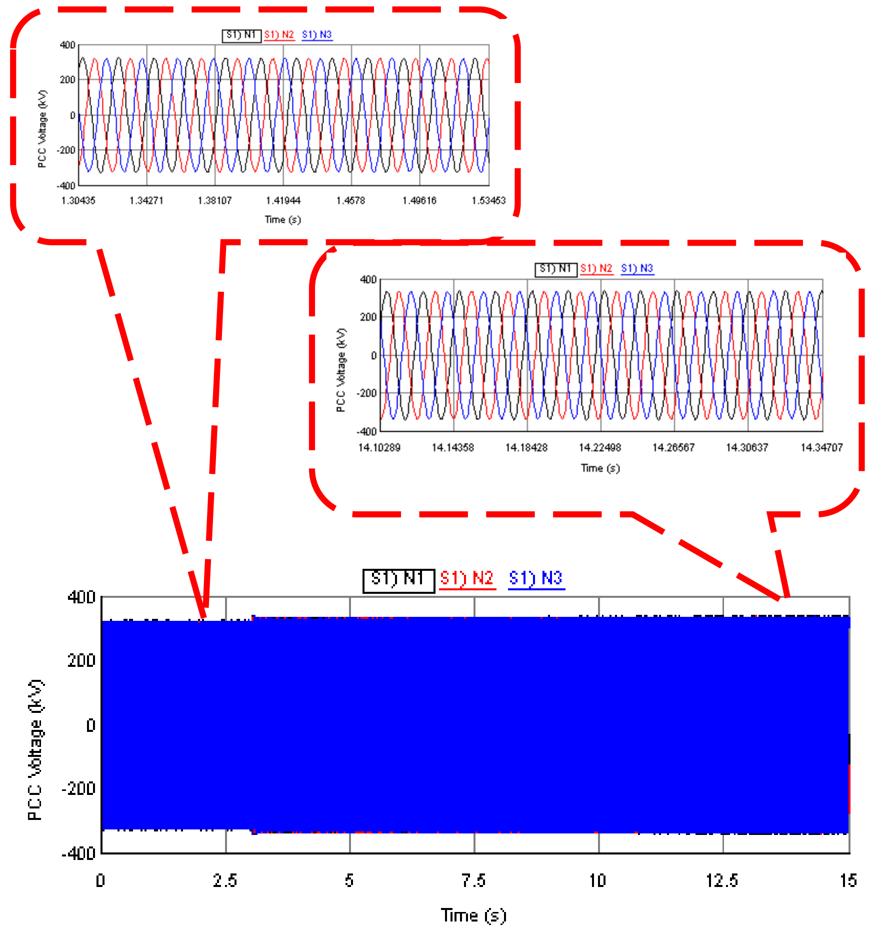
Closed loop results from RSCAD

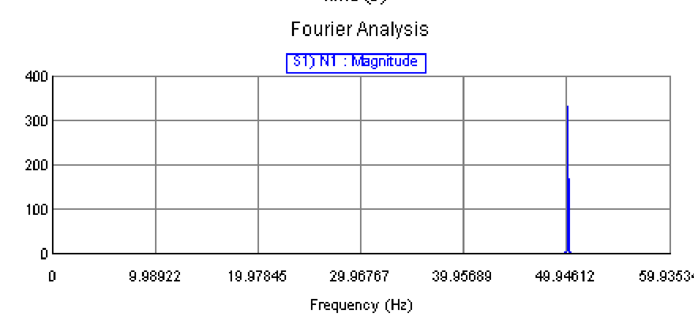
- PCC voltage without damping controller





