Webinar: “Voltage Stability of Converter Dominated Grids”

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TW 9 January 2019

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Agenda

Presentation (30 - 40 minutes)

- Project Background - Information
- Modelling & Simulation Studies
  - Methodology
  - Simulation System
- Results & Analysis
  - What is causing the results we see?
- Conclusions & Next steps

Question & answer (15-25 minutes)

Project Background-Information

Yun Li,
National Grid ESO

Project Information

"Transient Voltage Stability of Inverter Dominated Grids and Options to Improve Stability"

- Network Innovation Allowance (NIA) project, managed by National Grid ESO
- Project undertaken by HVDC TECH, Transmission Excellence and Power Technologies
- CIGRE 2018 Paris Session Paper C4: "Inverter Dominated UK Grid"

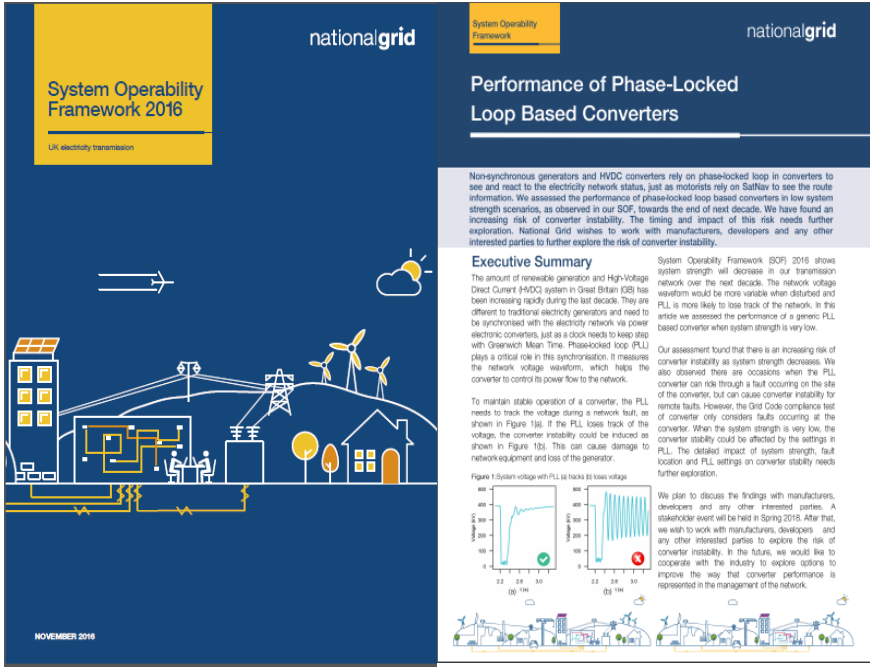
Transmission Excellence Ltd	HVDC Technologies Ltd	Power Technologies Ltd	National Grid ESO
Sean Kelly Wesley Maurier	Spyros Karamitsos Andre Canelhas	Masoud Bazargan	Ben Marshall Richard Ierna Mark Horley Yun Li

More detailed information about this project can be found in ENA 'Smarter Networks Portal.

GB Experience

System Operability Framework (SOF) shows system strength in GB network is decreasing

- **SOF - PLL assessment**, shows an increasing risk of converter instability, also addressed by **CIGRE TWG B4.62** - Connection of wind farms to weak AC networks.
- **NIA Projects** exploring improved PLL-RMS models for converters and Virtual Synchronous Machine concepts potential implementation.
- **Bilateral user agreements within GB** for converter-based connections and **Grid Code review (GC0100** - associated with ENTSO-e code adoption) of fault ride through response, regarding active / reactive fast fault current injection requirements.
- **Follow-on expert working group** considering Virtual Synchronous Machine (VSM) technology and other grid forming approaches.


System Operability Framework 2016
UK electricity transmission
nationalgrid
NOVEMBER 2016

System Operability Framework
nationalgrid

Performance of Phase-Locked Loop Based Converters

Non-synchronous generators and HVDC converters rely on phase-locked loop in converters to see and react to the electricity network status, just as motorists rely on SatNav to see the route information. We assessed the performance of phase-locked loop based converters in low system strength scenarios, as observed in our SOF, towards the end of next decade. We have found an increasing risk of converter instability. The timing and impact of this risk needs further exploration. National Grid wishes to work with manufacturers, developers and any other interested parties to further explore the risk of converter instability.

Executive Summary

The amount of renewable generation and High-Voltage Direct Current (HVDC) system in Great Britain (GB) has been increasing rapidly during the last decade. They are different to traditional electricity generators and need to be synchronised with the electricity network via power electronic converters, just as a clock needs to keep step with Greenwich Mean Time. Phase-locked loop (PLL) plays a critical role in this synchronisation. It measures the network voltage waveform, which helps the converter to control its power flow to the network.

To maintain stable operation of a converter, the PLL needs to track the voltage during a network fault, as shown in Figure 1(a). If the PLL loses track of the voltage, the converter instability could be induced as shown in Figure 1(b). This can cause damage to network equipment and loss of the generator.

Figure 1: System voltage with PLL (a) tracks (b) loses voltage

System Operability Framework (SOF) 2016 shows system strength will decrease in our transmission network over the next decade. The network voltage waveform would be more variable when disturbed and PLL is more likely to lose track of the network. In this article we assessed the performance of a generic PLL based converter when system strength is very low.

Our assessment found that there is an increasing risk of converter instability as system strength decreases. We also observed there are occasions when the PLL converter can ride through a fault occurring on the site of the converter, but can cause converter instability for remote faults. However, the Grid Code compliance test of converter only considers faults occurring at the converter. When the system strength is very low, the converter stability could be affected by the settings in PLL. The detailed impact of system strength, fault location and PLL settings on converter stability needs further exploration.

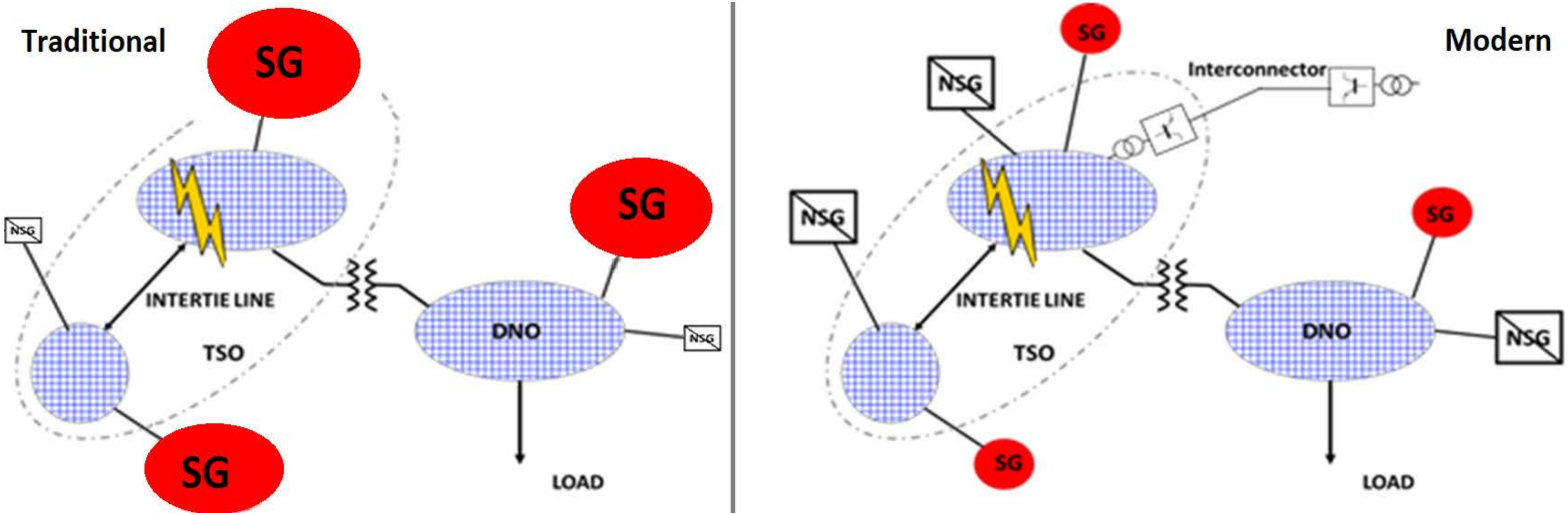
We plan to discuss the findings with manufacturers, developers and any other interested parties. A stakeholder event will be held in Spring 2018. After that, we wish to work with manufacturers, developers and any other interested parties to explore the risk of converter instability. In the future, we would like to cooperate with the industry to explore options to improve the way that converter performance is represented in the management of the network.

