GC0100 - Fast Fault Current Injection, Fault Ride Through and Banding

Antony Johnson

July 2017

Summary

- Overview - why are Fast Fault Current Injection, Fault Ride Through and Banding related
- Proposals
  - Fast Fault Current Injection
  - Fault ride Through
  - Banding
- Conclusions

Why are Fast Fault Current Injection, Fault Ride Through and Banding related

nationalgrid

- The amount of fault current injected is a function of the volume of Generation at a specific location
- The retained voltage during the period of the fault is a function of the amount of reactive current injected - The lower the fault infeed, the lower the retained voltage seen across the system
- Fault ride performance is the ability of Generation to remain connected and stable under fault conditions. Its assessment is based on the retained voltage at the connection point which is directly related to the fault infeed.
- All Generation needs to play its part in supporting the System under fault conditions.
- A higher fault current infeed will enable a higher retained voltage to be specified as part of the fault ride through requirements.
- RfG specifies Generators are split into Bands. The fault ride through requirements are different between Synchronous and Asynchronous Plant with different parameters permitted between different bands

System Voltage profile under fault conditions – High / Low Synchronous Generation Background

nationalgrid

Figure 31
Current Network Effect of 3-phase Earth Fault at Walpole 400kV

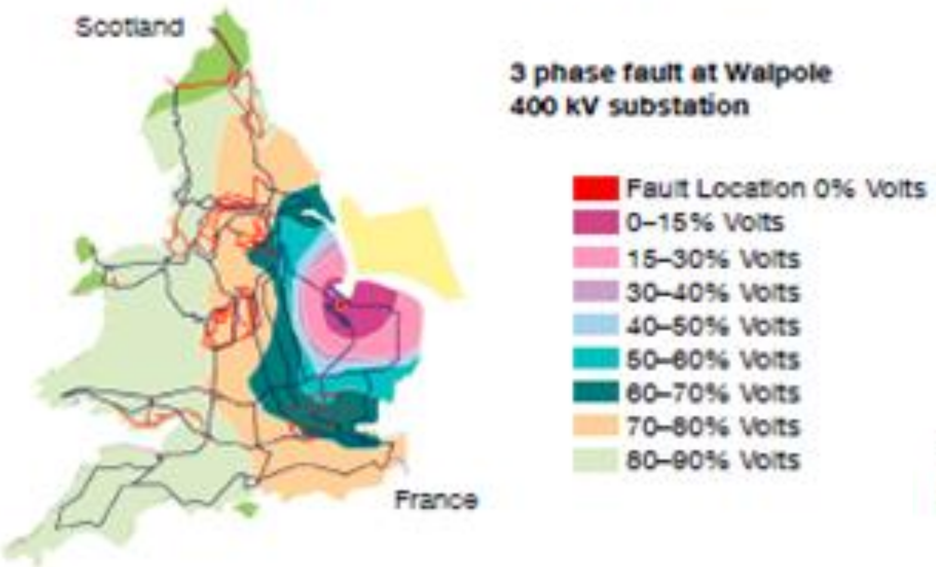
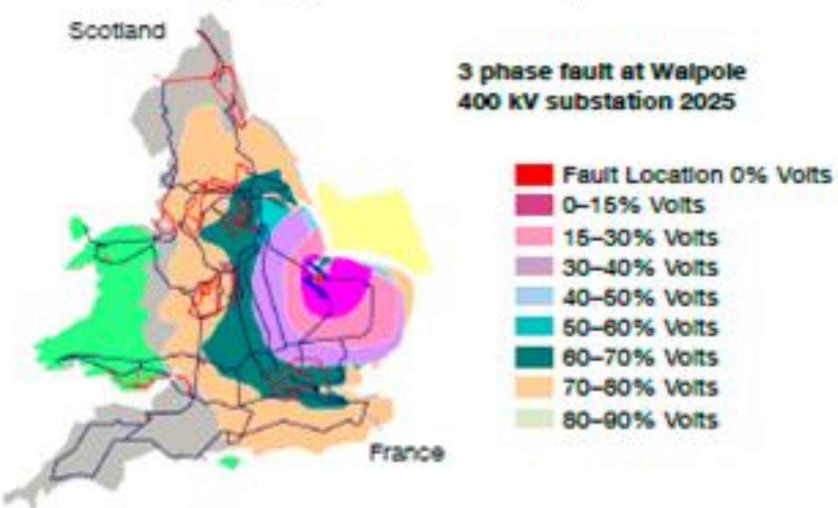


Figure 32
2025 Gone Green Effect of 3-phase Earth Fault at Walpole 400kV



The effect of connecting higher volumes of Converter based plant without FFCI

nationalgrid

- The Transmission System is changing - Large directly connected Synchronous Plant is rapidly being replaced by renewable technologies (eg wind, wave, solar and storage) – many of which utilise Converter based technologies
- Under fault conditions a Synchronous Generator will contribute 5 – 7pu current
- Converter based plant has a limited ability to supply fault current, (1 - 1.25pu current max),
- These effects significantly affect the design and operational characteristics of the System including the ability to maintain resilience and correctly detect and isolate a fault condition.
- At National Grid we want to promote the use of different generation technologies to ensure they grow whilst ensuring the safe, secure and efficient operation of the System.
- The System Operability Framework (SOF) published over the last few years have started to show the impacts on the System of high penetrations of converter based plant

High Converter Penetrations - Options

nationalgrid

- With current technology/models, the system can 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 exceed by 9.2% -21,3% p.a. in 2023/24 and by 24.6% - 31.6% p.a.in 2026/27.

