HVDC Implementation
Fault Ride Through

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Summary

- Summary
- Definitions
- Overview
- Offshore Structure Application of Codes
- Fault Ride Through Requirements for HVDC Converters – Title II Chapter 3
- Fault Ride Through Requirements for DC Connected Power Park Modules - Title III, Chapter 1
- Fault Ride Through Requirements for Remote End HVDC Converter Stations - Title III, Chapter 2
- Discussion

Definitions

No	EU Term	Definition
3	Voltage	unless otherwise specified means the difference in electrical potential between two points measured as the root-mean-square value of the positive sequence phase-to-phase voltages at fundamental frequency;
4	Apparent Power	Unless otherwise specified means the product of voltage and current at fundamental frequency, and the square root of three in the case of three-phase systems, usually expressed in kilovolt-amperes ('kVA') or megavolt-amperes ('MVA');
20	Active Power	Unless otherwise specified means the real component of the apparent power at fundamental frequency, expressed in watts or multiples thereof such as kilowatts ('kW') or megawatts ('MW');
22	Frequency	Unless otherwise specified means the electric frequency of the system expressed in hertz that can be measured in all parts of the synchronous area under the assumption of a consistent value for the system in the time frame of seconds, with only minor differences between different measurement locations. Its nominal value is 50Hz;
28	Reactive Power	Unless otherwise specified means the imaginary component of the apparent power at fundamental frequency, usually expressed in kilovar ('kVAr') or megavar ('MVAr');
31	Current	Unless otherwise specified means the rate at which electric charge flows which is measured by the root-mean-square value of the positive sequence of the phase current at fundamental frequency;
55	fast fault current'	Unless otherwise specified means a current injected by a power park module or HVDC system during and after a voltage deviation caused by an electrical fault with the aim of identifying a fault by network protection systems at the initial stage of the fault, supporting system voltage retention at a later stage of the fault and system voltage restoration after fault clearance;

Overview

- Title II, Chapter 3 – Article 25, 26, 27, Annex V – Fault Ride Through requirements for HVDC Converters including post fault active power recovery and recovery from DC faults
- Title III, Chapter 1 – Requirements for DC Connected Power Park Modules – As per RfG (Articles 14(3), 16(3), plus fast fault current injection 20(2) and 20(3)) and HVDC Code Article 40(3). All requirements apply at the HVDC Interface Point
- Title III, Chapter 2 – Requirements for Remote End HVDC Converter Stations – As per Title II and applicable at the Remote End Converter Station Network?

Overview of Requirements

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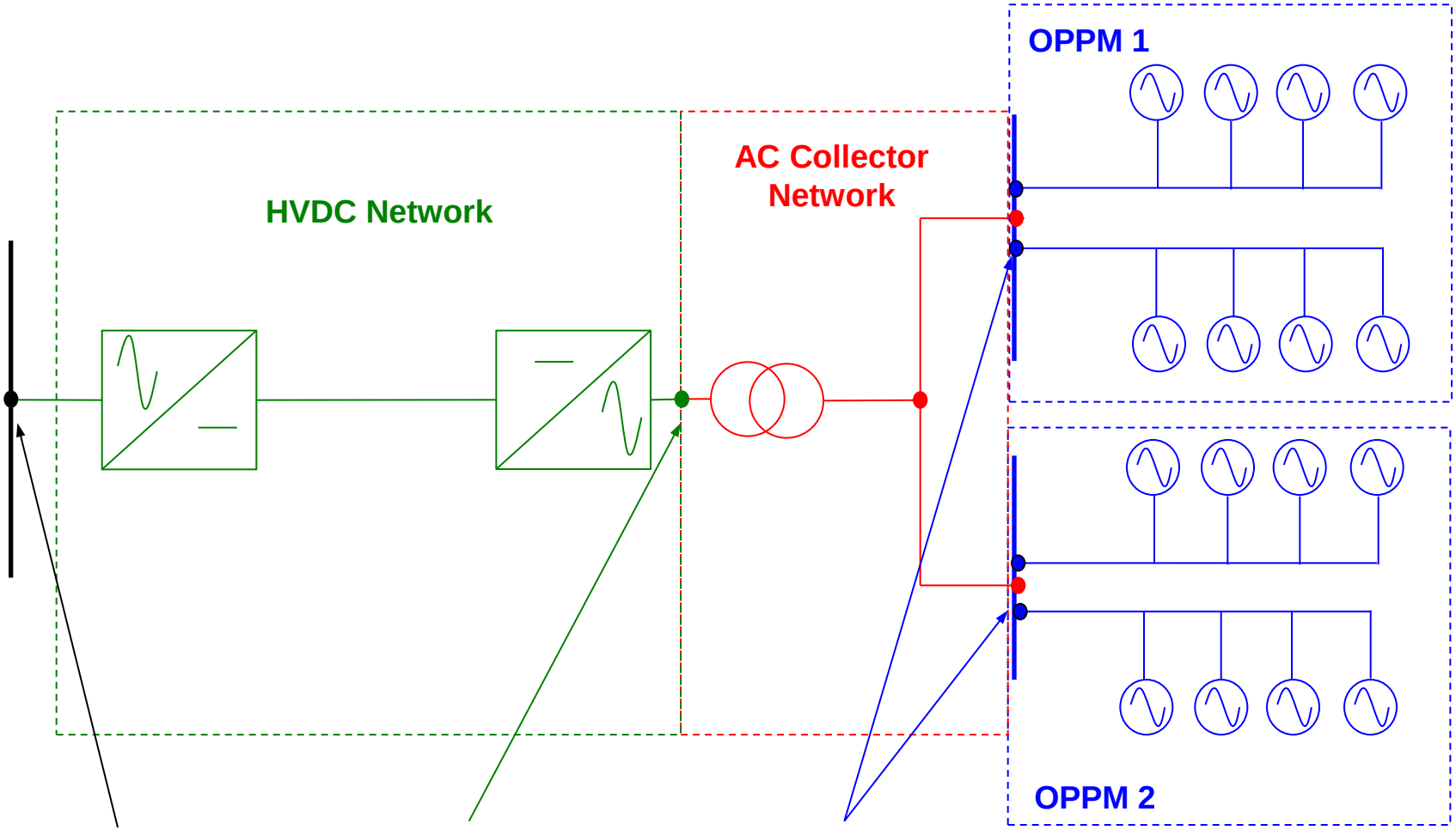

Overview of Requirements

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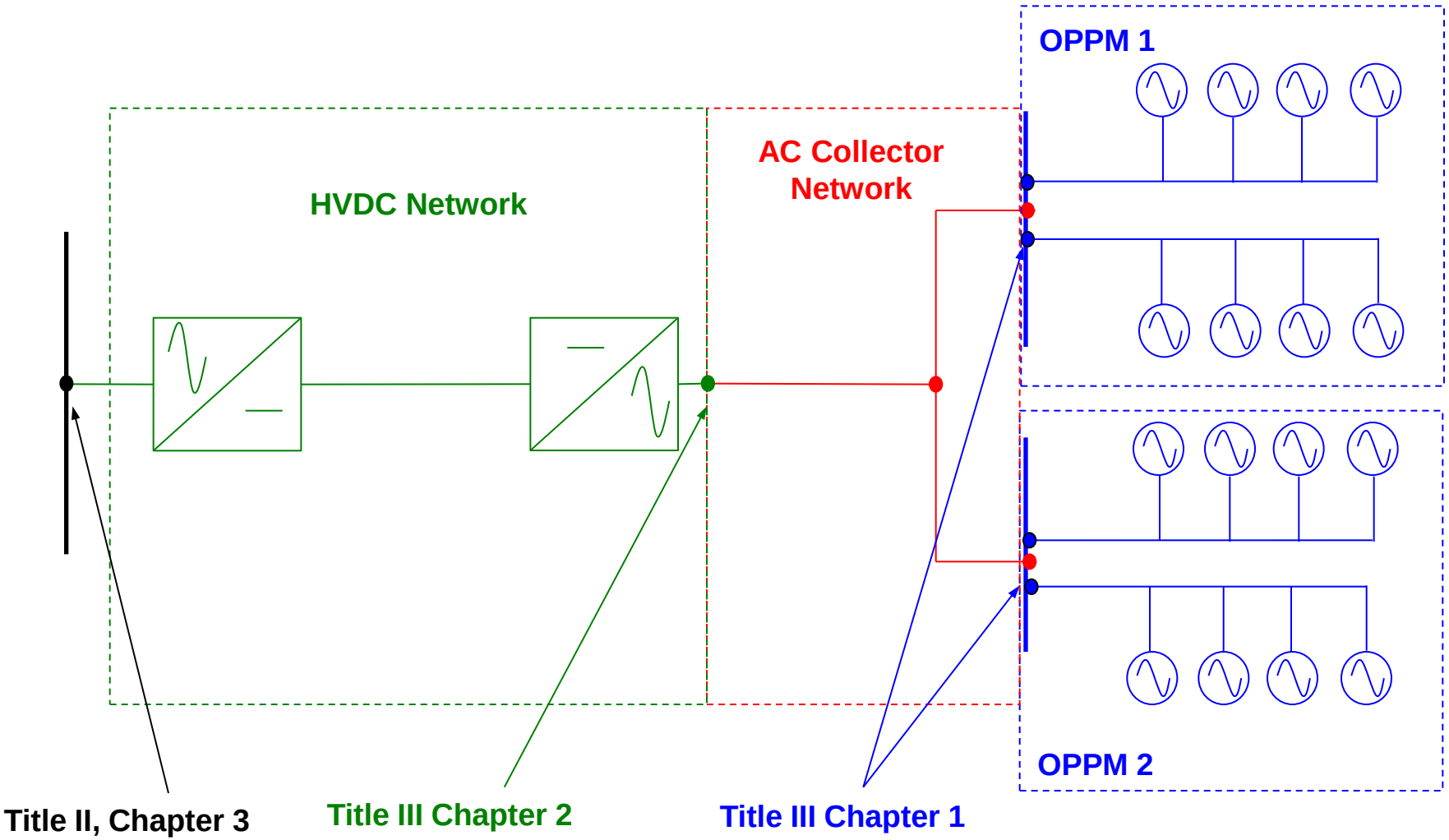
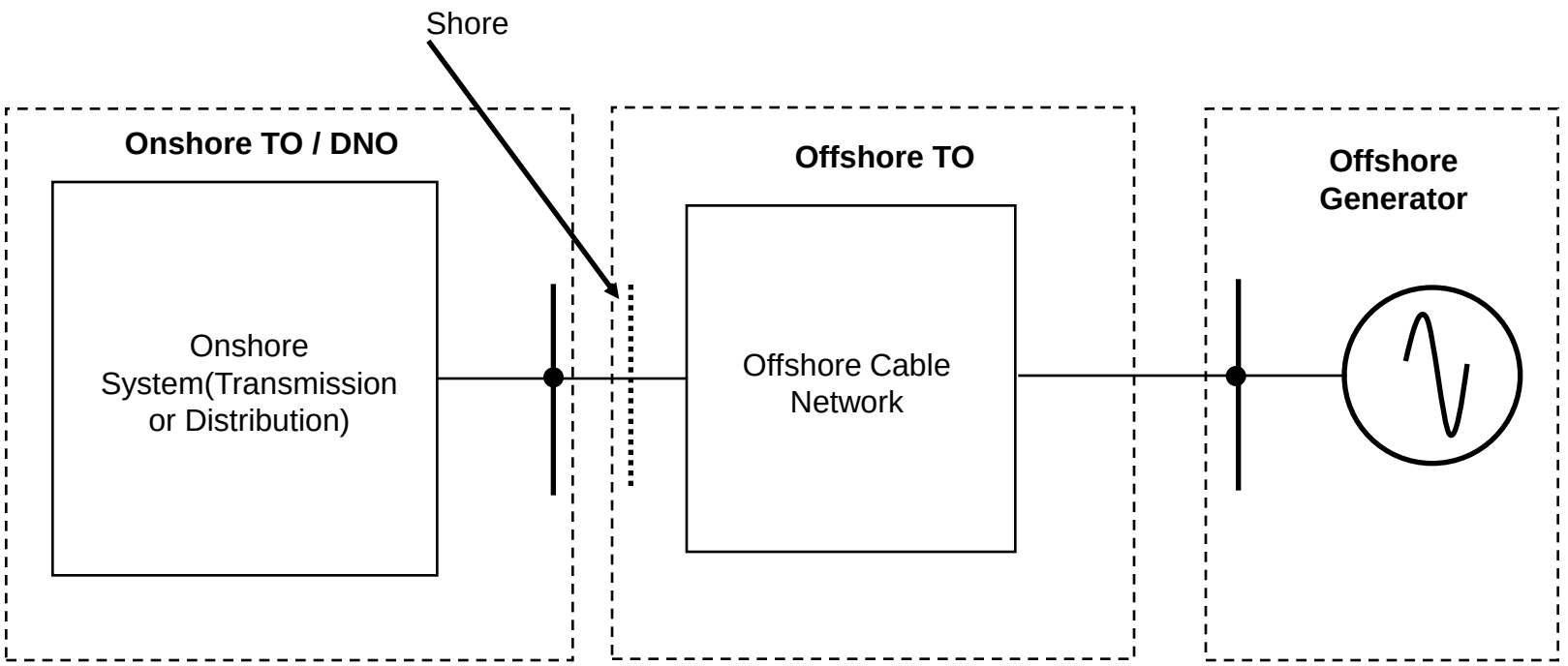