Wider international Experience

ENTSO-e Codes require more precise definition of performance across Fault Ride Through

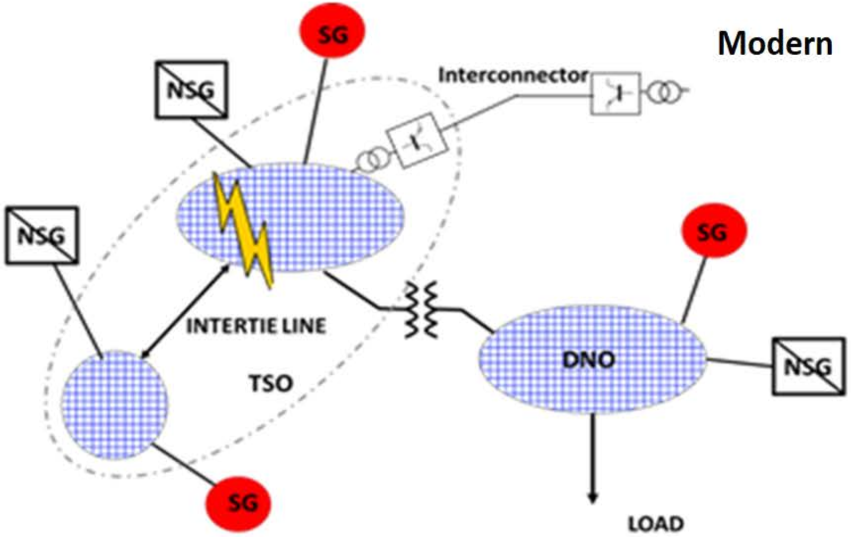
- **CIGRE Science & Engineering** published: “Effects of increasing PE based technology on power system stability”, June 2018.
- **CIGRE JWG B5/C4.61** reviews the challenges of protecting electrical networks with reduced inertia and changing fault level characteristics.
- **CIGRE TWG B4.62** - Connection of wind farms to weak AC networks. **CIGRE TWG B4.77** assesses the VSC-HVDC response options in modern grids.
- **CIGRÉ International Symposium at Aalborg, Denmark, June 3-6, 2019** - Challenges of the future power grid - Operation and system stability of weak networks with DC/AC infeed.
- **EU Migrate programme** investigation into the whole network EMT analysis needs.
- **AEMO, w.r.t. Dr Alan Finkel report**, investigations into EMT modelling needs.

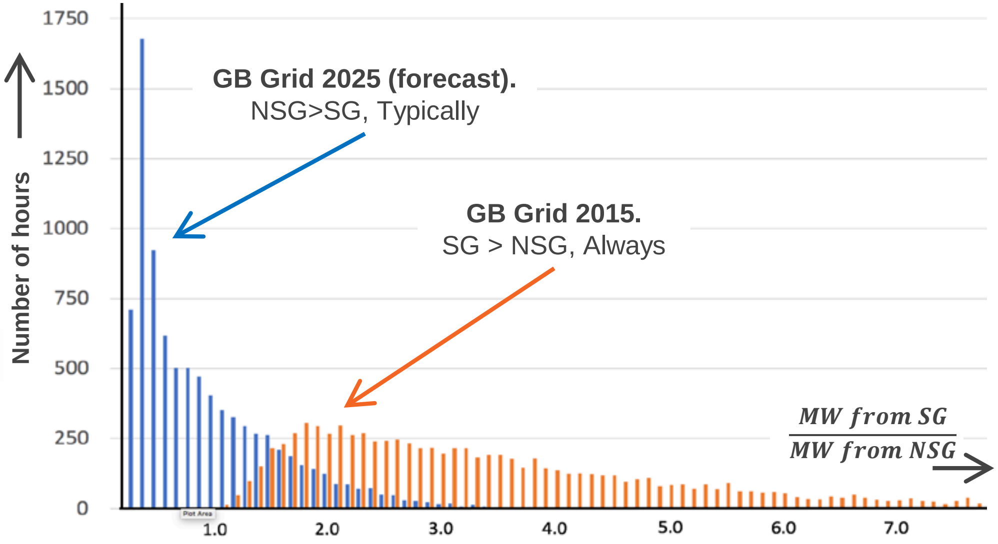
Traditional vs Modern Grids



SG: Synchronous Generation
NSG: Non-Synchronous Generation

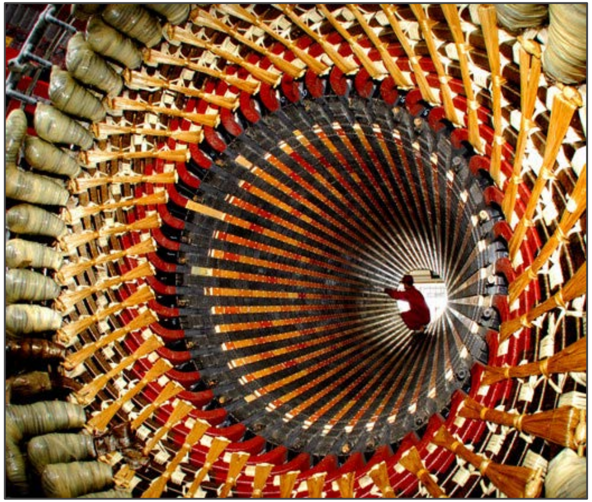
Traditional vs Modern Grids





SG: Synchronous Generation
NSG: Non-Synchronous Generation

SG vs NSG dominated Network Stability



Fault Ride Through: SCC several times of Rated Current

- **Increased System Strength**
- Standard Protection Operation

System benefits from SG-Inertial Response

- Small Frequency Deviation of AC Voltage

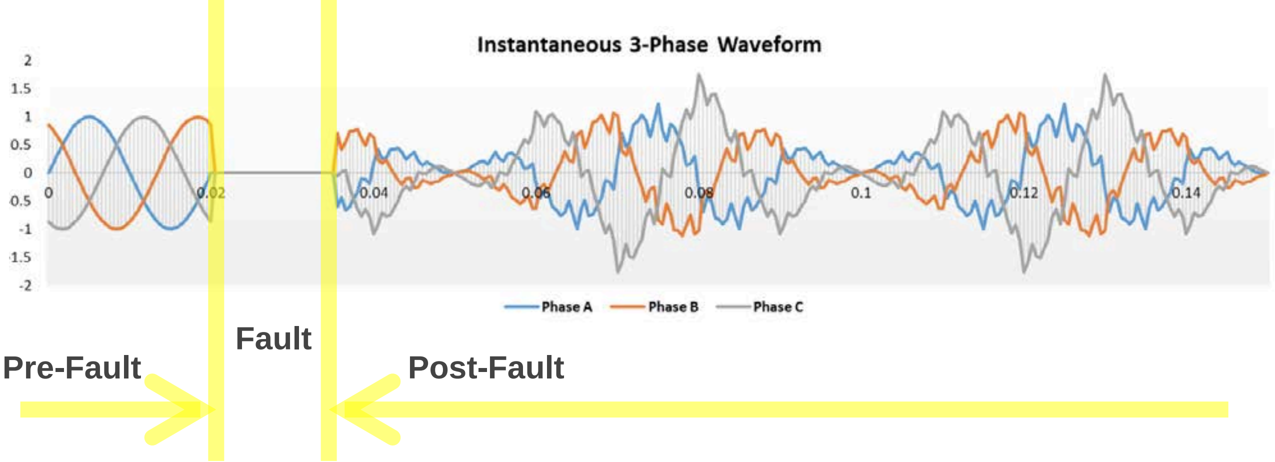
FRT: Limited Overload Capability

- **Potential Weak AC System Spots - Voltage Stability**
- Protection Challenge - Rotor Angle Stability

Deterioration of System Inertia

- Increased RoCoF - Frequency Stability

Advanced Voltage Stability Assessment



➢ **Network Operators traditionally use RMS tools for Dynamic Stability Studies**

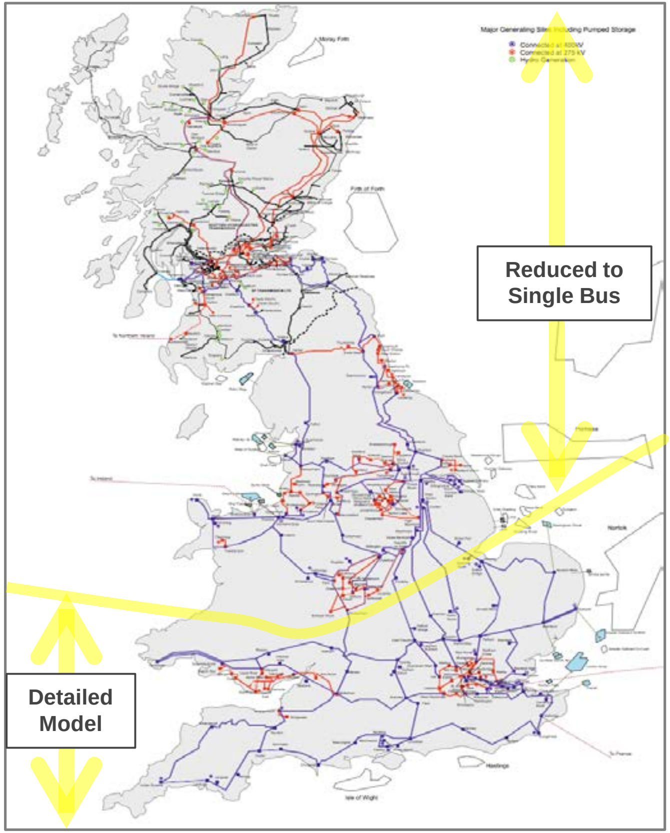
- Reliable results with synchronous machines but tend to consider only balanced 50Hz waveforms
- Converters rely on PLLs - sensitive to voltage distortion, harmonic corruption and unbalances.
- Assumption of “clean”, balanced, 50Hz waveform - no longer reasonable in NSG dominated systems .