Key

No	Doesn't Resolve Issue
P I	Potential 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)	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
	Now	2019	2019	Now	2020	Now	Now	2025	2025

Fast Fault Current Injection – Power Park Modules and Converter based Plant

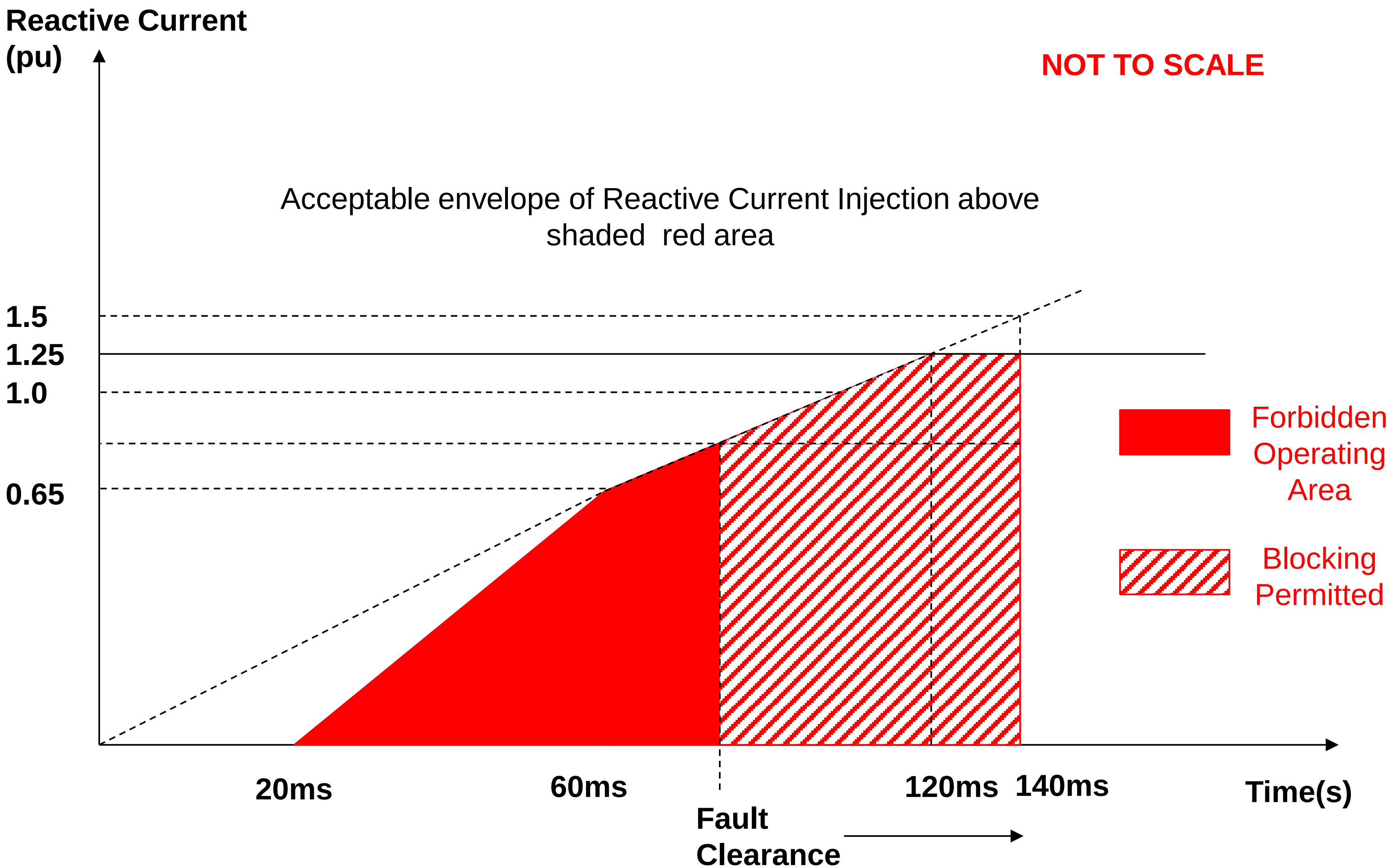
nationalgrid

- In the first quarter of 2017 extensive studies were run to understand the implications and control functions of converter based plant.
- These studies and results were presented to the GC0048 Workgroup in April 2017 available at:-
  - http://www2.nationalgrid.com/WorkArea/DownloadAsset.aspx?id=8589940887
  - http://www2.nationalgrid.com/WorkArea/DownloadAsset.aspx?id=8589940886
- These studies demonstrated the considerable variation in System behaviour as a result of changing the Converter control system. The following key conclusions were drawn from this work
  - The fault current needs to be injected in phase with the System during the fault otherwise both Transmission and Distribution performance is de-graded
  - Higher volumes of Generation connected to the Distribution System have a significant effect on the performance of the System even for Transmission System faults
  - If there is no fault current injection from the converter or it is injected out of phase with the system it places much more onerous requirements on the fault ride through requirements (U_{ret}).
  - Before 2021 there is still a reasonable contribution from Synchronous Generation connected to the System. Post 2021 these levels start to fall away very quickly

