RfG Implementation
Fault Ride Through

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Summary

- Background to Fault Ride Through
- GC0062 – Scope
- RfG Fault ride Through Requirements
- Findings of GC0062 Workgroup
  - Suggested RfG voltage against time curve
  - Demonstration of Compliance
- Next Steps

Background to Fault Ride Through

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Ride Through Capability

Why is it Required?

- Introduced into the Grid Code in June 2005 following consultation H/04
- Justification and need for fault ride through covered in Section 5.1 - Appendix 2 of the H/04 Consultation Document available at:-
  - http://www.nationalgrid.com/NR/rdonlyres/3DD7D7C7-6460-4257-BF99-E168D794C13E/7027/aacp_h04.pdf
- Applies to Synchronous and Asynchronous Generating Plant

Ride Through Capability
Introduction

- Fault Ride Through is a requirement necessary for Generators to remain connected to healthy Transmission circuits until the faulted element of Plant and Apparatus has been cleared from the Transmission System
- If Fault Ride Through Capability is not installed, Generation would be susceptible to tripping when subject to a voltage dip (typically below 90% of nominal) even when connected to a healthy circuit for less than normal protection operating times (eg 80ms or 100ms).
- If left unchecked, the consequences would be significant resulting in loss of Generation and frequency collapse followed by a Blackout.
- Initially identified as an issue with Wind Generation employing Power Electronic Converters but the concept equally applies to all Generation Types

Fault Ride Through Capability
Voltage Dip Propagation - The Wash

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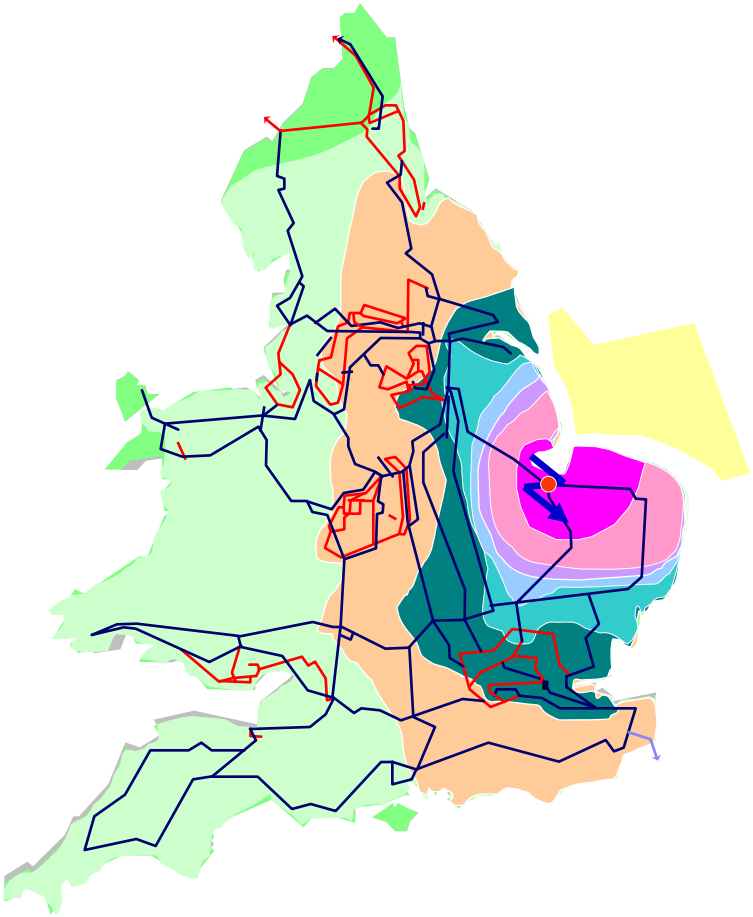

3 phase fault a Walpole 400 kV substation

- Fault Location 0 % Volts
- 0 - 15 % Volts
- 15 - 30 % Volts
- 30 - 40 % Volts
- 40 - 50 % Volts
- 50 - 60 % Volts
- 60 - 70 % Volts
- 70 - 80 % Volts
- 80 - 90 % Volts

Fault Ride Through

Protection Operation under Fault Conditions (1)

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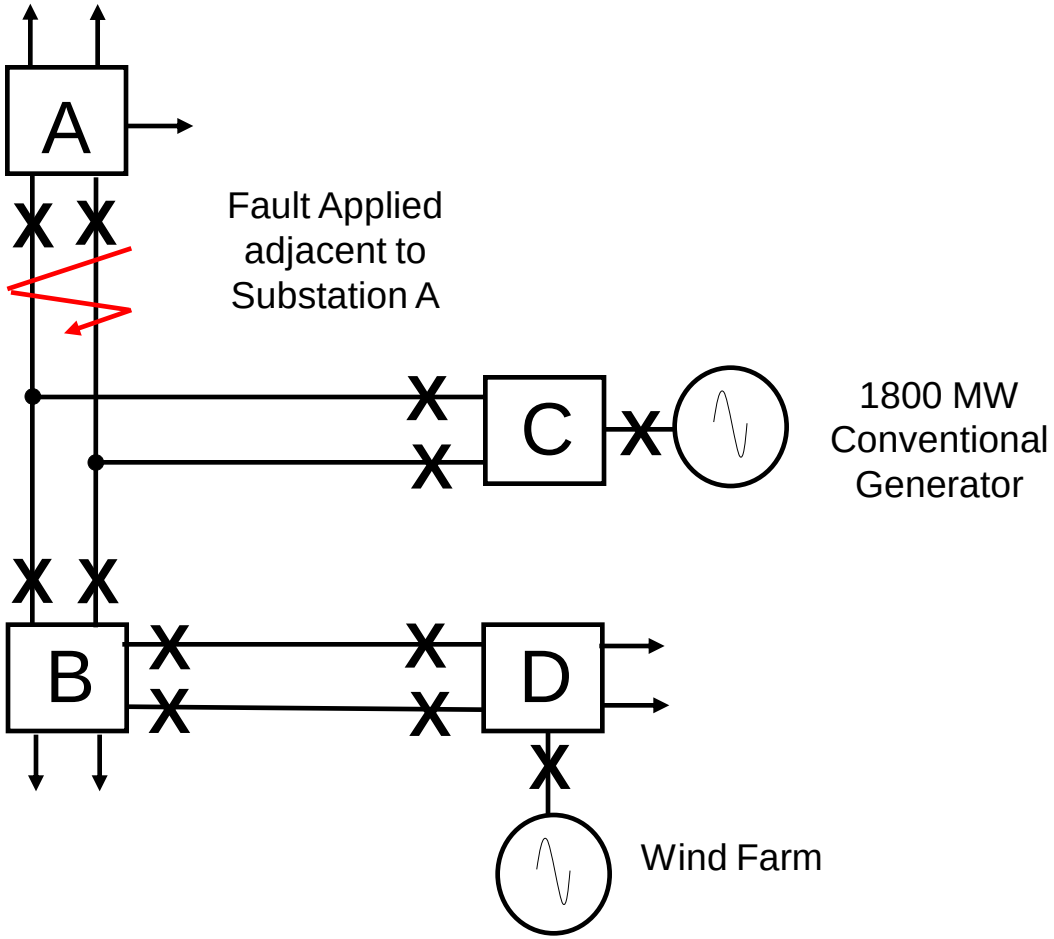
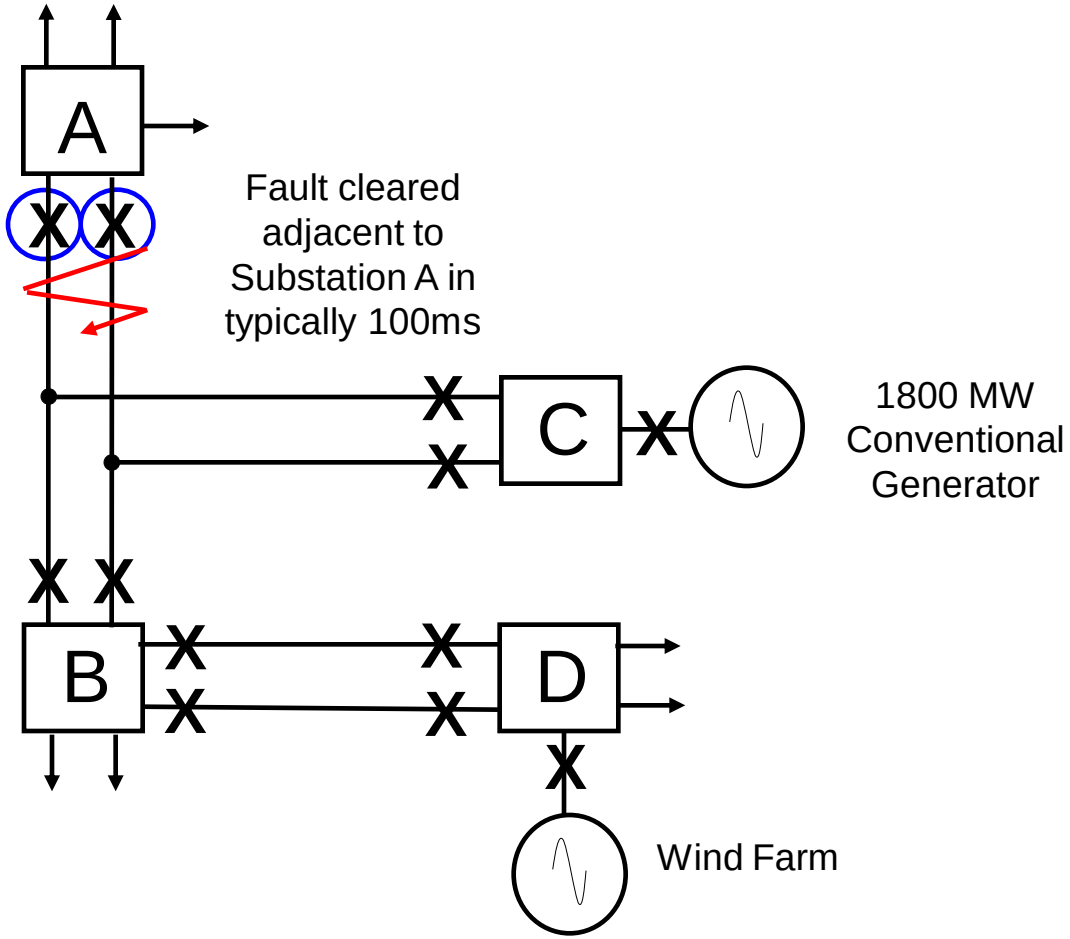
Low voltage seen across all parts of the Network



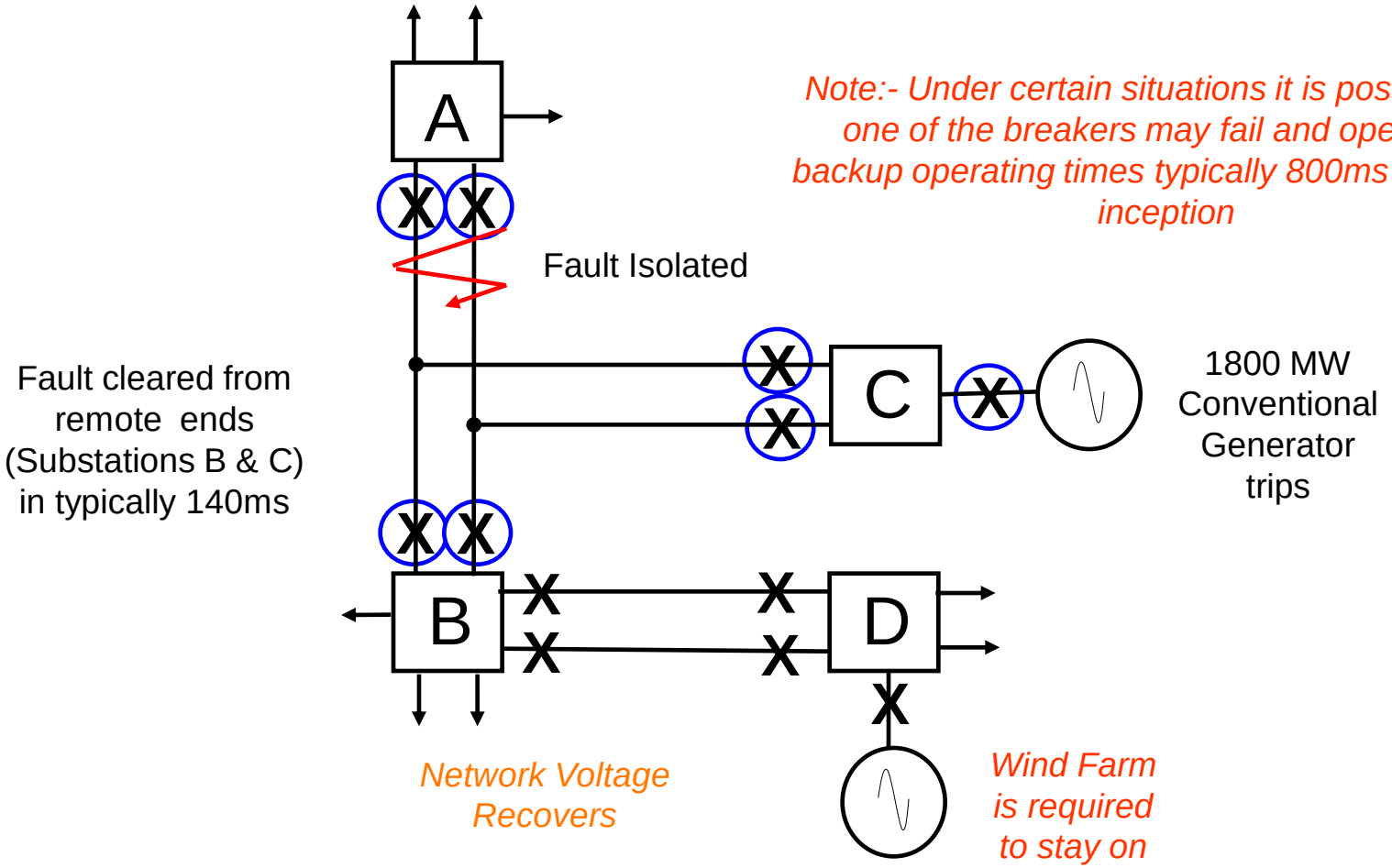
Fault Ride Through

Protection Operation under Fault Conditions (2)



