VSM Expert Group

Meeting 1

National Grid

April 2018

Overview

- Aims
- Background
- System Need / Justification
- RfG and HVDC Implementation
- GB Expert Group
- Examples including a System Split
- Options
- Next Steps

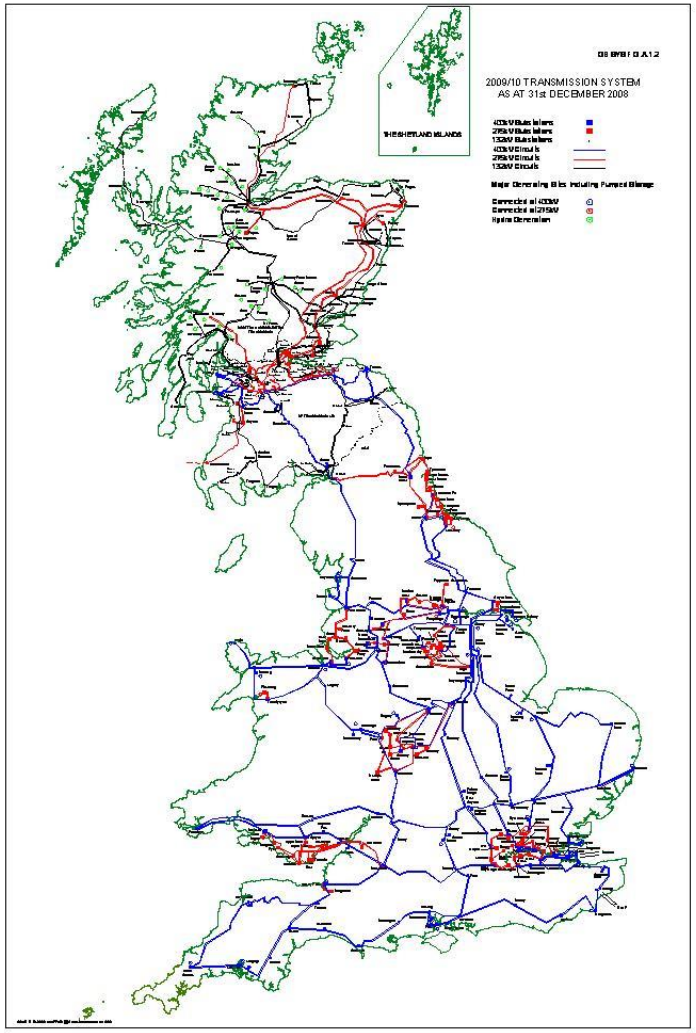
Aims - Stage 1

- Covered under the Terms of Reference
- Stage 1
  - Evaluate VSM type technologies and enhanced converter control strategies
  - Review International practice, technical feasibility and costs
  - Develop and review a VSM type converter control specification and the relationship between fault ride through and fast fault current injection
  - Assess the a capability for sub 1MW plant
  - Assess costs of VSM type technologies for all plant from the smallest to the largest
  - Assess Questionnaire responses
  - Consider impact of wider Grid Code requirements
  - Timescales

Aims – Stage 2

- Covered under the Terms of Reference
- Stage 2
  - Develop a cost benefit analysis to identify the most economic and efficient solution fit for operating a secure System in the 2020's
  - The application of VSM type technologies fitted to Generation, HVDC and Storage Technologies
  - The application of other market mechanisms including the use of de-rating or adjusting the plant mix
  - The use of synchronous compensation equipment or de-clutched Generation
  - The implications and costs if fault ride through and VSM type specifications are introduced to sub 1MW plant and its impact on the costs
  - The balance and costs between equipment installed by Generators, HVDC System Owners or Storage Owners and Network Licensees
  - Interactions between reserve holding, inertial response and operation of the Low Frequency Demand Disconnection Scheme
  - Consider total system costs under normal and abnormal conditions

The GB Electricity Transmission System (2016)



- National Grid operate the entire GB Transmission System and own the assets in England and Wales only
- The Scottish Transmission Licensee's (Scottish Hydro Electricity Transmission and Scottish Power Transmission) own the Transmission Assets in the North and South of Scotland respectively
- Peak Demand ~ 61 GW
- Minimum Demand ~ 15.7 GW