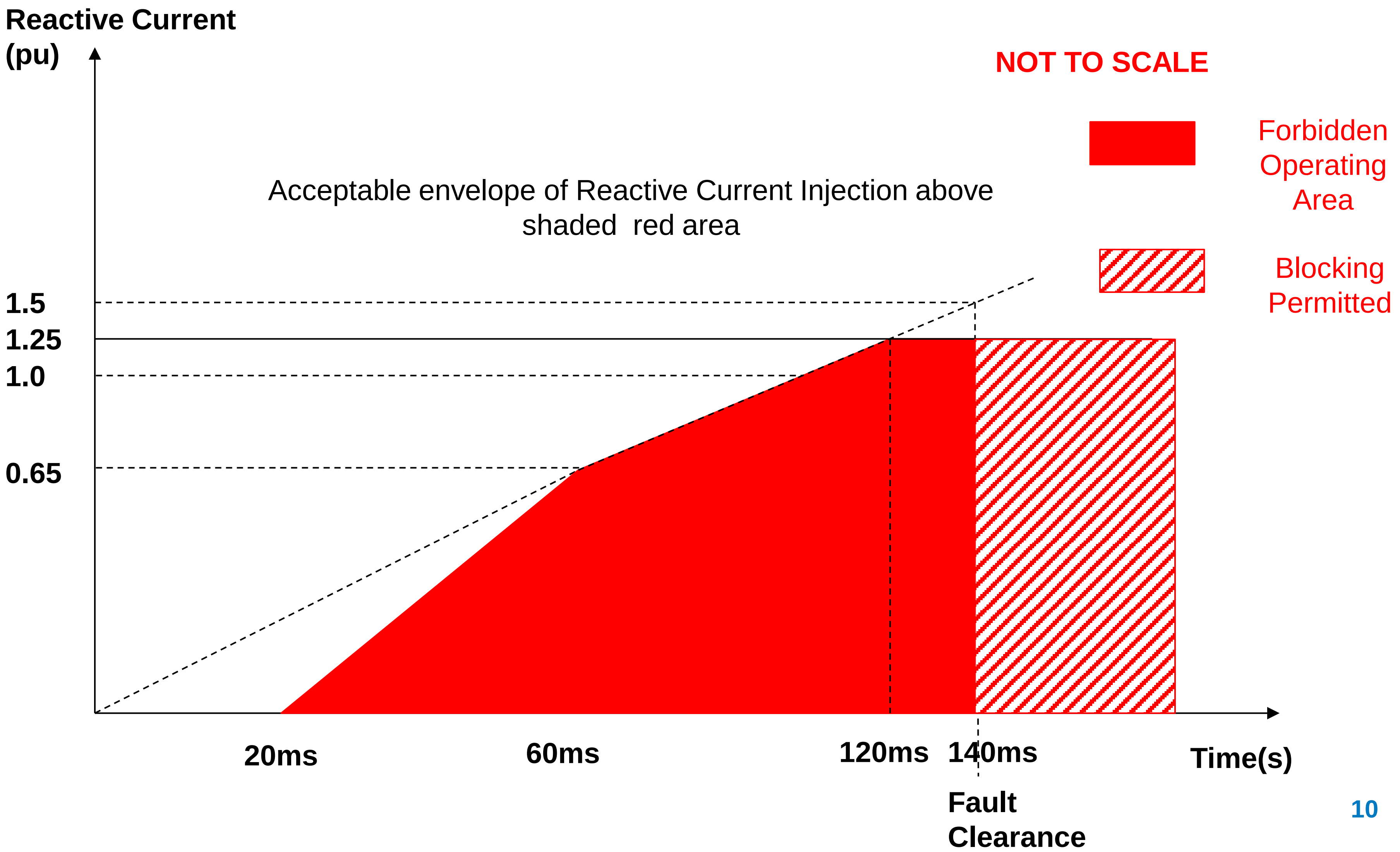
Proposals for Fast Fault Current Injection

- Two Options have been proposed
  - Option 1 – The Converter controller behaves in the same way as a synchronous machine (see attached presentation)
  - Option 2 – Conventional Converter – required to meet a minimum fault current injection requirement – option available only until 1 January 2021
- Option 1 is not new and similar technologies have been employed in the marine industry for several years in addition to a number of detailed studies
- Option 2 has also been employed previously as an option in areas of high converter penetration
- 2021 indicates FFCI (Option 1) as essential in studies presented to GC0048 in April
- The longer it takes for the technology to be implemented, the more onerous the requirements on new plant
- A European working group are investigating the implications of Grid Forming Converters

FFCI Option 2



FFCI Option 2



Fault Ride Through (1)