Offshore Structure - Application of Codes

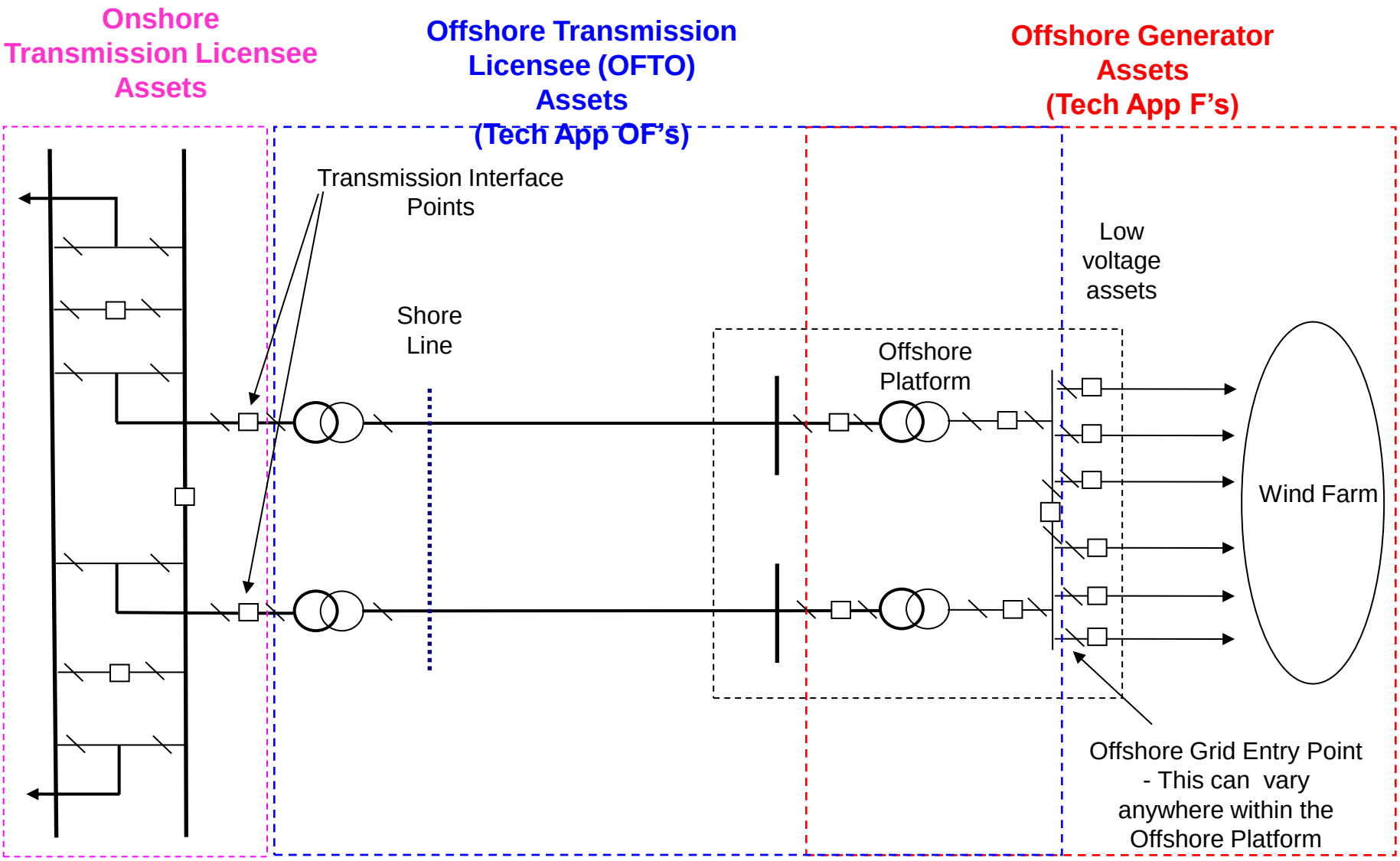


STC / Grid Code
SQSS
Distribution Code
CUSC
DCUSA
(HVDC Code – Title II Chapter 3)

STC
SQSS
(HVDC Code for Remote End HVDC Converters)- Title III Chapter 2

Grid Code (RfG)
CUSC
BSC
Bilateral Agreements

Typical Ownership Boundaries



Fault Ride Through Capability for HVDC Converters - Title II, Chapter 3

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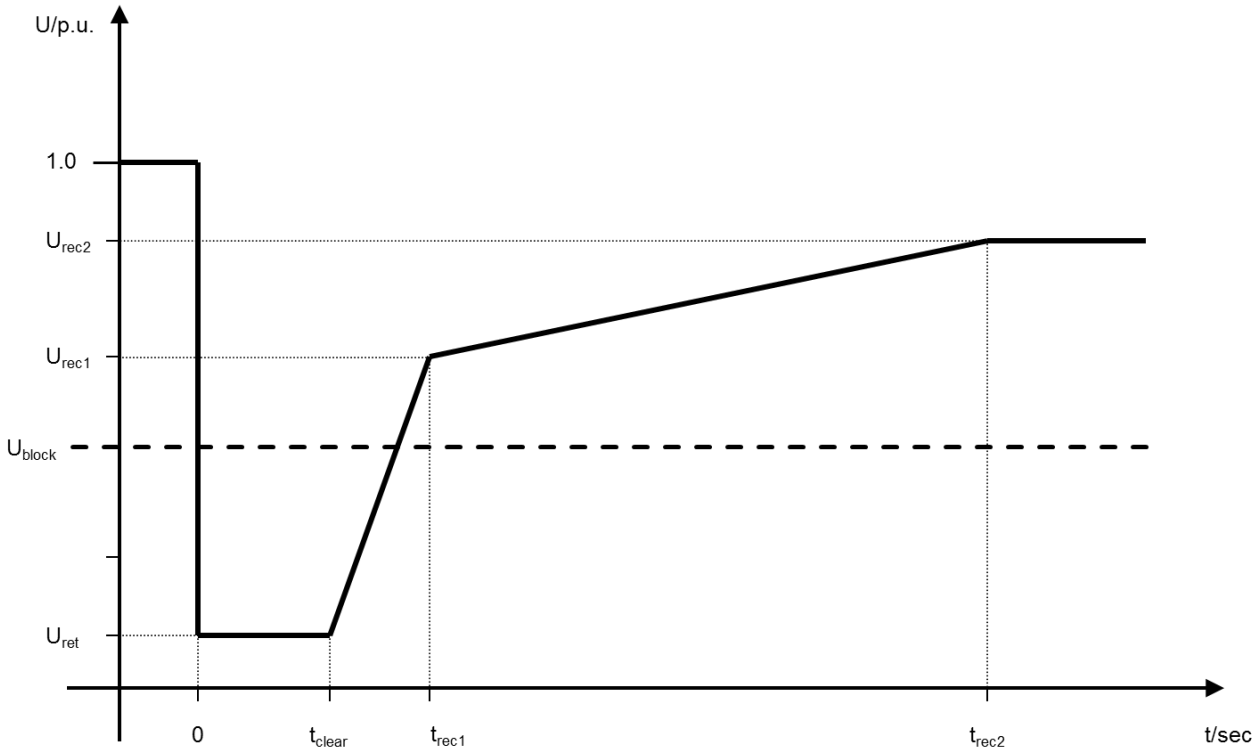
Annex V- HVDC Voltage against time curve – Figure 6

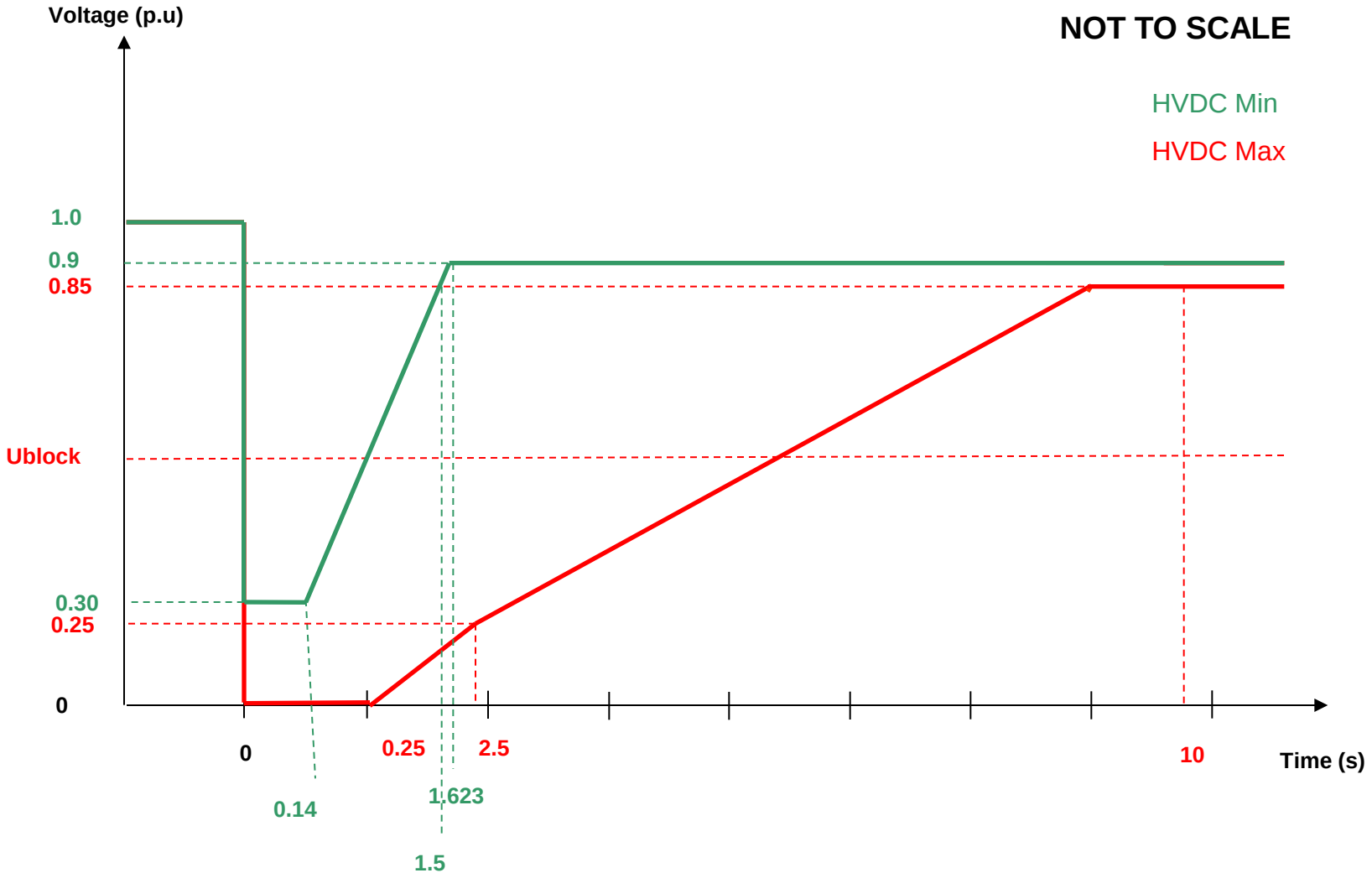


Fault-ride-through profile of an HVDC converter station. The diagram represents the lower limit of a voltage-against-time profile at the connection point, expressed by the ratio of its actual value and its reference 1 pu value in per unit before, during and after a fault. U_{ret} is the retained voltage at the connection point during a fault, t_{clear} is the instant when the fault has been cleared, U_{rec1} and t_{rec1} specify a point of lower limits of voltage recovery following fault clearance. U_{block} is the blocking voltage at the connection point. The time values referred to are measured from t_{fault}.

