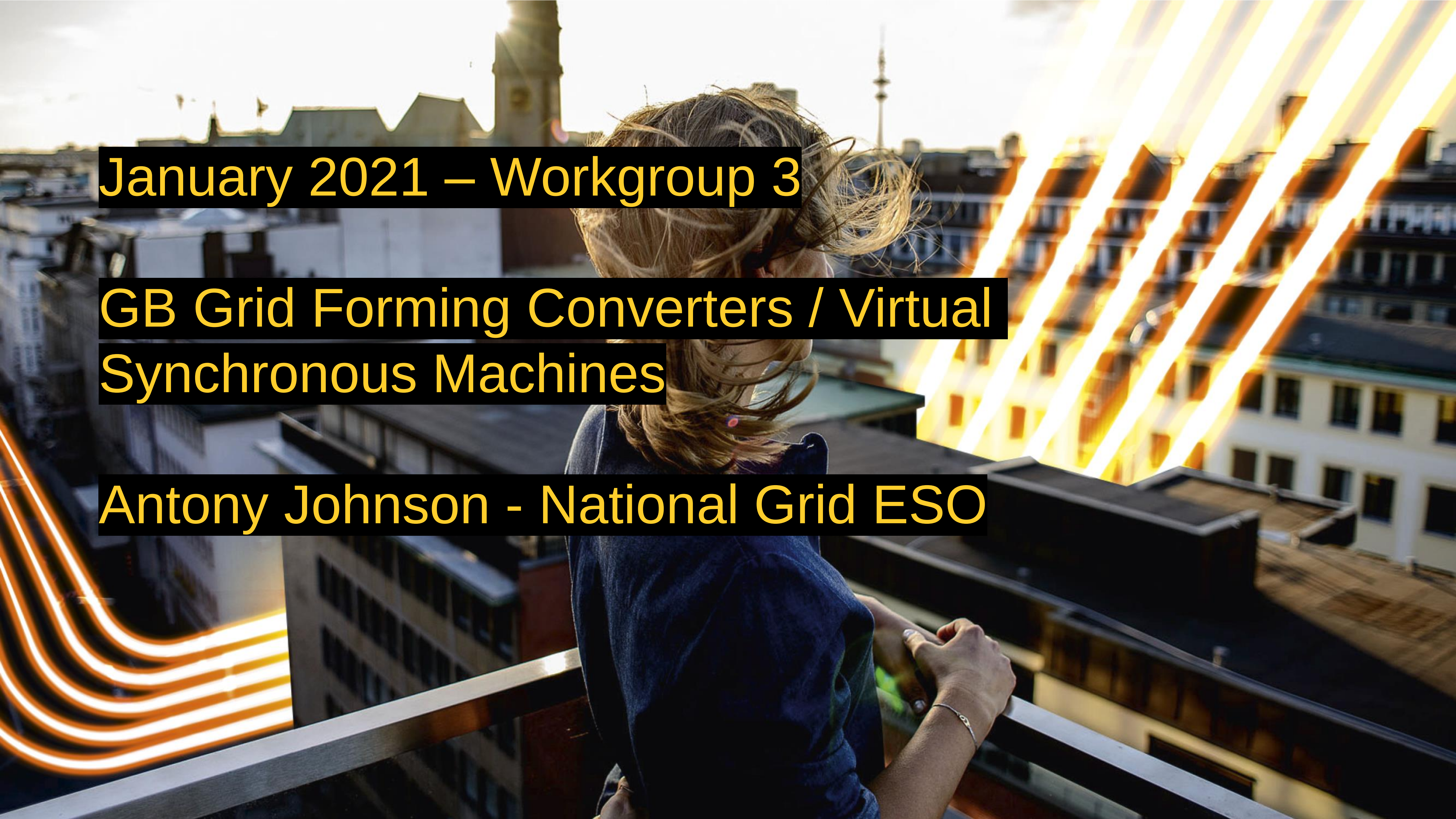

January 2021 – Workgroup 3

GB Grid Forming Converters / Virtual Synchronous Machines

Antony Johnson - National Grid ESO

Summary

- Acknowledgments
- Historical context and Summary of Progress to date
- Updated High Level Grid Code Requirements
  - Fast Fault Current Injection
- Data Submission and Models
- Compliance Testing and Simulation
- GB Grid Forming Best Practice Guide
- Monitoring
- Determination of System Needs
- Next Steps

Acknowledgements

- National Grid ESO would like to thank all those who have provided comments on the work presented at the last meeting and the subsequent discussion held.
- Special mention is to be made to Eric Lewis of ENSTORE who has contributed substantially to this work behind the scenes in particular on the preparation of the Grid Forming Guidance Note and also in providing feedback on the comments received.
- Many of the diagrams used in the presentation have been reproduced with the kind permission of ENSTORE unless otherwise stated

Developments / Actions

- Workgroup members to provide additional comments from the discussion and material presented at the last meeting held on 22 September 2020 by 6 October 2020 – *Completed*
- National Grid ESO to circulate the "Chat" document recorded at the previous meeting held on 22 September 2020 – Completed – *Circulated 30th October 2020*
- Updated Guidance GB Grid Forming Guidance Note circulated by ENSTORE – *Circulated – 1 December 2020*
- National Grid ESO to Respond to the "Chat" document and circulate to Workgroup Members - *Completed 4 December 2020*
- National Grid ESO to prepare Slide Pack and updated Grid Code Specification for Next Workgroup Meeting – *Completed*

Grid Forming in GB – A Transmission Perspective

- Limits to the maximum volume of non-synchronous generation connected to the Transmission System first identified in circa 2012/2013
- Papers of GB Grid Forming / Virtual Synchronous Machines (VSM) published in 2016
- VSM was considered as an option for fast fault current injection during implementation of GC0100 (RfG Implementation – Circa 2017)
  - https://www.nationalgrideso.com/industry-information/codes/grid-code/modifications/gc0100-eu-connection-codes-gb-implementation-mod
- VSM Expert Group Established in 2018
  - https://www.nationalgrid.com/uk/electricity/codes/grid-code/meetings/vsm-expert-workshop
- Grid Code Modification - GB Grid Forming Work Group Established 2019
  - https://www.nationalgrideso.com/industry-information/codes/grid-code-old/modifications/gc0137-minimum-specification-required
- A number of Developers are demonstrating Grid Forming Capabilities at a Commercial level
- An essential tool required to contribute to Net Zero and Zero Carbon Operation by 2025

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Aims of the GC0137 Workgroup

- Update the Grid Code to include a Technical Specification for GB Grid Forming
  - Technical Specification of Plant Requirements
    - Updates received from previous meeting
    - New Section on Fast Fault Current Injection
  - Submission of data and models
  - Compliance Simulation and Tests
- Preparation of a Grid Forming Best Practice Guide
  - This will sit outside the deliverables of the GC0137 Workgroup and will run in parallel with this work. It will aim to:-
    - Initially proposed as a Network Frequency Perturbation (NFP) Plot Best Practice Guide but the ESO feel it would be better to provide a more general Grid Forming Best Practice Guide
    - Aims to include models and data requirements
    - Covers NFP or equivalent subject to further analysis

Classification of Converters – Grid Behaviour

Current Controlled

Grid Following

- Fixed Current Source
- Follows P & Q (ref.)