Future Energy Scenarios and the System Operability Framework

- Each year National Grid produce two documents. These being the Future Energy Scenario's (FES) and System Operability Framework (SOF)
  - http://fes.nationalgrid.com/fes-document/
  - https://www.nationalgrid.com/uk/publications/system-operability-framework-sof
- The FES details the expected Generation and Demand profiles against four scenarios (Consumer Power, Two Degrees, Steady State and Slow Progression) to the year 2050 based on the most accurate data available
- The System Operability Framework (SOF) takes a holistic view of the changing energy landscape to assess the future operation of Britain's electricity networks. The SOF combines insight from the Future Energy Scenarios with a programme of technical assessments to identify medium-term and long-term requirements for operability.

General Trends

- Fall in volume of Transmission connected Generation particularly synchronous (already over 50% in winter and summer)
- Increase in the growth of converter connected generation and storage technologies particularly to the Distribution System
- Operational challenges are becoming more apparent during low demand periods due to the high volume of Embedded Generation
- Significant challenges around regulation of voltage at Grid Supply Points during minimum demand conditions
- Displacement of synchronous generation by converter based plant is becoming a major issue post 2021 with concerns over lack of synchronising torque, falling levels of system inertia, low fault current injection under fault conditions, reduction in fault levels (by 70% of current levels) and concerns over protection operation to name but a few.
- Many of these issues were initially detected several years ago but as the decade has progressed there is greater evidence that these effects are real.

GB Research into Converter Based Control Strategies

- National Grid in co-ordination with the University of Strathclyde started to look into the control strategies of converter based plant in circa 2013. Whilst this initially started as a research project, the aim was to explore the issues of high penetrations of converter based plant to the System.
- Several papers have since been published in 2013 and 2016.
- As time has progressed, there is increasing concern over the use of Phase Locked Loop (PLL) as a converter control strategy and this issue has been documented in the SOF.
  - https://www.nationalgrid.com/sites/default/files/documents/Phase%20locked%20loop%20FINAL.pdf

High Convertor Penetration - Options

With current technology/models, the system may become unstable when more than 65% of generation is Non-Synchronous

For the FES 2Degrees, Consumer Power and Slow Progression scenarios, it is currently forecast this level could be exceeded for 800-1800Hrs p.a. in 2023/24 and for 2100-2750Hrs p.a.in 2026/27.