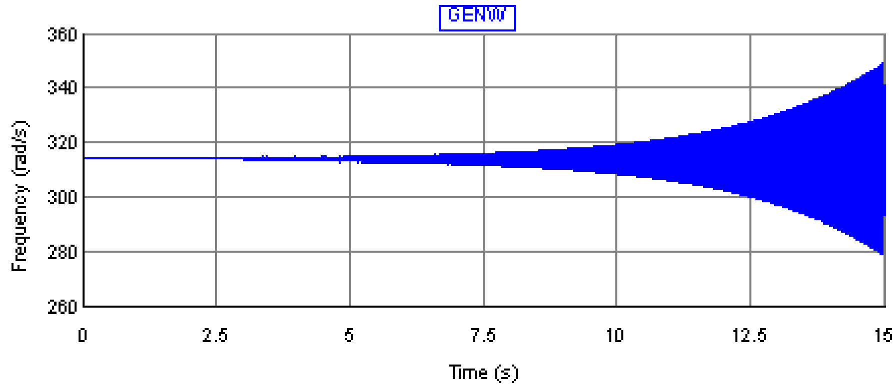
- PCC voltage with damping controller

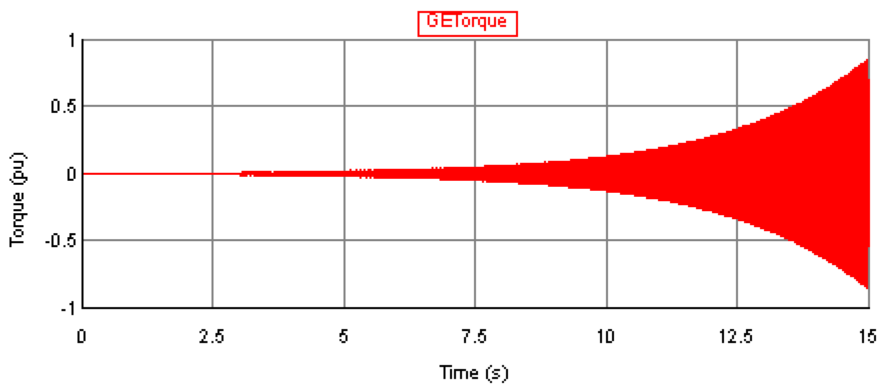


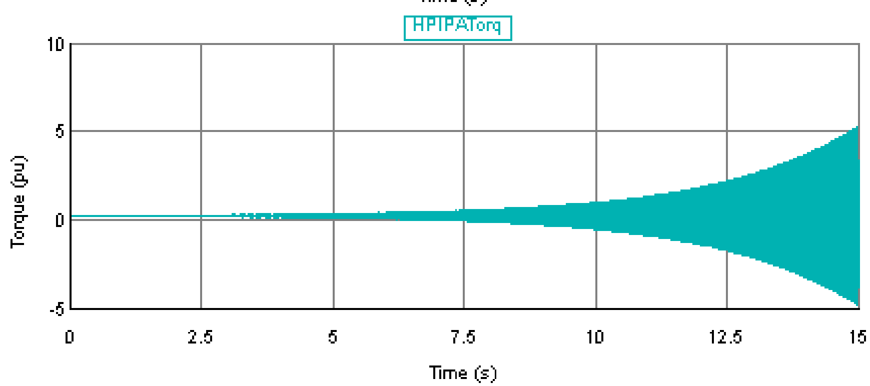


Closed loop results from RSCAD

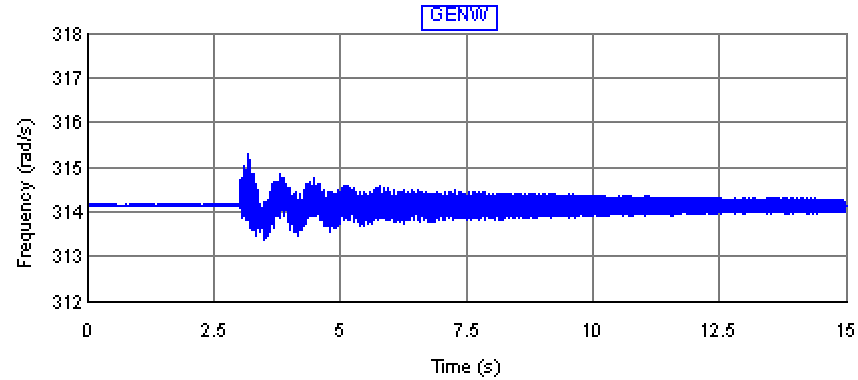
- Machine Torques without damping controller

