European Network of Transmission System Operators for Electricity

MONITORING REPORT ON CONNECTION NETWORK CODES IMPLEMENTATION

Final Version | 1 December 2020

From: Steering Group Connection Network Codes – Implementation Monitoring Team

TABLE OF CONTENTS

EXECUTIVE SUMMARY

In the framework of its legal mandate to monitor the implementation of the Connection Network Codes (CNCs) in the European Union Member States, ENTSO-E redacted the second edition of its Implementation Monitoring Report (IMR). This document summarizes the findings related to the implementation of the CNCs across United Europe, focusing on the approved proposals of the non-exhaustive requirements. The IMR assesses and presents the data that have been submitted by the relevant TSO experts from each Member State and highlights, where applicable, divergencies. The second edition is released together with a detailed Excel table that includes all values and ranges for non-exhaustive requirements.

As particular feature of the current IMR, the Annex offers the comparison in tabular form of the different Fault Ride-Through parameters for different types of Power Generating Module together with a general summary of the implementation of these requirements across Member States.
In general, the 2020 monitoring process has shown that implementation is well on track across all Member States. For the NC RfG only 4,43% of the mandatory non-exhaustive requirements as such have not been implemented followed by the NC DCC with 5,47% of the mandatory non-exhaustive requirements as such which have not been implemented. For the NC HVDC 10,63% of the mandatory non-exhaustive requirements as such have not been implemented.

1 Objective and Scope

1.1 Background of the Monitoring Report derived from the legal Framework

ENTSO for Electricity (**ENTSO-E**) is obliged to monitor the implementation of the European Connection Network Codes (**CNC**) which has been established in each connection code:

- Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code of requirements for grid connection of generators (**NC RfG**);
- Commission Regulation (EU) 2016/1388 of 17 August 2016 establishing a network code on demand connection (**NC DCC**); and
- Commission Regulation (EU) 2016/1447 of 26 August 2016 establishing a network code on requirements for grid connection of high voltage direct current systems and direct current connected power park modules (**NC HVDC**);

in accordance with Article 8(8) of Regulation (EC) No 714/2009.

Article 59 of NC RfG, Article 57 of NC DCC and Article 76 of NC HVDC define the monitoring process for implementation of the regulations:

1. ENTSO for Electricity shall monitor the implementation of this Regulation in accordance with Article 8(8) of Regulation (**EC**) No 714/2009. The monitoring shall cover in particular the following matters:
   a) Identification of any divergences in the national implementation of this Regulation;
   b) Assessment of whether the choice of values and ranges in the requirements applicable to power-generating modules under this Regulation continues to be valid.
2. The Agency for the Cooperation of Energy Regulators (**ACER**), in cooperation with ENTSO for Electricity, shall produce by 12 months after the entry into force of this Regulation a list of the relevant information to be communicated by ENTSO for Electricity to the Agency in accordance with Article 8(9) and Article 9(1) of Regulation (EC) No 714/2009. The list of relevant information may be subject to updates. ENTSO for Electricity shall maintain a comprehensive, standardised format, digital data archive of the information required by the Agency.
3. Relevant TSOs shall submit to ENTSO for Electricity the information required to perform the tasks referred to in paragraphs 1 and 2.

The ENTSO-E Implementation Monitoring Report – hereinafter called the Report or IMR – analyses and provides an overview of the national implementation status of NC RfG, NC DC and NC HVDC. Country-wise divergences between the national implementation of Network Codes and the Connection Network Codes themselves are identified and presented.

2 Input Data for the Report

2.1 Approach of 2020 Implementation Monitoring Report

The 2020 IMR focuses on the timing of implementation of the non-exhaustive requirements of the Connection Network Codes. CNC implementation can be either as general implementation on a national level or site-specific implementation for realization of a specific project.

A non-exhaustive requirement can be defined as such in the National Connection Network Code (**NCNC**) or later just before or during the specific project realization. The related non-exhaustive requirement's specific values or ranges can be additionally defined in the NCNC or project-specific e.g. in the grid connection agreement between the Transmission System Operator (**TSO**) and the Power Generating Facility Owner (**PGFO**) / system user. The definition of a non-exhaustive requirement such as values/ranges between general and site-specific implementation, is reflected through a graphical analysis among the participating TSOs. The outcome reveals the specific countries' approach to the fulfilment of non-exhaustive requirements as defined by the CNCs.

The 2020 IMR covers only the non-exhaustive requirements as implemented by the TSOs.

2.2 Introduction of the Report's Structure

The IMR chapters are clustered according to the three CNCs: NC RfG, NC DCC and NC HVDC. Each CNC is separated into four main issues:

- Frequency Issues,
- Voltage Issues,
- System Restoration Issues and
- Instrumentation, Simulation Models and Protection Issues

These include the relevant non-exhaustive requirements of these issues. Each issue represents a subsection within the related CNC chapter. The implementation status (as general/site-specific) of the non-exhaustive requirements for the related issue is presented according to the alphabetic order of the EU Member State. Each chapter starts with a numeric introduction of the implemented non-exhaustive requirements depicted in a bar chart. The x-axis lists the country codes, the y-axis the grand total of non-exhaustive requirements. On the right hand side of each bar chart the reference number of the related CNC can be read and compared to the individual solution of each country.

The structure of the NC RfG chapter slightly differs from the before mentioned general chapter structure of all three CNCs. Additionally, the NC RfG chapter starts with the country-wise comparison of the limit of the maximum capacity threshold from which a PGM is either of type B, C or D (please refer to section 3.1). For the benefit of the reader, a bar chart visualizes the differences between European TSOs and refers to the thresholds pursuant to article 5, table 1 of RfG distinguished by SAs. Table 1 in section 3.2, summarizes reasons for deviations from NC RfG as far as provided by TSOs in case of other chosen thresholds.

The examined non-exhaustive requirements which appear beneath the bar charts are referenced in the annex (section 6.6) of this report and directly linked to the respective articles of all 3 CNC for the benefit of the reader. The available Implementation Monitoring Report is based upon a survey which has been circulated among the Network Code Link Persons (**NCLPs**) of relevant TSOs. For further detailed information, which goes beyond the presented content of this Report it is referred to the consolidated Monitoring Excel File on ENTSO-E website.

The following subsections of each CNC, deal with implementation of the country specific non-exhaustive requirements' for each issue. A binary coding presentation for facilitating the graphical analysis of each general application vs. site-specific implementation has been chosen and will be explained in the following.

2.2.1 Introduction of binary coding approach for analysis of countries' non-exhaustive requirements' implementation status

Comparing the large number of the non-exhaustive requirements of several countries and three CNCs raises the challenge of providing a clear presentation in which the results are easy to understand.

Therefore, in order to facilitate a clear overview of the results of participating countries, a graphical approach based upon a binary coding strategy of the implementation status has been developed in the following way.

A country-specific evaluation bar chart lists the non-exhaustive requirements on the x-axis whereas the y-axis depicts the "general application" status of a non-exhaustive requirement as a positive oriented column, a "site-specific implementation" means a negative oriented non-exhaustive requirement of the corresponding country. A very flat column means no implementation of the considered requirement. In case of a missing column / a blank entry for a requirement, this requirement is treated as exhaustive in the regarding CNC and needs no further implementation on national level.

2.2.2 Example for interpretation of applied bar charts

The former definitions are illustrated in the example of the German implementation status of timing of proposal for NC RfG frequency issues in Figure 1 below.

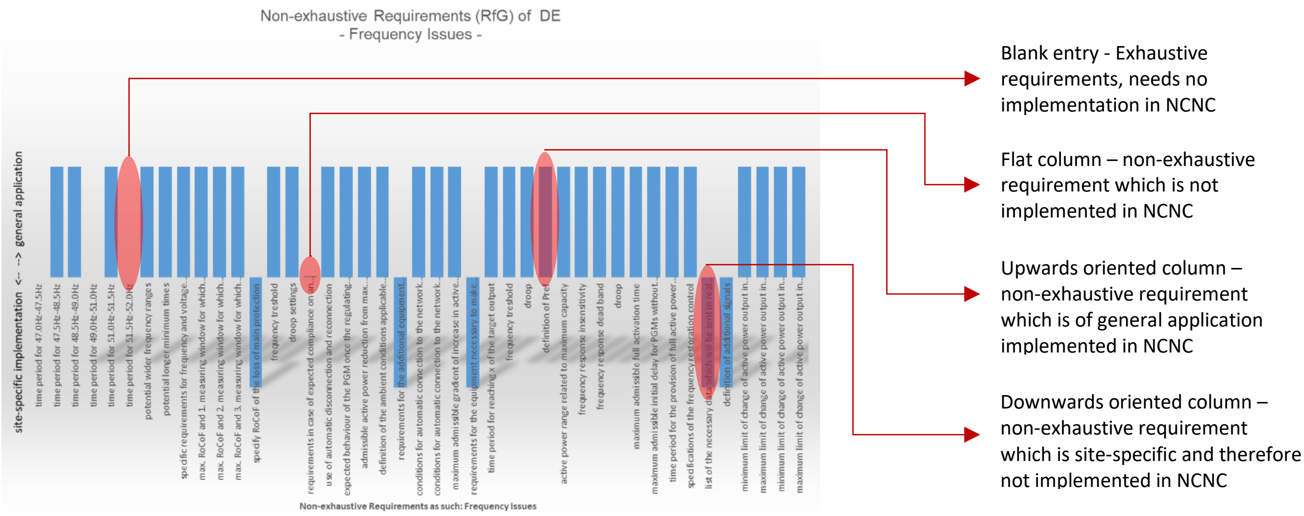


Figure 1: Example bar chart for demonstration and interpretation of binary coding approach

At the beginning of each subsection, the relevant CNC timing of the proposal for each issue is presented. This diagram serves as reference for comparison of the country specific application and implementation of the non-exhaustive requirements. This kind of presentation reveals derogations from the CNCs as well as among the participating TSOs and facilitates the comparison of compliance and non-compliance on national level to the CNCs.

2.3 Definitions

As source of recommendation if a non-exhaustive requirement is to be considered as "general implementation" or "site-specific implementation" it is referred to the published IGD "Parameters of non-exhaustive requirements". In the following subsections further definitions are listed.

2.3.1 Definition of a "non-exhaustive requirement as such" to be considered as general implementation

A non-exhaustive requirement is considered to be general if CNC demands this requirement to be implemented in the NCNC of the according country.

2.3.2 Definition of a "non-exhaustive requirement as such" to be considered as site-specific implementation

A non-exhaustive requirement is considered to be site-specific if CNC demands fulfilment of requirement in due time of plant design, grid connection contract, commissioning or start of permanent operation at latest.

2.3.3 Definition of the "value/range of a non-exhaustive requirement" to be considered as general implementation

The value/range of a non-exhaustive requirement is considered to be general if CNC demands the value/range of the regarding non-exhaustive requirement to be implemented in the NCNC of according country.

2.3.4 Definition of the "value/range of a non-exhaustive requirement" to be considered as site-specific implementation

The value/range of a non-exhaustive requirement is considered to be site-specific if CNC demands fulfilment of value/range of the regarding non-exhaustive requirement in due time of plant design, grid connection contract, commissioning or start of permanent operation at latest.

2.4 Other used acronyms

- CNC: Connection Network Code which are RfG, DCC, HVDC
- NCNC: National Connection Network Code as national implementation of the CNC
- RfG: Regulations for Generators
- DCC: Demand Connection Code
- HVDC: High Voltage Direct Current
- TSO: Transmission System Operator
- SA: Synchronous Area
- PGM: Power Generating Module
- SPGM: Synchronous Power Generating Module
- PPM: Power Park Module
- PGFO: Power-Generating Facility Owner
- NCLP: Network Code Link Person

3 NC RfG Implementation

3.1 Capacity thresholds

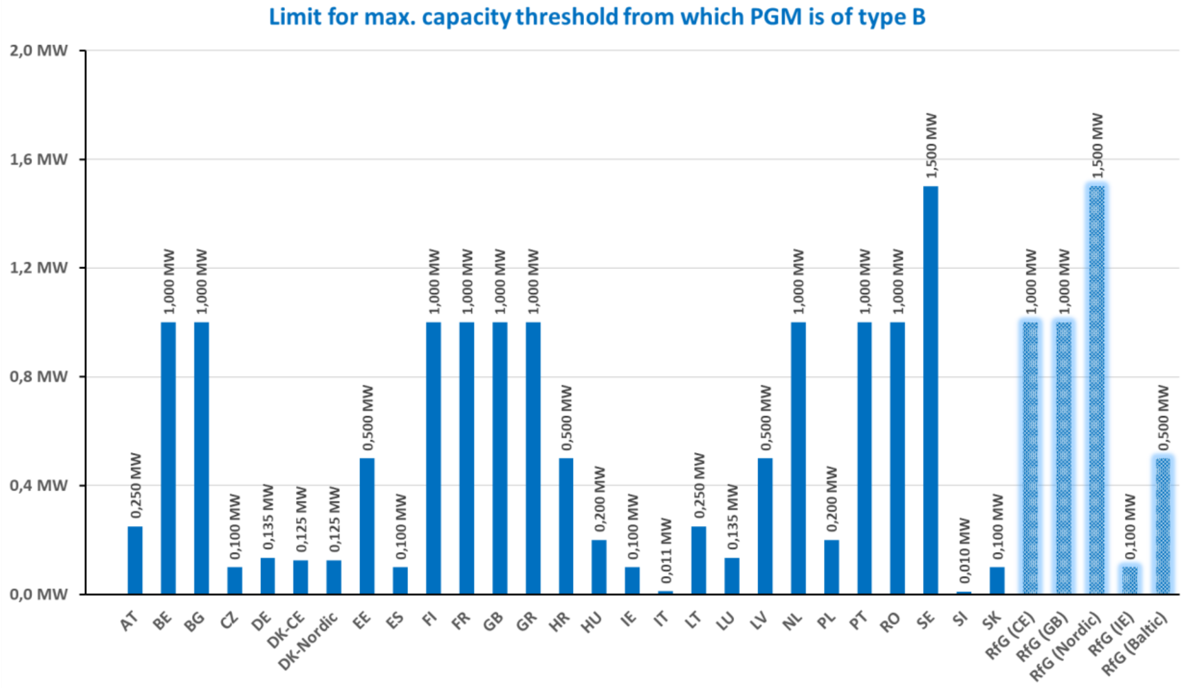


Figure 2: Limit for max. capacity threshold from which PGM is of type B

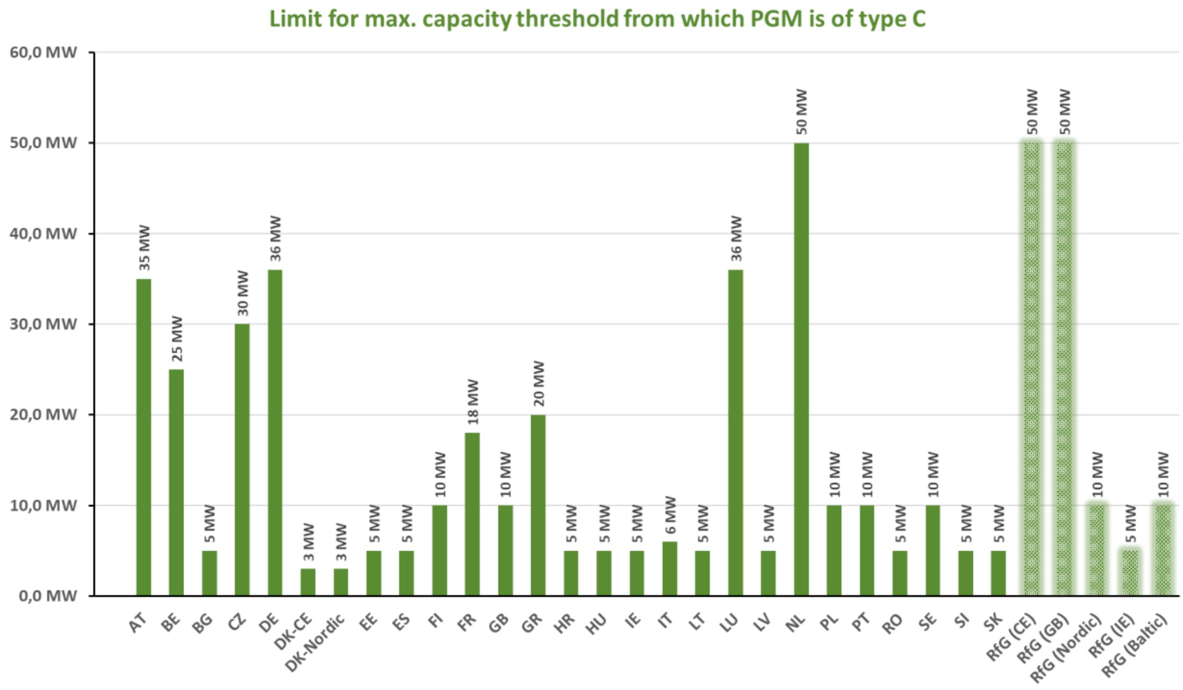


Figure 3: Limit for max. capacity threshold from which PGM is of type C

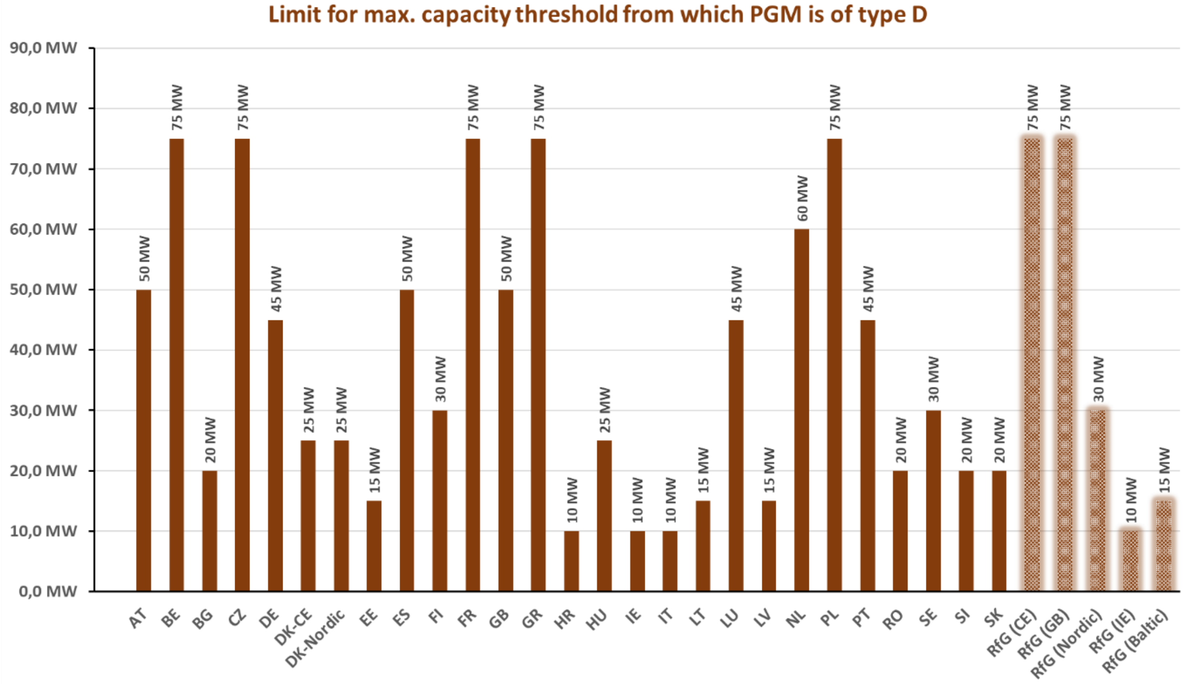


Figure 4: Limit for max. capacity threshold from which PGM is of type D

3.2 Information regarding RfG capacity threshold of PGM of type B/C/D

Country	SA	Information regarding capacity threshold limit for PGM of type B	Information regarding capacity threshold limit for PGM of type C	Information regarding capacity threshold limit for PGM of type D	Additional remarks
AT	CE	• Voltage control and reactive power management. • FRT requirements. • General system management • Observability of small units (information exchange).	• Voltage control and reactive power management. • Remote active power control (e.g. for congestion management).	• MV connections are typically in the range up to a maximum of 50 MW. • HV connection will automatically become Type D.	General aspects for threshold selection: • Alignment with existing grid codes (TOR). • Characteristics of current and future national portfolio of generation units. • Characteristics of the transmission and distribution system development (i.e. more decentralized power plants, more RES,…).
BE	CE	–	–	–	–
BG	CE	–	–	–	–

Country	SA	Information regarding capacity threshold limit for PGM of type B	Information regarding capacity threshold limit for PGM of type C	Information regarding capacity threshold limit for PGM of type D	Additional remarks
CZ	CE	–	–	–	According to the national (state) energy conception (SEC) the most of new connected PGMs will be of types A and B, therefore the following categorization has been implemented: • A1/A2 – 11 kW • A2/B1 – 100 kW • B1/B2 – 1 MW • B2/C – 30 MW • C/D – 75 MW
DE	CE	• (Almost) all generators connected in LV are of type A and those connected in MV are of type B. • Due to the high RES generators at LV at MV, it is ensured that all MV generators are of type B and German LV connection rules will go far beyond type A requirements of RfG (e.g. inroducetion of FRT for type A). • No extension of type B to LV connected generators (which would be possible by lowering the threshold even further), because of the certification for compliance, that comes up with type B. • The total installed capacity of all PGM's (that each have less than 1 MW) is approx. 38 GW. This sum is relevant for the overall system. • Application and approval cost/effort must be considered. In association with other German energy-market-laws the threshold needs to be chosen without creating disadvantages to other market participants.	• Plants of this size are usually connected to the high voltage grid. • In practice there are no type C generators - expect for the untypically large generators connected in MV.	• All PGMs with a capacity > 45 MW are connected to > 110 kV and are therefore automatically of type D. • Generators connected in HV and EHV are of type D.	–
DK	CE	–	–	–	–
DK	Nordic	–	–	–	–
EE	Baltic	–	–	–	–

Country	SA	Information regarding capacity threshold limit for PGM of type B	Information regarding capacity threshold limit for PGM of type C	Information regarding capacity threshold limit for PGM of type D	Additional remarks
ES	CE	Several reasons can be found in the link attached in the remarks, but the main ones are: • consistency with thresholds existing in current national regulation • size and amount of the future power generating modules, mainly PPMs	• Same as for type B	• Same as for type B	Justification document at: https://api.esios.ree.es/documents/354/download?locale=es
FI	Baltic	–	–	–	–
FR	CE	–	–	–	–
GB	GB	–	–	–	–
GR	CE	–	–	–	–
HR	CE	–	–	–	–
HU	CE	–	–	–	–
IE&NI	IE	–	–	–	–
IT	CE	–	–	–	–
LT	Baltic	–	–	–	–
LU	CE	–	–	–	Alignment with current connection requirements defined according the connected voltage level LV, MV and HV: • (Almost) All LV connected generators to be of type A • (Almost) All MV connected generators to be of type B • (Currently) No generators of type C and D connected to HV • Luxembourg is part of the German Market and intends to participate to the German balancing Market. In order to avoid any discrimination with type A,B generators connected to German TSO/DSO, we proposed to align the thresholds with Germany.
LV	Baltic	–	–	–	–
NL	CE	–	–	–	–
PL	CE	–	–	–	–
PT	CE	–	–	–	• Fault-ride-through capability similar to type B is requested for power generating modules with maximum capacity at or above 15 kW.

Country	SA	Information regarding capacity threshold limit for PGM of type B	Information regarding capacity threshold limit for PGM of type C	Information regarding capacity threshold limit for PGM of type D	Additional remarks
RO	CE	–	• The maximum limit for type B was set to the value of 5 MW compared to 50 MW declared in RfG, based upon the current generation structure and similarity with former technical requirements regarding power range. The former regulations for PGMs from 1 to 5 MW was similar to the present one for type B. • Using the same range of installed power from 1 to 5 MW for similar requirements, the transition to RfG was easier for type B (maintaining same range specially for PPMs).	• The limit between types C and D was set to 20 MW compared to 75 MW in order to respect the capacity generation structure of types C and D, the development forecasts of investments in SPGMs and future decommissioning, but also to ensure a continuity with the previous requirements. • In former requirements, the following ranges have been defined: 5 to 10 MW for HPP, 5 to 20 MW for TPP or 5 to 10 MW for PPMs with requirements similar to type C. That means for generation capacity above 20 MW all PGMs had the same maximum technical demand (similar to current type D requirements). The highest value (20 MW) has been chosen in order to take into account the installed power trend in future PGMs and PPMs to have sufficient PGMs capable to ensure type D requirements.	–
SE	Nordic	–	–	–	–
SI	CE	• Voltage stability and control in distribution system (LV/MV). • General system management: observability of small PGMs (information exchange) particularly for power system restoration and island operation.	• Possibility of providing ancillary services: particularly important for RES, currently no regulating capabilities required. • Frequency stability: LFSM-U and FSM.	• Existing distribution grid code: PGMs above 10 MW are obliged to be connected to 110 kV level and above.	Main criteria for determining thresholds between individual types: • Alignment with existing distribution grid code: currently only 1 unit above 10 MW connected to distribution level, i.e. below 110 kV. • Characteristics of current and future national portfolio of generation units. • Characteristics of the transmission and distribution system development (i.e. more decentralized power plants, more RES, …). • Provision on security of operation (balancing reserves) and system restoration.
SK	CE	• Need for generation	• Generators connected to	• Technical limitations of	–

Table 1: Reasons deviation from RfG capacity thresholds of PGM type B/C/D

3.3 Number of implemented non-exhaustive requirements in NC RfG

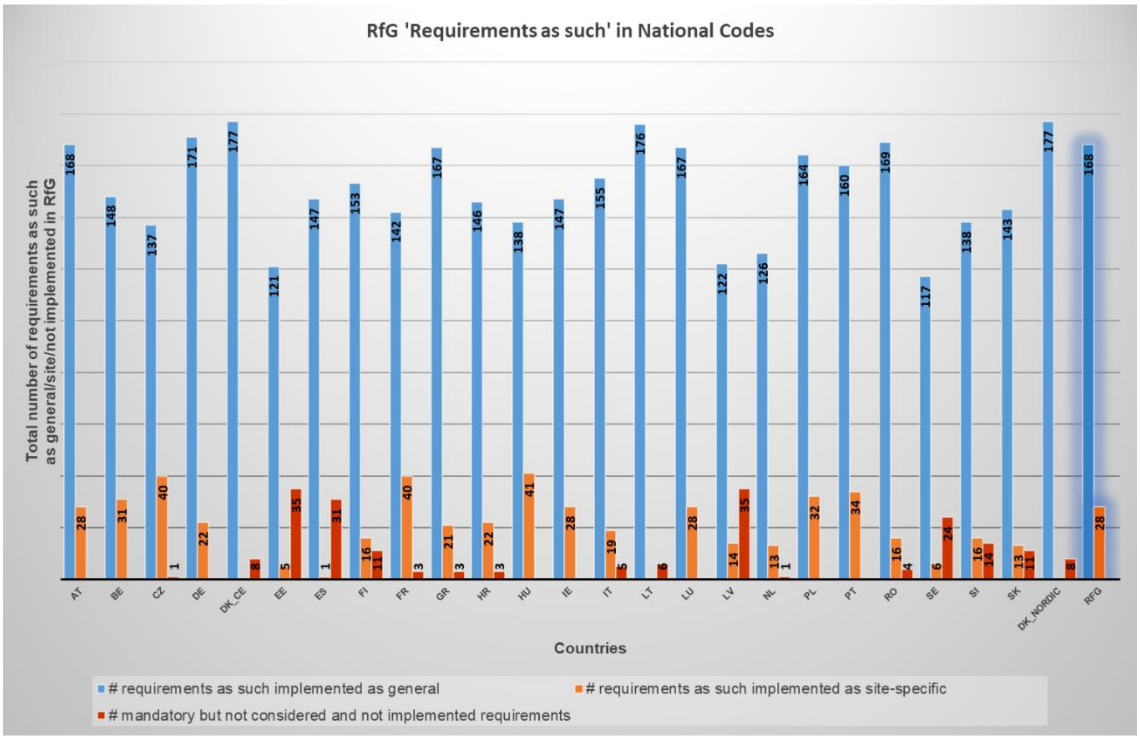


Figure 5: Reference total number of to be implemented RfG non-exhaustive requirements as such

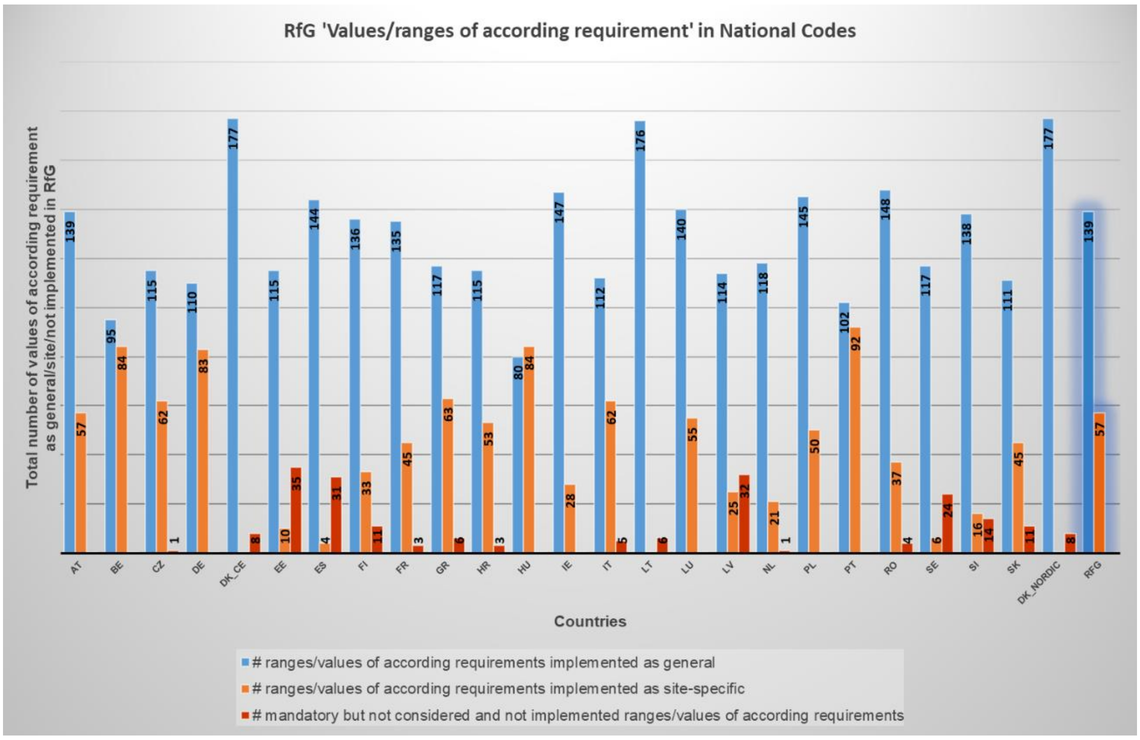


Figure 6: Reference total number of to be implemented values/ranges of regarding RfG non-exhaustive requirements

3.4 Frequency Issues of NC RfG

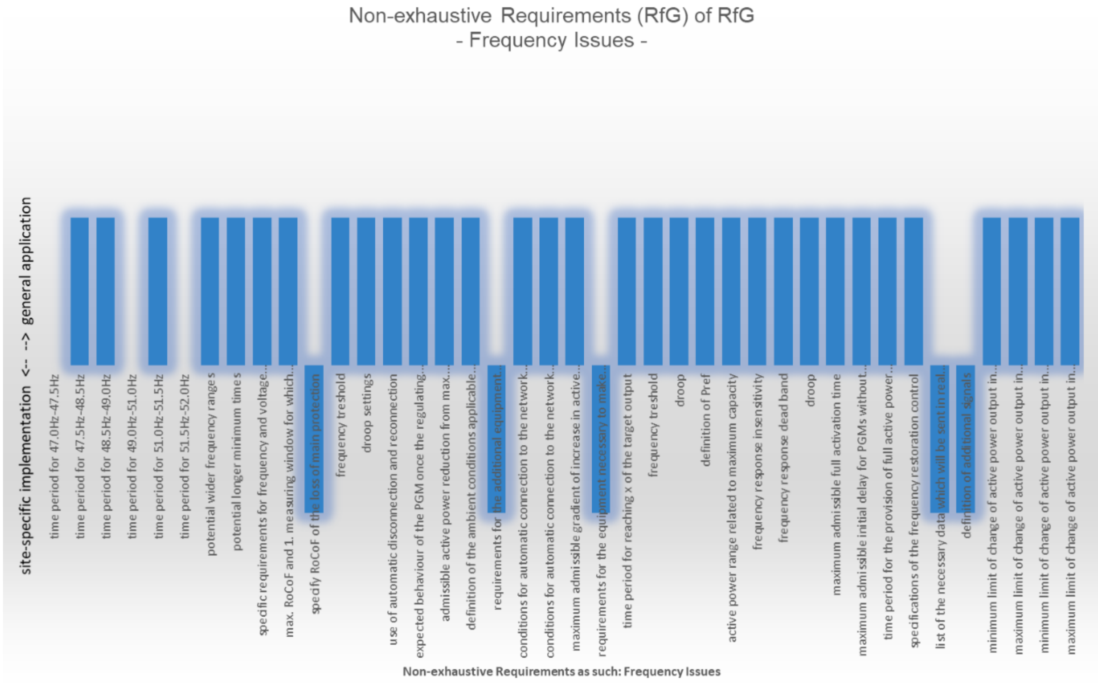


Figure 7: Reference values of non-exhaustive RfG frequency issues

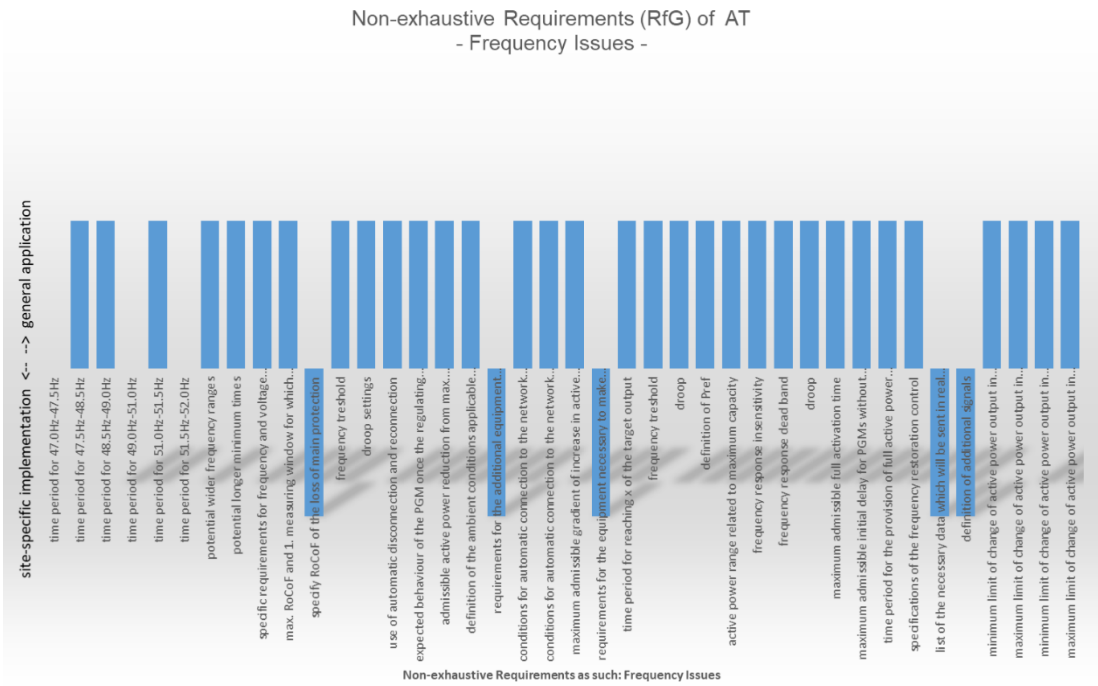


Figure 8: Austria (AT)

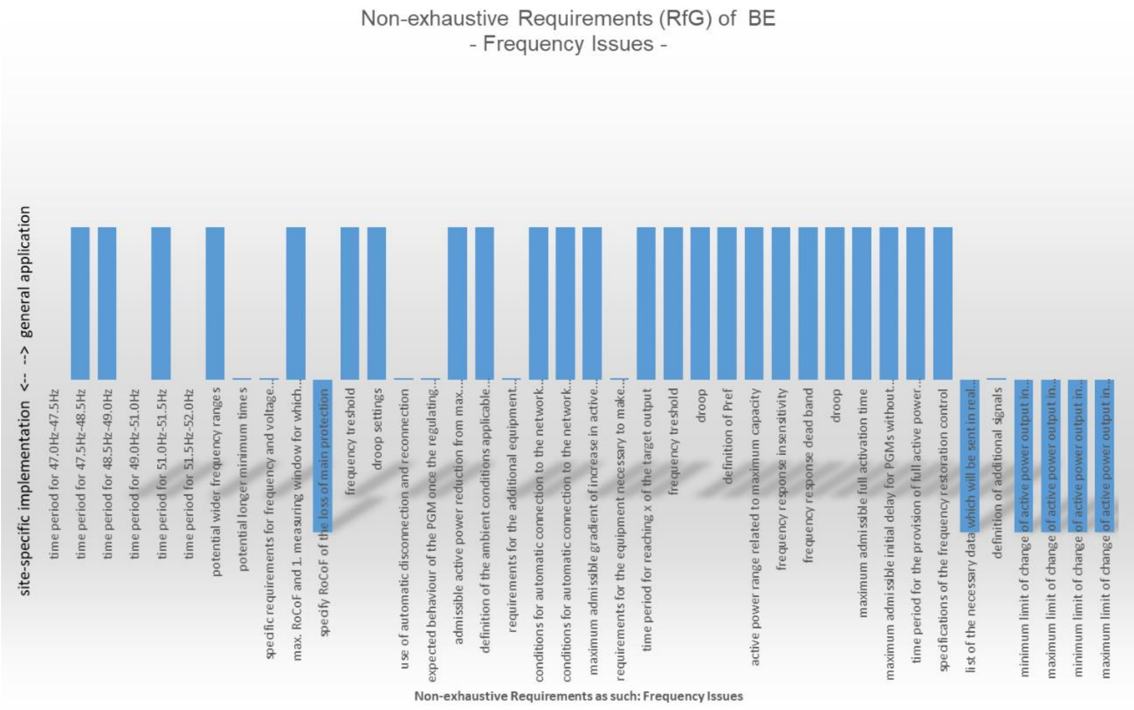


Figure 9: Belgium (BE)

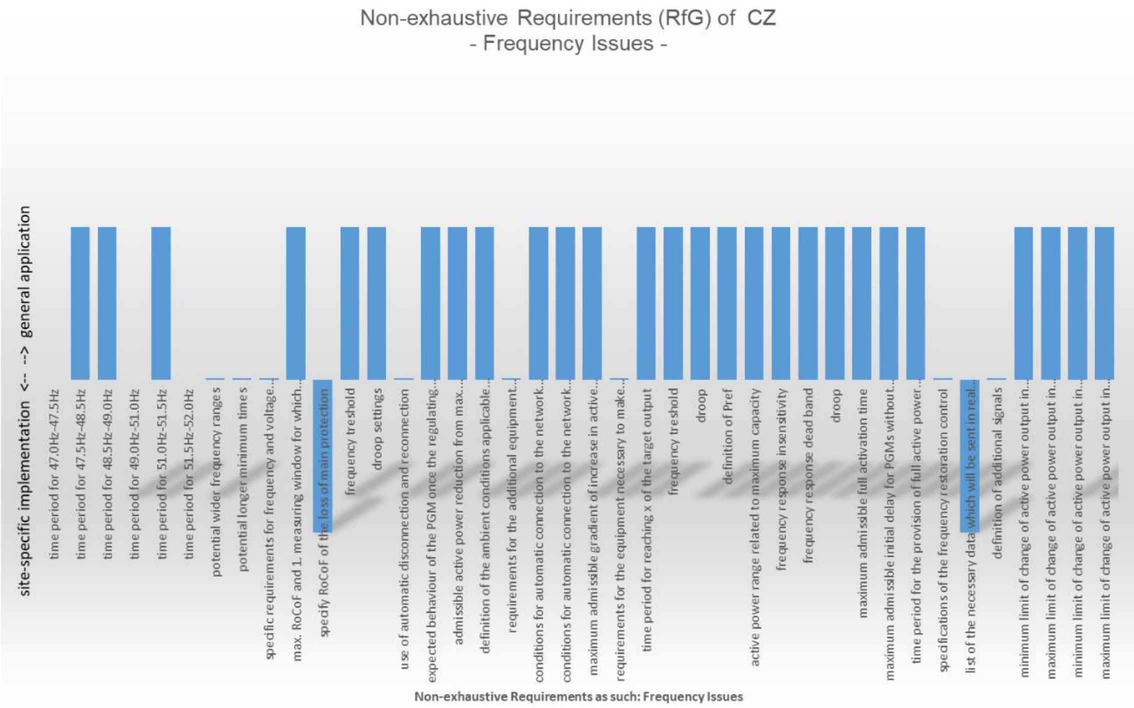


Figure 10: Czech Republic (CZ)

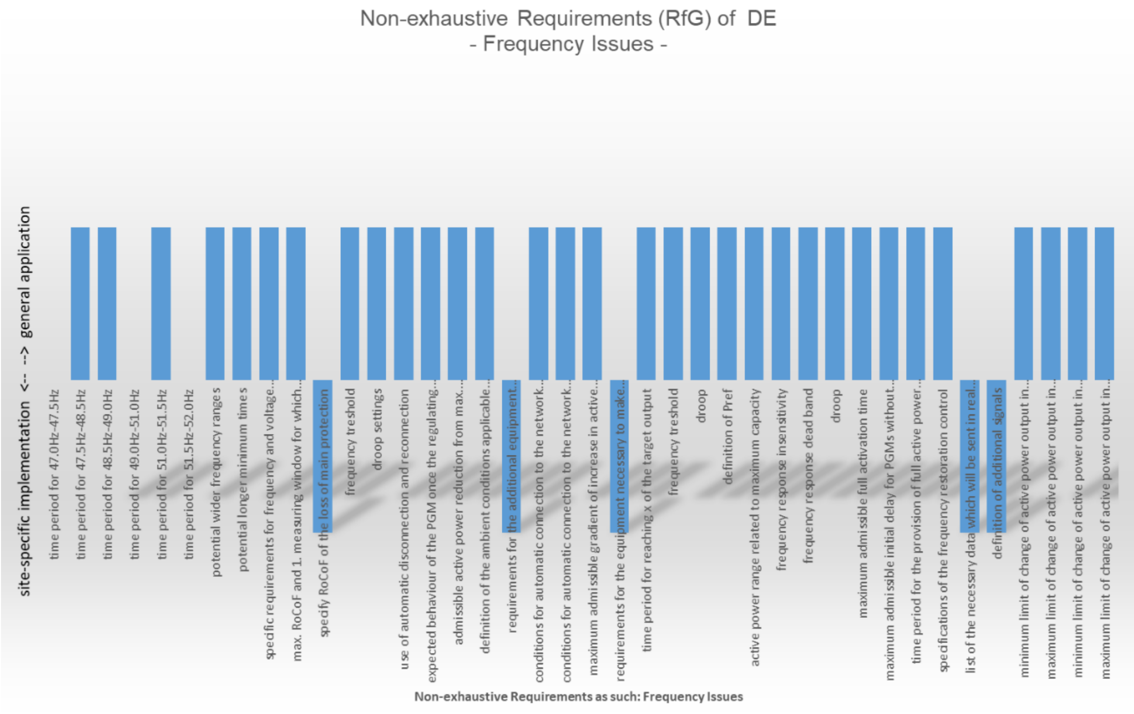


Figure 11: Germany (DE)

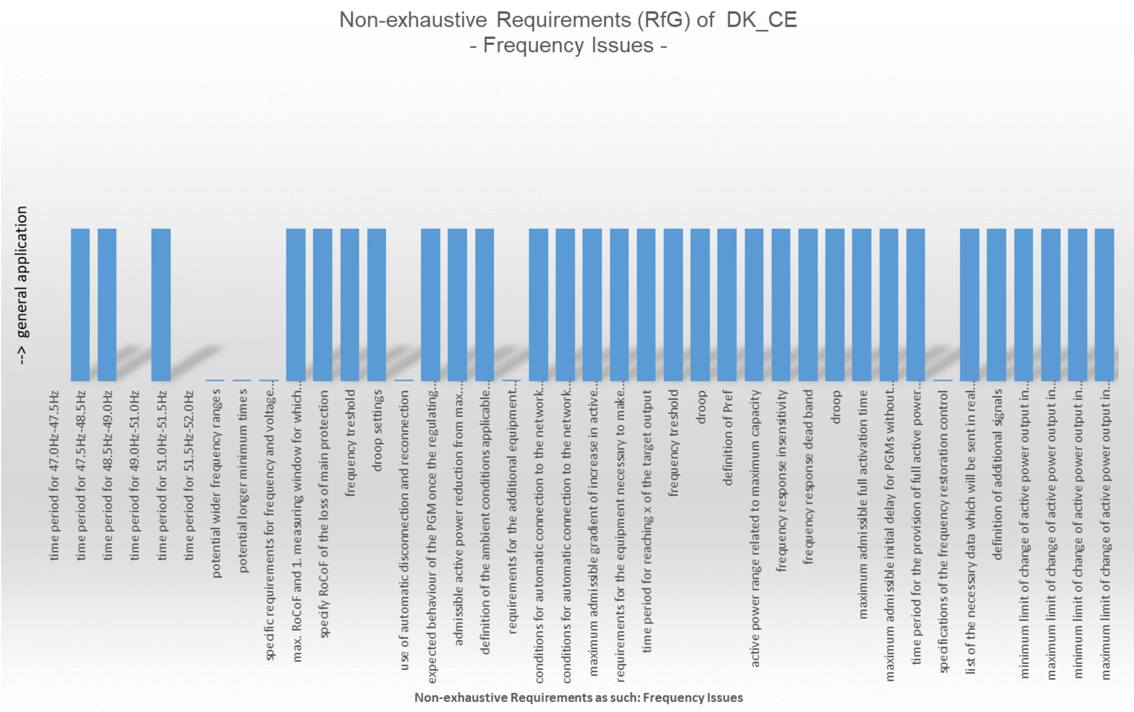


Figure 12: Denmark 1 (DK-CE)