Grid Supporting

- Controlled Current Source
- Ajusts P & Q (ref.)
  P(f), Q(V)

Voltage Controlled

Grid Leading

- Fixed Voltage Source
- Provides fixed V & f (ref.)

Grid Forming

- Controlled Voltage Source
- Provides V & f (ref.)
  f(P), (Q)

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Grid Forming - Key Features

- Comprises a synchronous internal voltage Source behind an impedance (similar to a Synchronous Generator) operating over the range DC to 1KHz
- Capable of contributing to:-
  - Inertia Power (ie Contribution to System Inertia)
  - Phase Jump Power (Instantaneous contribution to System Disturbances – eg synchronising torque)
  - Damping Power (Contribution to Damping)
- Capable of control of Active and Reactive Power through independent control
- Directly responds in milliseconds to changes in the phase of the AC grid without any actions being required in the associated control system.
- Ability to change the Voltage or Phase of the Grid Forming Plant's Internal Voltage Source but only at bandwidths below 5Hz so as to prevent undue interactions to the System or other Users Plant and Apparatus
- Capable of riding through Grid Faults and supplying fast fault current injection
- Option for a Black Start Capability
- These features were traditionally provided for free by synchronous generation as a by product of their technical characteristics. They have a fundamental behaviour on the characteristics of the Transmission System which is essential for it retained robustness and stability
- Going forward these features will now have to be paid for

Comparison of Technologies

Capability	Synchronous Machine	GBGFC	VSM0H	Conventional Converter
Phase Based Inertia Power	Yes	Yes	No	No
Control based frequency response power	Yes	Yes	Yes	Yes
Phase Based Phase Jump Power	Yes	Yes	Yes	No
Phase Based Damping Power	Yes	Yes	Yes	No
Response (within one cycle)	Yes	Yes	Yes	No
Operate in Synchronism with the System	Yes	Yes	Yes	Yes
Contribution to Fault infeed	Yes - High	Yes and value depends on the design	Yes and value depends on the design	Yes - *Limited*
Bandwidth of optional control system features in normal operation	Below 5 Hz	Below 5 Hz	Below 5 Hz	Faster than 5 Hz

VSM0H systems are a subset of the GBGFC technology for supporting the Grid during system disturbances but only deliver Control based frequency response power.

It is these deficiencies, in particular lack of injected active power and reactive power that lead to power system stability issues particularly under disturbed conditions .

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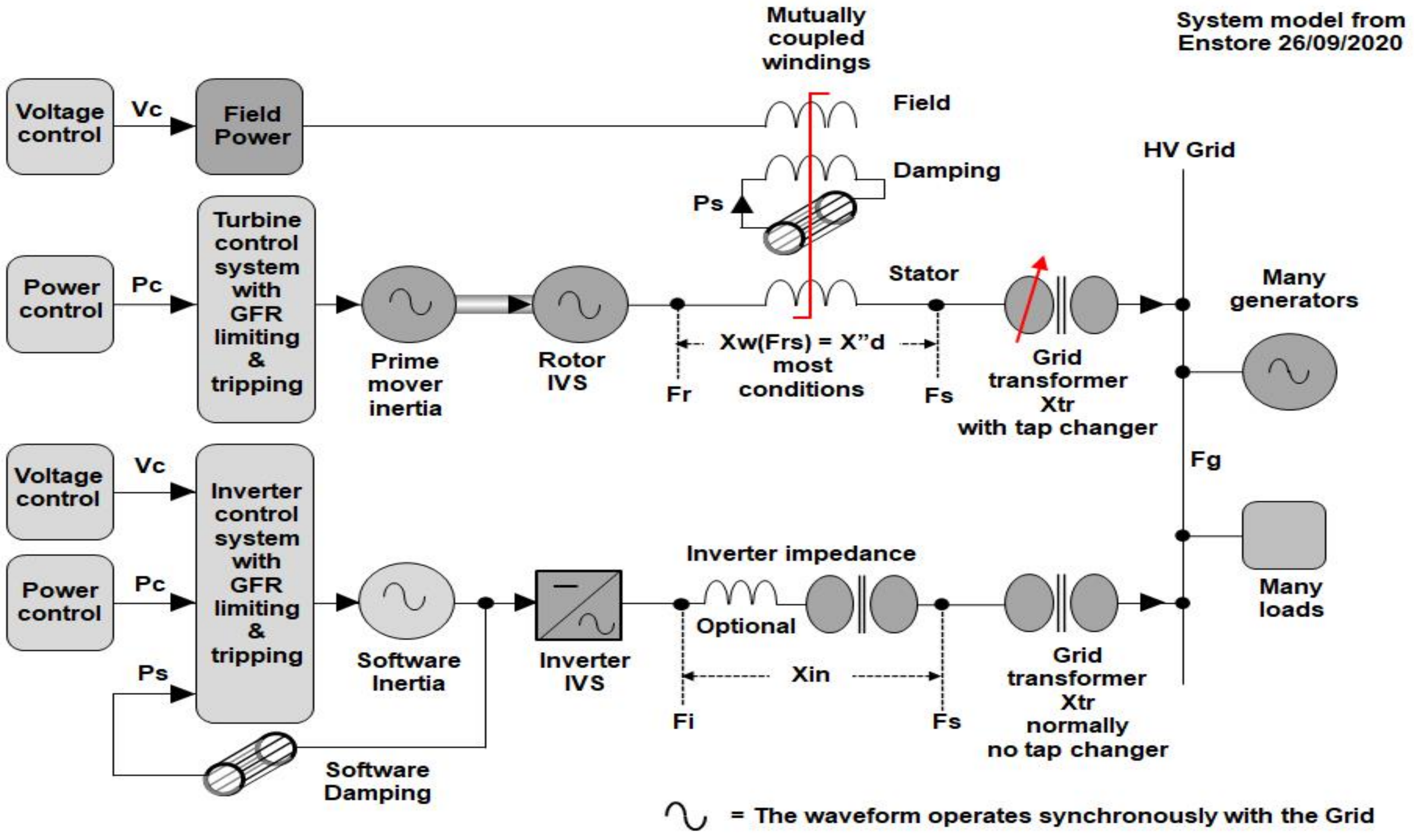
Equivalent Circuits – Synchronous Generator / GB Grid Forming Converter