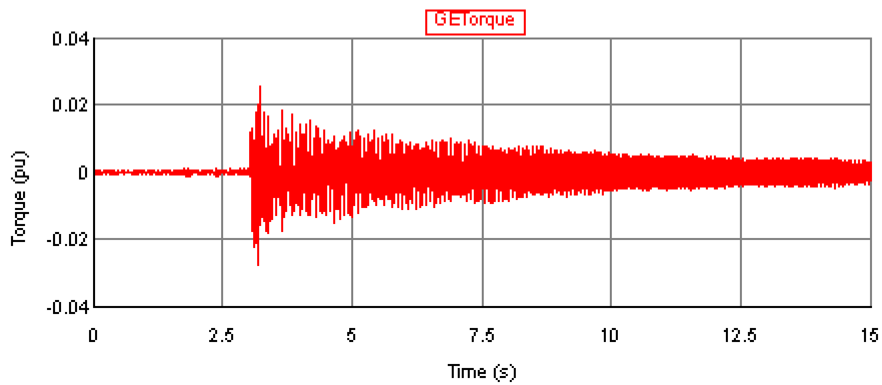


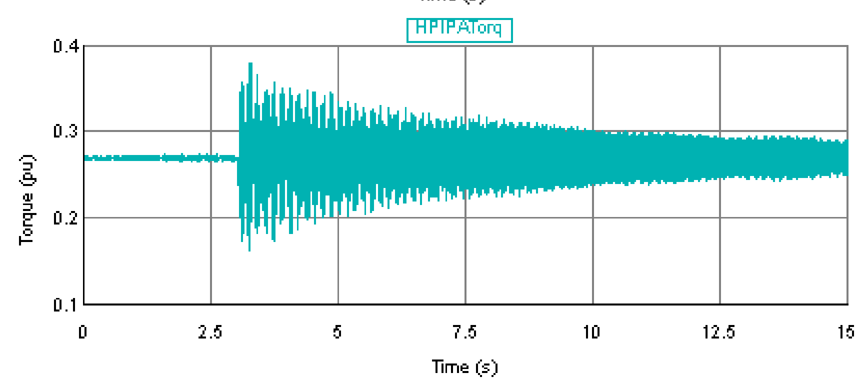




- Machine Torques with damping controller

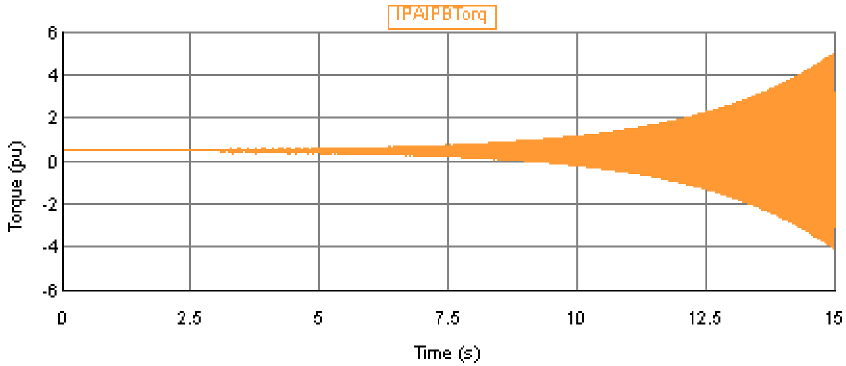


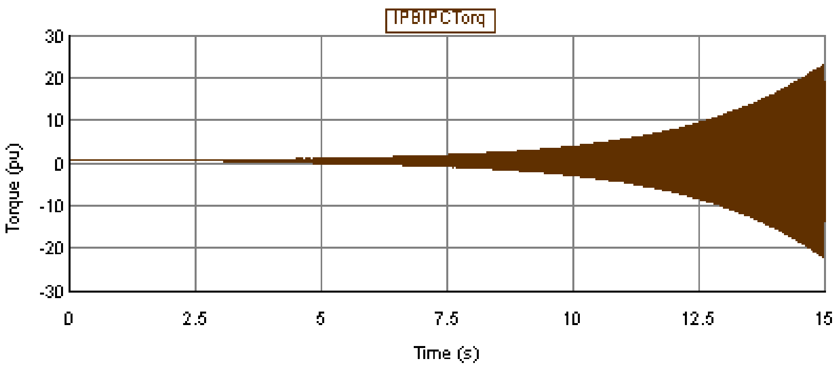