Fault Ride Through

Protection Operation under Fault Conditions (3)



Note:- Under certain situations it is possible that one of the breakers may fail and operate in backup operating times typically 800ms after fault inception

Ride Through Capability (CC.6.3.15)

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- Under the Grid Code fault ride through defines:
  - The requirements for Generating Plant to remain connected and stable for balanced and unbalanced faults up to 140ms in duration (CC.6.3.15.1(a)).
  - The requirements for Generating Plant to remain connected and stable for balanced voltage dips in excess of 140ms (CC.6.3.15.1(b)).

Ride Through Capability
Faults up to 140ms in duration (CC.6.3.15.1(a))

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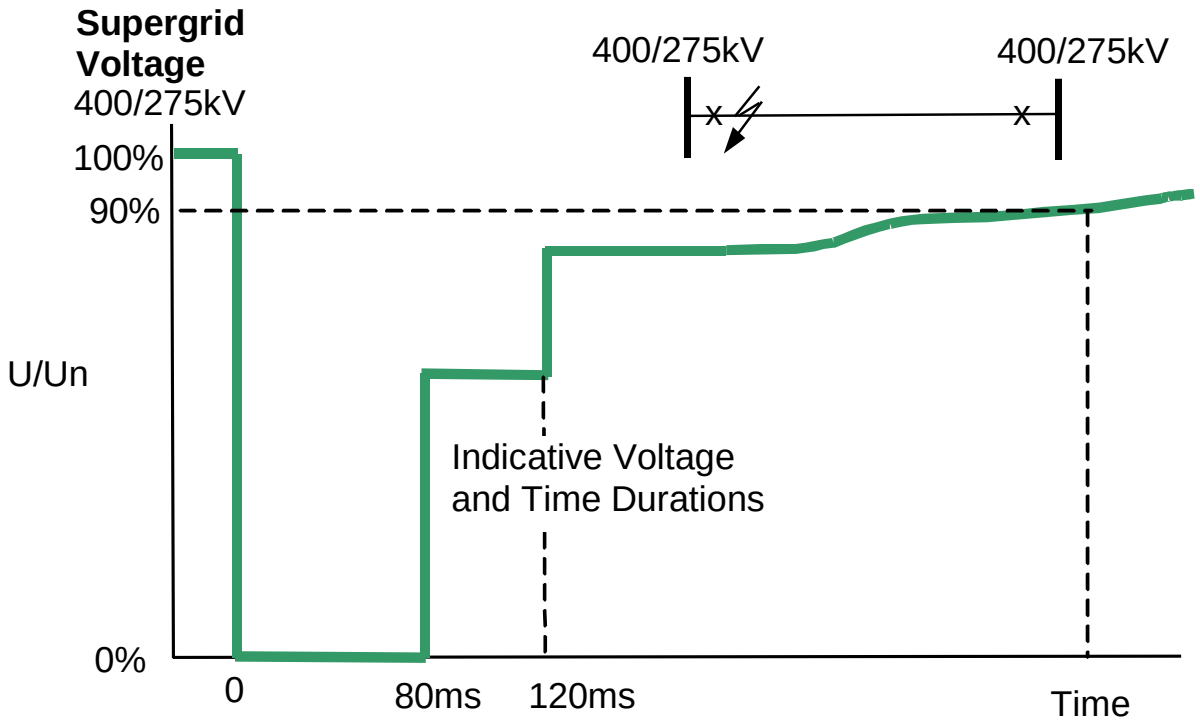
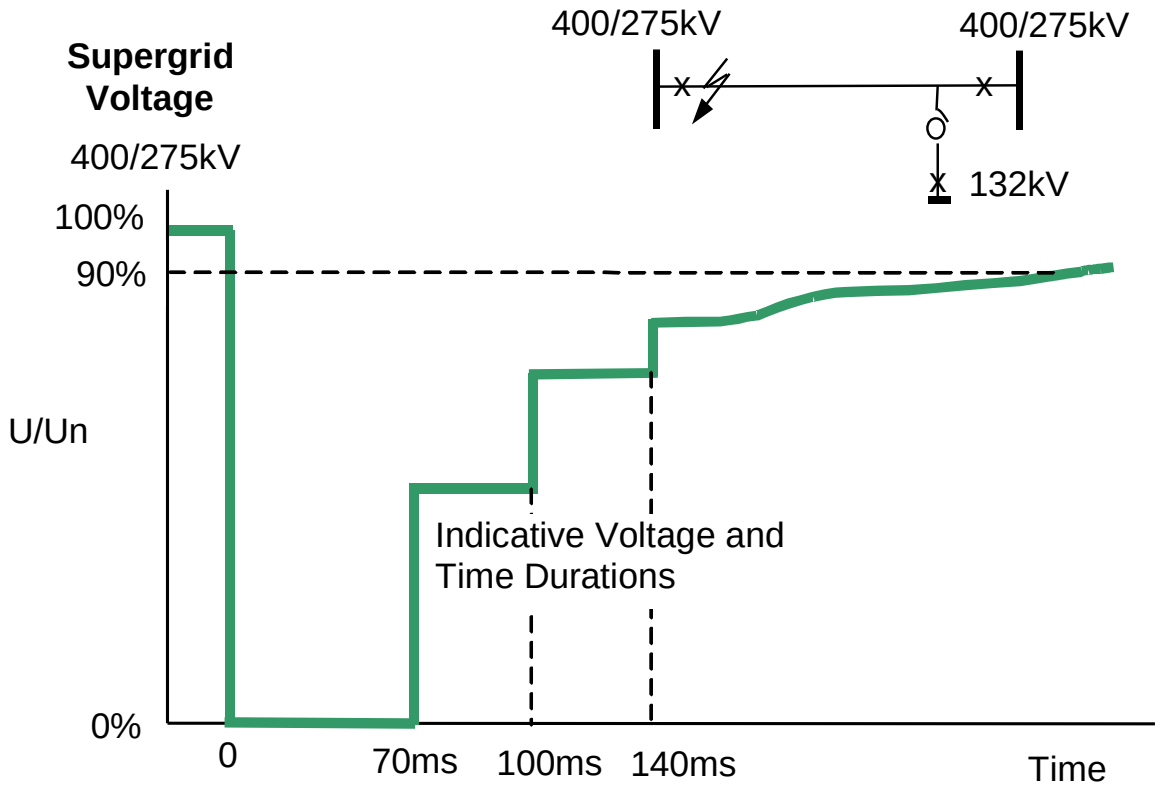
- Generating Units and Power Park Modules are required to remain stable and connected for any balanced or unbalanced fault on the Transmission System operating at 200kV or above and lasting for up to 140ms.
- Each Generating Unit and Power Park Module is required to generate maximum reactive power without exceeding its transient rating limit.
- Active Power output should be restored to at least 90% of the level available immediately before the fault and within 0.5 seconds of restoration of the voltage at the Connection Point
- Active Power Oscillations are acceptable provided:-
  - The total energy delivered during the period of the oscillations is at least that if the Active Energy was constant and
  - The Oscillations are adequately damped
- Examples provided in Connection Conditions – Appendix 4.

Faults up to 140ms in duration
Two Ended Circuit *(CC – Appendix 4A)*



Typical fault cleared in less than 140ms: 2 ended circuit

Faults up to 140ms in duration
Three Ended Circuit *(CC – Appendix 4A)*



Typical fault cleared in 140ms:- 3 ended circuit

Voltage Dips in excess of 140ms in duration (CC.6.3.15.1(b))

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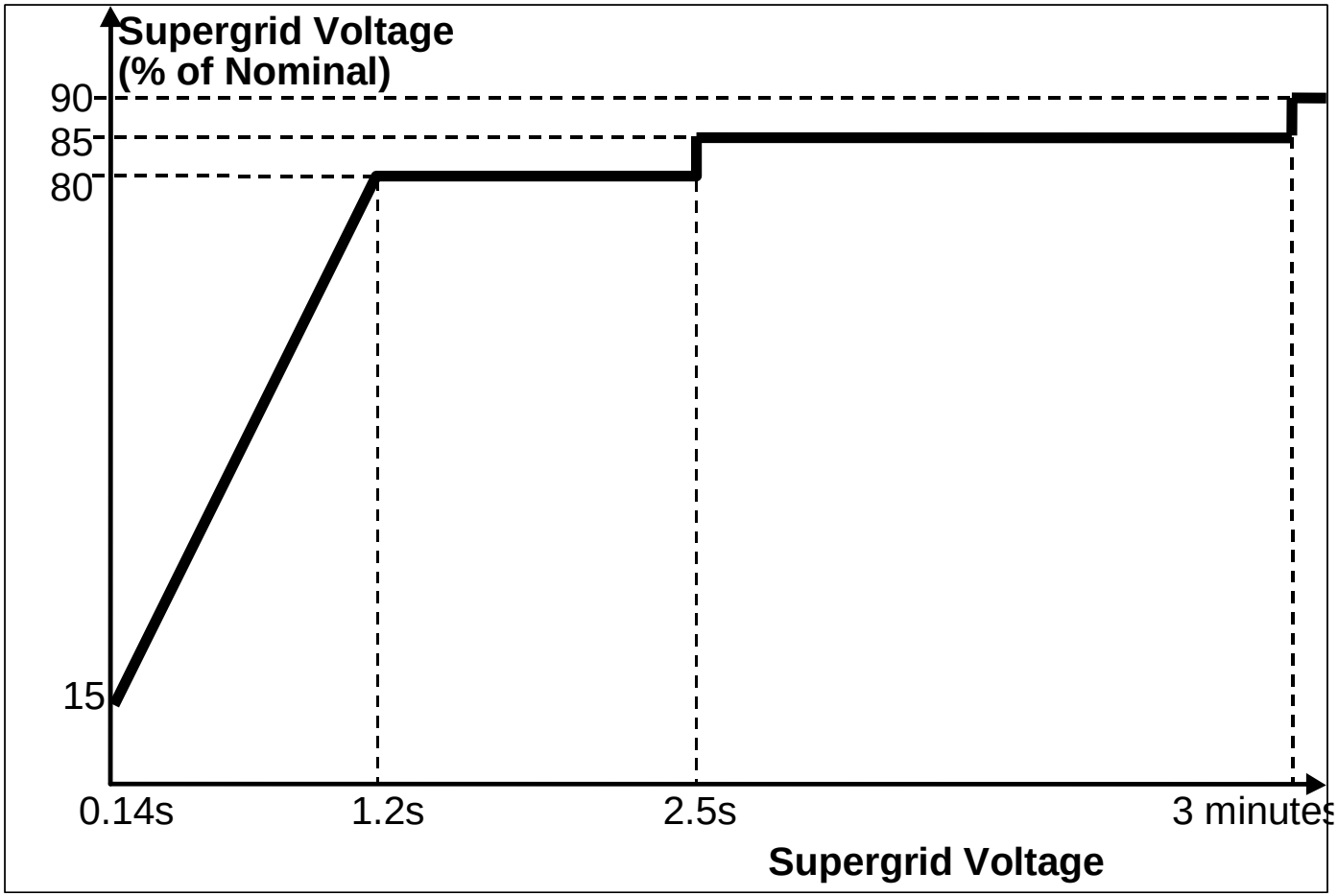
- Generating Units and Power Park Modules are required to remain stable and connected for any balanced Supergrid voltage dip on the Onshore Transmission System anywhere on or above the heavy black line shown in Figure 5 of the Grid Code (see next slide).
- Each Generating Unit and Power Park Module is required to generate maximum reactive power without exceeding its transient rating limit.
- Active Power output should be supplied at least in proportion to the retained balanced voltage at the Connection Point
- Restore Active Power output following Supergrid Voltage dips on the Onshore Transmission System within 1 second of restoration of the voltage at the Connection Point to at least 90% of the Active Power available before the voltage dip unless there has been reduction in the intermittent power source, during the period of the voltage dip.
- Active Power Oscillations are acceptable provided:-
  - The total energy delivered during the period of the oscillations is at least that if the Active Energy was constant and
  - The Oscillations are adequately damped