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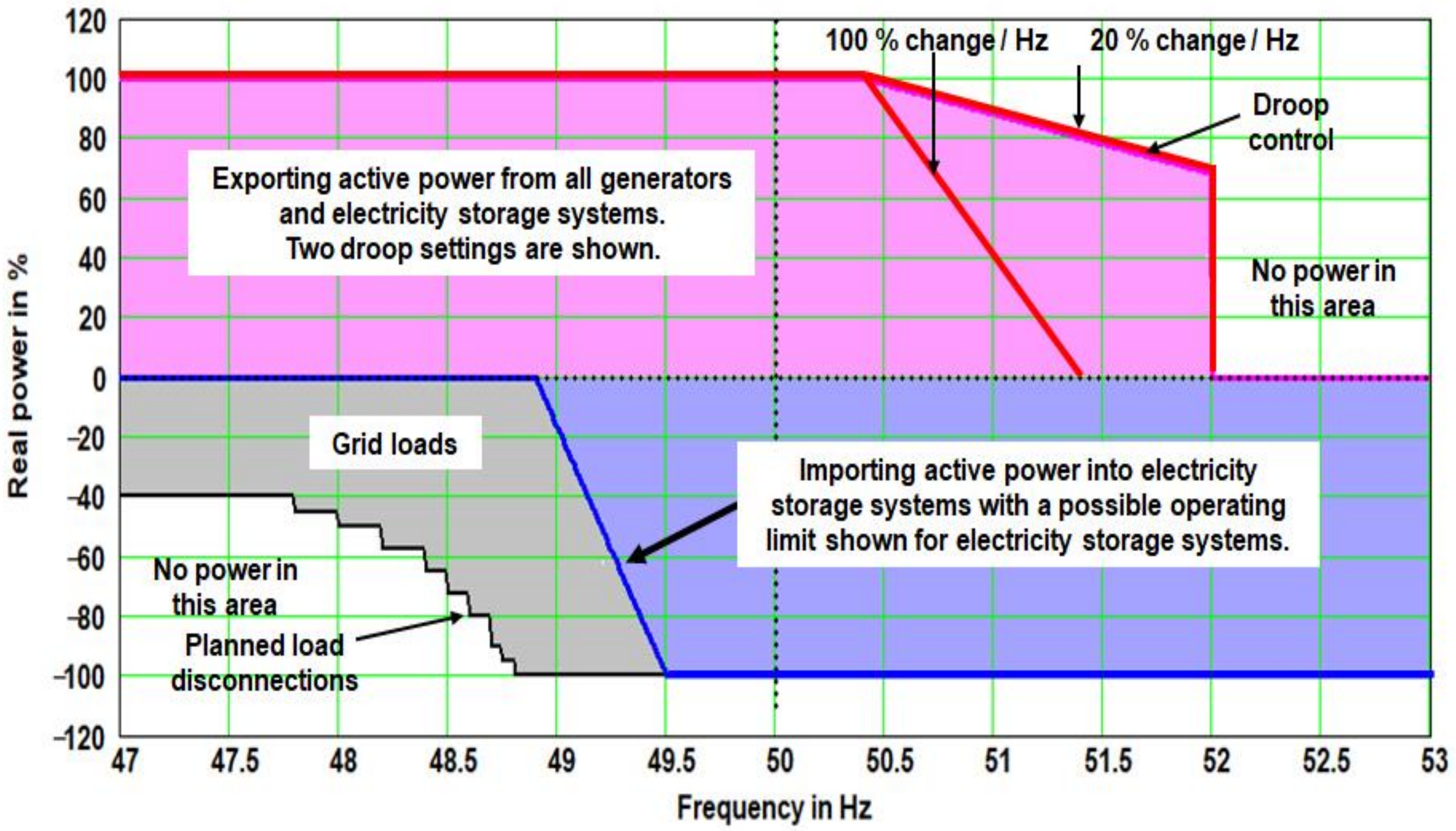
Design Parameters

- Phase Jump Angle Limit – 5 Degrees?
- Phase Jump Angle Withstand – 60 degrees
- Phase Jump Angle Rating
- Maximum Damping Factor (ζ) – 1.0pu
- Minimum Damping Factor (ζ) – 0.2pu
- Inertia Constant Range – 2 – 25 MWs/MVA (ENTSO-E values)
- Grid Oscillation – 0.05Hz peak to peak at 1Hz frequency for rating the damping power
- ROCOF Operating Limit – 1.0Hz/s without saturation (ENTSO-E values)
- ROCOF Withstand Limits – 2.0Hzs – Saturation permitted (ENTSO-E values)

Operating Range – Including Electricity Storage Modules



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Note – For Electricity Storage Modules the requirements to automatically reduce Demand during low System Frequencies will be introduced through Grid Code modification GC0148

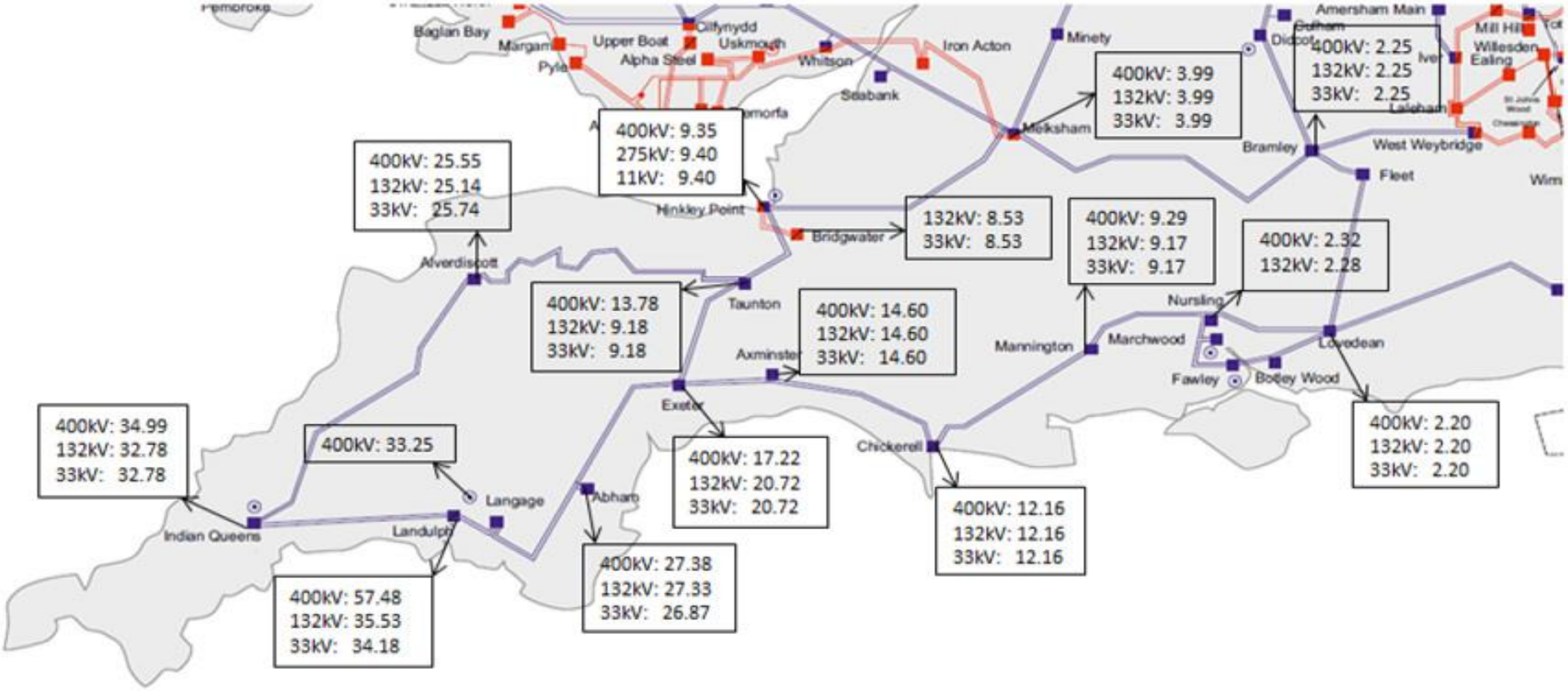
Normal Operating Requirements and Ranges