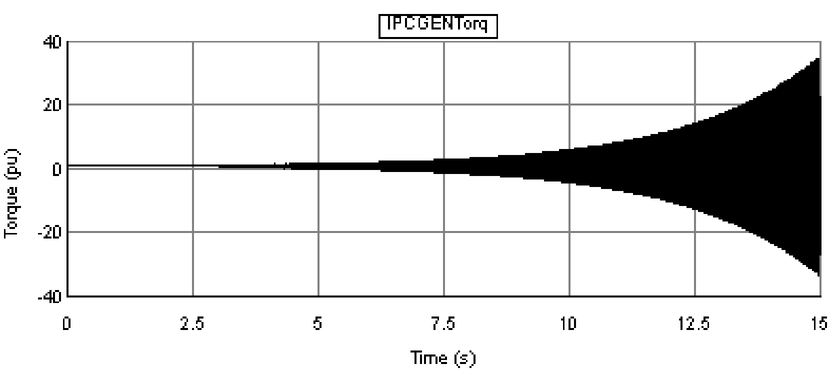


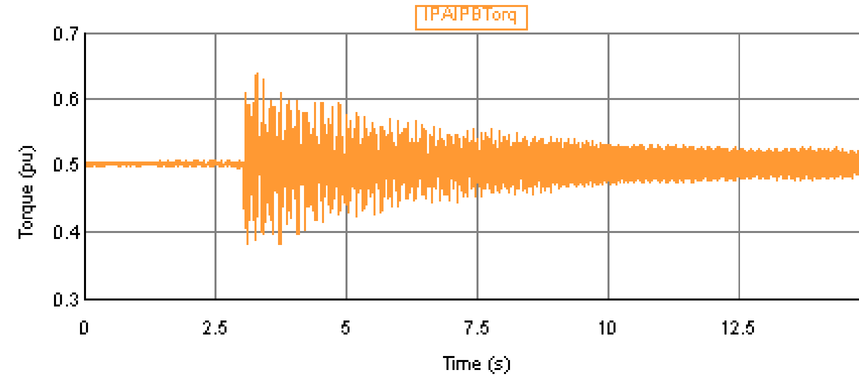
Closed loop results from RSCAD

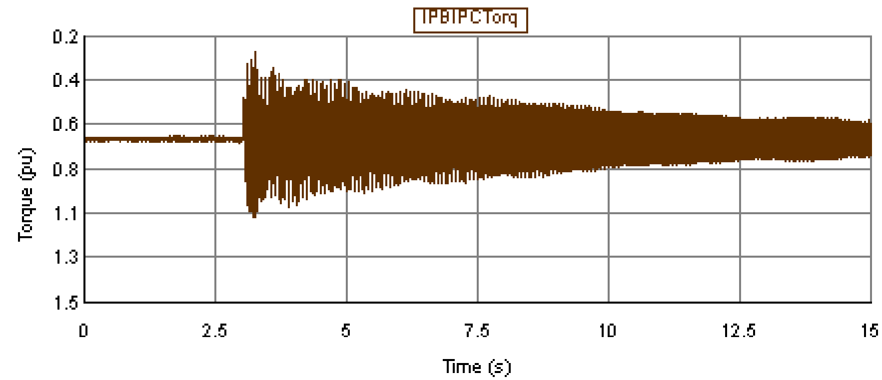
- Machine Torques without damping controller
- Machine Torques with damping controller