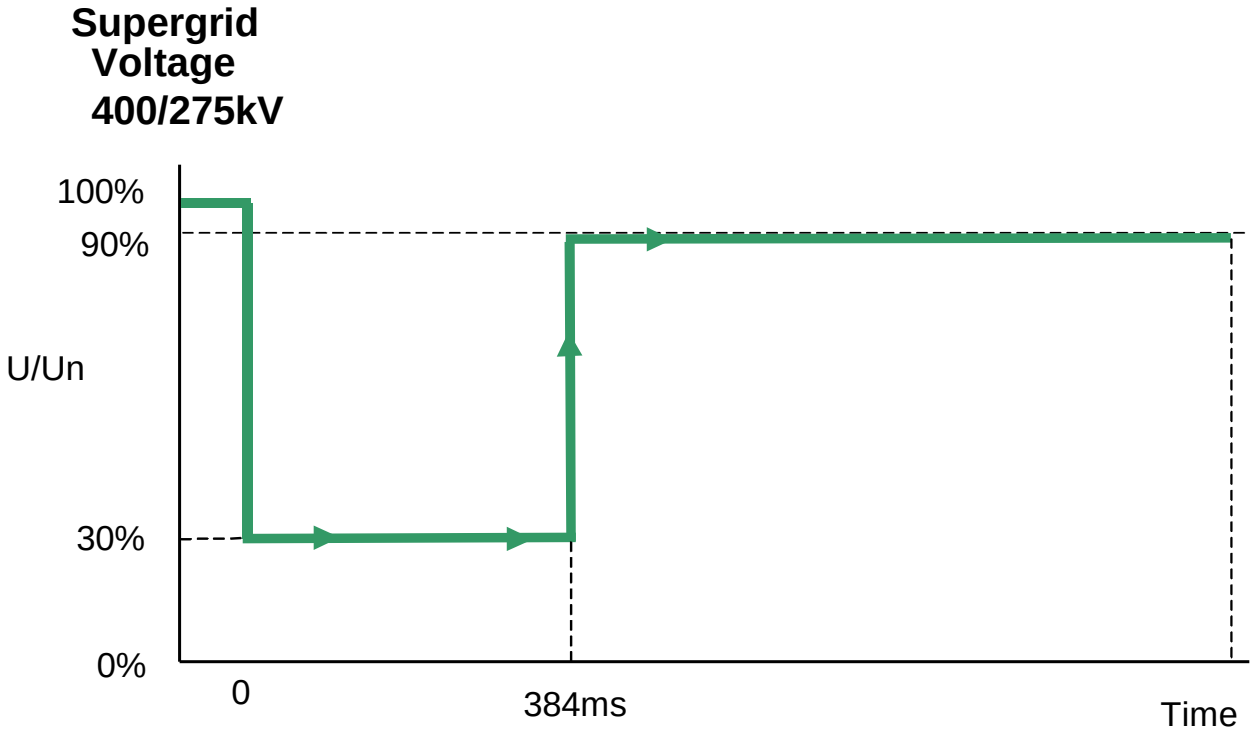
Voltage Duration Curve

Post 140ms Faults – CC.6.3.15 Figure 5



Voltage dips in excess of 140ms

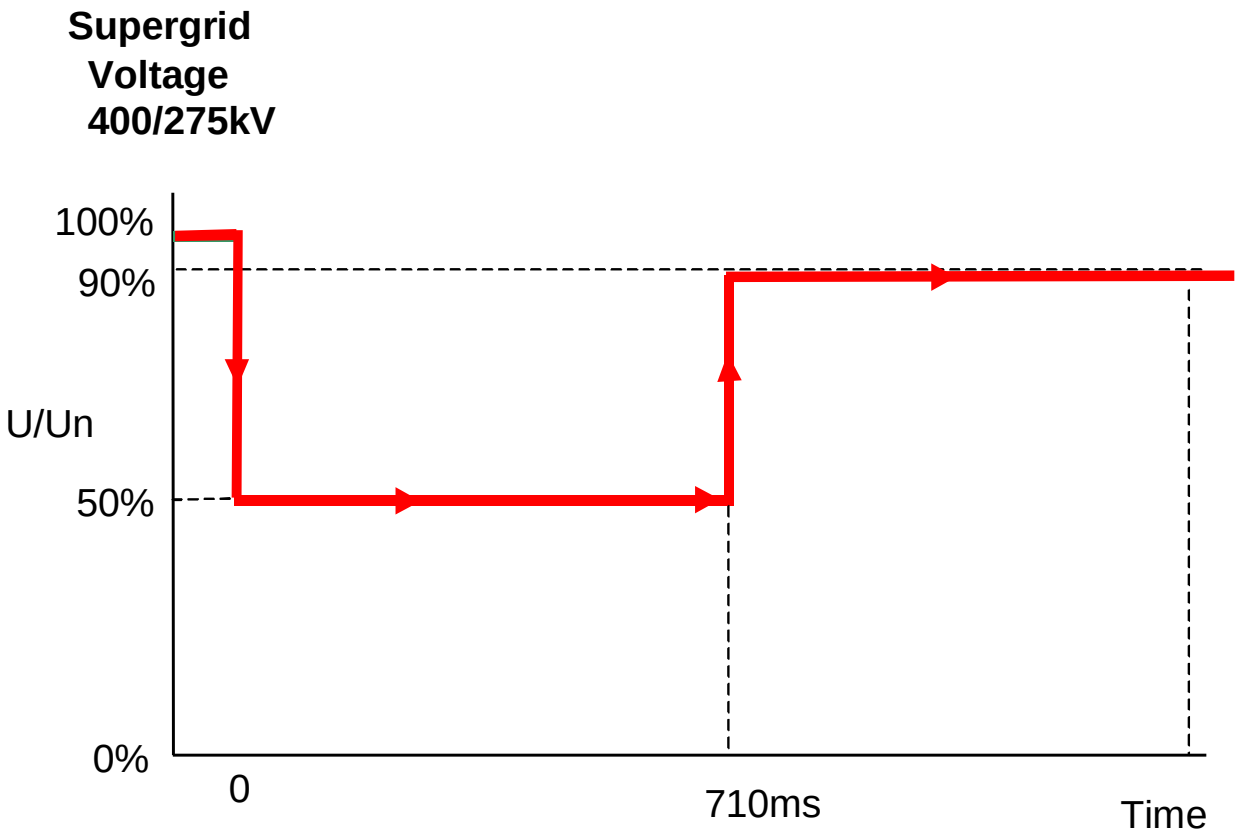
30% Retained Voltage (CC – Appendix 4A)



30% retained voltage, 384ms duration

Voltage dips in excess of 140ms

50% Retained Voltage (CC – Appendix 4A)



50% retained voltage, 710ms duration

Issues

- In GB the Fault Ride Through requirements are the same for both Synchronous Generation and Power Park Modules
- Synchronous Generating Units have struggled to meet the requirements especially for longer duration voltage dips (ie dips in excess of 140ms) – This issue has been addressed by GC0062.
- RfG Only covers requirements for Secured faults (ie faults cleared in up to 140ms) so the intention is for Mode B faults to remain within the GB Code as it falls outside RfG.

GC0062 Scope

GB Grid Code Fault Ride Through Working Group

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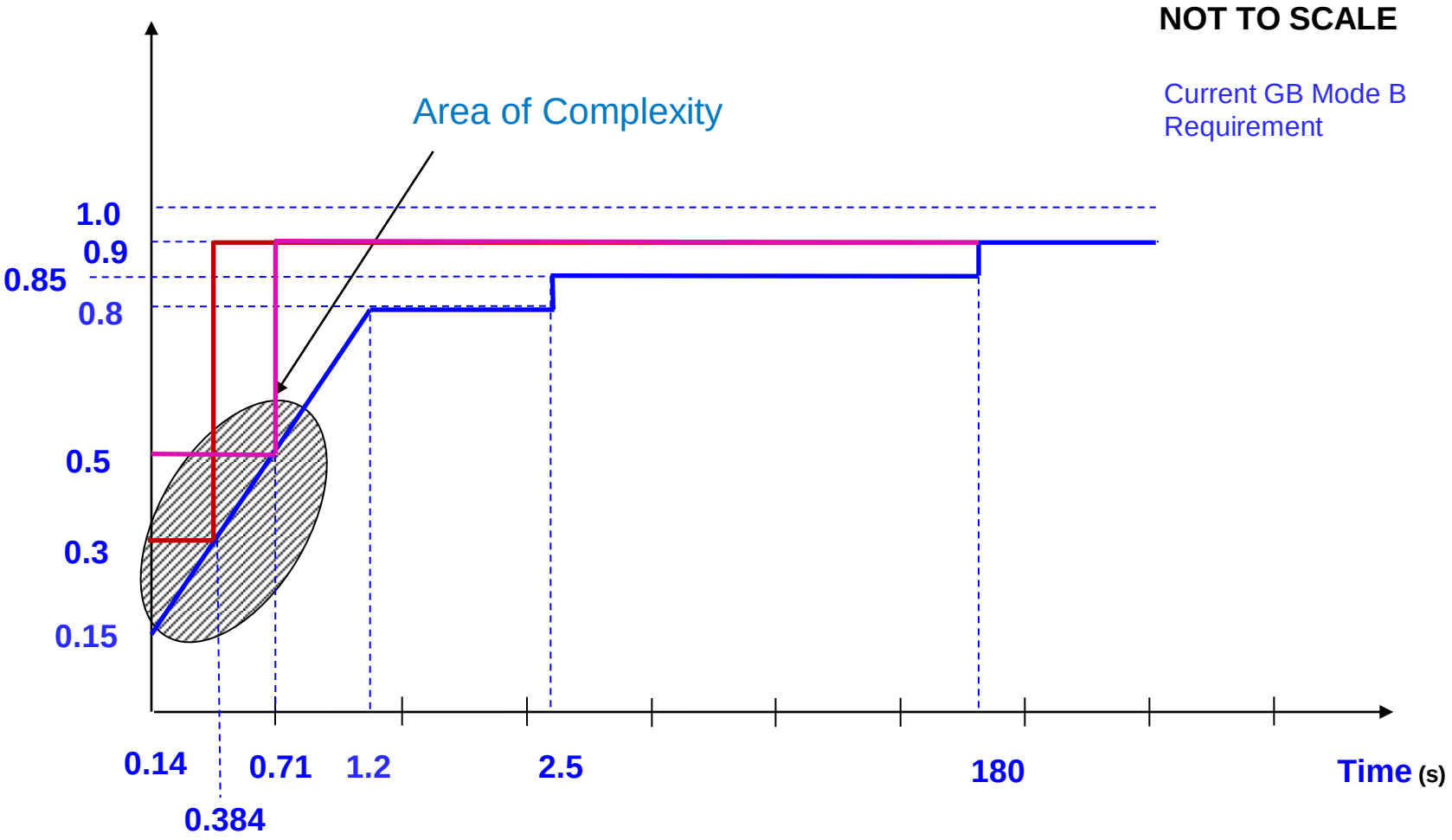
Grid Code Defect

CC.6.3.15(b) – "…..each Generating Unit ….each with a Completion Date on or after 1 April 2005 shall:

(i) remain transiently stable and connected to the system without tripping of any Generating Unit…..for balanced Supergrid Voltage dips and associated durations on the Onshore Transmission System anywhere on or above the heavy black line shown in Figure 5… "

- EDF requested (PP12/04) a revision to CC.6.3.15.1(b) on the basis that a number of Synchronous Generators struggled to meet this requirement particularly for voltage depressions of between 15 – 50% of nominal lasting several hundred milliseconds.
- Industry Workgroup established and although the RfG Fault Ride through requirements were initially considered as a solution it was soon realised they would not address the original Grid Code defect as they only cover Mode A faults.
- Option taken to revise voltage duration curve (Figure 5) following extensive study work