- Operating Voltage Range as per CC/ECC.6.1.4
- Frequency Operating Range as per CC.6.1.2/CC.6.1.3 and ECC.6.1.2
- Reactive Capability operating range as per CC/ECC.6.3.2
- Full Inertia Power to be supplied at a Rate of Change of Frequency below 1Hz/s
- Plant Withstand ROCOF Capability 2Hz/s
- Provision of Damping Power as per ECP.A.9.1.9.8
- Inertia power to be supplied for a phase change
- Phase Jump Angle withstand limit – 60 degrees
- Full operation required when operating below Peak Rated Current
  - The Peak rated current is the larger of i) the combined Inertia Power and Damping Power or Phase Jump Angle limit Power
- Ability to ride through Grid Faults and supply fast fault current to the Network
- Withstand unbalanced voltage and currents
- Note – A plant caught by the requirements of the Grid Code – eg a Power Park Module would still have to meet the full obligations of the Grid Code with the additional requirements specified through the Grid Code Grid Forming Specification

Abnormal Operating Requirements and Ranges

- Satisfy the fault ride through requirements as per CC/ECC.6.3.15
- Supply Fast fault current injection – See new revised section – Slides 15 - 19
  - Supply up to the Maximum Peak Rated Current within 5ms
  - Grid Code updated – see section ECC.6.3.19.5
  - Adopts a similar approach to ECC.6.3.16 with amendments
- Operating Modes
  - Mode 1 – Operating in the normal voltage operating range – 0.9pu – 1.1pu
  - Mode 2 – Operating in the normal voltage operating range - 0.9pu – 1.1pu and at rated Peak Current – eg caused by a rapid phase jump in the Grid
  - Mode 3 – Operation below 0.9pu voltage but not at peak current rating (eg a low voltage dip below 0.9 pu – eg a retained voltage of say 0.75pu – This requires the magnitude, frequency and phase of the Internal Voltage Source to be changed to respond to phase jumps
  - Mode 4 – Operation below 0.9pu and supplying full rated peak current, eg a solid three phase short circuit fault where the current injected to the network is largely reactive.
  - In Modes 1 and 2, following the disturbance operation of the voltage control (which operates more like an Automatic Voltage Regulator) to give a smooth transition back to the normal voltage operating range.

Abnormal Operating Requirements and Ranges – Phase Jumps



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Fault Ride Through – Type D Power Park Modules and HVDC