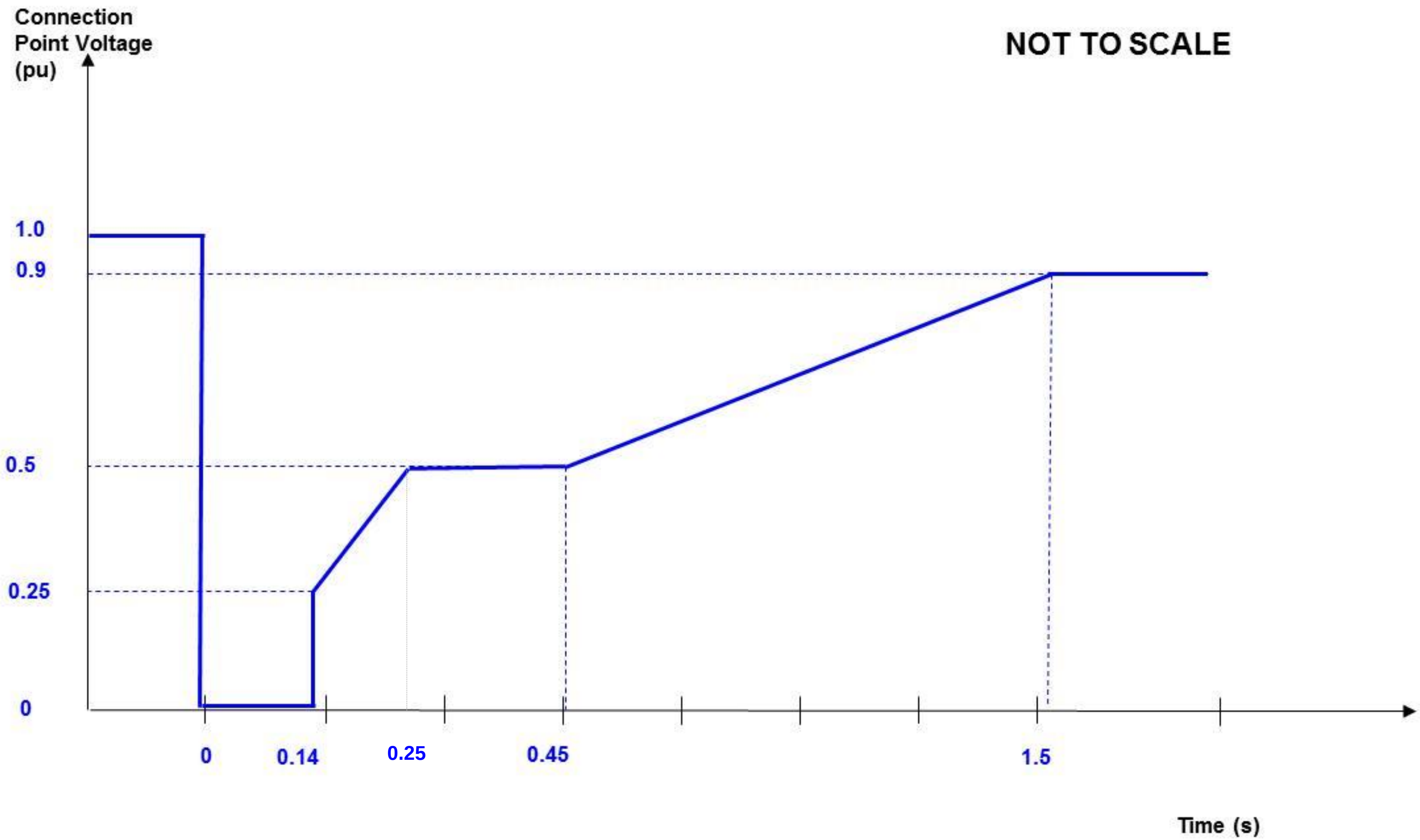
- The retained voltage at the connection point under faulted conditions is a function of the volume of fast fault current injected at the connection point
- For a solid three phase Transmission System fault, zero voltage will be observed at the point of the fault for the duration of the fault.
- For Type D plant connected at 110kV or above, the retained voltage (U_{ret}) would need to be set at zero volts (a mandated requirement under RfG)
- For Type B – D Embedded Plant (excluding Type B Synchronous) system studies (April 2017 GC0048 meeting) indicate requirements for a retained voltage (U_{ret}) of 10% if the assumptions on fast fault current injection are made.
- If Fast Fault Current Injection is not delivered in line with the proposals on slide 8, then the retained voltage (U_{ret}) delivered would need to be reduced to a value in the order of 5%.

Fault Ride Through (2)

- For Type B Synchronous Plant, the value of U_{ret} would need to be set to 30%. This is on the basis that small scale reciprocating plant (ie reciprocating gas and diesel engines) would struggle to meet a lower retained voltage for which there is no known technical solution. It is however recognised that Synchronous Generation is capable of supply high volumes of reactive current under fault conditions.
- The actual shape of the voltage against time curves have been documented and discussed at previous GC0048 Workgroup Meetings – The cost implications of these decisions are covered later in this presentation