Annex V- HVDC Voltage against time curve Parameters – Table 7

Voltage Parameters [pu]		Time Parameters [seconds]	
U_{ret}	0.00 – 0.30	t_{clear}	0.14 - 0.25
U_{rec1}	0.25 – 0.85	t_{rec1}	1.5 - 2.5
U_{rec2}	0.85 – 0.90	t_{rec2}	T_{rec1} – 10.0

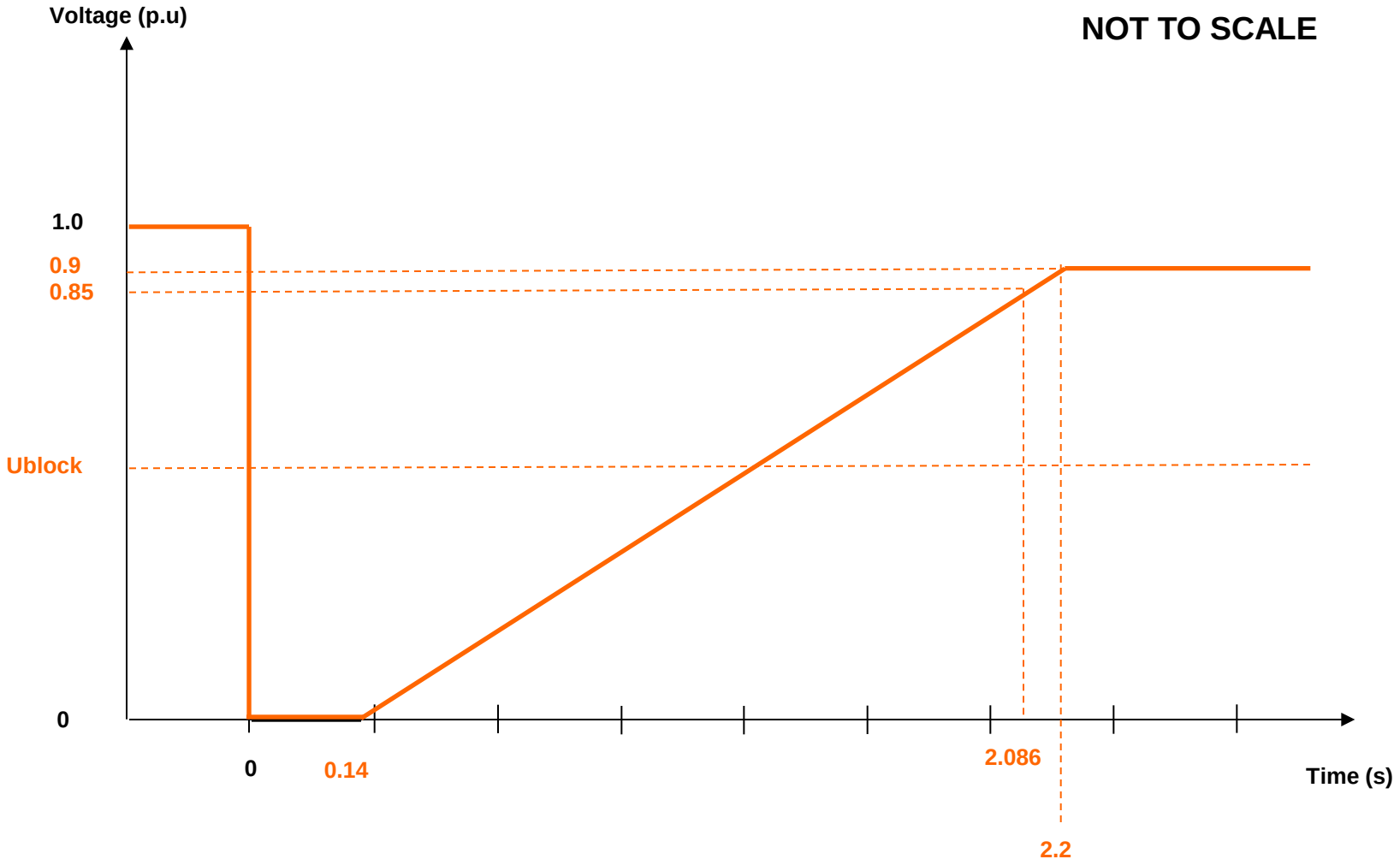
HVDC Proposed Voltage Against Time Curve Profile - Ranges



Fault Ride Through Capability for HVDC Converters – Parameter Settings

- U_{ret} set at zero Volts – solid three phase short circuit fault
- t_{clear} set at 140ms – maximum protection operating time consistent with RfG.
- U_{rec1} set at 0.85 p.u volts to retain consistency with RfG – Type D Power Park Modules on the basis the technology in some instances is similar.
- t_{rec1} set at 2.086 consistent with Type D Power Park Modules
- U_{rec2} set at 0.9 consistent with return back to the normal operational range under the SQSS
- t_{rec2} set at 2.2 seconds to ensure consistency with SQSS
- U_{block} to be discussed with Stakeholders
- Profile is consistent with RfG for Type D Power Park Modules

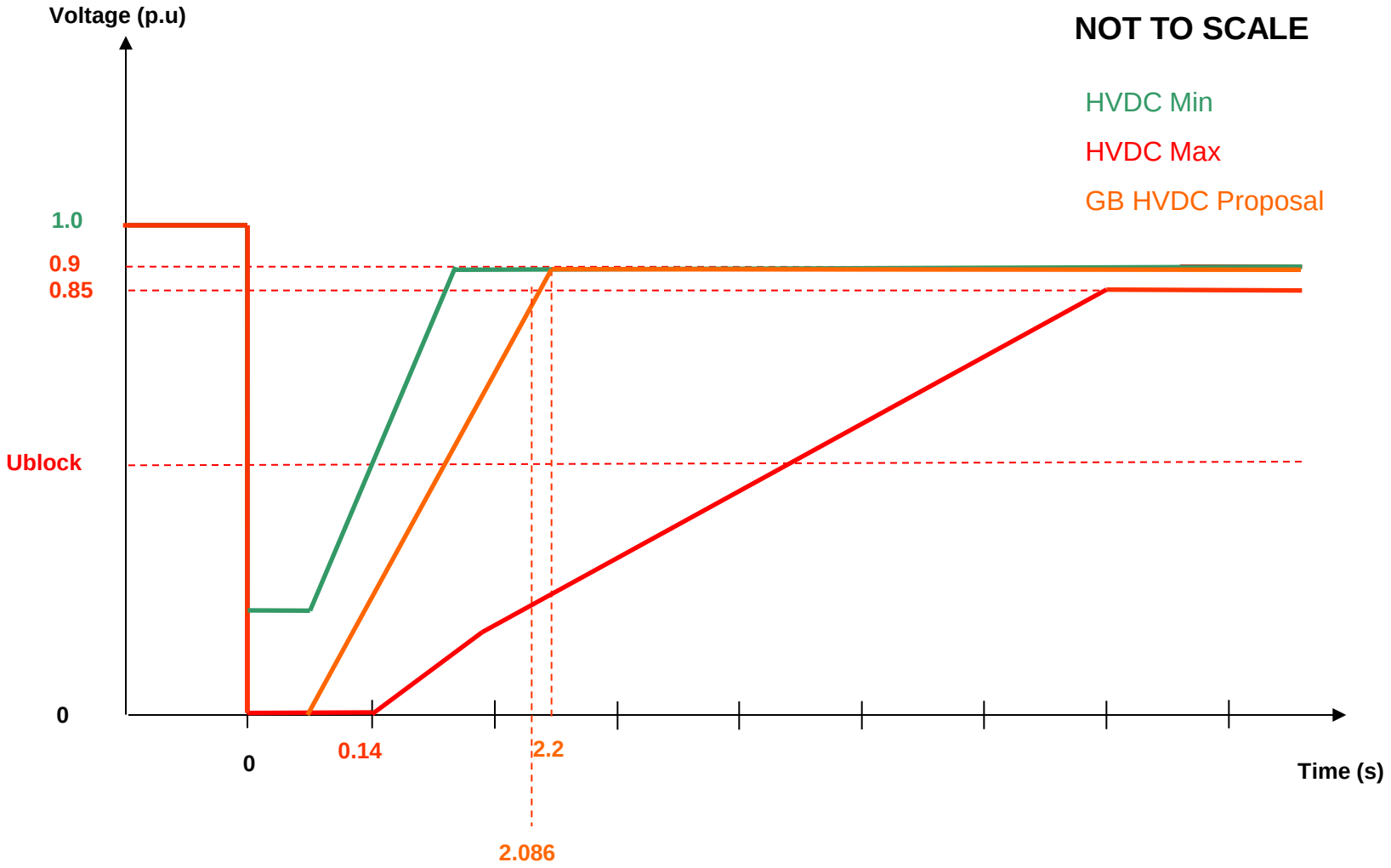
HVDC Proposed Voltage Against Time Profile



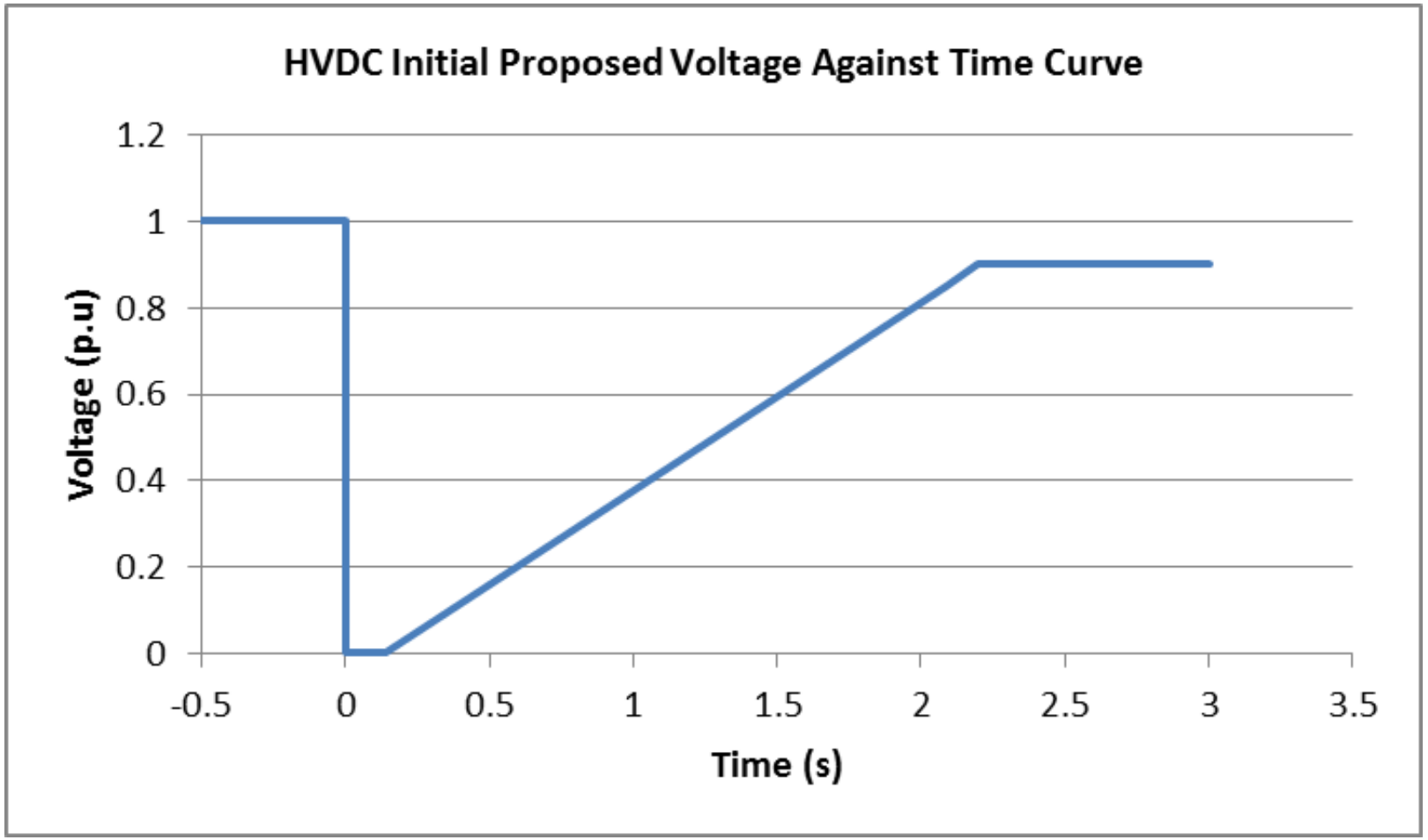
Proposed Voltage against time curve GB Parameters

Voltage Parameters [pu]		Time Parameters [seconds]	
U_{ret}	0.00	t_{clear}	0.14
U_{rec1}	0.85	t_{rec1}	2.086
U_{rec2}	0.90	t_{rec2}	2.2

HVDC Proposed Voltage Against Time Curve - Initial Proposal



HVDC Proposed Voltage Against Time Curve
Initial Proposal *(To Scale)*



Fault Ride Through Capability for HVDC Converters (Title II - Chapter 3 – Art 25(2))

- On request by the HVDC system owner, the relevant system operator shall provide the pre-fault and post-fault conditions as provided for in Article 32 regarding:
  - NGET will specify the pre-fault and post fault minimum short circuit capacity at each connection point expressed in MVA in the Bilateral Agreement
  - The DC Converter Station would be expected to be operated at Rated MW output and full leading MVAr capability (ie importing MVAr)

Fault Ride Through Capability for HVDC Converters (Title II - Chapter 3 – Art 26 & 27)

- Article 26 – Post Fault Active Power Recovery
  - Each DC Converter shall be capable of achieving full active power transfer within 0.5 seconds of fault clearance (ie restoration of the voltage to 0.9p.u or above)
- Article 27 – Fast Recovery from DC Faults
  - HVDC systems, including DC overhead lines, shall be capable of fast recovery from transient faults within the HVDC system. Details of this capability shall be subject to coordination and agreements on protection schemes and settings pursuant to Article 34.