Key

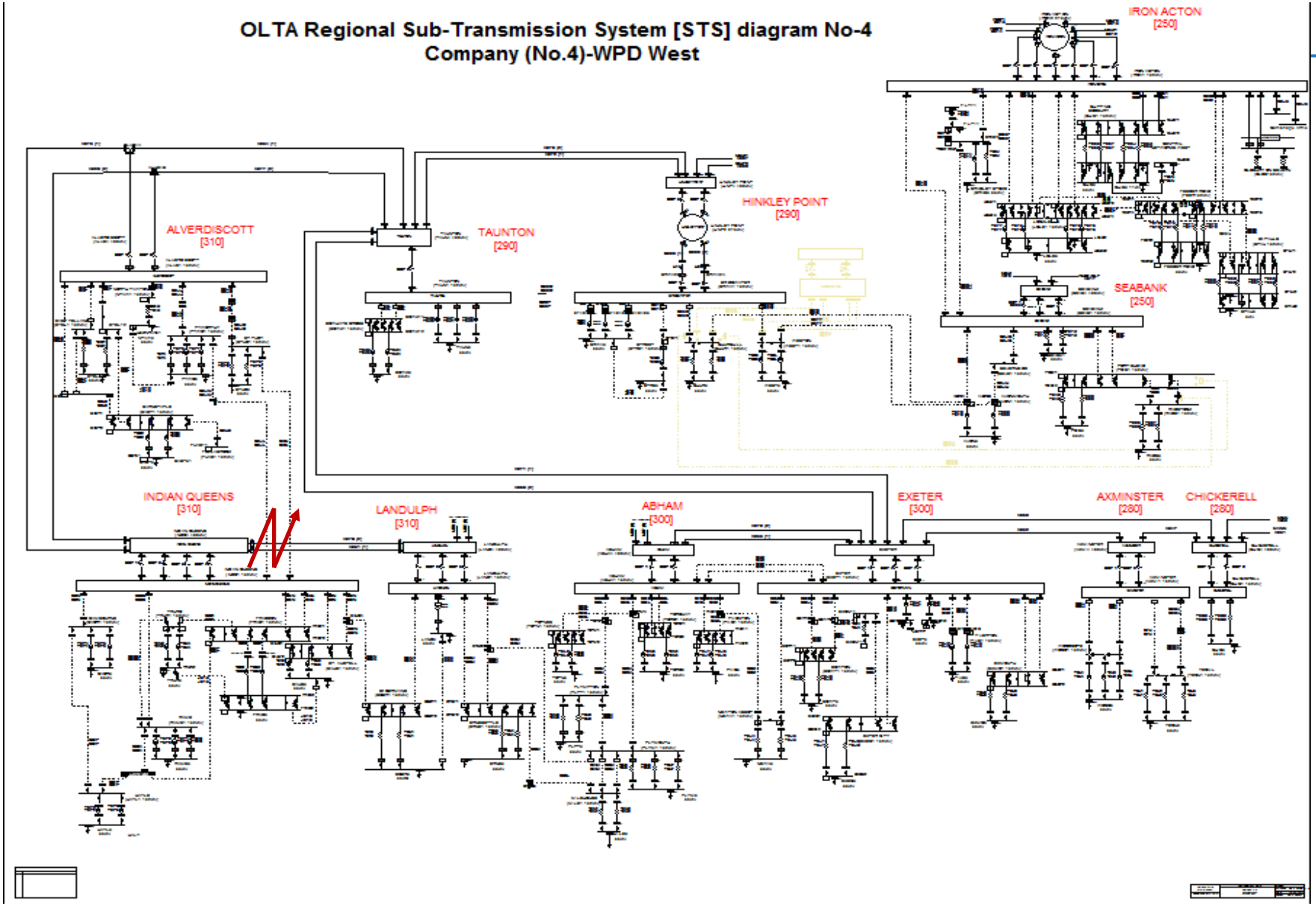
No	Doesn't Resolve Issue
P	Potential
I	Improves
Yes	Resolves Issue

Solution	Estimated Cost	RoCoF	Sync Torque/Power (Voltage Stability/Ref)	Prevent Voltage Collapse	Prevent Sub-Sync Osc. / SG Compitable	Hi Freq Stability	RMS Modelling	Fault Level	Post Fault Over Volts	Harmonic & Imbalance	System Level Maturity	Notes
Constrain Asyncronous Generation	Hgh	I	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Proven	These technologies are or have the potential to be Grid Forming / Option 1
Syncronous Compensation	High	I	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Proven	
VSM	Medium	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	P	Modelled	
VSM0H	Low	No	Yes	Yes	No	P	P	P	Yes	P	Modelled	Has the potential to contribute but relies on the above Solutions
Synthetic Inertia	Medium	Yes	No	No	P	No	No	No	No	No	Modelled	
Other NG Projects	Low	Yes	P	Yes	No	No	No	P	P	No	Theoretical	
Timescale (Based on work by SOF team)		Now	2019	2019	Now	2020	Now	Now	2025	2025		