Grid Code Defect

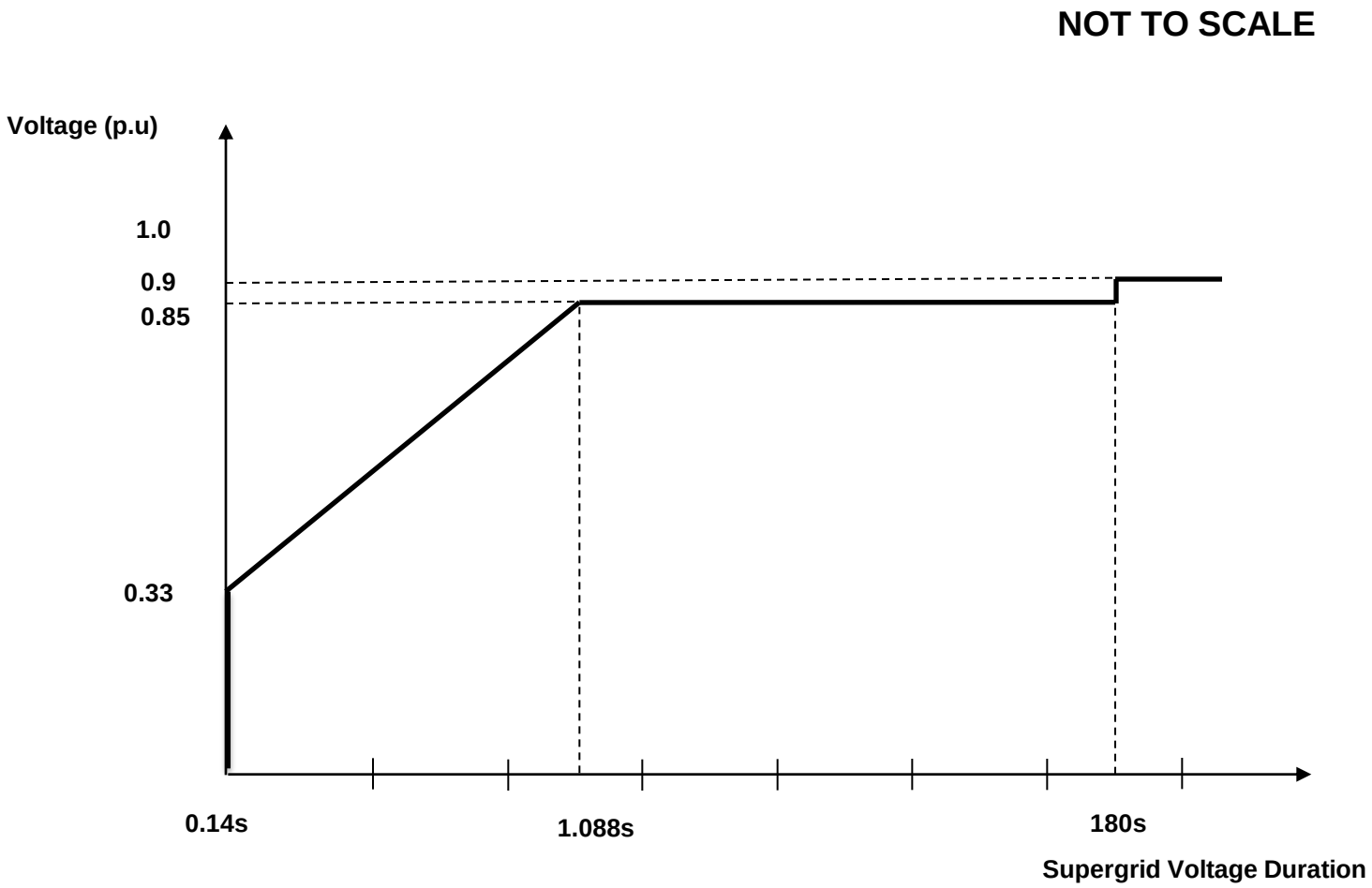


CC.6.3.15.1(b) - Figure 5

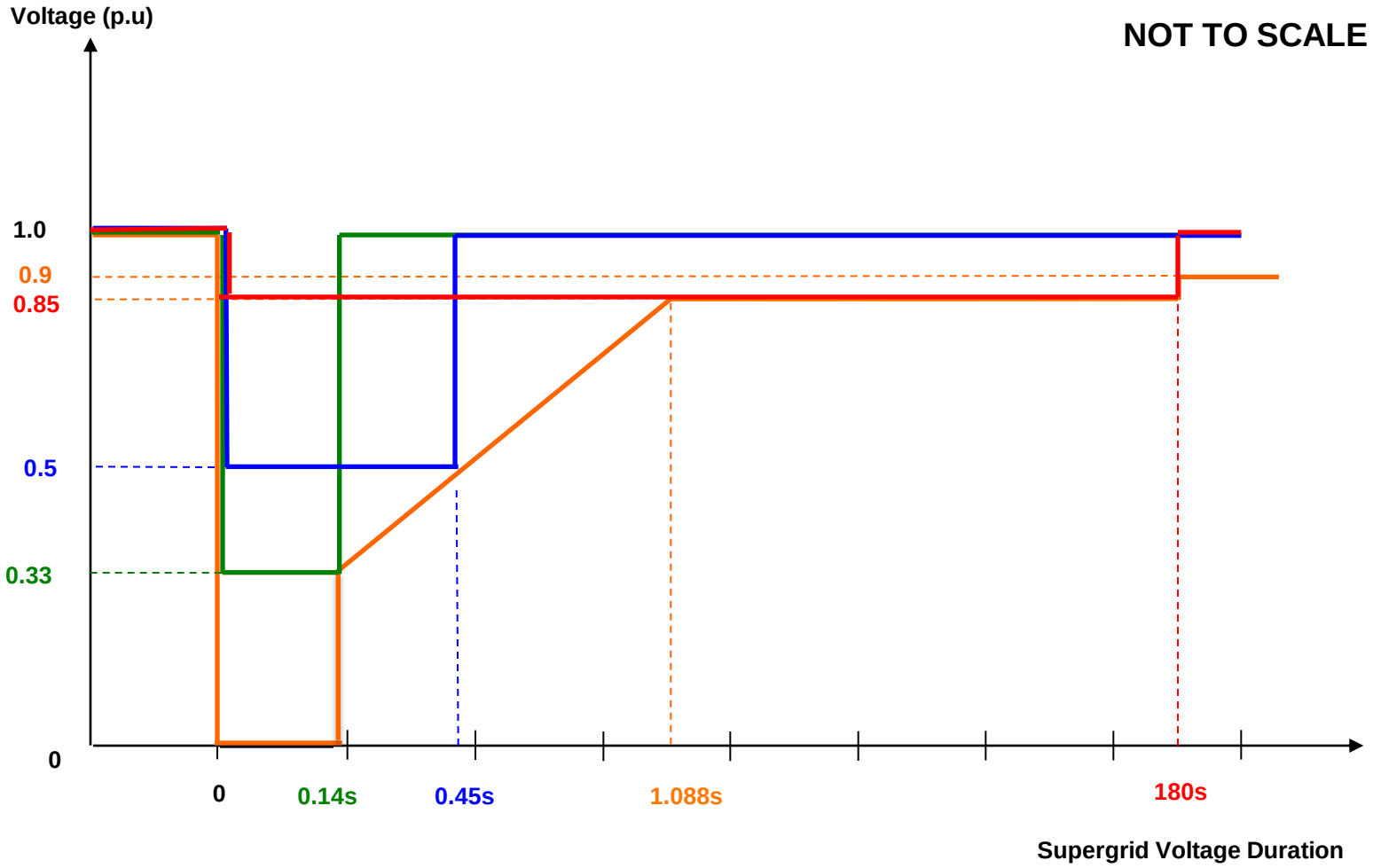
Proposed Solution

- Revised amendments to Grid Code CC.6.3.15.1(b)(i) and Appendix 4 of the Grid Code Connection Conditions
  - Proposed amendments to Figure 5 of CC.6.3.15.1(b)(i) – voltage duration curve specifically for Synchronous Generating Units
  - The existing voltage duration curve would remain for Power Park Modules.
  - No change to active power recovery characteristics
  - Significant study work undertaken to determine revised voltage duration curve.
  - Examples of how compliance should be demonstrated included within Workgroup report
  - Appendix 2 of the Workgroup report includes an interpretation of the RfG fault ride through requirements as applicable to Transmission Connected Synchronous plant. **This will be useful for the GC0048 Workgroup but substantial work will still be required to include the RfG fault ride through requirements into the GB Grid Code**

Revised Voltage Duration Curve – Figure 5



Revised Voltage Duration Curve – Figure 5



Next Steps

- The Workgroup believes it has investigated the Grid Code Fault Ride Through deficiencies identified in EDF's paper PP12/04 and proposed a revised voltage duration curve and associated legal text to address this issue.
- The Workgroup support the conclusions of the report
- There is no conflict with the RfG as a result of these proposals
- The GC0062 Consultation is due for imminent release

RfG Fault Ride Through Requirements

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RfG Fault Ride Through
Summary

- Under RfG, the requirements are defined in terms of a Voltage against Time Curve at the Connection Point
- The requirements vary depending upon the Type of Plant (Synchronous or Power Park Module)
- The requirements for Type D are different to those than for Types B and C (both Synchronous and Power Park Modules)
- The RfG requirements apply only for **Secured Faults** (ie in GB faults cleared up to 140ms in duration).
- GC0062 has suggested a proposed Voltage against time curve for a directly connected Synchronous Power Generating Module (ie Type D connected at 400/275kV).
- RfG also contains compliance provisions. Part of the GC0062 Workgroup Report (Appendix 2) provides examples of how compliance can be demonstrated.

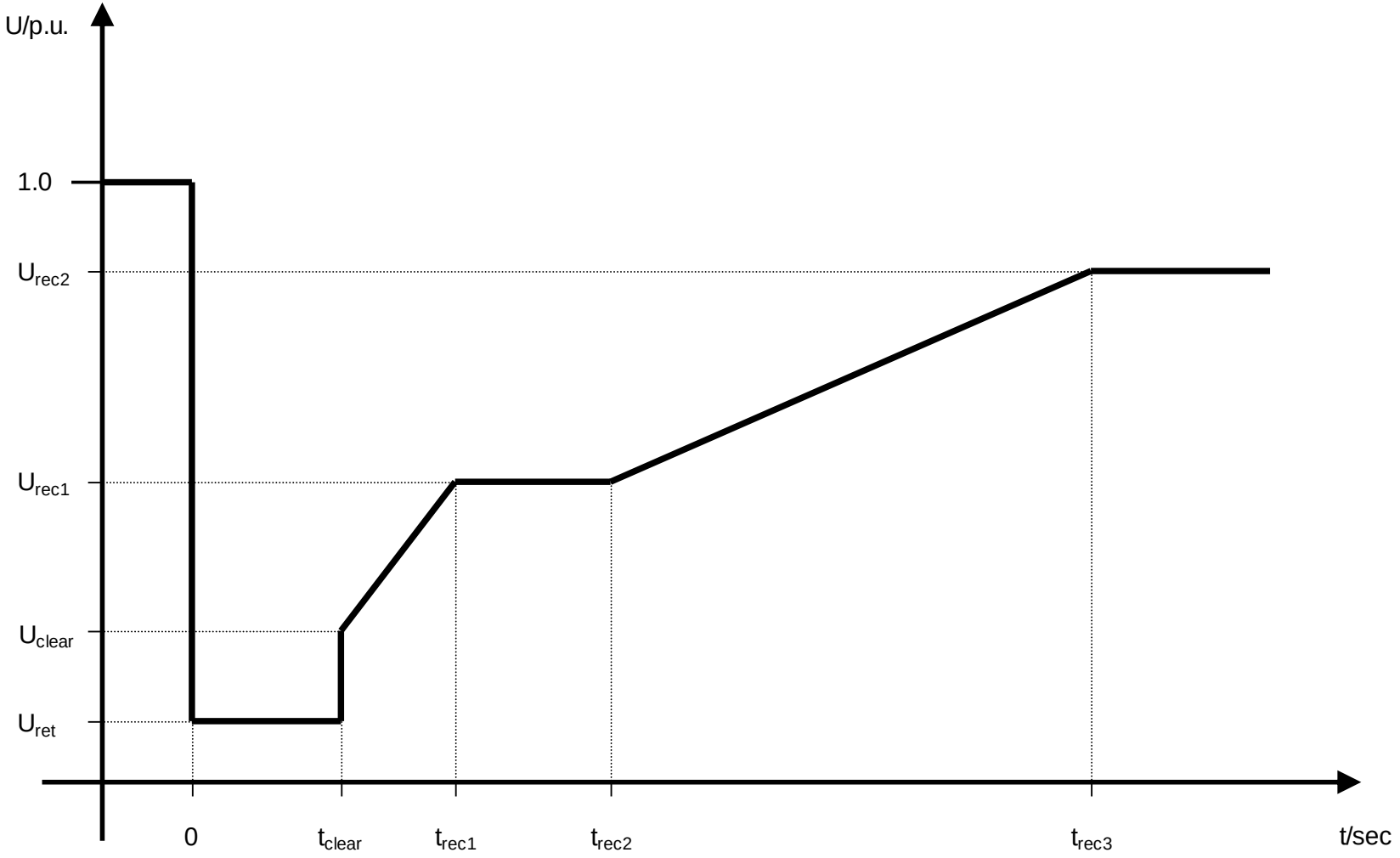
General Requirements for Type B and C Power Generating Modules (1)

- Article 13 - Type A Power Generating Modules (800W – 1MW) – There are no Fault Ride Through requirements for Type A Power Generating Modules.
- Article 14 – Type B Power Generating Modules (1MW – 50MW?)
  - Each TSO shall define a voltage – against time profile in line with Figure 3 at the connection point for fault conditions, which describes the conditions in which a power generating module is capable of staying connected to the network and continuing to operate stably after the power system has been disturbed by secured faults on the transmission system.
  - The voltage against time profile shall express a lower limit of the actual course of the phase-to-phase voltages on the network voltage level at the connection point during a symmetrical fault, as a function of time before, during and after the fault.
  - The lower limit referred to in point (ii) shall be specified by the relevant TSO using the parameters set out in Figure 3, and within the ranges set out in Tables 3.1 and 3.2

General Requirements for Type B and C Power Generating Modules (2)

- Article 14 – Type B Power Generating Modules (1MW – 50MW?)
  - Each TSO shall specify and make publically available the pre-fault and post fault conditions for the fault ride through capability in terms of:
    - The calculation of the pre-fault minimum short circuit capacity at the connection point
    - Pre-fault active and Reactive Power operating point of the Power Generating module at the connection point and voltage at the connection point
    - Calculation of the of the post fault minimum short circuit capacity at the connection point
  - At the request of the power generating facility owner, the relevant system operator shall provide the pre-fault and post fault conditions to be considered for fault ride through capability as an outcome of the calculations at the connection point as specified in point (iv) regarding
    - Pre-fault minimum short circuit capacity at each connection point expressed in MVA
    - Pre-fault operating point of the power generating module expressed in active power output and reactive power output at the connection point and voltage at the connection point
    - Post fault minimum short circuit capacity at each connection point expressed in MVA
  - Alternatively, the relevant System Operator may provide generic values derived from typical cases.