Fault Ride Through requirements for DC Connected Power Park Modules -

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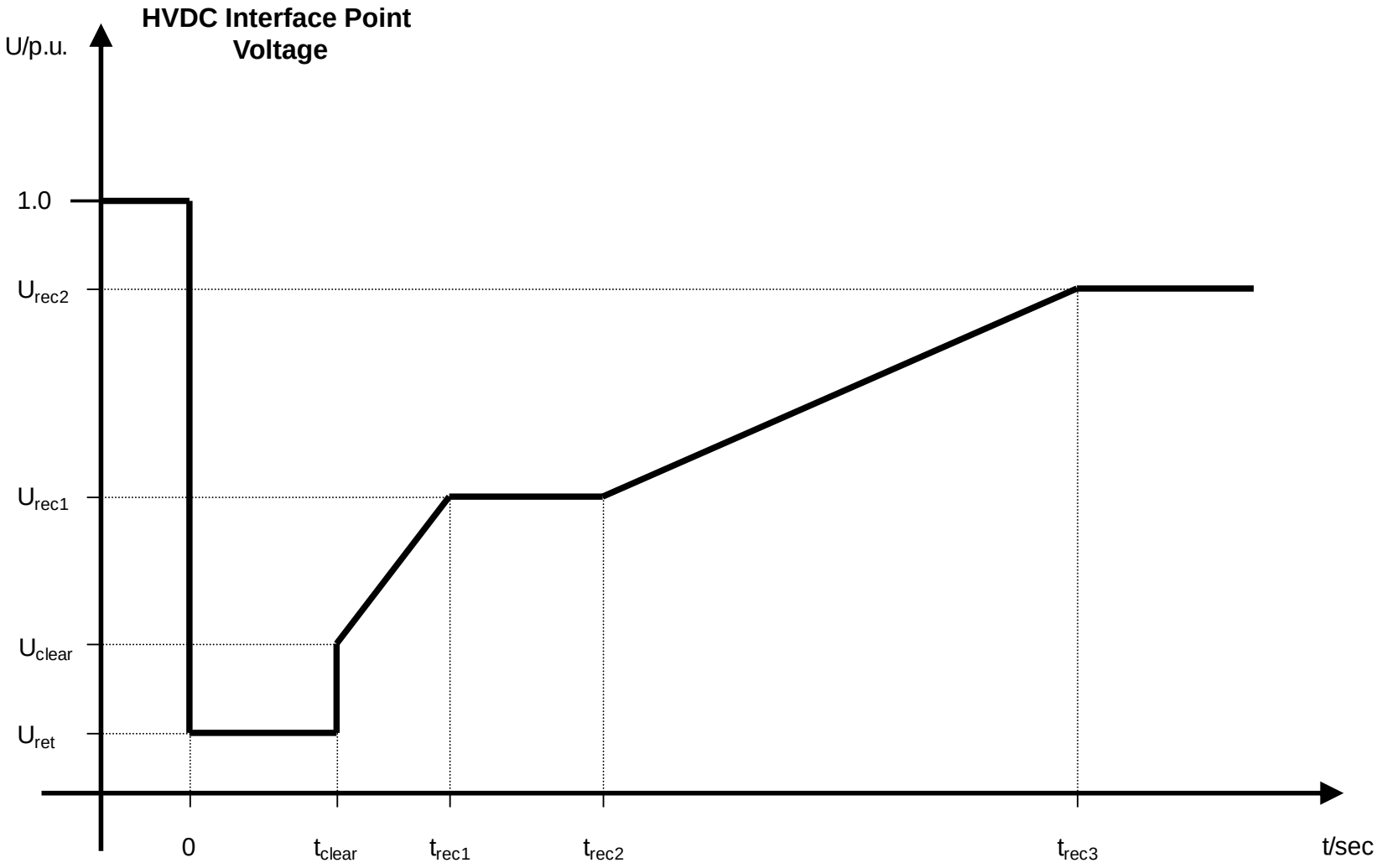
Summary

- Proposed Voltage against time curve for Type D Synchronous Power Generating Modules connected at or above 110kV
- Type B, C and D Synchronous Power Generating Modules Connected below 110kV – General Requirements
- Proposed Voltage against time curve for Type C and D Synchronous Power Generating Modules Connected below 110kV
- Proposed Voltage against time curve for Type B Synchronous Power Generating Modules
- Proposed Voltage against time curve for Type D Power Park Modules connected at or above 110kV
- Proposed Voltage against time curve for Type B, C and D Power Park Modules connected below 110kV

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



Type D Synchronous Power Generating Modules connected at or above 110kV

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RfG - Voltage Against Time Parameters – Table 7.1 – Type D Synchronous Power Generating Modules ≥ 110kV

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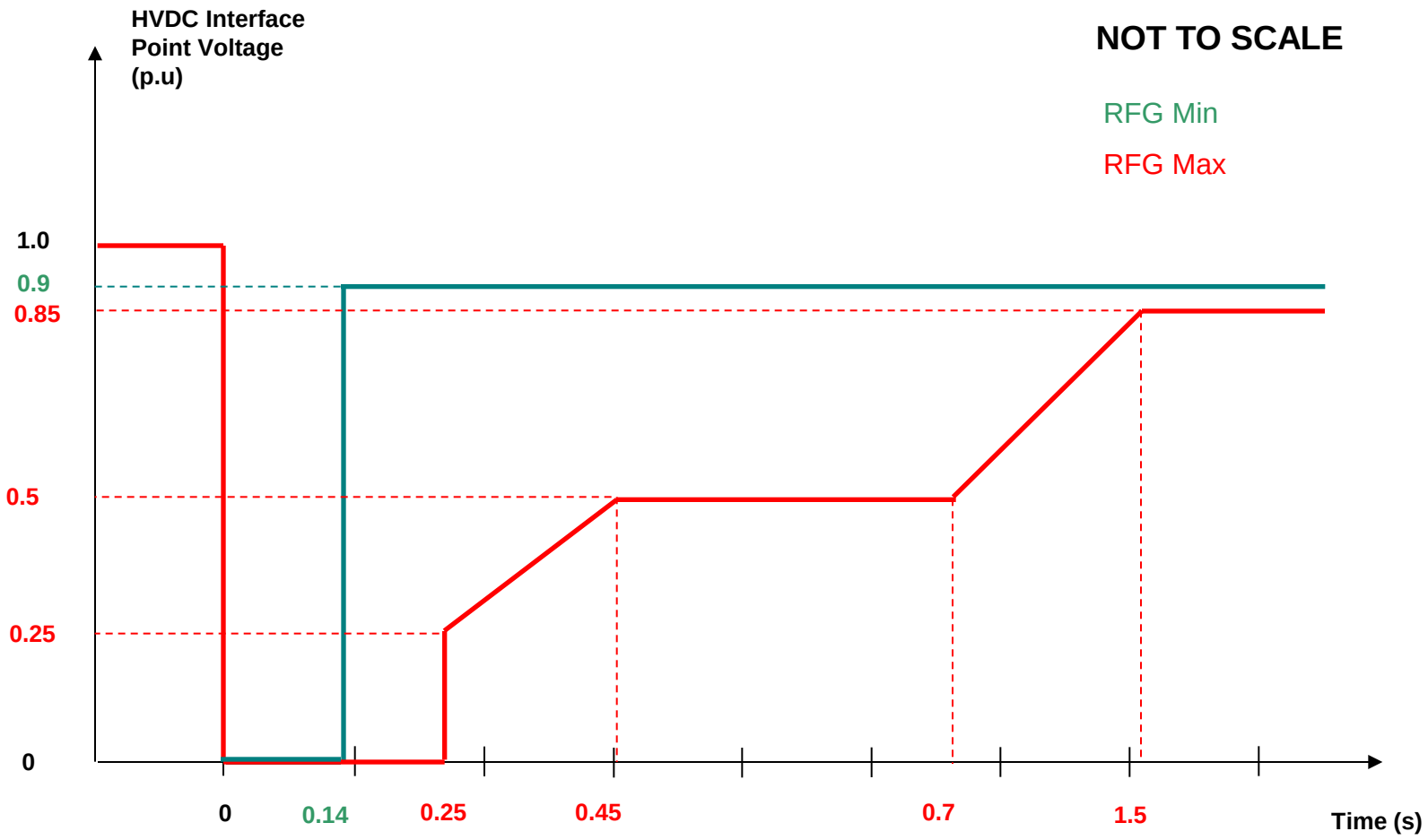
Voltage parameters [pu]		Time parameters [seconds]	
U_{ret}:	0	t_{clear}:	**0.14 – 0.15** (or 0.14 – 0.25 if system protection and secure operation so require)
U_{clear}:	0.25	t_{rec1}:	t_{clear} – 0.45
U_{rec1}:	0.5 – 0.7	t_{rec2}:	t_{rec1} – 0.7
U_{rec2}:	0.85 – 0.9	t_{rec3}:	t_{rec2} – 1.5