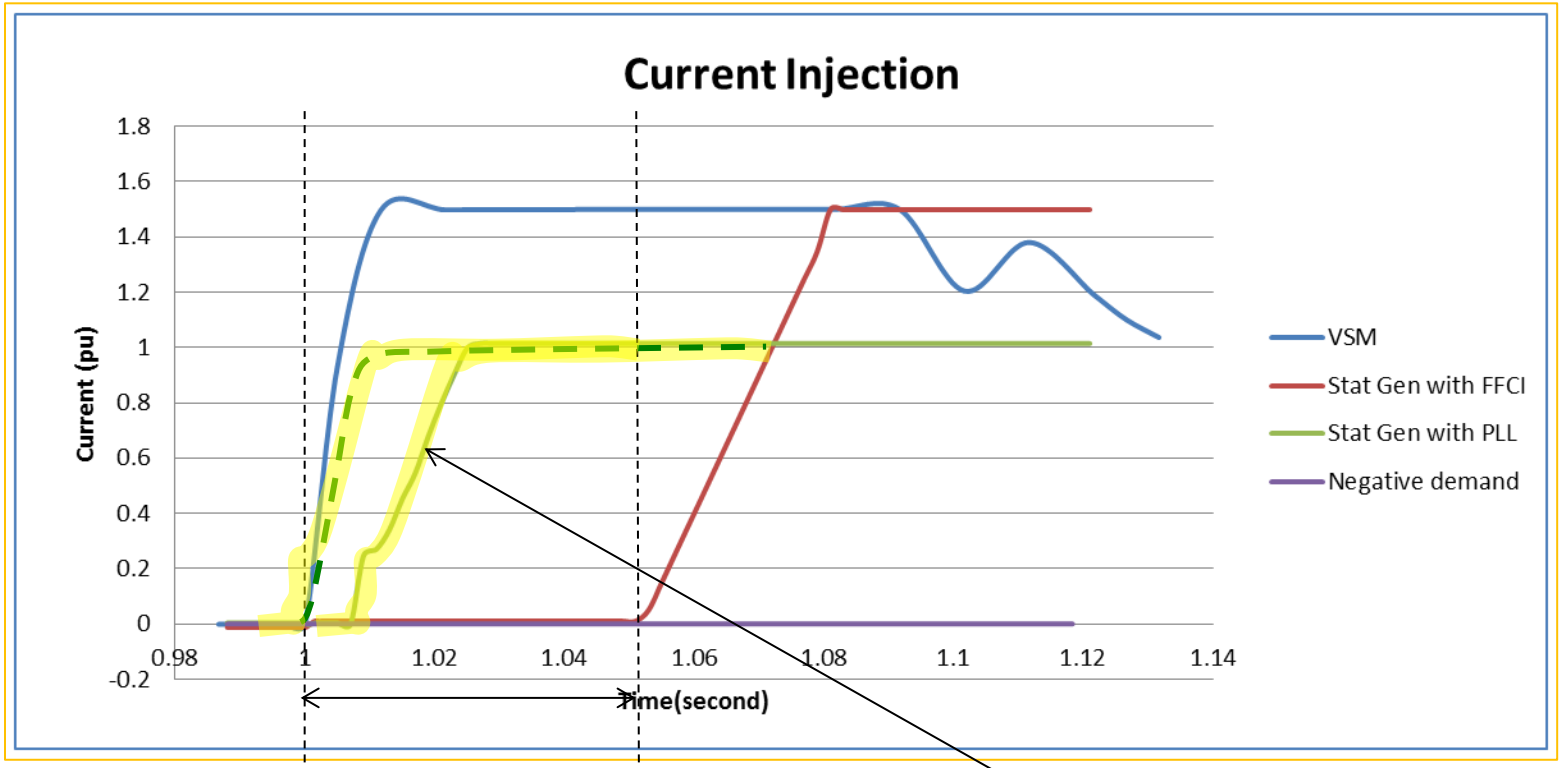
RfG and HVDC Code Implementation in GB (FRT and FFCI)

- In the early part of 2017 extensive work (including system studies) was undertaken to develop the GB requirements for Fault Ride Through and Fast Fault Current Injection
- A full system study was set up including a DNO system complete with the embedded generation.
- The Converter based plant was modelled with different types of controller. In one of the cases, the converter based plant was fitted with a controller that behaved in the same way as a synchronous machine (the so called VSM or Virtual Synchronous Machine).
- The results of these studies demonstrated an inherent linkage between the current injected by generation and the retained voltage observed across the system.
- The VSM provided the better retained voltage profile – largely as all the plants operate in synchronism and thereby contribute to maintaining an overall higher voltage profile. Full details of the study and reports are available from the following link https://www.nationalgrid.com/sites/default/files/documents/Annex%206%20-%20GC0100.docx