ENTSO-E RfG - Fault Ride Through Requirements – Voltage Against Time Profile – Figure 3



Interpretation of Voltage against time profile

- Figure 3 defines the Fault Ride Through profile of a Power Generating Module (Synchronous and Asynchronous). The diagram represents the lower limit of a voltage-against time profile of the voltage at the Connection Point, expressed as the ratio of its actual value and its reference 1p.u value before, during and after a fault. Uret is the retained voltage at the connection point during a fault, tclear is the instant when the fault has been cleared. Urec1, Urec2, trec1, trec2 and trec3 specify certain points of lower limits of voltage recovery after fault clearance.

ENTSO-E RfG - Voltage Against Time Parameters – Table 3.1 – Type B & C Synchronous Power Generating Units

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Voltage parameters [pu]		Time parameters [seconds]	
Uret:	**0.05 – 0.3**	**tclear:**	**0.14 – 0.15** (or 0.14 – 0.25 if system protection and secure operation so require)
Uclear:	**0.7 – 0.9**	**trec1:**	**tclear**
Urec1:	**Uclear**	**trec2:**	**trec1 – 0.7**
Urec2:	**0.85 – 0.9 and > Uclear**	**trec3:**	**trec2 – 1.5**

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

ENTSO-E RfG - Voltage Against Time Parameters – Table 3.2 – Type B & C Power Park Modules

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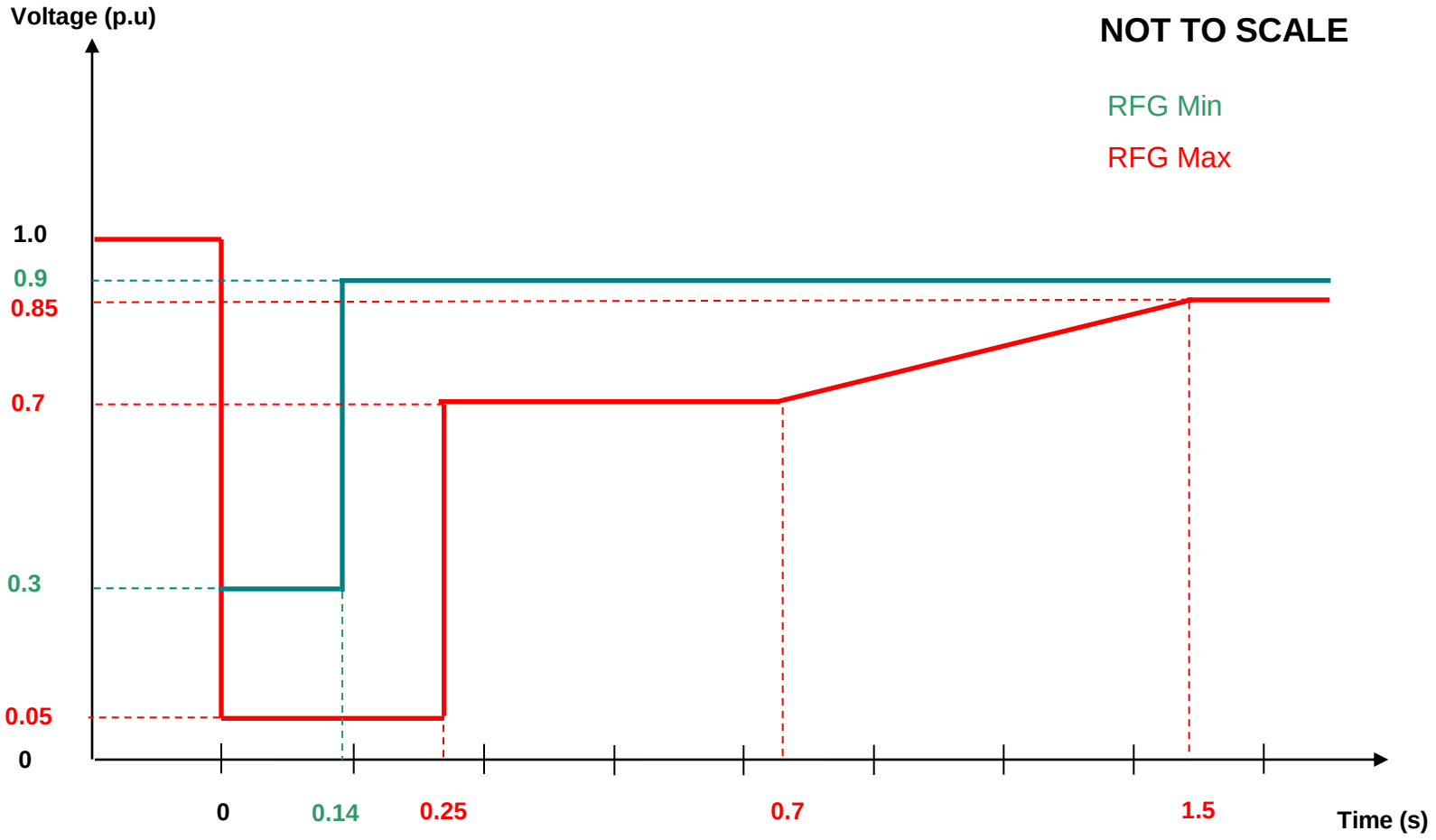
Voltage parameters [pu]		Time parameters [seconds]	
Uret:	**0.05 – 0.15**	**tclear:**	**0.14 – 0.15** (or 0.14 – 0.25 if system protection and secure operation so require)
Uclear:	**Uret – 0.15**	**trec1:**	**tclear**
Urec1:	**Uclear**	**trec2:**	**trec1**
Urec2:	**0.85**	**trec3:**	**1.5 – 3.0**

Table 3.1 – Fault Ride Through Capability of Power Park Modules

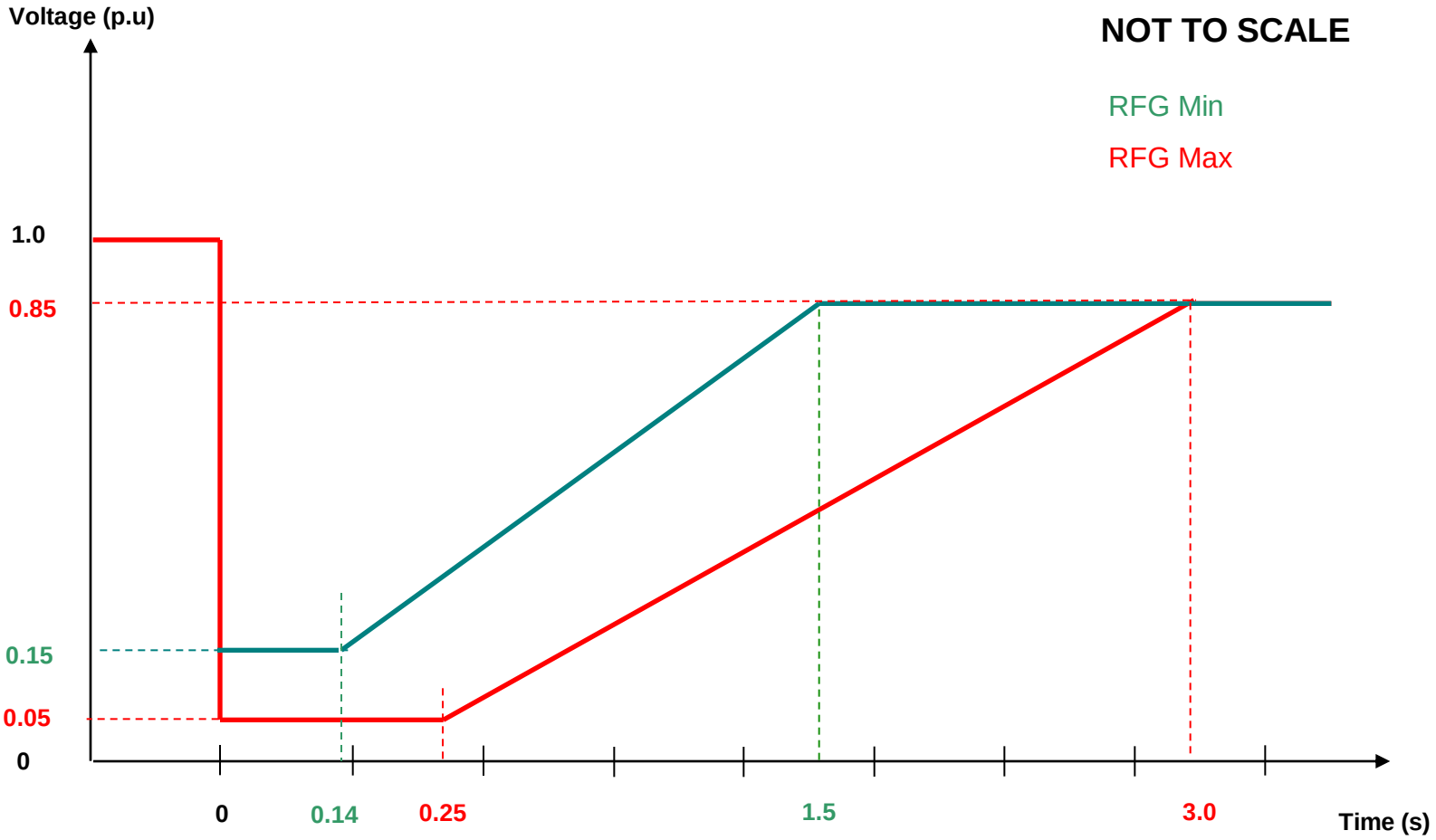
ENTSO-E RfG - Voltage Against Time Profile

Type B & C Synchronous Power Generating Modules - Table 3.1



ENTSO-E RfG - Voltage Against Time Profile

Type B & C Power Park Modules - Table 3.2



Additional Requirements for Type B & C Power Generating Modules

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- The power generating module shall be capable of remaining connected to the network and continuing to operate stably when the actual course of the phase to phase voltages on the network voltage level at the connection point during a symmetrical fault, given the pre and post fault conditions in points (iv) and (v) of paragraph (3)(a), remain above the lower limit specified in point (ii) of paragraph (3)(a), unless the protection scheme for internal electrical faults requires the disconnection of the power generating module from the network. The protection schemes and settings for internal electrical faults must not jeopardise fault ride through performance.
- Without prejudice to point (vi) of paragraph (3)(a),undervoltage protection (either fault ride through capability or minimum voltage specified at the connection point voltage) shall be set by the power generating facility owner according to the widest possible technical capability of the power generating module, unless the relevant system operator requires narrower settings in accordance with point (b) of paragraph (5). The settings shall be justified by the power generating facility owner in accordance with this principle.
- Fault ride through capabilities in case of asymmetrical faults shall be specified by each TSO.