➢ **Increasing need to use Electromagnetic Transient (EMT) simulation tools.**

Modelling & Simulation Studies

Spyros Karamitsos,
HVDC TECH

GB Grid – Test for Converter Instability



- We decided to investigate converter instability in the South East Coast (SEC) as an application.

- The GB grid system needed to be simplified at 400kV to allow EMT simulation.

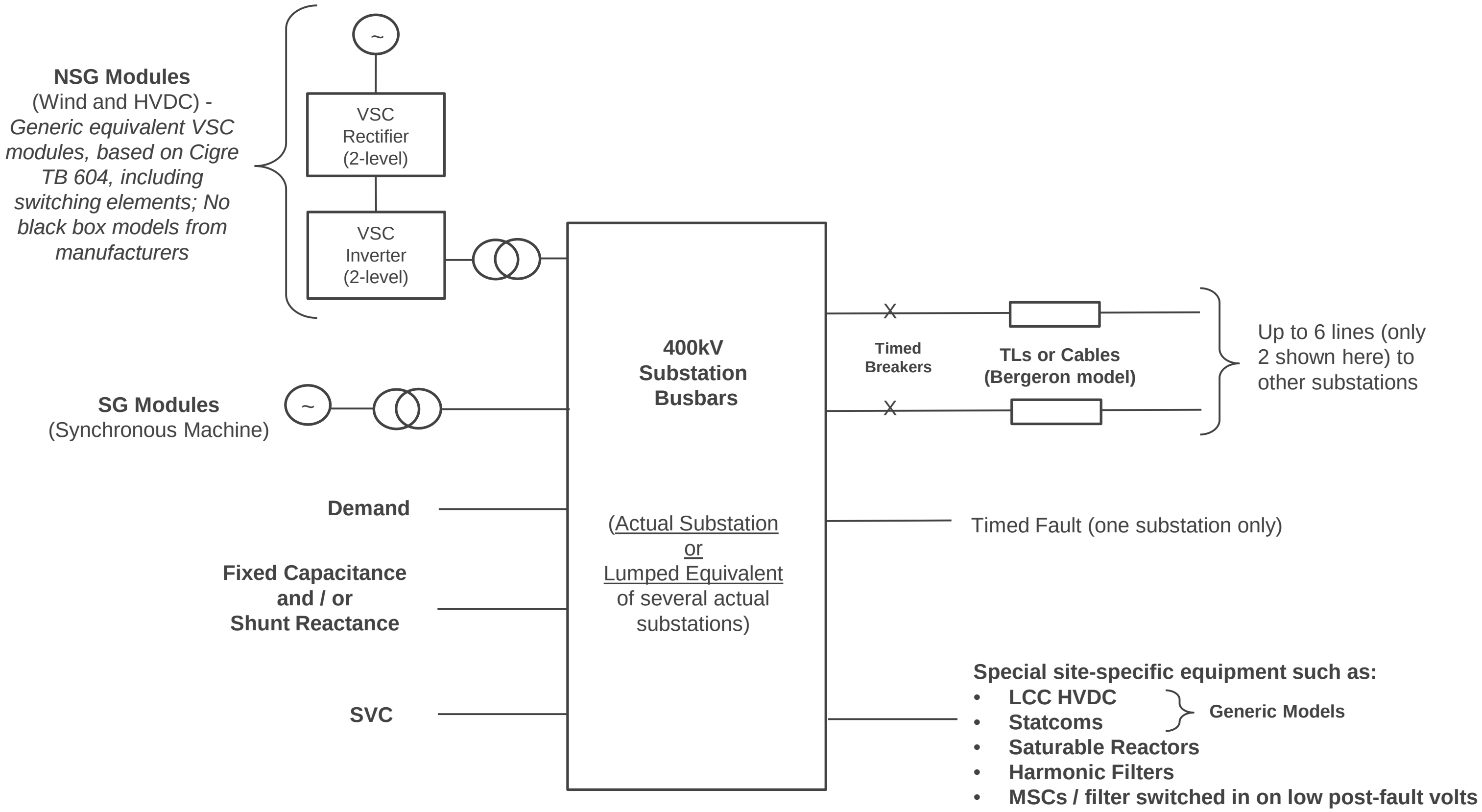
- Since focus is on the SEC, the northern part of the country was reduced to (in effect) a single busbar with:
  - A single equivalent SG module
  - A single equivalent NSG module (VSC).
  - The equivalent demand of these areas.

Methodology - Detailed Representation of South

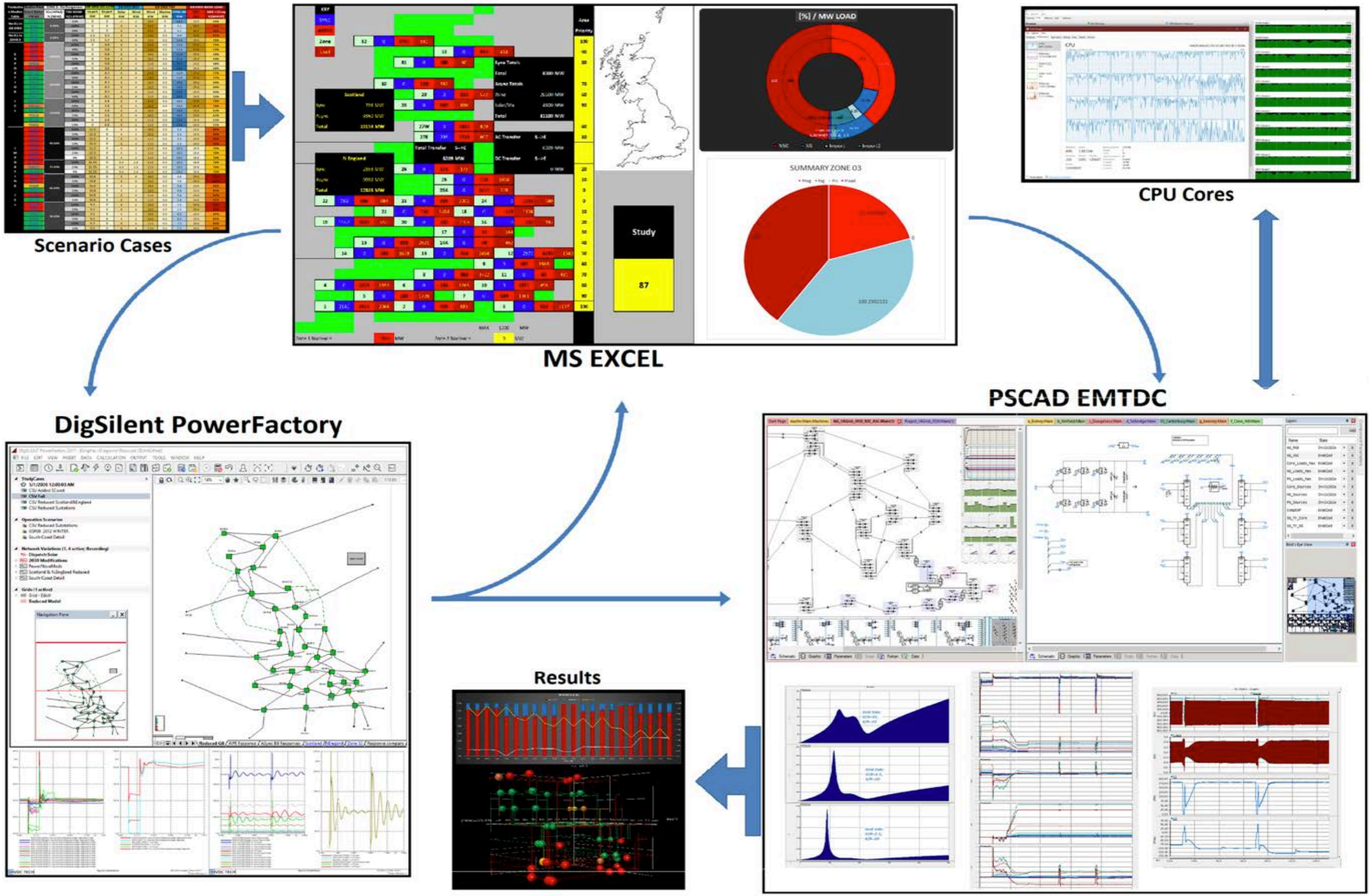
Several 400kV Substations represented by Lumped Substations & Equivalent TLs.