Area Under Study



Reactive Current Injection performance from different converter control strategies

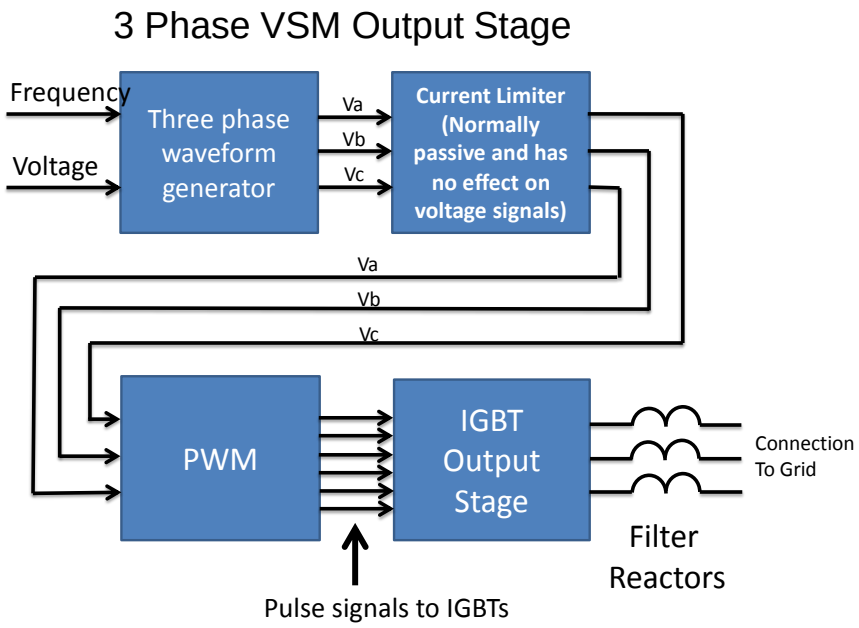


50ms delay for illustration, shorter delay would be prescribed in practice

Area across which PLL behaviour cannot be guaranteed, injection is potentially out of phase with the retained voltage

Virtual Synchronous Machine (VSM)

Both VSM & VSM0H use similar output stages



Changes for VSM

1. Simulate inertia
2. Reduce the bandwidth of F and V to 5Hz

Advantages (main)

1. Contributes to RoCoF
2. Compatible with SG
3. Reduced interaction and HF instability risks
4. Can be modelled in RMS system studies

Disadvantages

1. Requires additional energy
2. Possibility of traditional power system instability

Outcome of the GB Proposals for FRT and FFCI

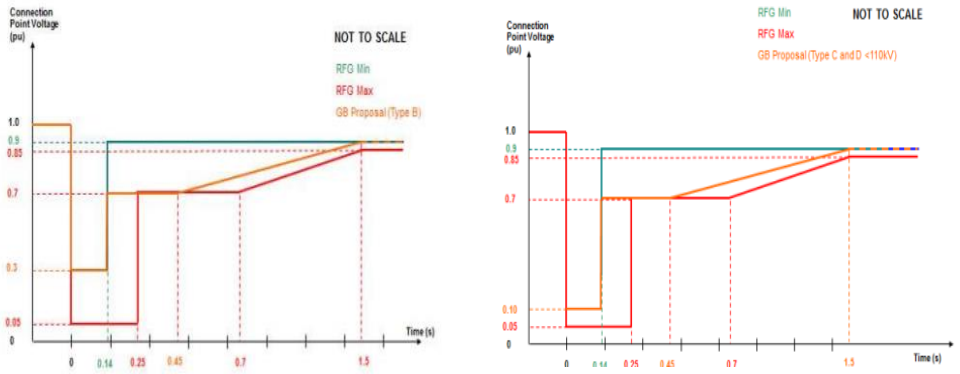
- The outcome of this work was that three proposals were suggested:-
  - Option 1 - VSM Type Technology
  - Option 2 - Conventional PLL requirement with a 1.25pu ceiling current
  - Option 3 - Conventional PLL requirement with a 1.0pu ceiling current.
- National Grid's original position (option 1) was to specify a requirement for VSM from 2021 with a PLL available for use before this time.
- A full specification for each of the above options was prepared and included within the consultation document which are available from the following links:-
  - Consultation Document
  - https://www.nationalgrid.com/sites/default/files/documents/Final%20Workgroup%20consultation_0.pdf
  - Legal Text- FFCI Options 1,2 and 3
  - ttps://www.nationalgrid.com/sites/default/files/documents/Annex%202%20Grid%20Code%20Draft%20Legal%20text_0.pdf