Type D Synchronous Power Generating Modules connected at ≥110kV

GB Type D Voltage Against Time Curve



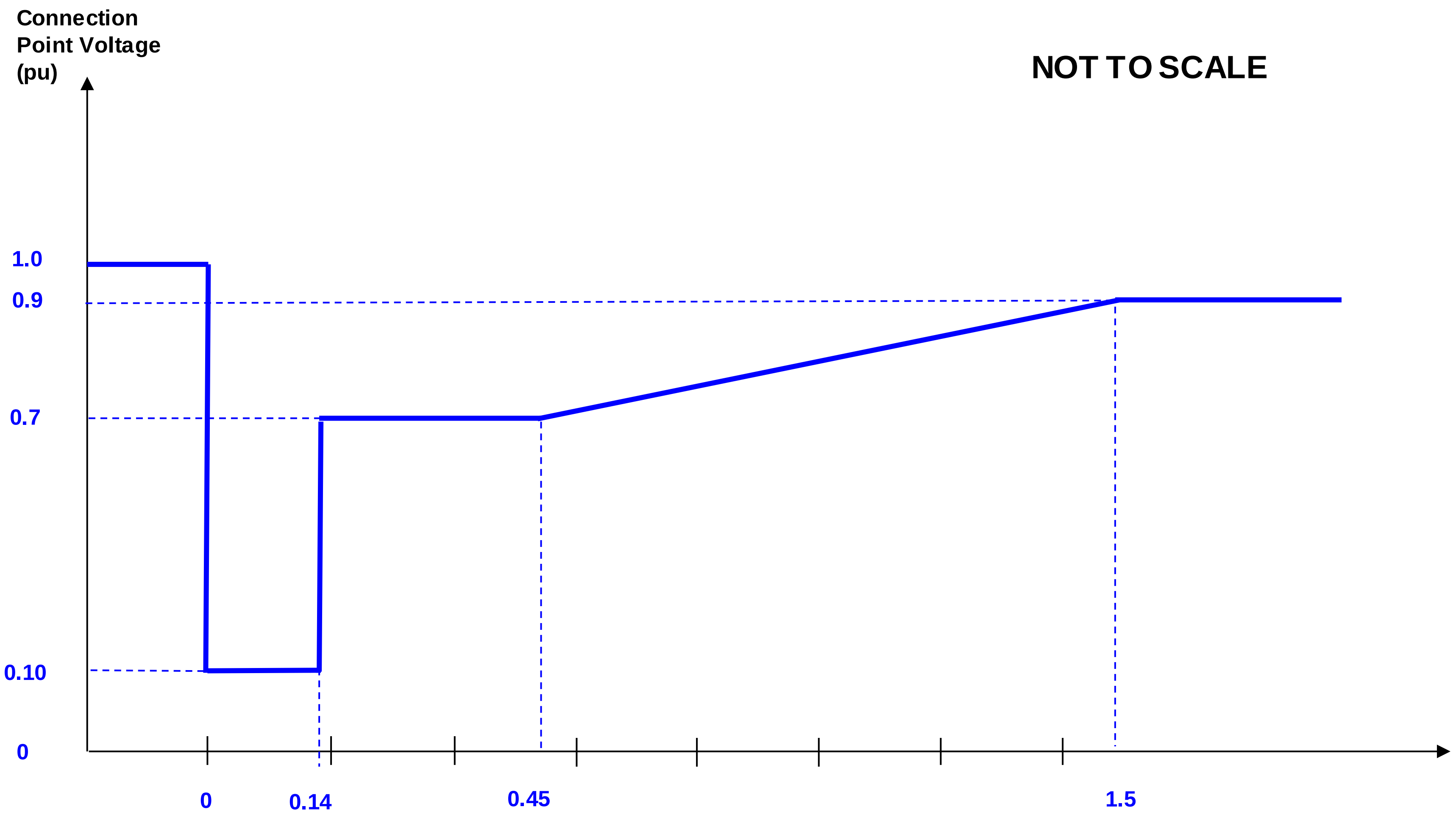
nationalgrid

Voltage Against Time Parameters

Voltage parameters [pu]		Time parameters [seconds]	
U_{ret}	0	t_{clear}	0.14
U_{clear}	0.25	t_{rec1}	0.25
U_{rec1}	0.5	t_{rec2}	0.45
U_{rec2}	0.9	t_{rec3}	1.5

Table 7.1 – Fault Ride Through Capability of Synchronous Power Generating Modules

Suggested Voltage Against Time Profile – Type C and D



nationalgrid

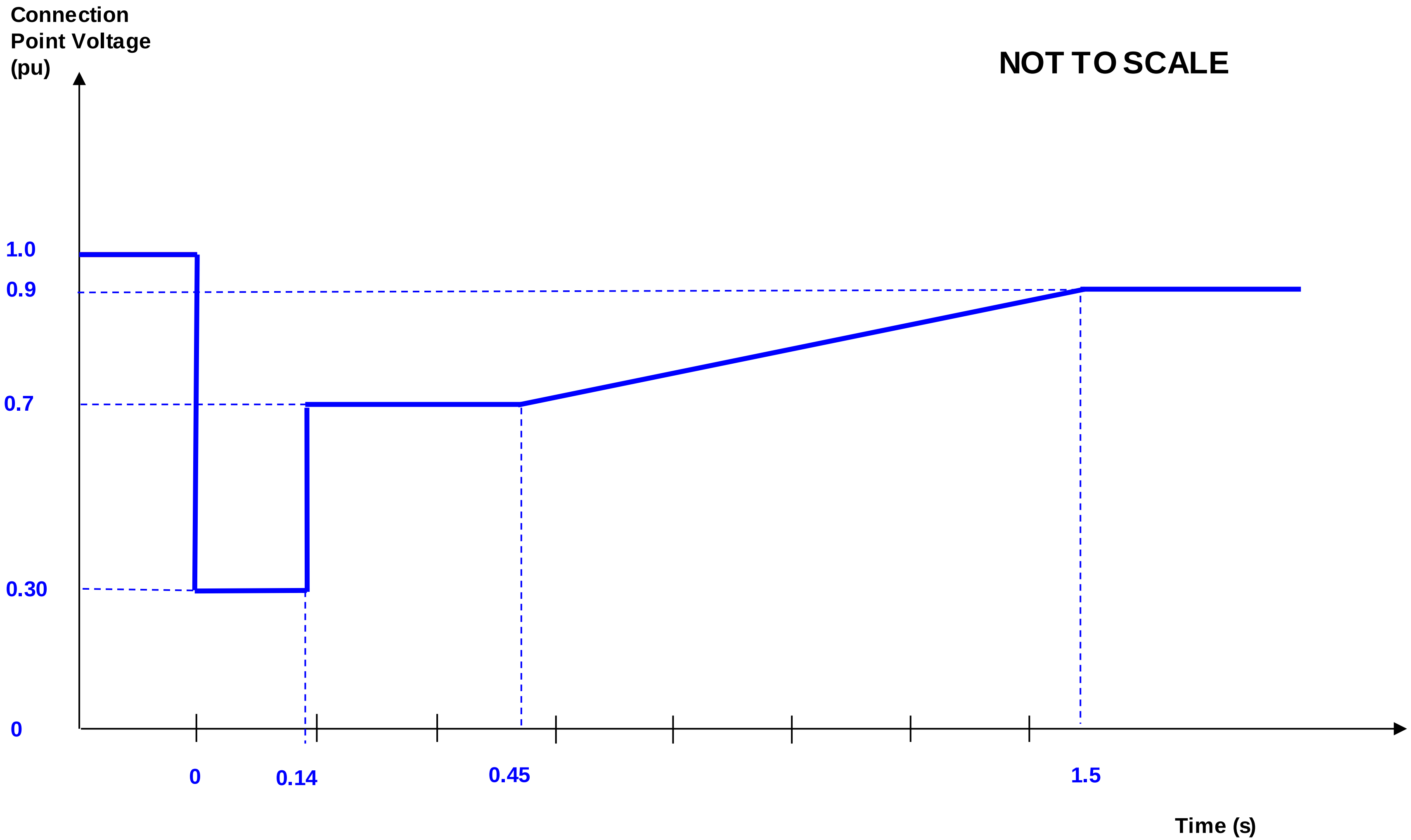
Voltage Against Time Parameter Ranges

Voltage parameters [pu]		Time parameters [seconds]	
U_{ret}	0.1	t_{clear}	0.14
U_{clear}	0.7	t_{rec1}	0.14
U_{rec1}	0.7	t_{rec2}	0.45
U_{rec2}	0.9	t_{rec3}	1.5

Table 3.1 – Fault Ride Through Capability of Synchronous Power Generating Modules