Full representation of 400kV Substations and TLs

Each Substation Contains…



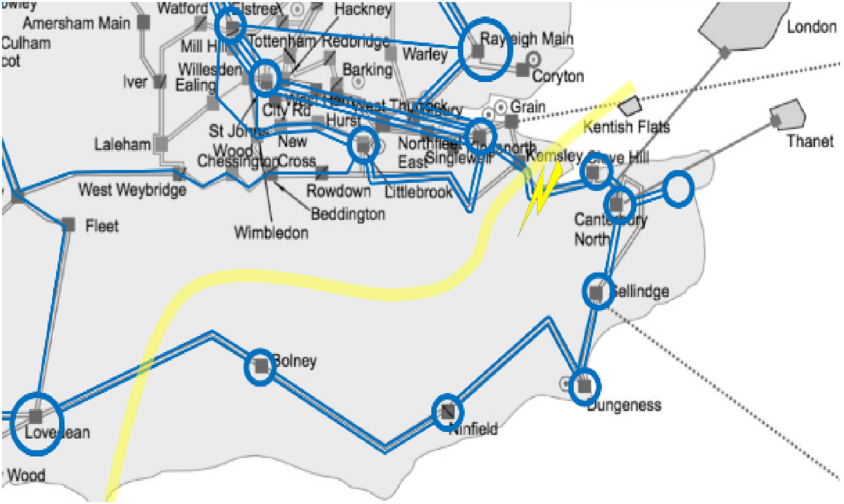
Advanced Simulation System



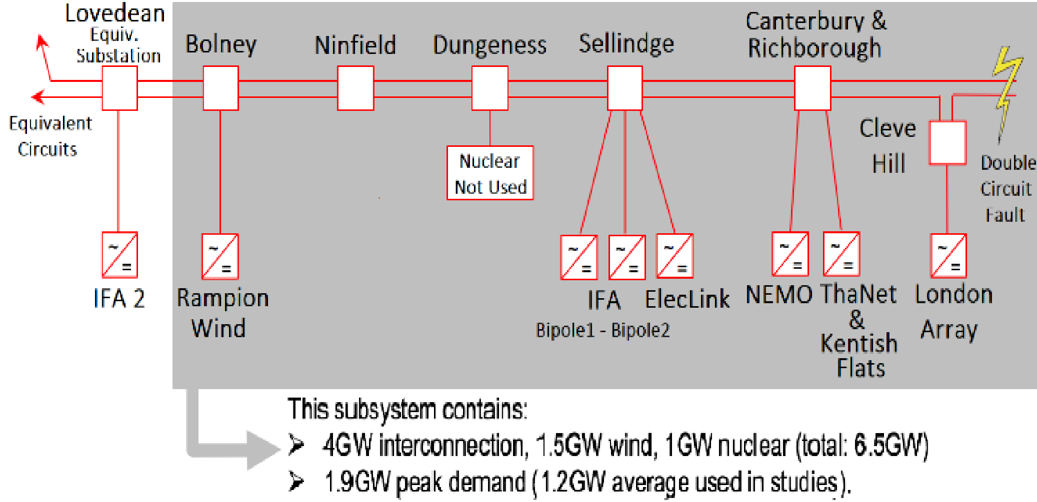
Load-Flow, RMS and EMT Simulation Studies Performed

Simulated Fault Event

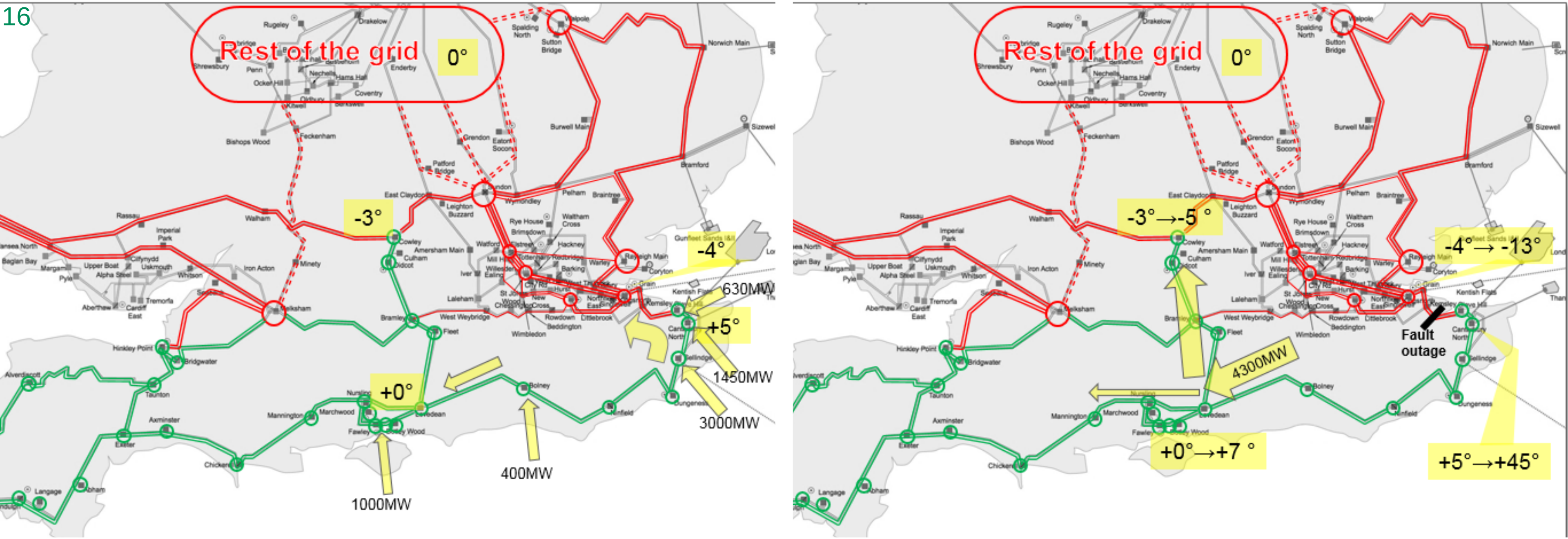
Simulated Fault Event: 140ms 3ph-Fault followed by Transmission Line Tripping



a) Geographical Location showing the Critical Fault event



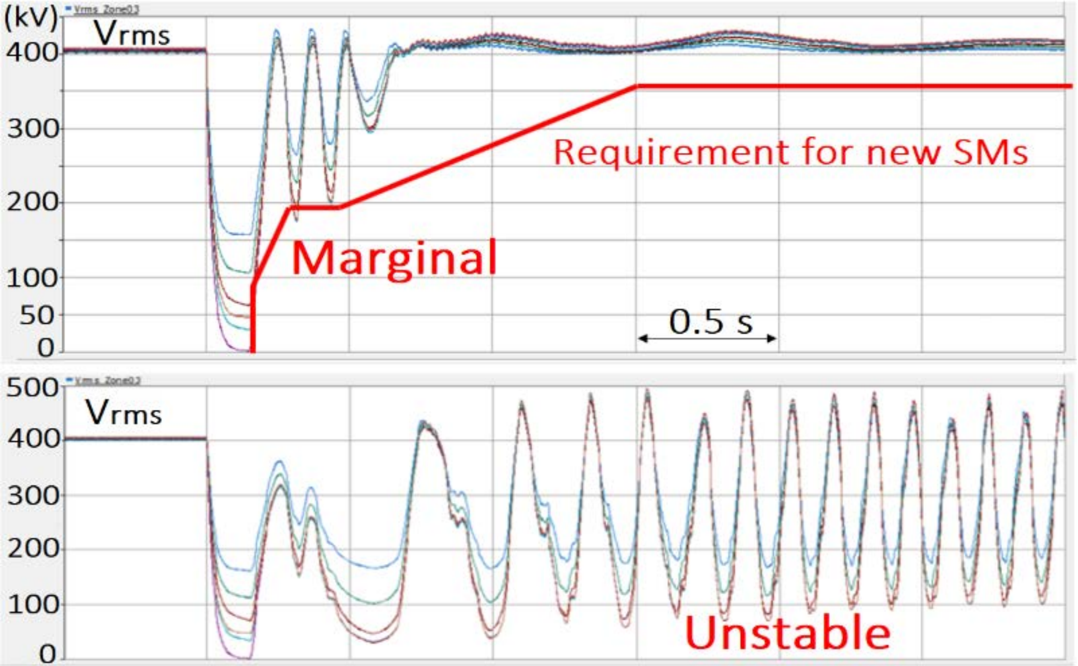
b) Schematic Diagram showing the Critical Fault event



Pre-Fault / Post Fault

Combination of voltage depression, phase jump and sudden weakening of grid.

Classification of Results



PASS: Acceptable Post-Fault AC Voltage Recovery (No THD considered).

FAIL: Comprising Dynamic Instability, Voltage Collapse, Unacceptable Transient or Temporary Over-Voltages, etc.

MARGINAL: After the event, the system either finds a Steady State that marginally fails to meet post-fault voltage recovery requirements, or it has issues finding a Steady State, but this contingency could be dealt locally (e.g. protection scheme).

When PSCAD Output Voltage fails to recover after fault, then it usually oscillates at around 6Hz.