Outcome of the GB Proposals for FRT and FFCI

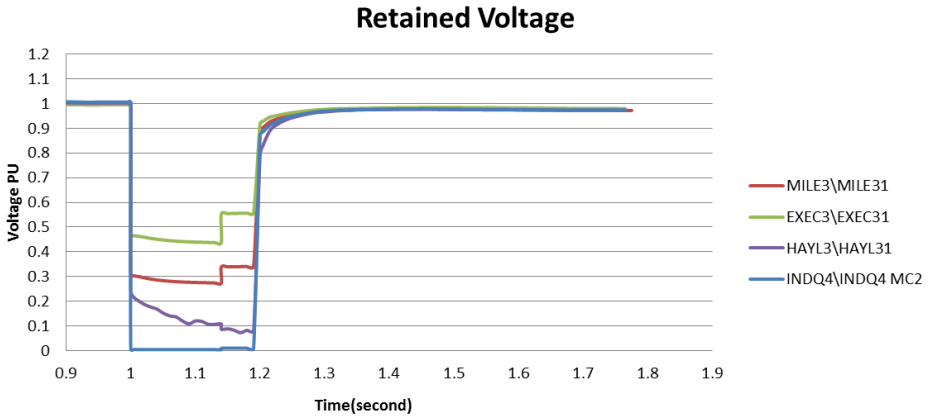
- Following the consultation, there was an overwhelming response for Option 3.
- National Grid's view is that based on the FES and SOF there is a real concern over the decline in Transmission Connected Synchronous Generation. Based on the SOF urgent action is required by 2021 to ensure compliance with fault ride through requirements and fast fault current injection.
- It was therefore agreed that to implement RfG and HVDC, Option 3 would be taken forward but we would wish to set up an expert group to:-
  - Consider and refine the requirements for Virtual Synchronous Machine Controllers (VSM) in addition to considering the use of market based solutions or otherwise including the use of synchronous compensators
  - It is acknowledged that the specification for VSM requires further assessment
  - The contribution from sub 1MW plant including fault ride through will be a particularly important part of this study
  - Inherent relationship between fault current injection and inertial behaviour (ie any response to a voltage or frequency disturbance should be in phase with the system)

The problem statement (1):-

- Current measurement-led converter control is unable to deliver the *instantaneous* support to maintain voltage against time support

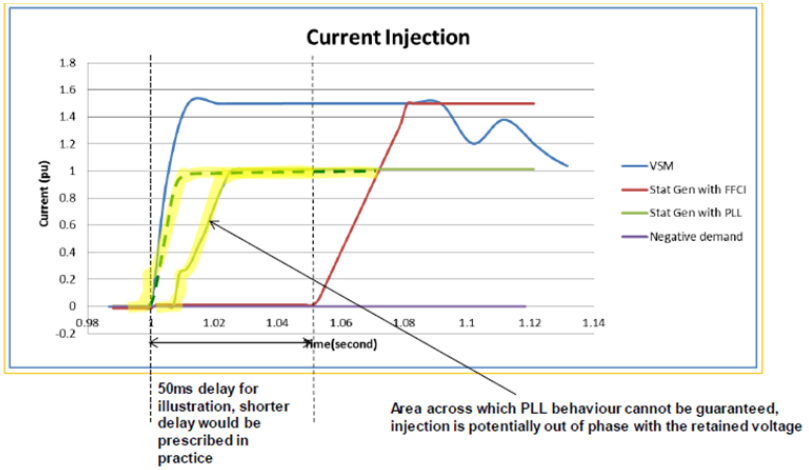


- An option 1-(GC0100) like *non- measurement dependant* approach can achieve this at the point of connection interface.