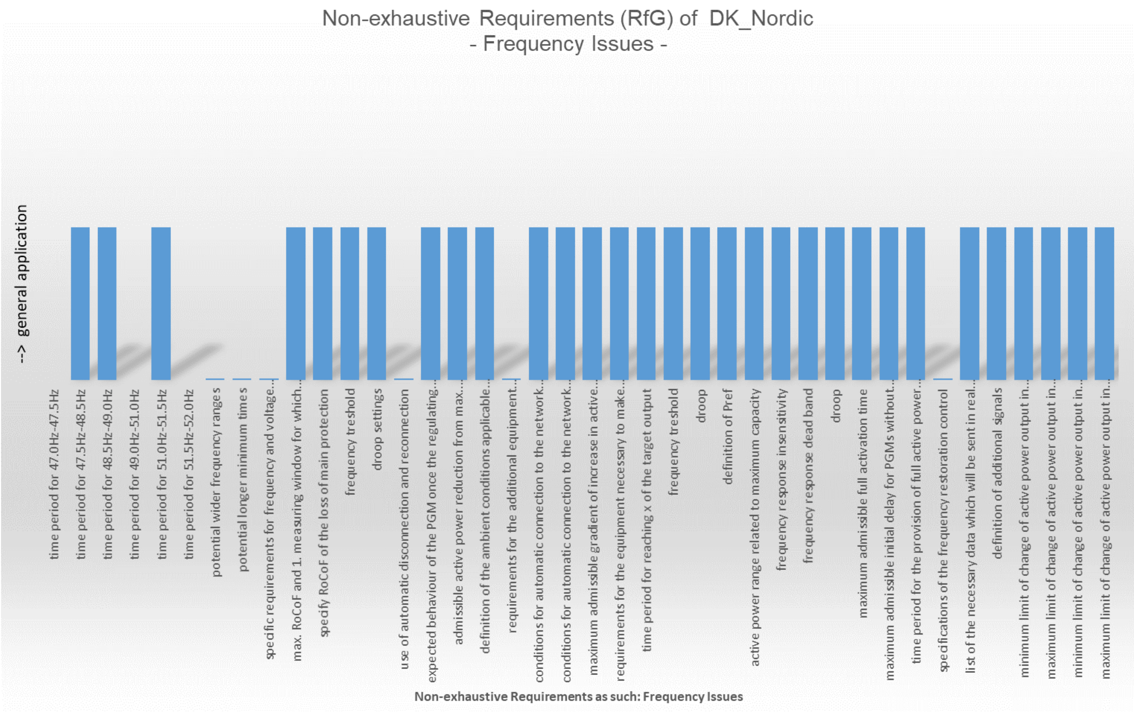


Figure 13: Denmark 2 (DK-Nordic)

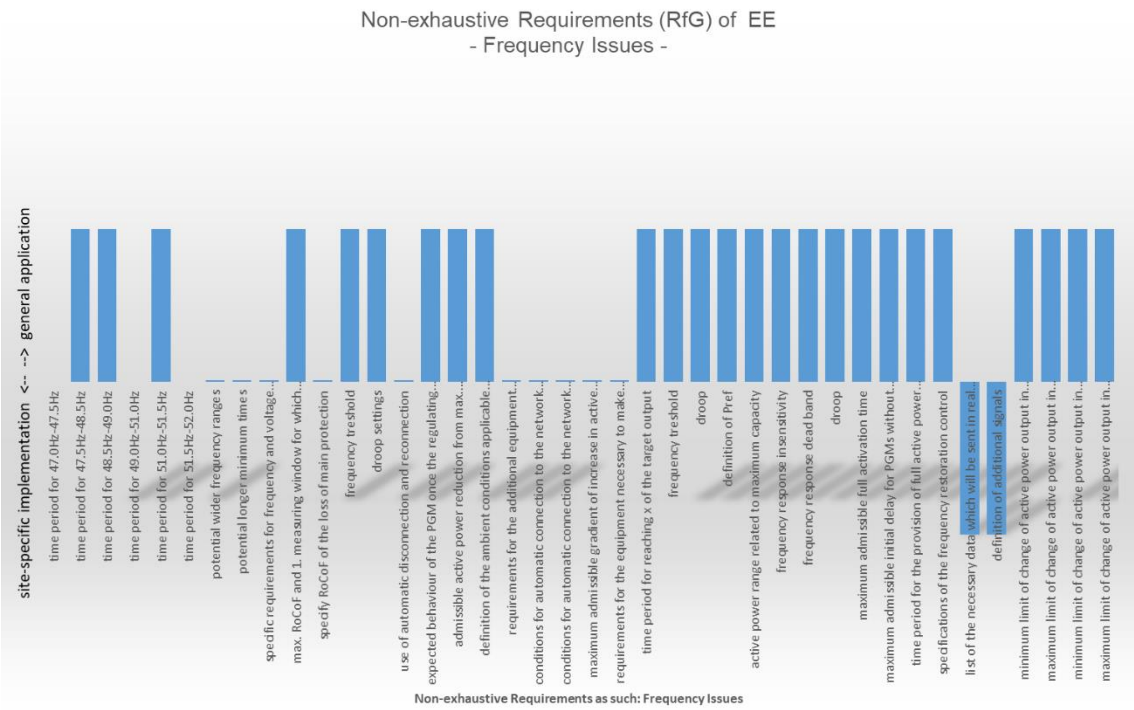


Figure 14: Estonia (EE)

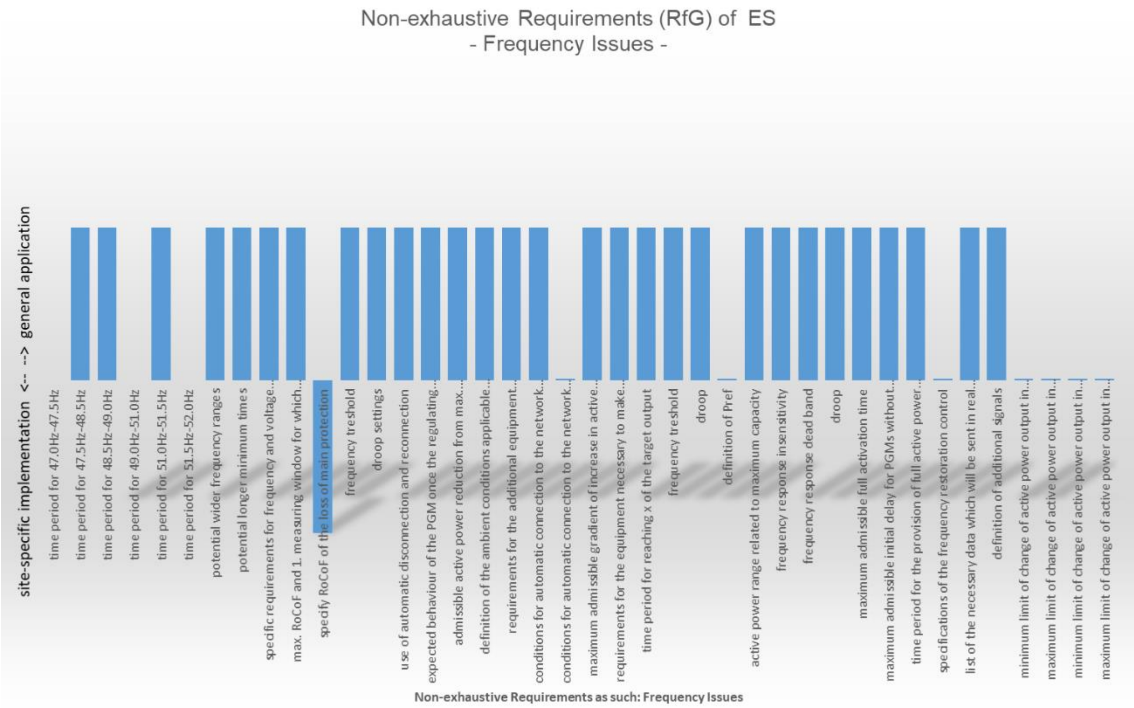


Figure 15: Spain (ES)

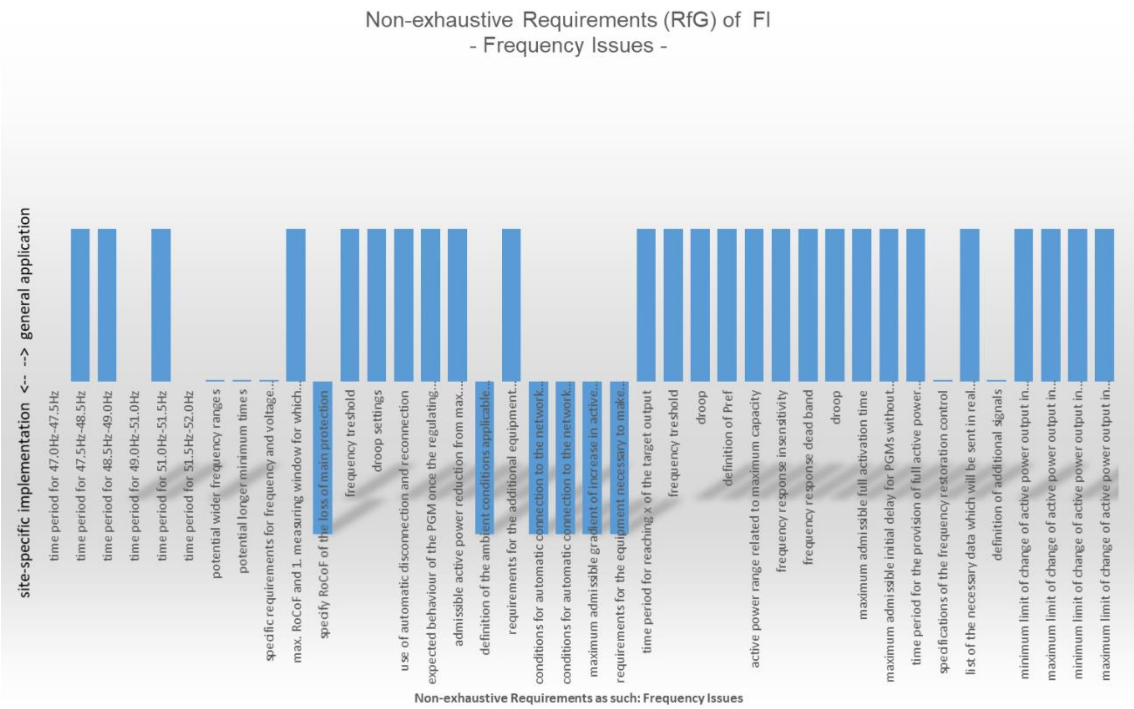


Figure 16: Finland (FI)

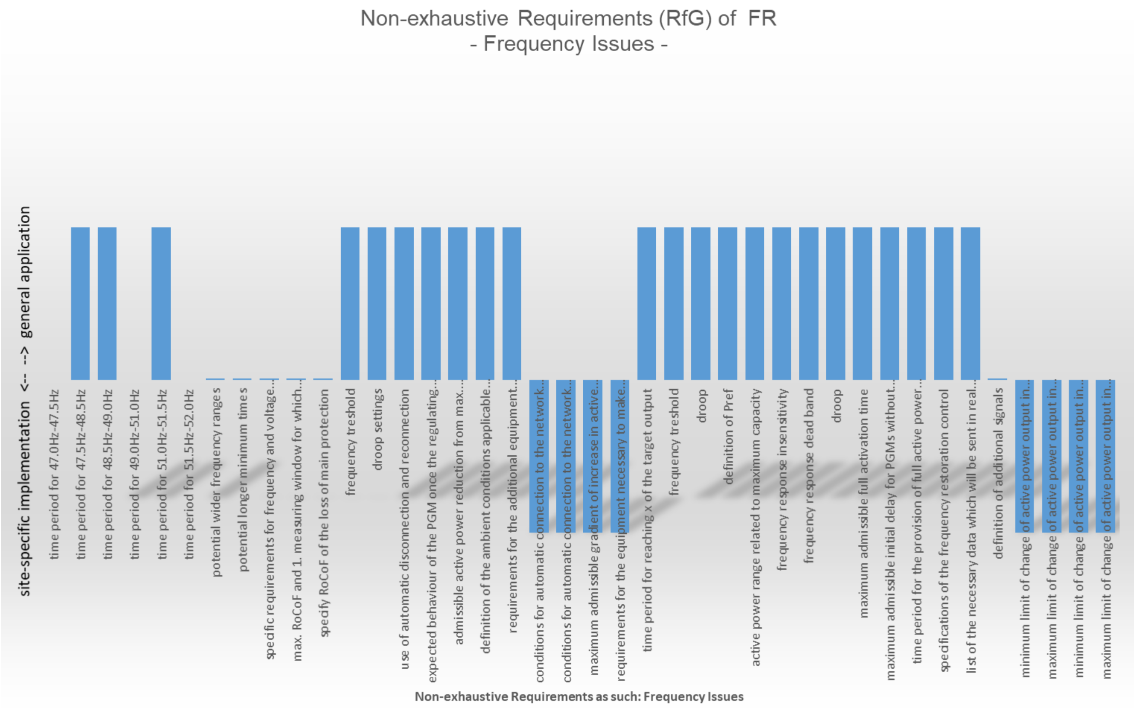


Figure 17: France (FR)

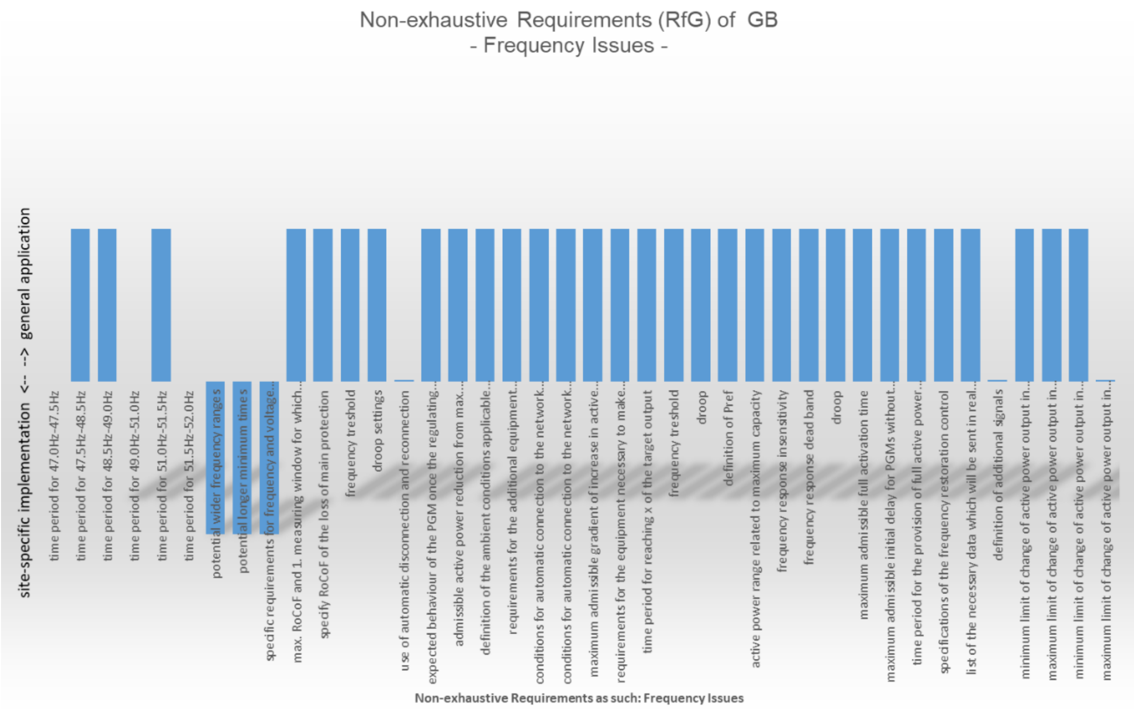


Figure 18: Great Britain (GB)

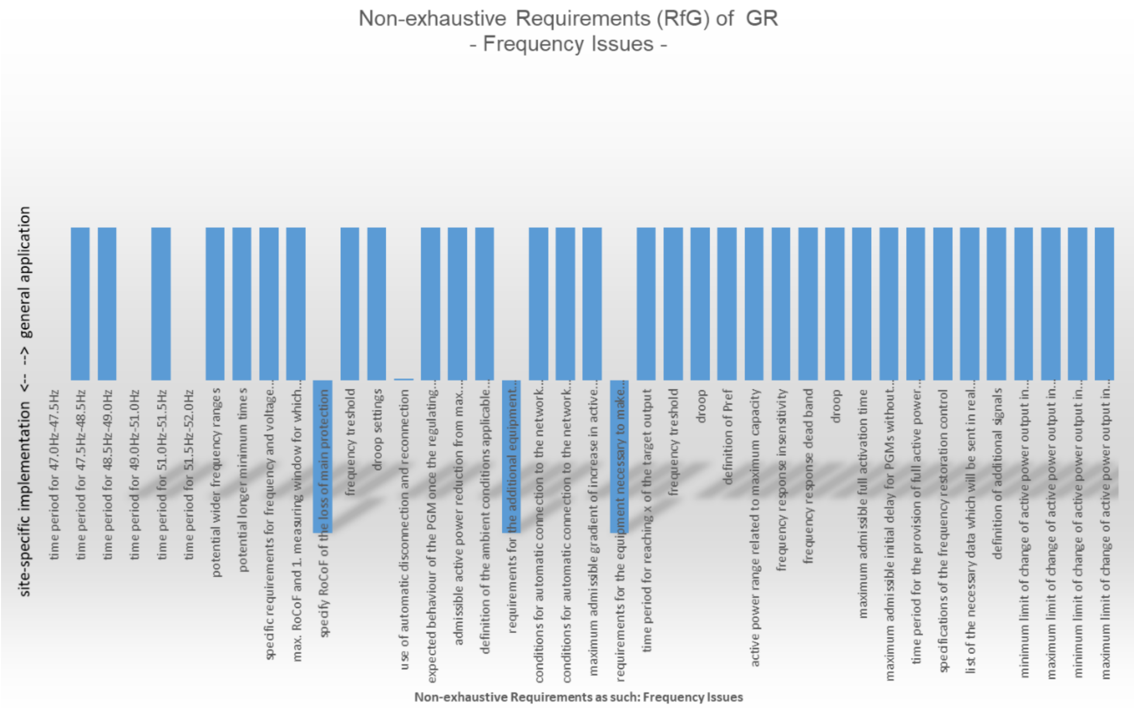


Figure 19: Greece (GR)

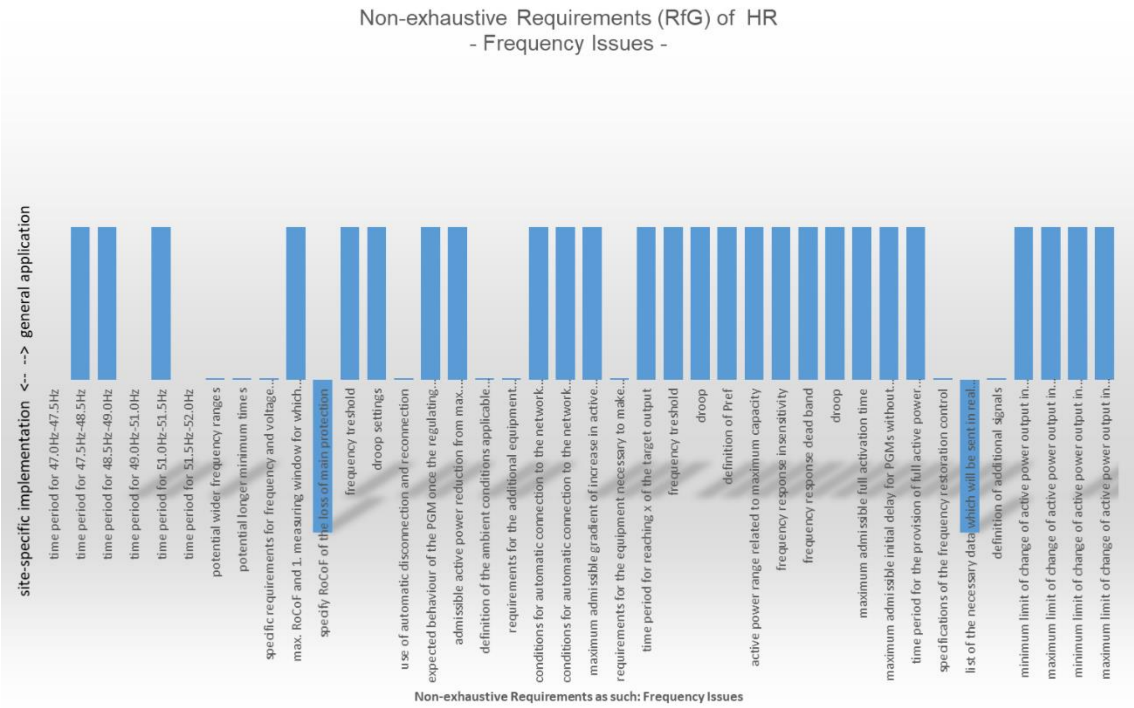


Figure 20: Croatia (HR)

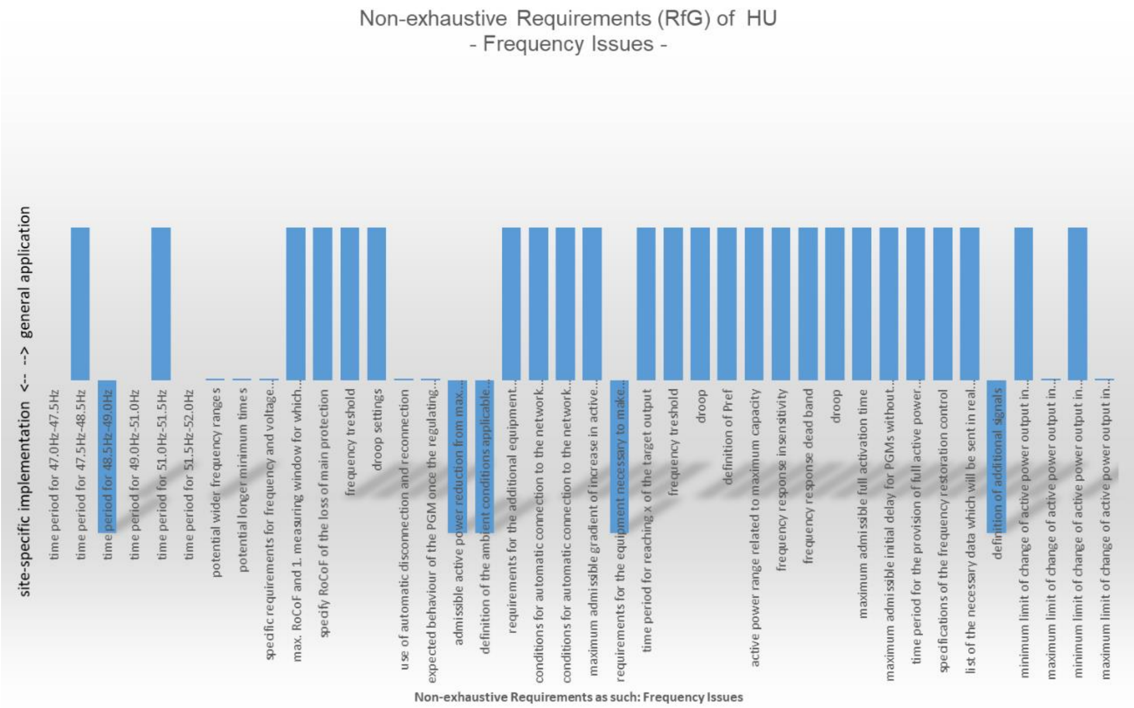


Figure 21: Hungary (HU)

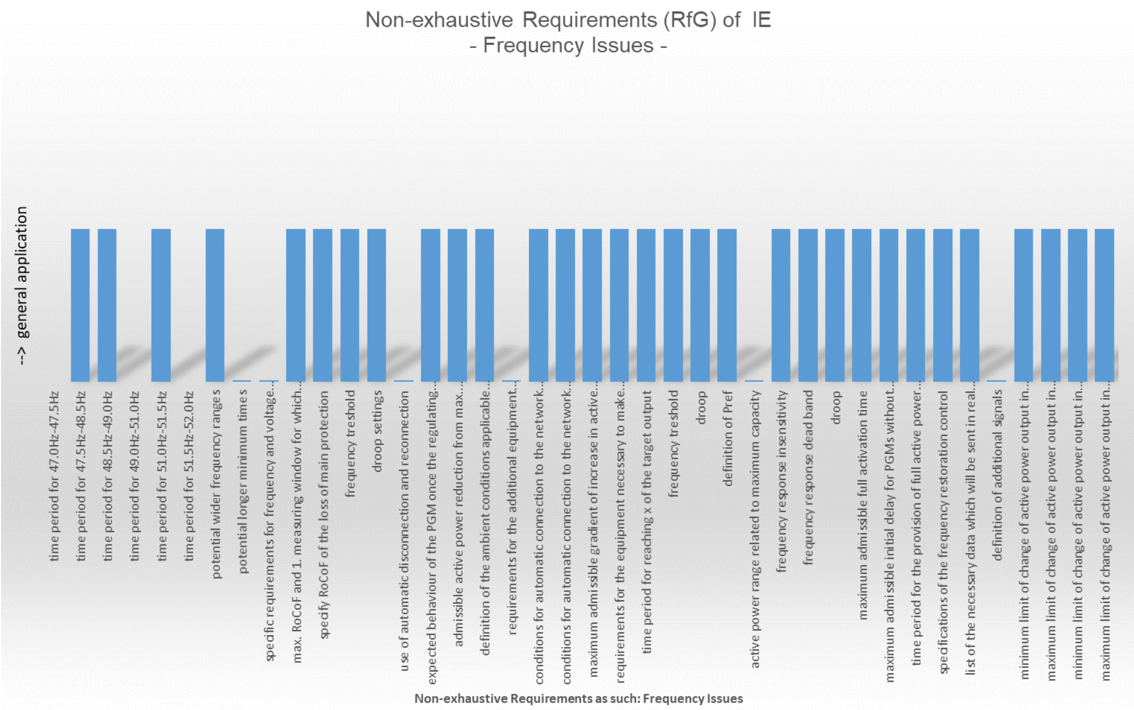


Figure 22: Ireland (IE)

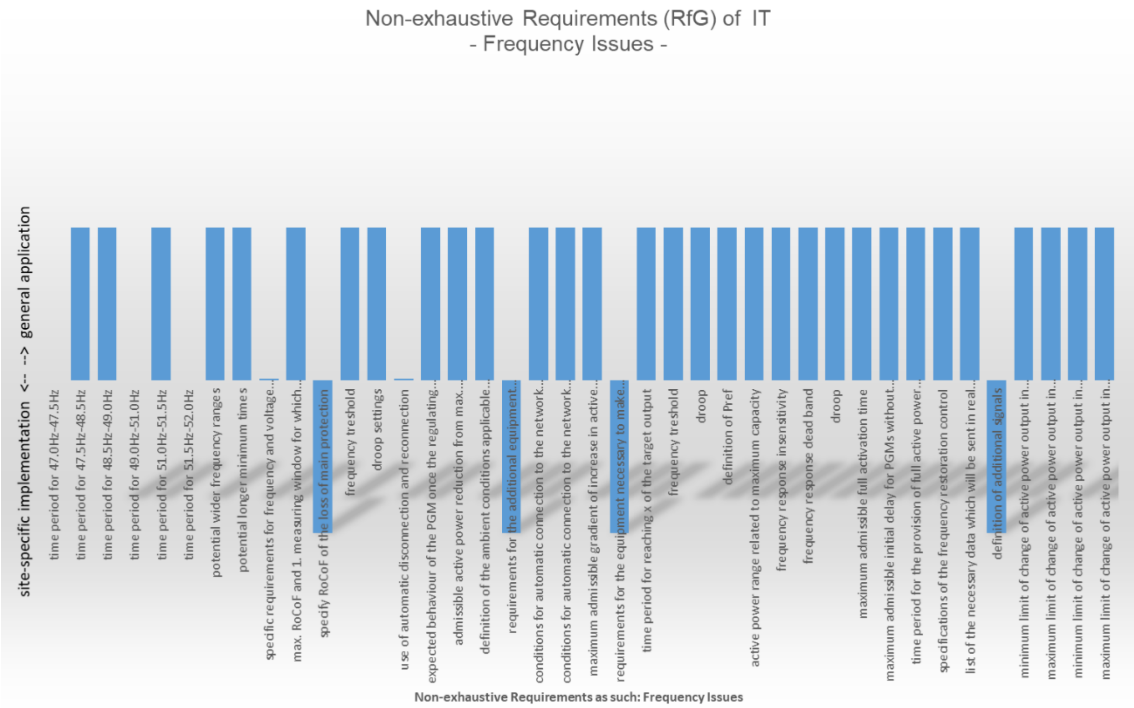


Figure 23: Italy (IT)

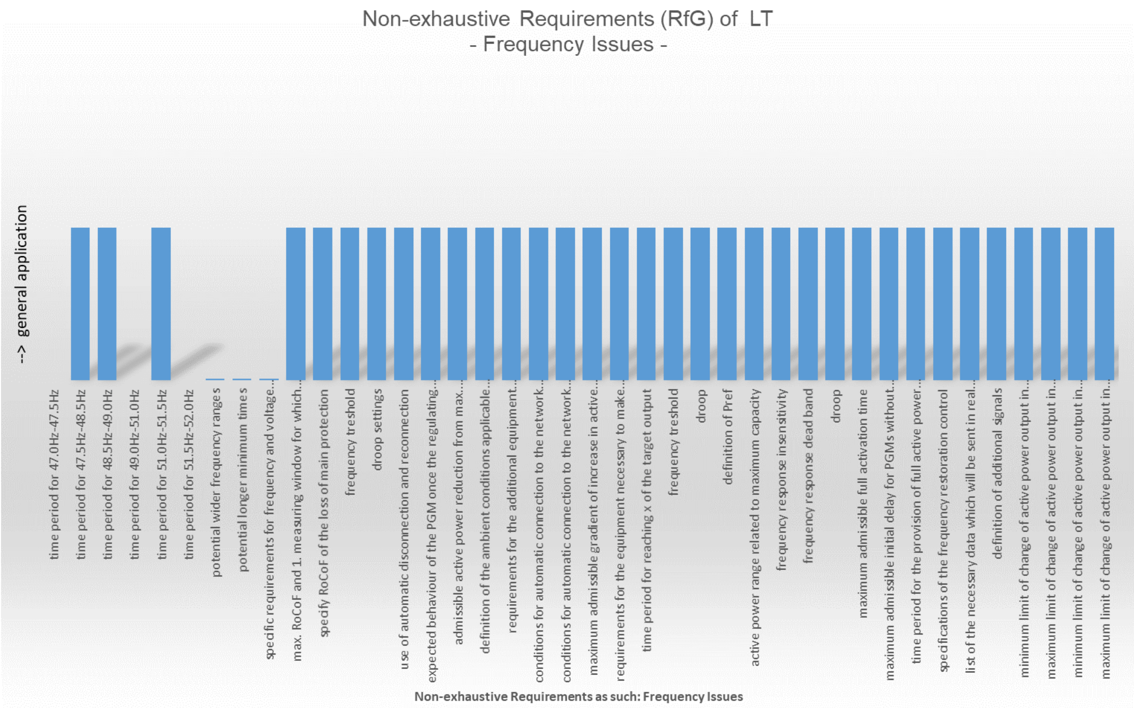


Figure 24: Lithuania (LT)

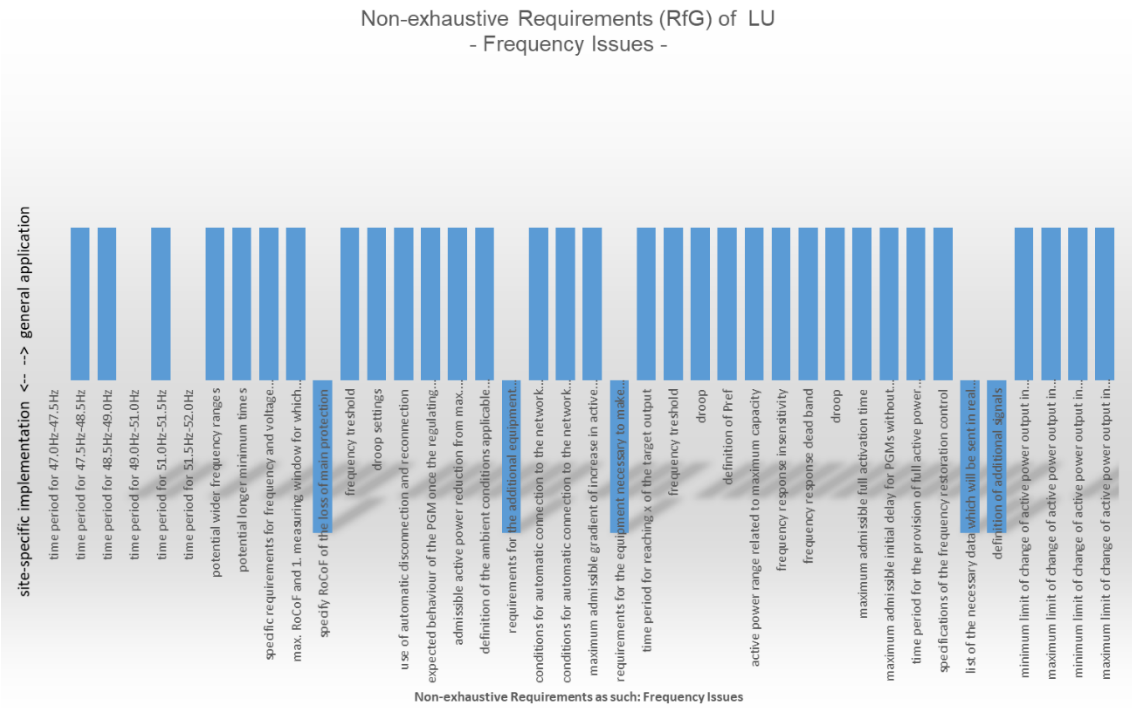


Figure 25: Luxembourg (LU)

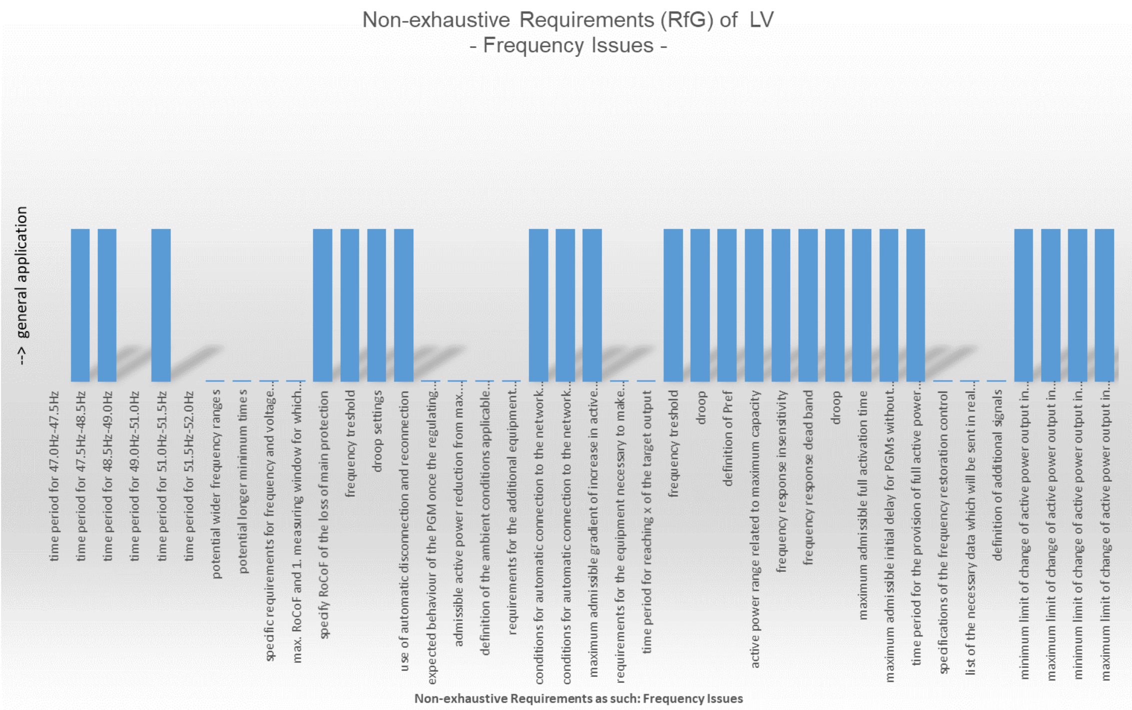


Figure 26: Latvia (LV)

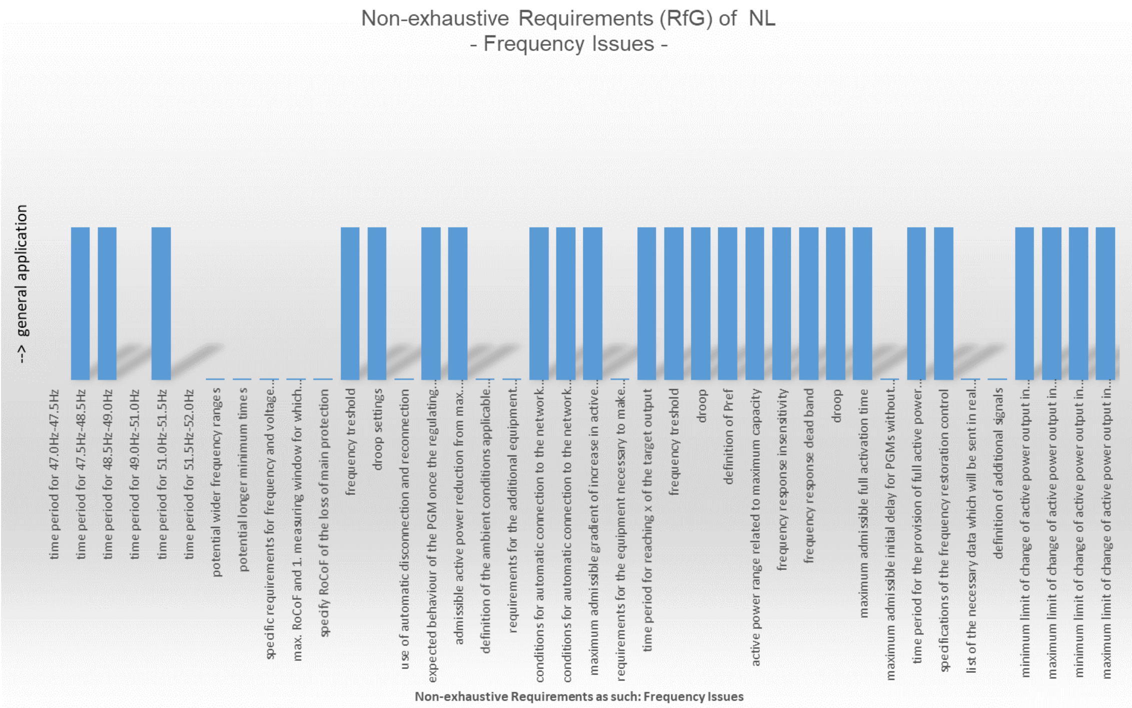


Figure 27: Netherlands (NL)

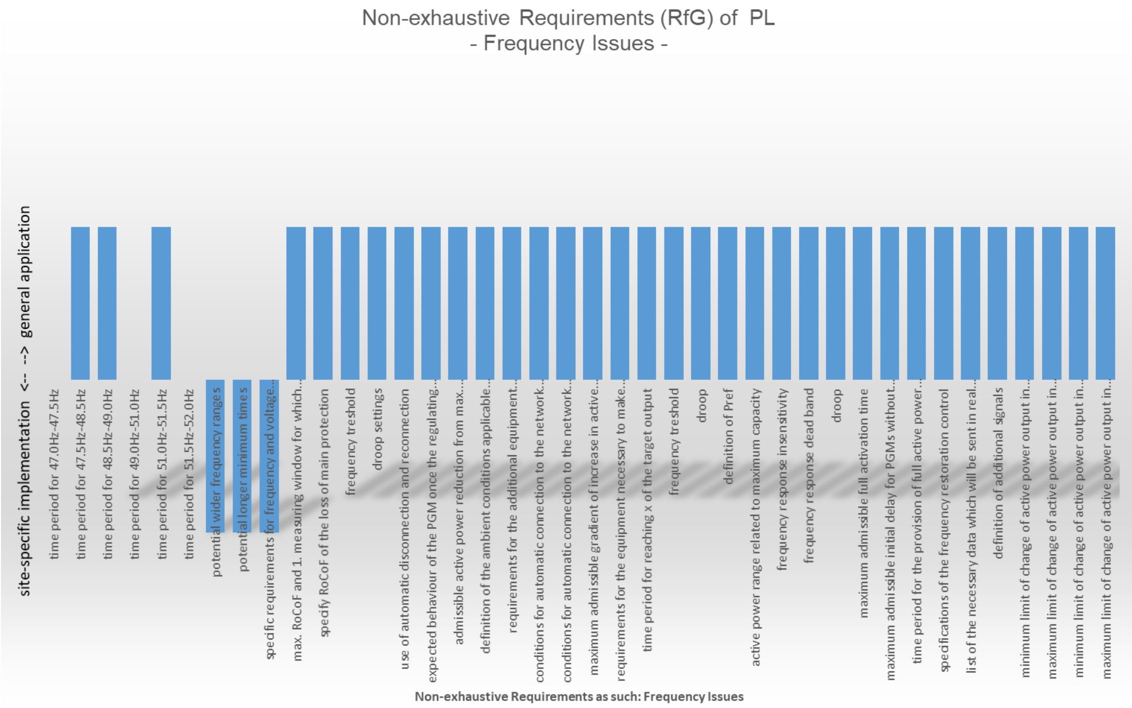


Figure 28: Poland (PL)

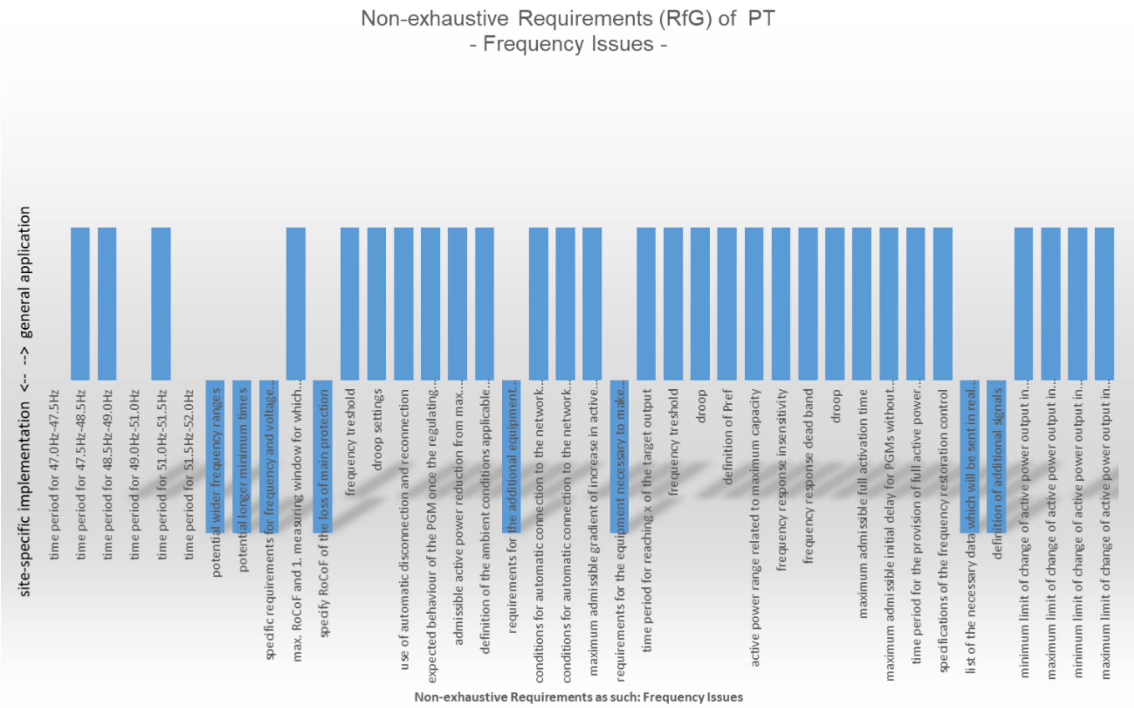


Figure 29: Portugal (PT)

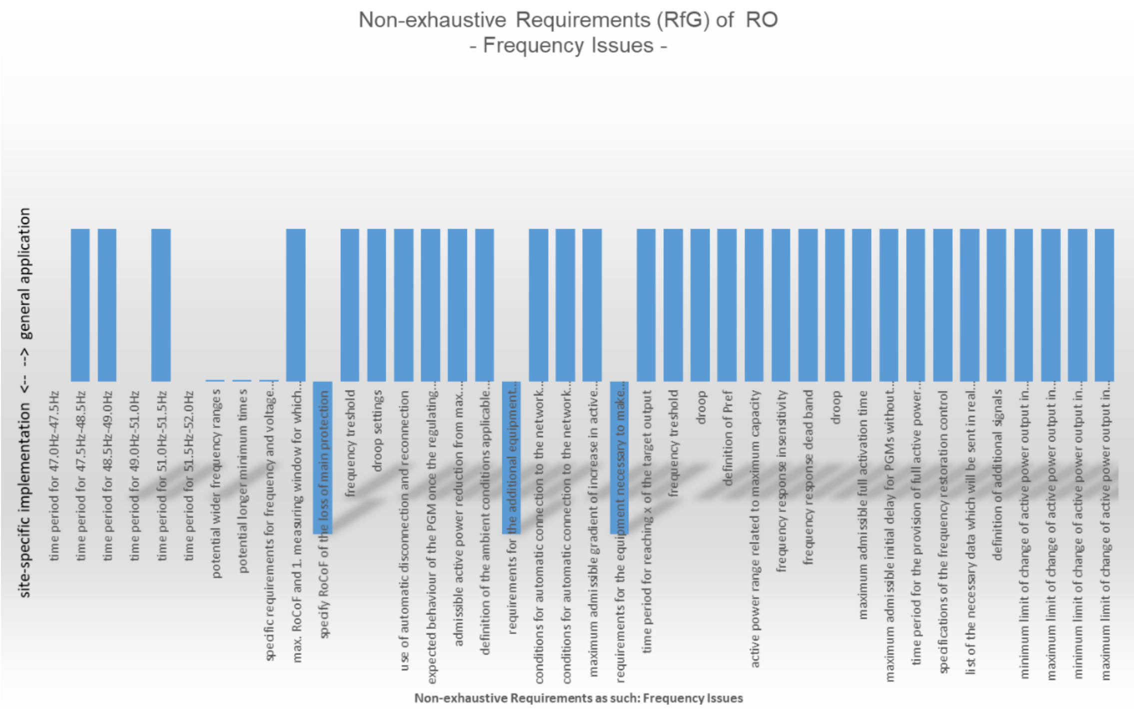


Figure 30: Romania (RO)