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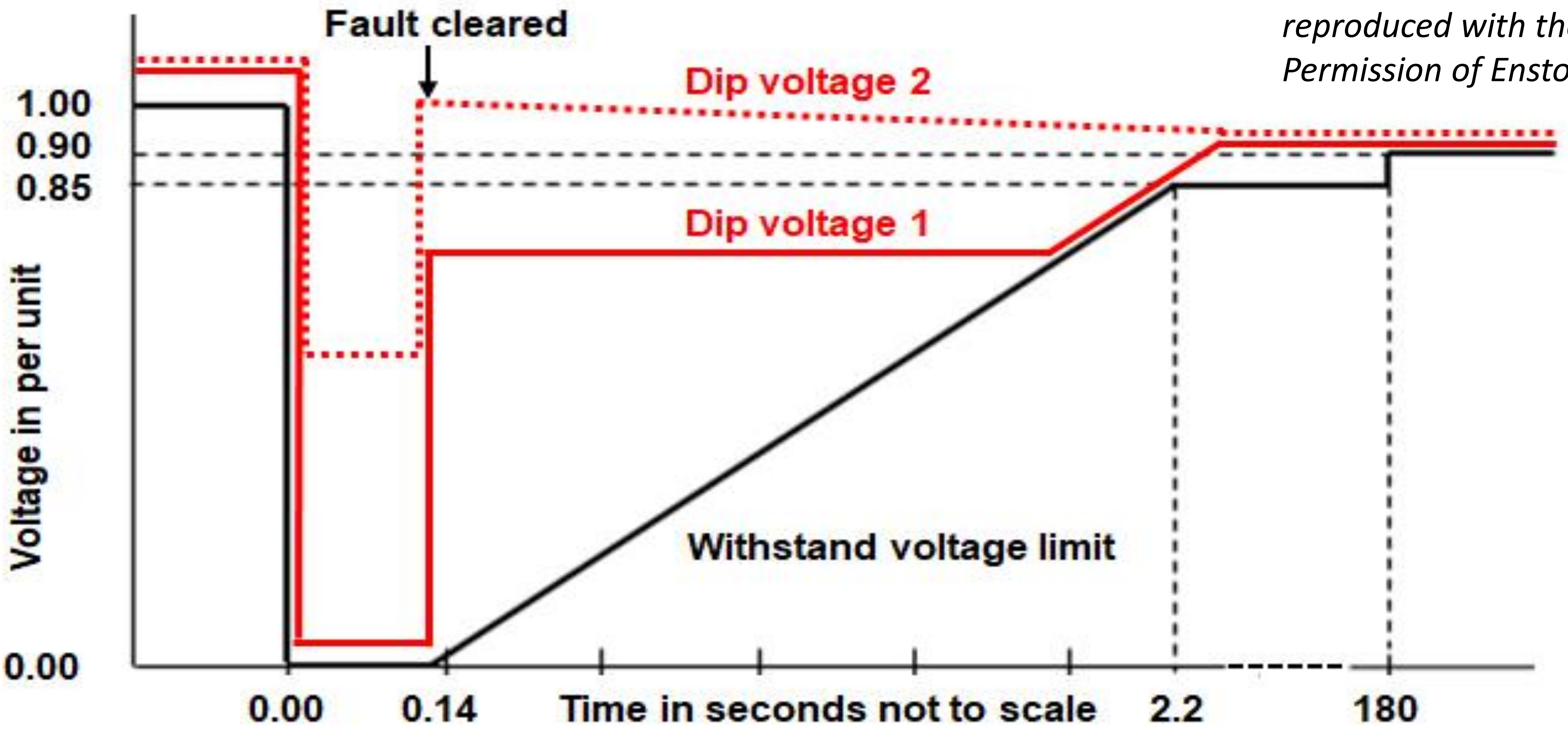
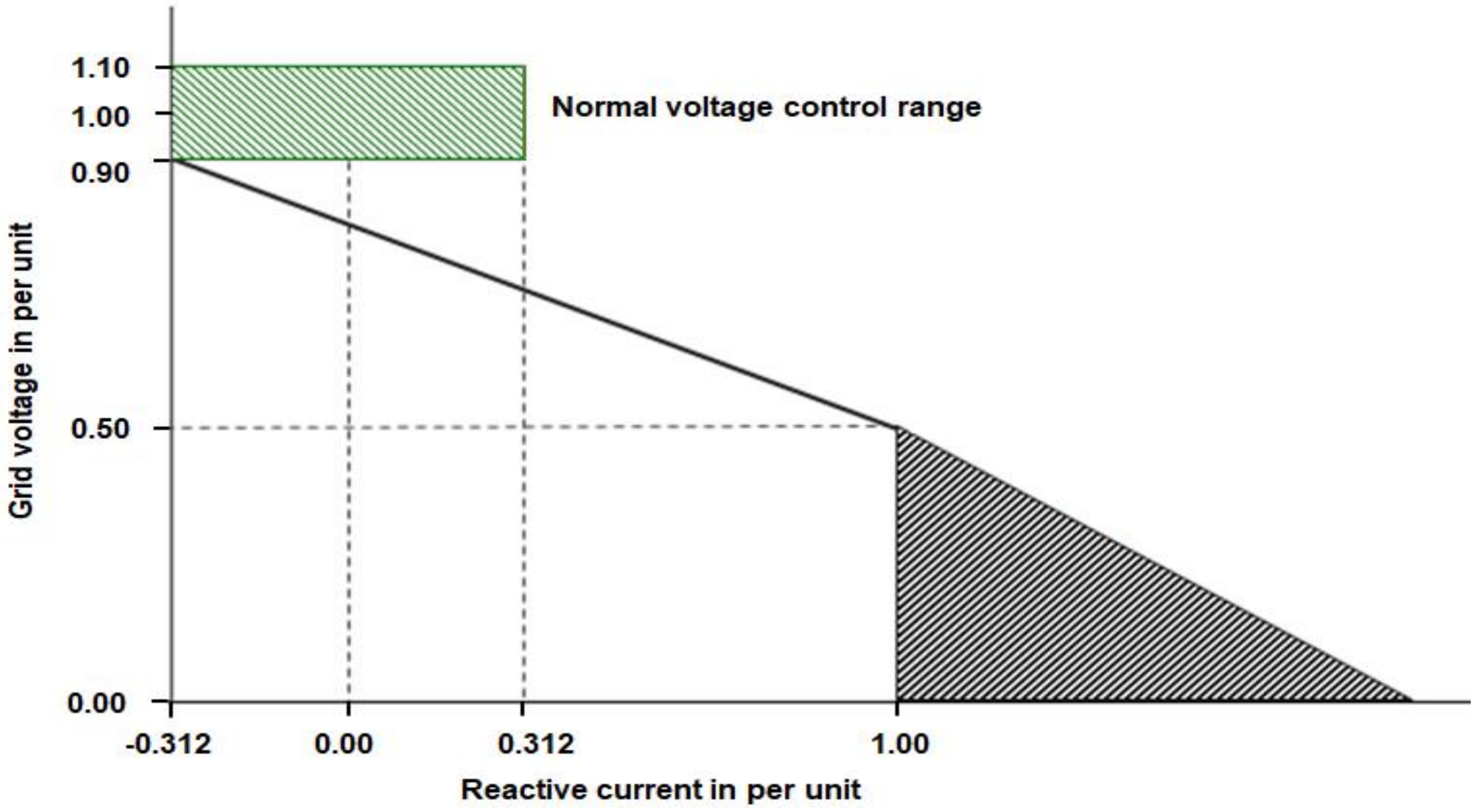
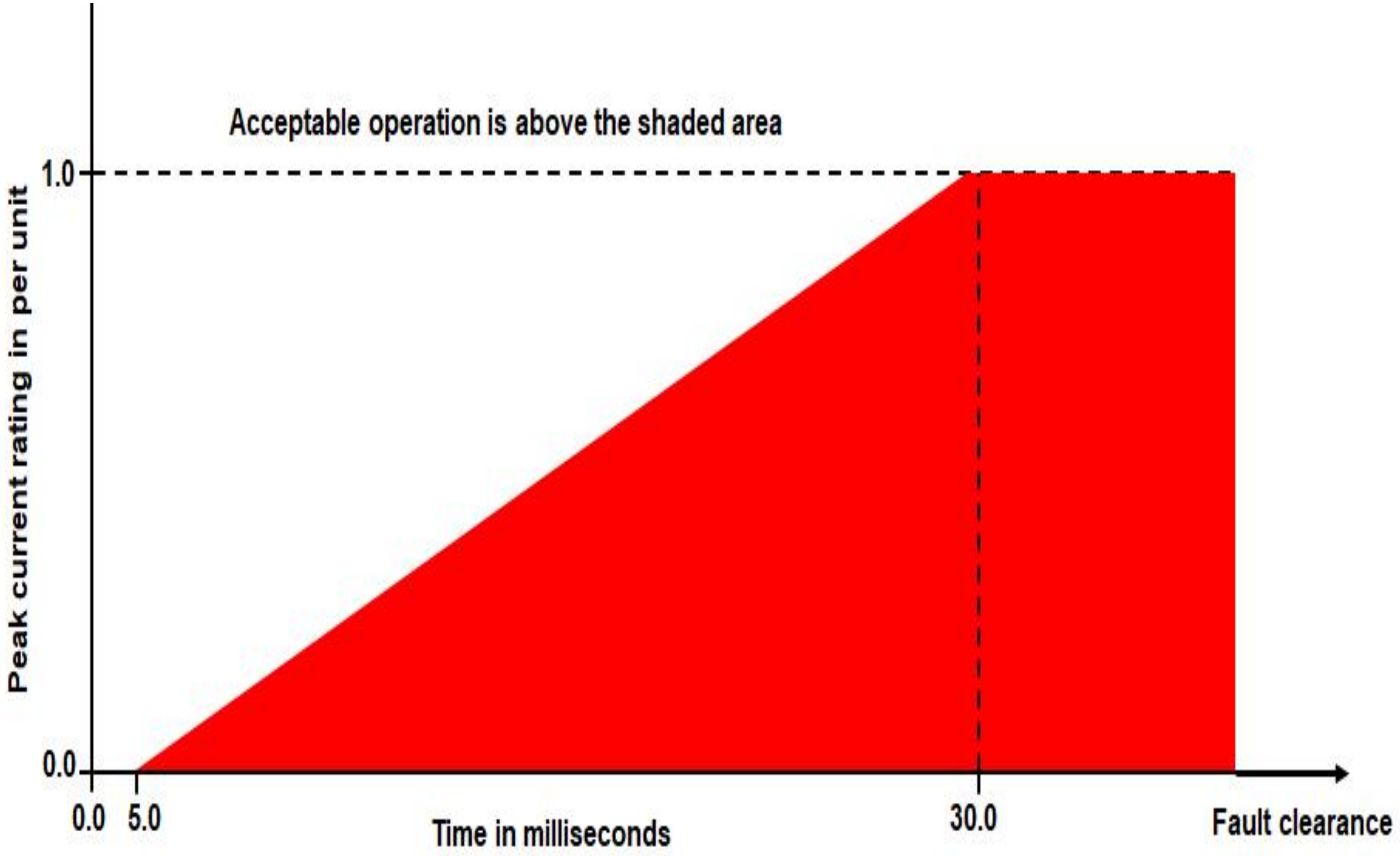


Fast Fault Current Injection (1)



Fast Fault Current Injection (2)