Type B Synchronous Power Generating Modules Connected <110kV

GB Voltage Against Time Profile – Type B



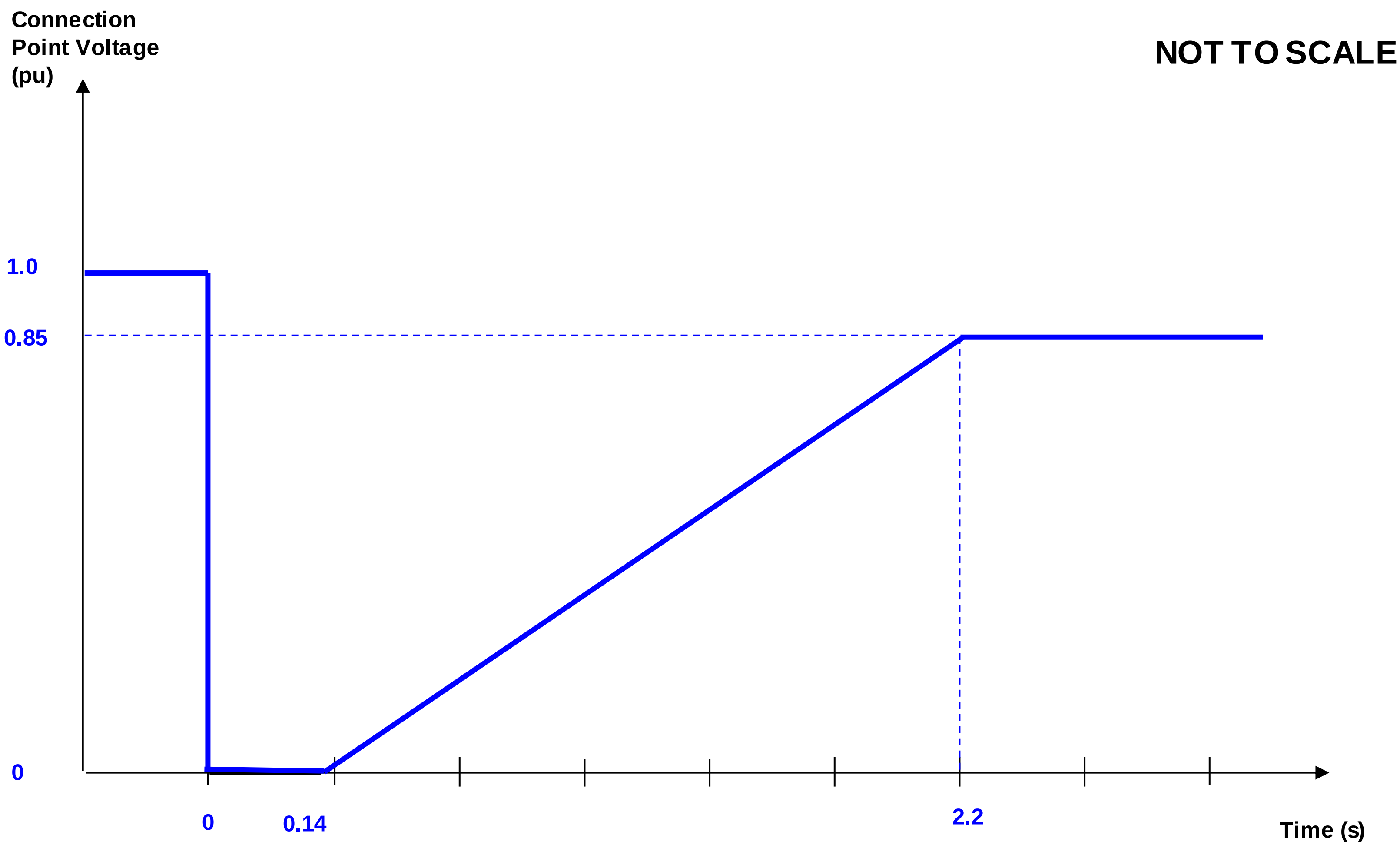
Voltage Against Time Parameter Ranges

Voltage parameters [pu]		Time parameters [seconds]	
U_{ret}	0.3	t_{clear}	0.14
U_{clear}	0.7	t_{rec1}	0.14
U_{rec1}	0.7	t_{rec2}	0.45
U_{rec2}	0.9	t_{rec3}	1.5

Table 3.1 – Fault Ride Through Capability of Synchronous Power Generating Modules