Fault Ride Through Requirements for Type D Power Generating Modules

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- Type D Power Generating Modules (75MW+?) shall be capable of staying connected to the network and continuing to operate stably after the power system has been disturbed by secured faults. The capability shall be in accordance with a voltage against time profile at the connection point for fault conditions specified by the relevant TSO.
- The voltage against time profile shall express a lower limit of the actual course of the phase to phase voltages on the network voltage level at the connection point during a symmetrical fault as a function of time before during and after the fault.
- That lower limit shall be specified by the relevant TSO, using the parameters set out in Figure 3 and within the ranges set out in Tables 7.1 and 7.2 for **Type D power generating modules connected at or above the 110kV level**.
- That lower limit shall also be specified by the relevant TSO, using parameters set out in Figure 3 and within the ranges set out in Tables 3.1 and 3.2 for Type D Power Generating Modules connected below the 110kV level.
- Each TSO shall specify the pre-fault and post fault conditions for the fault ride through capability referred to in point (iv) of Article 14(3) (a). The specified pre-fault and post fault conditions for the fault ride through capability shall be made publically available.

ENTSO-E RfG - Voltage Against Time Parameters – Table 7.1 – Type D Synchronous Power Generating Modules

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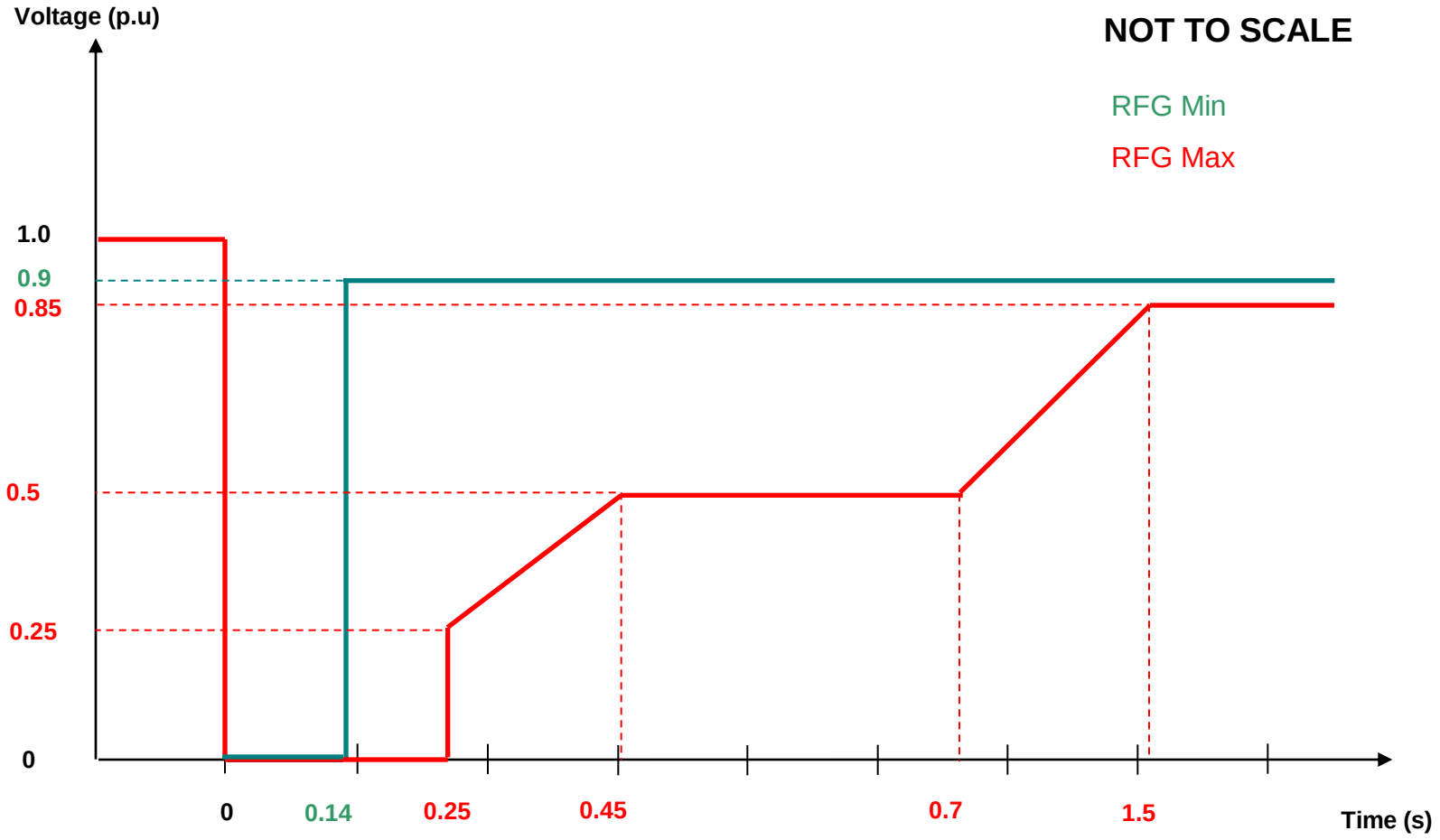
Voltage parameters [pu]		Time parameters [seconds]	
Uret:	**0**	**tclear:**	**0.14 – 0.15** (or 0.14 – 0.25 if system protection and secure operation so require)
Uclear:	**0.25**	**trec1:**	**tclear – 0.45**
Urec1:	**0.5 – 0.7**	**trec2:**	**trec1 – 0.7**
Urec2:	**0.85 – 0.9**	**trec3:**	**trec2 – 1.5**

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

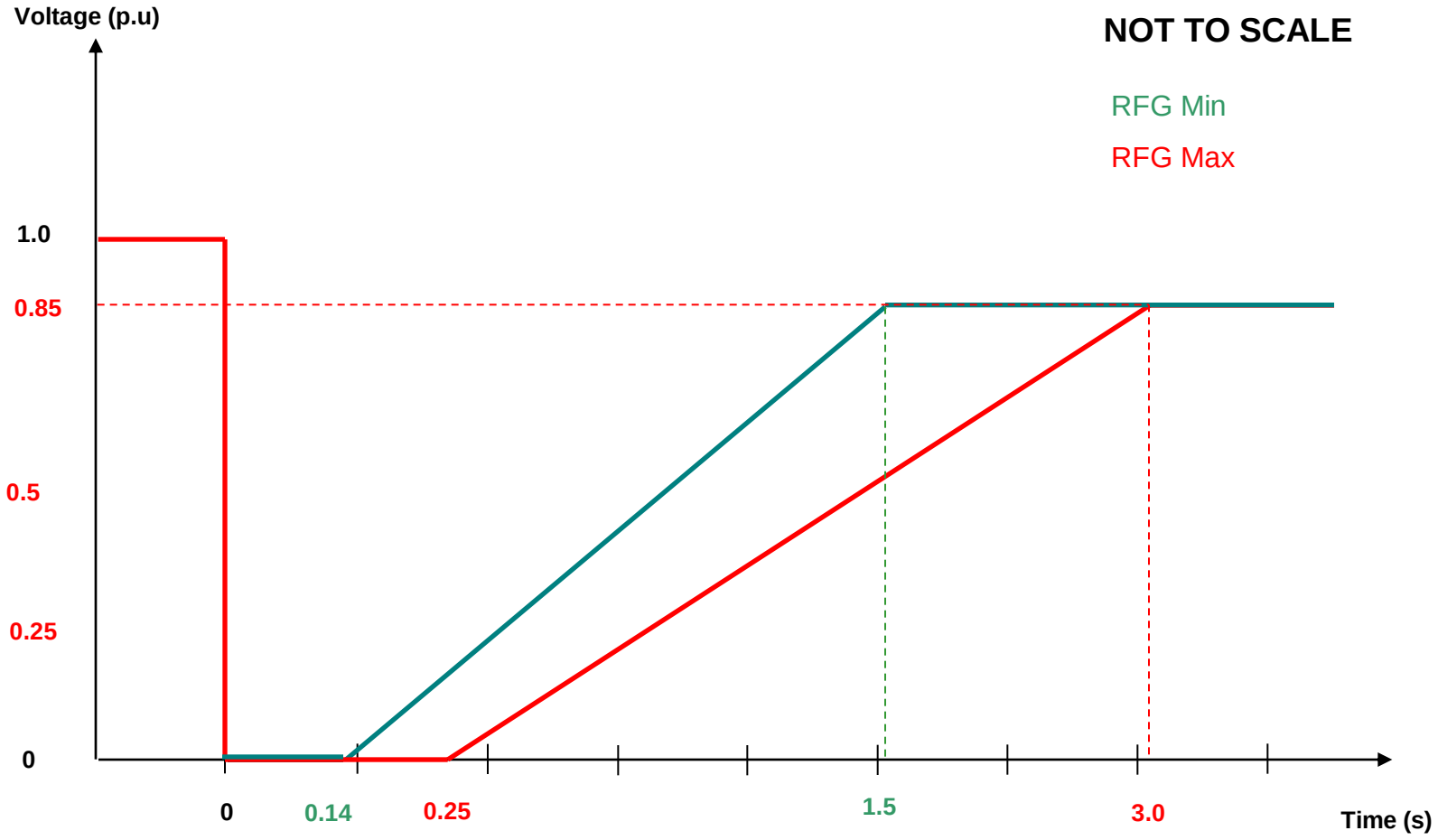
ENTSO-E RfG - Voltage Against Time Profile

Type D Synchronous Power Generating Modules Table 7.1



ENTSO-E RfG - Voltage Against Time Profile

Type D Power Park Modules Table 7.2



Fault Ride Through Requirements for Type D Power Generating Modules

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- At the request of a power generating facility owner, the relevant System Operator shall provide the pre-fault and post fault conditions to be considered for fault ride through capability as an outcome of the calculations at the connection point as specified in point (iv) of Article 14(3)(a) regarding:
- (i) pre-fault minimum short circuit capacity at each connection point expressed in MVA
- (ii) pre-fault operating point of the power generating module expressed as active power output at the connection point and voltage at the connection point and
- Post fault minimum short circuit capacity at each connection point expressed in MVA
- Fault ride through capabilities in case of asymmetrical faults shall be specified by each TSO.

Additional Fault Ride Through Requirements

- Article 17(2)(b) – Type B Synchronous Power Generating Modules – shall be capable of providing post fault active power recovery. The relevant TSO shall specify the magnitude and time for active power recovery.
- Article 19(3) – Type D Synchronous Power Generating Modules - The relevant TSO and Power Generating facility owner shall enter into an agreement regarding technical capabilities of the power generating module to aid angular stability under fault conditions.
- Article 20(2)(b) – Type B Power Park Modules – Fast Fault current injection – to be covered at a later stage of the RfG Fault Ride Through Implementation Group.
- Article 21(3)(e) – Type C Power Park Modules – prioritisation of active or reactive power - to be covered at a later stage of the RfG Fault Ride Through Implementation Group.
- Article 26(2) – Offshore Power Park Modules – as per Onshore requirements.

Example – Figure 9 – Taken from FAQ 24 – Power Park Module

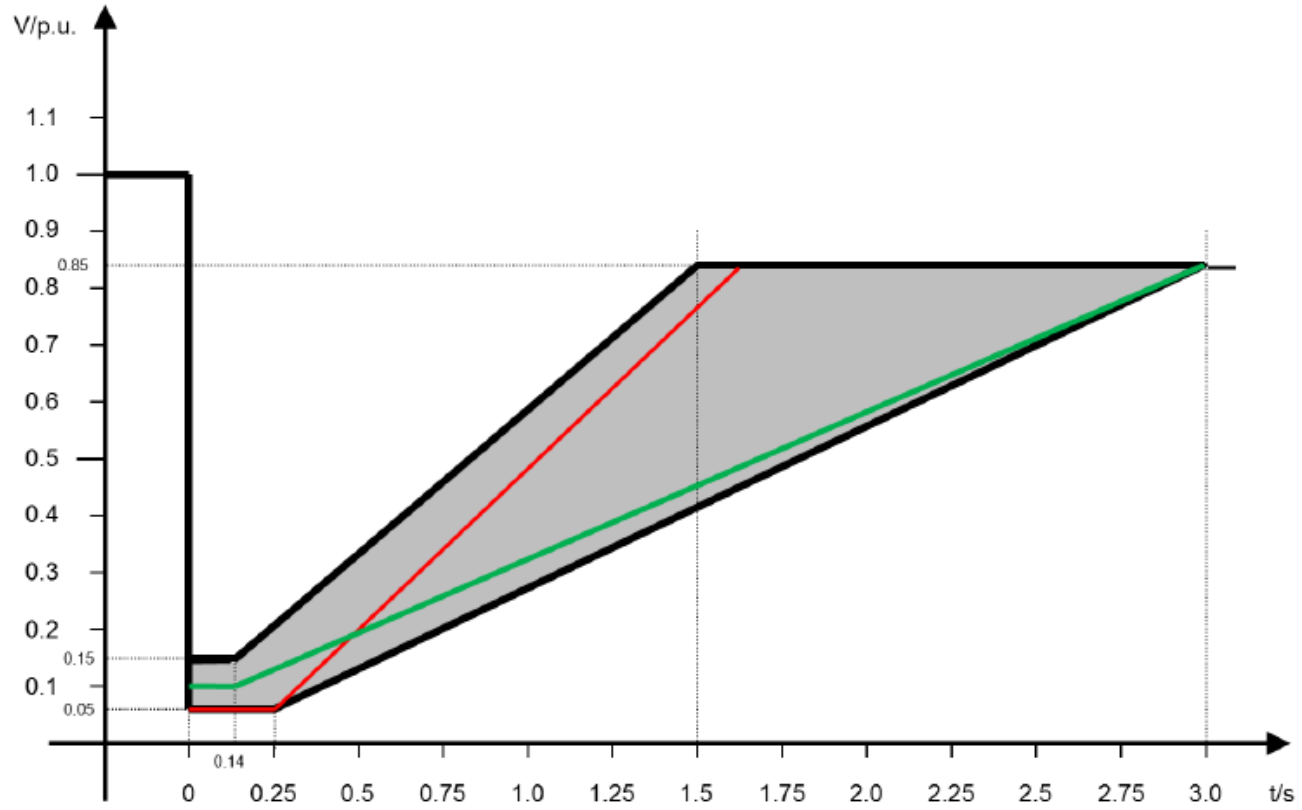

Figure 9: Area (grey) within which a voltage-against-time curve can be defined by the TSO for a Type B PPM, e.g. the given green or red curve