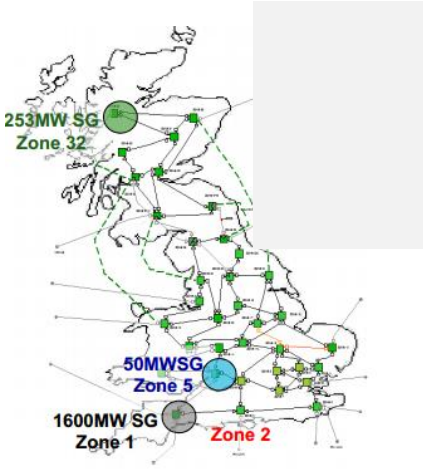


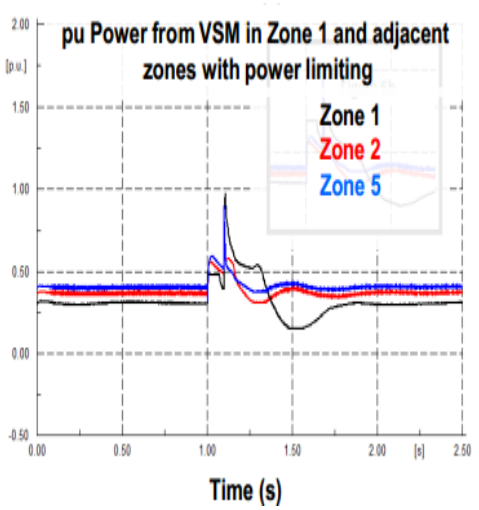
The problem statement (2):-

- Measurement-less reactive current supplied in phase with the load up to a potential maximum continuous rating of 1.5pu *during a fault* in order to ensure that voltage against time curves are met from 2021 across all FES scenarios considered.



- Measurement-less control implies that for a fault of a generator circuit the control system needs also to support increased damped *active power* (SQSS definition of system instability)





System Islanding at 93% NSG with 40GW load

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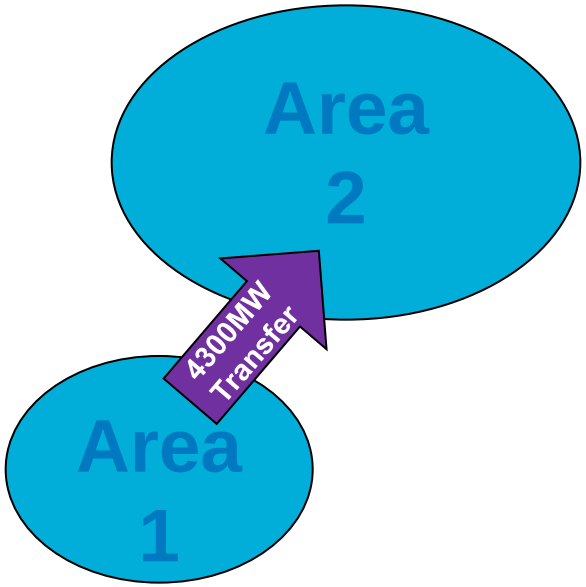
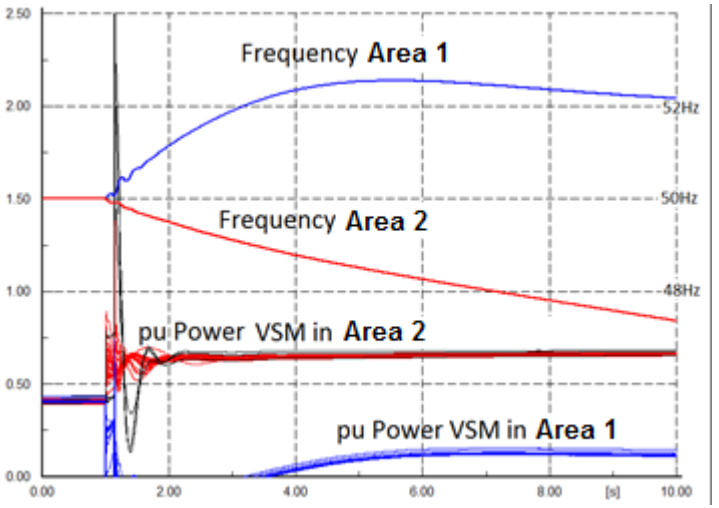