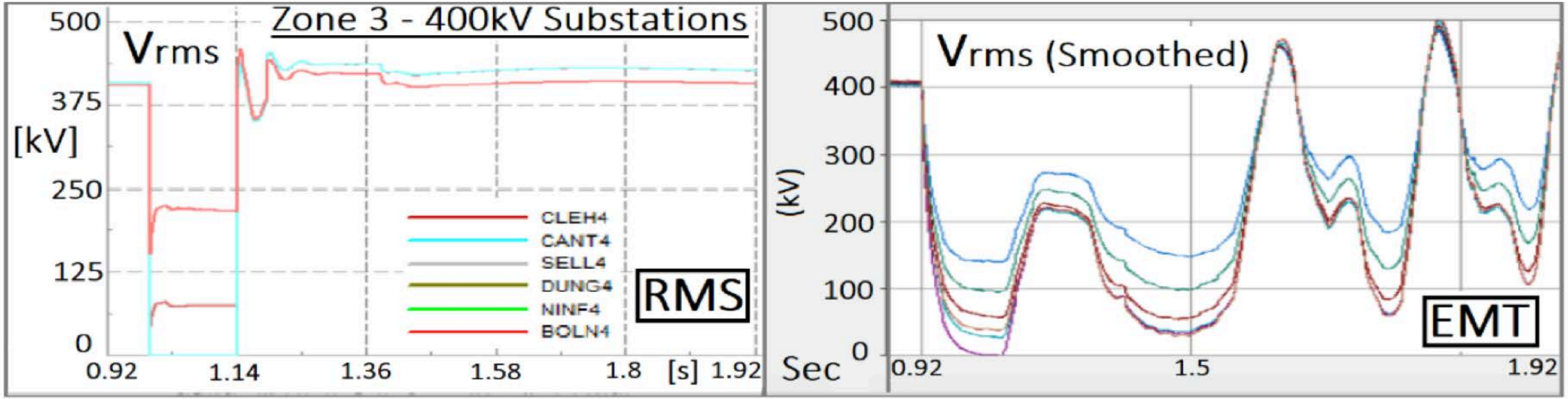
- Texas recorded instability looked similar, with oscillations there around 4Hz.

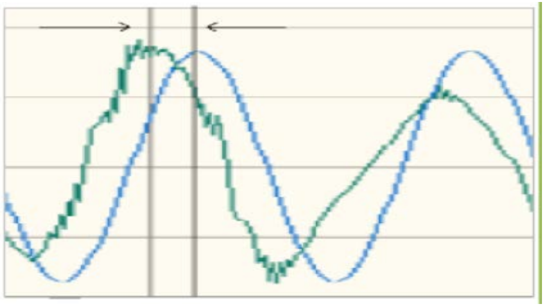
The Red - Line margin comes from the GB Grid code adoption criteria which engage with the ENTSO-e acceptable Voltage over Time specification

EMT vs RMS Stability Study – Example Case

Example Case of the same Scenario (High NSG)

RMS Transient Stability Study (left): Stable **EMT study (right): Converter Induced Instability**





(Left) Example of poor PLL tracking

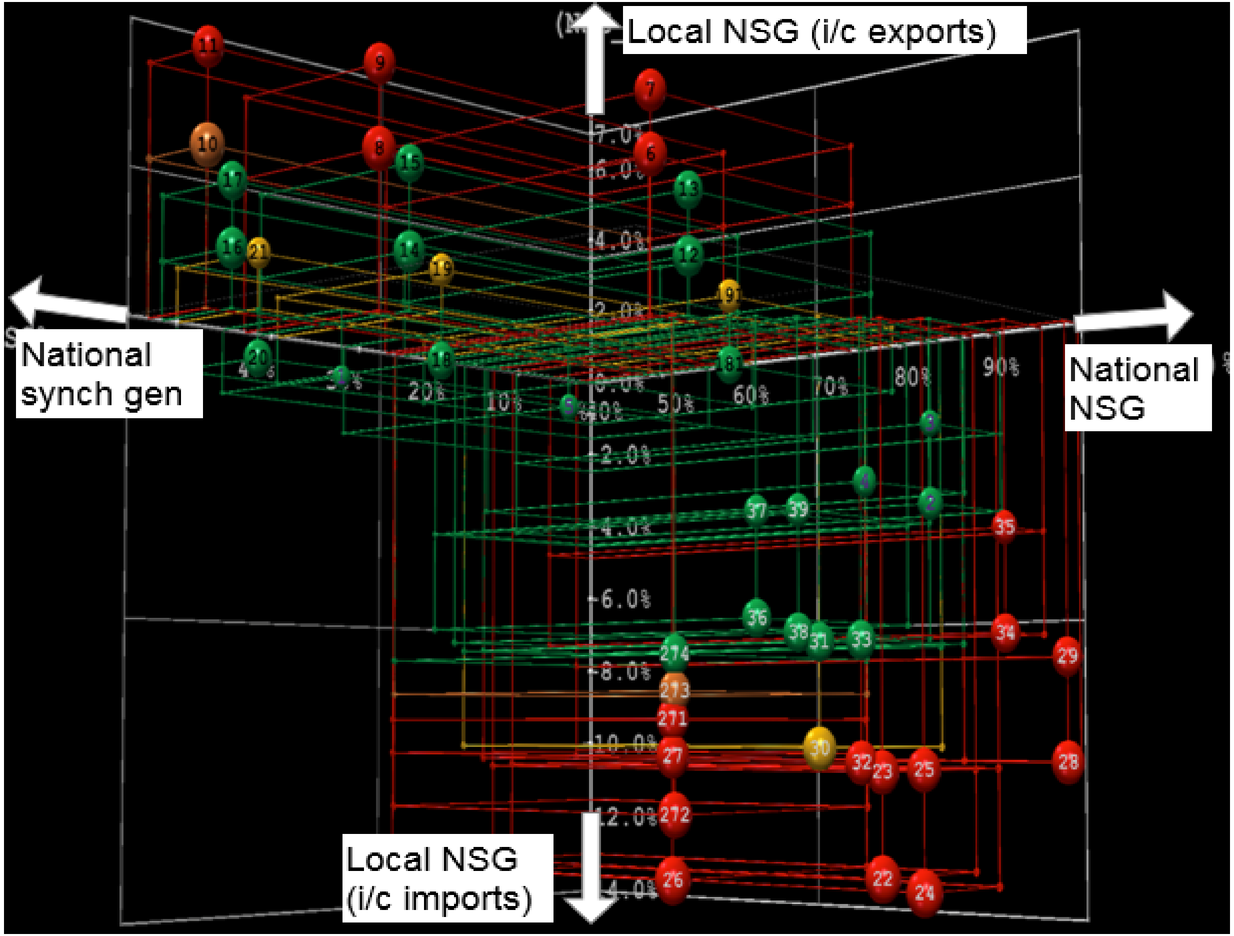
Note: *large difference in angle between the actual waveform (green) and the waveform indicated by the PLL's output (blue).*

Example of a phenomenon that cannot be assessed by RMS

Results & Analysis

Sean Kelly,
Transmission Excellence

Local v National Factors



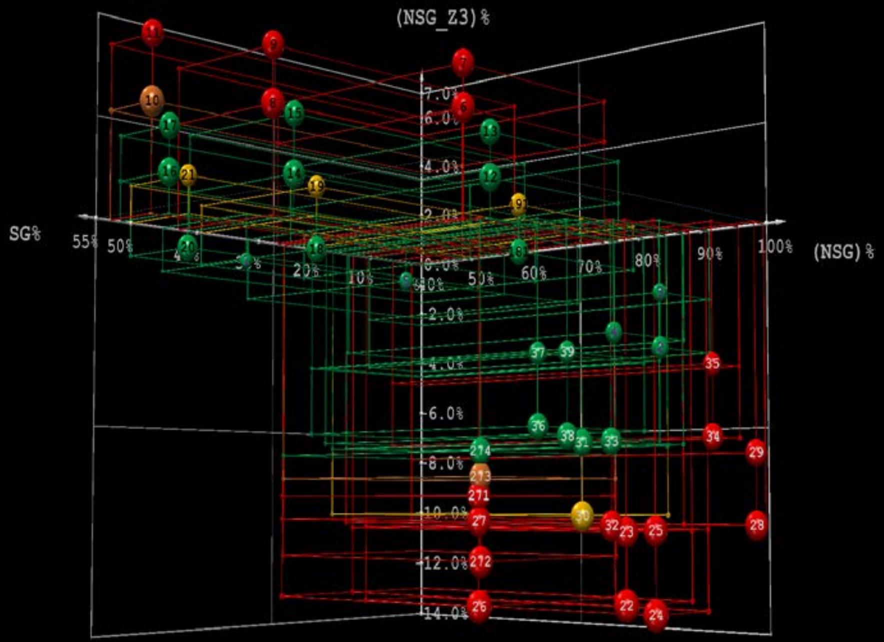
- Vertical axis: Local amounts of Non-Synchronous Generation (NSG) in the South East Coast area.