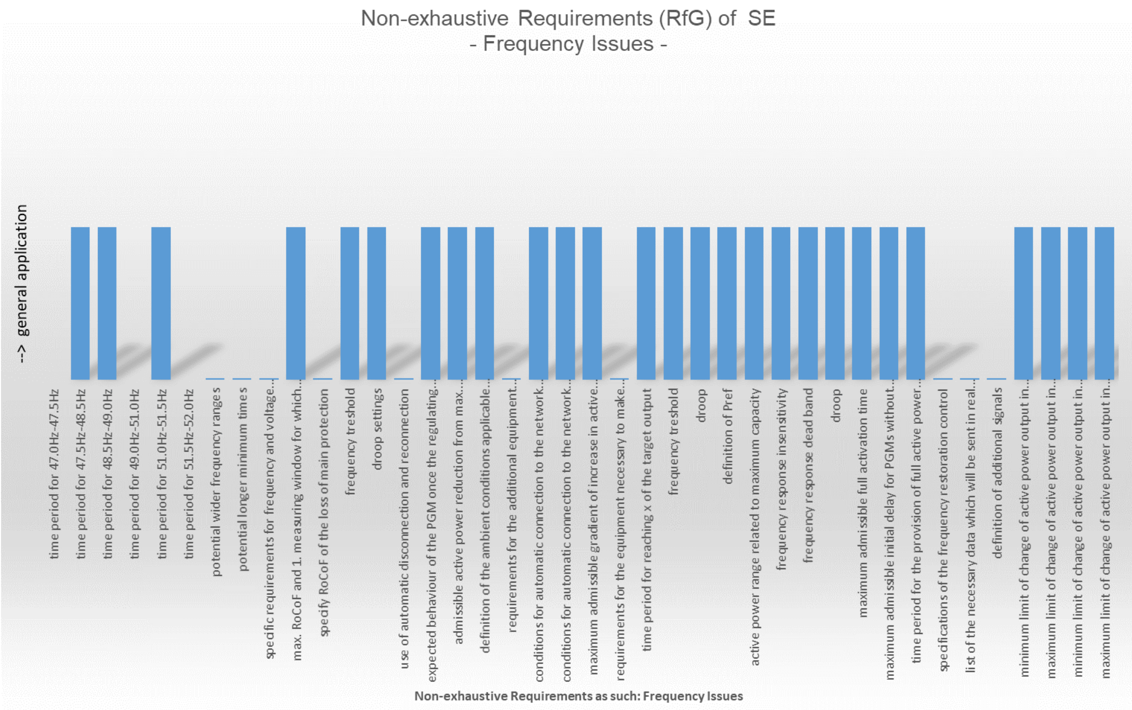


Figure 31: Sweden (SE)

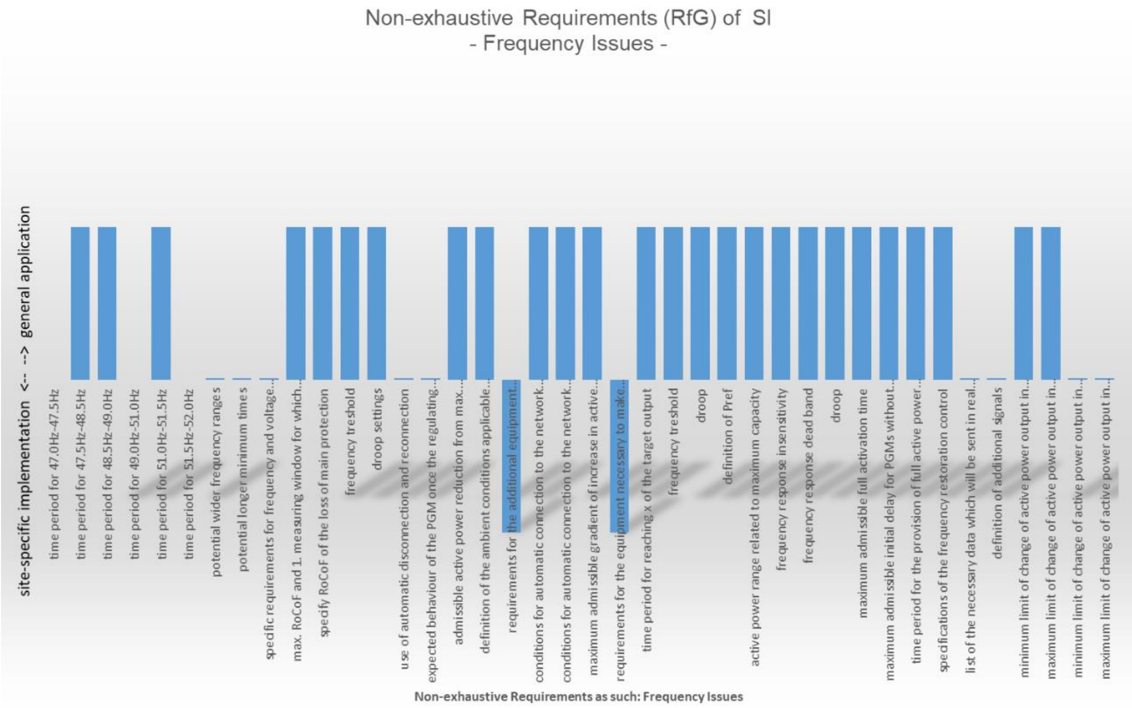


Figure 32: Slovenia (SI)

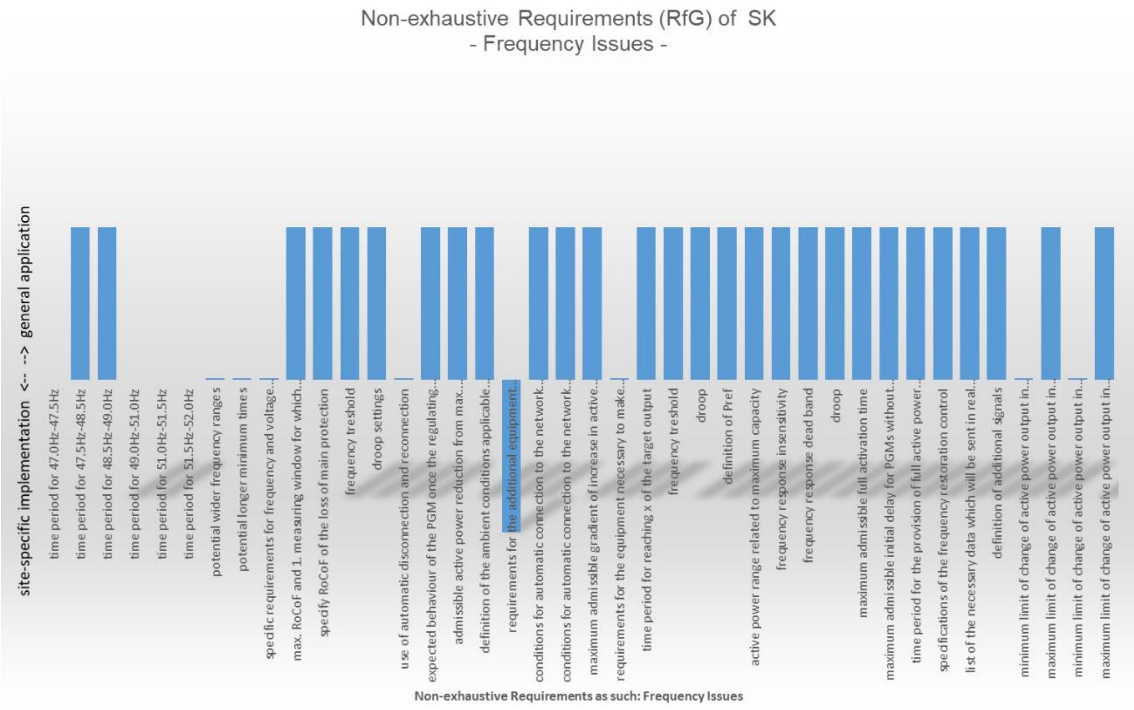


Figure 33: Slovakia

3.5 Voltage Issues (1) – FRT according to Article 14(3) of NC RfG

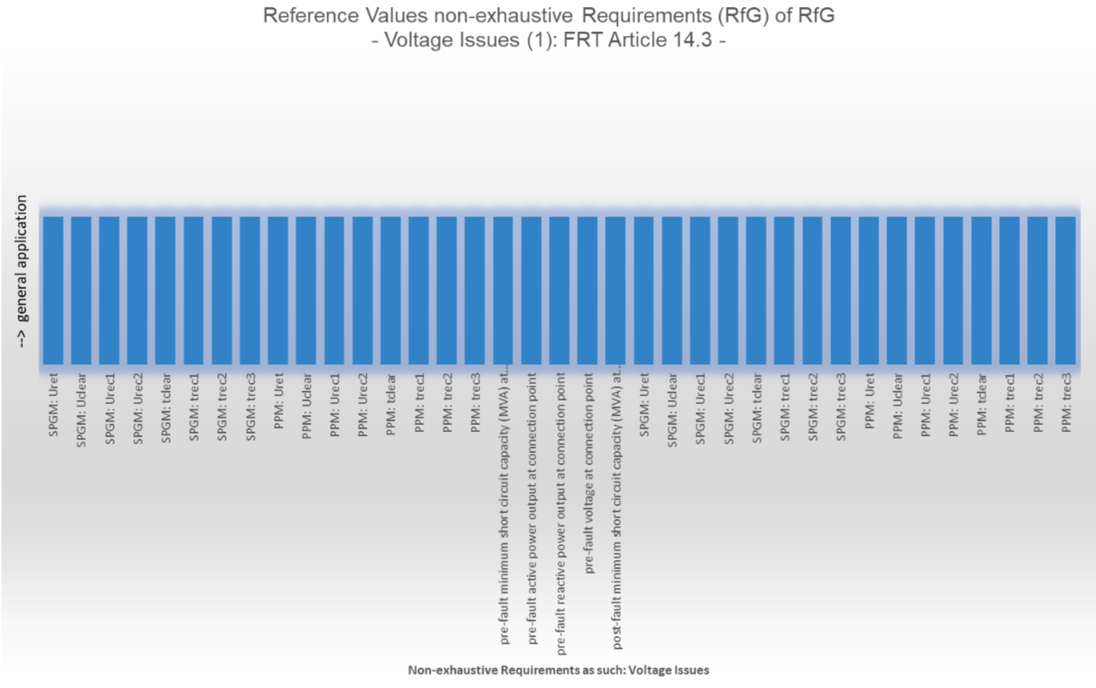


Figure 34: Reference values of non-exhaustive RfG voltage issues (1) - FRT article 14.3

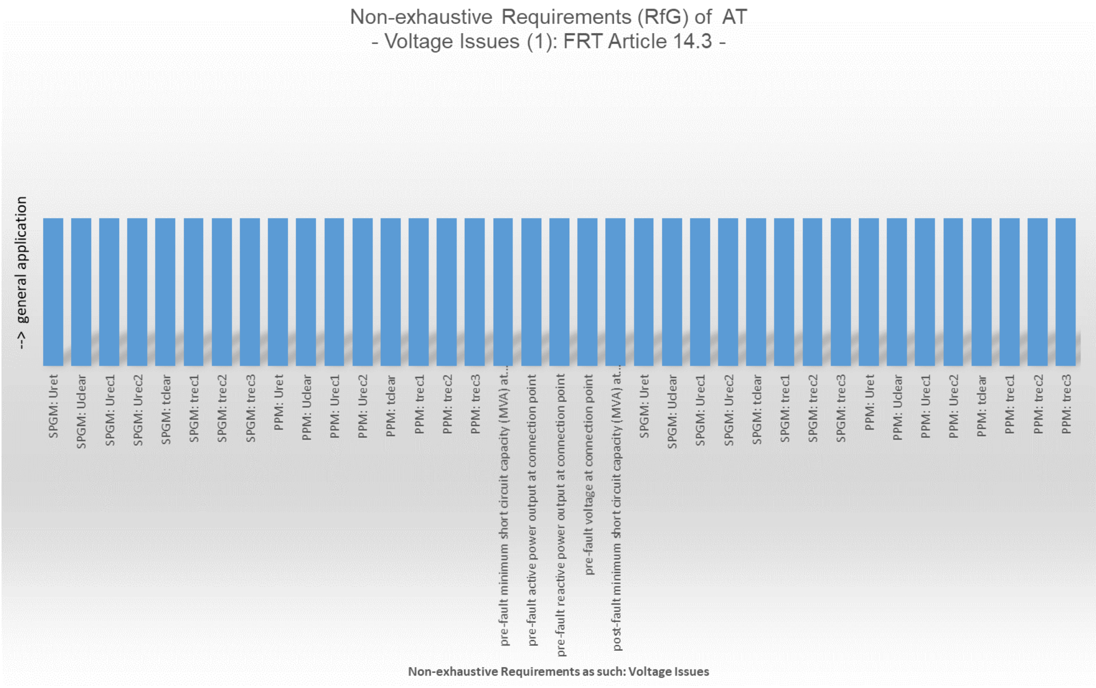


Figure 35: Austria (AT)

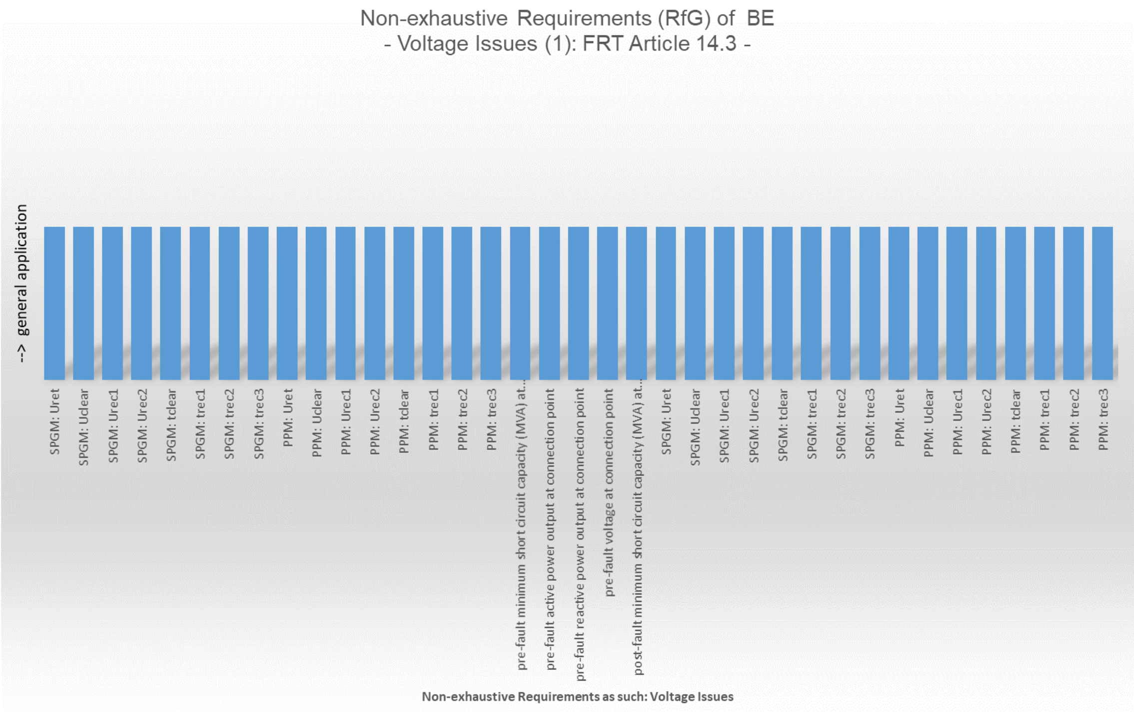


Figure 36: Belgium (BE)

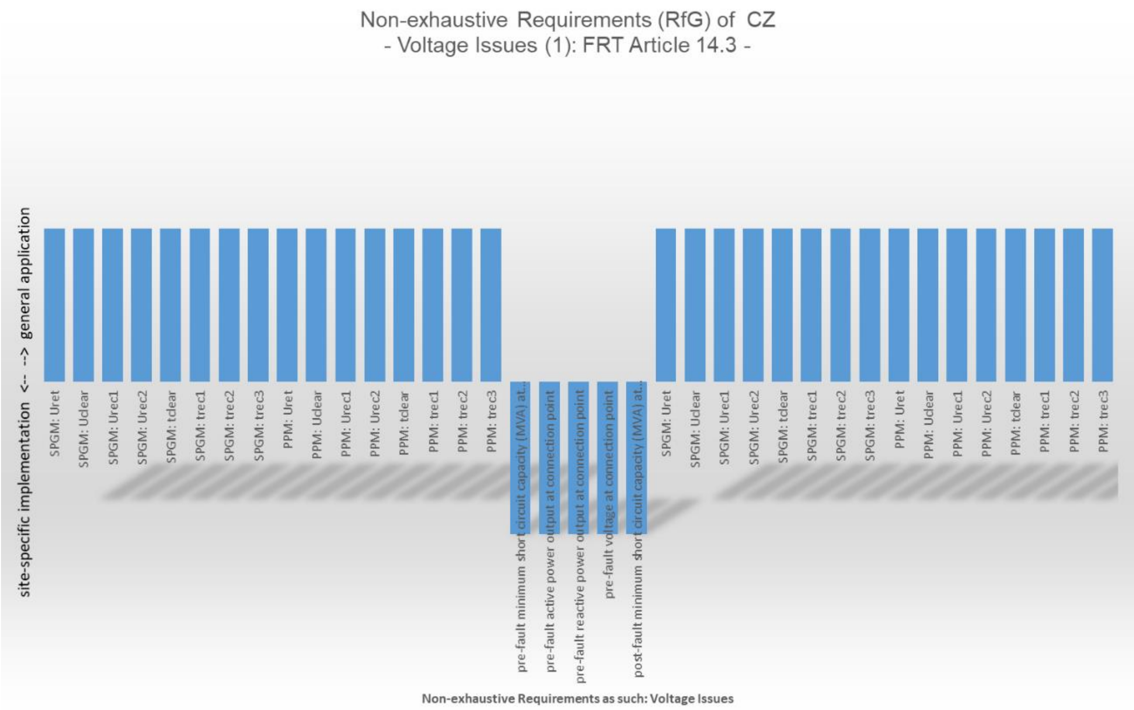


Figure 37: Czech Republic (CZ)

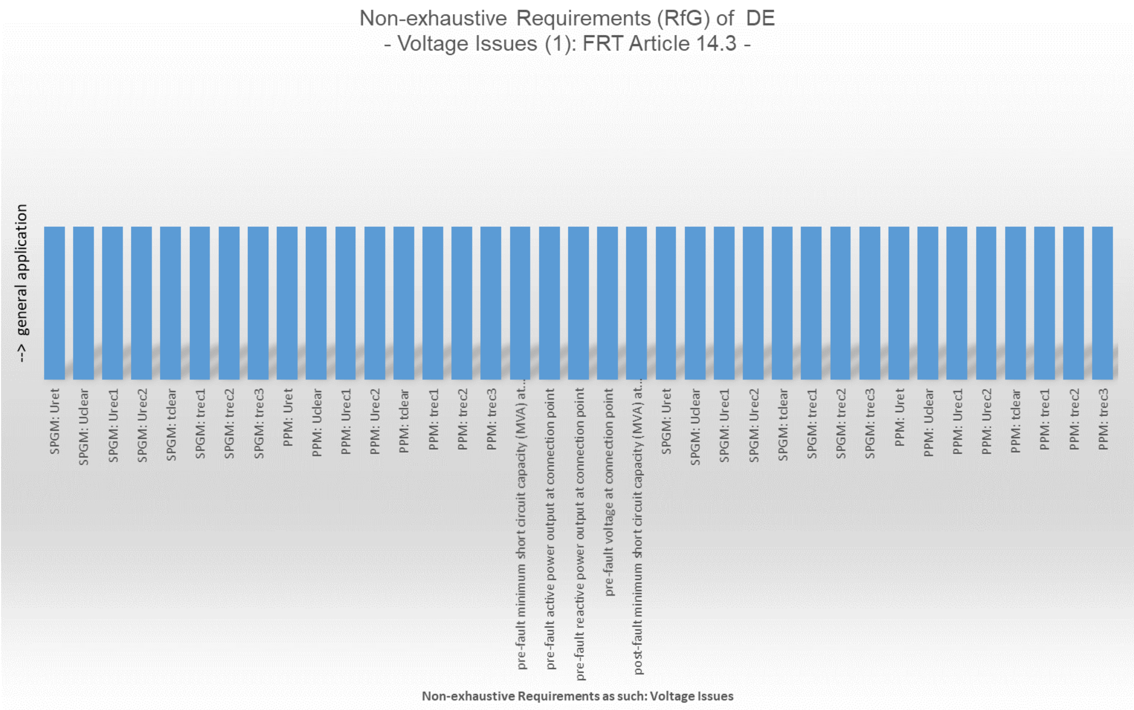


Figure 38: Germany (DE)

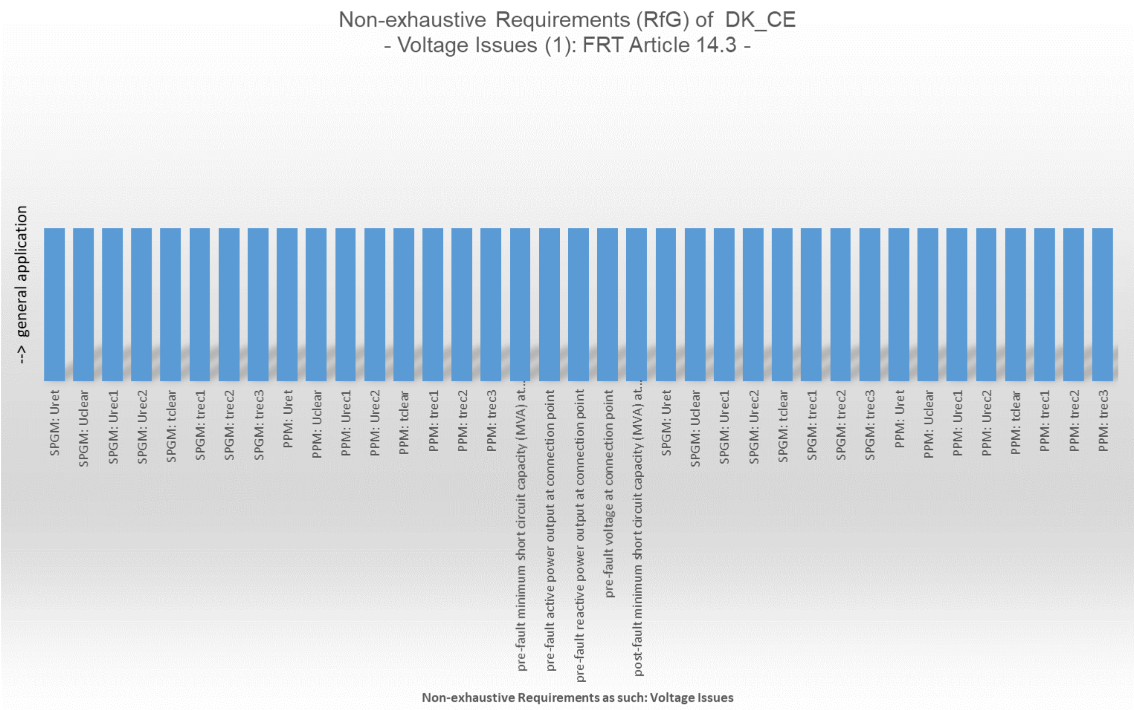


Figure 39: Denmark 1 (DK-CE)

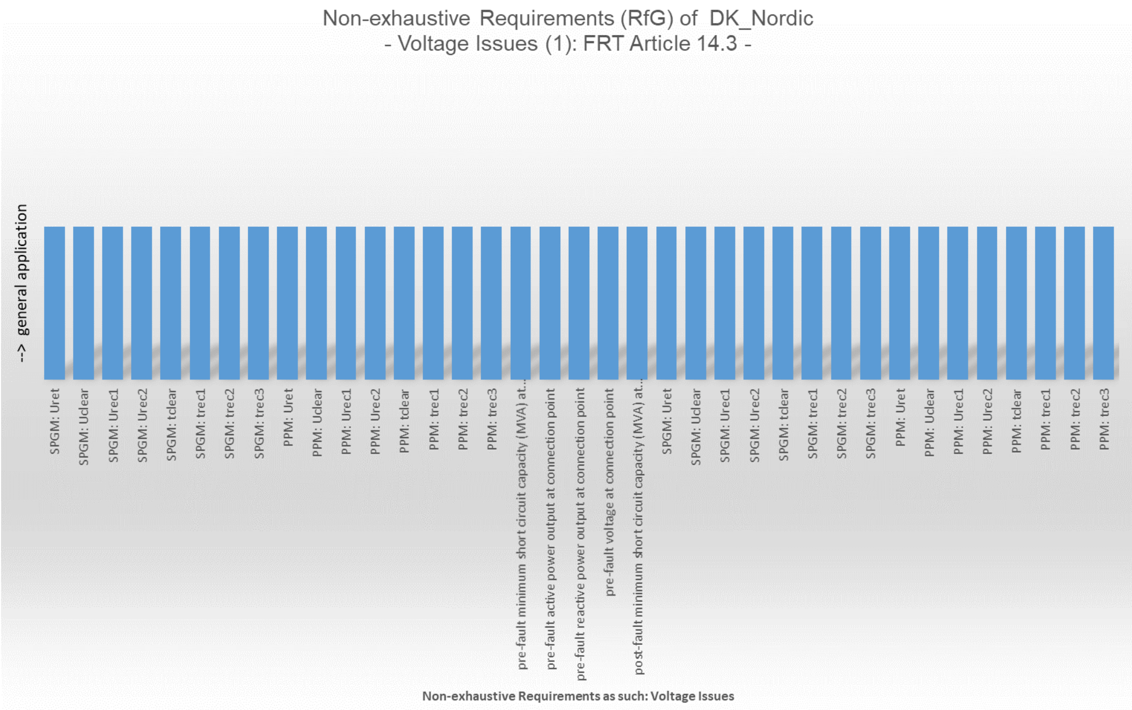


Figure 40: Denmark 2 (DK-Nordic)

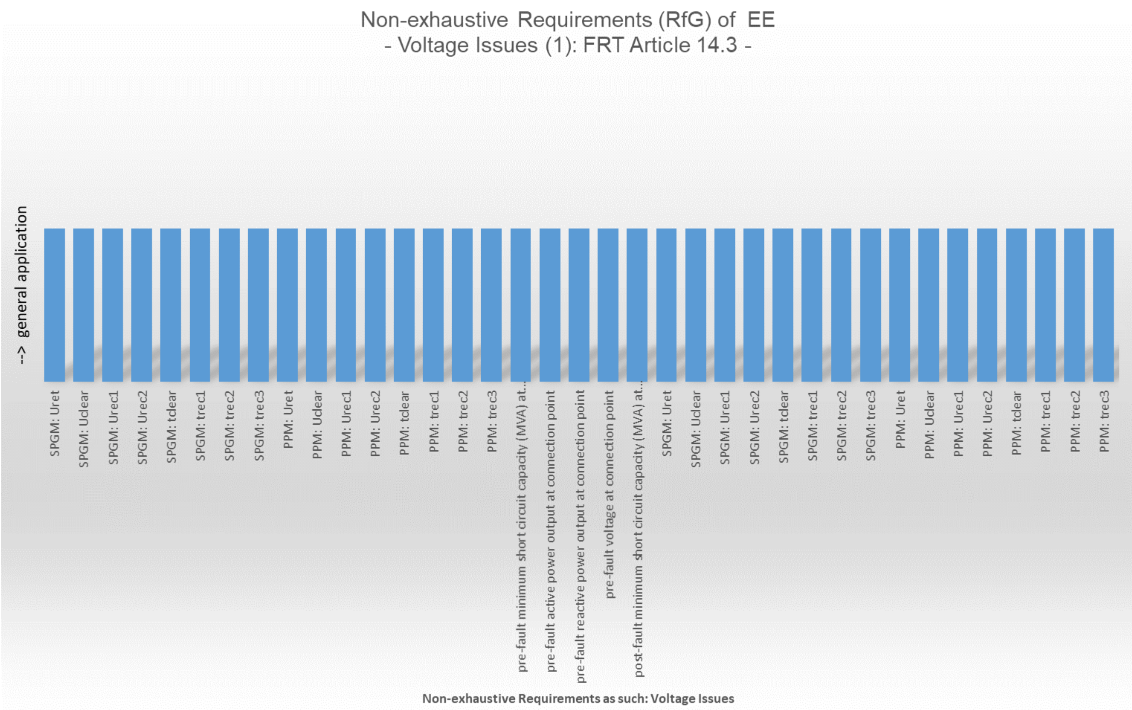


Figure 41: Estonia (EE)

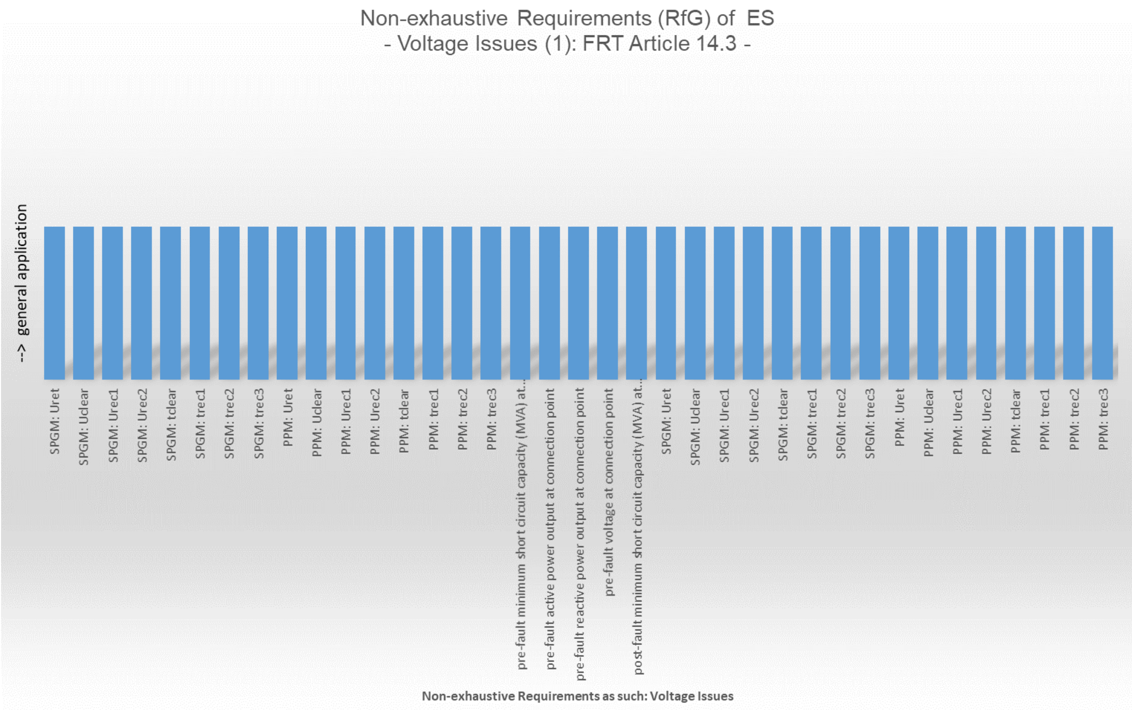


Figure 42: Spain (ES)

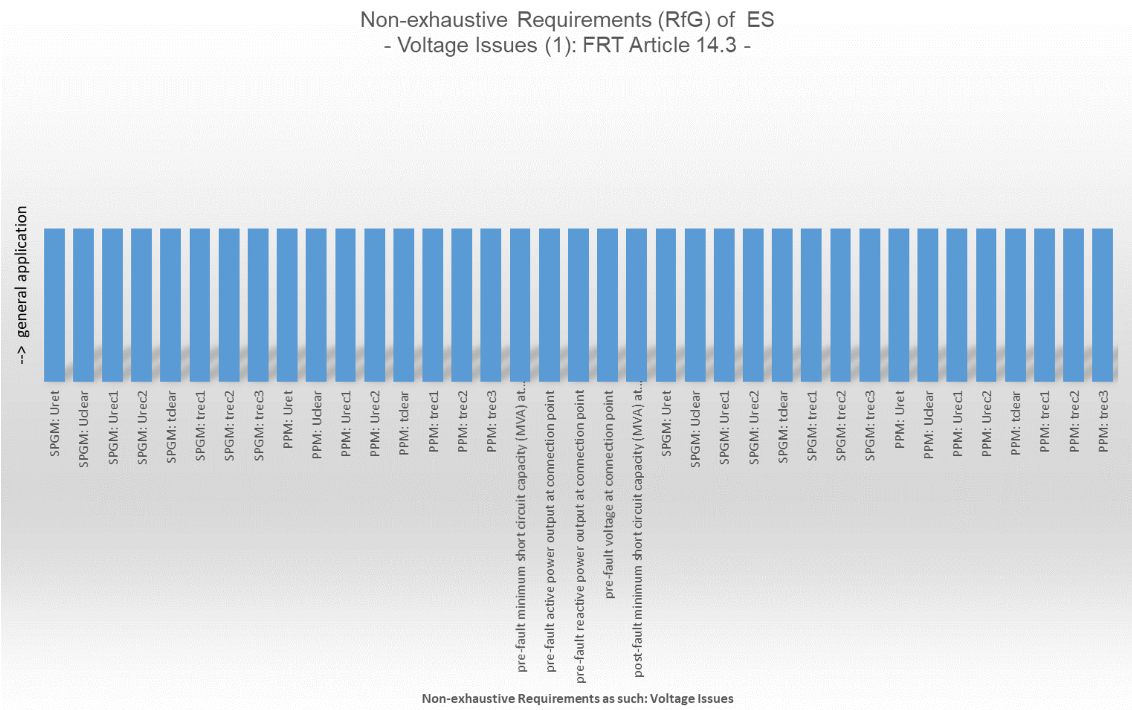


Figure 43: Spain (ES)

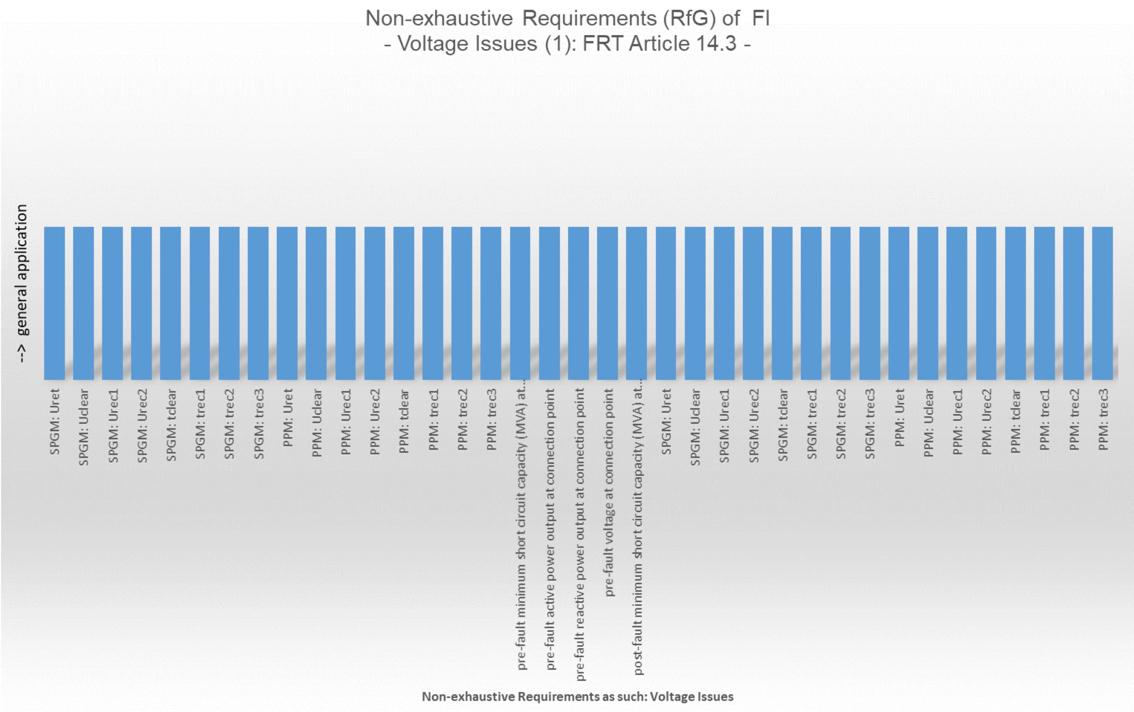


Figure 44: Finland (FI)

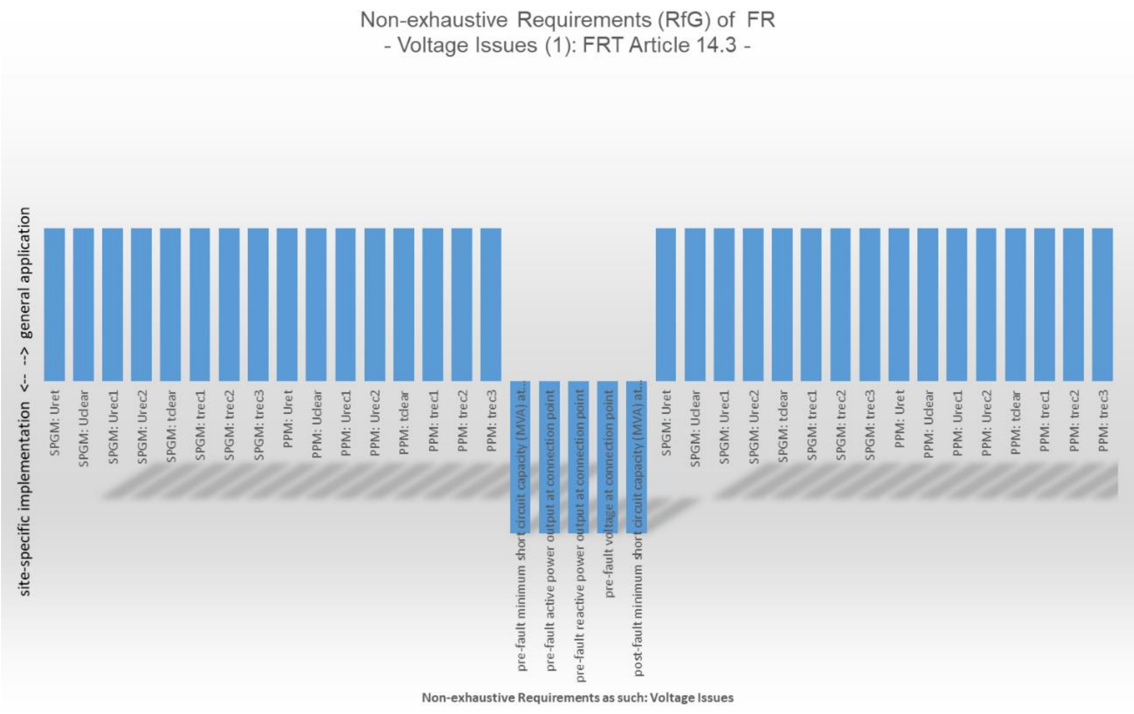


Figure 45: France (FR)

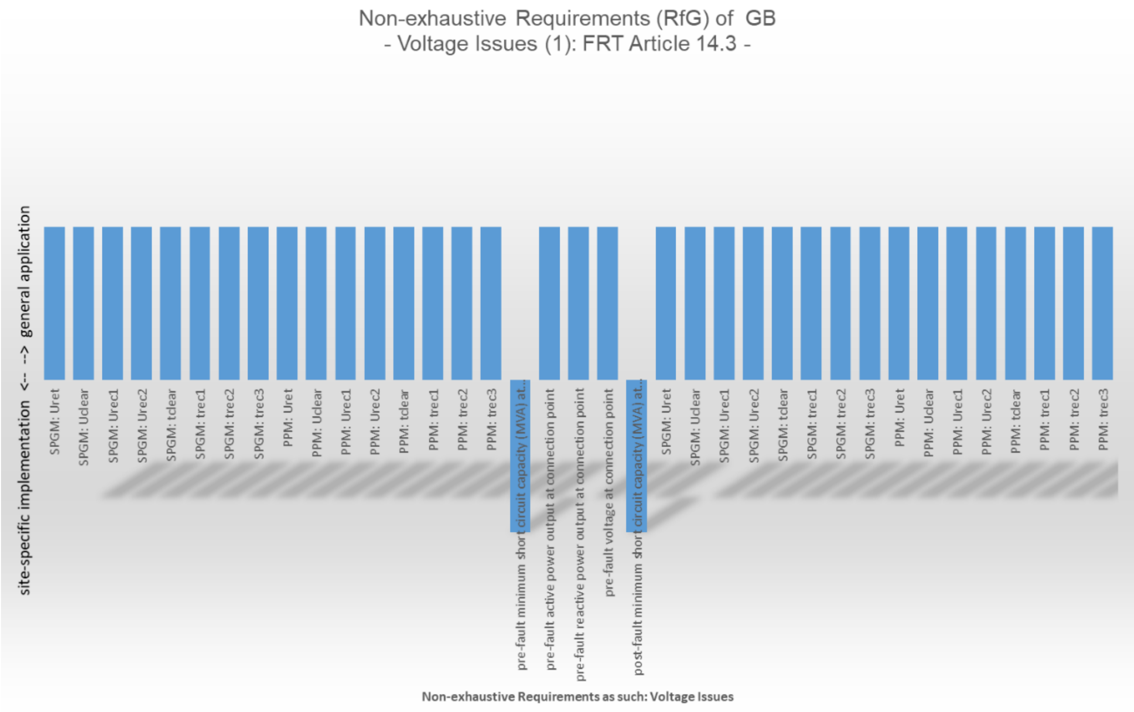


Figure 46: Great Britain (GB)

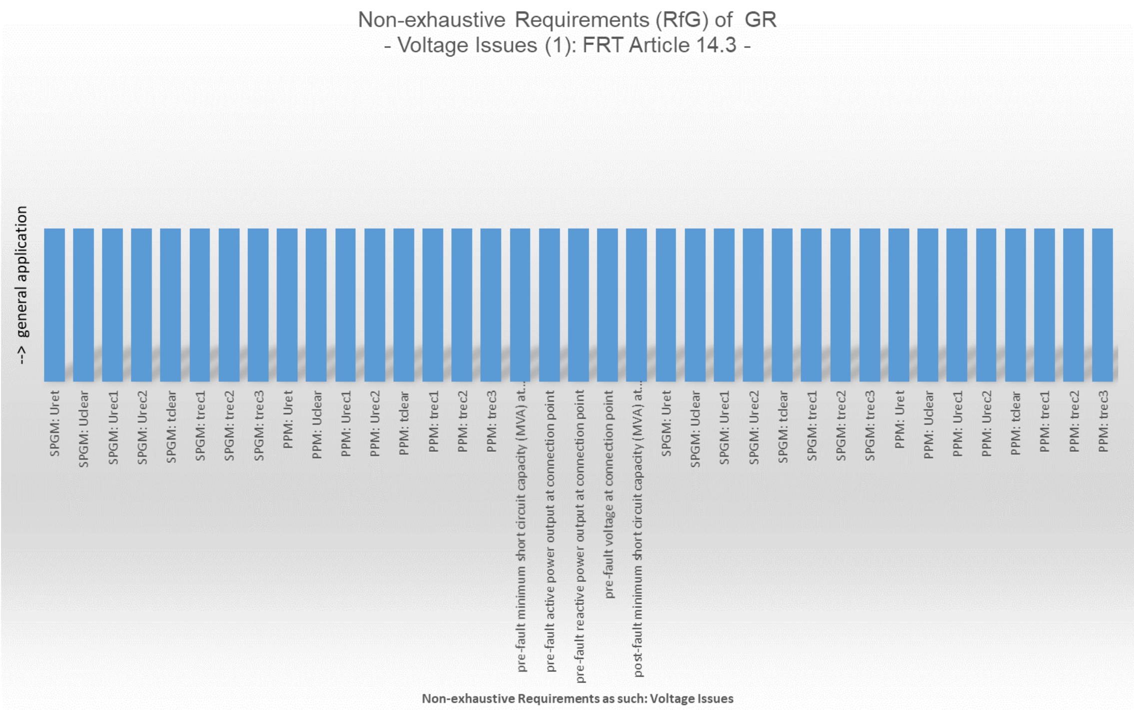


Figure 47: Greece (GR)

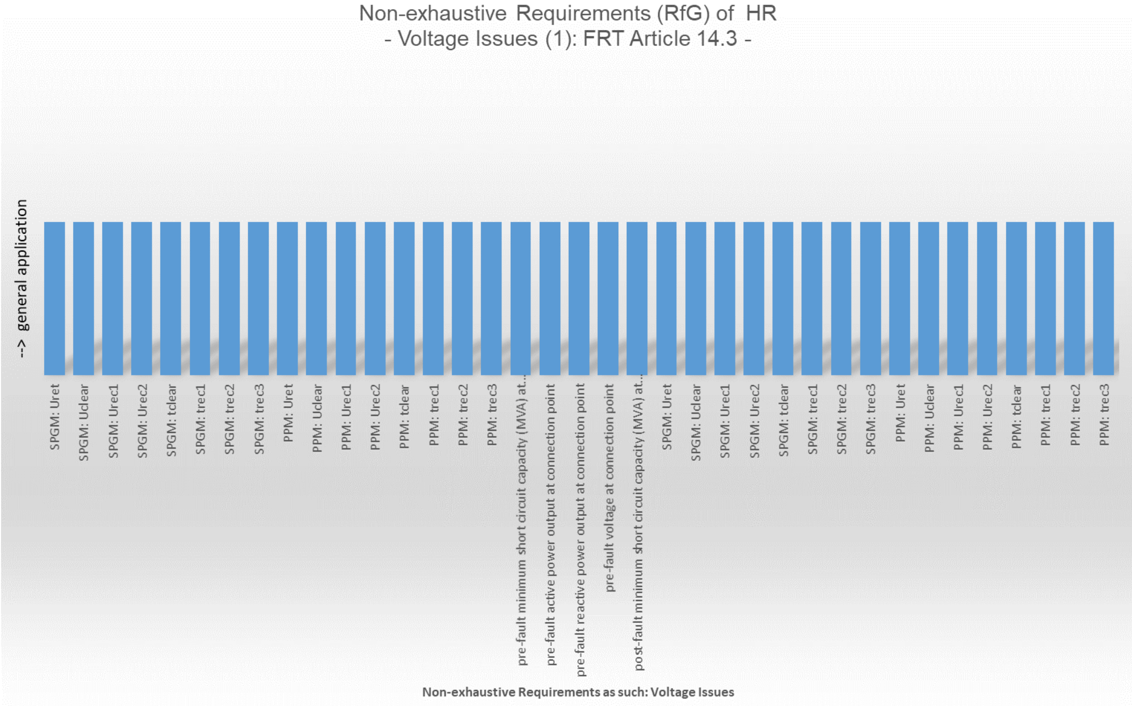


Figure 48: Croatia

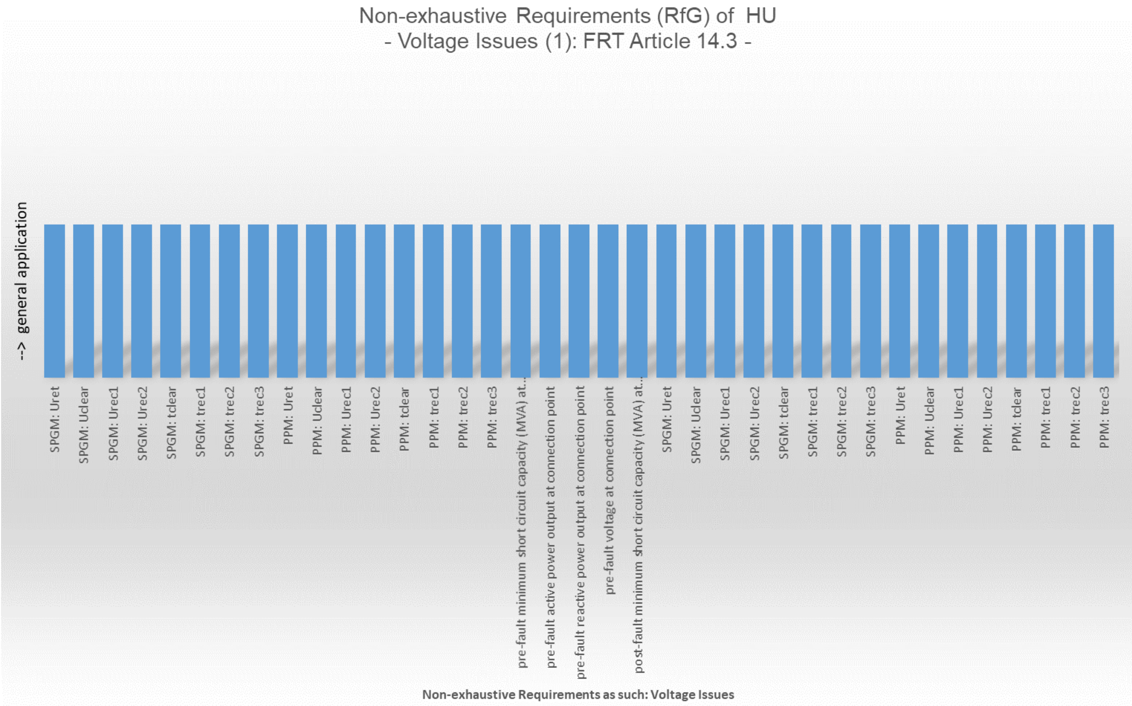


Figure 49: Hungary (HU)