Scenario

- System is operating at 93% NSG
- System load is 40GW
- Short circuit is applied to AC interconnection
- Loss of AC interconnection between exporting Area 1 and importing Area 2
- Does LFDD work?

pu Power from VSM (all zones) without power limiting



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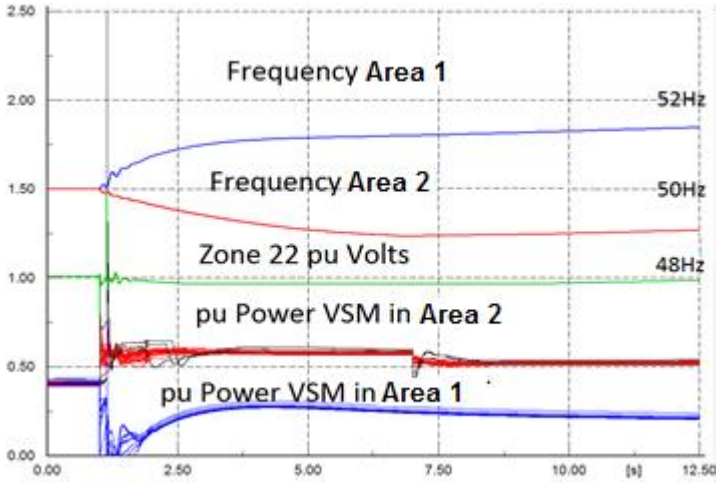

A Range of Options:-

- **Control system modification & development.**
  - It is not clear to what extent the capability of the User convertors can be developed with appropriate modification to achieve the above measurement-less control nor where appropriate use of storage or other short term resources may be needed, or external network support in the case of HVDC in order that the inertial active power requirement may be met.
  - De-loading convertor-based output in the steady state and using the same control approach equally may be an option; should the above modification not be efficient/economic.
- **Supplementary asset support**
  - The benefits of using more conventional support such as synch comps, synchronous generation constraint, de-clutched generation operation is unclear and requires assessment.
  - It is not clear across Network Owners and Users of the transmission system where and how such a requirement may be most appropriately delivered.
  - The impact of support from sub 1MW providers is expected to have quite an impact on the results and will form an important part of the study

Code Specification and Options:-

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- **Flexible, enabling, code specification**
  - The above is needed, potentially in combination with other mechanisms, to achieve a specification providing clarity to users without prejudicing their ability to drive innovative efficient solutions or driving excessive industry cost/ barriers to entry.
  - A CBA will be run under Phase 2 of this project to assess the most economic and efficient solution from a System perspective
  - The VSM specification will require fine tuning and further analysis:-
    - Security Standard Limits – 1800MW in GB
    - Inertial Response 4 – 5 GW for 20 seconds?
    - Facilitation of LF Disconnection
  - Does not preclude other market-based measures complementing or supporting any end delivery of requirements.

Related Work

- National Grid are working with the University of Nottingham to develop a prototype VSM to demonstrate proof of concept . Note VSM has been used in the commercial Marine industry and products are also available in the solar industry
- We are not directly contributing to CIGRE but are aware of their work.
- ENTSO-E are investigating the concepts of Grid Forming Converters
- Current research has developed some very promising results. The main aim is to encourage maximum market share whilst ensuring security of supply
- The contribution of sub 1MW plant and their fault ride though capability is an important component of this study work
- Need to focus on GB challenges whilst being aware of wider international activity/research

Next Steps

- Understand the capabilities and availability of current converter control strategies, in particular what is either in development of commercially available:-
  - Examples of projects/ experiences in other countries
  - Responses to the Questionnaire
  - Expert Group representation experiences
  - Development timeframes
  - Typical costs as a percentage of total converter cost
  - Confidentiality
- Feedback on the Questionnaire issued with the Terms of Reference
- Feedback / comments on the outline VSM functional requirements