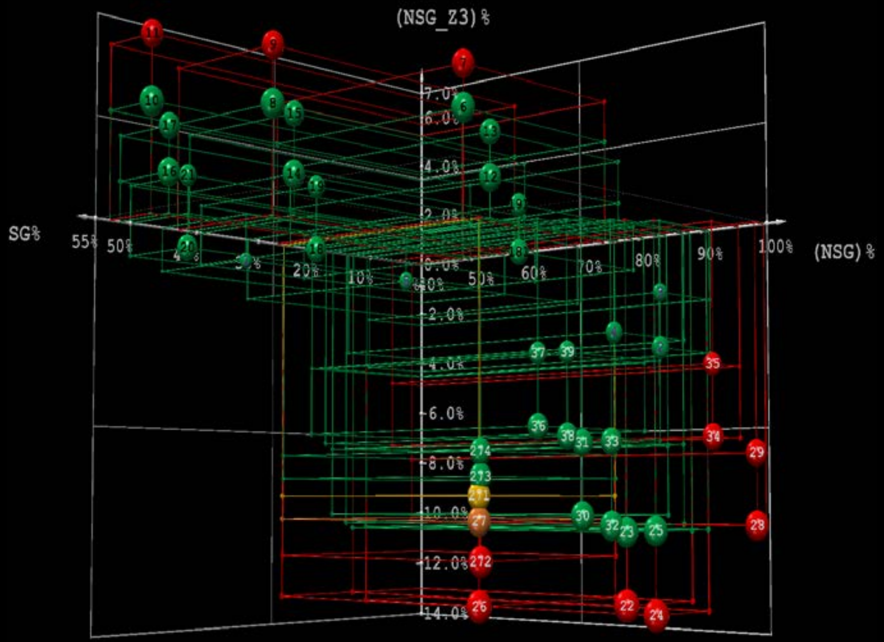
- Horizontal Axes: National amounts of SG and NSG,.

  - Spheres represent study results, color coded for **pass** / **fail** / **marginal**

Note: *Local factors (vertical axis) are most important, but national generation mix has some impact as well.*

Effect of Mitigation Measures

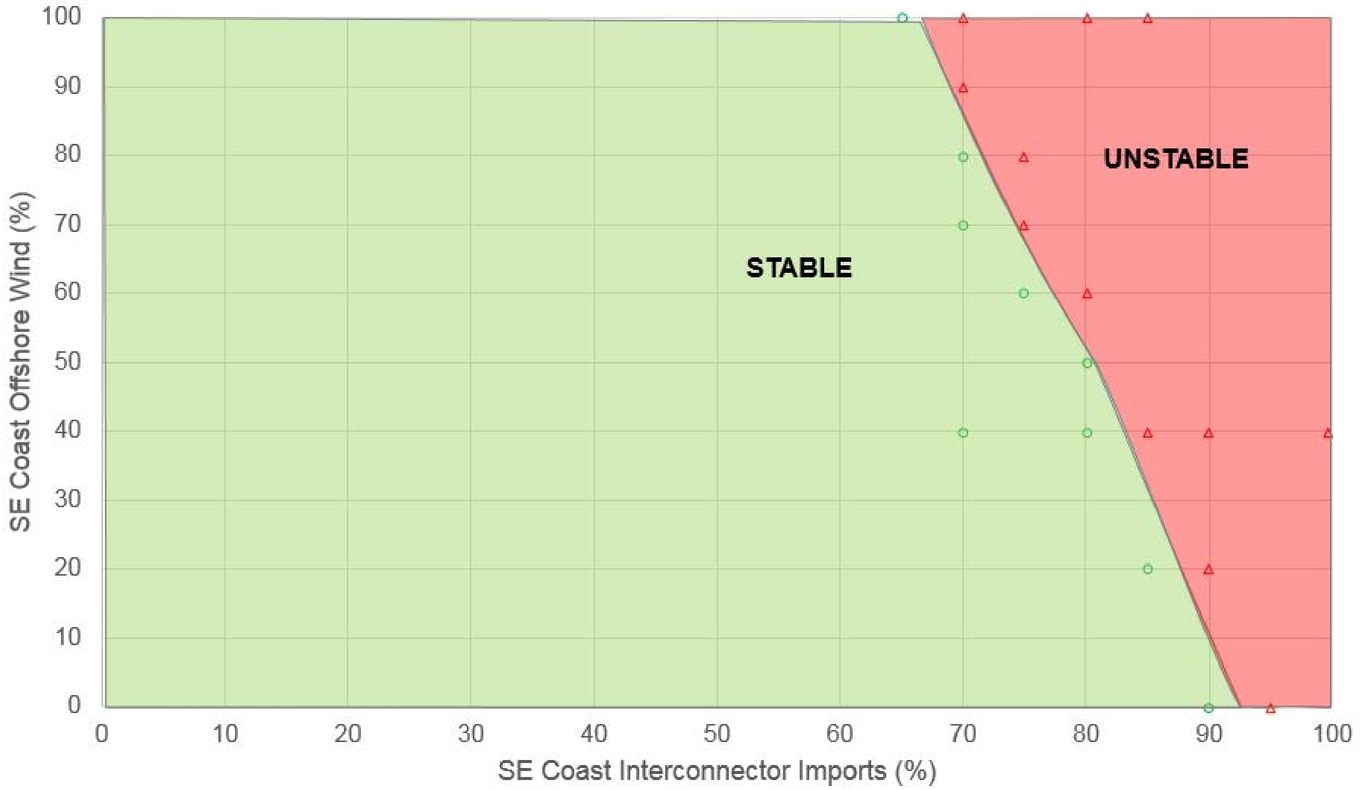




Case Studies Results: a) Without Sync-Comps

b) With Extra Sync-Comps

Example of Stable Operational Area
(driven by local factors)



Becomes Unstable when the total converter infeed into SEC exceeds limit.

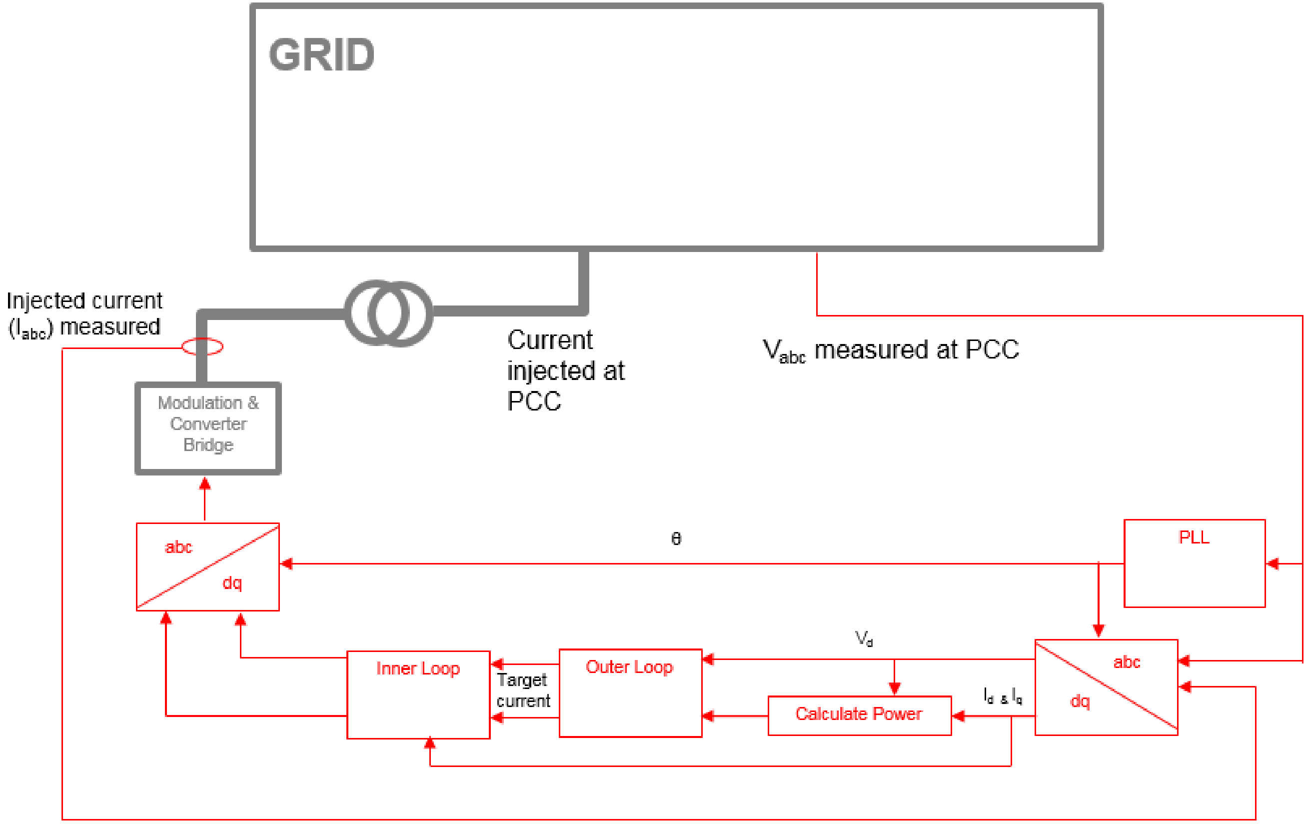
This analysis* represents generic converter modelling assumptions