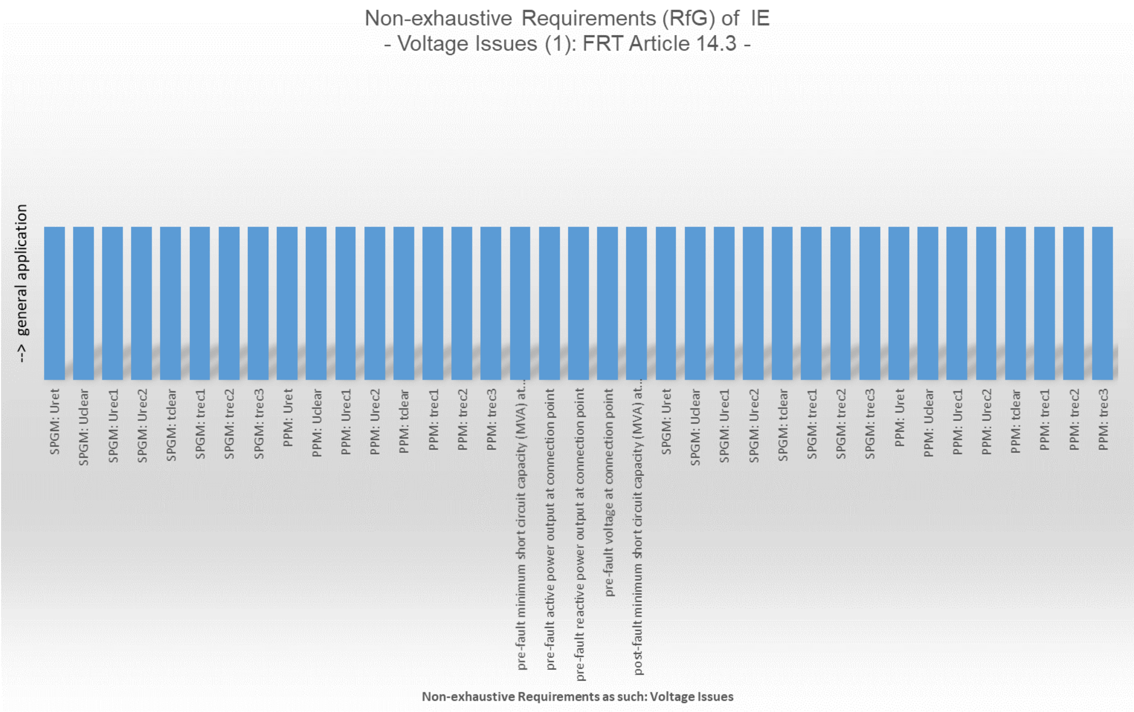


Figure 50: Ireland

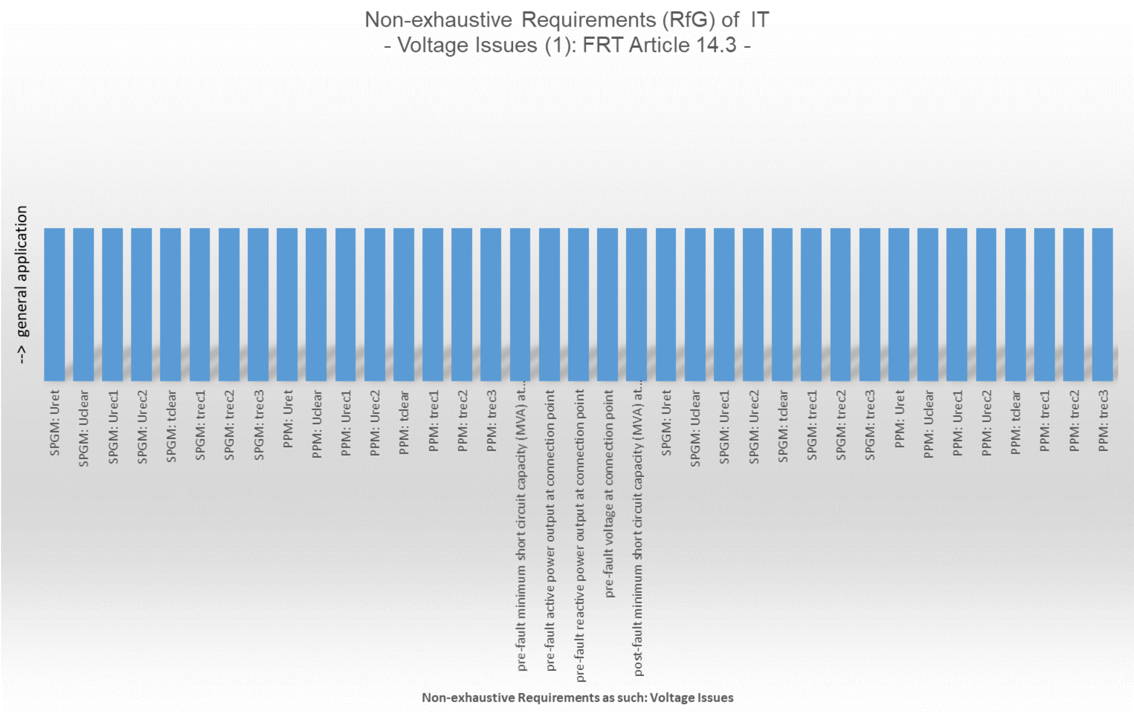


Figure 51: Italy (IT)

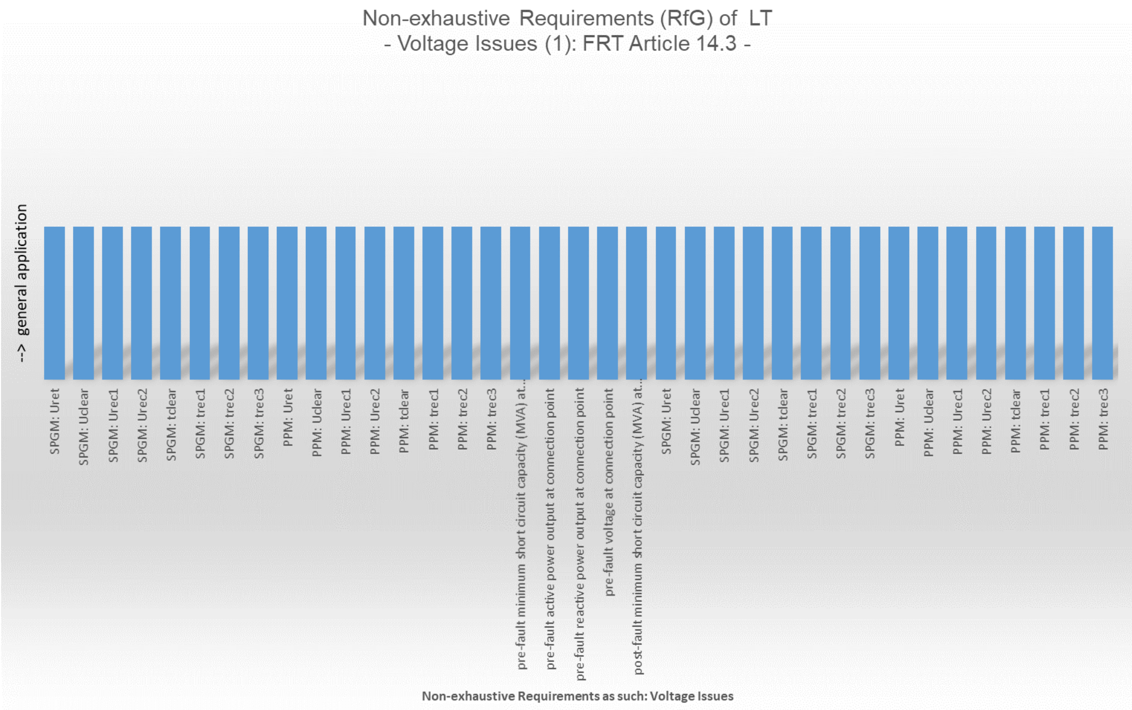


Figure 52: Lithuania (LT)

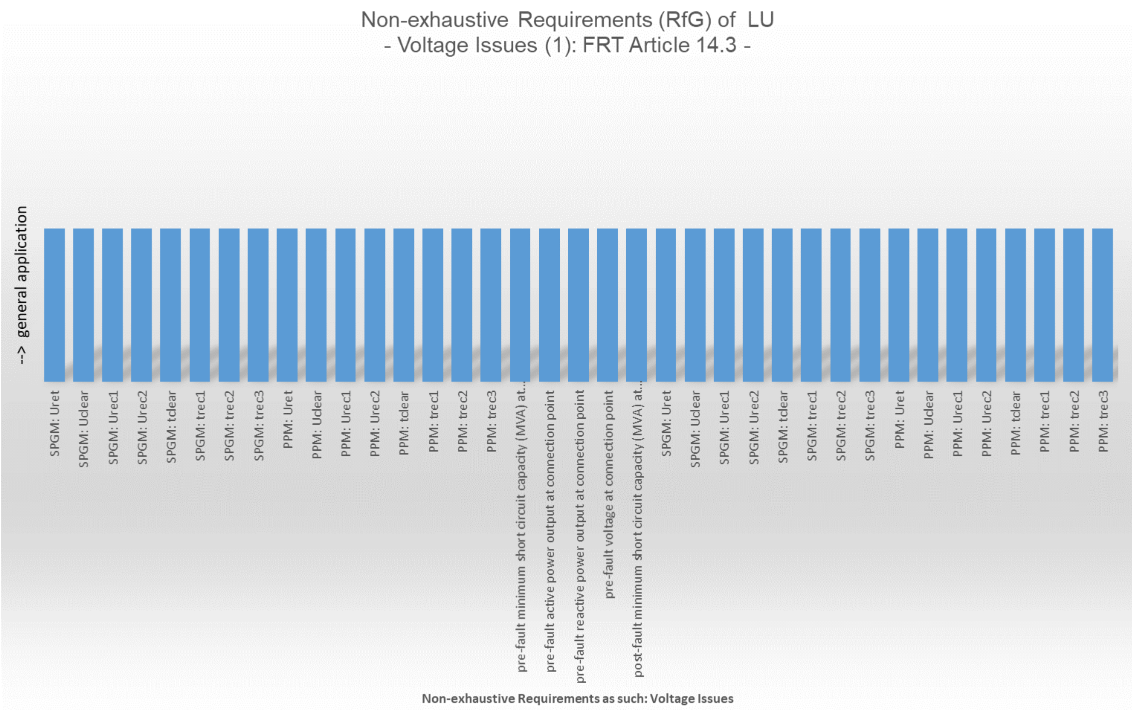


Figure 53: Luxembourg (LU)

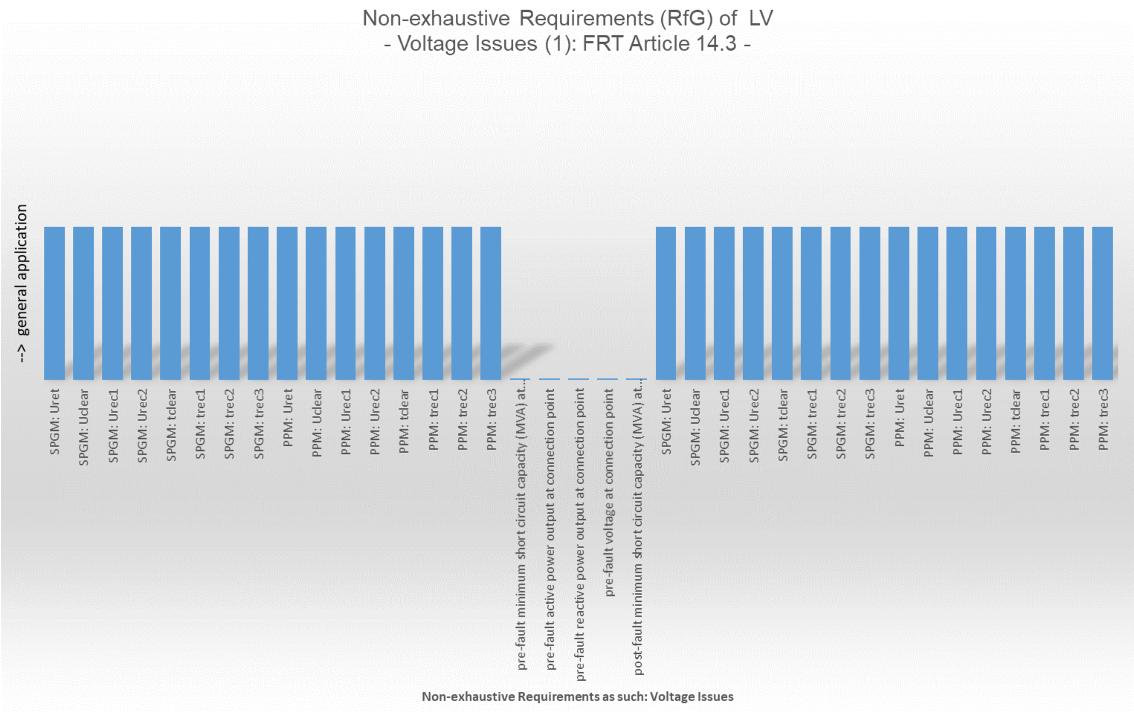


Figure 54: Latvia (LV)

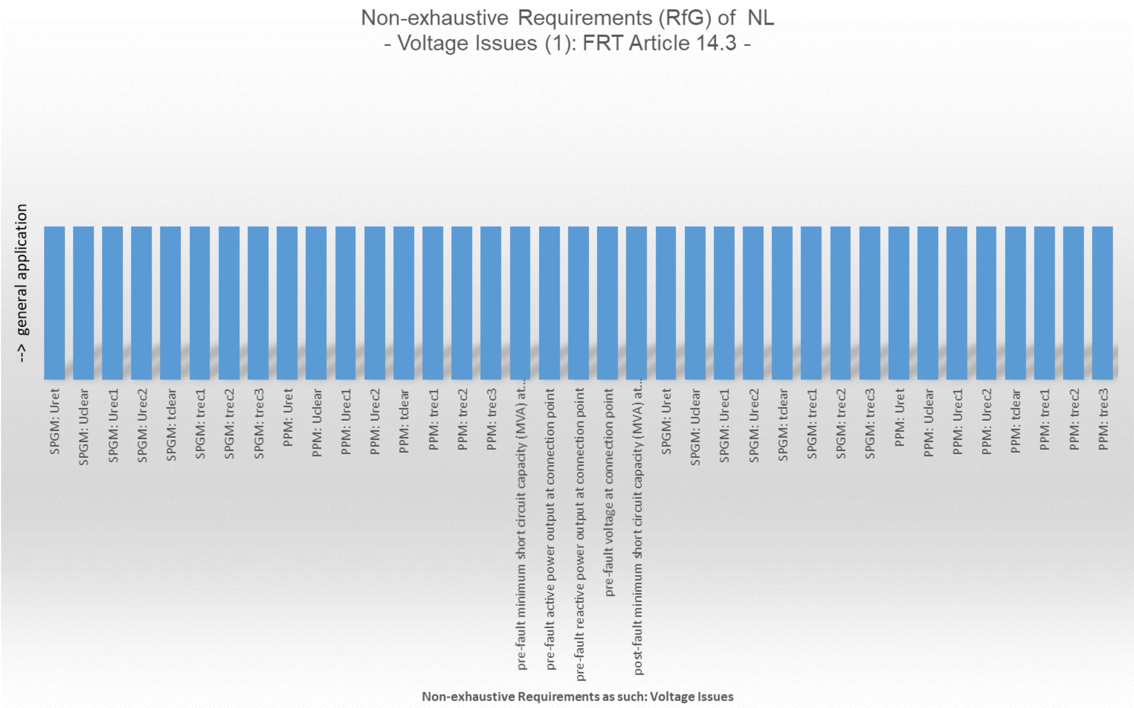


Figure 55: Netherlands (NL)

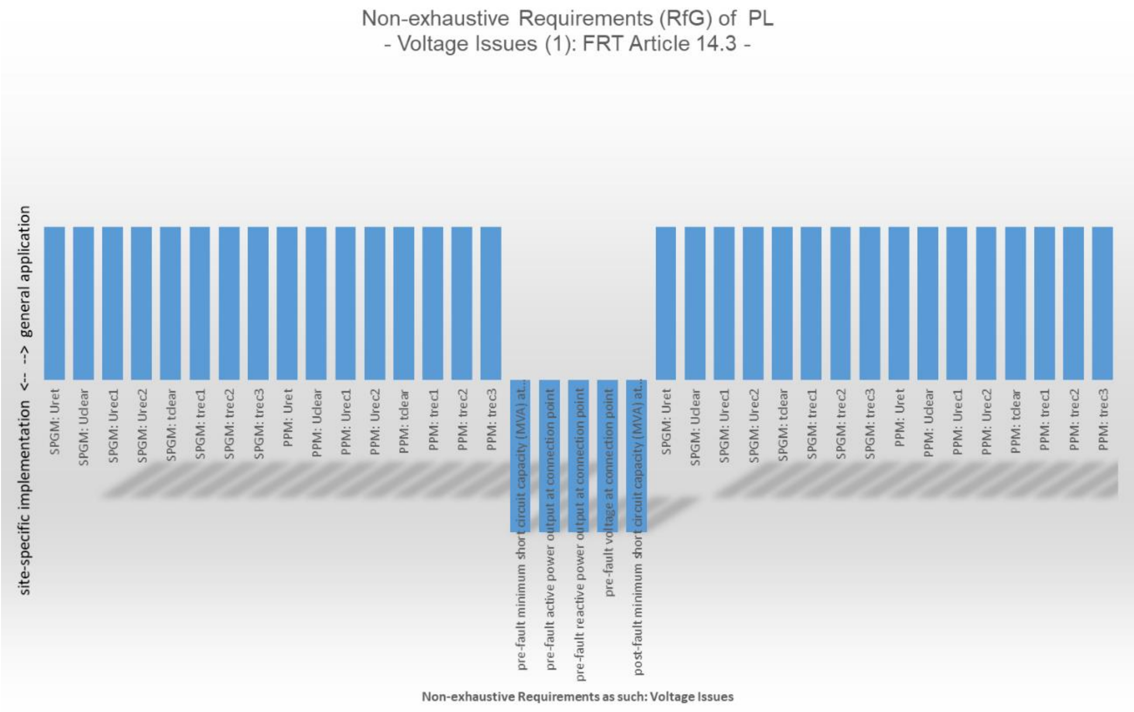


Figure 56: Poland (PL)

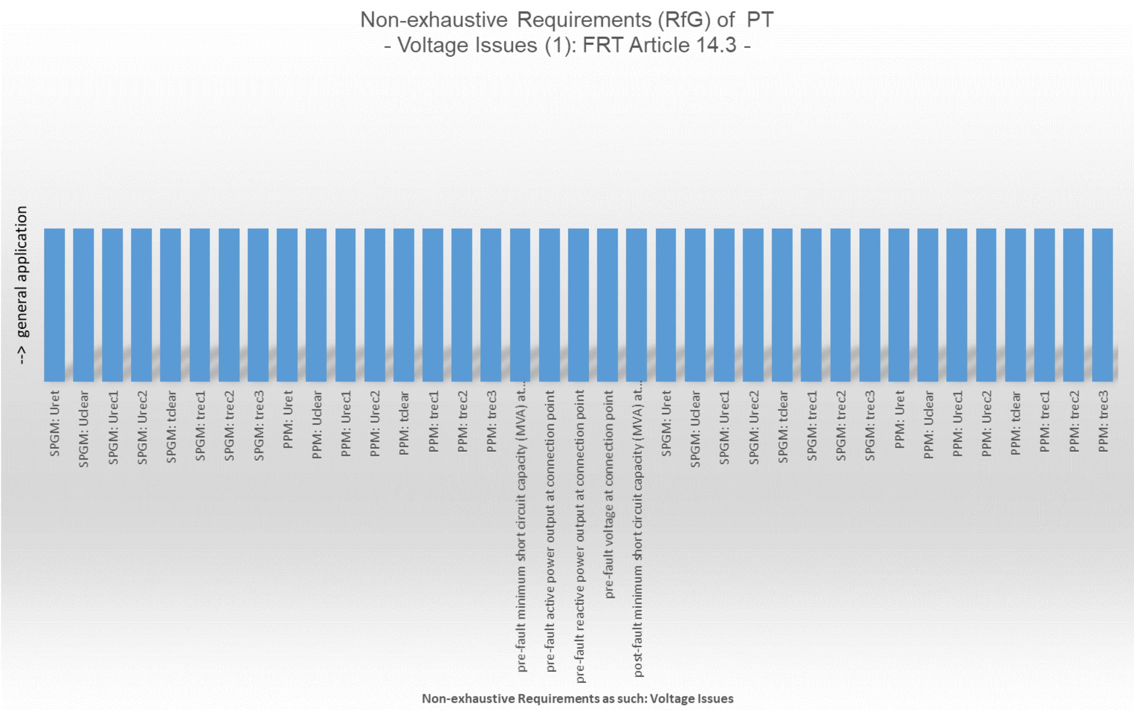


Figure 57: Portugal (PT)

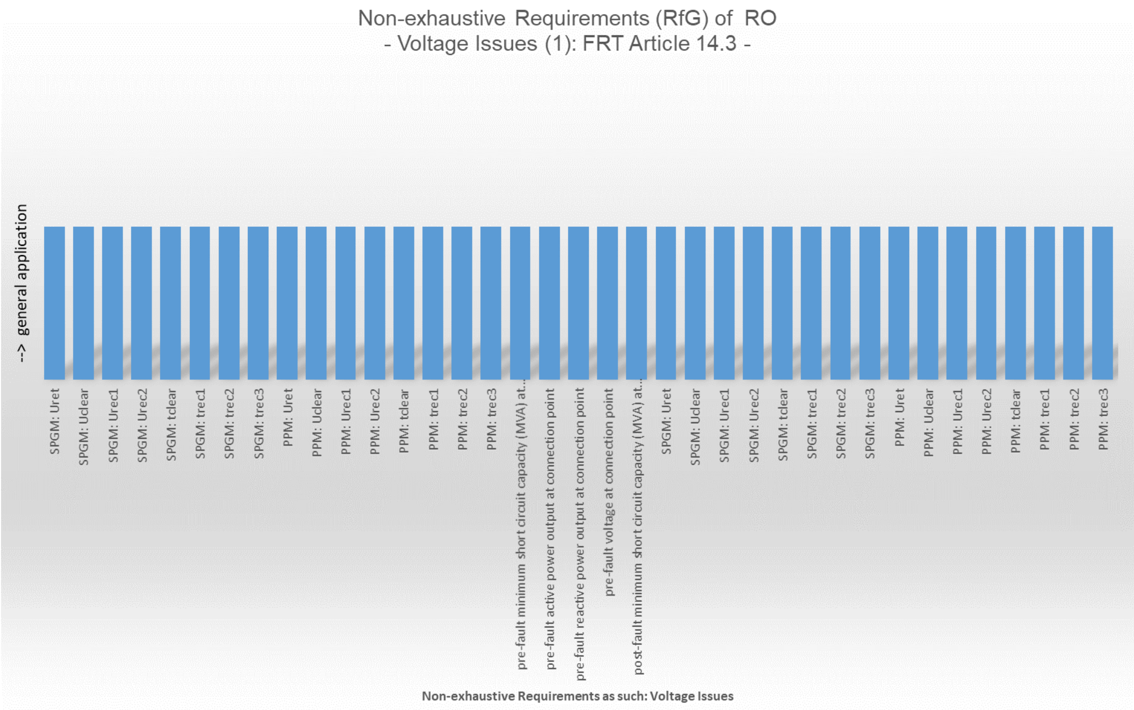


Figure 58: Romania (RO)

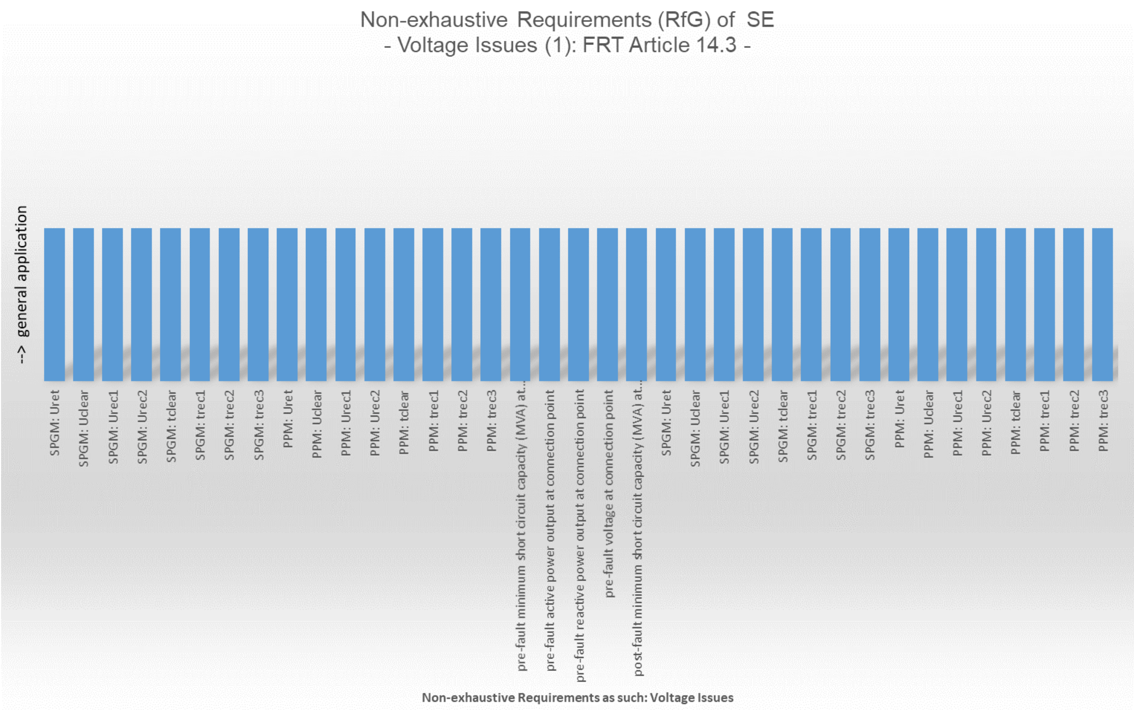


Figure 59: Sweden (SE)

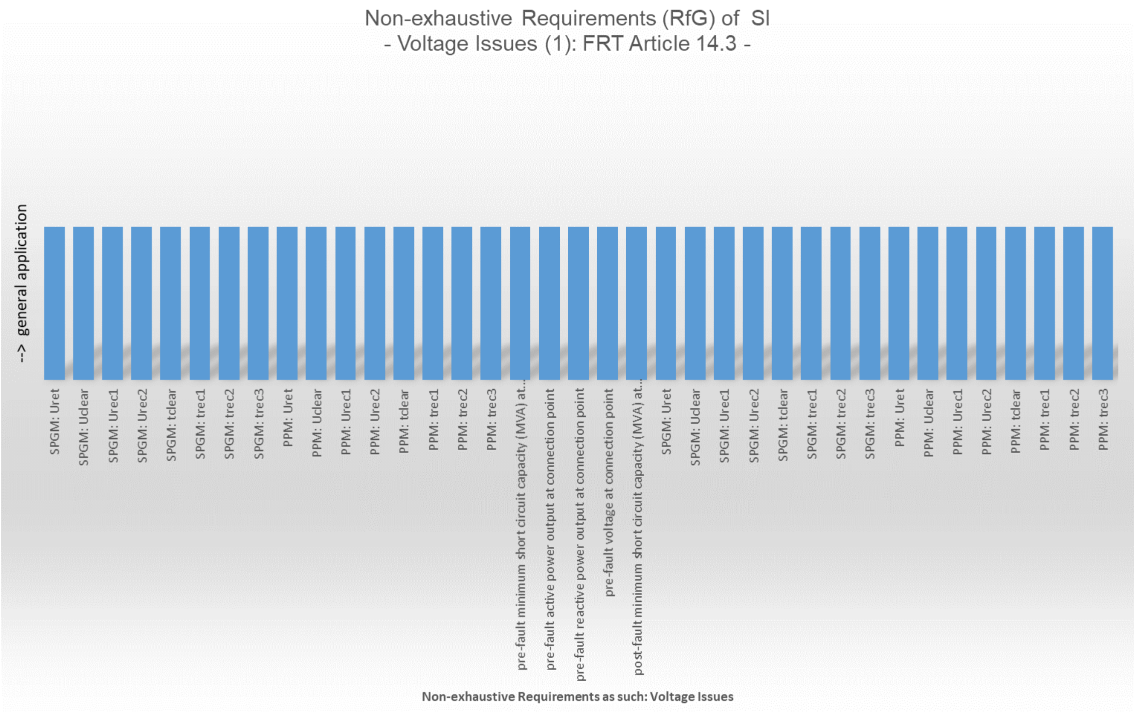


Figure 60: Slovenia (SI)

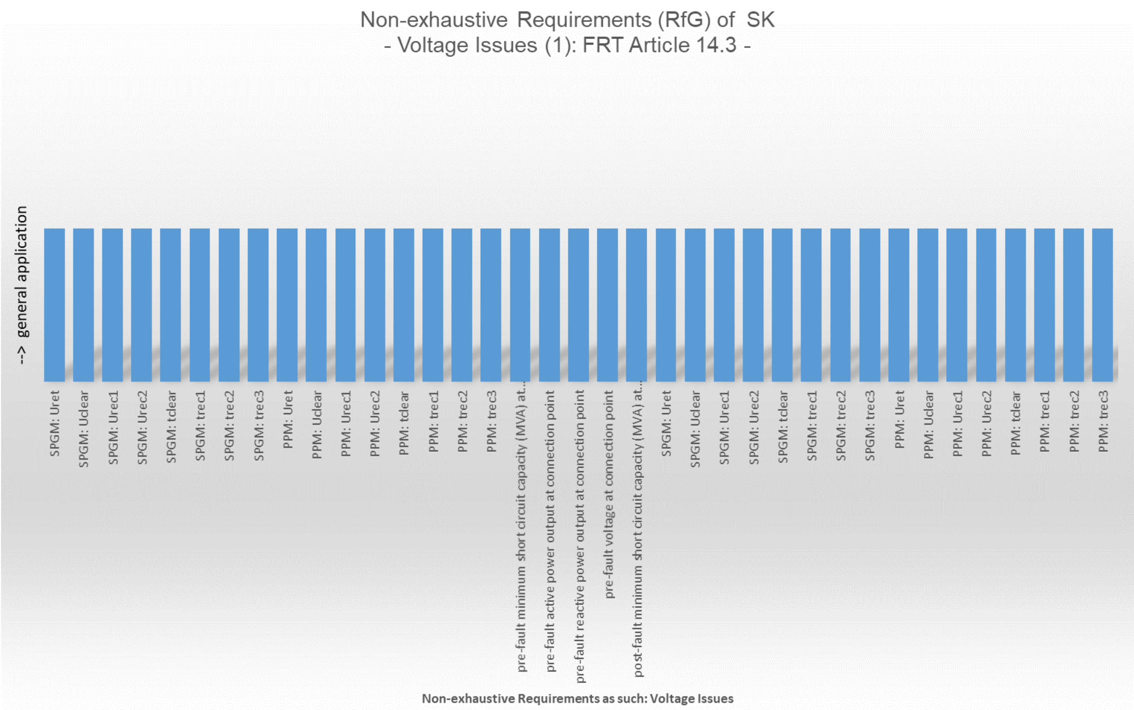


Figure 61: Slovakia (SK)

3.6 Voltage Issues (2) – FRT according to Article 16(3) of NC RfG

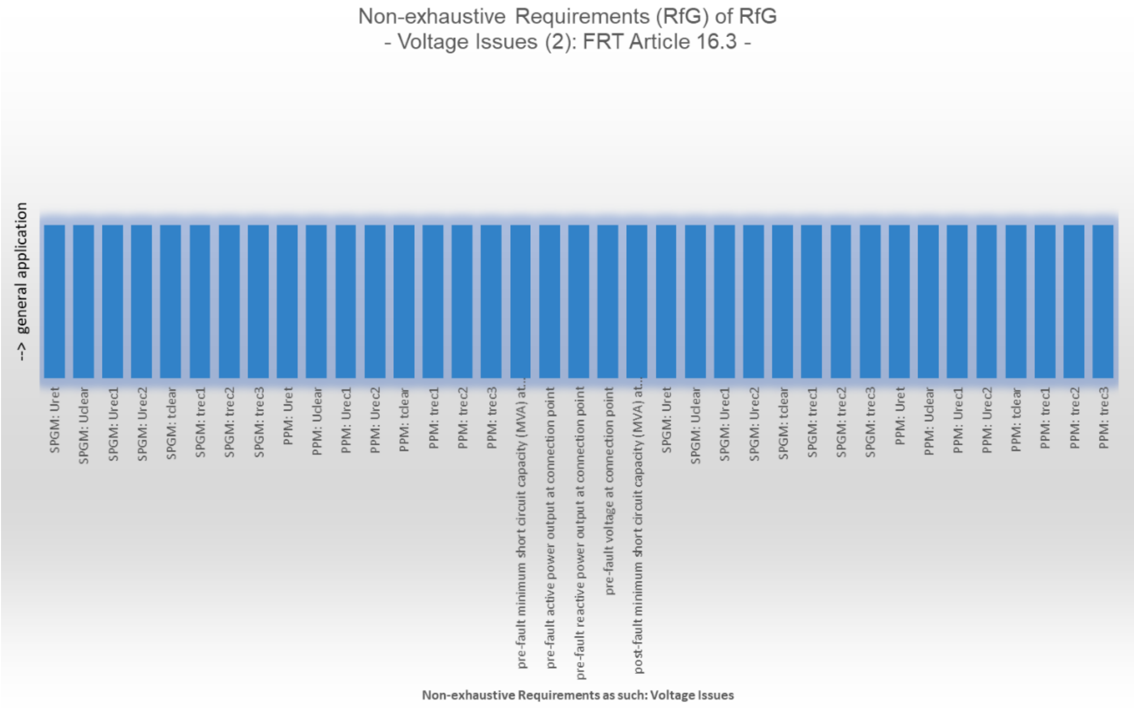


Figure 62: : Reference values of non-exhaustive RfG voltage issues (2) - FRT article 16.3

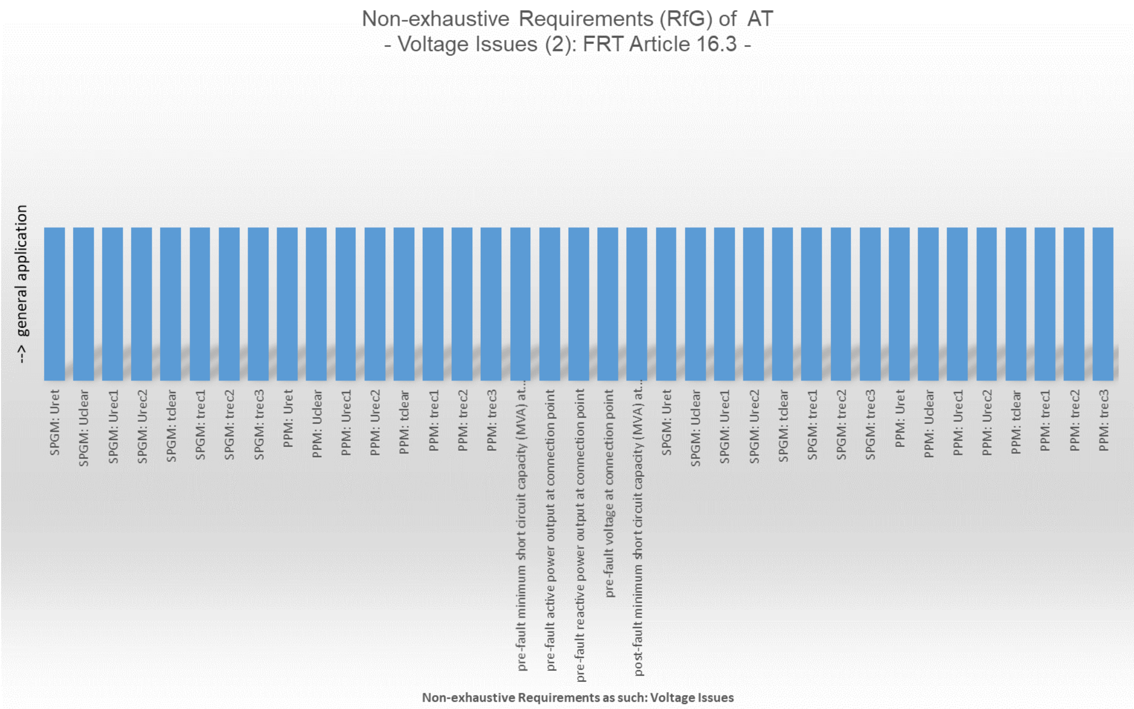


Figure 63: Austria (AT)

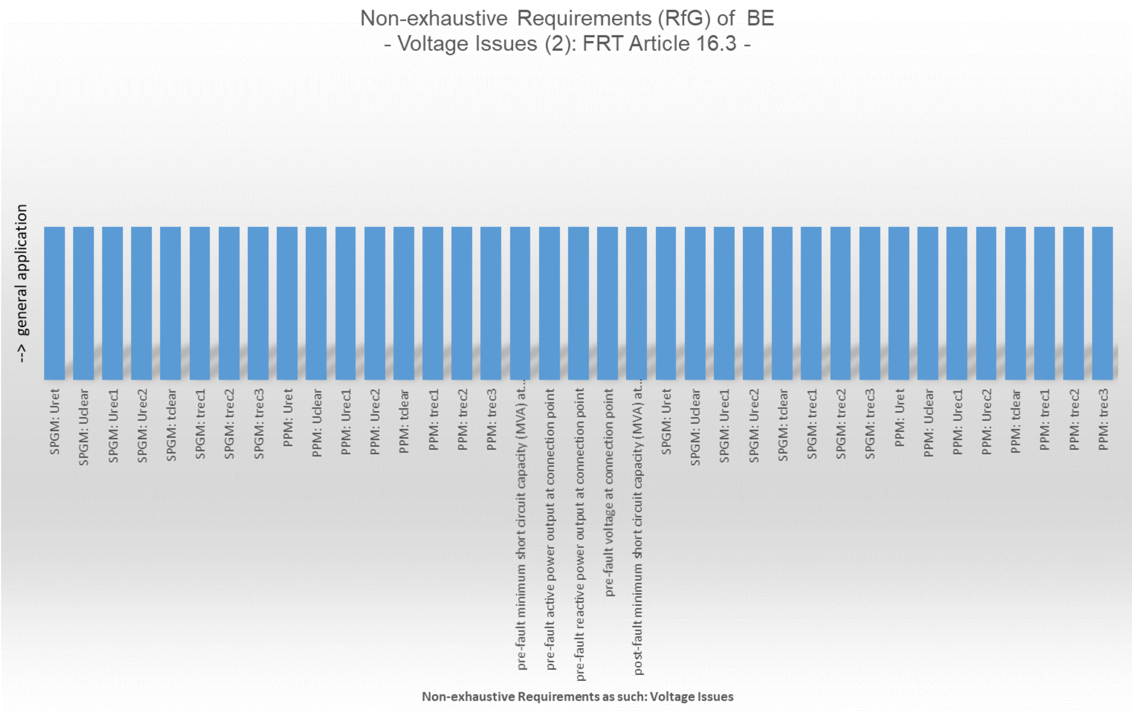


Figure 64: Belgium (BE)

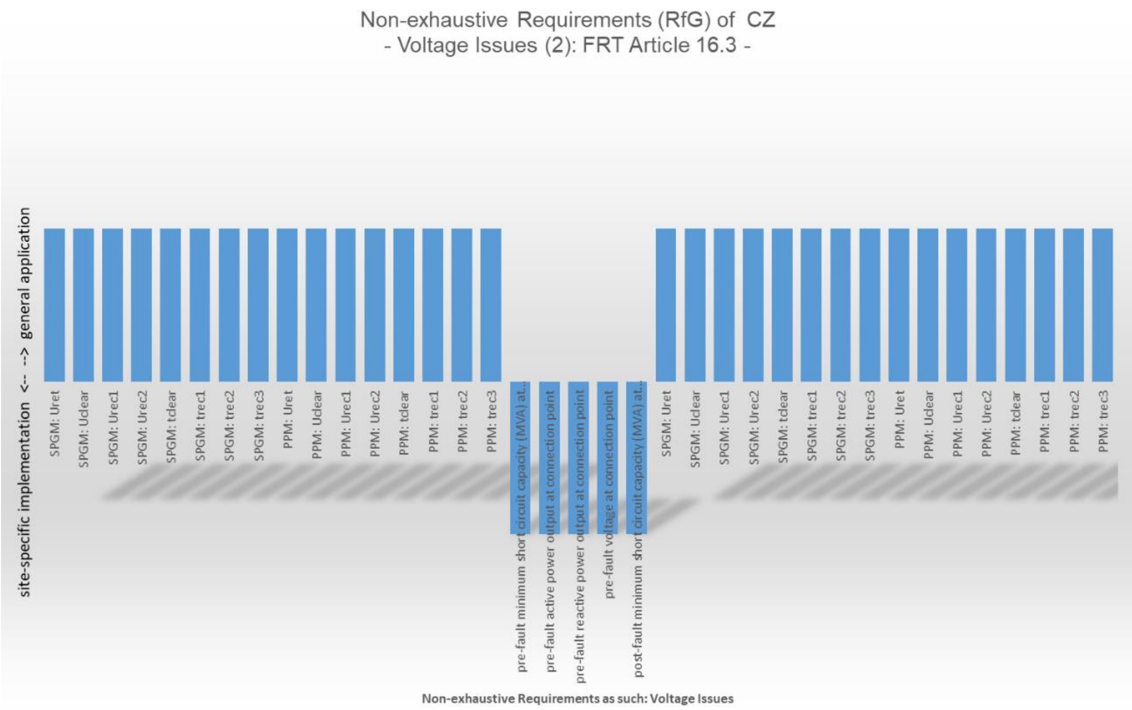


Figure 65: Czech Republic (CZ)

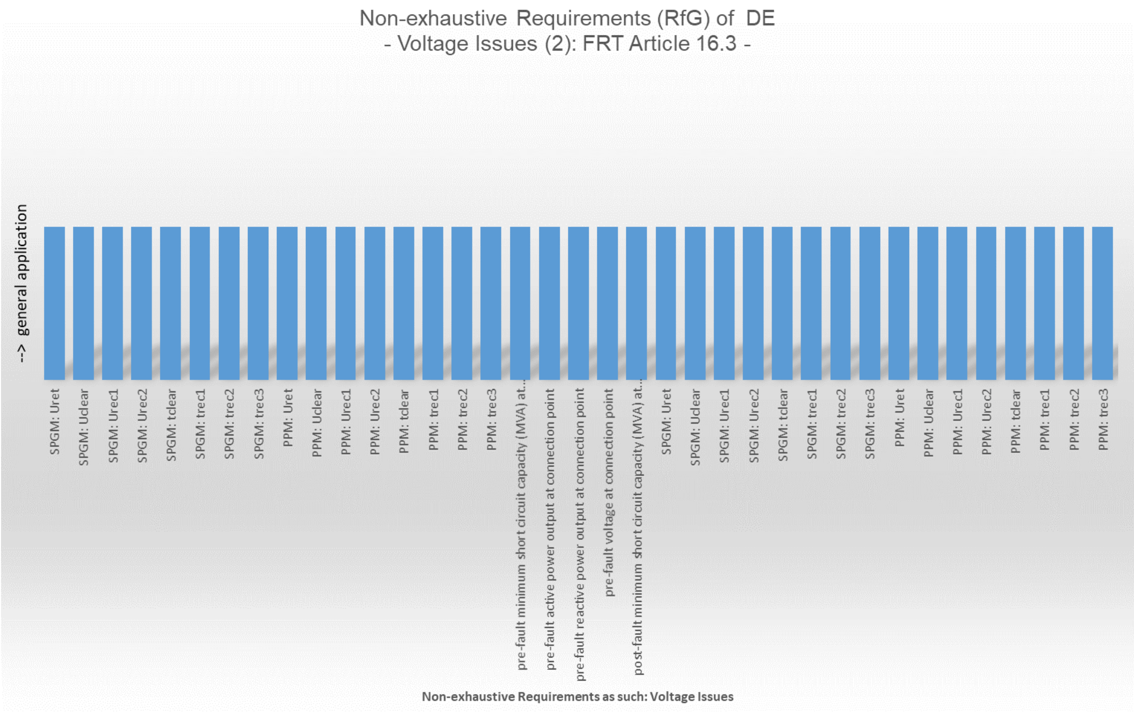


Figure 66: Germany (DE)