Example – Figure 10 – Taken from FAQ 24 – Power Park Module

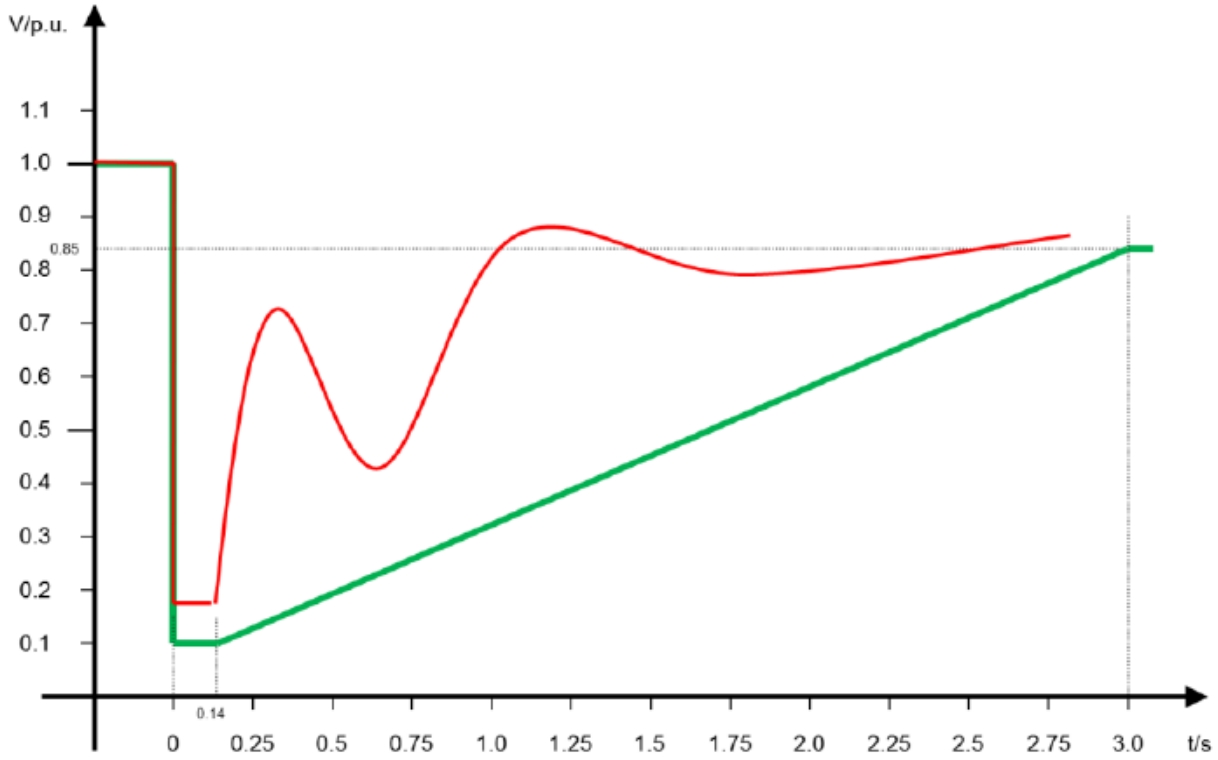

Figure 10: Case in which the recovery voltage (red curve) remains above the defined voltage-against-time curve (green curve) and because of which automatic disconnection of the Power Generating Module is not allowed.

Example – Figure 11 – Taken from FAQ 24 – Power Park Module

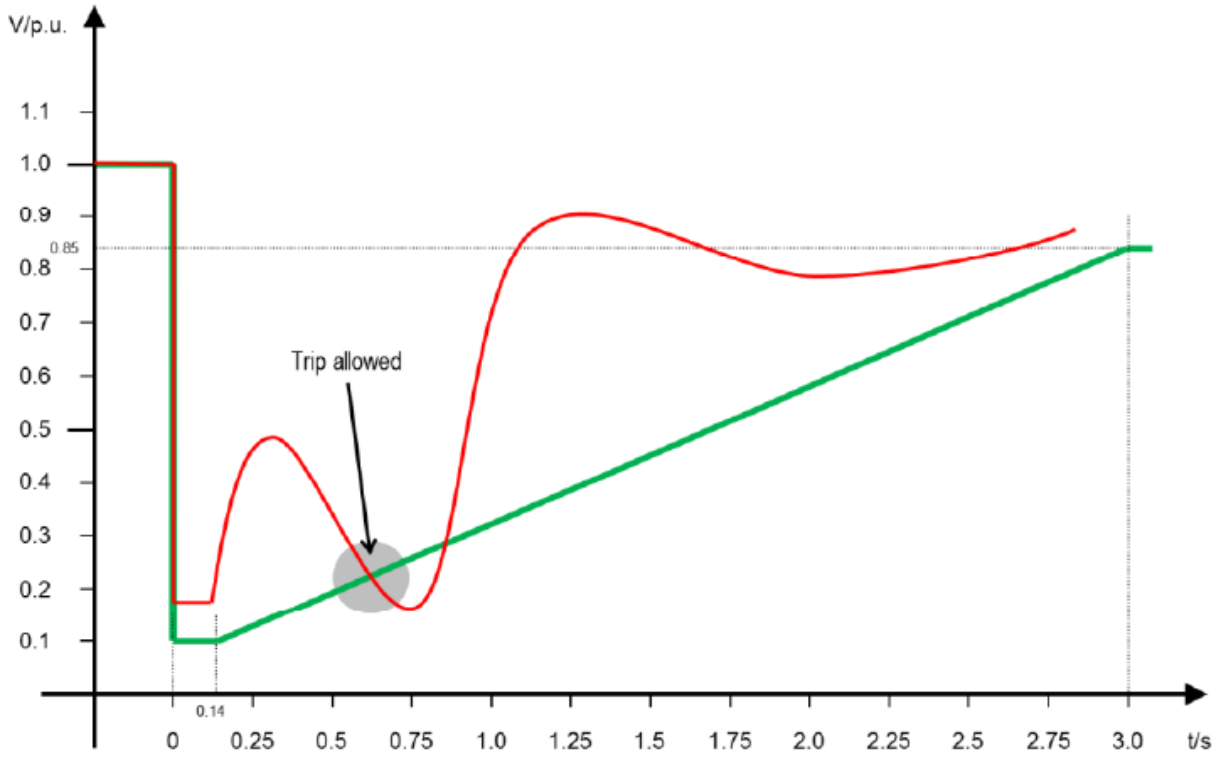

Figure 11: Case in which the recovery voltage (red curve) goes lower than the defined voltage-against-time curve (green curve) and because of which automatic disconnection of the Power Generating Module is allowed.

Explanation of ENTSO-E Fault Ride Through Requirements – FAQ 24

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- FAQ 24 clearly states that the TSO is not requiring the actual voltage recovery curve to be the shape of the voltage against time profile.
- The Voltage recovery curve will have a free controlled response during the post disturbance recovery period that will depend on the PPM technology (eg full converter, doubly fed etc) and the short circuit power of the Grid Connection Point.
- The voltage against time profile just expresses the lower limit for the actual voltage recovery curve for FRT capability

High Level differences with GB Grid Code FRT Requirements

- The Fault Ride Through Requirements in GB apply only to faults at Supergrid Voltages (ie 200kV) or above
- Split into two sections – faults up to 140ms in duration and faults in excess of 140ms.
- For voltage dips in excess of 140ms a voltage – duration profile is defined which is not a voltage response curve that would be obtained by plotting the transient voltage response at a point on the Onshore Transmission System to a disturbance but rather each point on the profile (ie the heavy black line) represents a voltage level and an associated time duration which connected Generating Units and Power Park Modules must ride through (CC.A.4A.3).
- The same requirement applies to both Power Park Modules and Synchronous Generating Units.
- Requirements exist for Reactive Power Injection during the fault and Active Power recovery on fault clearance

Findings of GC0062 Workgroup

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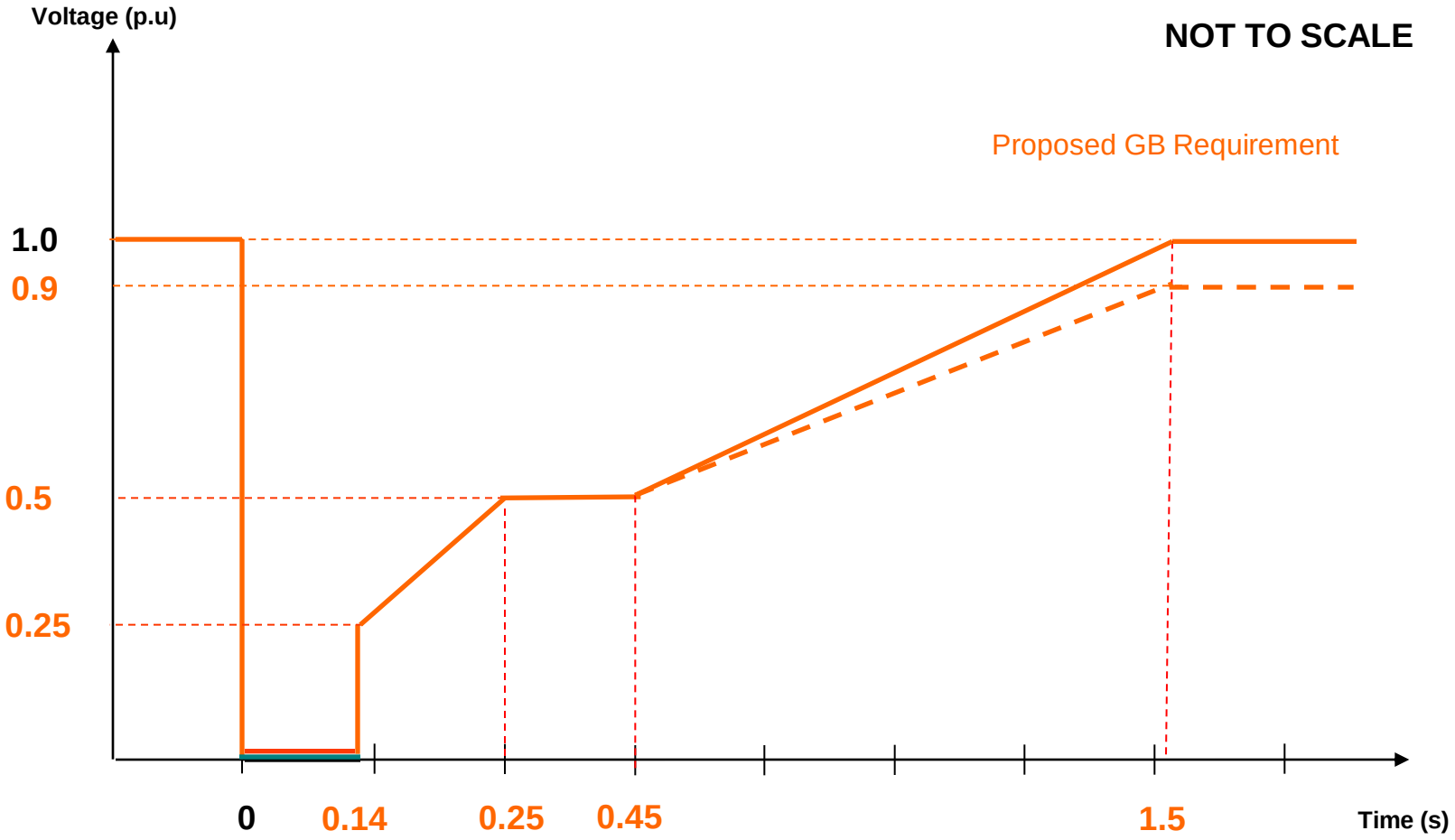
Summary

- GC0062 identified the Grid Code defect identified in paper PP12/04 could not be addressed through early adoption of RfG.
- As GC0062 initially advised that that early adoption of RfG may offer a solution to this issue, Appendix 2 of the GC0062 Workgroup report provides detailed analysis of how RfG should be interpreted and suggested a possible Voltage against time curve / parameter list for a Transmission Connected Synchronous Power Generating Module.
- Further work is still required in this area but the following slides give an indication of the work completed to date

Proposed GB Type D Requirement

Voltage Against Time Curve



GB Suggested Parameters – Consistent with Table 7.1 (Type D SPGM)

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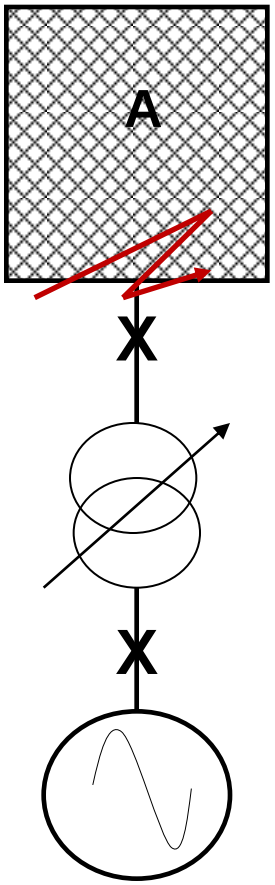
Voltage parameters [pu]		Time parameters [seconds]	
Uret:	0	tclear:	0.14
Uclear:	0.25	trec1:	0.25
Urec1:	0.5	trec2:	0.45
Urec2:	(1.0)? (0.9)?	trec3:	1.5

Table 7.1 – Parameters for Figure 3 for fault ride through capability of synchronous power generating modules.