*for illustrative purpose only

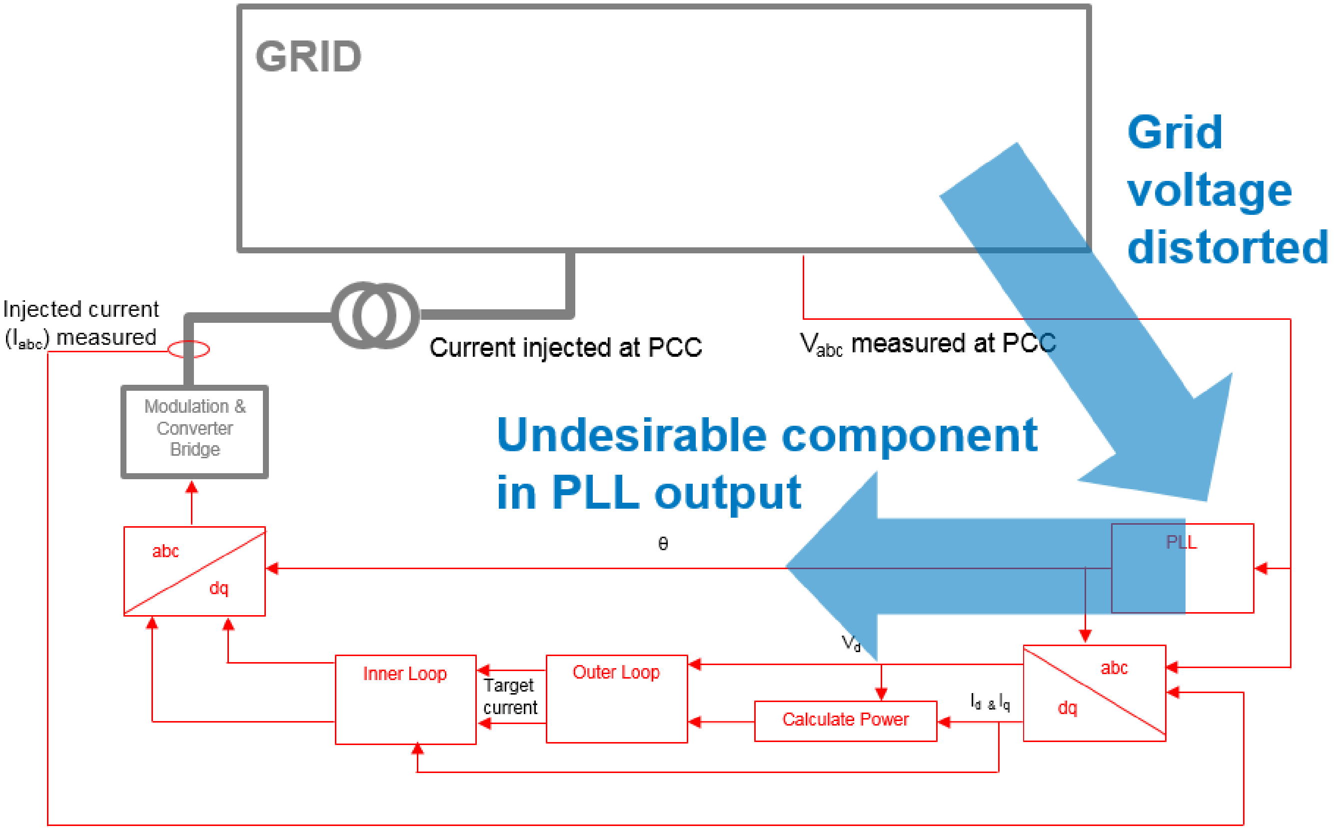
Study is Conservative

- Grid assumptions err on the side of stability.
  - Reduces risk of a false alarm due to poor grid modelling.
  - Leaves the use of a generic converter model as the major uncertainty.
- Some examples of conservative grid modelling assumptions:
  - Most WTGs are modelled as directly connecting at transmission voltages.
  - Generation& Demand background are based on expectations for 2025+, but in the South East Coast we only include converters already in service or under construction.
  - The “rest of the grid” is modelled as being electrically closer to the South East Coast than is actually the case.

Typical Vector Current Control VSC



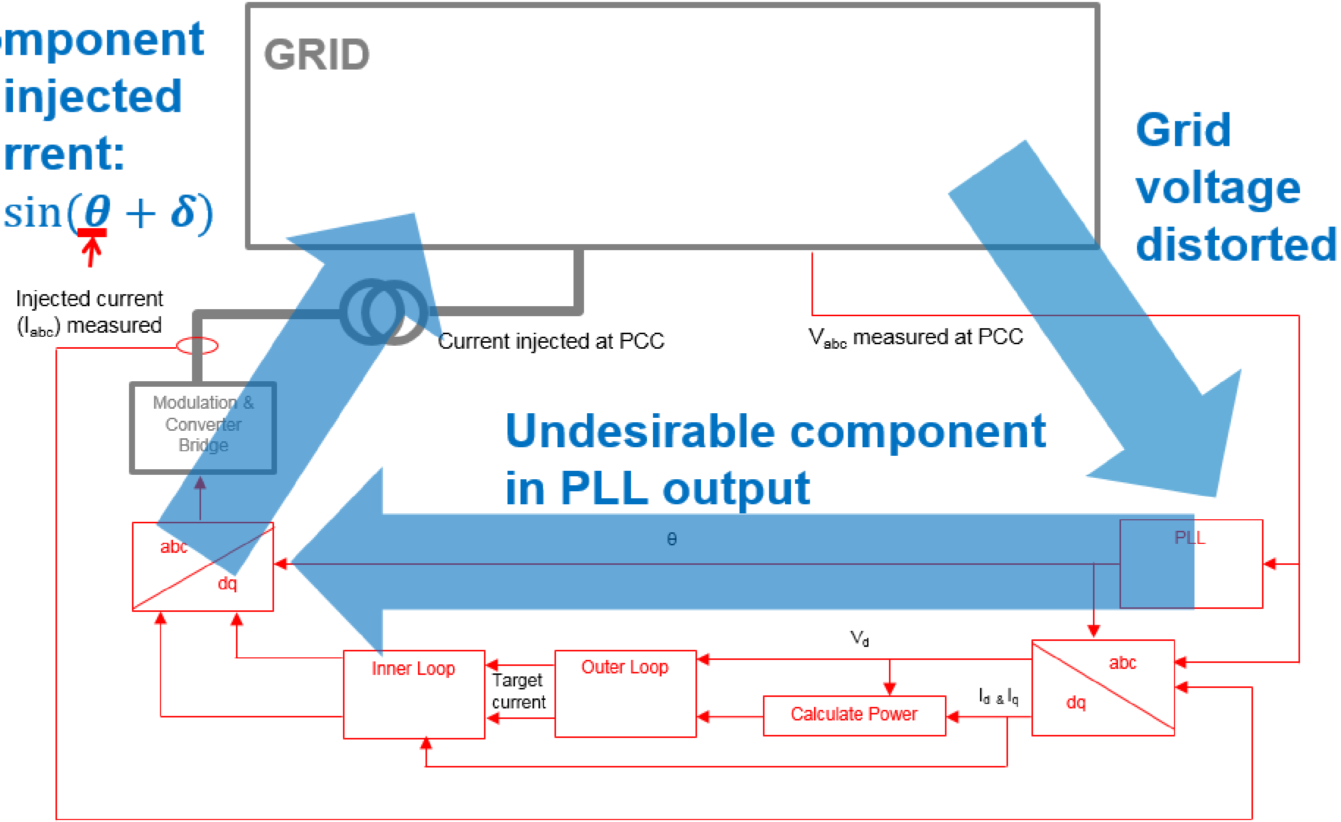
PLL Picks Up Distorted Voltage



This Affects the Injected Current

Undesirable component in injected current:

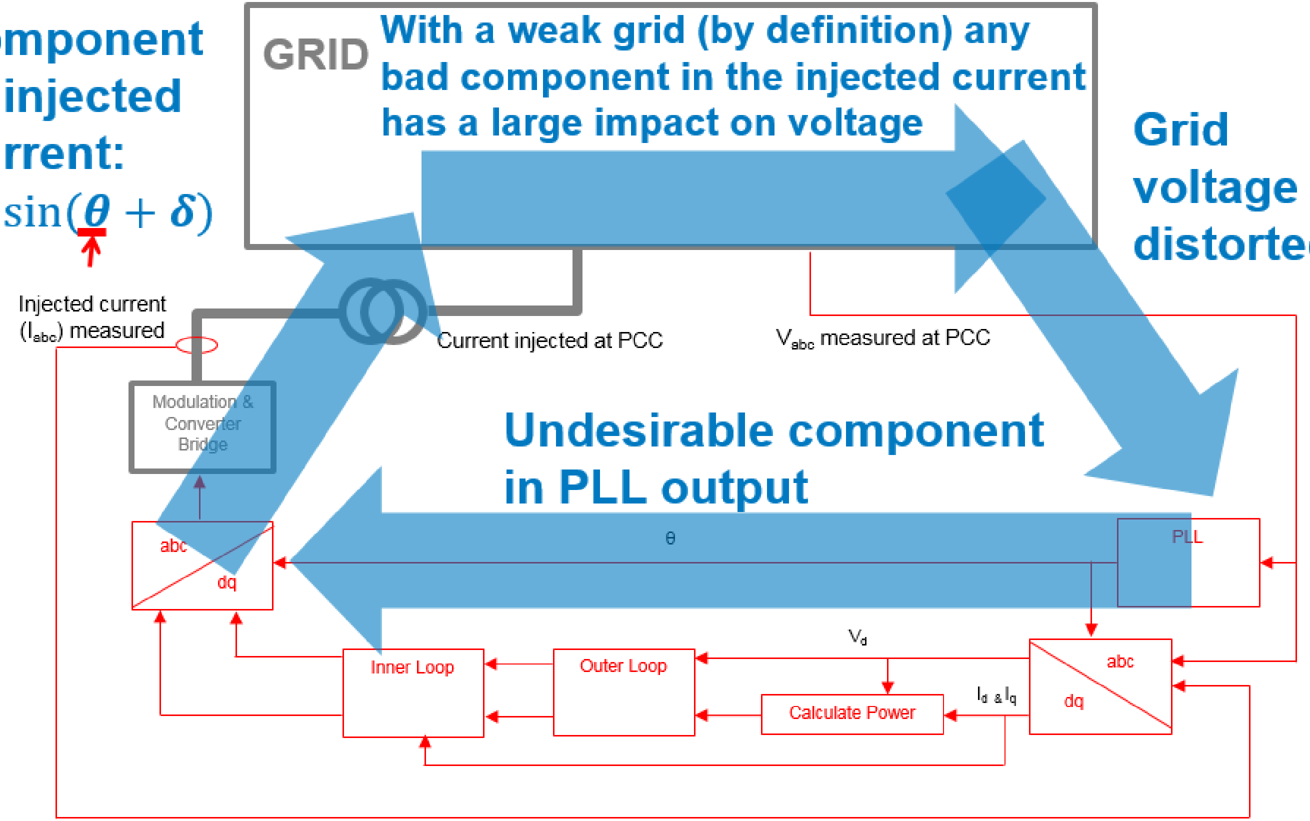
$$I_c \sin(\theta + \delta)$$



Results in an Unwanted Feedback Loop

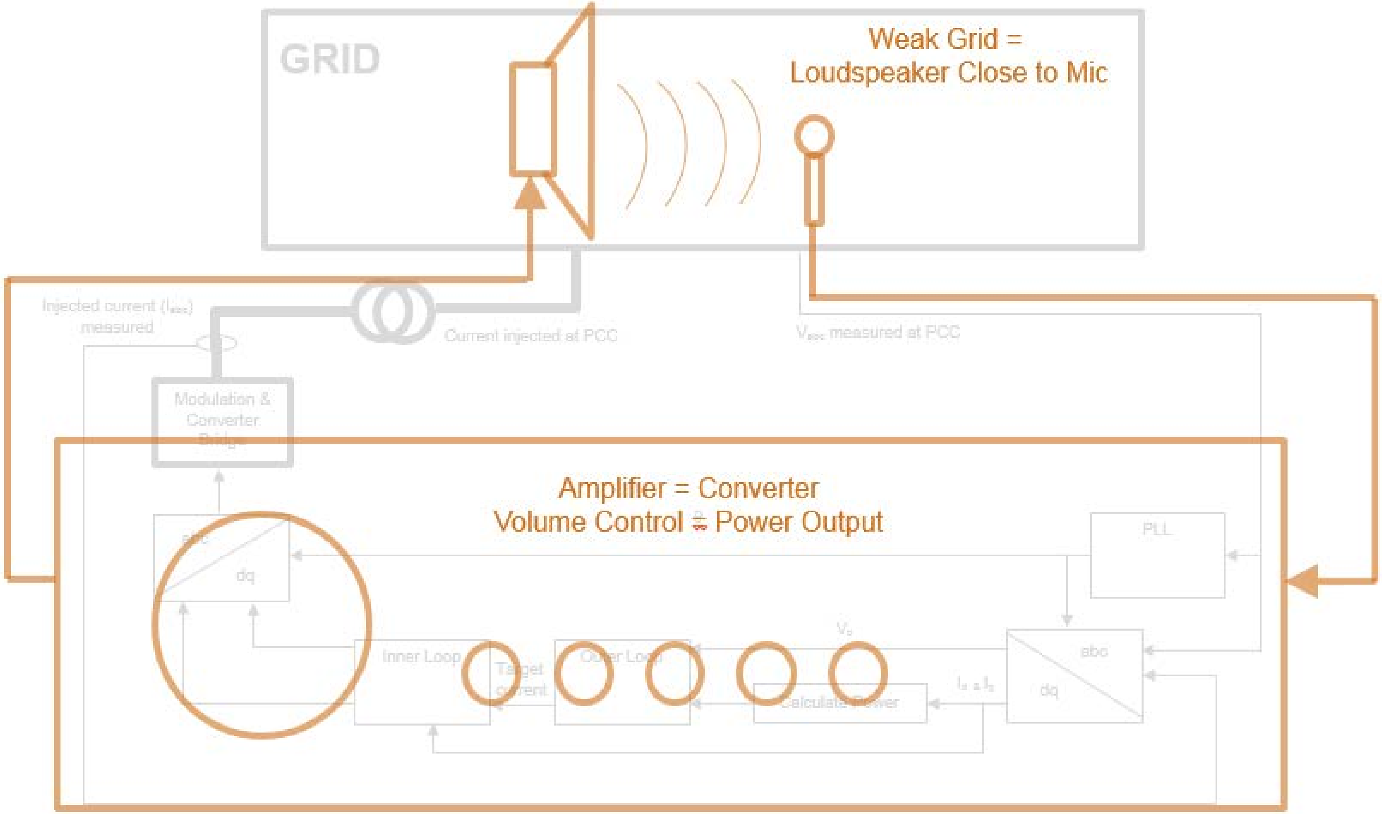
Undesirable component in injected current:

$I_c \sin(\theta + \delta)$



Grid voltage distorted

An Analogy
Feedback involves grid and converter



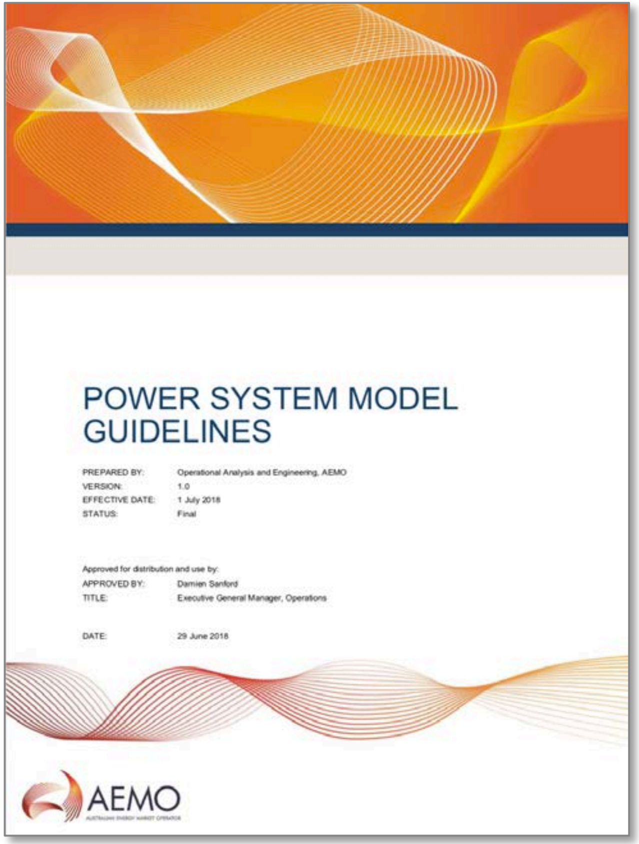
Conclusions & Next Steps

**Ben Marshall,
National Grid ESO**

Conclusions

- Need for EMT studies to investigate all drivers of instability in converter dominated grids.
  - Traditional (RMS) tools don’t see converter instability risk – can mislead.
  - An advanced system model helps but relies on the data within it being available and representative.
- The converter instability is predominantly a regional phenomenon.
  - It is not uniquely a control or network phenomenon, but both.
  - Network-control Interaction of increasing complexity with greater penetrations of diverse converters.
  - Requires coordinated modelling function to support high levels of regional converter penetration.
- Our analysis illustrates that for the South East Coast, there is also a potential risk of converter instability when a credible double-circuit fault occurs during a period of high Wind and interconnector import.
  - The instability predicted by EMT studies takes the form of voltage and power oscillations.
  - Sync-Comps and Innovative control placed in the SEC can alleviate voltage instability in the region.
- These results are indicative for just the South East Coast region.
  - Other potential types of converter interaction / instability may occur elsewhere within the British Grid.

Next Step – Manufacturer Provided Models



- Studies used generic converter models.
- Detailed manufacturer EMT models are required for converters, StatComs, SVCs.
- Some TSOs already collecting this information (as a regulatory requirement).
- The same level of technical detail would be required to further this investigation.
- Complements network modelling and monitoring activity.

Potential Solutions to Converter Instability

- The project has considered proof of concept around a range of potential solutions.
- Alternative Improved tuning of converter control systems available?
- Synchronous compensation?
  - Project has tested options in South East Coast.
- Improved converter software?
  - Project has considered some concepts, but further testing needed before they can be deployed.
- Grid forming converters
  - Potentially a good long-term solution under discussion within Grid Code Expert Working Group. Account of existing grid-following converters and their existing concentrations required.

Q & A

Please Submit Questions via the Webex Chat