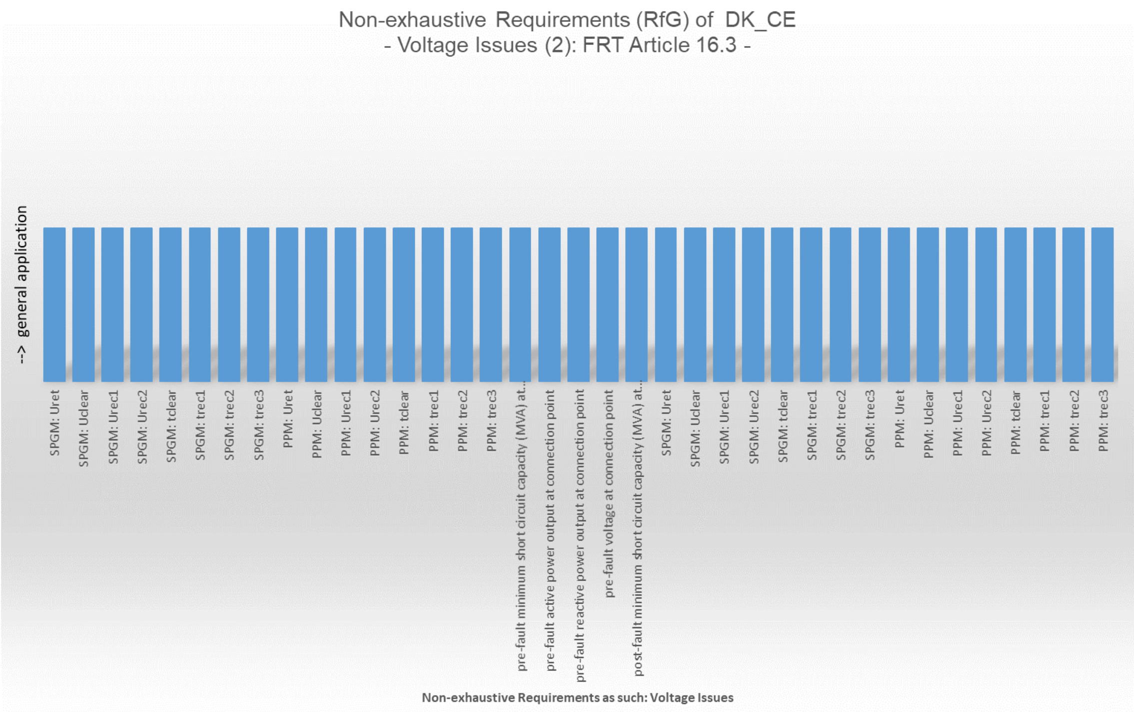


Figure 67: Denmark 1 (DK-CE)

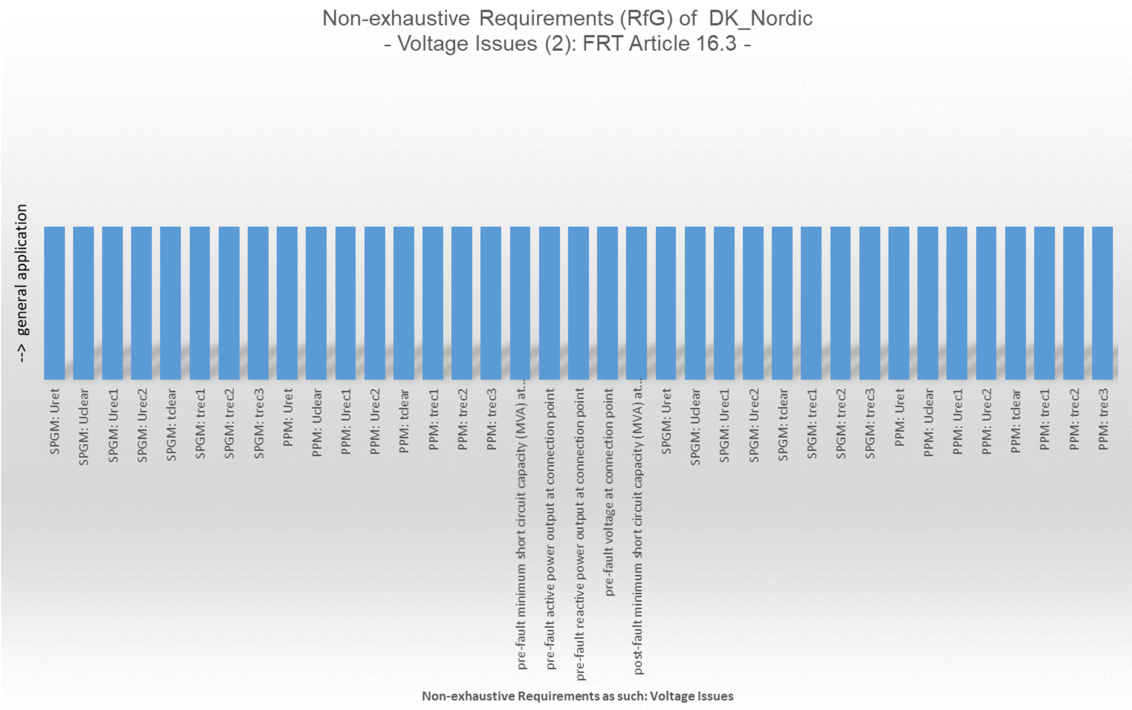


Figure 68: Denmark 2 (DK-Nordic)

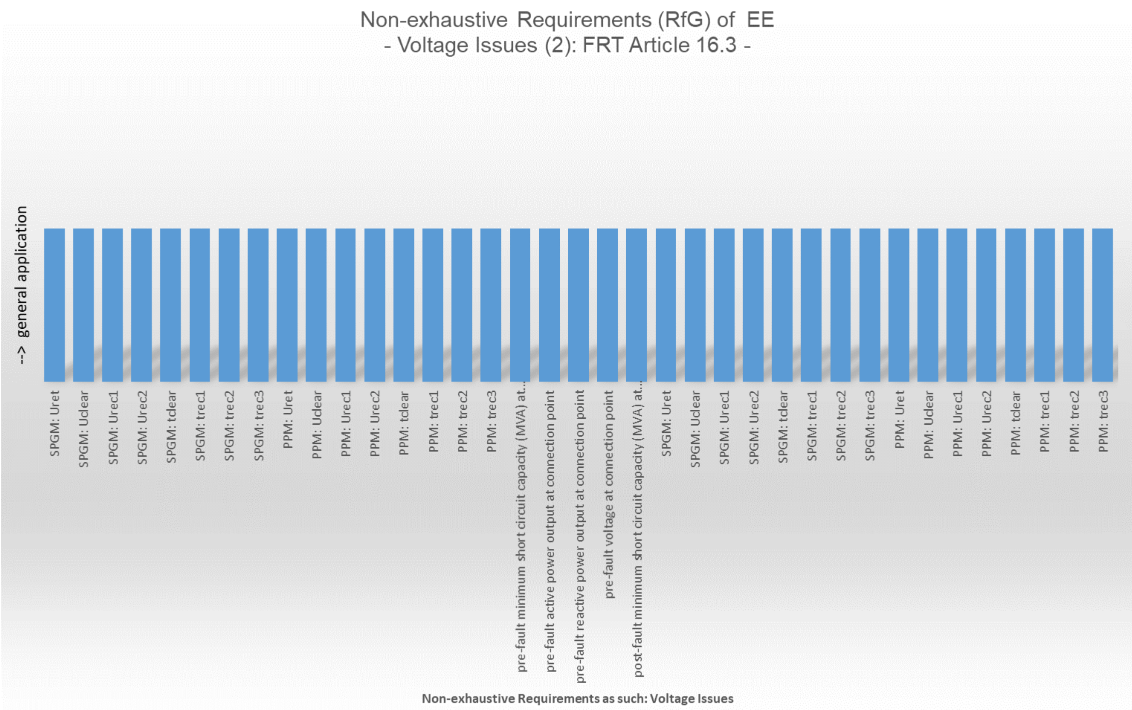


Figure 69: Estonia (EE)

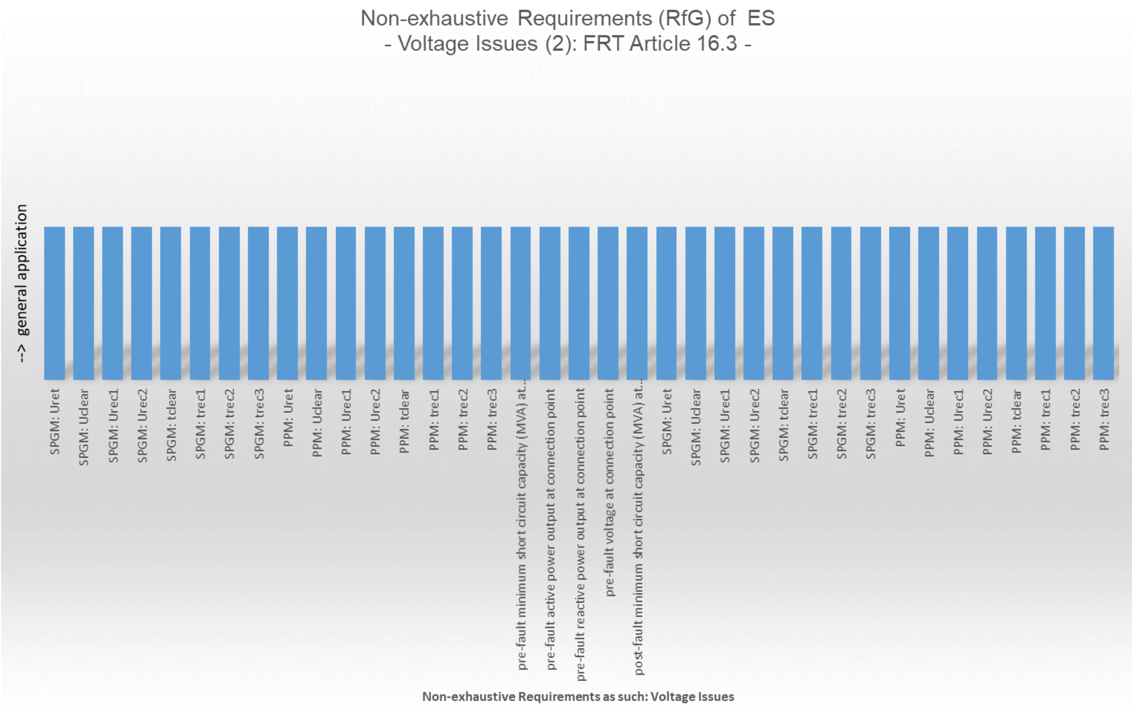


Figure 70: Spain (ES)

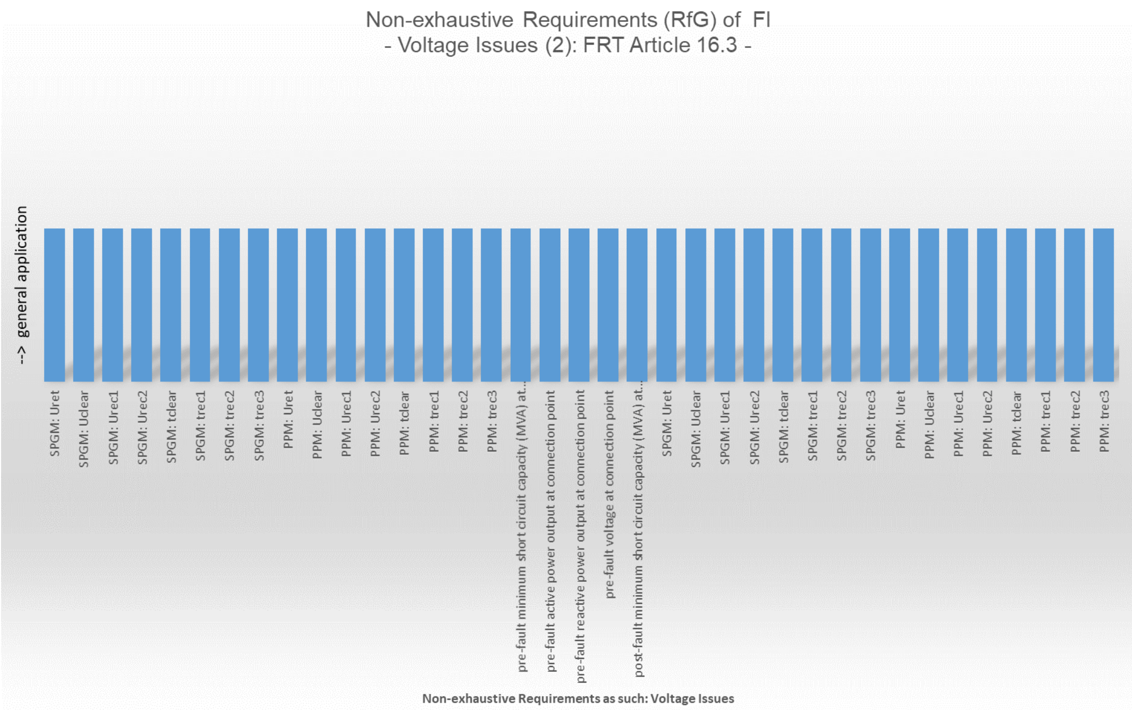


Figure 71: Finland (FI)

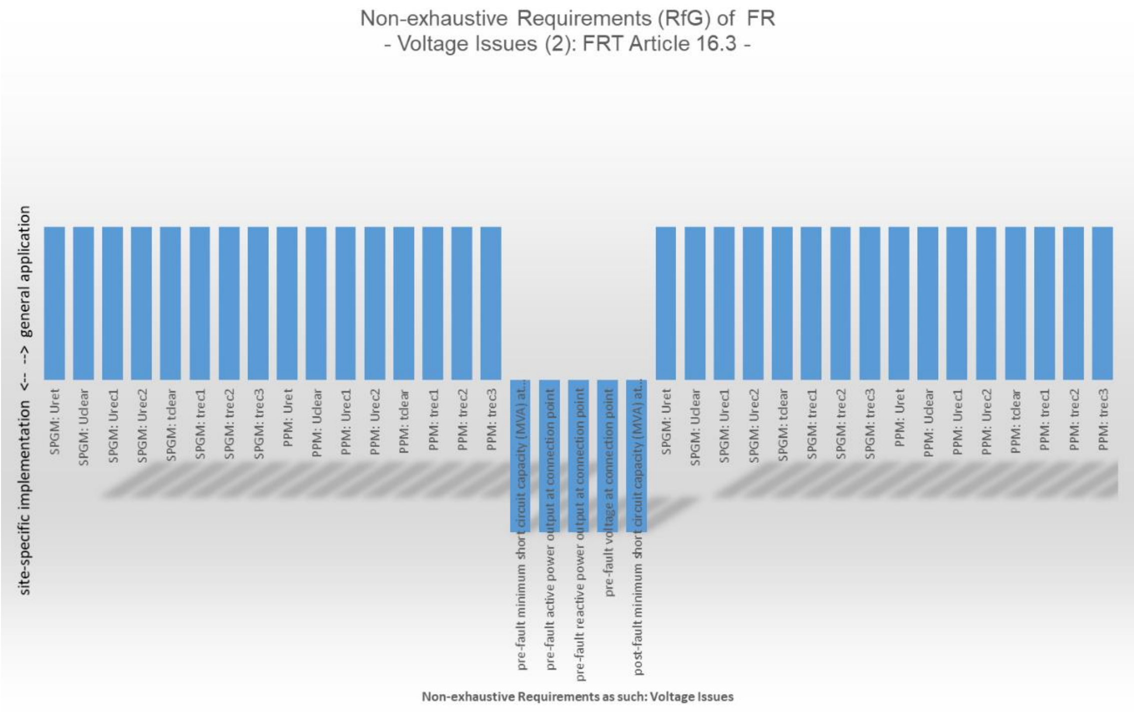


Figure 72: France (FR)

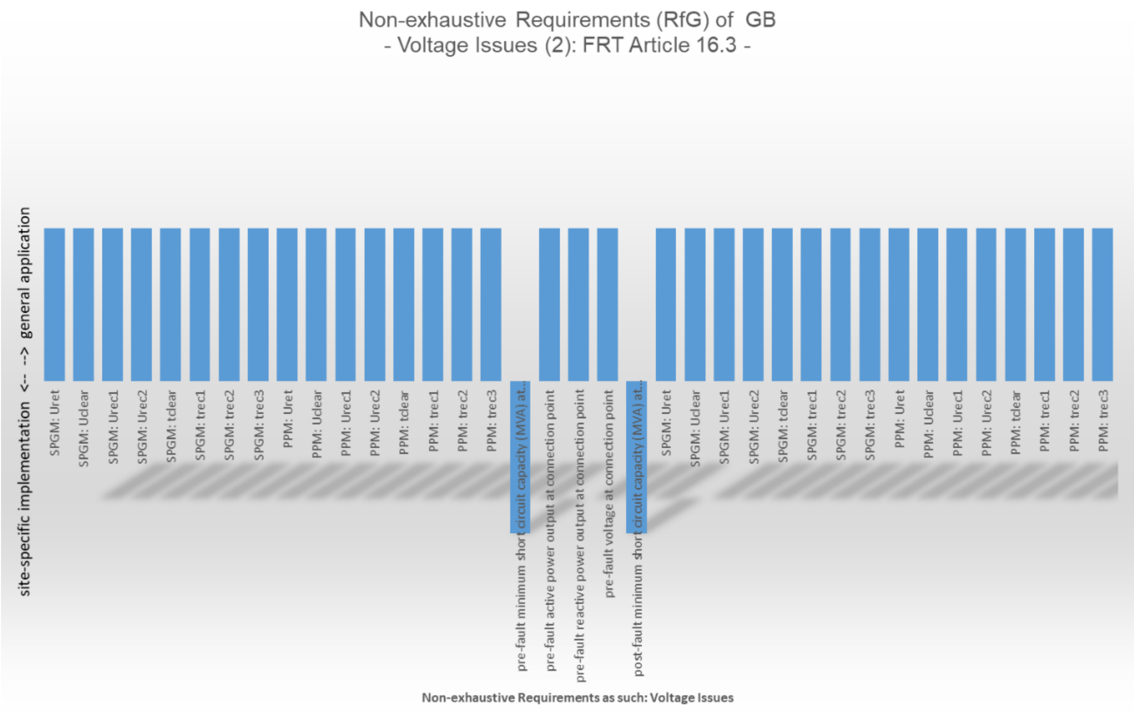


Figure 73: Great Britain (GB)

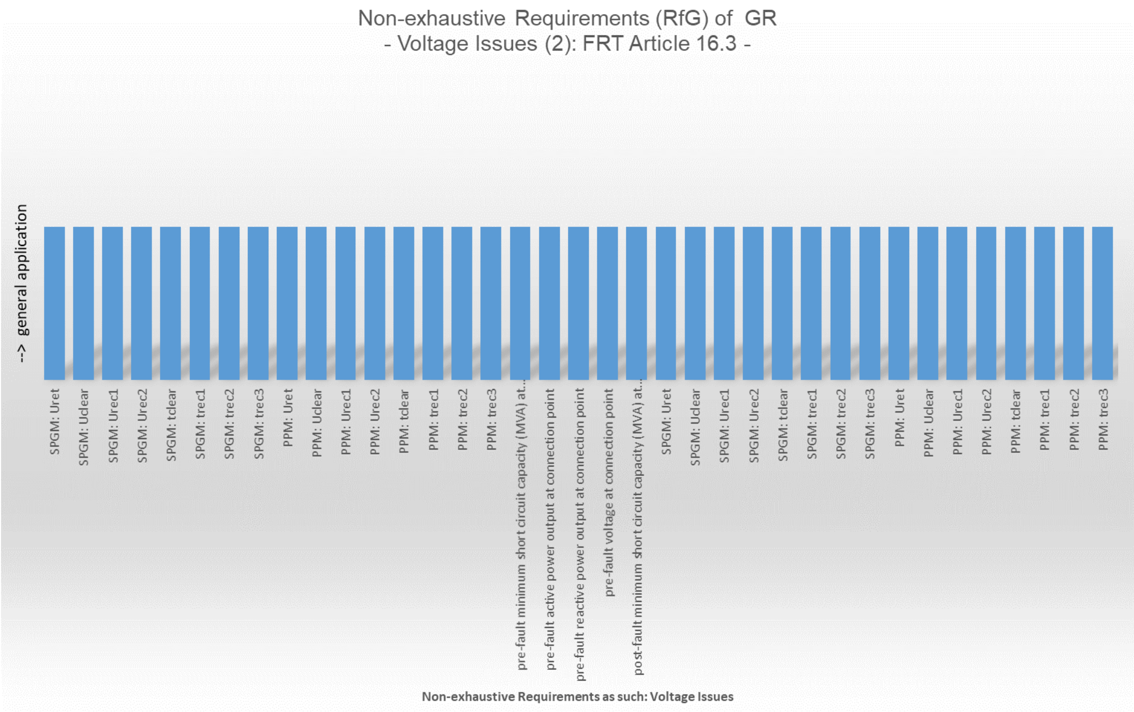


Figure 74: Greece (GR)

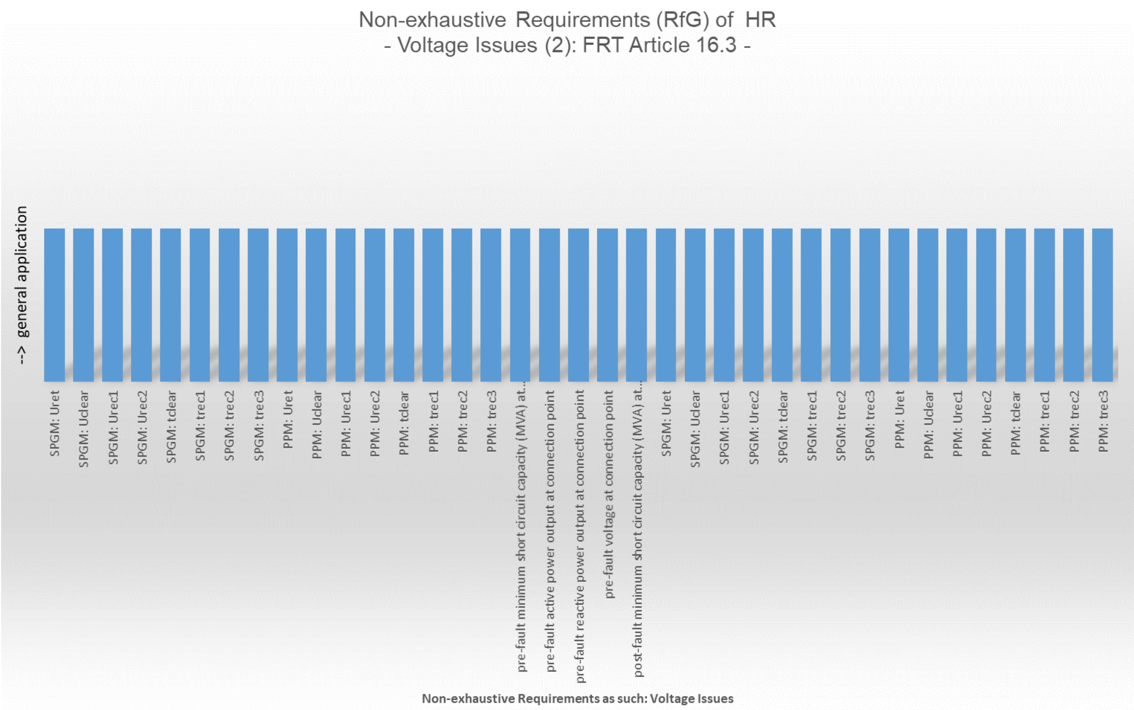


Figure 75: Croatia (HR)

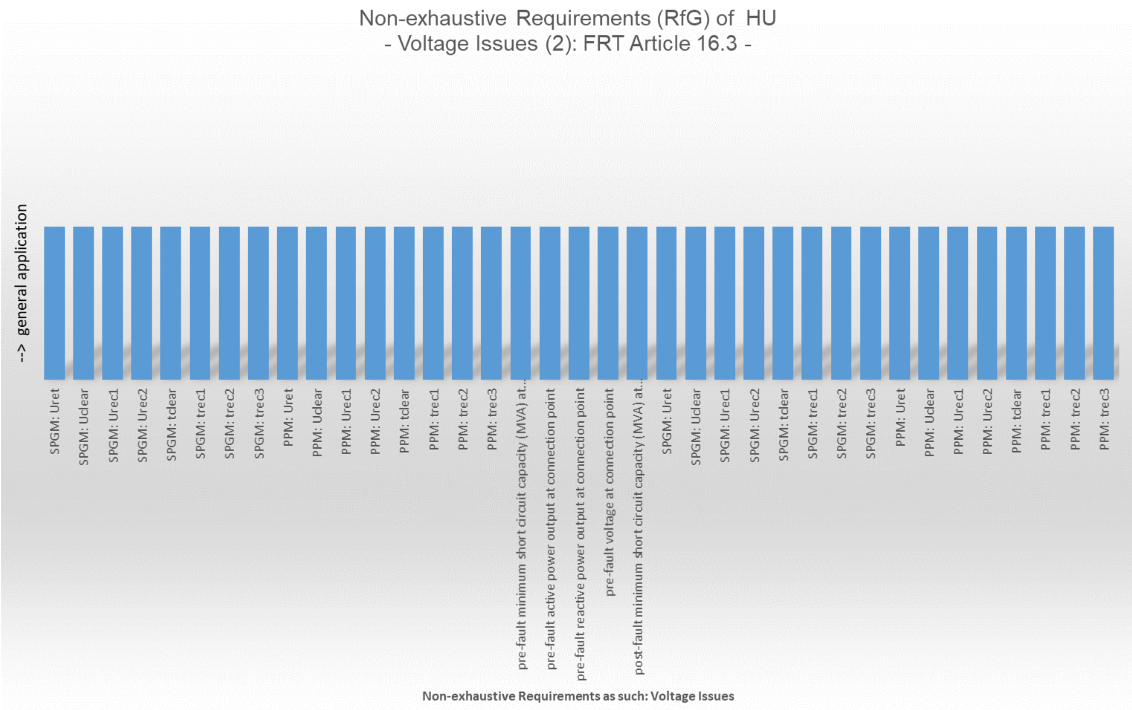


Figure 76: Hungary (HU)

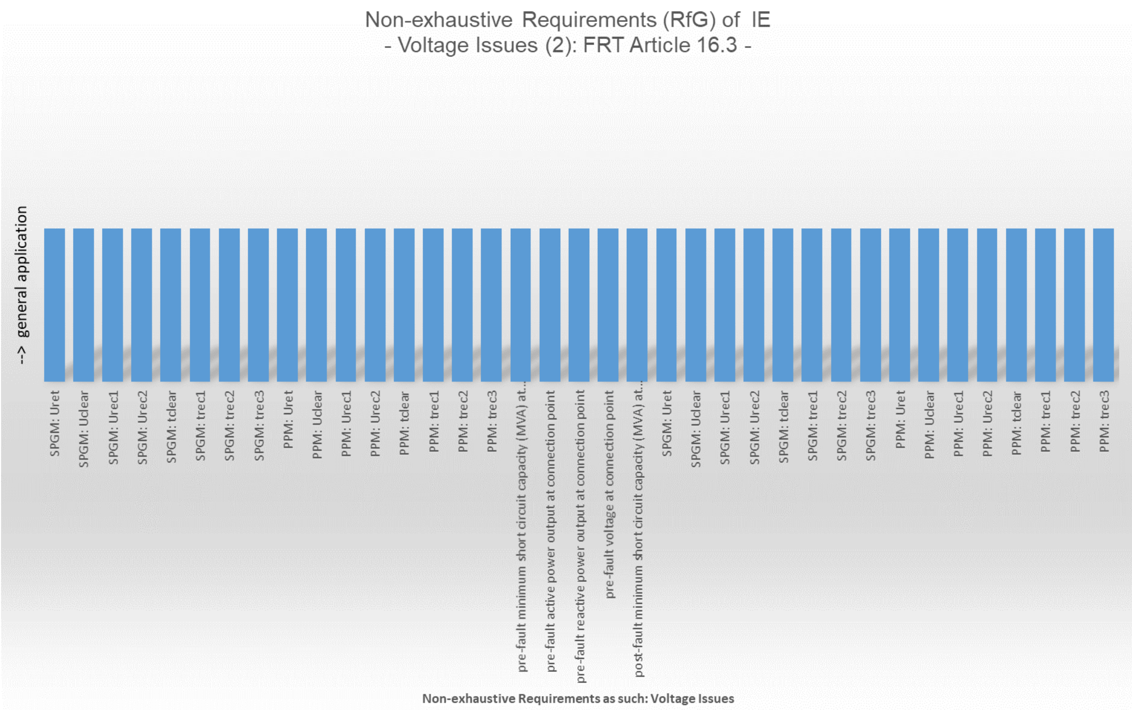


Figure 77: Ireland (IE)

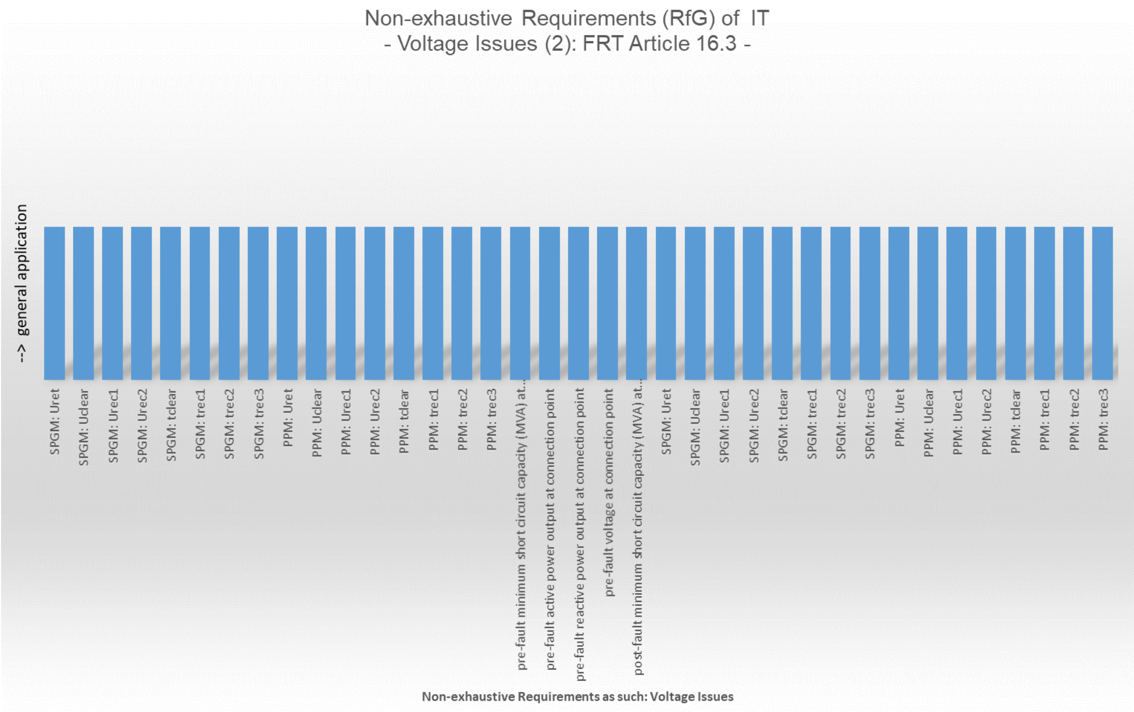


Figure 78: Italy (IT)

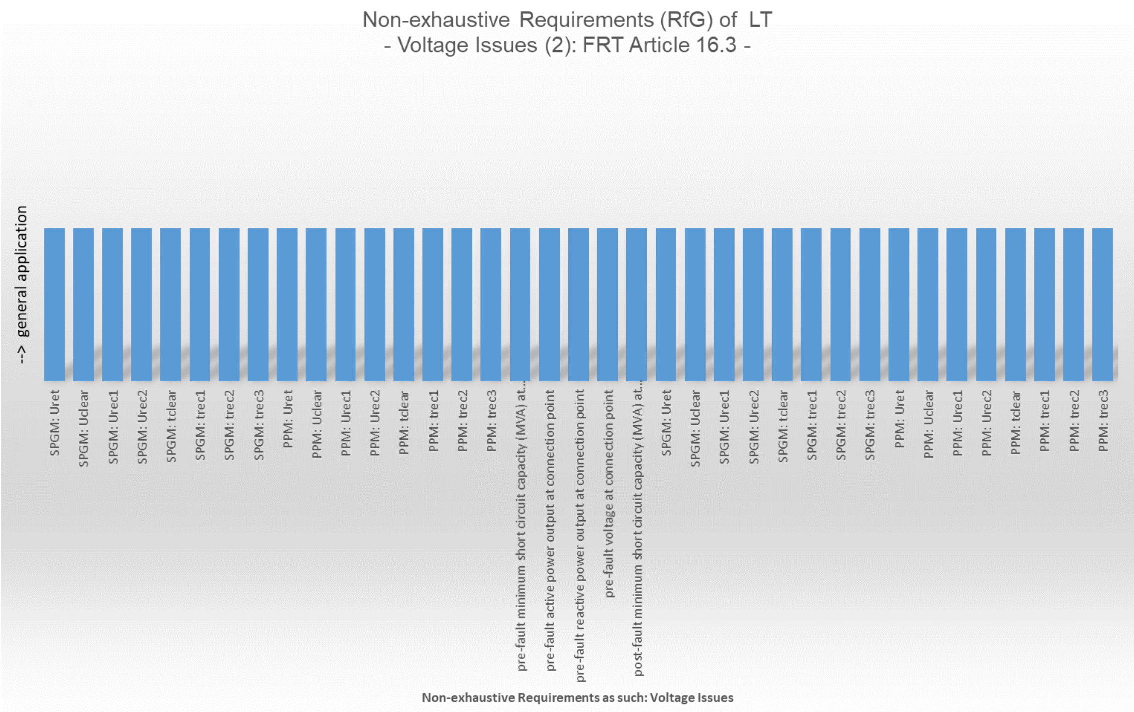


Figure 79: Lithuania (LT)

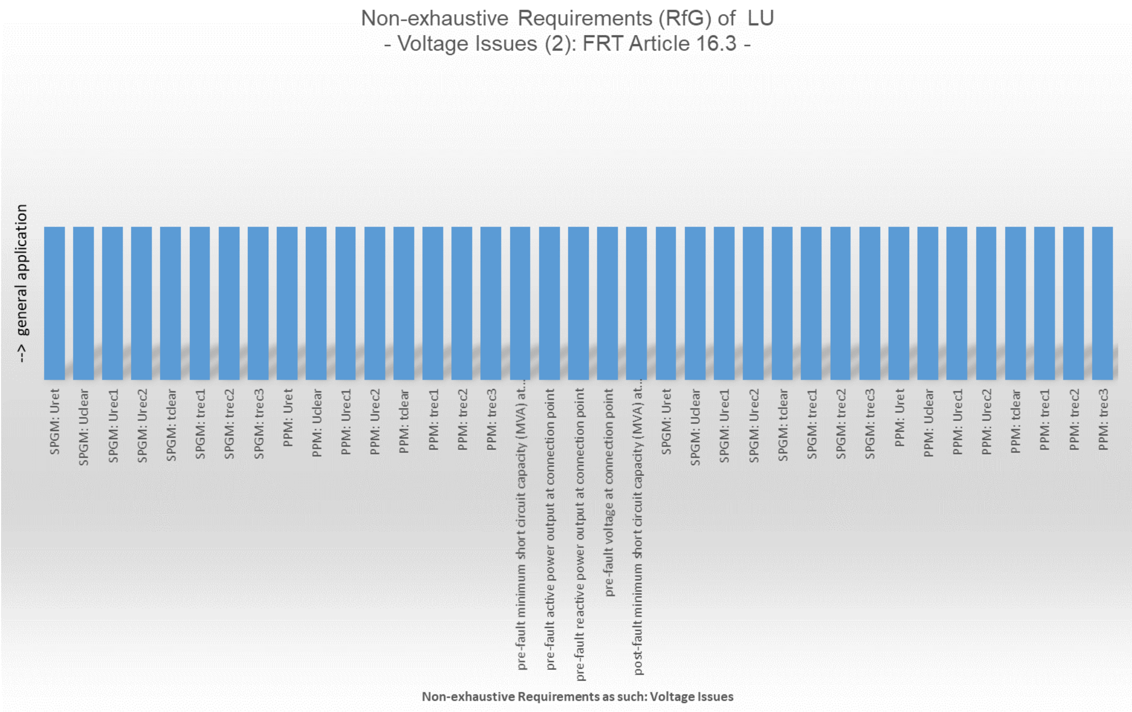


Figure 80: Luxembourg (LU)

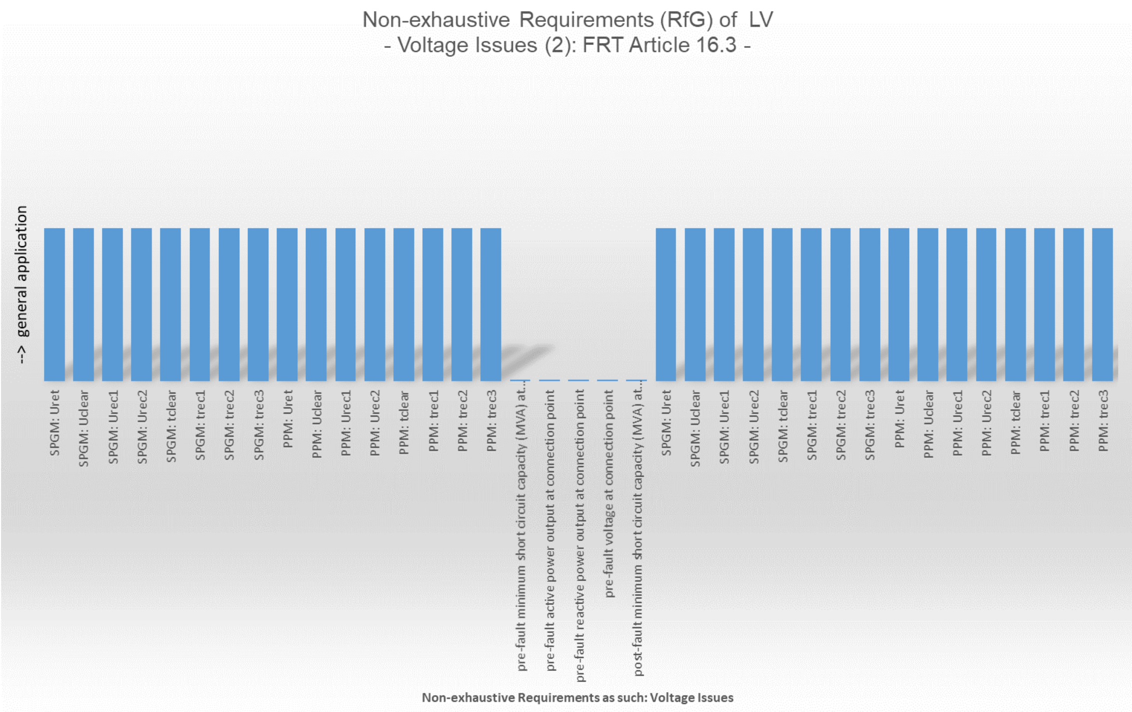


Figure 81: Latvia (LV)

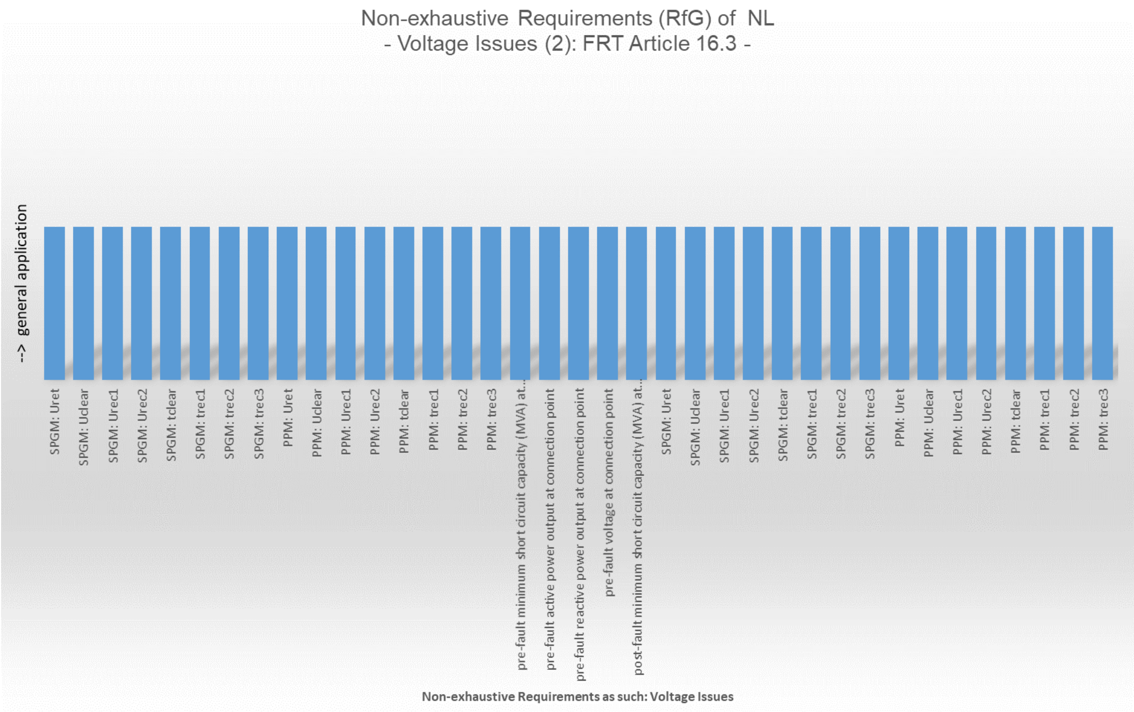


Figure 82: Netherlands (NL)

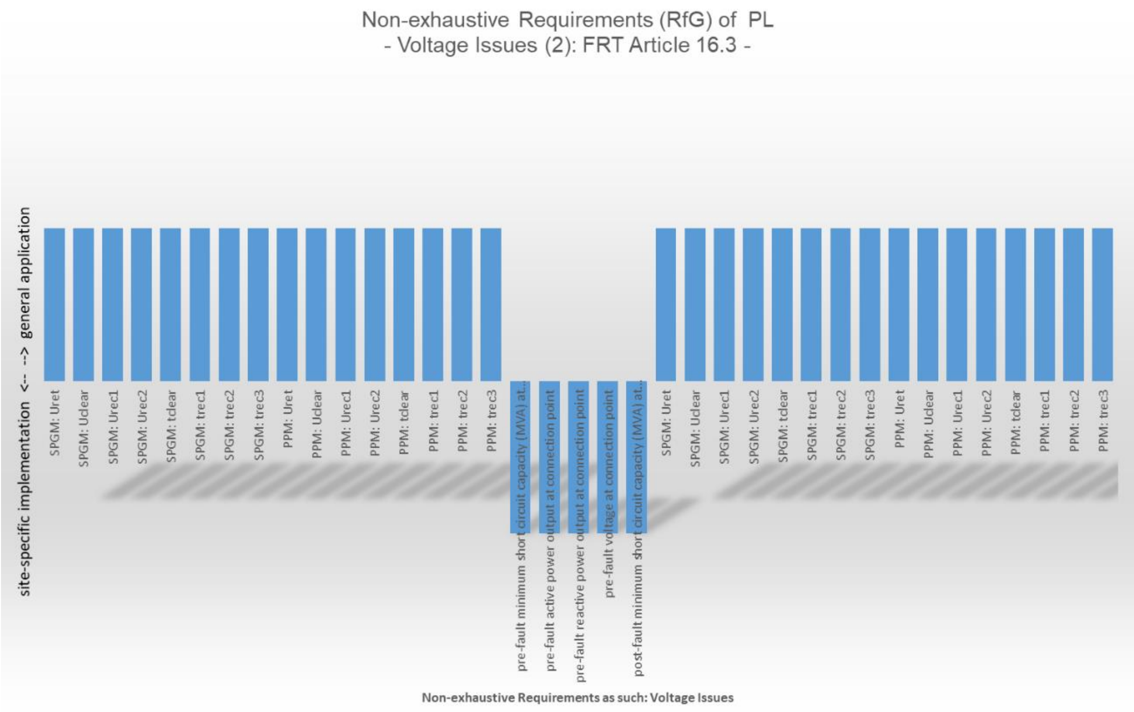


Figure 83: Poland (PL)

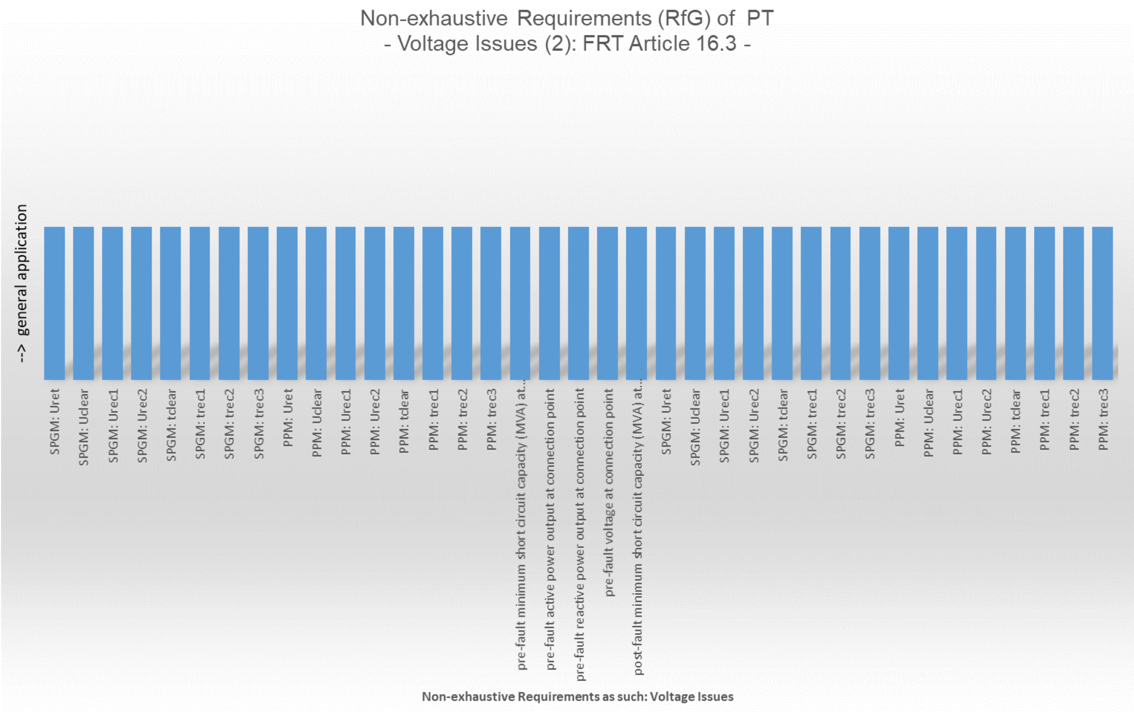


Figure 84: Portugal (PT)