Type D Power Park Modules connected ≥110kV

GB Voltage Against Time Profile – Type D



nationalgrid

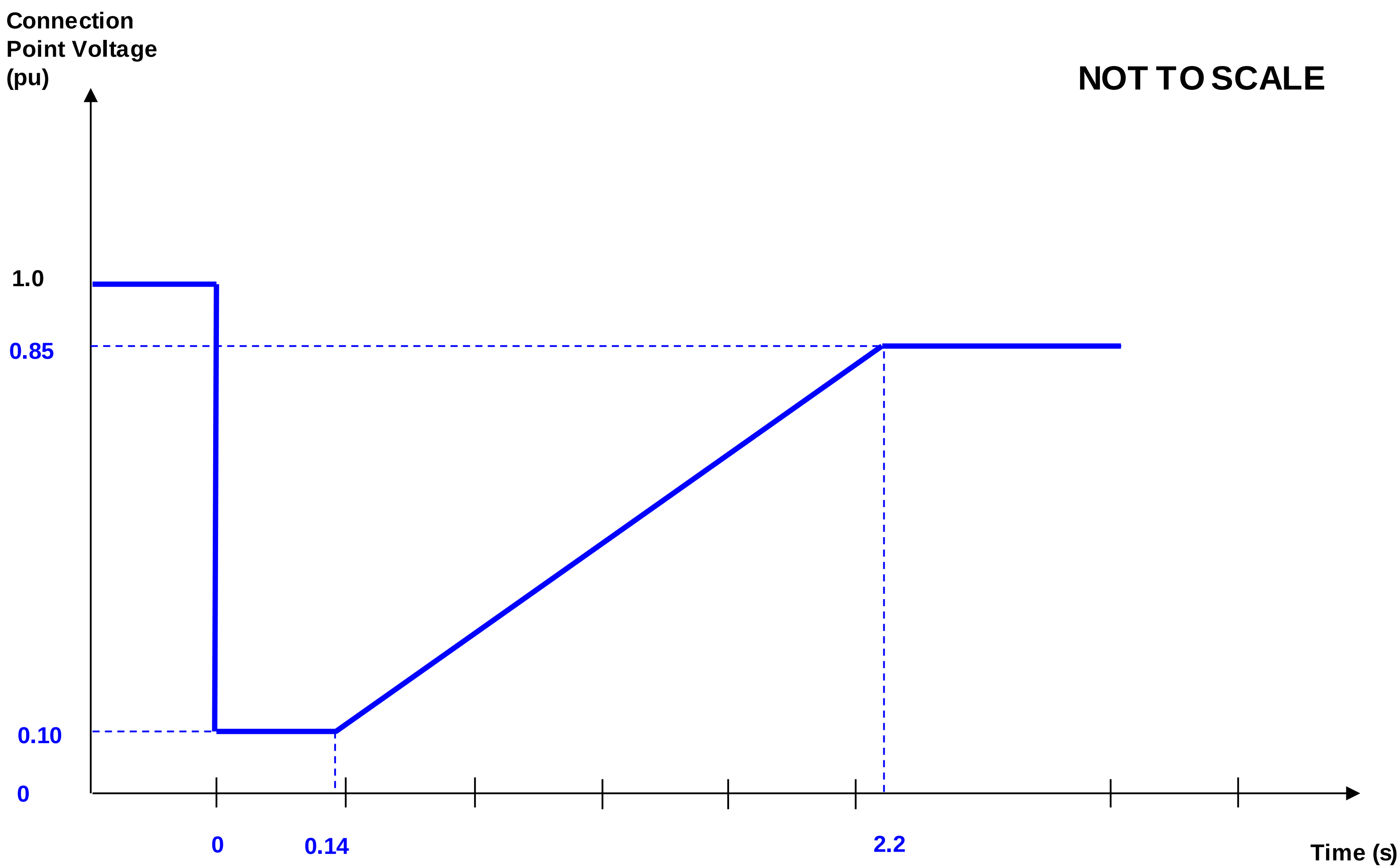
Voltage Against Time Parameters

Voltage parameters [pu]		Time parameters [seconds]	
U_{ret}	0	t_{clear}	0.14
U_{clear}	0	t_{rec1}	0.14
U_{rec1}	0	t_{rec2}	0.14
U_{rec2}	0.85	t_{rec3}	2.2

Table 7.2 – Fault Ride Through Capability of Power Park Modules

Type B, C and D Power Park Modules connected <110kV

GB Voltage Against Time Profile - Type B, C and D



nationalgrid

Voltage Against Time Parameters

Voltage parameters [pu]		Time parameters [seconds]	
U_{ret}	0.1	t_{clear}	0.14
U_{clear}	0.1	t_{rec1}	0.14
U_{rec1}	0.1	t_{rec2}	0.14
U_{rec2}	0.85	t_{rec3}	2.2

Table 7.2 – Fault Ride Through Capability of Power Park Modules

Banding Introduction

- Three banding options (high/mid/low) were discussed during GC0048
- Under RfG, NGET has to propose a set of Banding Thresholds for the GB Synchronous Area
- The banding values have a close relationship with fast fault current injection and fault ride through requirements
- ***Fast Fault Current Injection and Fault Ride Through apply to Type B and above.***

RfG Requirements / Band At A Glance

Technical Requirements	Type A	Type B	Type C	Type D
Operation across range of frequencies	•	•	•	•
Rate of change of System Frequency (ROCOF)	•	•	•	•
Limited Frequency Sensitive Mode Over Frequency (LFSM-O)	•	•	•	•
Output Power with falling Frequency	•	•	•	•
Logic Interface (input port) to cease active power production	•	•	•	•
Conditions for automatic reconnection	•	•	•	•
Operation across range of frequencies	•	•	•	•
Ability to reduce Active Power on instruction		•	•	•
Fault Ride Through and Fast Fault Current Injection		•	•	•
Conditions for automatic reconnection following disconnection		•	•	•
Protection and Control		•	•	•
Operational Metering		•	•	•
Reactive Capability		•	•	•
Active Power Controlability			•	•
Frequency Response including LFSM-U			•	•
Monitoring			•	•
Robustness			•	•
System Restoration / Black Start			•	•
Simulation Models			•	•
Rates of Change of Active Power			•	•
Earthing			•	•
Enhanced Reactive Capability and control			•	•
Voltage Ranges				•
Enhanced Fault Ride Through				•
Synchronisation				•
Excitation Performance				•

National Grid Proposal for GB Banding

Band	MW Threshold/Connection Voltage
Band A	800W – 0.99MW and connected at or below 110kV
Band B	1MW – 9.99MW and connected at or below 110KV
Band C	10MW – 49.99MW and connected at or below 110kV
Band D	50MW plus or connected at 110kV or above

nationalgrid

Banding - Implications

- For Fault Ride Through, the value of U_{ret} proposed for all Type B – D plant connected below 110kV (excluding Type B Synchronous Plant) has been set to 10%.
  - This has been based on System Studies and assumes a minimum fault infeed as per the FFCI proposals
- For Type B Synchronous Plant the value of U_{ret} has been set to 30%. Note that they will be capable of supplying a reasonable degree of fault current
- Guidance from ENTSO-E has indicated that the voltage against time parameters must be defined for each Band