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

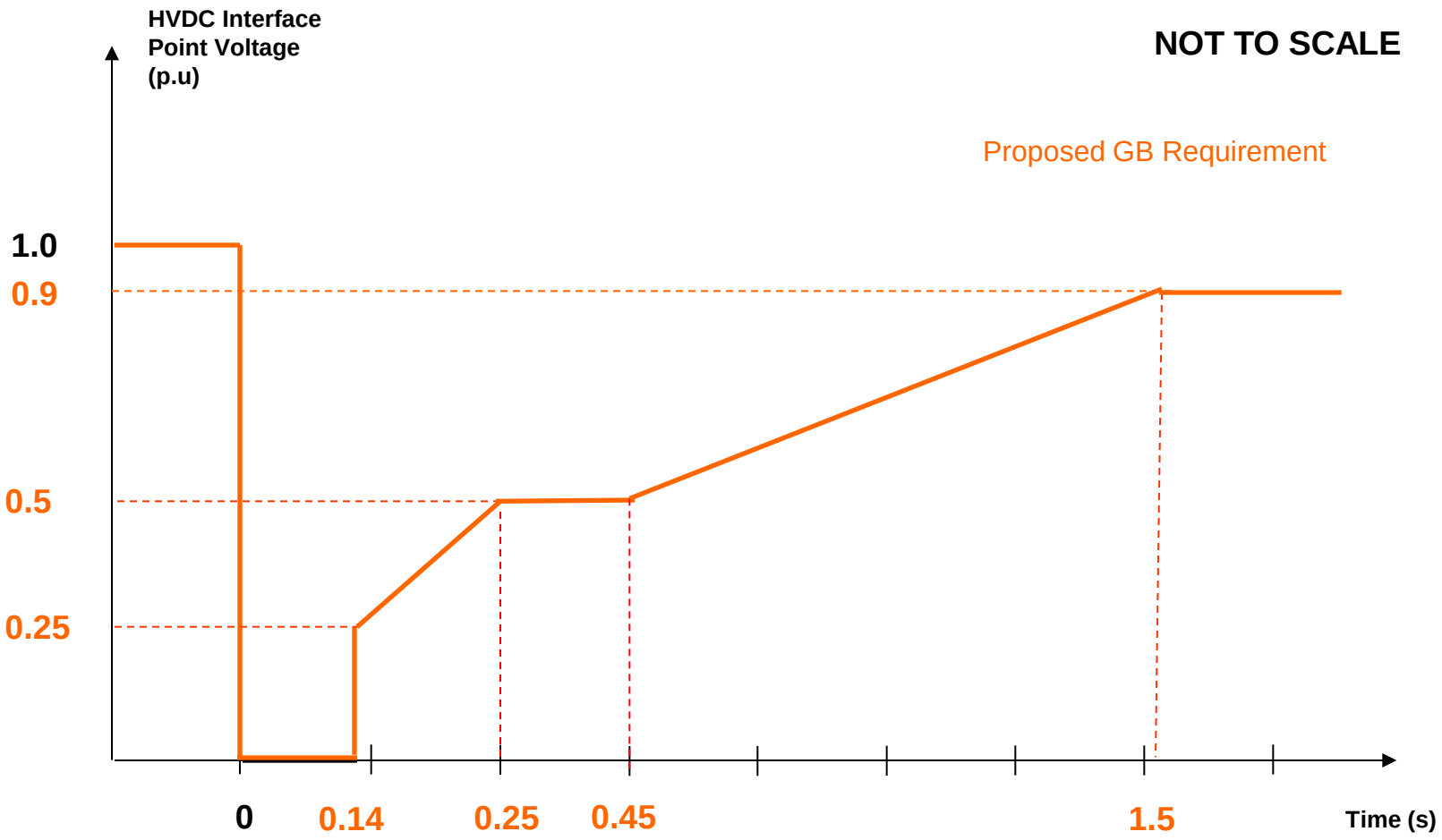
RfG - Voltage Against Time Profile

Type D Synchronous Power Generating Modules Connected ≥ 110kV - Table 7.1



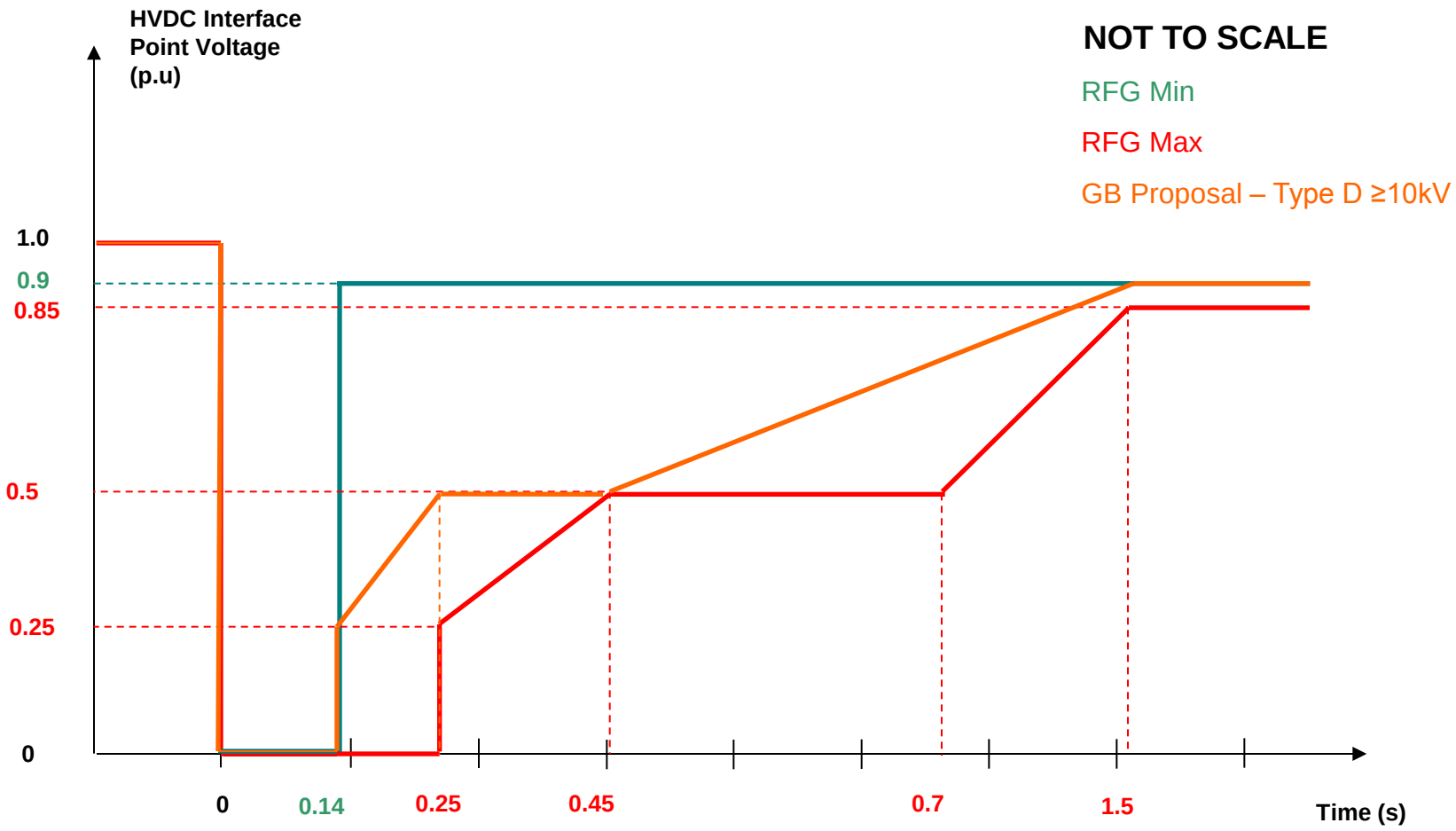
Proposed GB Type D Requirement ≥ 110kV

Voltage Against Time Curve



Proposed GB Type D Requirement ≥ 110kV

Voltage Against Time Curve



GB Proposed Parameters – Consistent with Table 7.1 (Type D SPGM connected at or above 110kV)

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

Type B, C and D Synchronous Power Generating Modules Connected below 110kV – General Requirements

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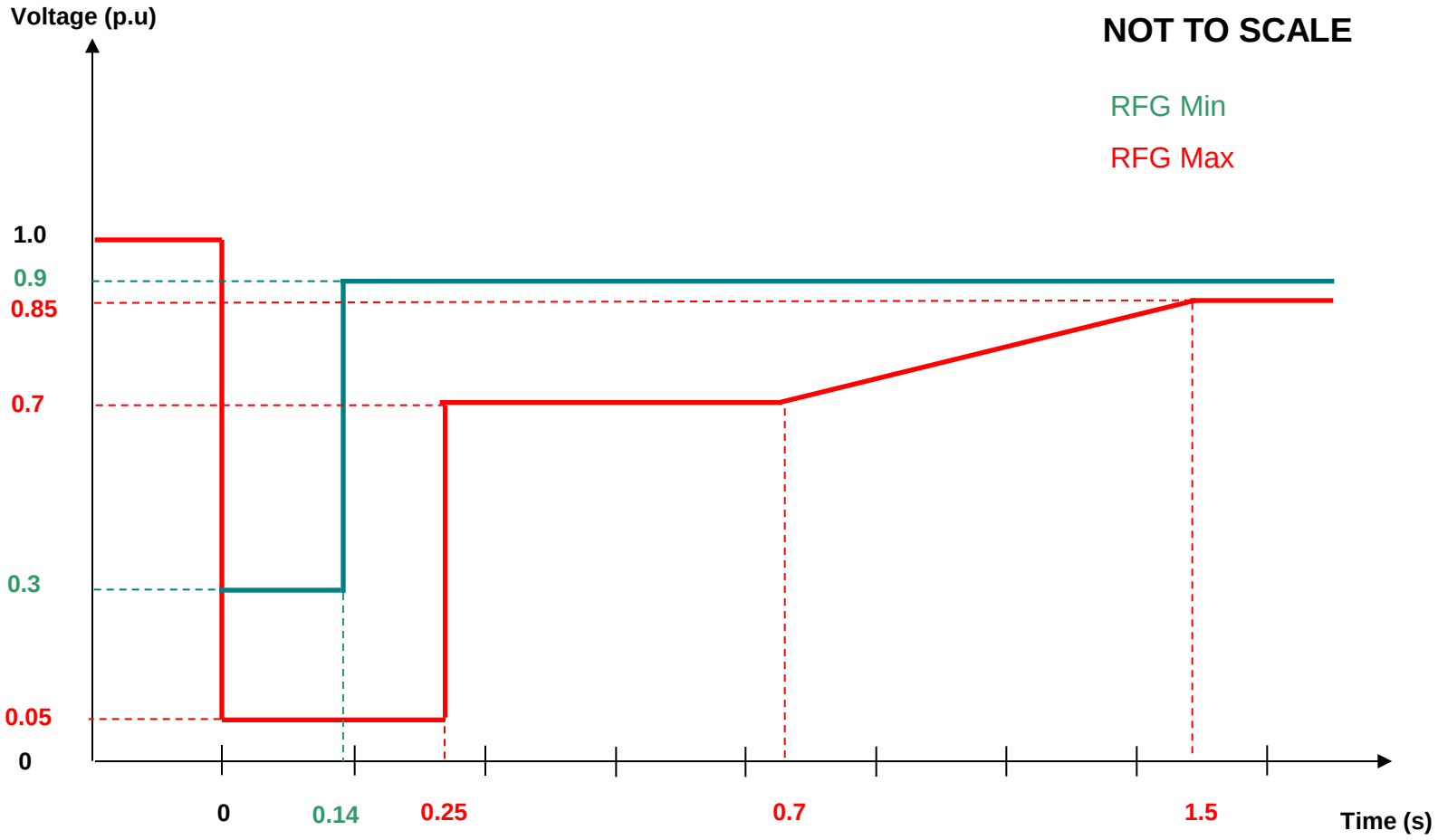
RfG - Voltage Against Time Parameters – Table 3.1 – Type B & C and D Synchronous Power Generating Modules connected below 110kV

Voltage parameters [pu]		Time parameters [seconds]	
U_{ret}:	**0.05 – 0.3**	t_{clear}:	**0.14 – 0.15** (or 0.14 – 0.25 if system protection and secure operation so require)
U_{clear}:	**0.7 – 0.9**	t_{rec1}:	t_{clear}
U_{rec1}:	U_{clear}	t_{rec2}:	t_{rec1} **– 0.7**
U_{rec2}:	**0.85 – 0.9 and** $\geq U_{clear}$	t_{rec3}:	t_{rec2} **– 1.5**

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

RfG - Voltage Against Time Profile

Type B / C and D Synchronous Power Generating Modules connected below 110kV



Type C and D Synchronous Power Generating Modules Connected below 110kV

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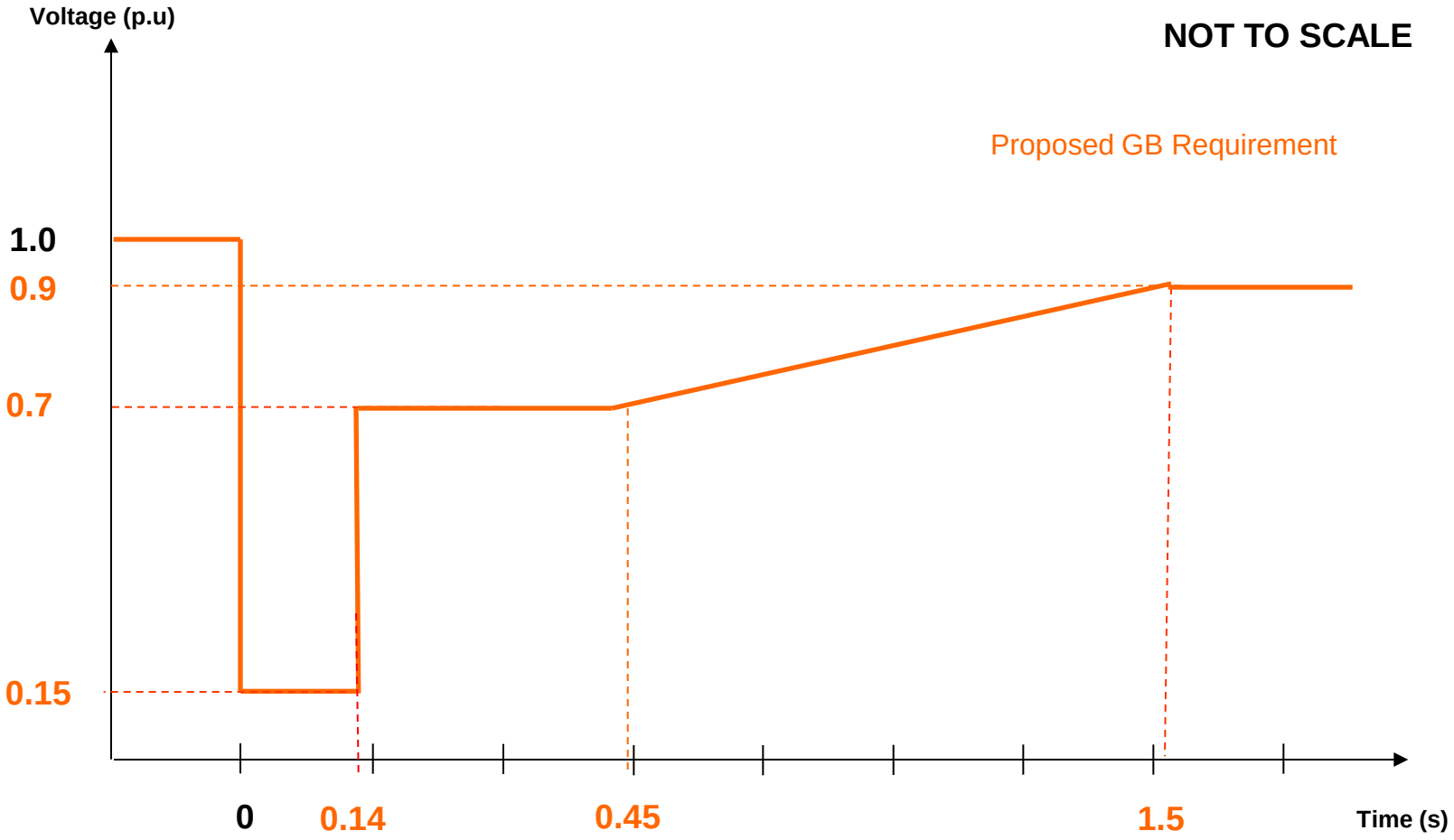
Proposed GB Type C and D Synchronous Power Generating Modules connected below 110kV

Voltage Against Time Curve



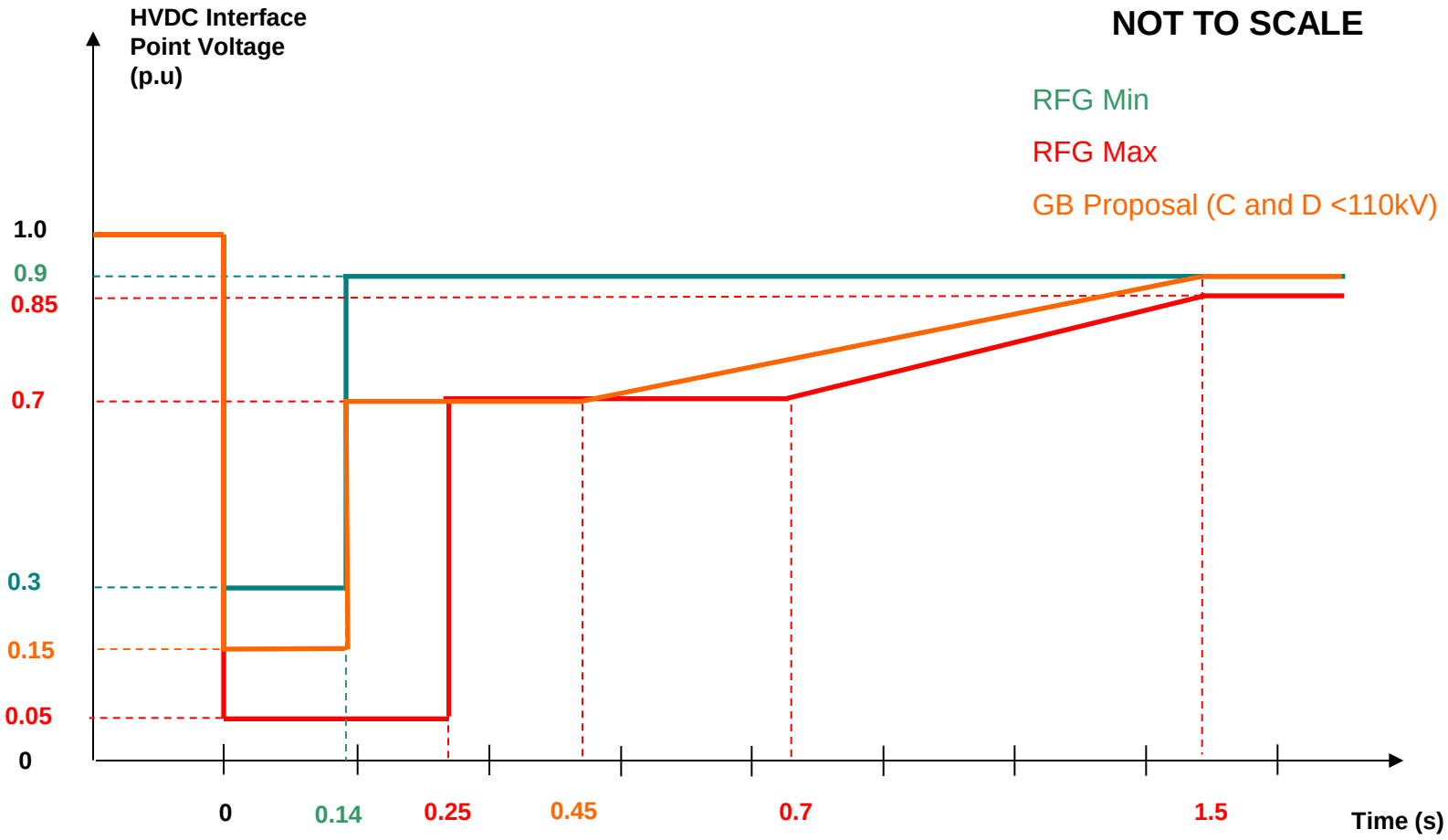
RfG - Voltage Against Time Parameters – Table 3.1 – Type C and D Synchronous Power Generating Units connected below 110kV