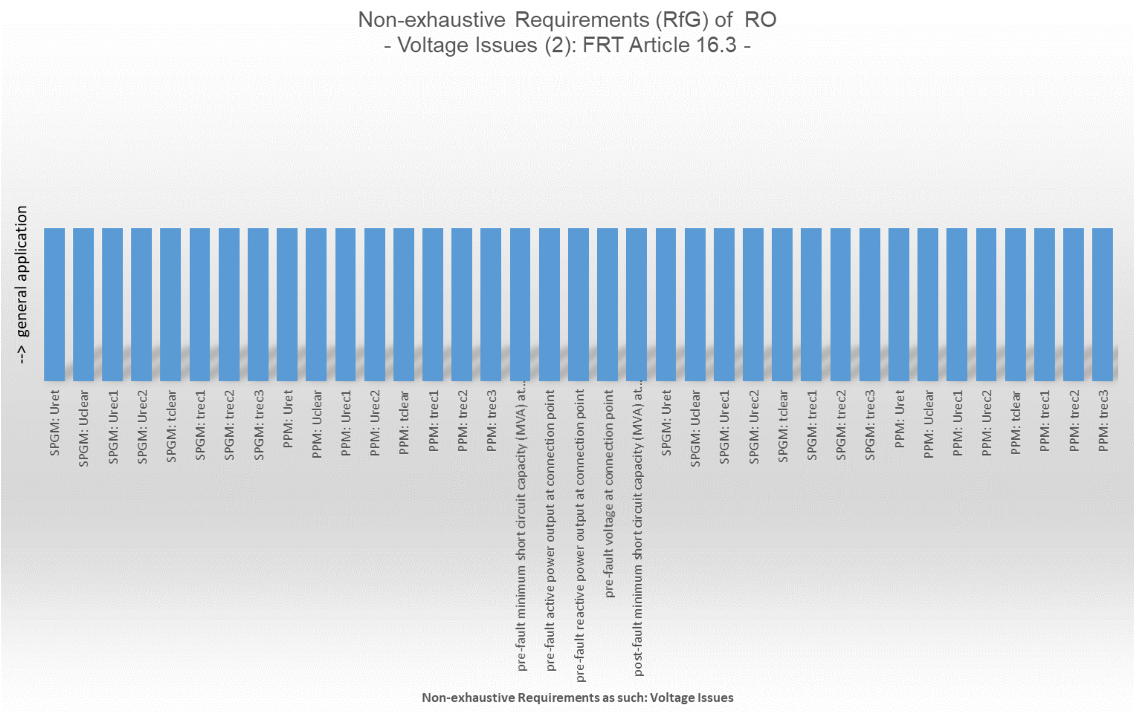


Figure 85: Romania (RO)

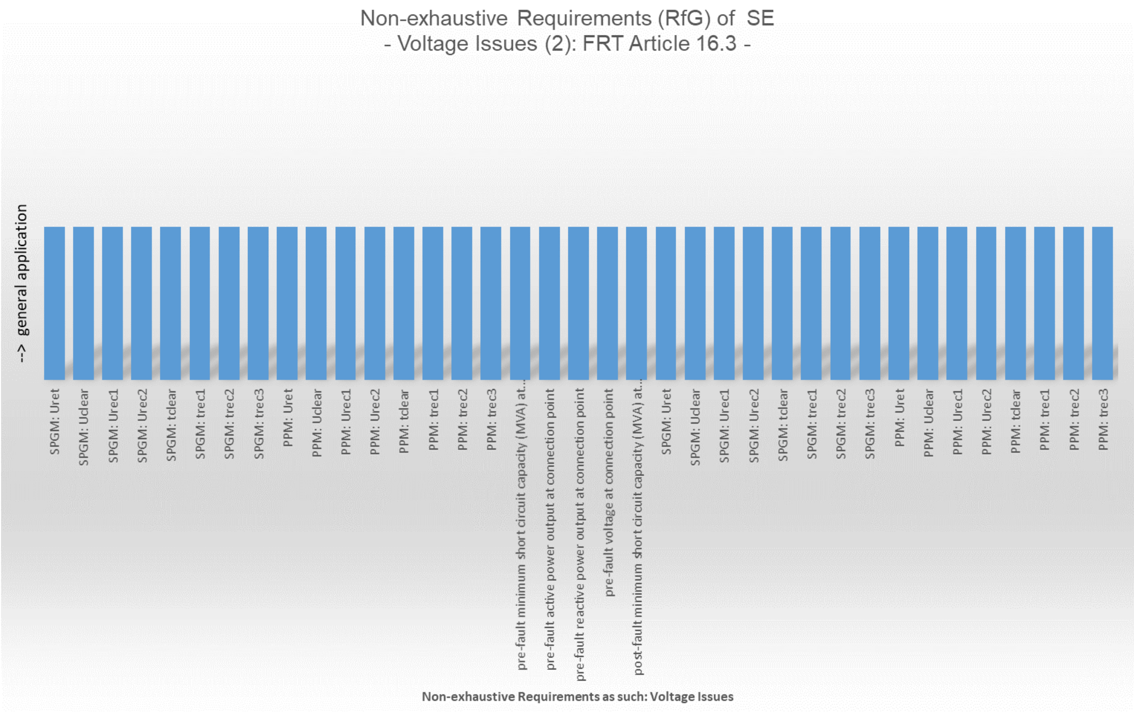


Figure 86: Sweden (SE)

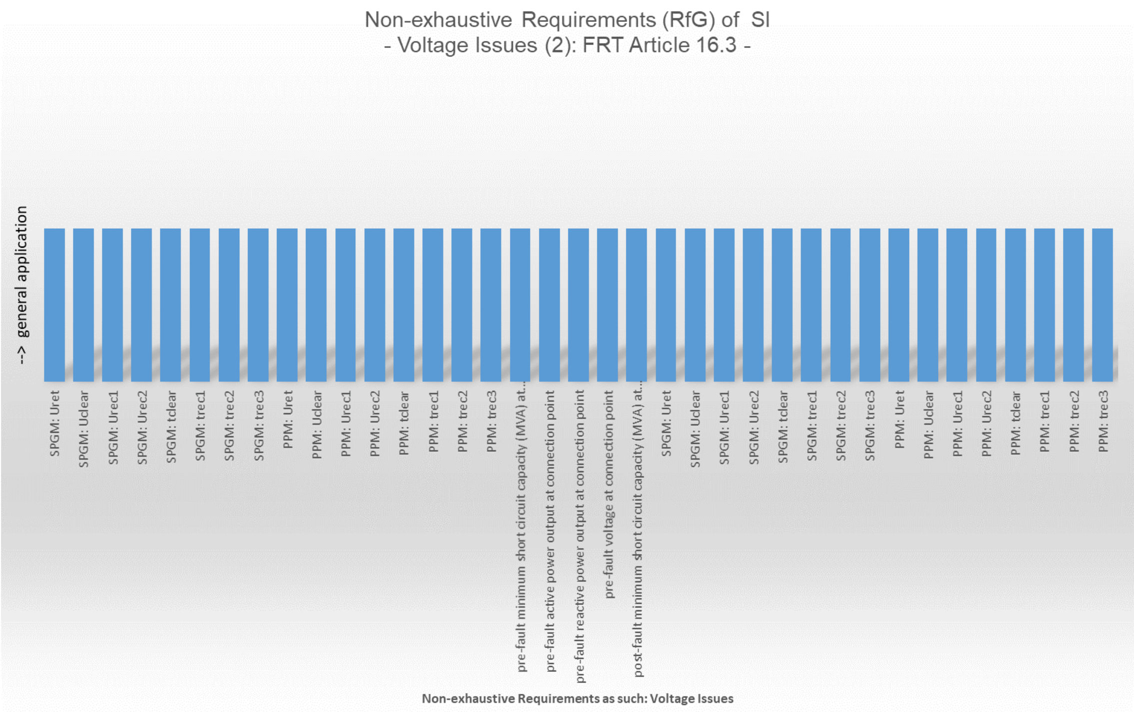


Figure 87: Slovenia (SI)

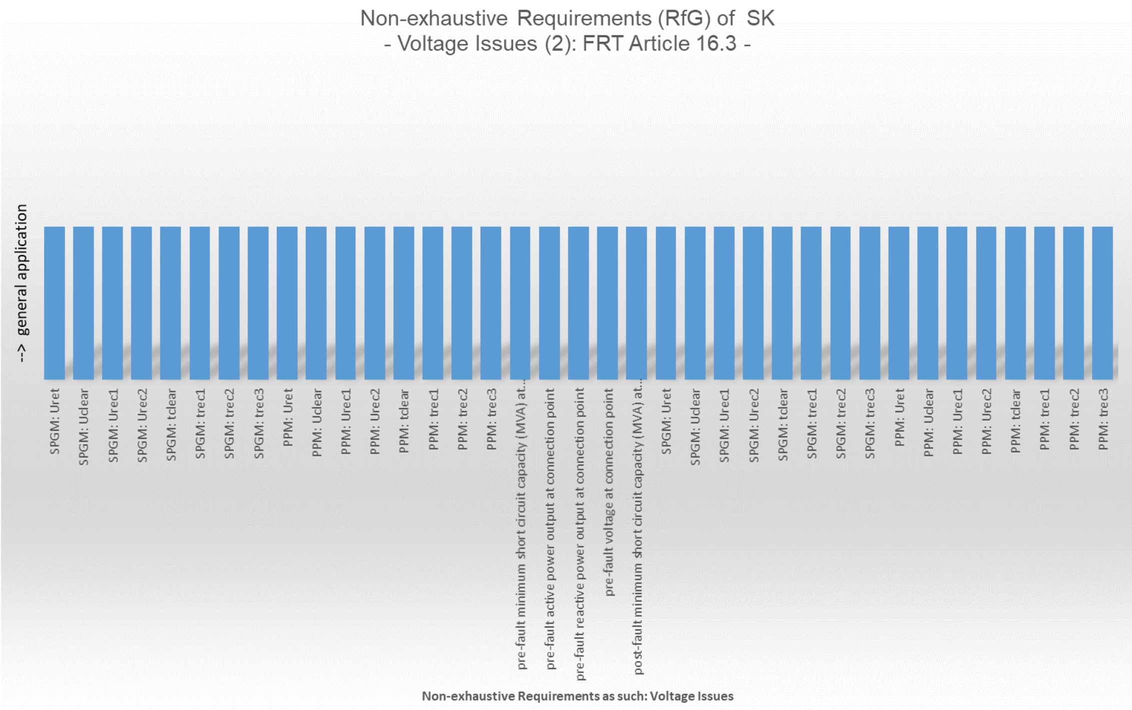


Figure 88: Slovakia (SK)

3.7 Voltage Issues (3) – Voltage Ranges PGM, Reactive Power SPGM/PPM

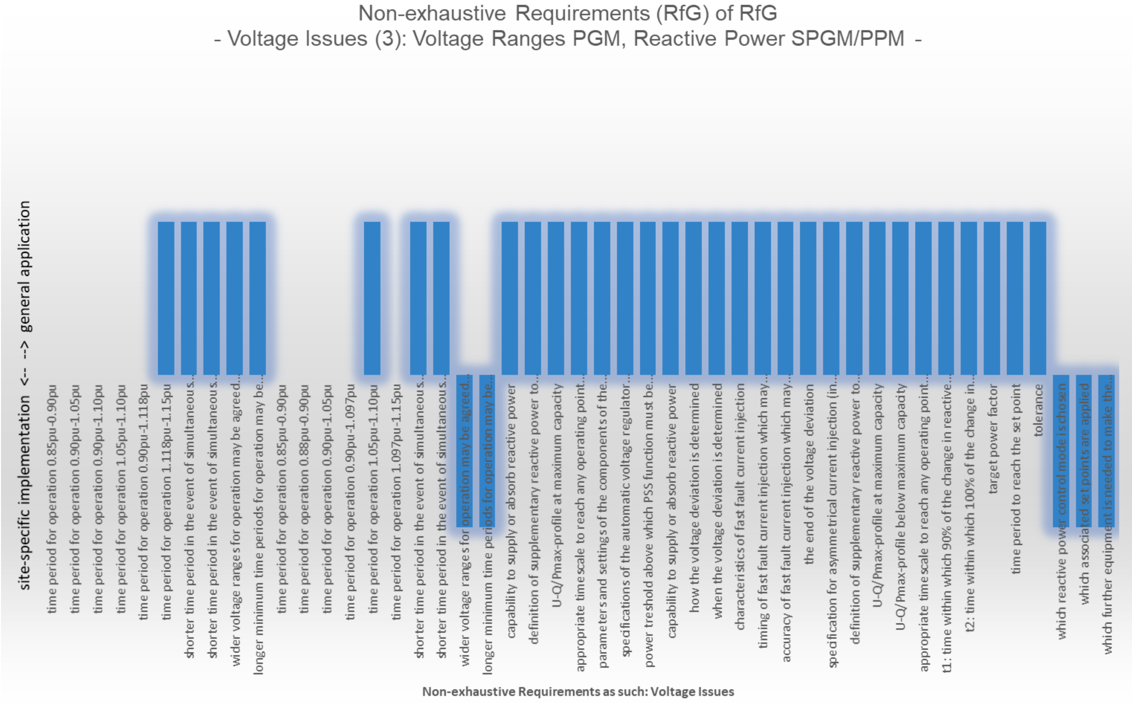


Figure 89: Reference values of non-exhaustive RfG voltage issues (3) - voltage ranges PGM, reactive power SPGM/PPM

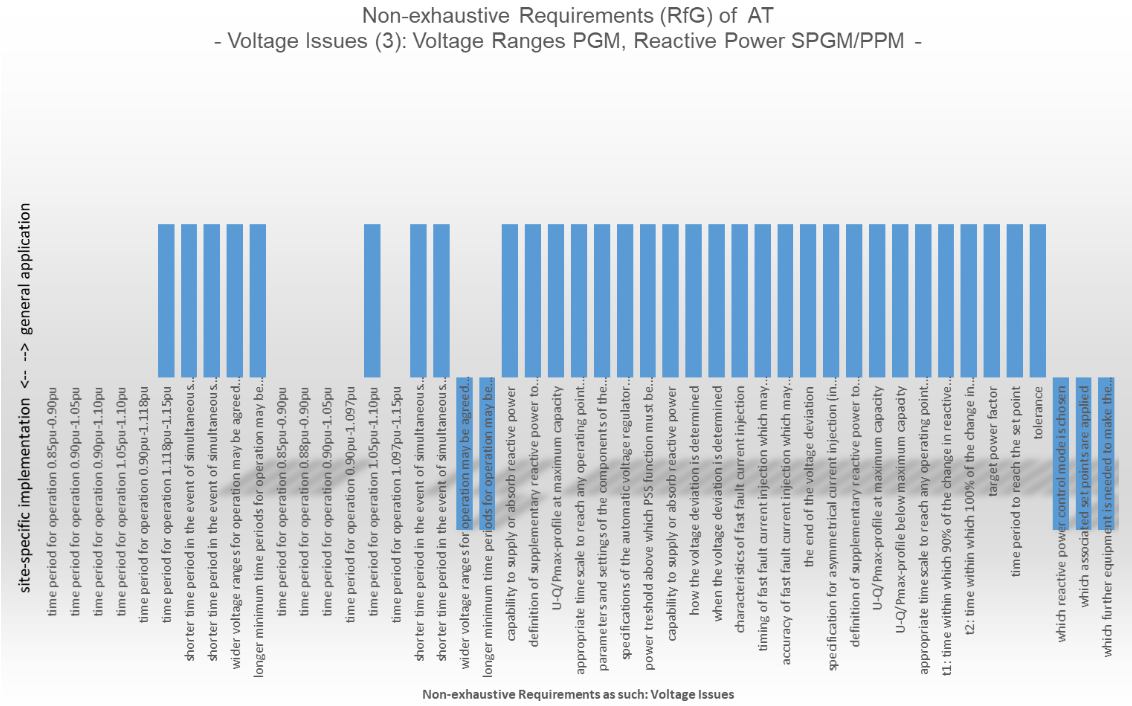


Figure 90: Austria (AT)

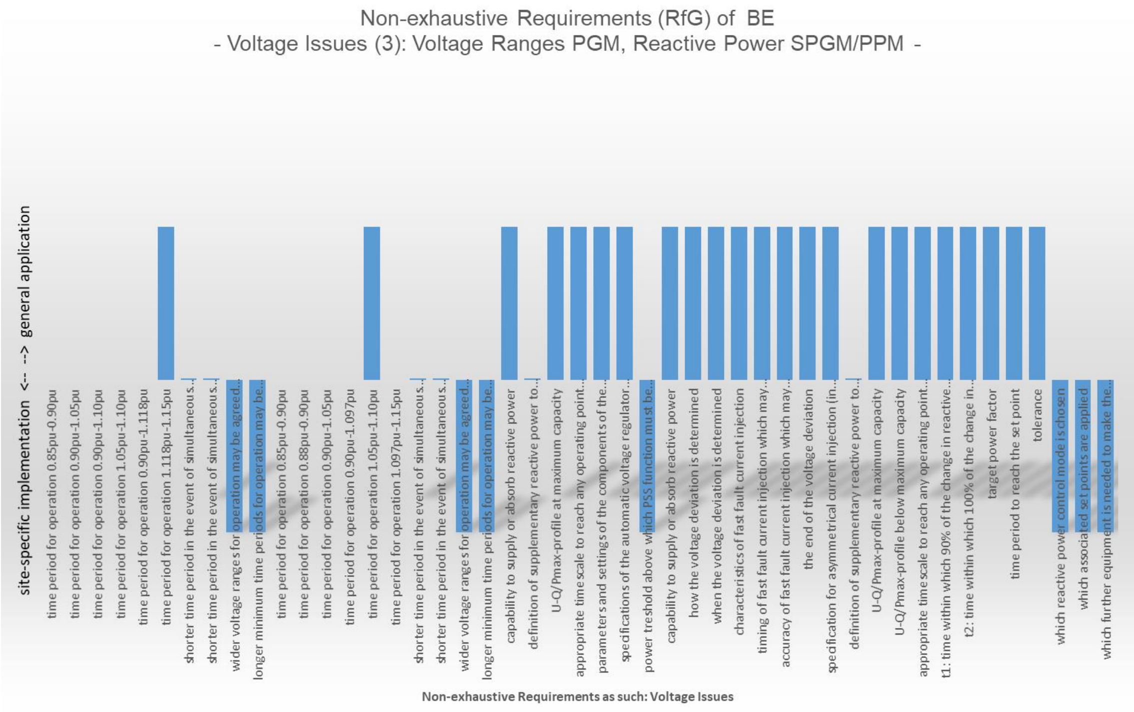


Figure 91: Belgium (BE)

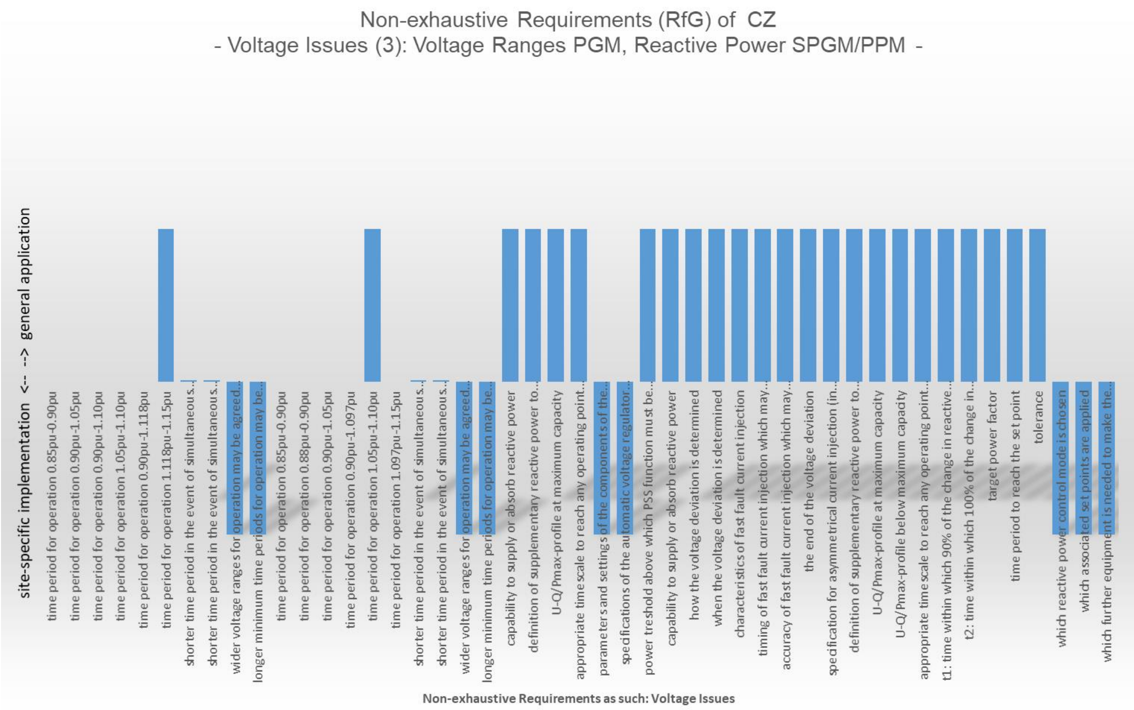


Figure 92: Czech Republic (CZ)

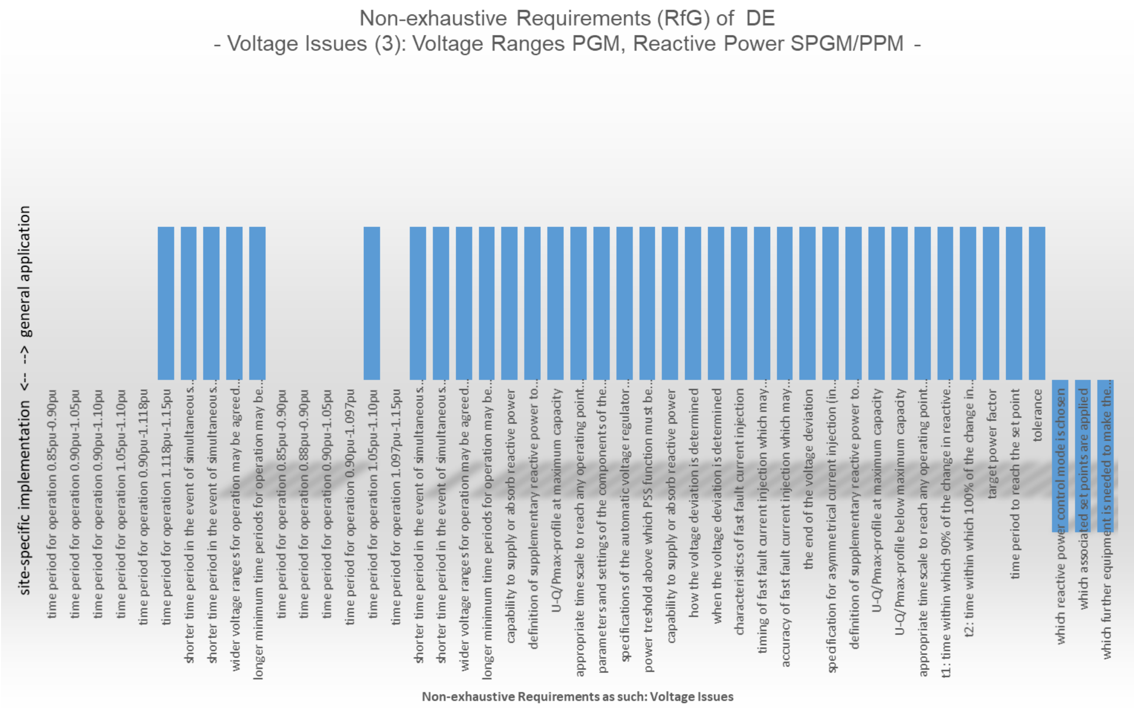


Figure 93: Germany (DE)

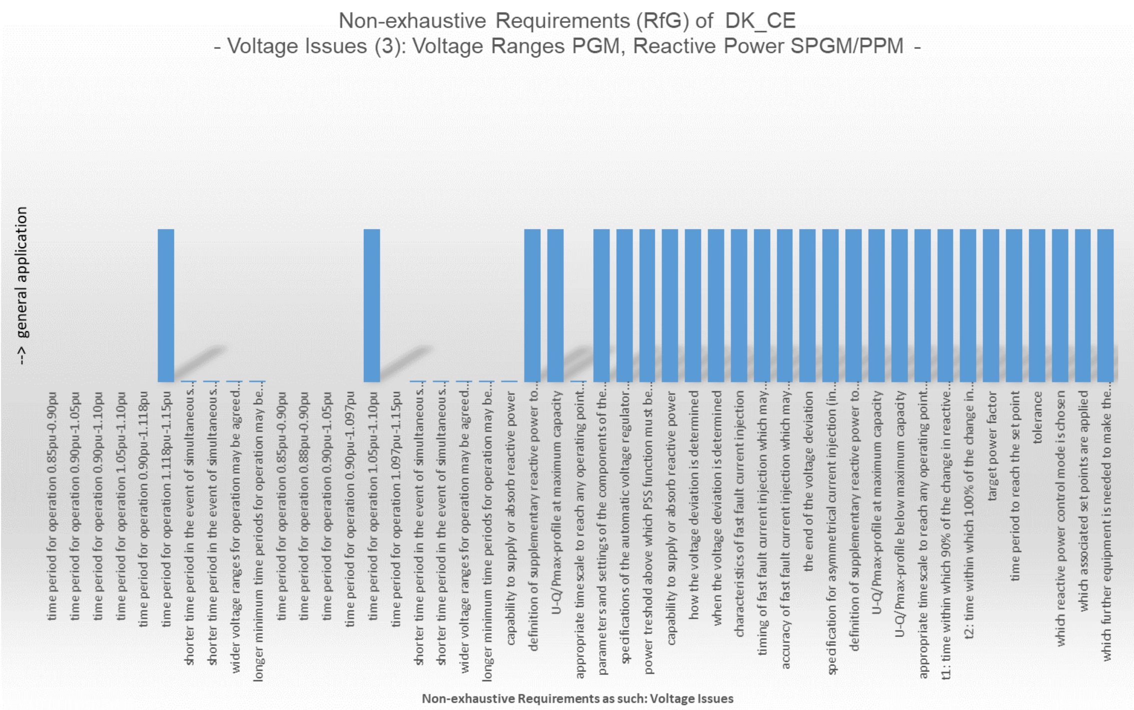


Figure 94: Denmark 1 (DK-CE)

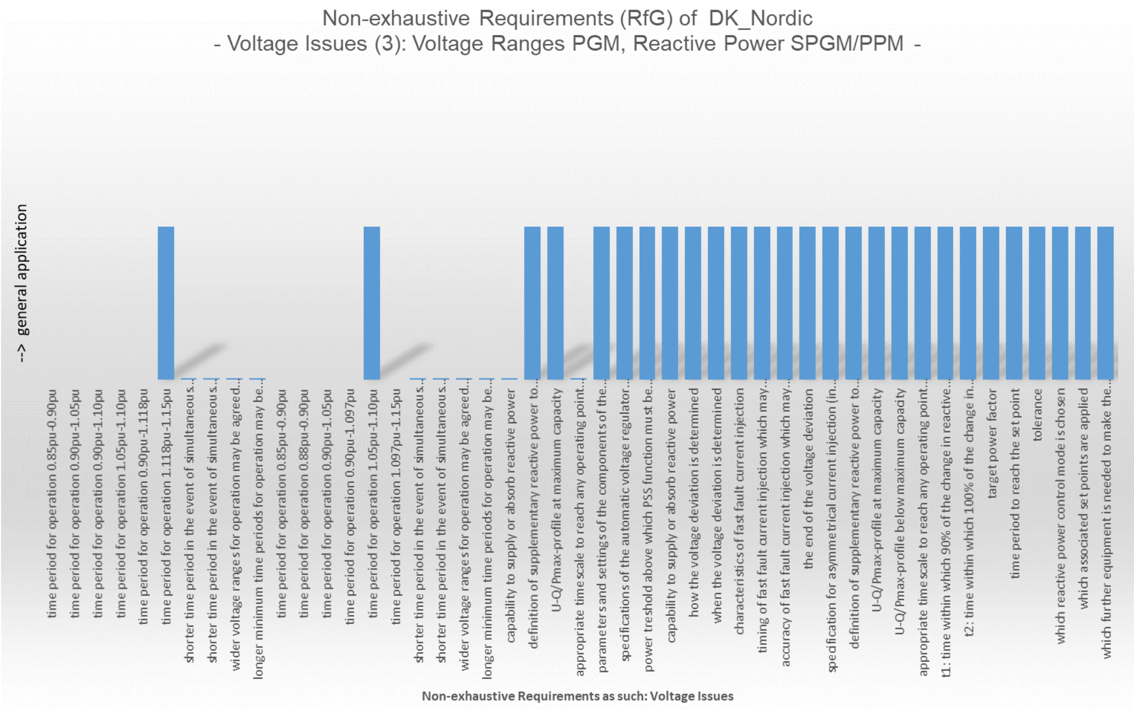


Figure 95: Denmark 2 (DK-Nordic)

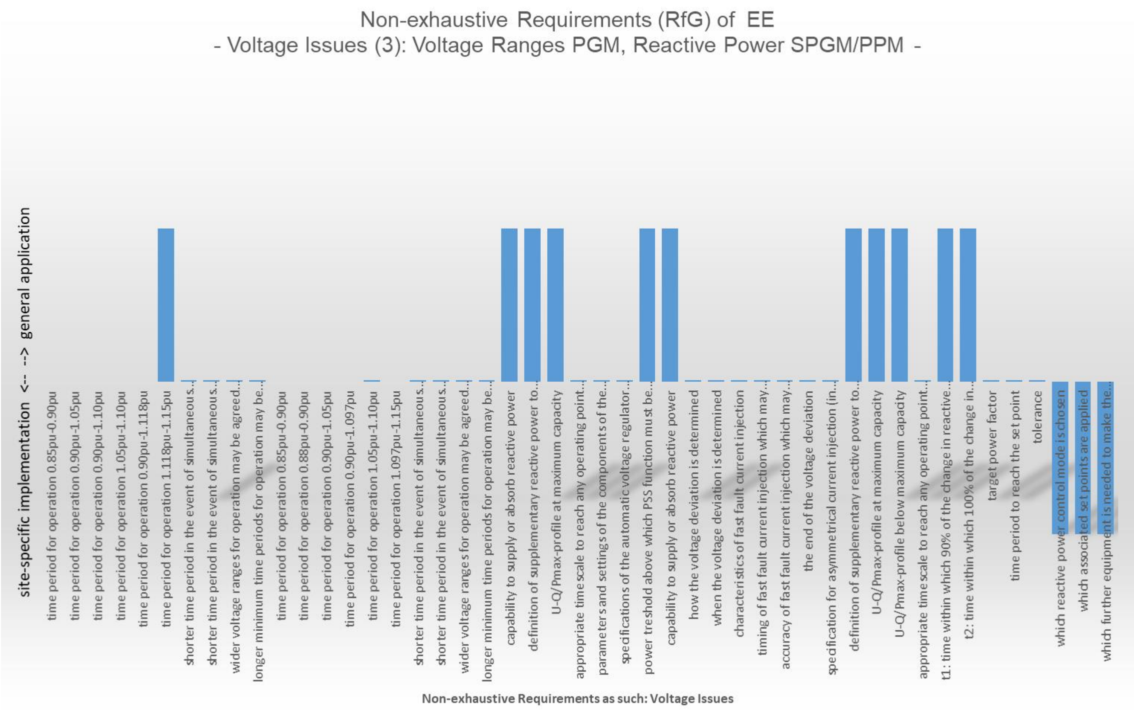


Figure 96: Estonia (EE)

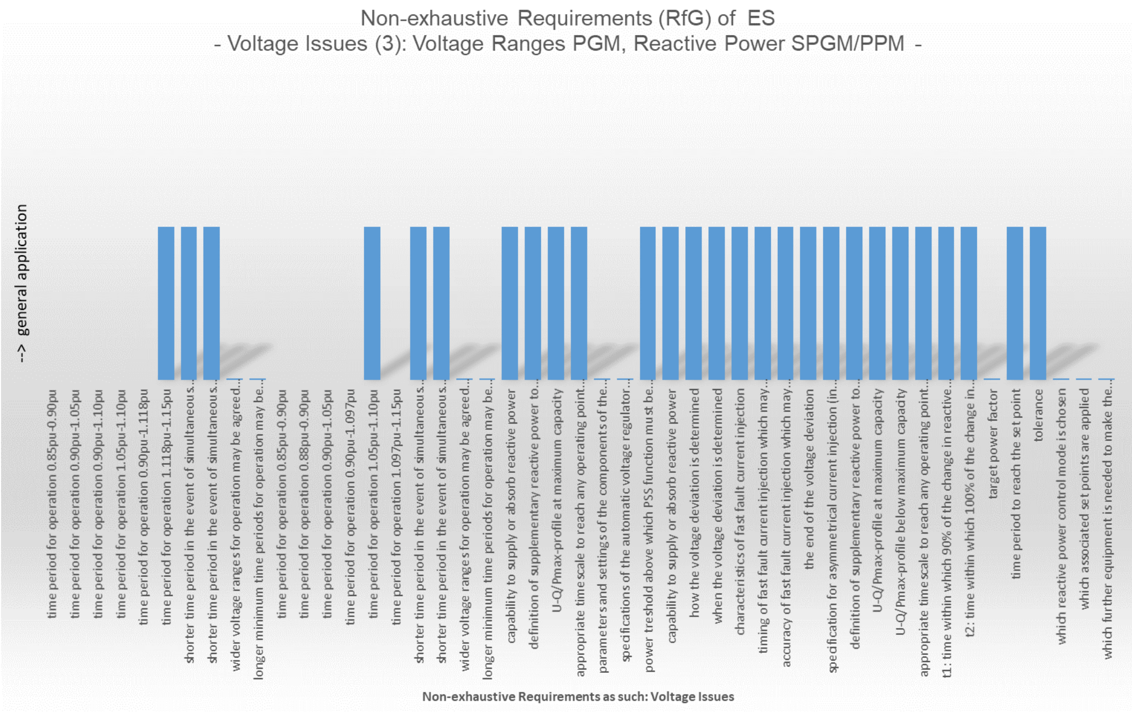


Figure 97: Spain (ES)

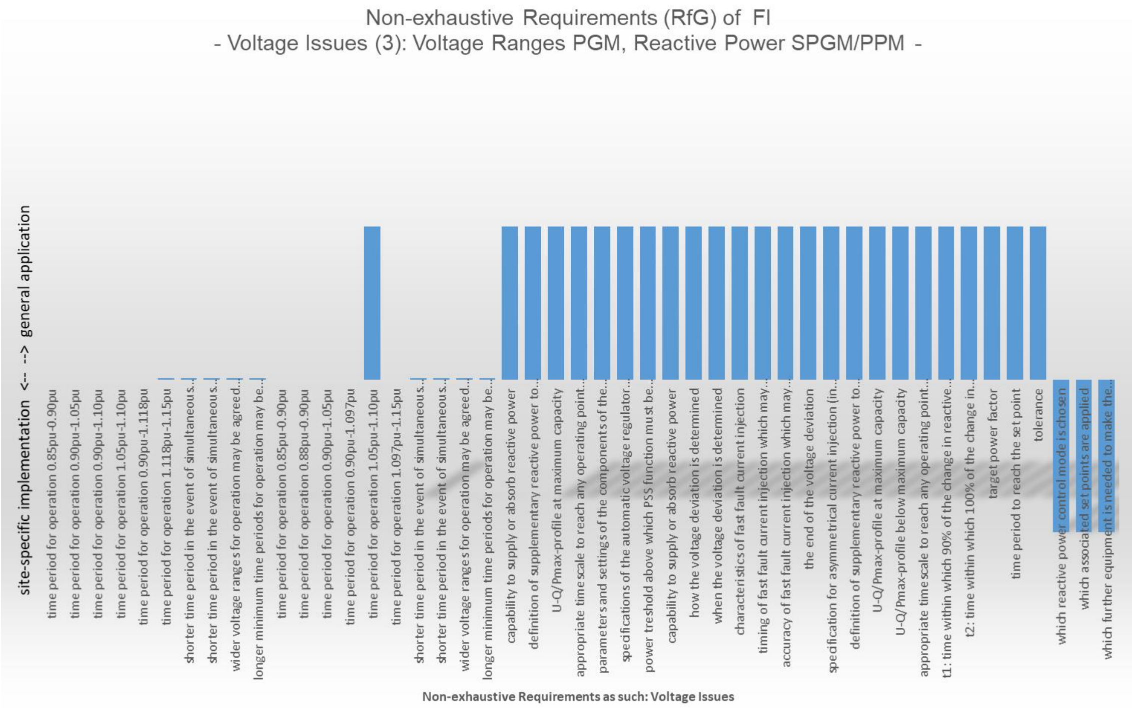


Figure 98: Finland (FI)

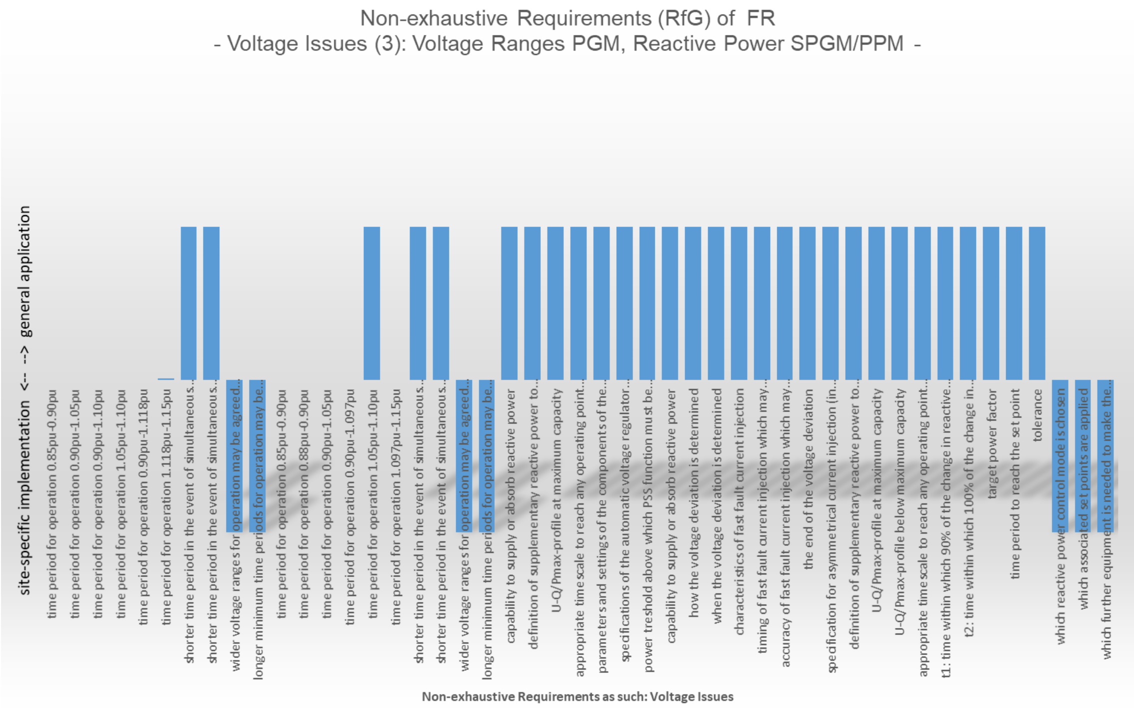


Figure 99: France (FR)

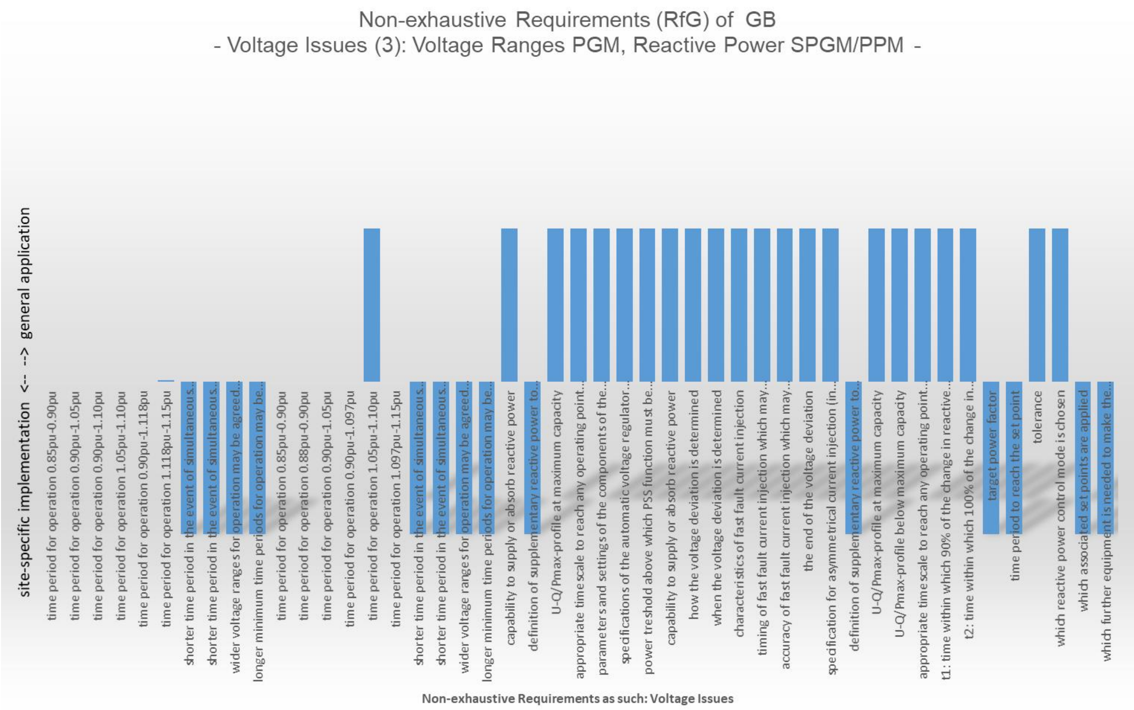


Figure 100: Great Britain (GB)

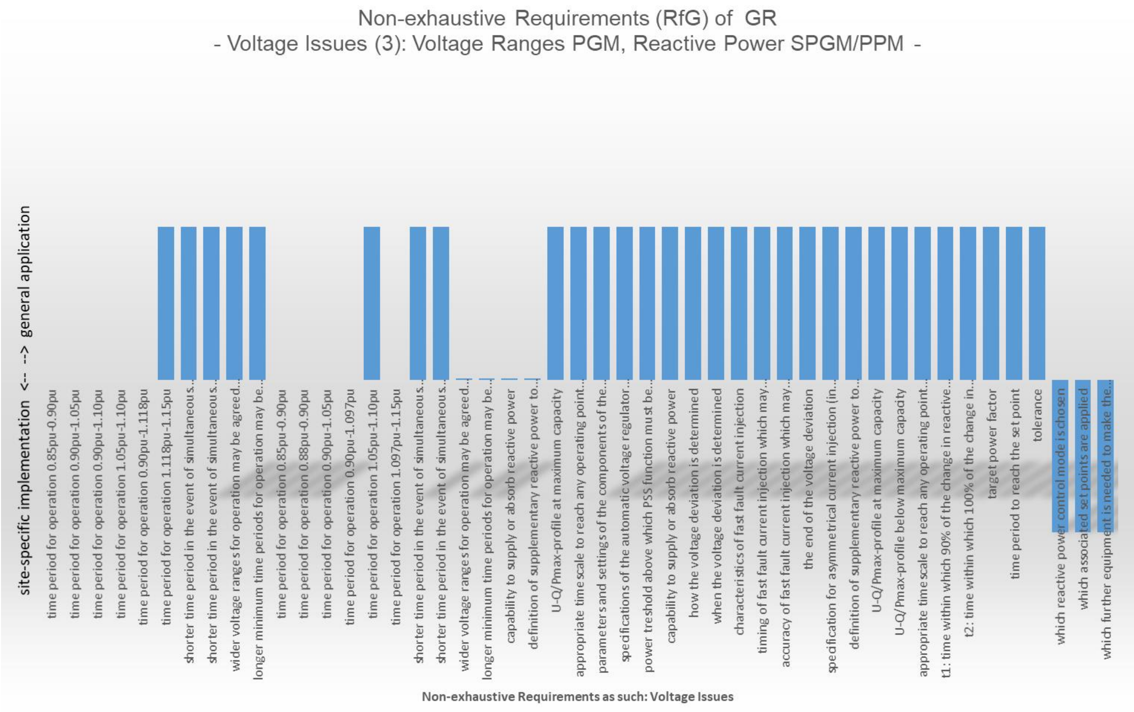


Figure 101: Greece (GR)

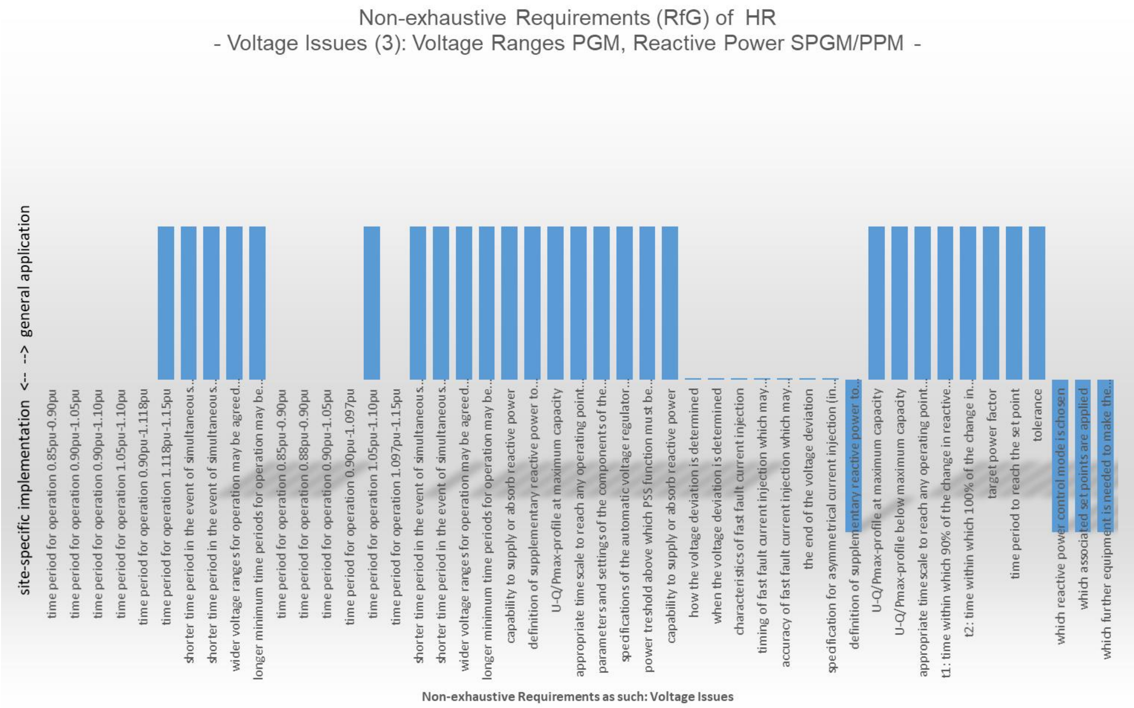


Figure 102: Croatia (HR)