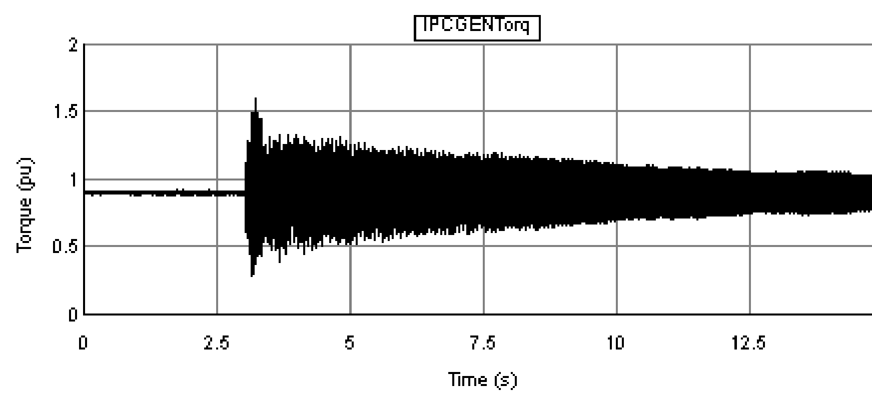






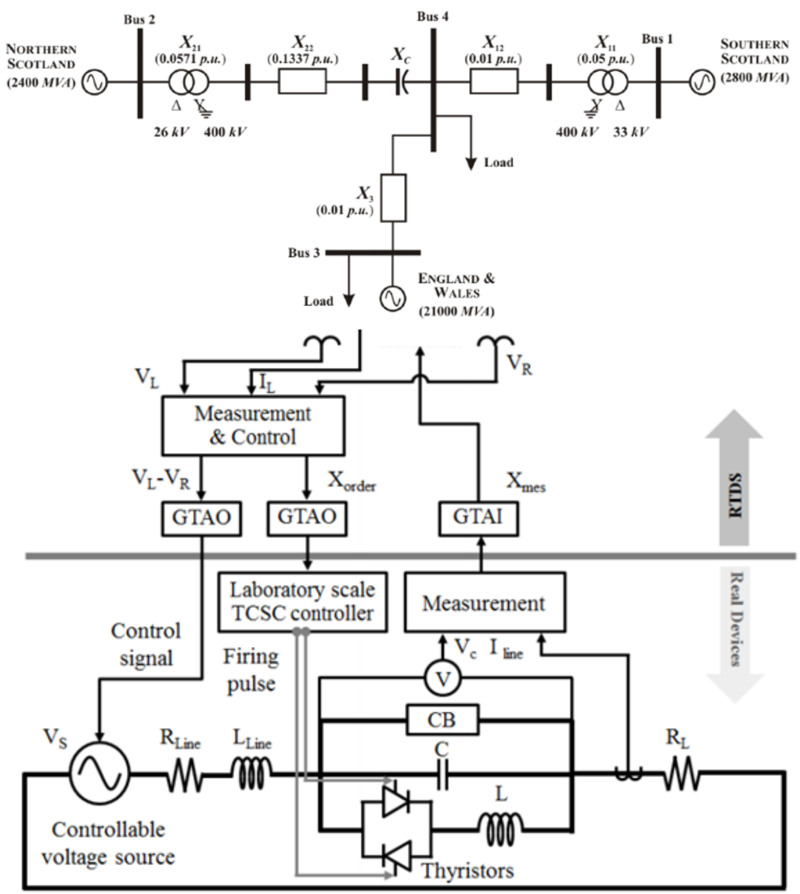






Experimental setup for TCSC compensation

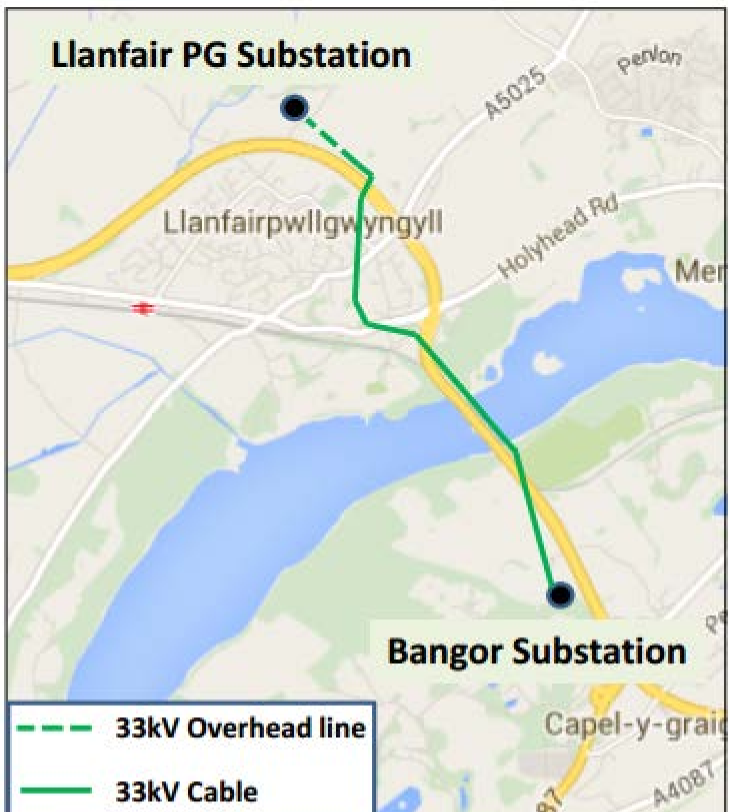
- To further investigate on the dynamic compensation methods and their impact on AC system stability
- To analyze and determine the dynamic behavior of TCSC under system operating conditions
- To study the interactions among multi components

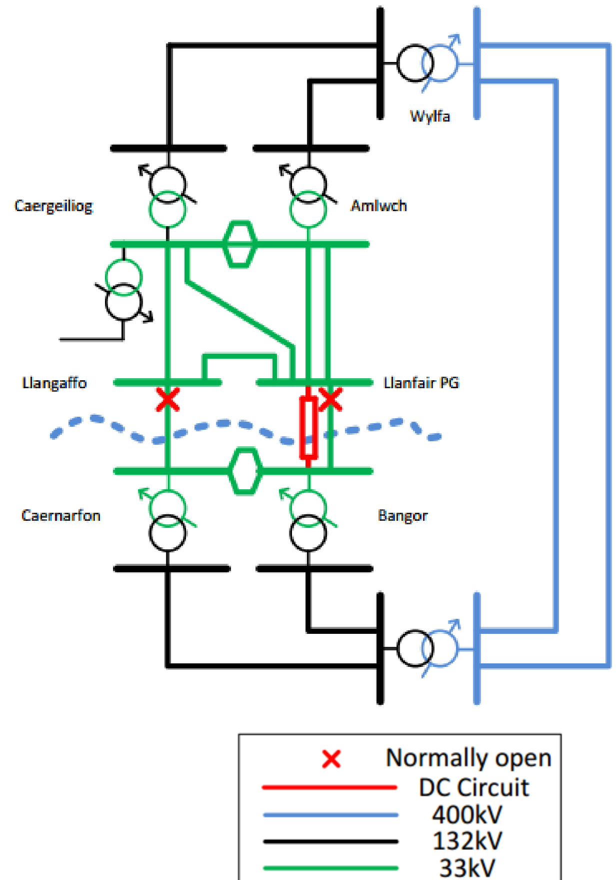


Laboratory scale TCSC

Real-time operation and control of MVDC link

- ANGLE-DC, is the flag ship project of Scottish Power Electricity Network (SPEN), to demonstrate a novel network reinforcement by converting an existing 33kV AC circuit to DC operation
- It is aimed to relieve the congested AC system by providing additional controllability and flexibility
- Real time operation, control, protection system testing and hardware validation will be performed with the Cardiff University test facility





Conclusions

- Negative interactions between converters and synchronous generators can destabilize the AC network operation
- Series compensation can amplify this impact through SSTI phenomenon
- The effectiveness of the SSR damping technique has been verified by real-time as well as closed loop HIL test
- PHIL tests for AC/DC interaction studies can de-risk the practical equipment application
- Further implementation of real time simulator for hybrid AC/DC operations are under development

Acknowledgements

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josepht@cardiff.ac.uk

www.medow.engineering.cf.ac.uk