Assessment of Compliance Design / Operational Requirements

- NGET will run initial stability studies at the application stage with the appropriate pre and post fault short circuit level.
- Results should demonstrate a stable system with the appropriate excitation system
- Generator to run detailed studies using the equivalent model supplied – see next slide
- In cases of non compliance discussions will need to be held with NGET on appropriate actions
  - Enhanced Excitation
  - Faster fault clearing times
  - Others

Fault Ride Through
Suggested Equivalent Model for Compliance Purposes



1) Solid (zero impedance) three phase short circuit fault applied at Substation A for 140ms
2) Pre fault Short Circuit Level = 15,000 MVA
3) Post Fault Short Circuit Level = 10,000 MVA
4) Maximum Reactive current to be injected during the period of the fault
5) Active power to be restored to 90% of the pre-fault active power within 0.5 seconds of fault clearance

Operating Conditions of Generator (all Values quoted at the terminals)
MVA Rating = 2082MVA
Pmax = 1750 MW
Full lead = -560 MVAr (ie 0.95 PF lead at the Generating Unit Terminals)
Pre Fault Operating Voltage at Substation A = 1.0p.u
Post Fault Operating Voltage at Substation A = To be advised by NGET during offer stage following multi machine studies

Voltage Against Time Curve Type B and C SPGM

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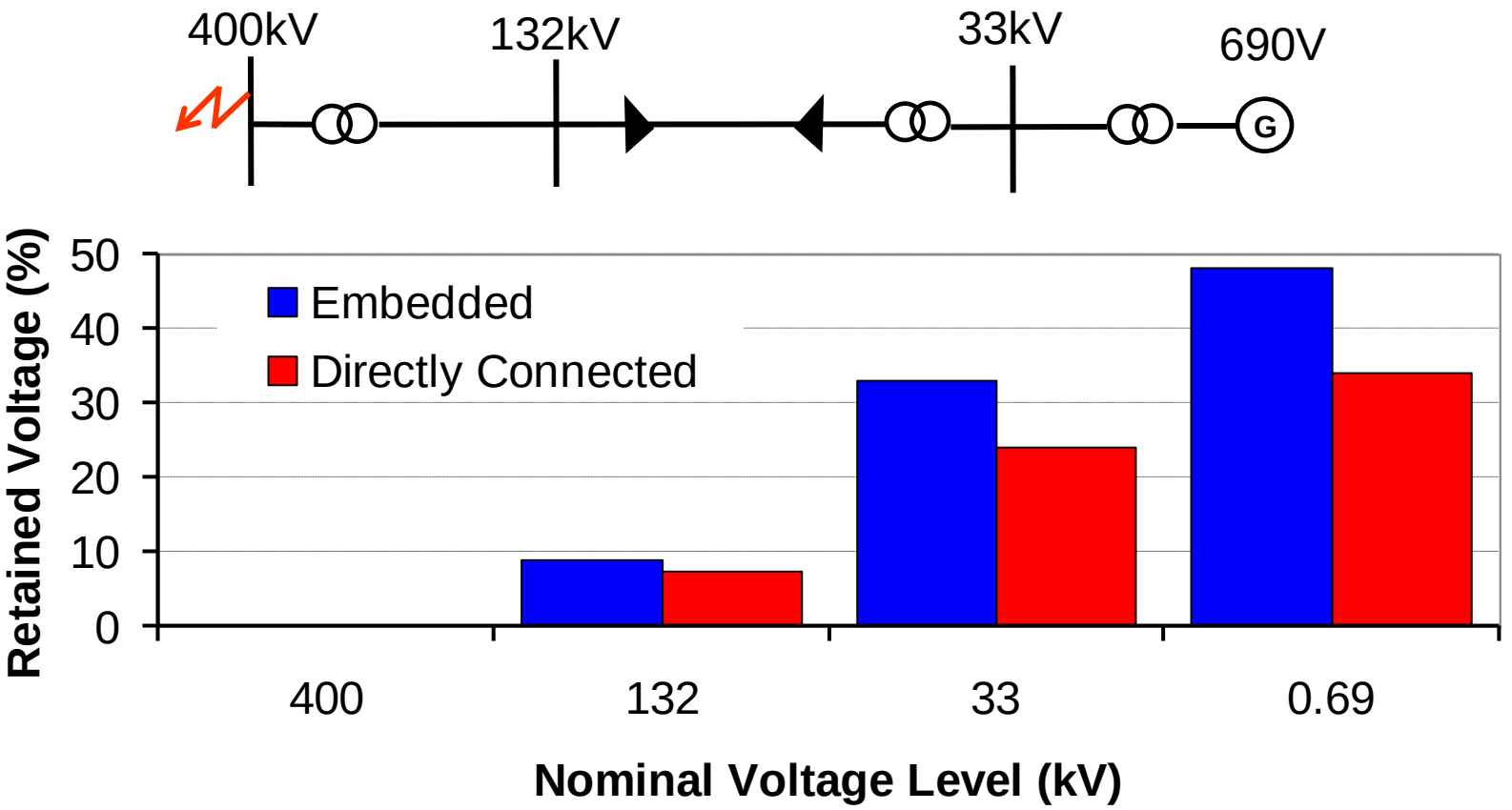
- Under Article 14(3)(a)(i) – specifies the conditions which the power Generating Module is capable of staying connected to the network and continuing to operate stably after the power system has been disturbed by **secured faults on the transmission system**.
- In other words for a solid three phase short circuit fault on the Transmission system Embedded Generation should remain connected and stable.
- In summary the voltage against time curve for B and C Synchronous Generators should be equivalent to that for Transmission Connected Generators allowing for the appropriate levels of transformation (see next slide).
- We also need to ensure that not more than 1800MW are not lost for a Distribution fault.

Retained Voltage at an Embedded Generator during a Transmission System Fault



Voltage Against Time Curve for Power Park Modules

- Further work required but would need to be between the ranges identified on slides 35 and 40.
  - Suggest the same approach is adopted as applied for Synchronous
  - Develop voltage against time curve for Type D Power Park Modules
  - Apply the equivalent requirements for Type B and C.
- Principles applied for Power Park Modules would be expected to be the same as Synchronous Power Generating Modules

Next Steps

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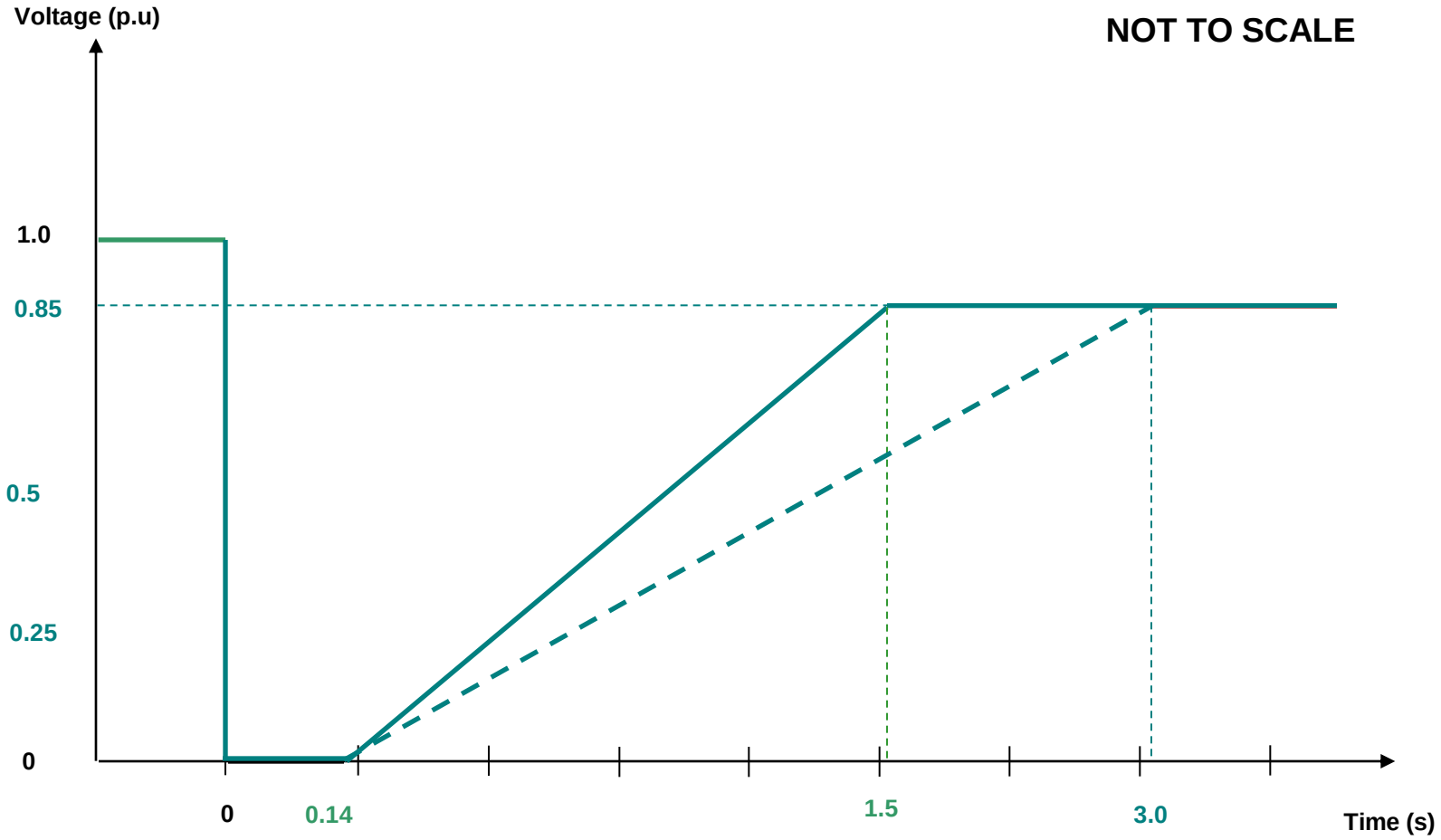
Next Steps

- Review suggested Voltage against time curve for Large (Type D Transmission Connected Plant) SPGM
- Apply equivalent requirement for Type B and C SPGM
- Develop requirements for Power Park Modules (Type D Transmission Connected) – noting choices are quite limited
- Apply equivalent for Type B and C.
- Fast Fault Current injection requirements for Power Park Modules to be addressed.
- Ensure correct industry representation
- Legal drafting

ENTSO-E RfG - Voltage Against Time Profile

Type D Power Park Modules GB Range Available



What has been achieved so far

- An understanding of the RfG fault ride through requirements
- Suggested voltage against time curve for Transmission Connected (Type D Plant) Table 7.1
- Methods for demonstrating compliance
- Other issues (eg Active Power Recovery following fault clearance (currently set at 0.5 seconds)) would remain unchanged
- More detailed information is available from GC0062 Workgroup Report (Appendix 2) and Consultation document
- National Grid will continue to run more detailed studies
- As part of this process we need engagement from all interested parties including any study work as we do not have details of Generator models especially those connected to the Distribution Network
- The requirements need to reflect Generator capability as well as the minimum needs of the Transmission System

Discussion