Voltage parameters [pu]		Time parameters [seconds]	
U_{ret}:	0.15	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

RfG - Voltage Against Time Profile

Type C and D Synchronous Power Generating Modules connected below 110kV



Type B Synchronous Power Generating Modules

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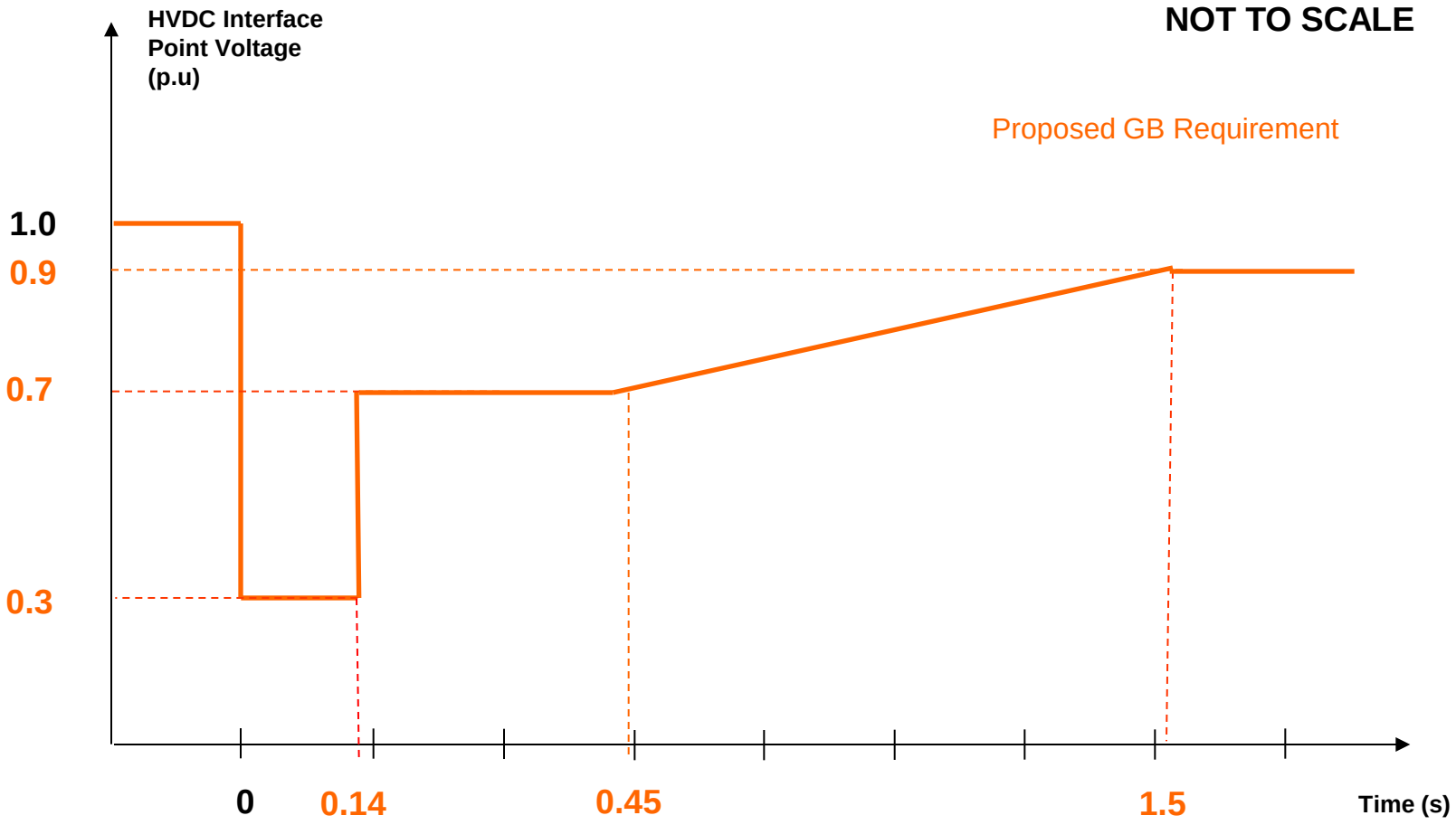
Proposed GB Type B Synchronous Power Generating Modules

Voltage Against Time Curve



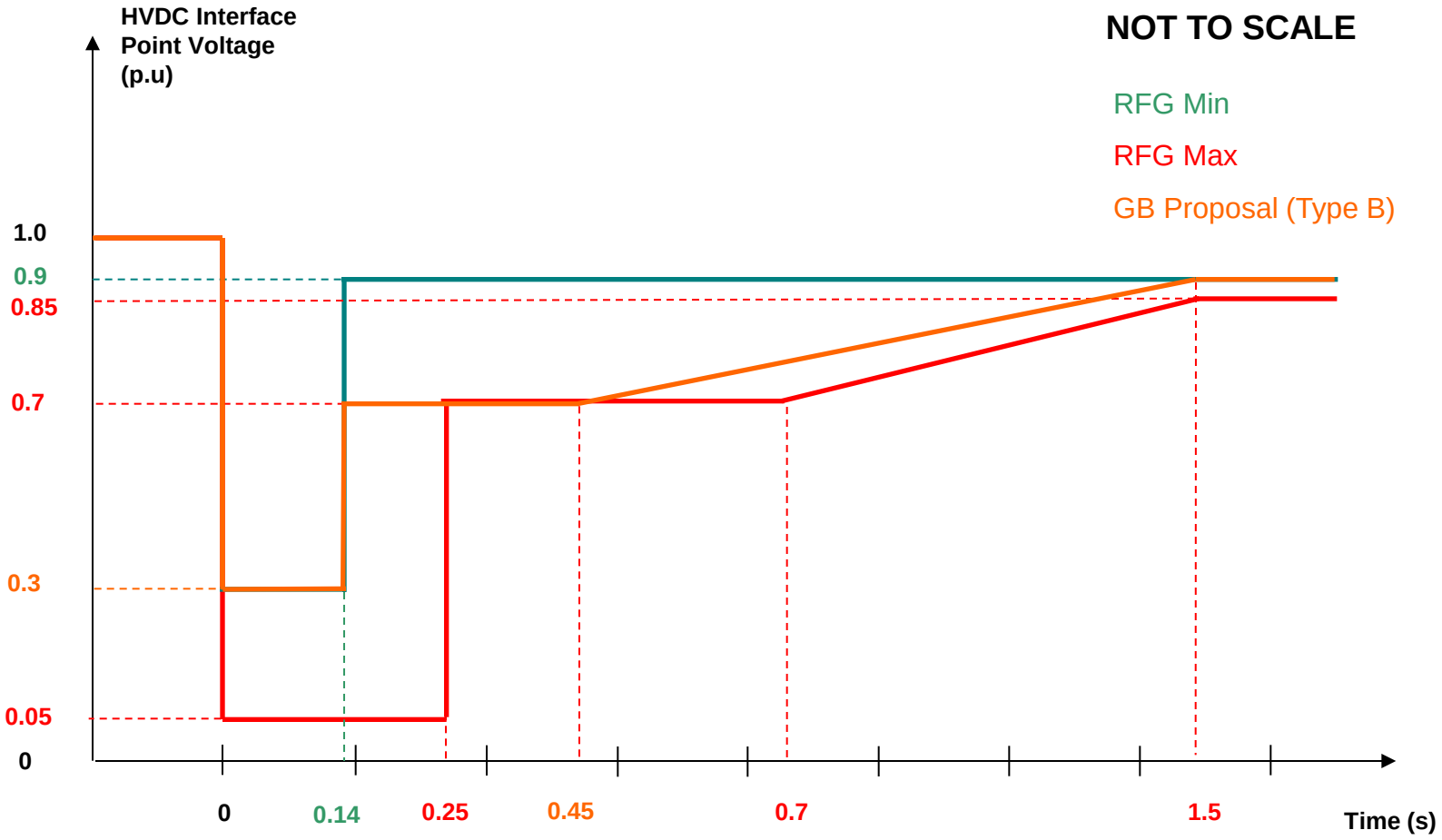
RfG - Voltage Against Time Parameters – Table 3.1 – Type B Synchronous Power Generating Units

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

RfG - Voltage Against Time Profile

Type B Synchronous Power Generating Modules



Type D Power Park Modules connected at or above 110kV

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RfG - Voltage Against Time Parameters – Table 7.2 – Type D Power Park Modules connected at or above 110kV

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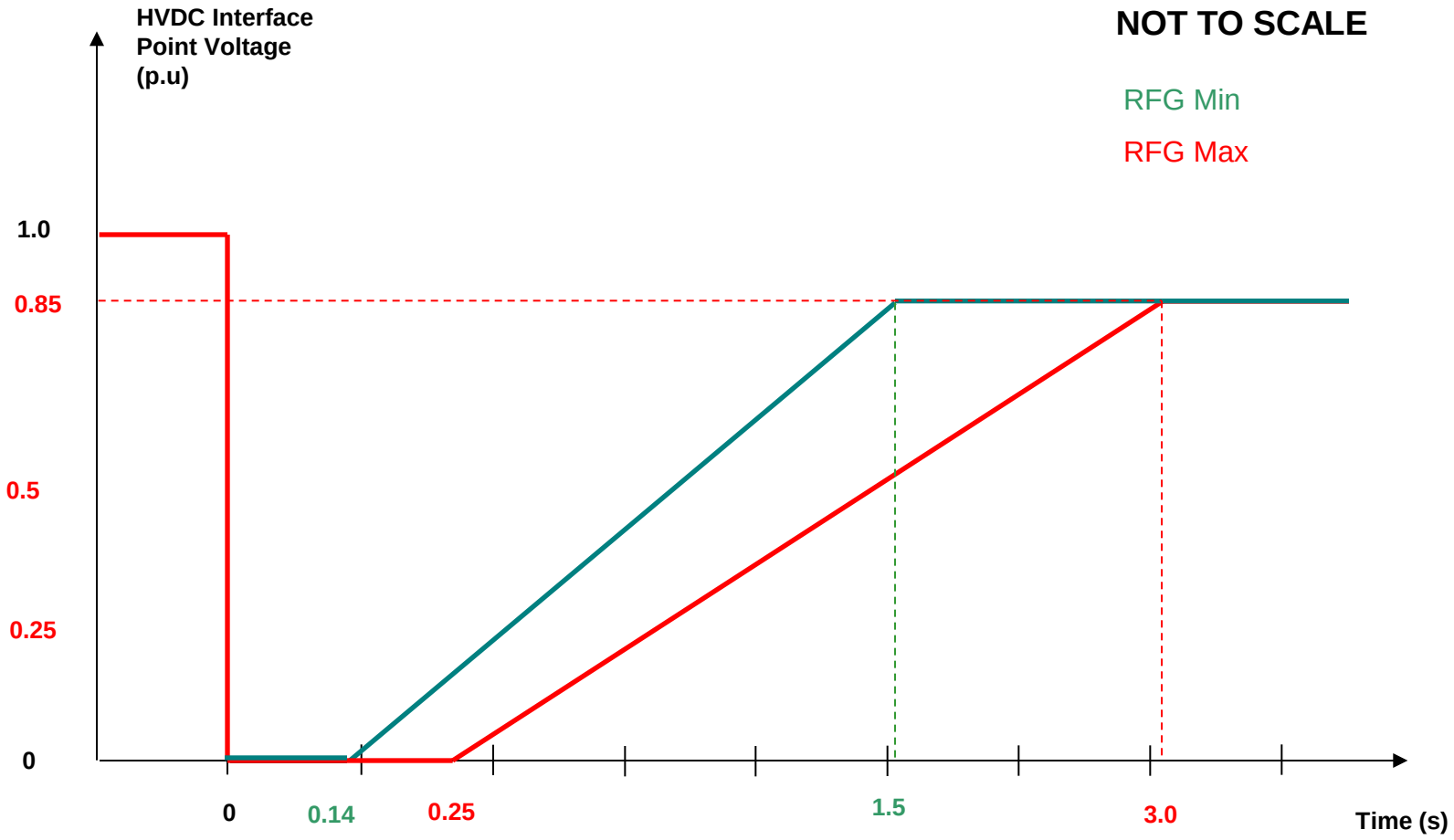
Voltage parameters [pu]		Time parameters [seconds]	
U_{ret}:	0	t_{clear}:	**0.14 – 0.15** (or 0.14 – 0.25 if system protection and secure operation so require)
U_{clear}:	U_{ret}	t_{rec1}:	t_{clear}
U_{rec1}:	U_{clear}	t_{rec2}:	t_{rec1}
U_{rec2}:	0.85	t_{rec3}:	1.5 – 3.0