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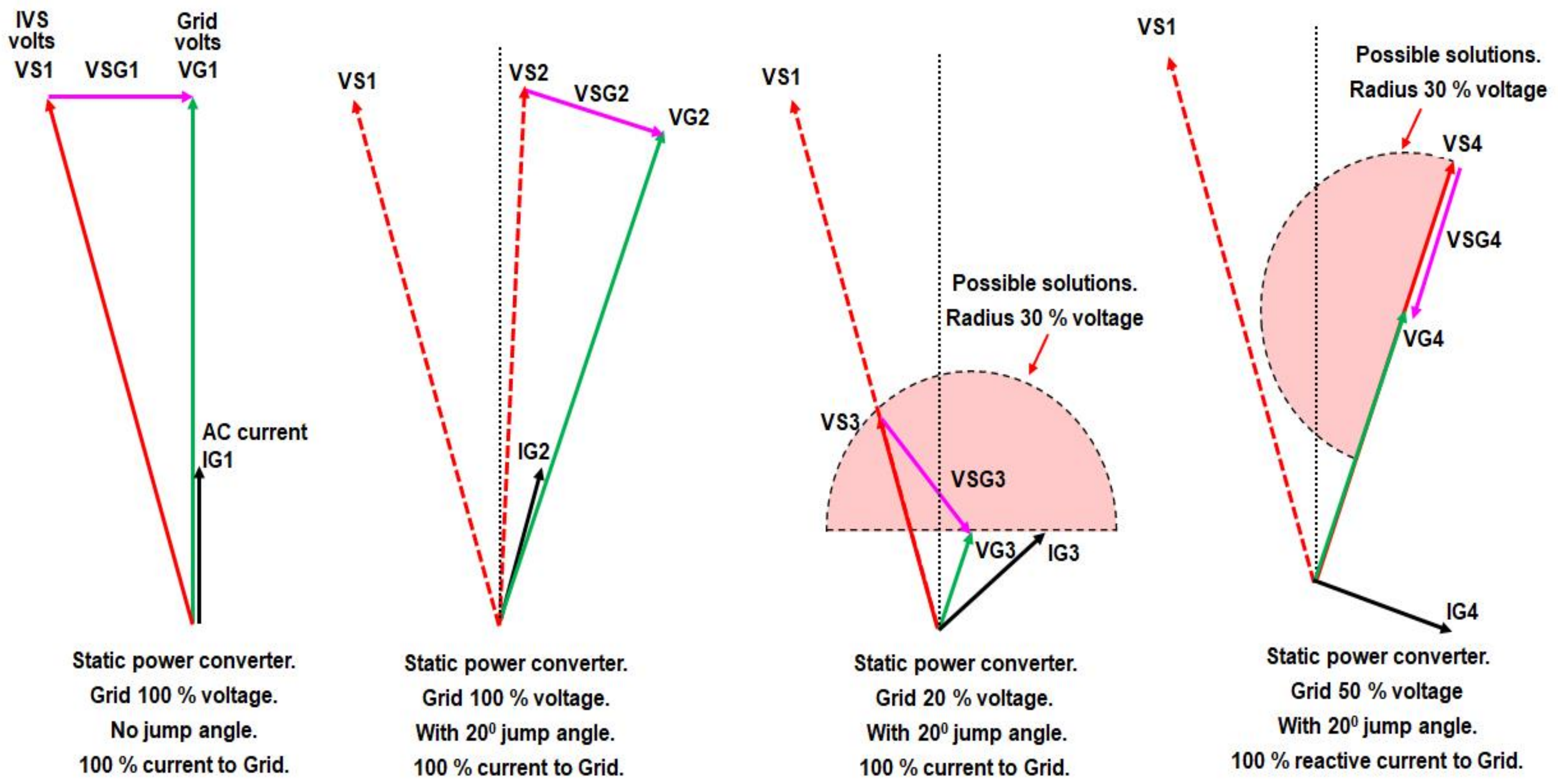
Fast Fault Current Injection – Vector Diagrams



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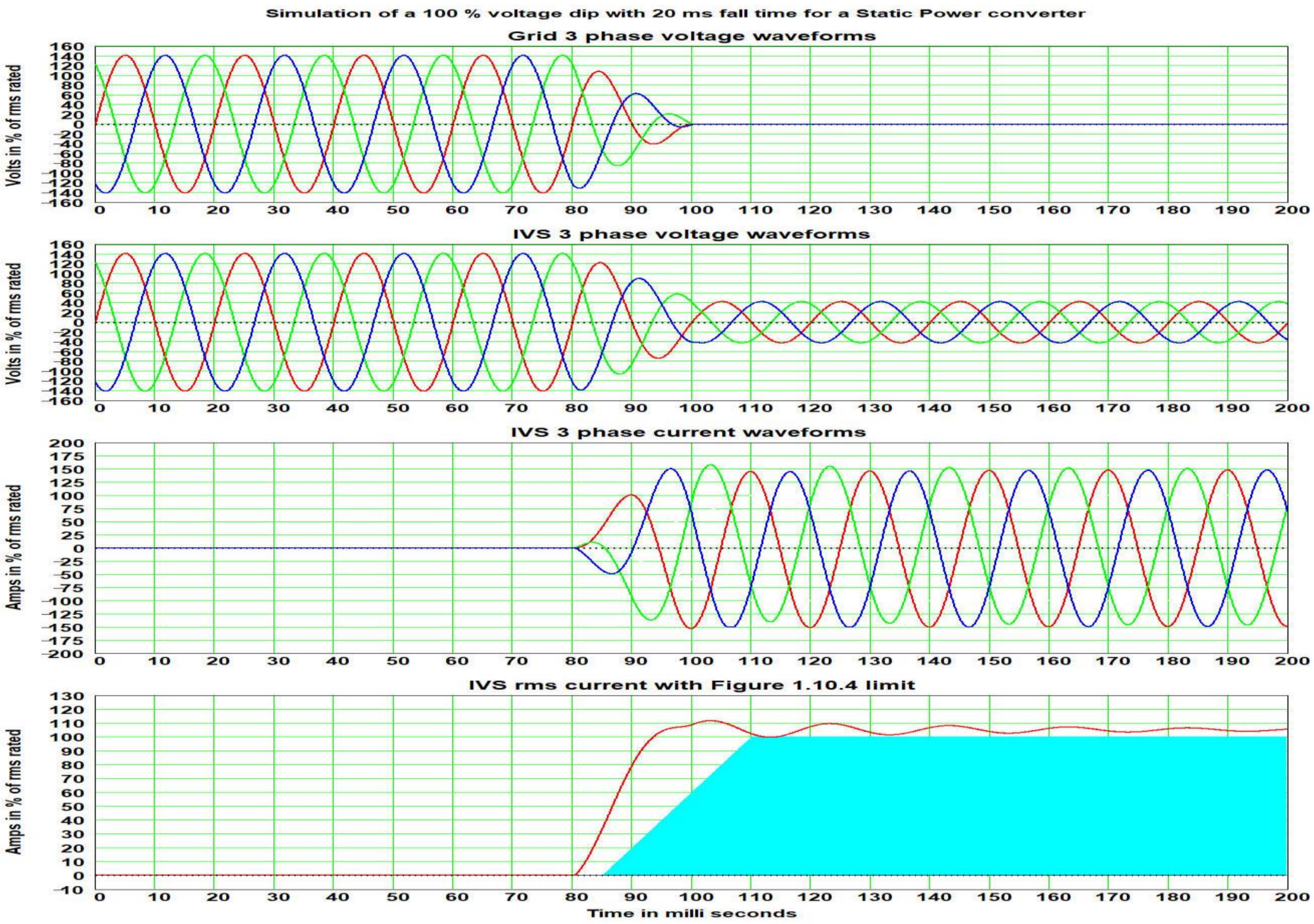
Fast Fault Current Injection – Simulation – 100% Voltage dip in 20ms for a Static Power Converter