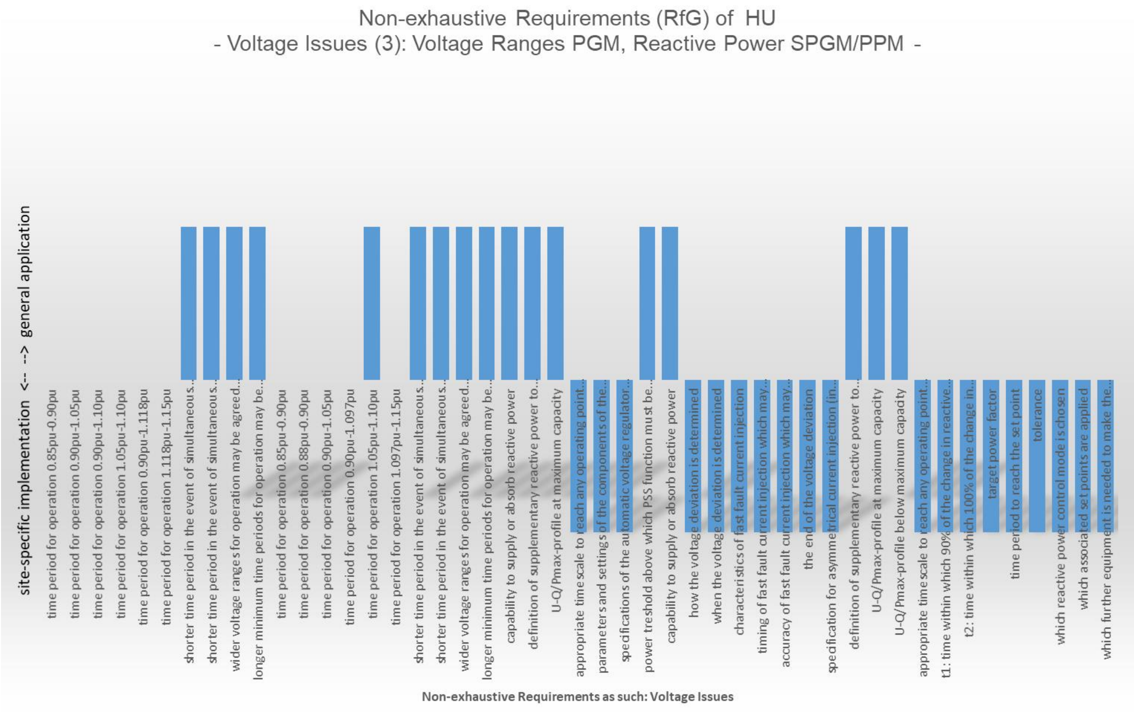


Figure 103: Hungary (HU)

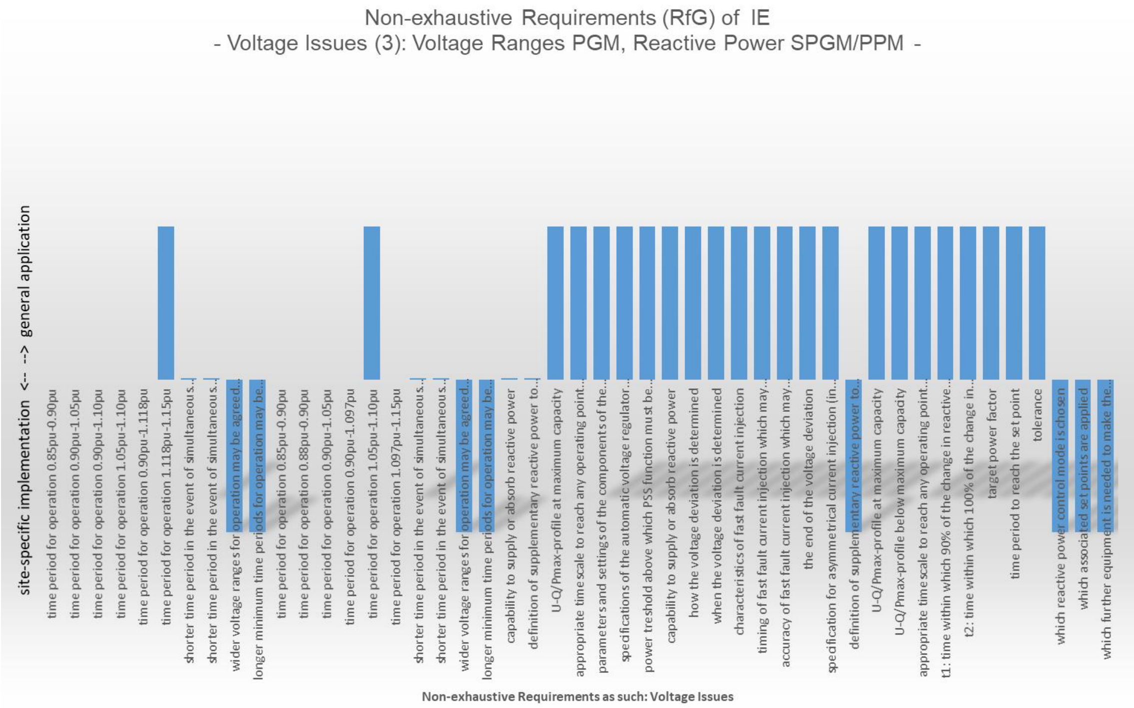


Figure 104: Ireland (IE)

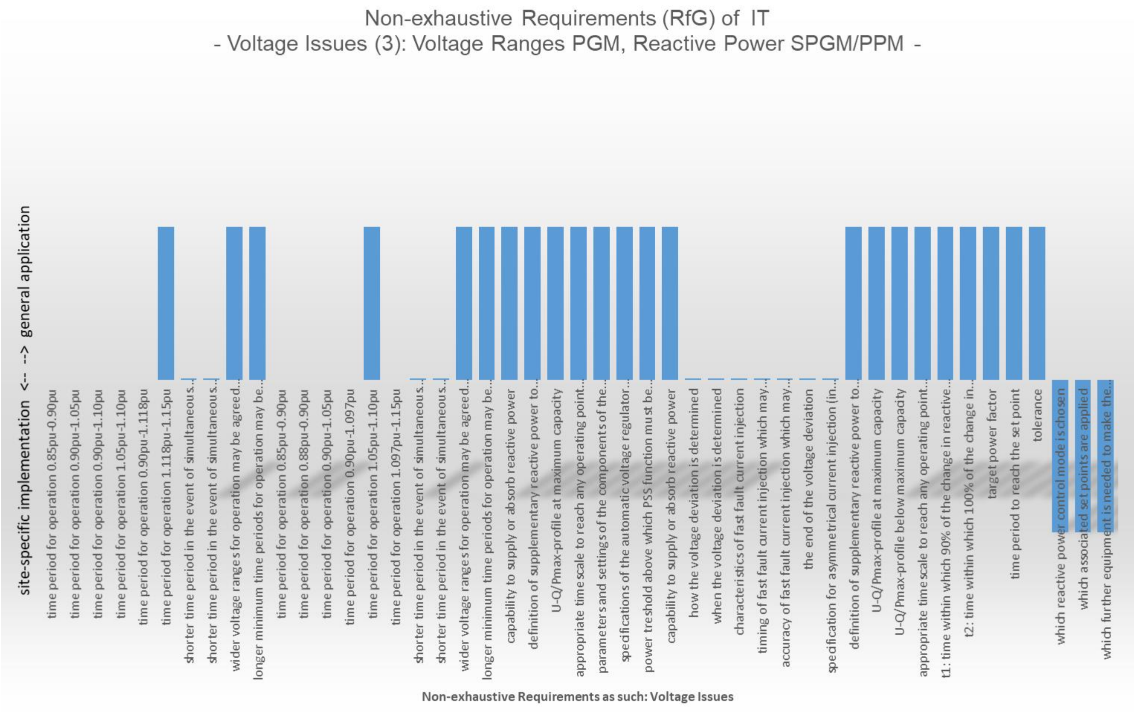


Figure 105: Italy (IT)

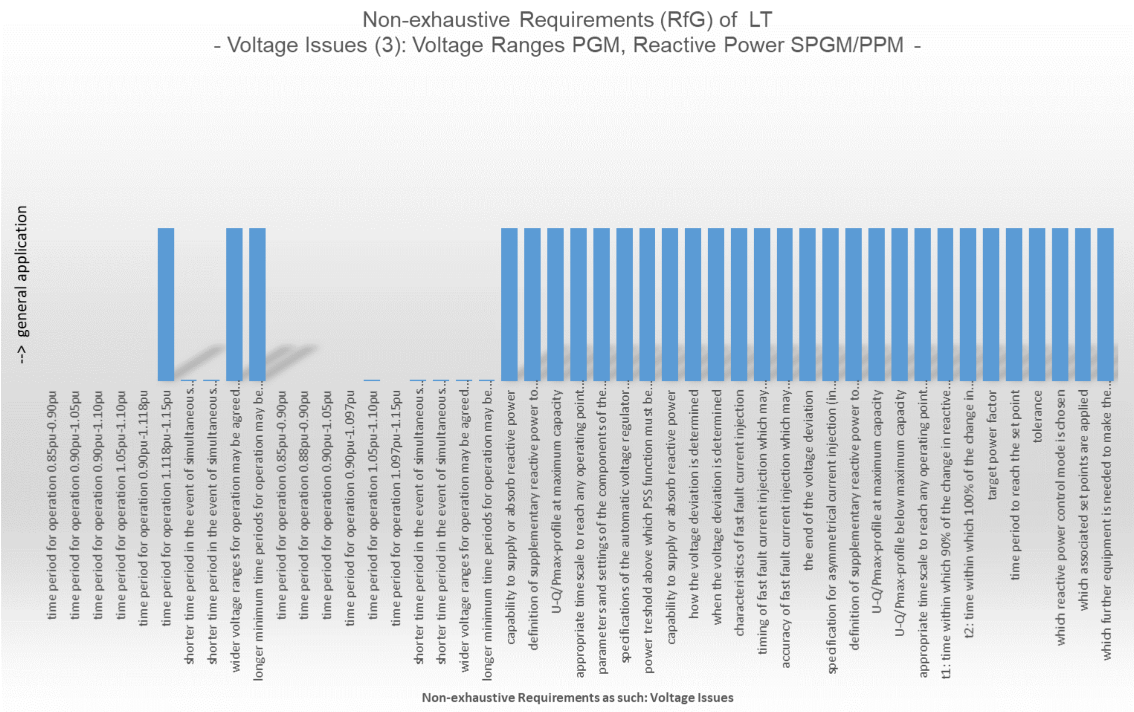


Figure 106: Lithuania (LT)

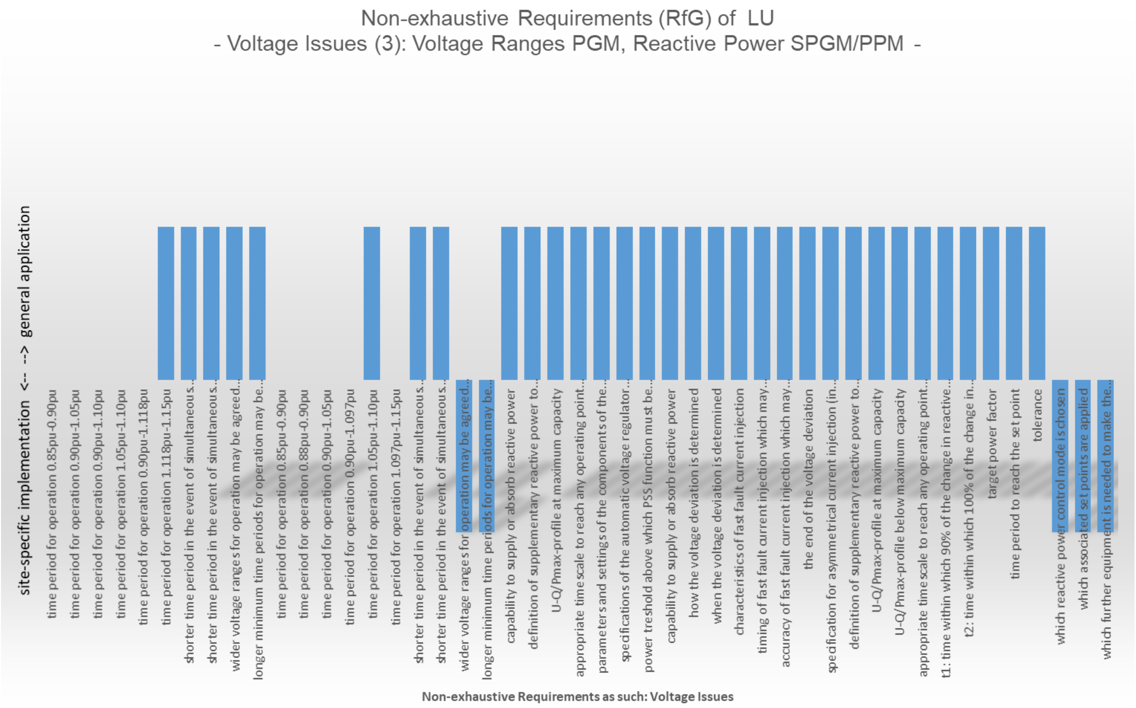


Figure 107: Luxembourg (LU)

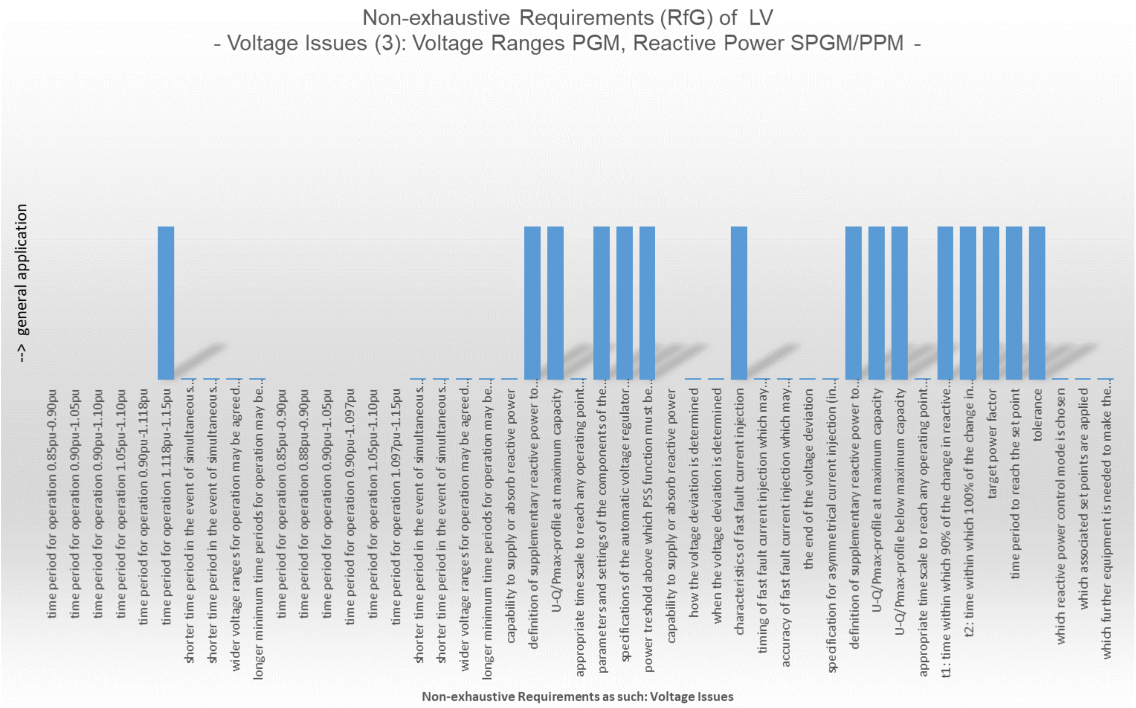


Figure 108: Latvia (LV)

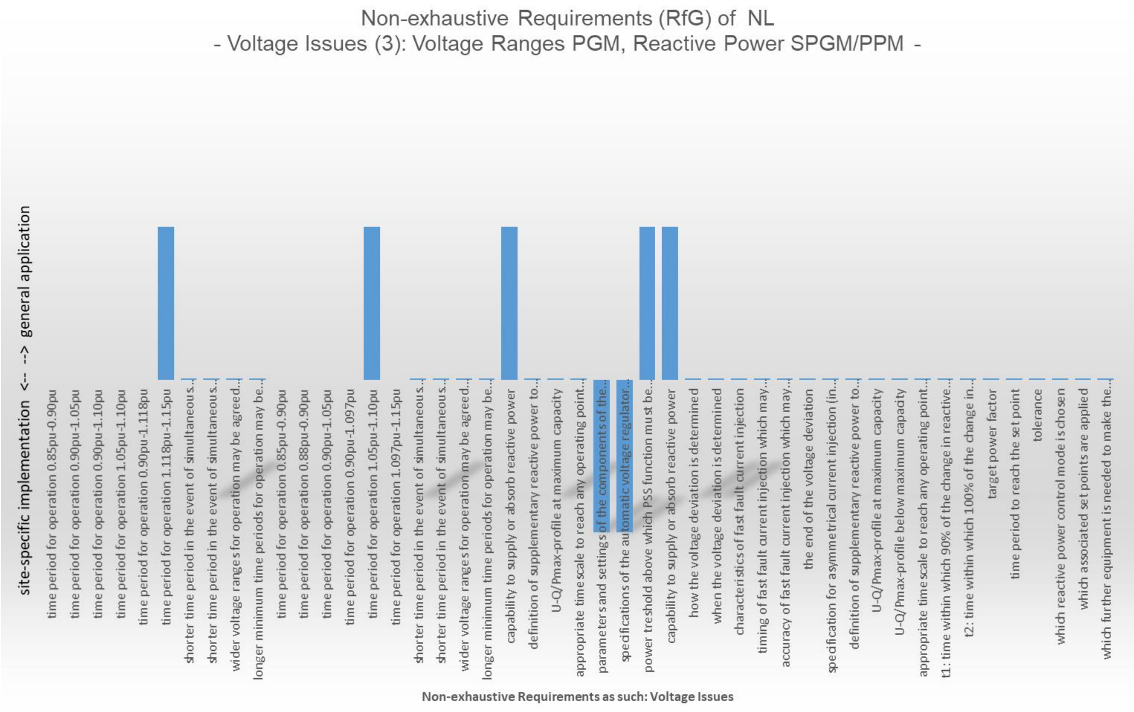


Figure 109: Netherlands (NL)

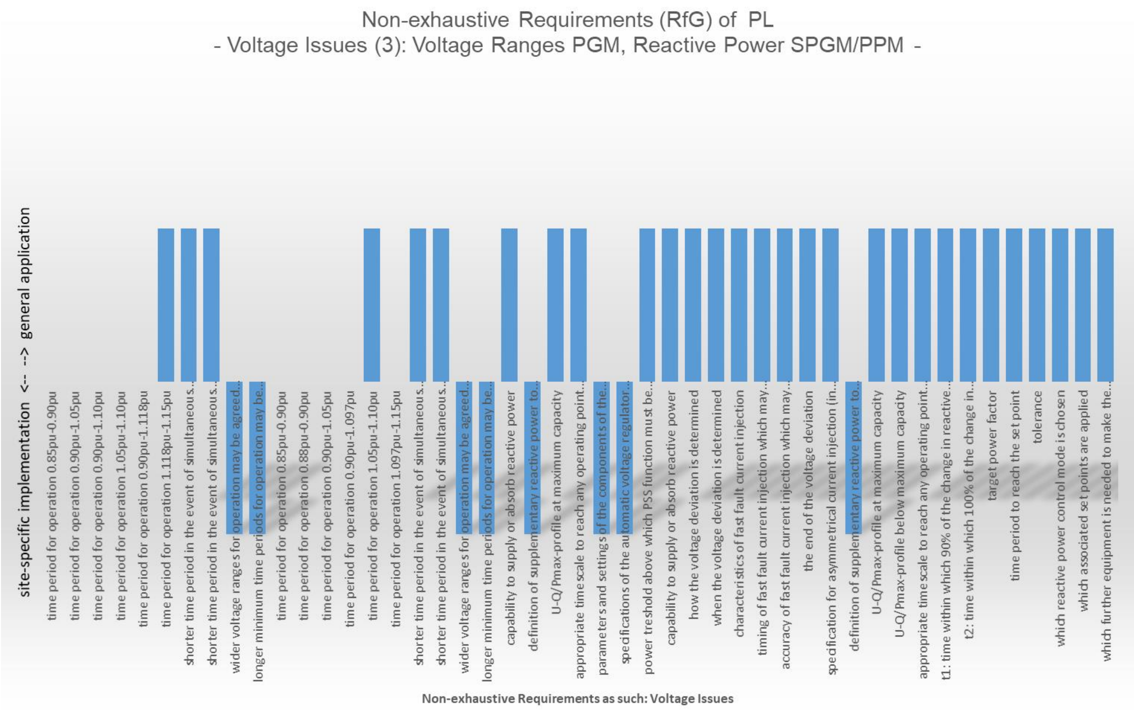


Figure 110: Poland (PL)

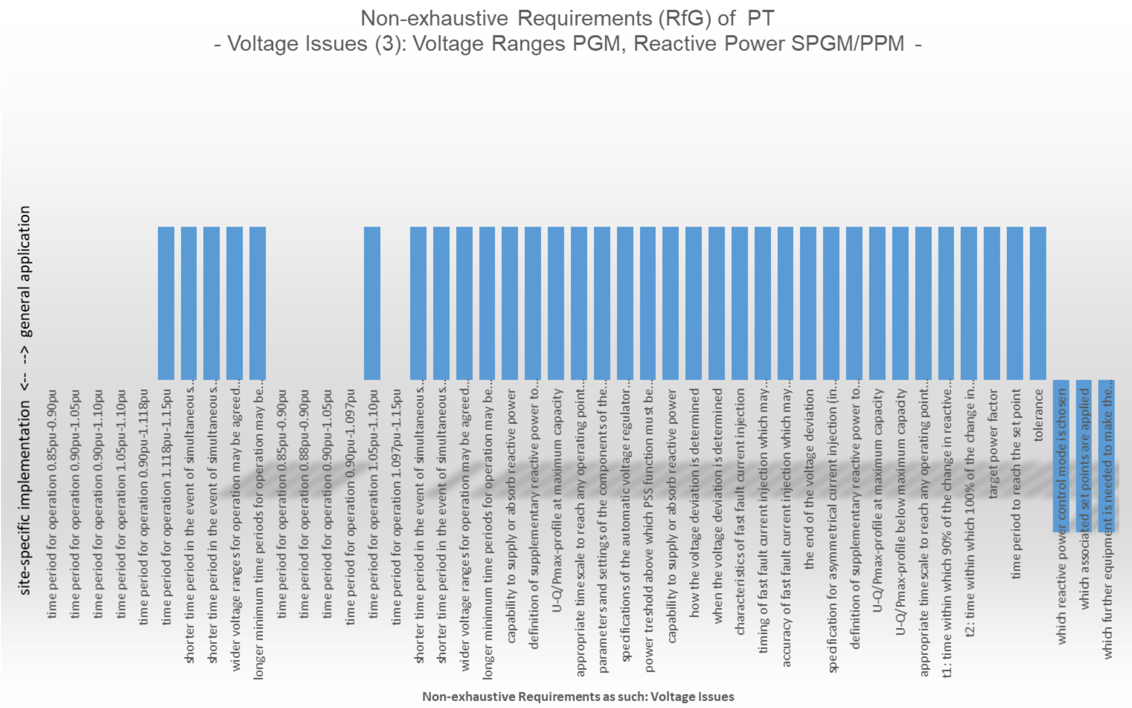


Figure 111: Portugal (PT)

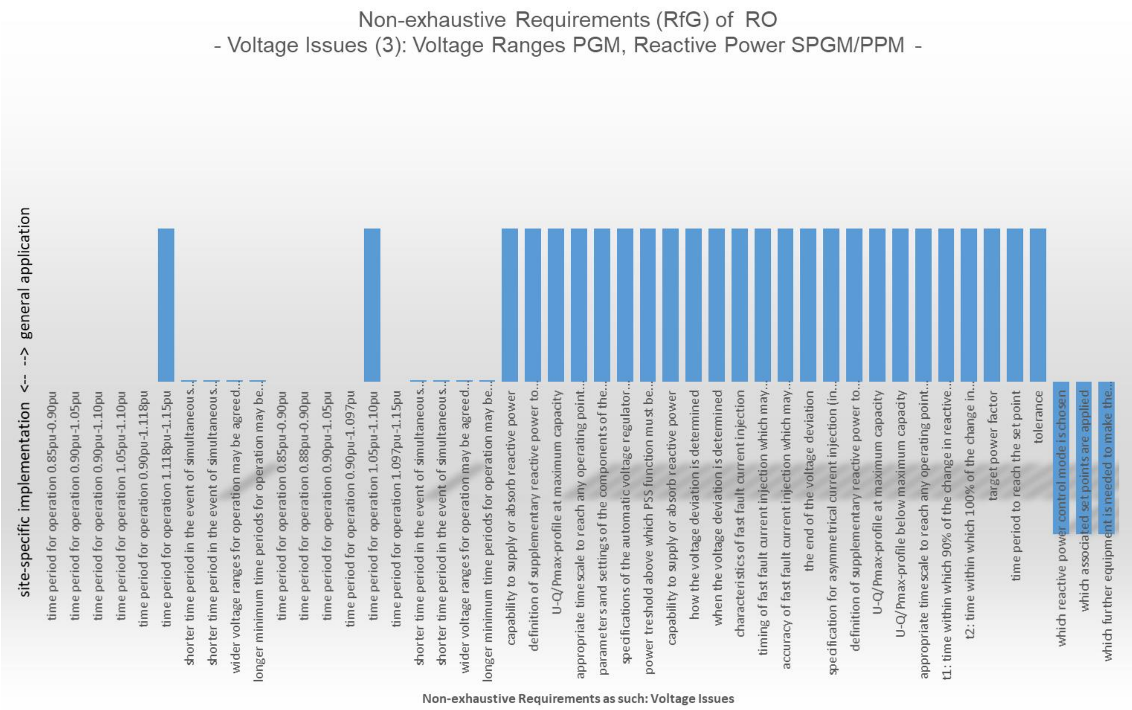


Figure 112: Romania (RO)

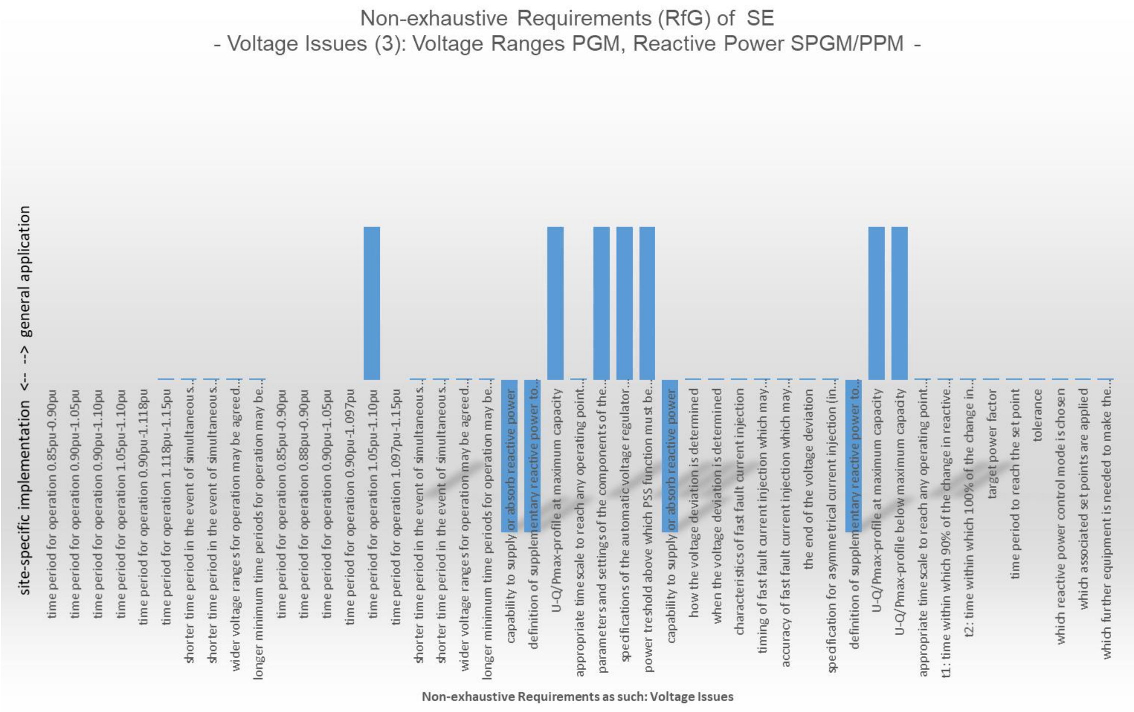


Figure 113: Sweden (SE)

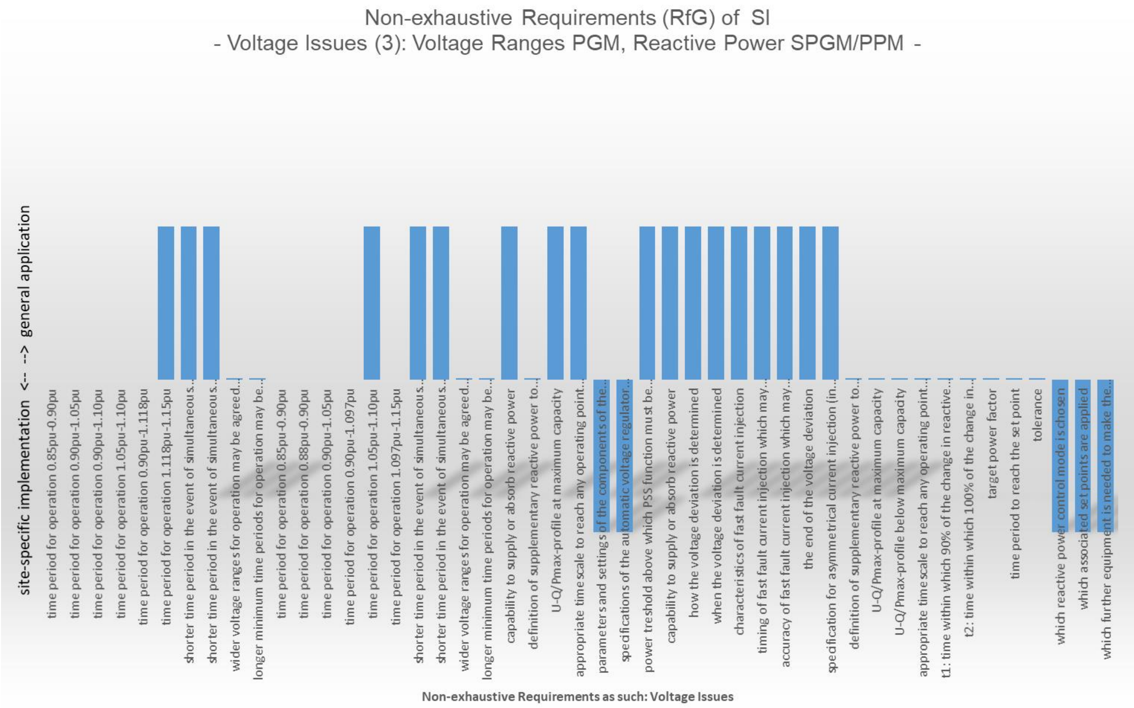


Figure 114: Slovenia (SI)

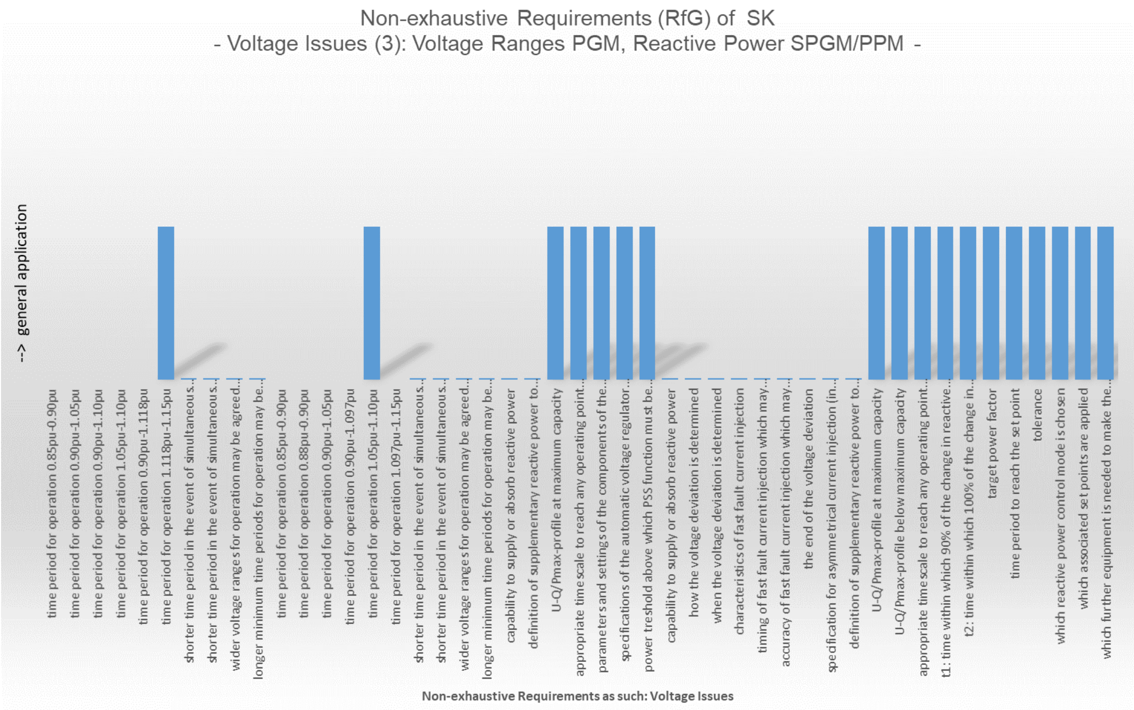


Figure 115: Slovakia (SK)

3.8 System Restoration Issues of NC RfG

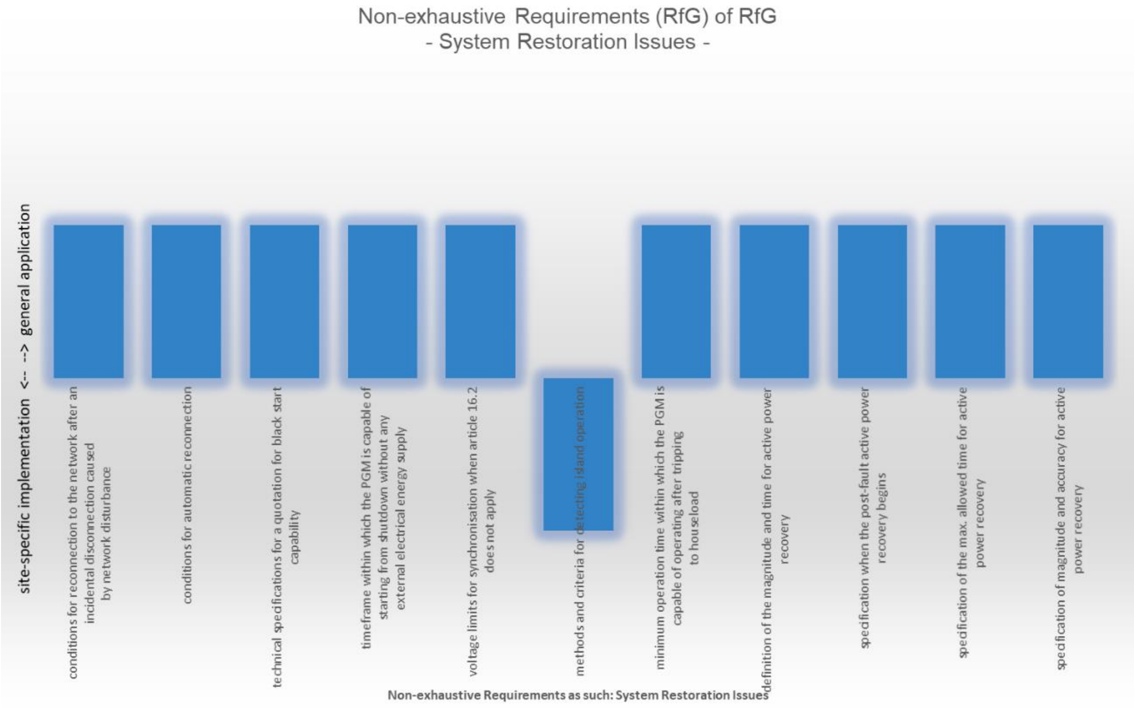


Figure 116: Reference values of non-exhaustive RfG - system restoration issues

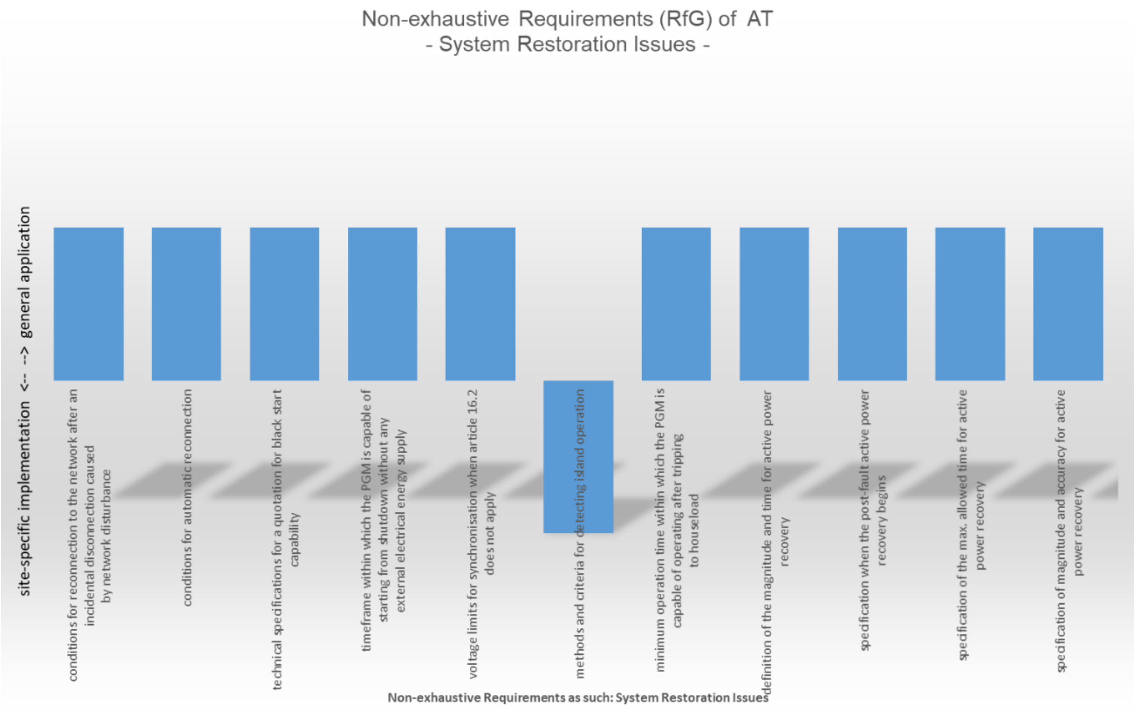


Figure 117: Austria (AT)

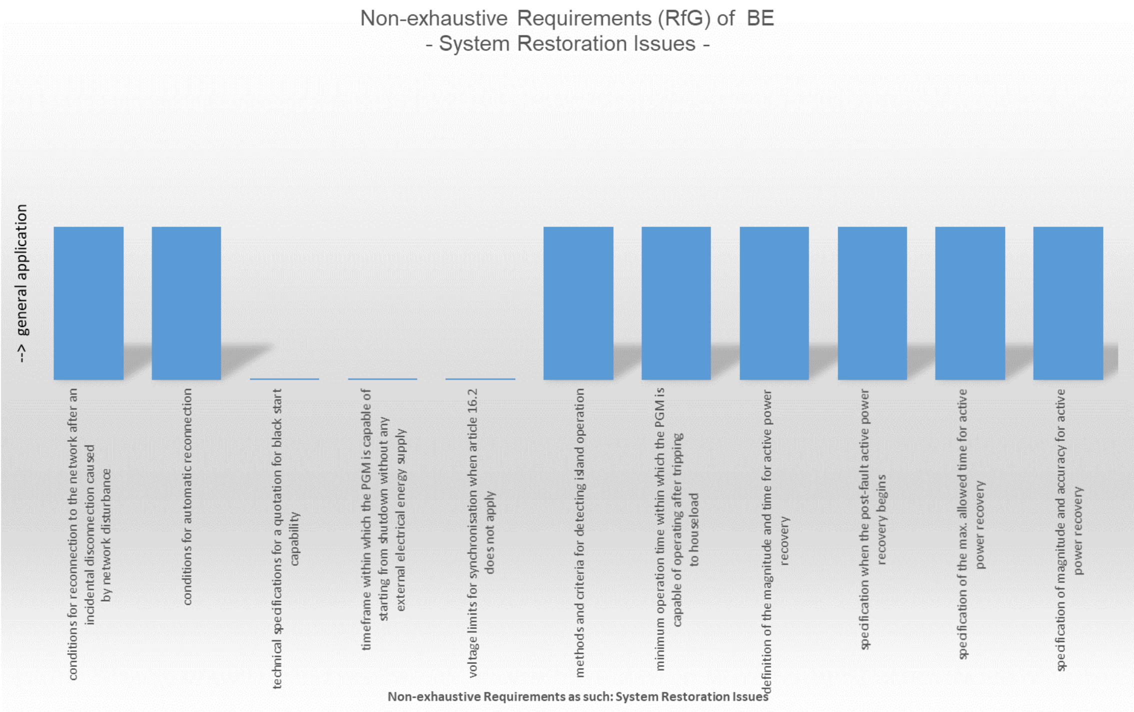


Figure 118: Belgium (BE)

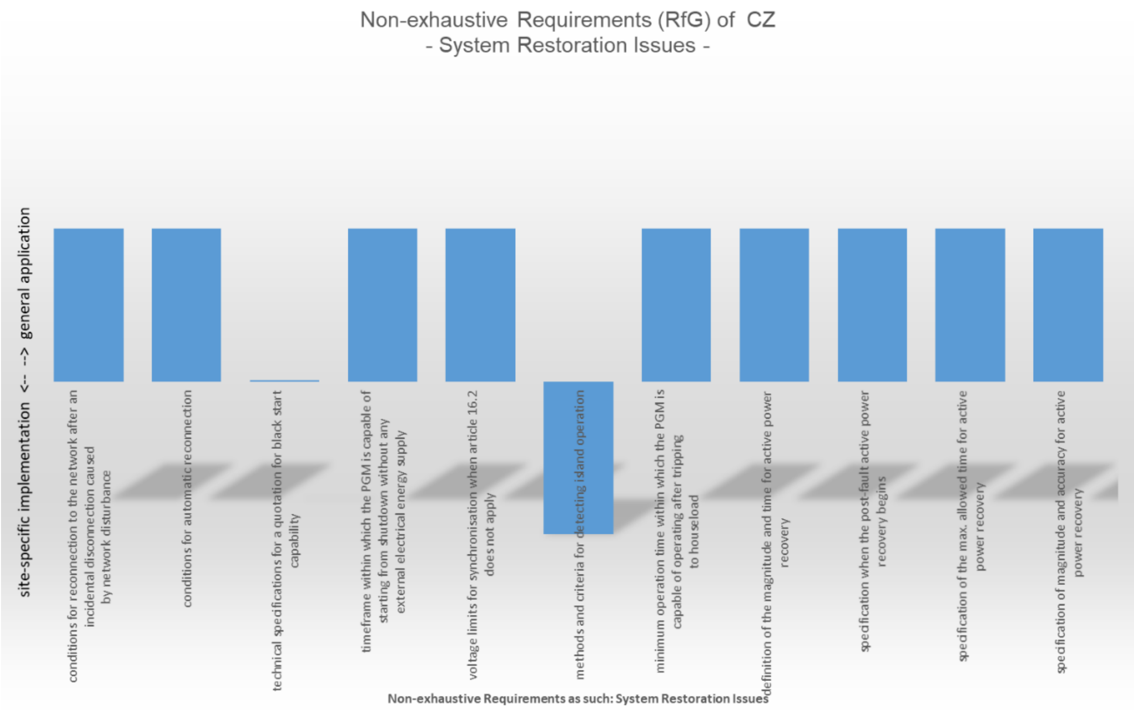


Figure 119: Czech Republic (CZ)

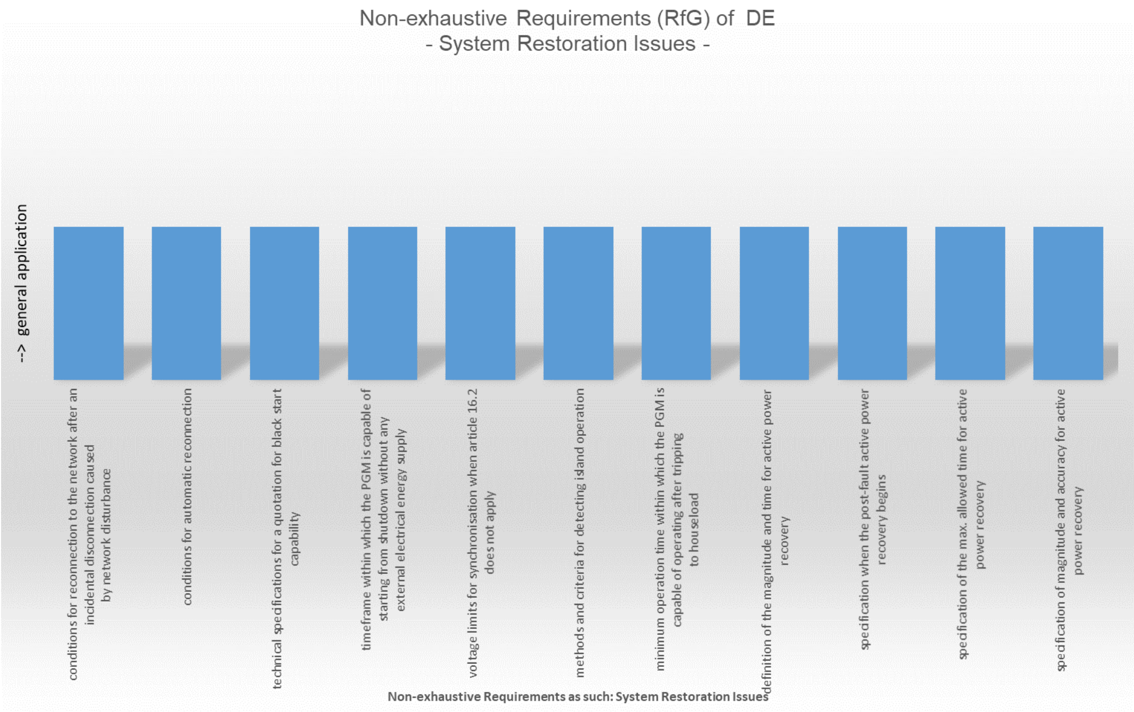


Figure 120: Germany (DE)