Table 7.2 – Fault Ride Through Capability of Power Park Modules

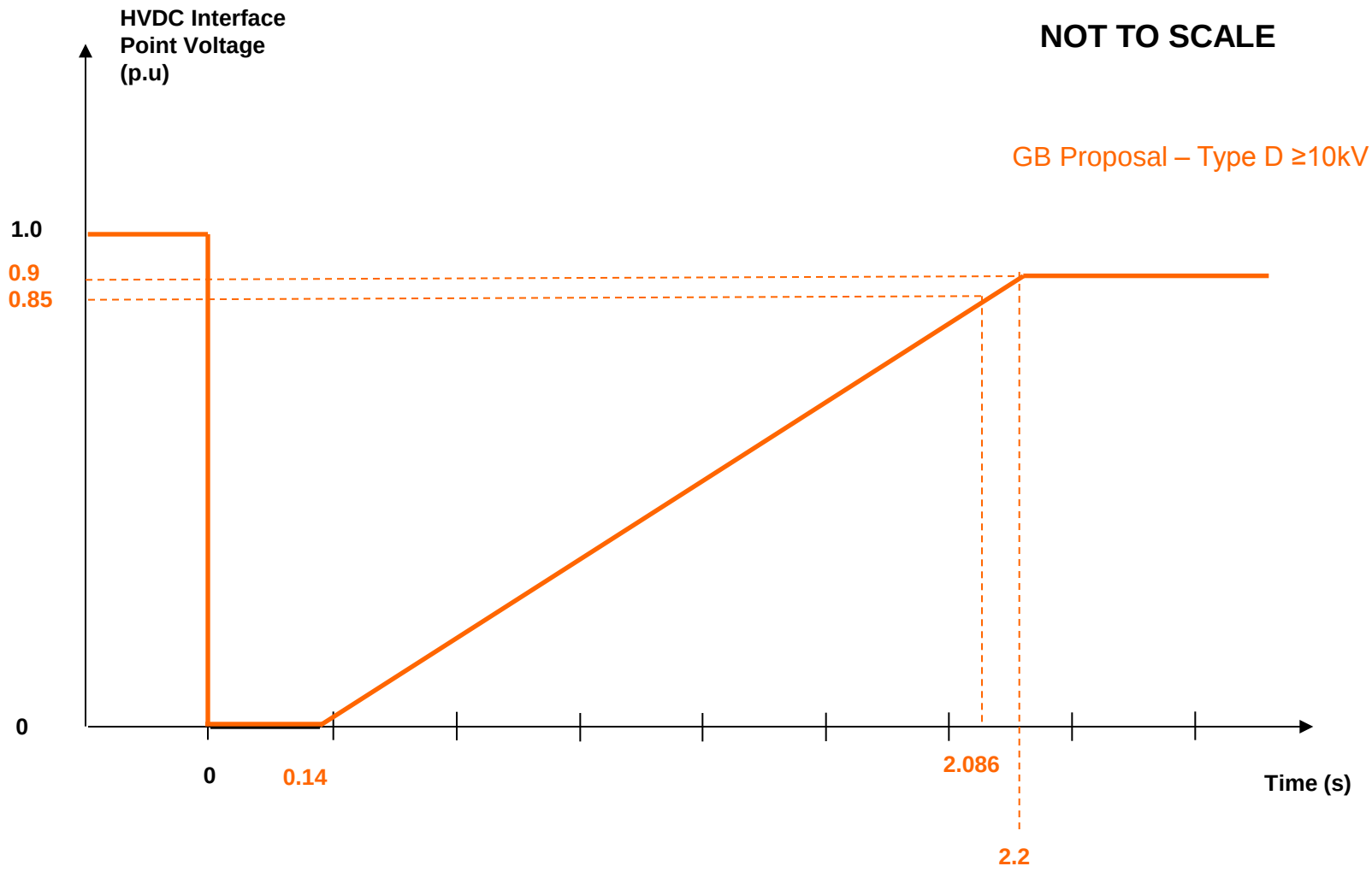
RfG - Voltage Against Time Profile

Type D Power Park Modules Table 7.2 connected at or above 110kV



RfG - Voltage Against Time Profile

Type D (connected at ≥110kV) Power Park Modules



RfG - Voltage Against Time Parameters – Table 7.2 – Type D Power Park Modules connected at or above 110kV

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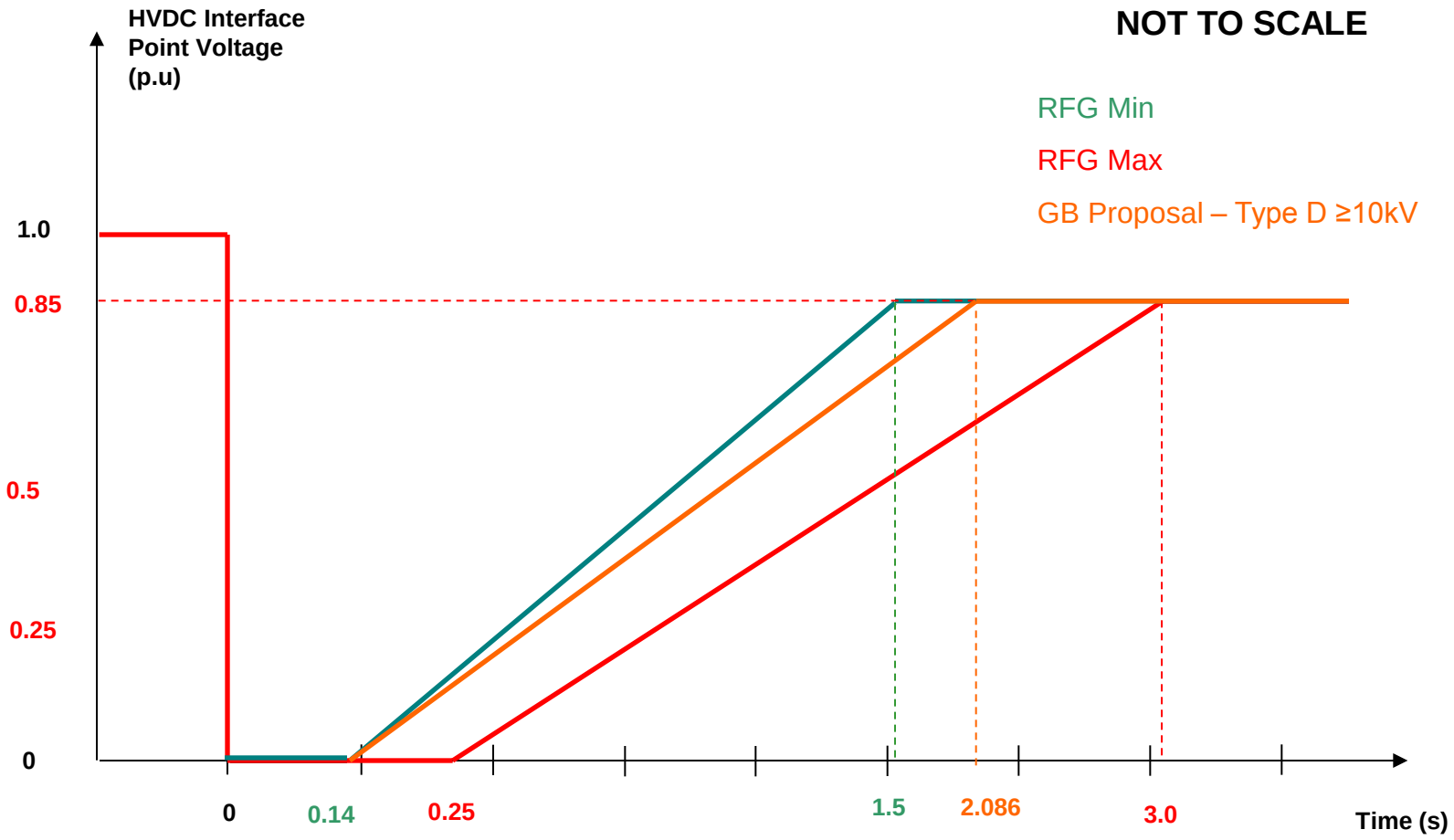
Voltage parameters [pu]		Time parameters [seconds]	
U_{ret}:	0	t_{clear}:	0.14
U_{clear}:	0	t_{rec1}:	0.14
U_{rec1}:	0	t_{rec2}:	0.14
U_{rec2}:	0.85	t_{rec3}:	2.086

Table 7.2 – Fault Ride Through Capability of Power Park Modules

RfG - Voltage Against Time Profile

Type D Power Park Modules Table 7.2 connected at or above 110kV



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

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RfG - Voltage Against Time Parameters – Table 3.2 – Type B & C and D Connected below 110kV Power Park Modules

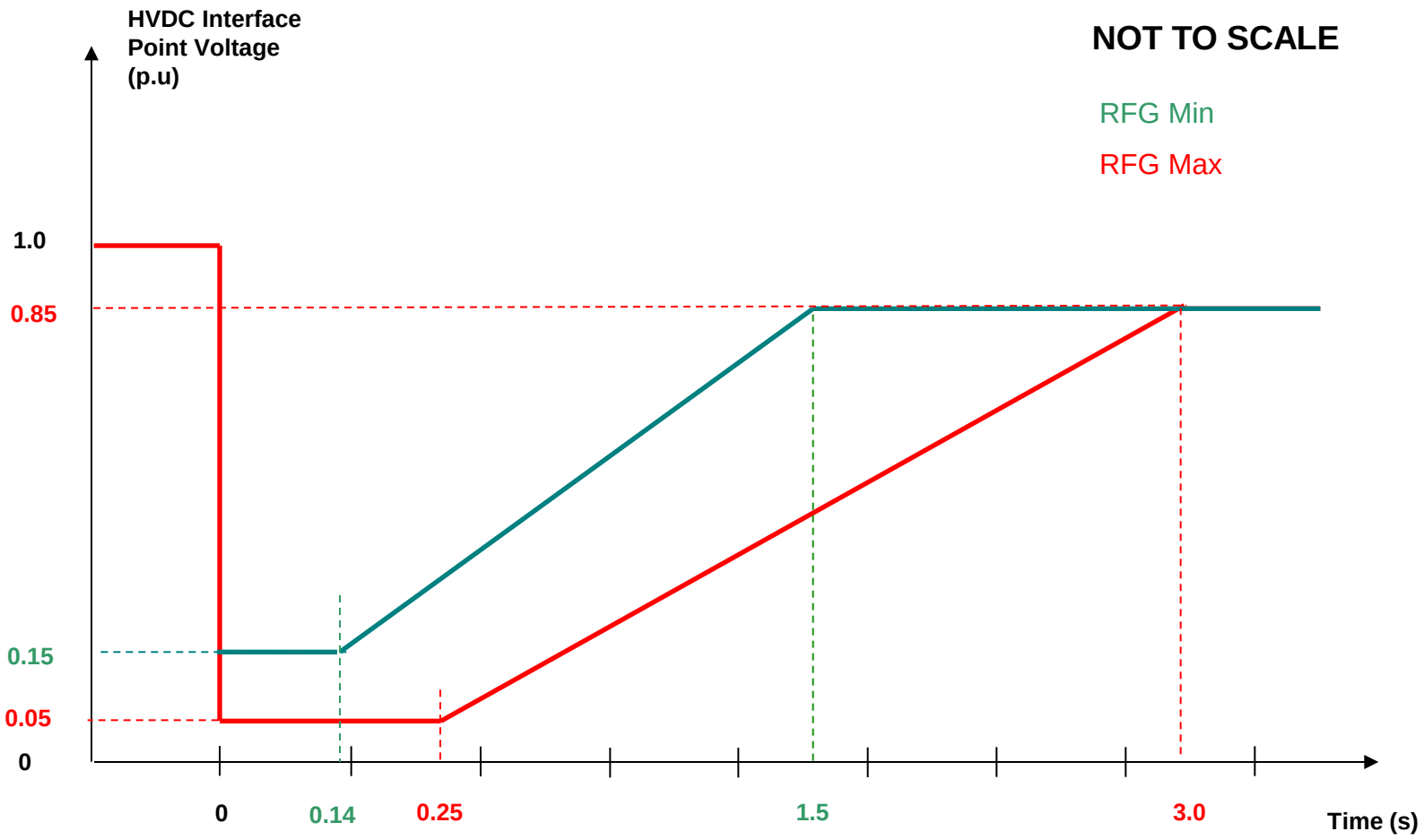
Voltage parameters [pu]		Time parameters [seconds]	
U_{ret}:	**0.05 – 0.15**	t_{clear}:	**0.14 – 0.15** (or 0.14 – 0.25 if system protection and secure operation so require)
U_{clear}:	U_{ret} – 0.15	t_{rec1}:	t_{clear}
U_{rec1}:	U_{clear}	t_{rec2}:	t_{rec1}
U_{rec2}:	0.85	t_{rec3}:	1.5 – 3.0