Banding - Comparison with Proposals of other EU TSOs

nationalgrid

Country	Band A*	Band B*	Band C*	Band D'
Belgium	800W – 250kW	0.25MW – 25MW	25MW – 75MW	75MW plus
France	800W – 1MW	1MW – 18MW	18MW – 36 MW	36MW plus
Netherlands	800W – 1MW	1MW – 50MW	50MW – 60MW	60MW plus
German TSO's	800W – 135kW	0.135MW – 36MW	36 MW – 45MW	45MW plus
Spain	800W – 100kW	0.1 MW – 5MW	5MW – 50MW	50MW plus
Ireland	800W – 100kW	0.1MW – 5MW	5MW – 10MW	10MW plus
GB	800W – 0.99MW	1MW – 9.99MW	10MW – 49.9MW	50MW plus

* Applicable MW threshold and connected below 110kV

‘ Applicable MW threshold or connected at or above 110kV

Justification for NGET's GC0100 Proposals

- The intention of the EU proposals is based on the principles of non-discrimination and transparency as well as on the principles of optimisation between the highest overall efficiency and lowest total cost for all involved parties.
- Through Stakeholder engagement we have understood technical limitations in setting retained voltage at 30% for Band B Synchronous Reciprocating Plant)
- If Converter based plant does supply reactive current in line with the FFCI proposals, the study run in the South West has indicated that approximately 550MW of Embedded Generation would see voltage drops of below 10% and hence trip. This would equate to approximately £240million/ annum in additional reserve costs alone.
- Without the assumed level of FFC I, lower values of U_{ret} would be required (0.05pu rather than 0.1pu) and it would also place more Band B Synchronous generation at risk from tripping at an estimated cost of £9.2million/annum in reserve costs alone.
- The Studies run in the South West are believed to be representative of the wider System – see next slide

How the South West compares to other areas of GB

Area		GC048 study			Future Of Energy documents					
		SCL studied 2025 (kA)	DG installed 2025 (MW)	DG studied 2025 (MW)	FES2025 max DG output (MW)	FES2025 min DG output (MW)	SOF regional SCL min (kA)	SOF regional SCL 95% confidencemin (kA)	SOF regional SCL 95% confidence max (kA)	SOF regional SCL max (kA)
1	North Scotland	N/A	N/A	N/A	1839.5	1167.6	6.8	11.9	16.5	18.6
2	South Scotland	N/A	N/A	N/A	2941.8	2024.4	9.5	13.1	20	21
3	North East England	N/A	N/A	N/A	1360.6	885.4	10.8	14.4	29.3	34.1
4	North West and West Midlands	N/A	N/A	N/A	3338.1	1990.1	0.7	5.7	21.1	22
5	East Midlands	N/A	N/A	N/A	3540.8	2029.3	2.7	7.1	24.4	28.4
6	North Wales	N/A	N/A	N/A	740.1	594.3	13.3	21.6	36.1	38
7	South Wales and West england	N/A	N/A	N/A	3677.3	2300.5	6.4	9.8	26.2	30.4
8	South West England	16.3	2522.4	2411	**3213**	**1999.7**	**2.4**	**7.3**	**22.1**	**25.9**
9	East England	N/A	N/A	N/A	3934.5	2543.1	9.1	17.4	41.5	45.6
10	Greater London	N/A	N/A	N/A	1716	1104.4	6.2	14.2	32.4	35.7
11	South East England	23.95345696	N/A	N/A	2059	1268.2	7.6	15.1	27.9	31.7

Justification for NGET’s GC0100 Proposals

- Larger Synchronous Generators, eg those derived from steam, gas or hydro turbines are not believed to suffer from these issues
- A questionnaire released to GB Stakeholders in 2016 revealed there would be no additional significant costs from a technical perspective if the lower threshold was applied.
- RfG enforces a consistent banding requirement across GB. The proposed Banding applies capabilities currently demonstrated in the North of Scotland across the whole GB System
- The majority of European TSO’s are proposing Banding lower than the maximum permitted under RfG
- The Continental Power System is of the order of 10 times larger than the GB System

Conclusions
FFCI / Fault Ride Through

- Based on the study work and analysis completed National Grid recommend the FFCI issues proposed. It is believed that the adoption of this option will result in a saving of approximately £240million / annum in reserve costs alone not including the wider significant benefits of contribution to synchronising torque, fault infeed and inertia.
- The Fault Ride Through voltage against time curves are recommended on the basis of minimum system need. These are based on the assumption of the delivery of FFCI. Without the proposed level of FFC I, lower values of U_{ret} in FRT would be required (0.05pu rather than 0.1pu)
- These measures would not be retrospective and would apply to new plant going forward.

Conclusions
Banding

- National Grid has lodged its proposal for the GB banding (slide 24)
  - The relationship between FFCI / Fault Ride Through and cost has been demonstrated
  - Without FFCI as proposed we will need to lower the value of U_{ret} (from 0.1pu to 0.05pu). There is also a cost of tripping synchronous generation in a higher band (10MW – 50MW) which would result in reserve costs alone of £9 million / annum.
  - Following public Stakeholder discussions U_{ret} of 0.3pu for Band B Synchronous Plant is proposed
  - The costs to which Generators are exposed for these thresholds was identified to be negligible following the responses to the Stakeholder questionnaire held in 2016, excluding market costs (ie BM participation costs).
  - Parity with European TSO proposals, particularly with regard to cross boarder trade
  - The proposals would apply the same technical requirements across the whole of GB
  - A Band B/C Threshold of 10MW would provide a greater proportion of Generation being capable of contributing to frequency response which drives competition and reduces net cost
  - System Operators will need to continue to operate a safe, secure and economic System against a rapidly changing Generation background
  - RFG Mandates TSO’s to propose banding thresholds