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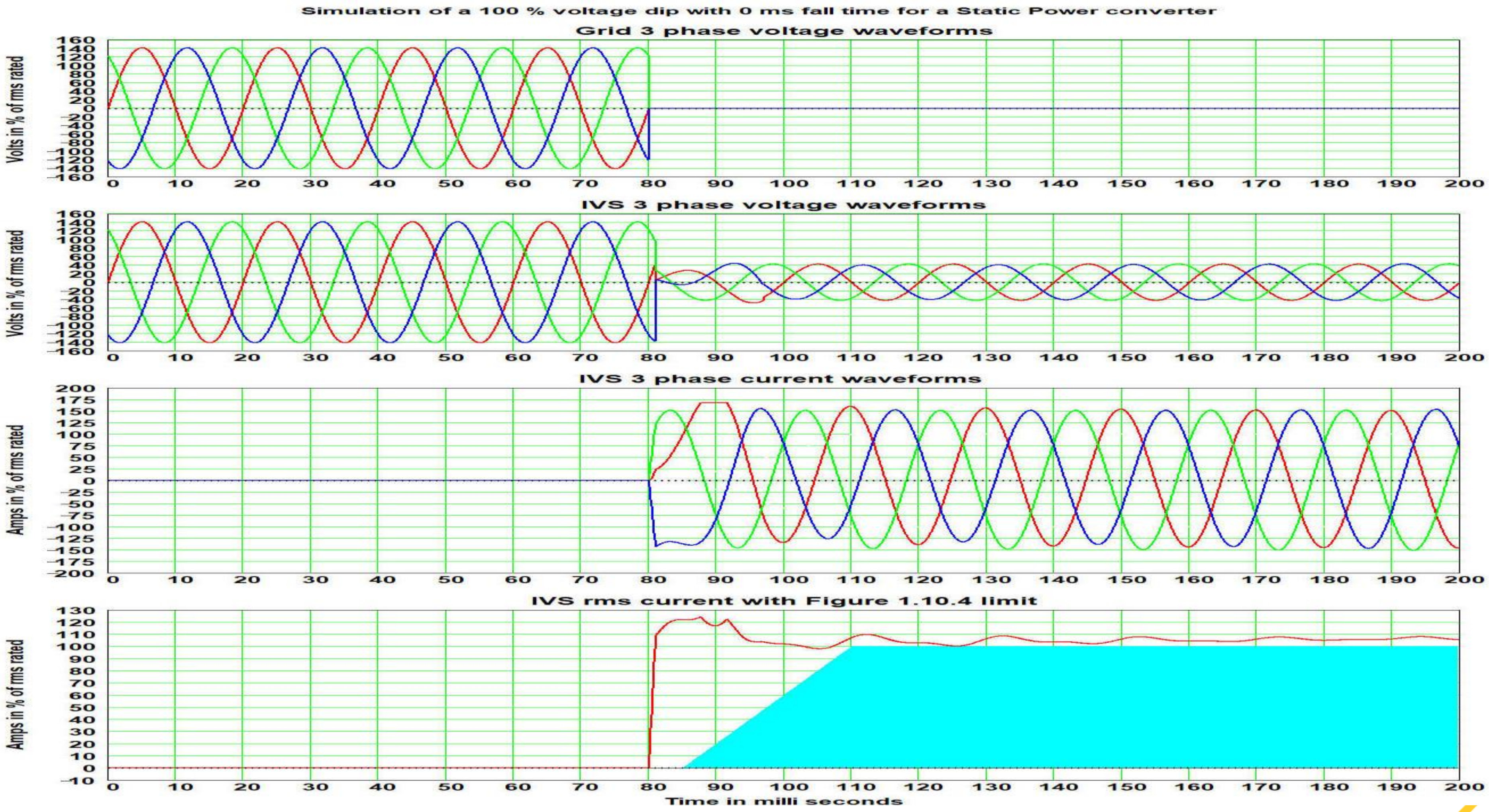
Fast Fault Current Injection – Simulation - 100% Voltage dip in 0ms for a Static Power Converter



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Models and Data

- Described in detail at the last meeting
  - Equivalent model to be submitted - see slide 10
  - Equivalent Block Diagram to be Submitted to NGESO
  - Developer to supply Network Frequency Perturbation Plot or equivalent
- NGESO is aiming to produce a Grid Forming Best Practice Guide as a separate piece of work. The aim is to have this document loaded onto the National Grid ESO website with other Grid Code Associated Documents. It would not form part of the Grid Code specification
- The key features of the Best Practice Guide are to:-
  - Provide guidance to Developers on Grid Forming Best Practice with an example?
  - Provide guidance on the model and data including an NFP plot or equivalent
  - Provide guidance on what demonstrates a good performance
  - Develop a set of rules on what provides a good performance
  - Simplify the data submission / results where other test / data submission –eg SSTI studies are deemed appropriate.