Table 3.1 – Fault Ride Through Capability of Power Park Modules

ENTSO-E RfG - Voltage Against Time Profile

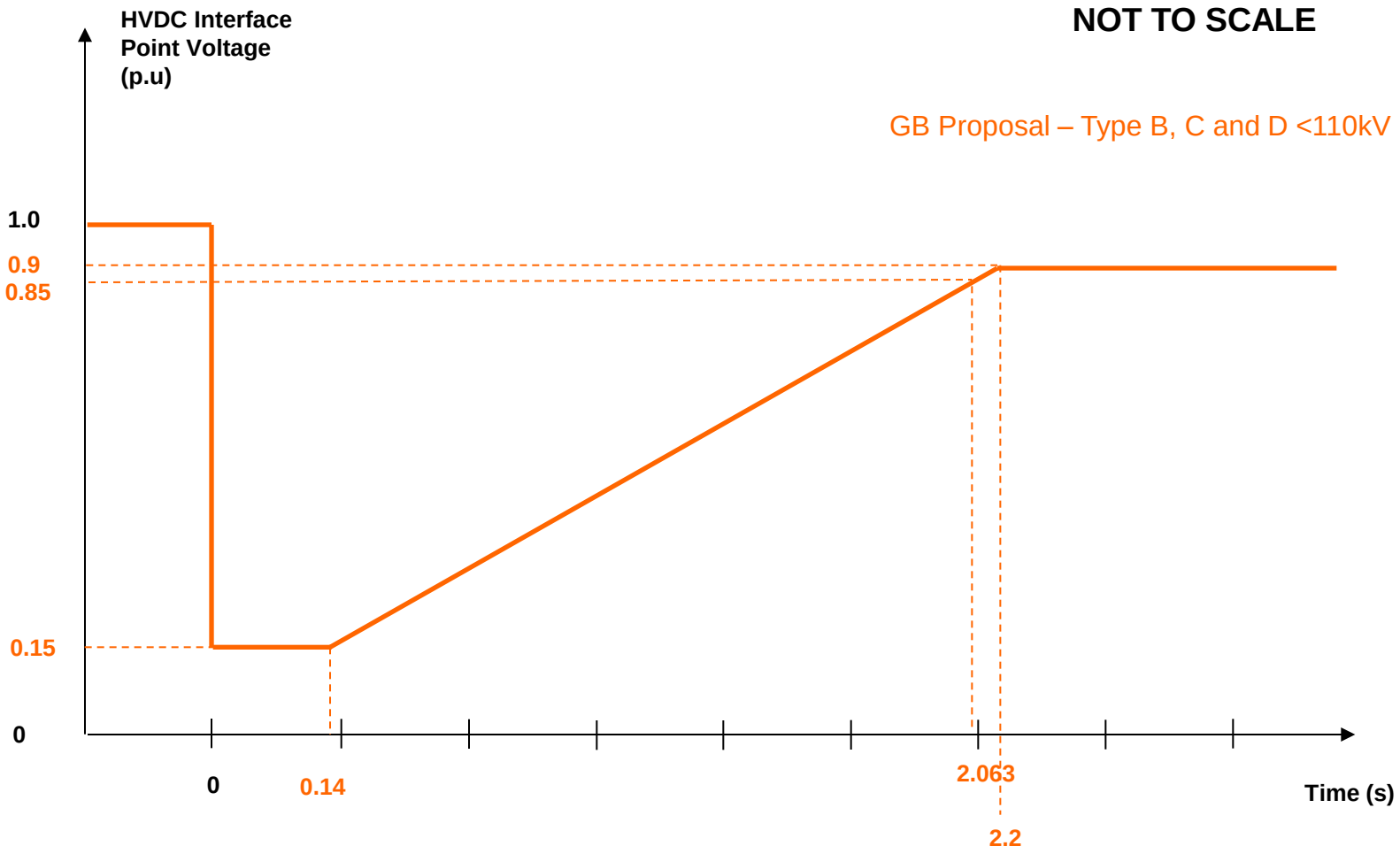
Type B / C and Type D Connected below 110kV

Power Park Modules - Table 3.2



RfG - Voltage Against Time Profile

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



RfG - Voltage Against Time Parameters – Table 3.2 – Type B & C and D Connected below 110kV Power Park Modules

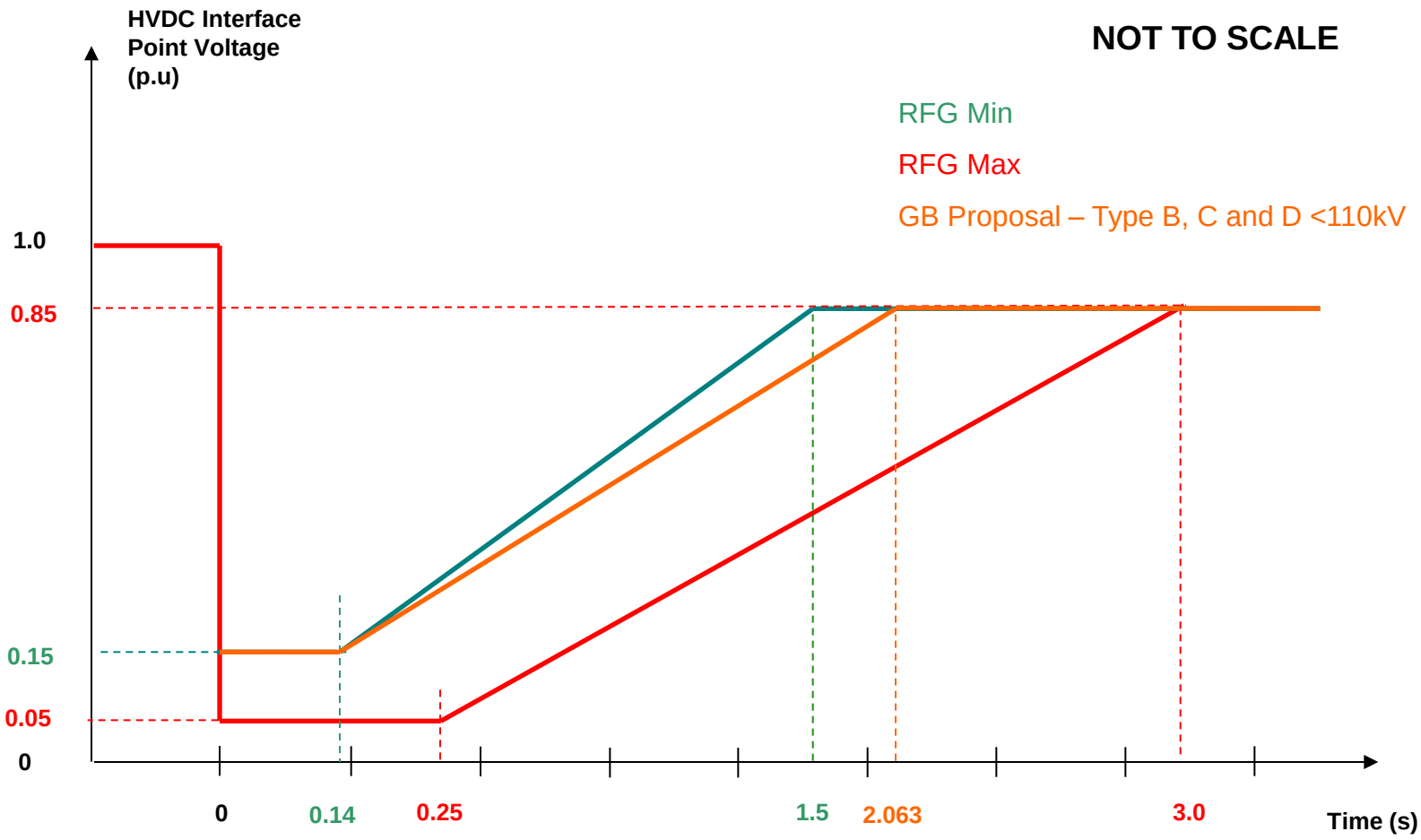
Voltage parameters [pu]		Time parameters [seconds]	
U_{ret}:	0.15	t_{clear}:	0.14
U_{clear}:	0.15	t_{rec1}:	0.14
U_{rec1}:	0.15	t_{rec2}:	0.14
U_{rec2}:	0.85	t_{rec3}:	2.063

Table 3.1 – Fault Ride Through Capability of Power Park Modules

ENTSO-E RfG - Voltage Against Time Profile

Type B / C and Type D Connected below 110kV

Power Park Modules - Table 3.2



Useful References

- RfG Fault Ride Through Working Group presentation material available at:- http://www2.nationalgrid.com/UK/Industry-information/Electricity-codes/Grid-code/Modifications/GC0048/

- Appendix 2 - GC0062 Grid Code Fault Ride Through Working Group "Report to the Authority" available at:- http://www2.nationalgrid.com/UK/Industry-information/Electricity-codes/Grid-code/Modifications/GC0062/

- ENTSO-E – Frequently Asked Questions document available at:-

https://www.entsoe.eu/fileadmin/user_upload/_library/consultations/Network_Code_RfG/120626_-_NC_RfG_-_Frequently_Asked_Questions.pdf

Fault Ride Through requirements for Remote-End HVDC Converter Stations - Title III, Chapter 2

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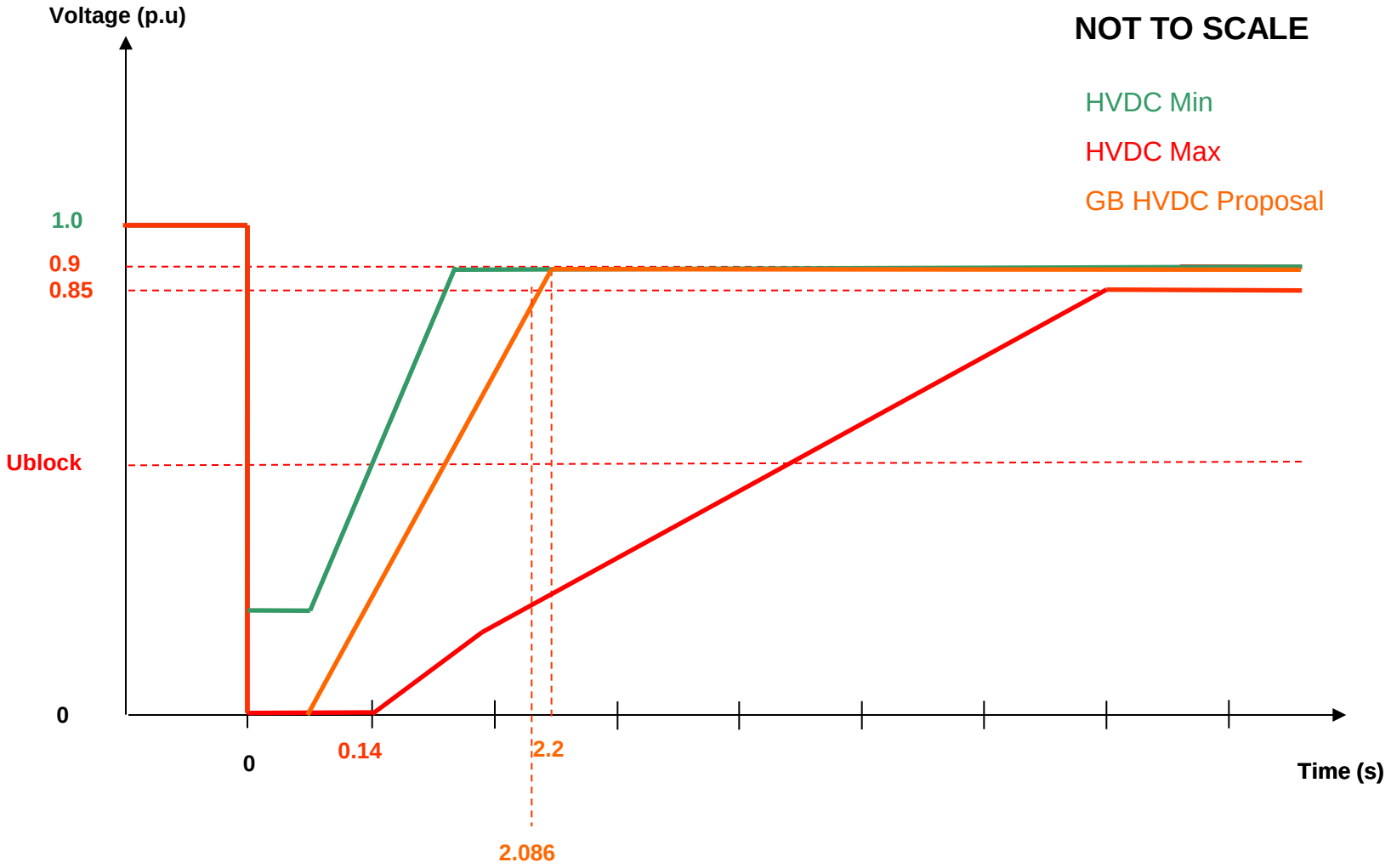
Title III – Chapter 2 – Article 46

- The requirements of Articles 11 to 39 apply to remote-end HVDC converter stations, subject to specific requirements provided for in Articles 47 to 50.
- There are no specific clauses within Articles 47 – 50 that relate to fault ride through.
- For the fault ride through requirements for HVDC Connections see slides 9 - 18.

Remote End HVDC Proposed Voltage Against Time Curve - Initial Proposal



Discussion