Equivalent Block Diagram of a GB Grid Forming Static Power Converter

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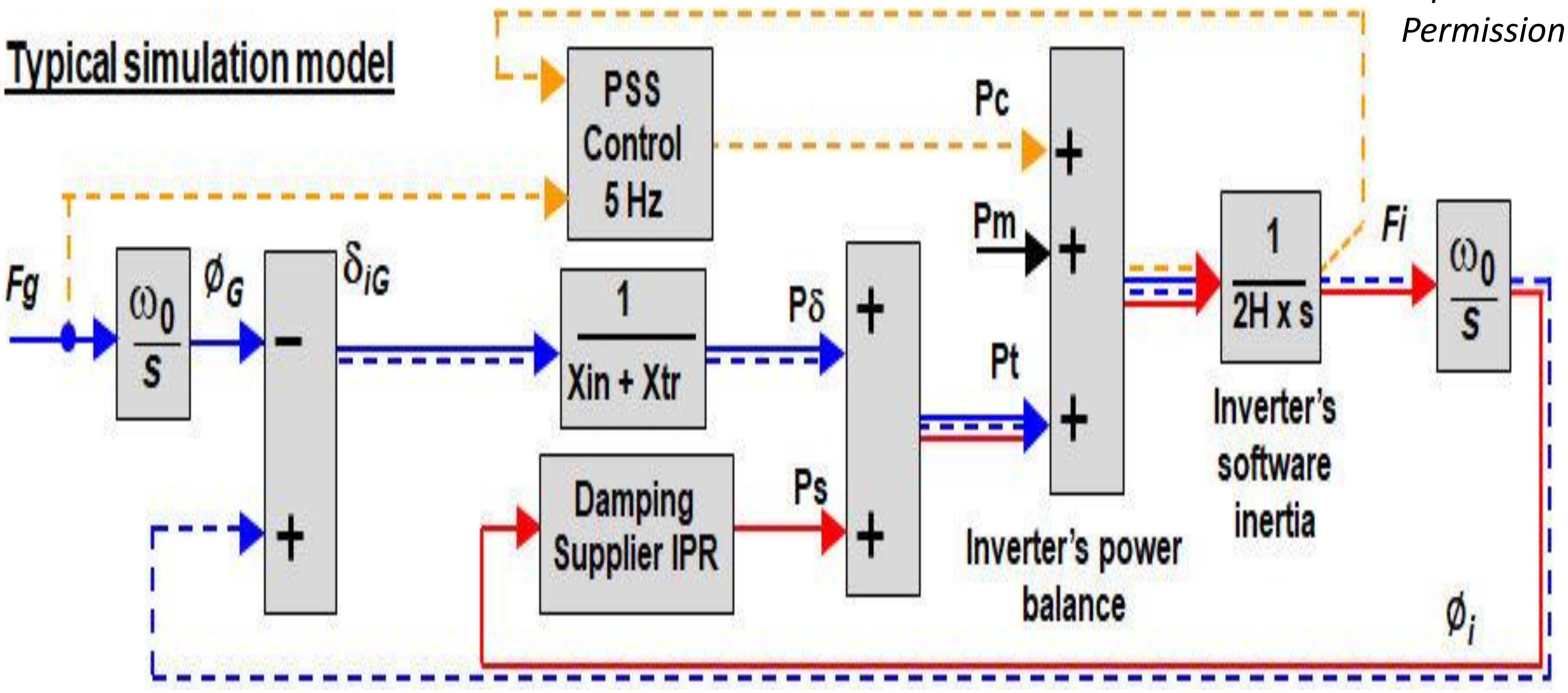
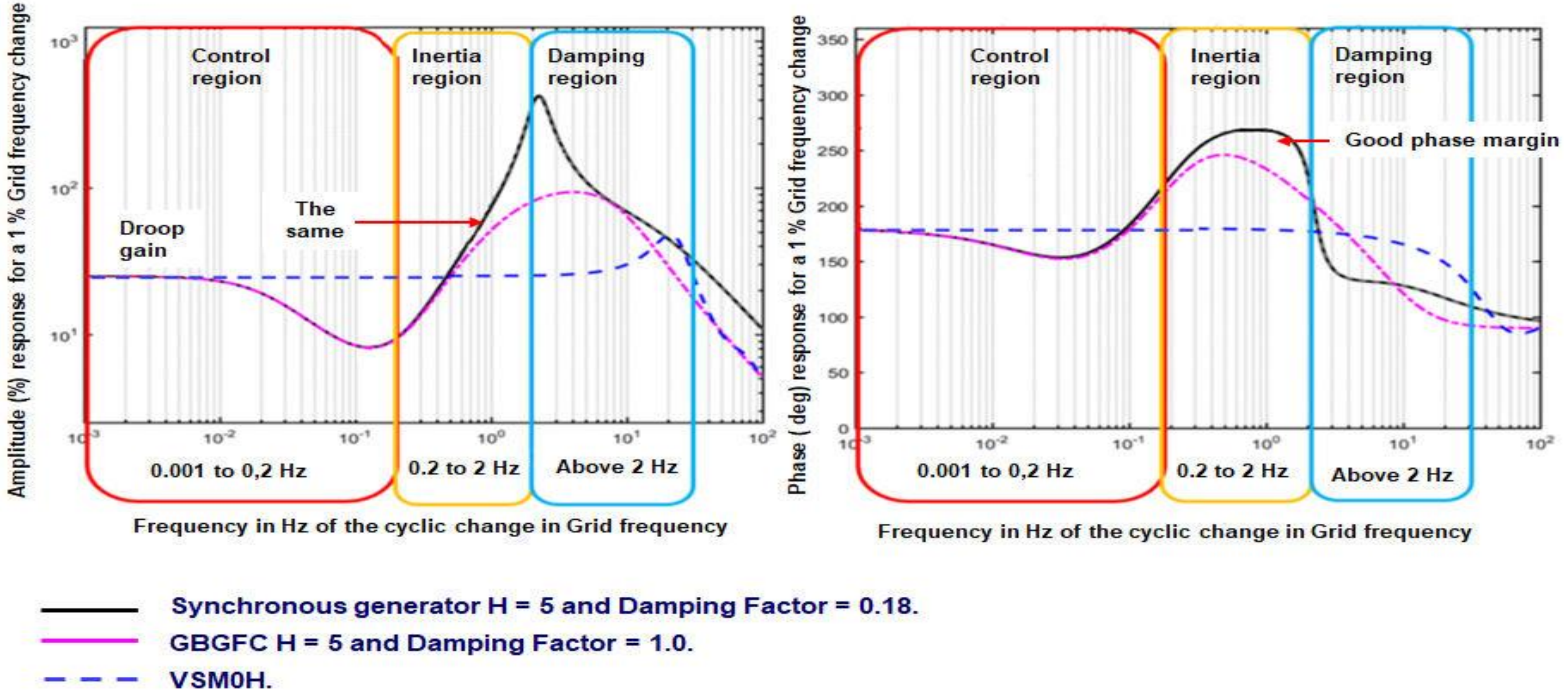


Example of an Network Frequency Perturbation



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Compliance Requirements

- The Grid Code legal text has been updated to include Compliance activities. In summary this includes:-
  - Simulations
  - Testing

- The tests and simulations were discussed at the last meeting and these have now been prepared as part of the draft legal text – see ECP.A.3.9, ECP.A.4 and ECP.A.9
- For testing purposes new tests to determine phase jumps and ROCOF events will require high sample rates.
- Some discussion is still required in terms of sampling

Compliance – Testing and Simulation - Overview

Grid Forming Plant

Tests and Simulations applicable under Grid Code Irrespective of Grid Forming (ECP.A.3 – ECP.A.7)

- Reactive Capability (including HV operation across voltage range)
- Voltage Control
- Active Power Control
- Power output with falling frequency
- Frequency Response (LFSM/FSM)
- Voltage and frequency control verification
- Control System Tests
- PSS Tuning / Damping control
- Quality of Supply Assessment
- Fault Ride Through and fast fault current injection

\+

Grid Forming Plant additional Tests and Simulations (ECP.A.3.9, ECP.A.4 and ECP.A.9)

- Phase Based Real Inertia Power
- Phase Based Real Phase Jump Power
- Phase Based Real Damping Power

→

Total suite of Tests and Simulations To be performed on Grid Forming Plant

Online Monitoring

- On Line Monitoring
  - As part of the Compliance Process, in addition to simulation and testing, there is also a requirement for online monitoring to take place.
  - The Grid Code requires online Dynamic Monitoring (ECC.6.6.1) for Type C and Type D Power Generating Modules and HVDC Systems in accordance with TS.3.24.70_RES
  - As high sampling is required to monitor phase changes, ROCOF Rates and Frequency it is expected that a new Electrical Standard based on TS.3.24.70_RES will be required. This would need to include:-
    - Calculated Grid frequency at a 10 ms rate, with high immunity to Phase Jumps
    - Calculated Grid ROCOF at 100ms rate with a high immunity to Phase Jumps
    - Calculated Grid Phase Jump data at a 10 ms rate.

Next Steps

- Discuss current specification and proposals
- Comments on latest specification
- Timelines for proceeding to Workgroup Consultation
- Discuss arrangements for a GB Grid Forming Best Practice Guide via a separate Expert Group
  - Basic operation
  - Models
  - Data
  - Analysis techniques (eg NFP Plots or otherwise)
  - Timelines for GB Grid Forming Best Practice Guide

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