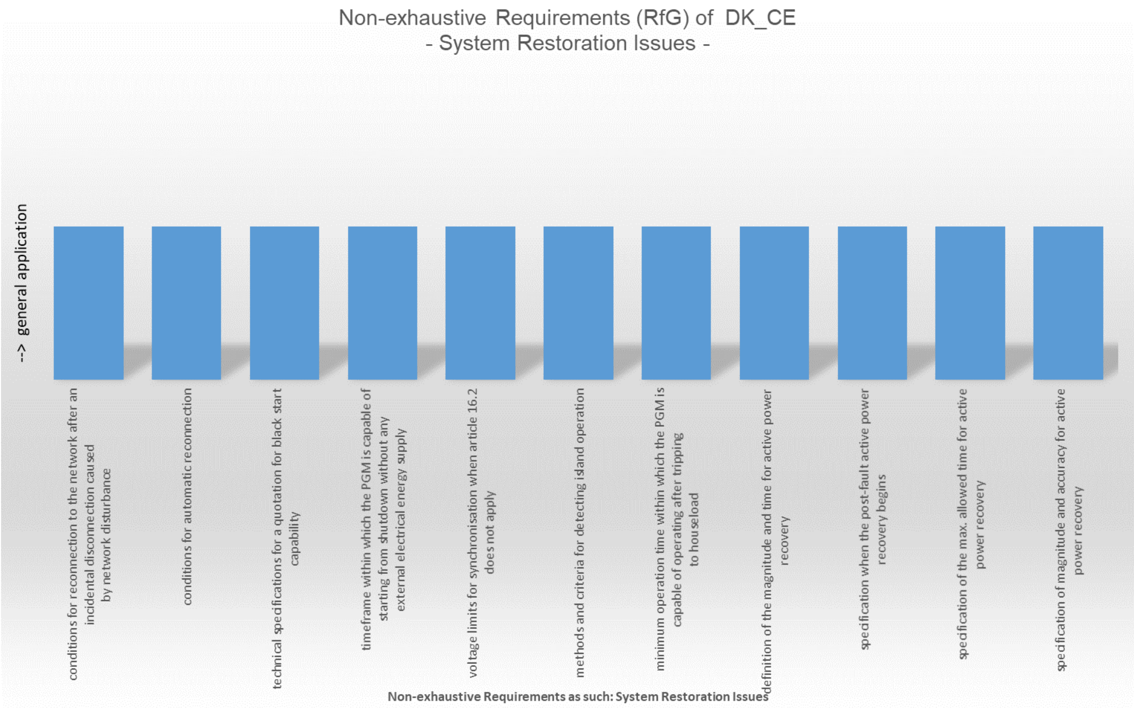


Figure 121: Denmark 1 (DK-CE)

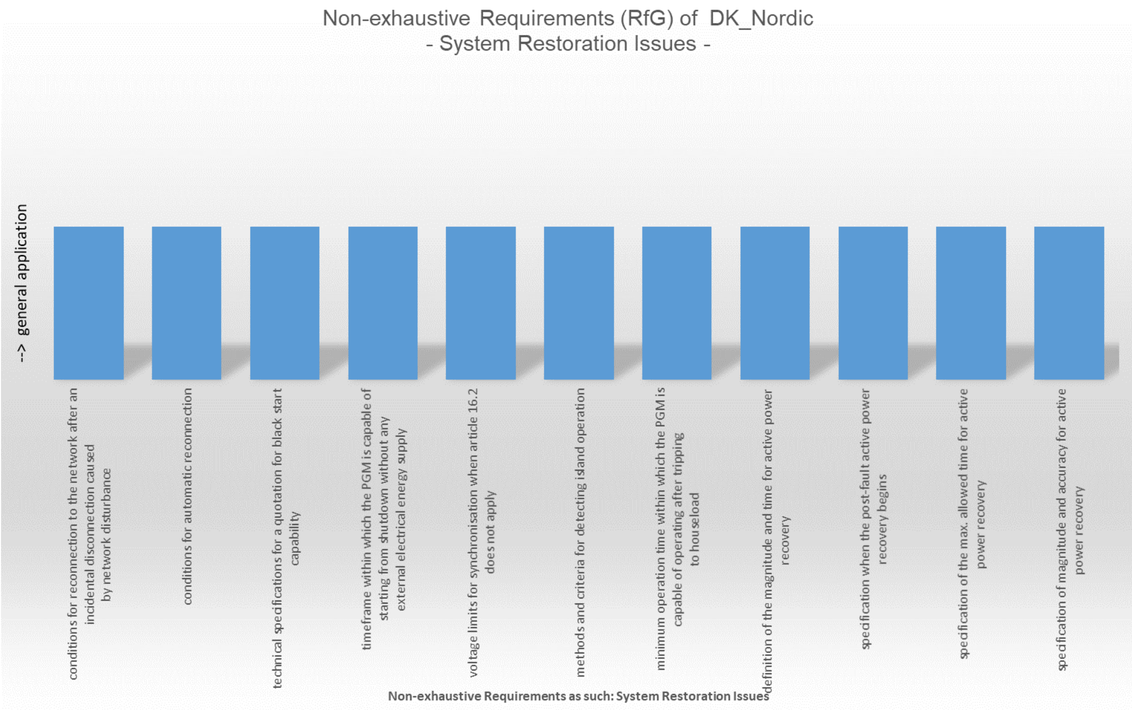


Figure 122: Denmark 2 (DK-Nordic)

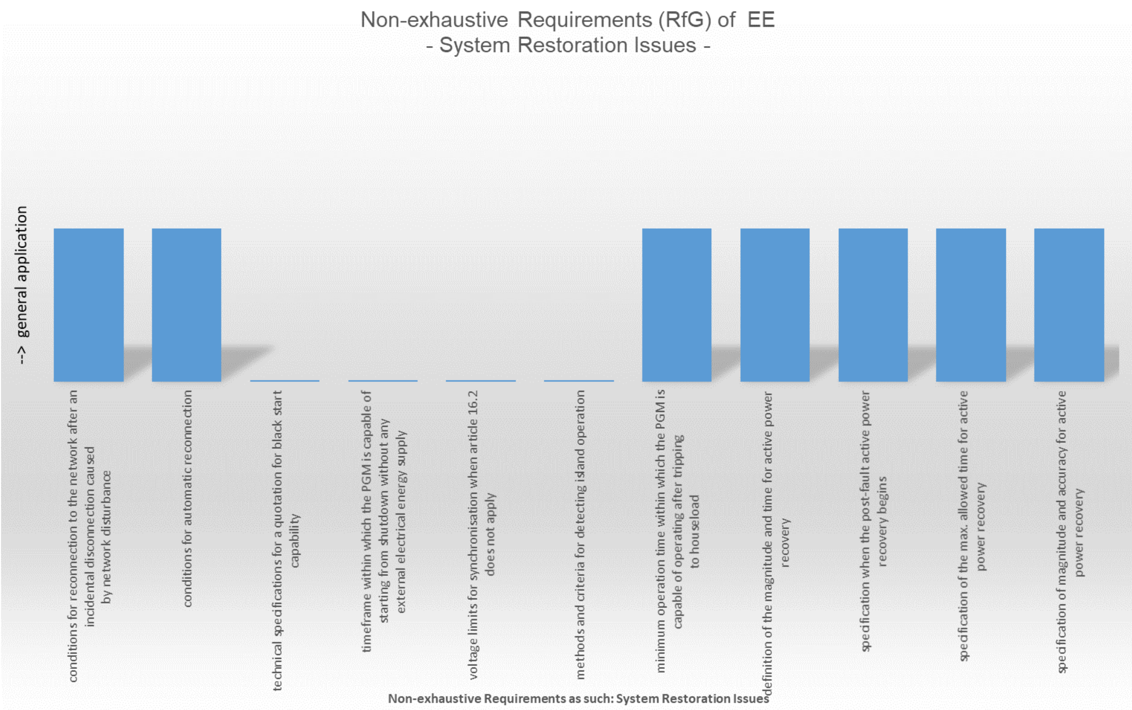


Figure 123: Estonia (EE)

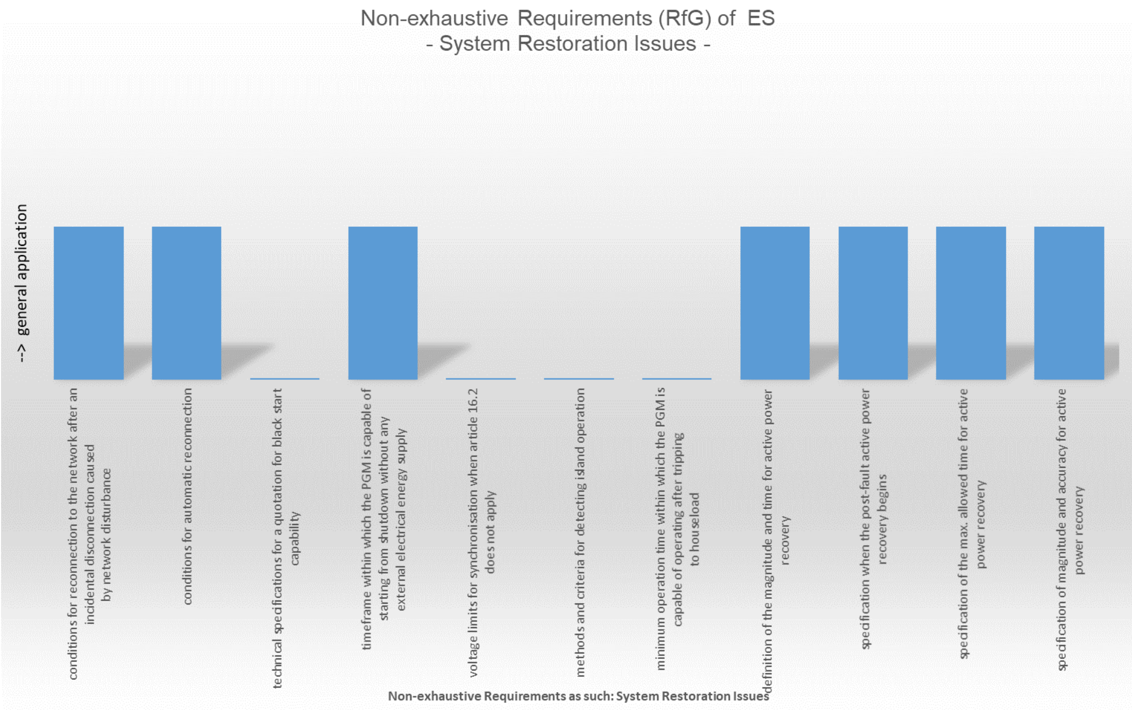


Figure 124: Spain (ES)

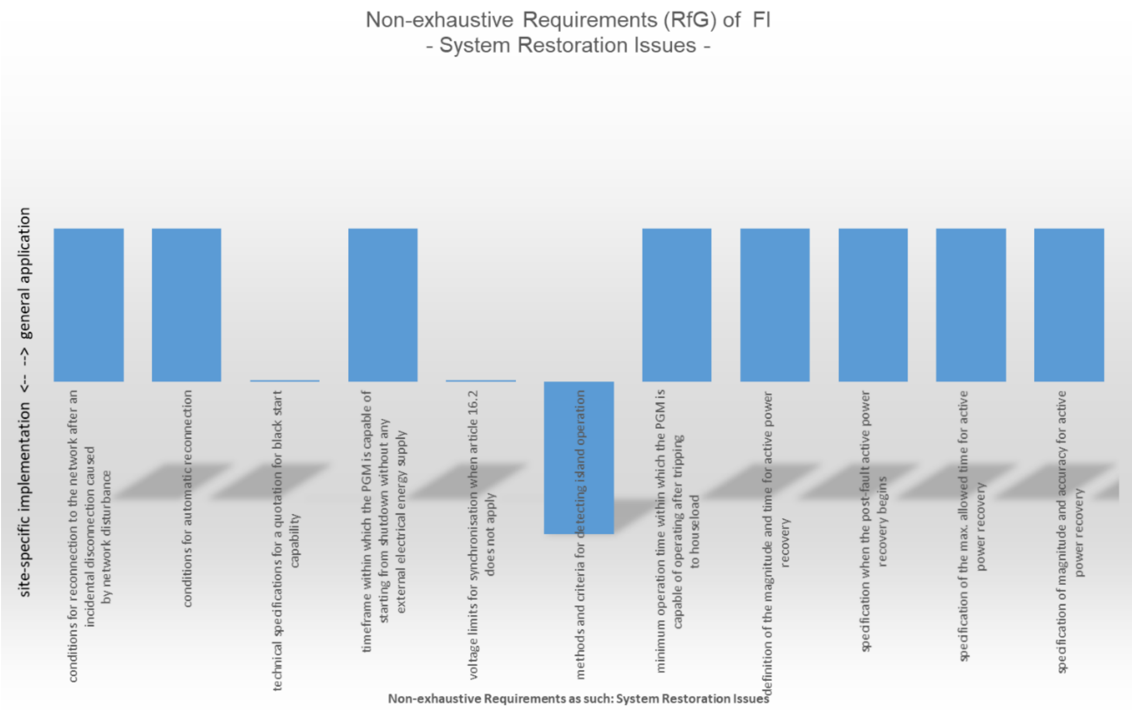


Figure 125: Finland (FI)

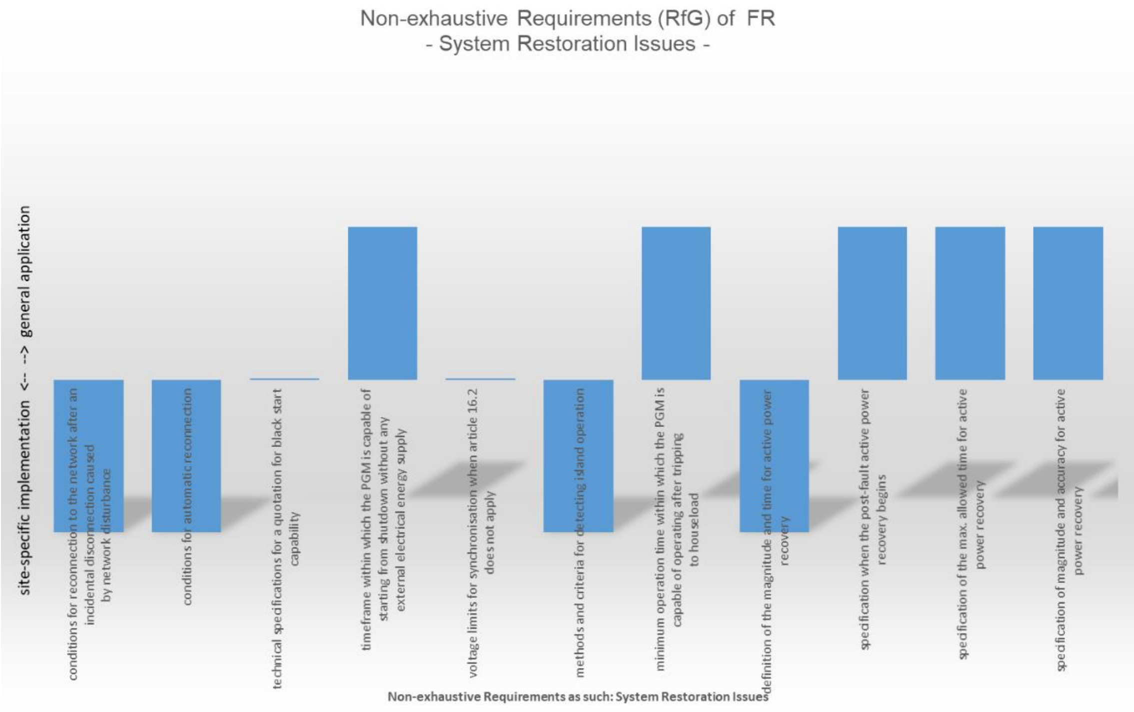


Figure 126: France (FR)

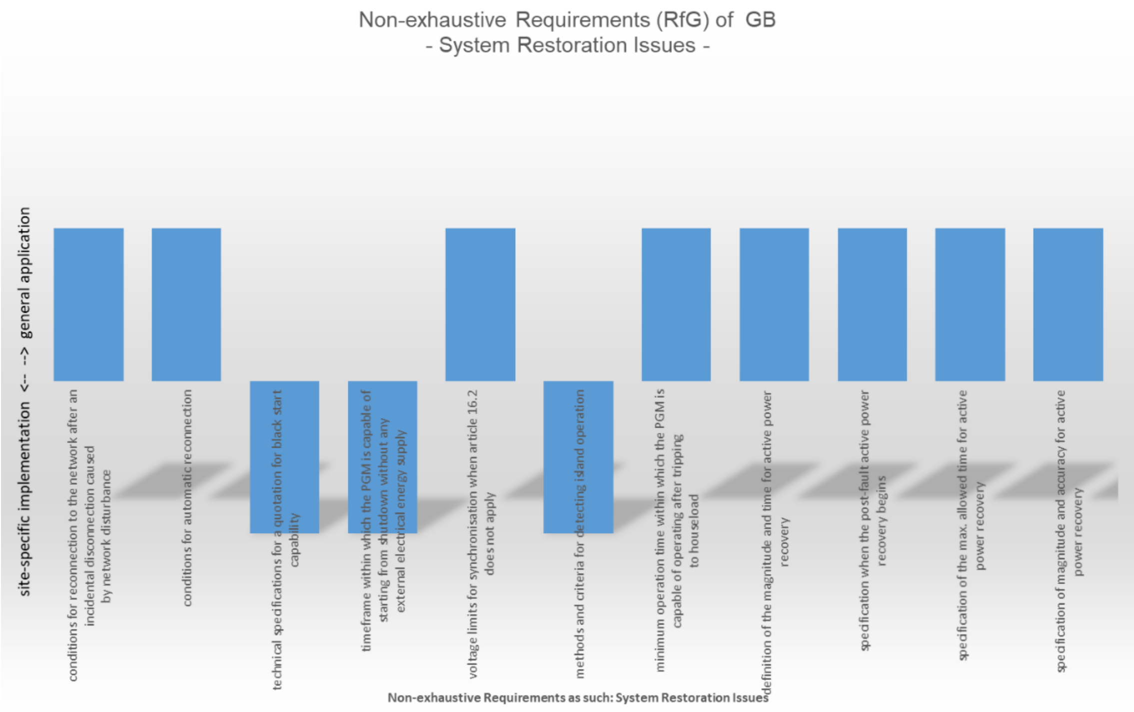


Figure 127: Great Britain (GB)

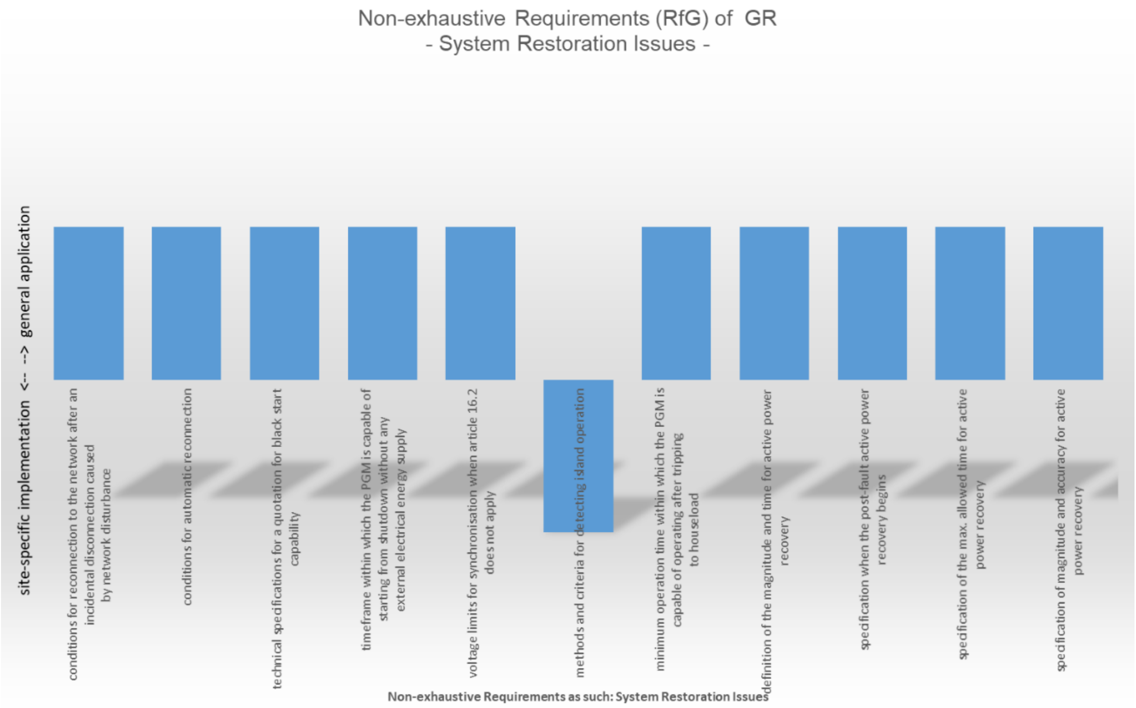


Figure 128: Greece (GR)

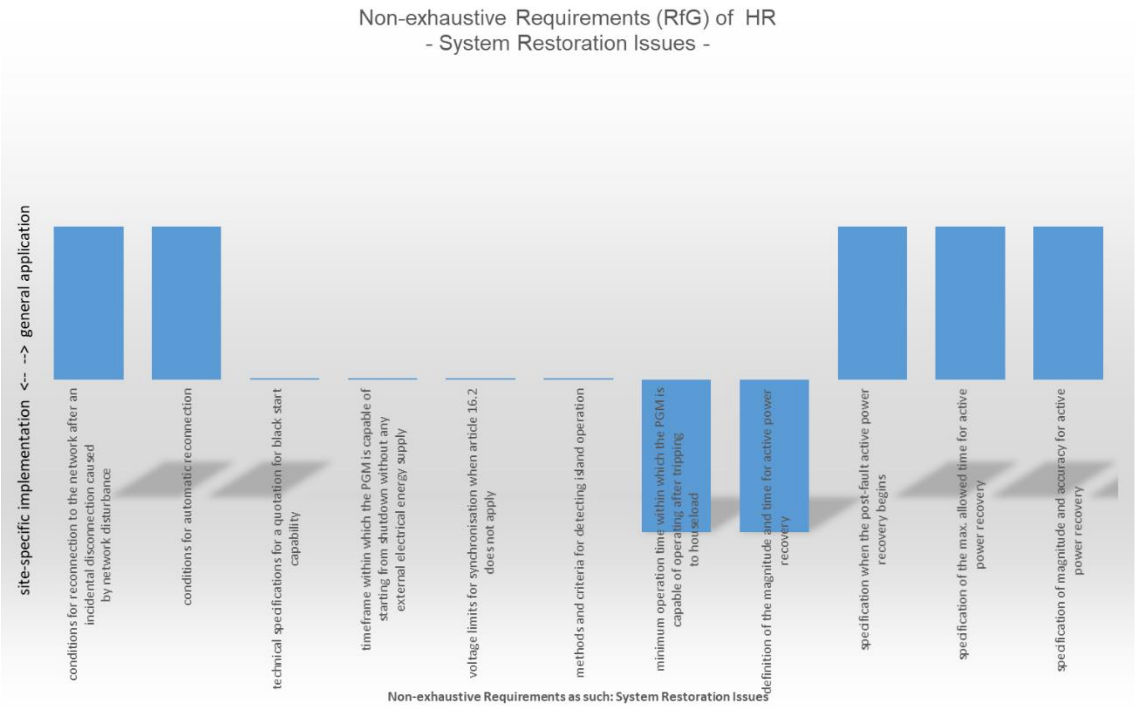


Figure 129: Croatia (HR)

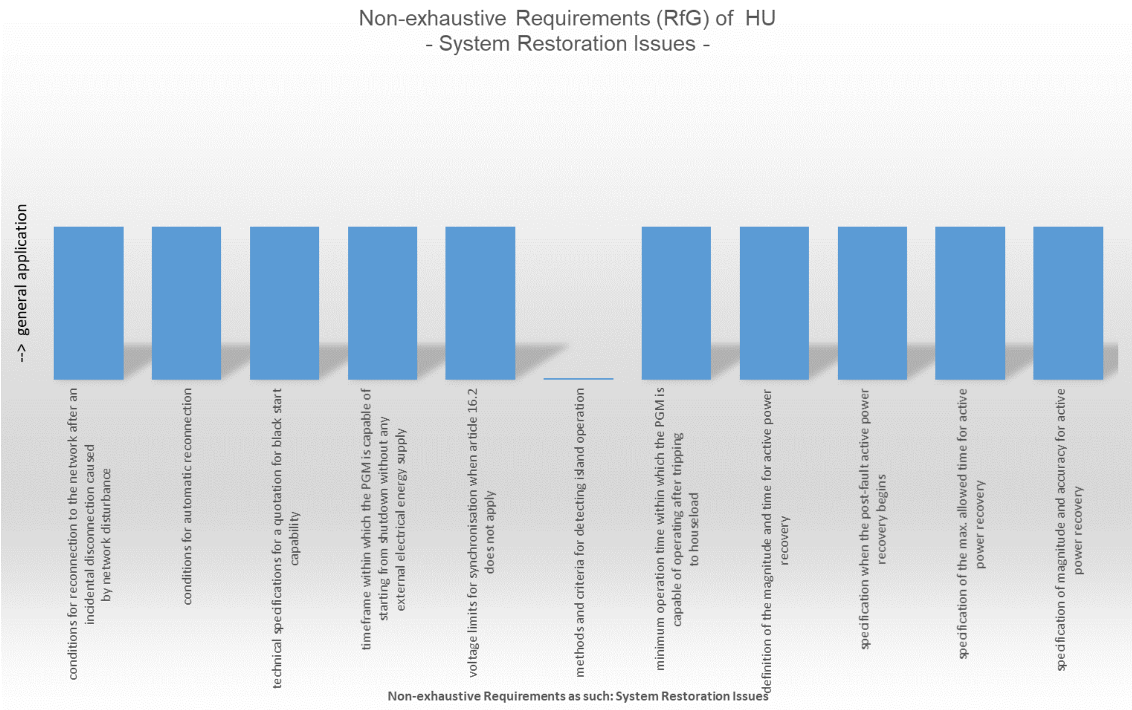


Figure 130: Hungary (HU)

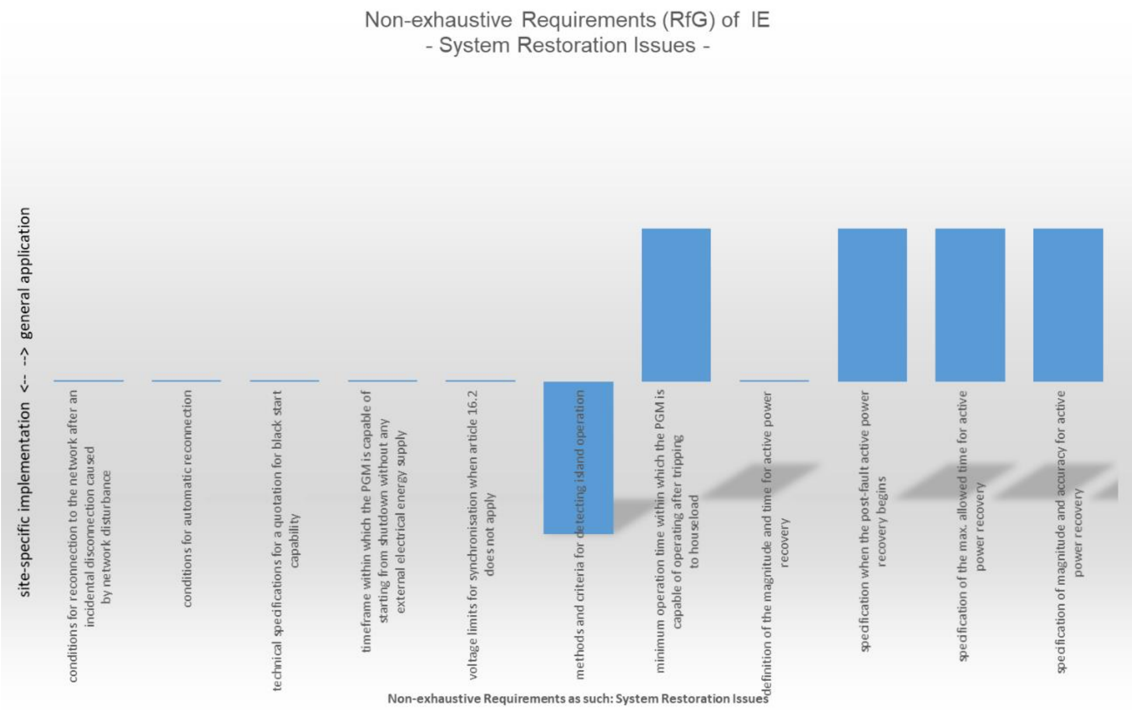


Figure 131: Ireland (IE)

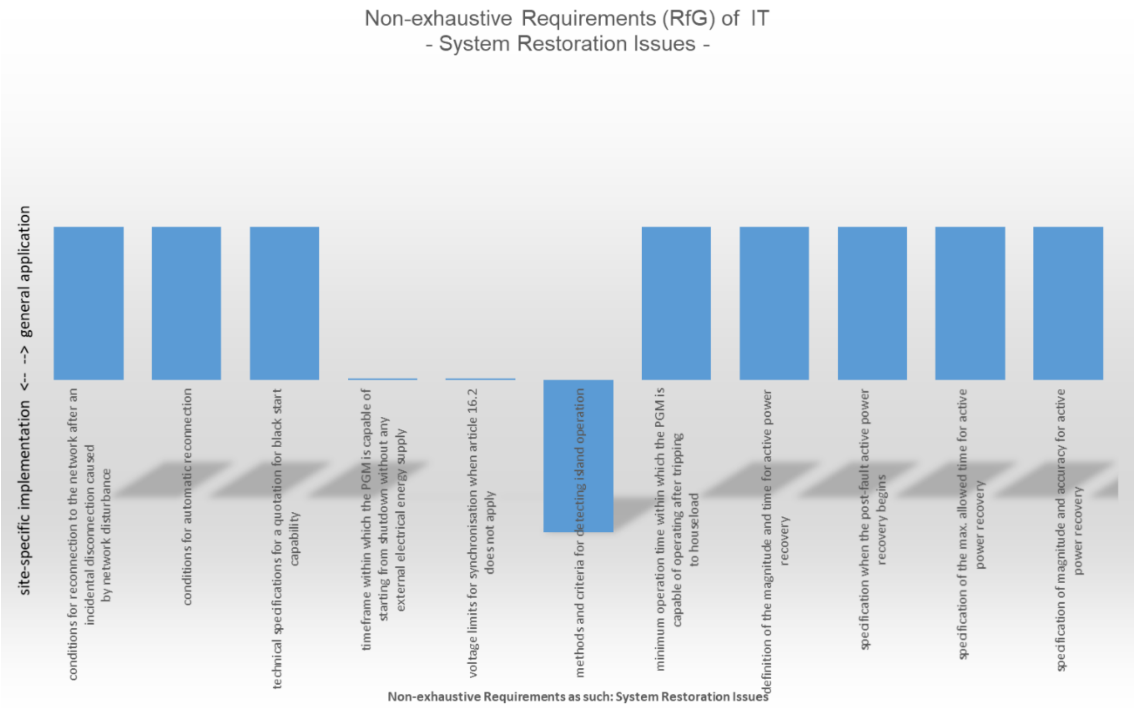


Figure 132: Italy (IT)

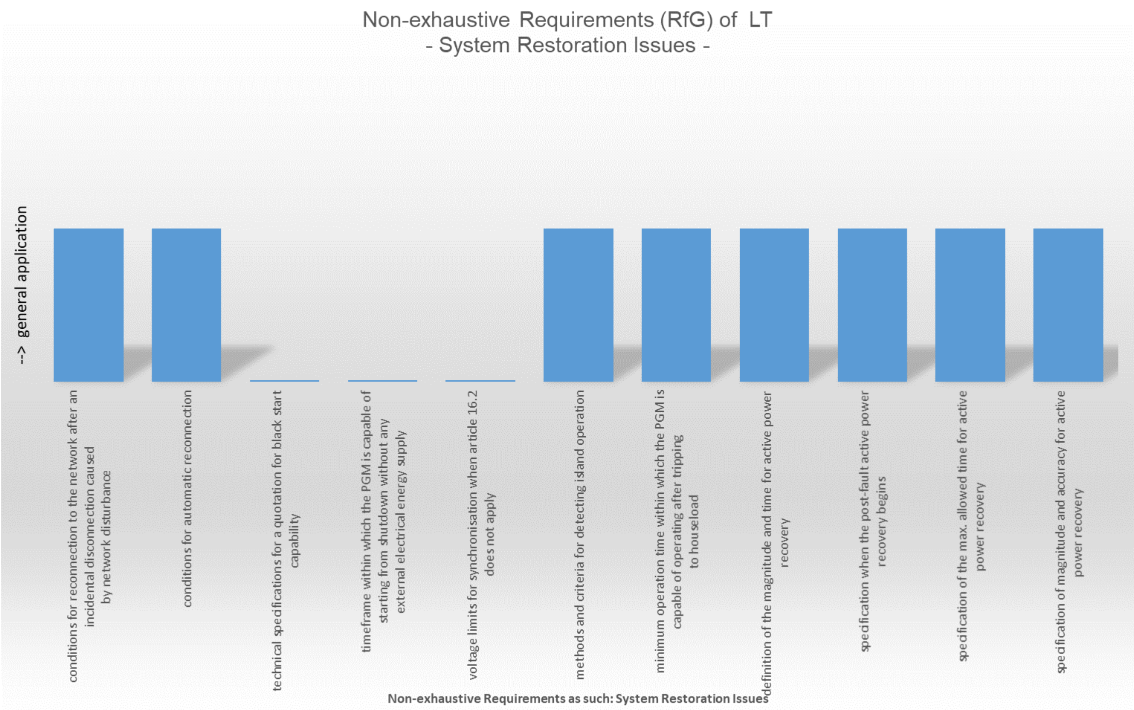


Figure 133: Lithuania (LT)

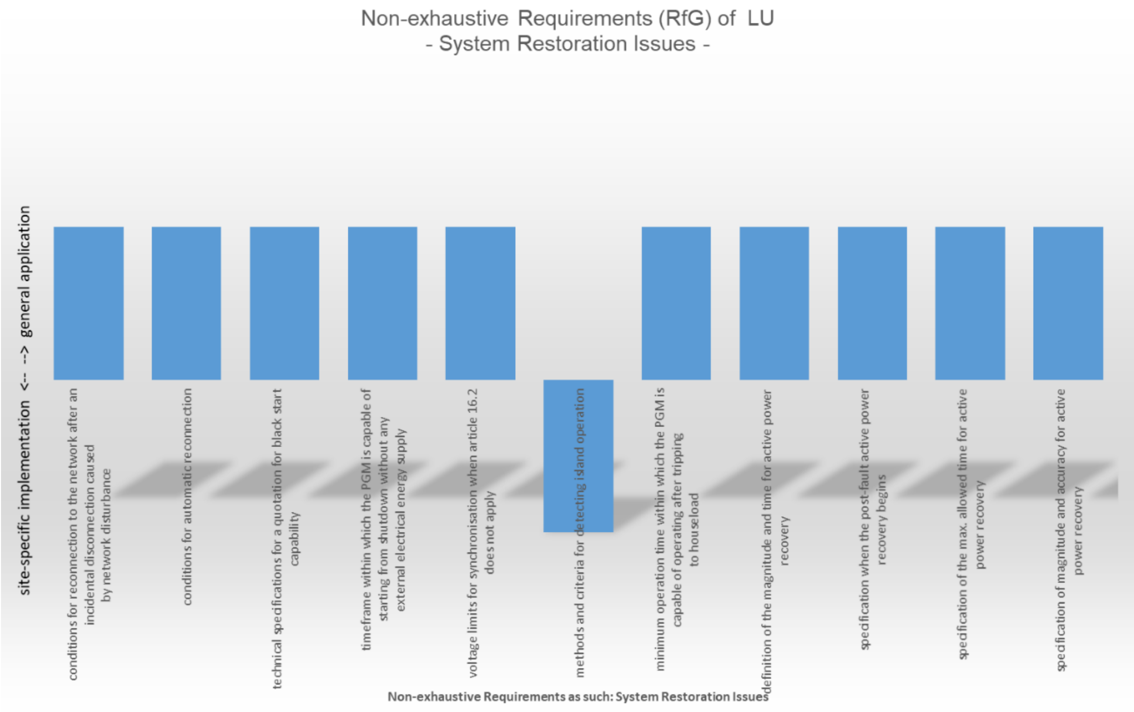


Figure 134: Luxembourg (LU)

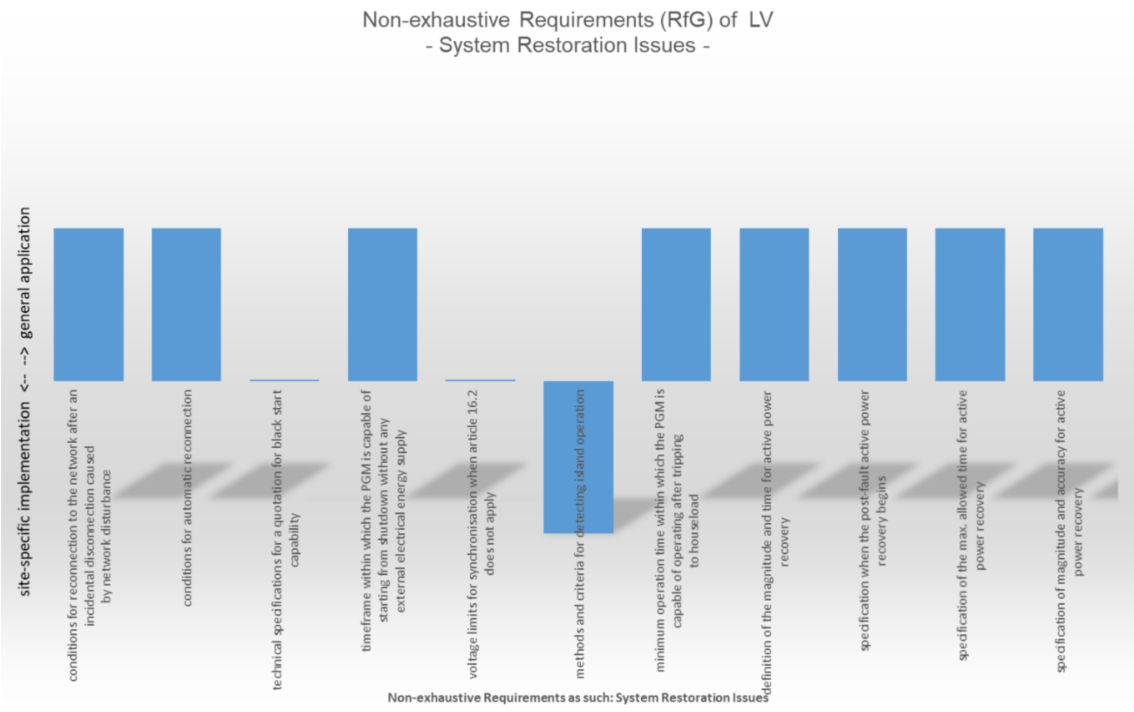


Figure 135: Latvia (LV)

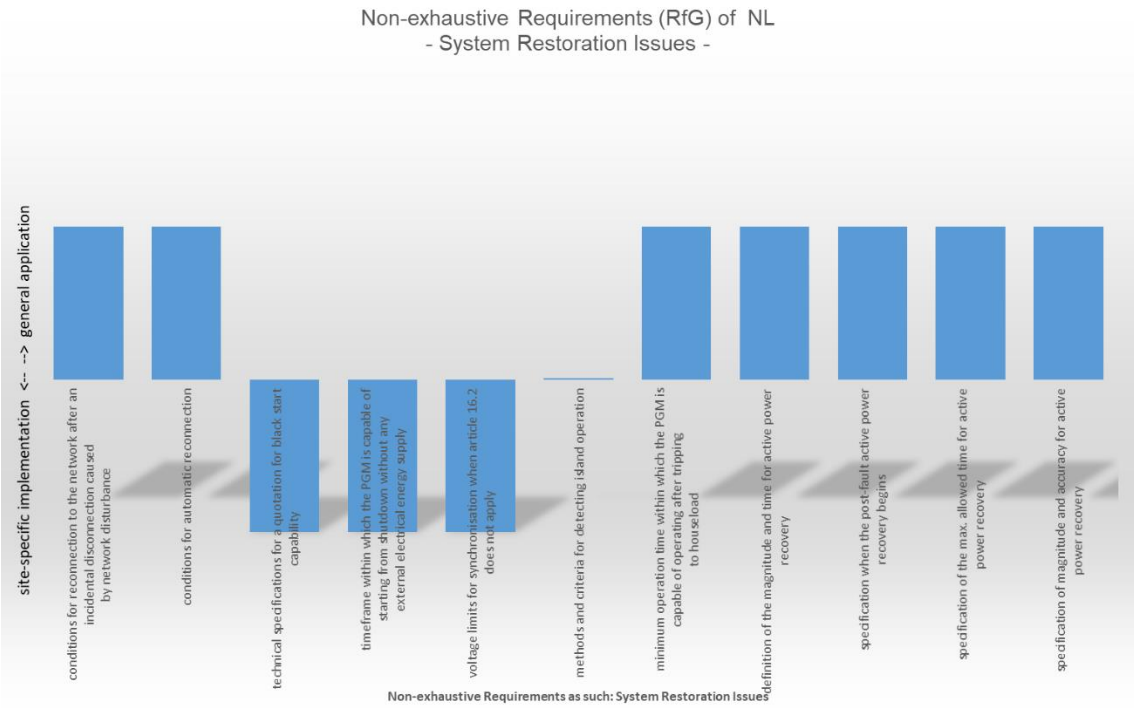


Figure 136: Netherlands (NL)

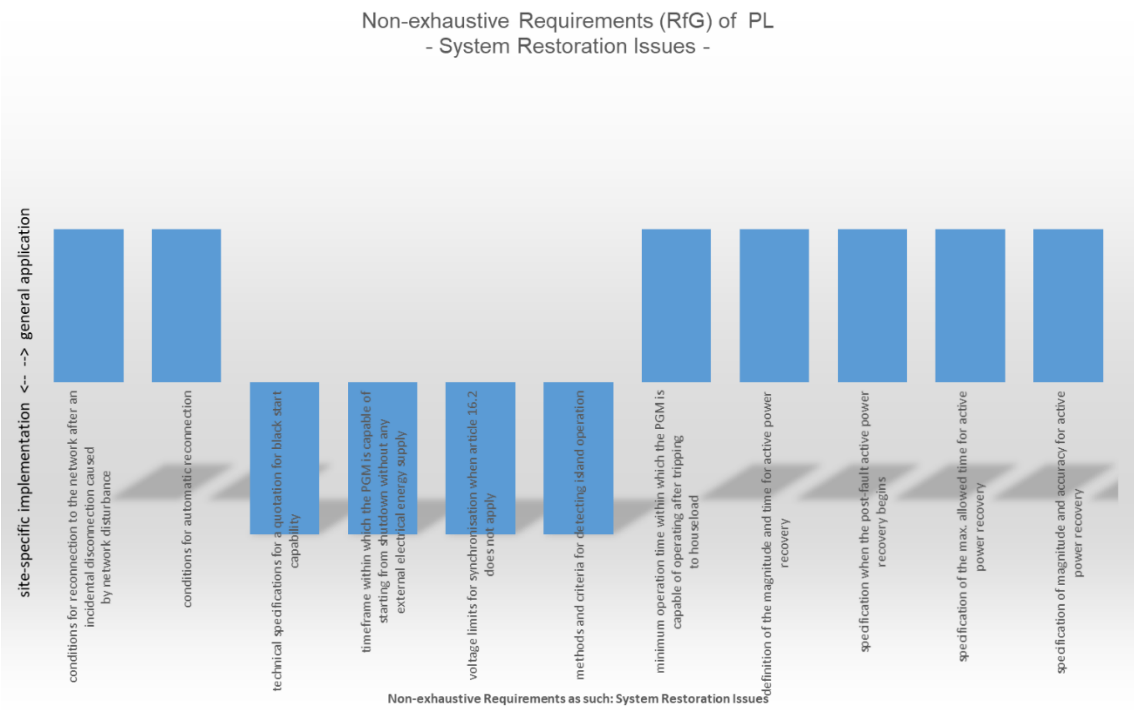


Figure 137: Poland (PL)

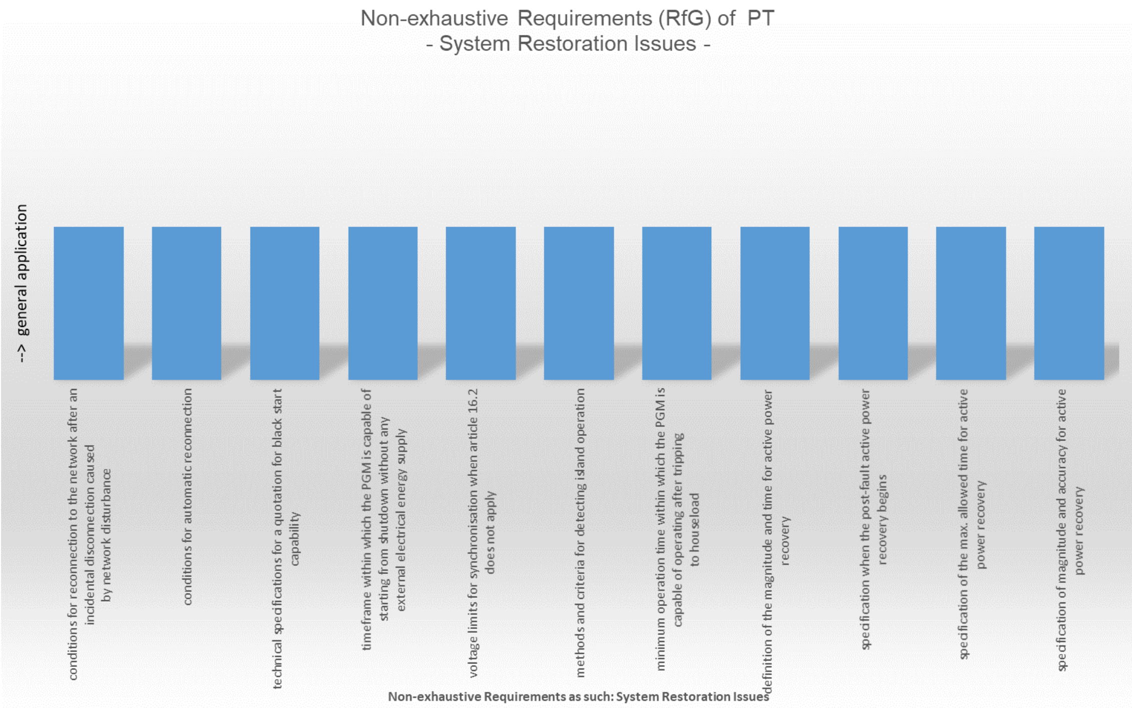


Figure 138: Portugal (PT)

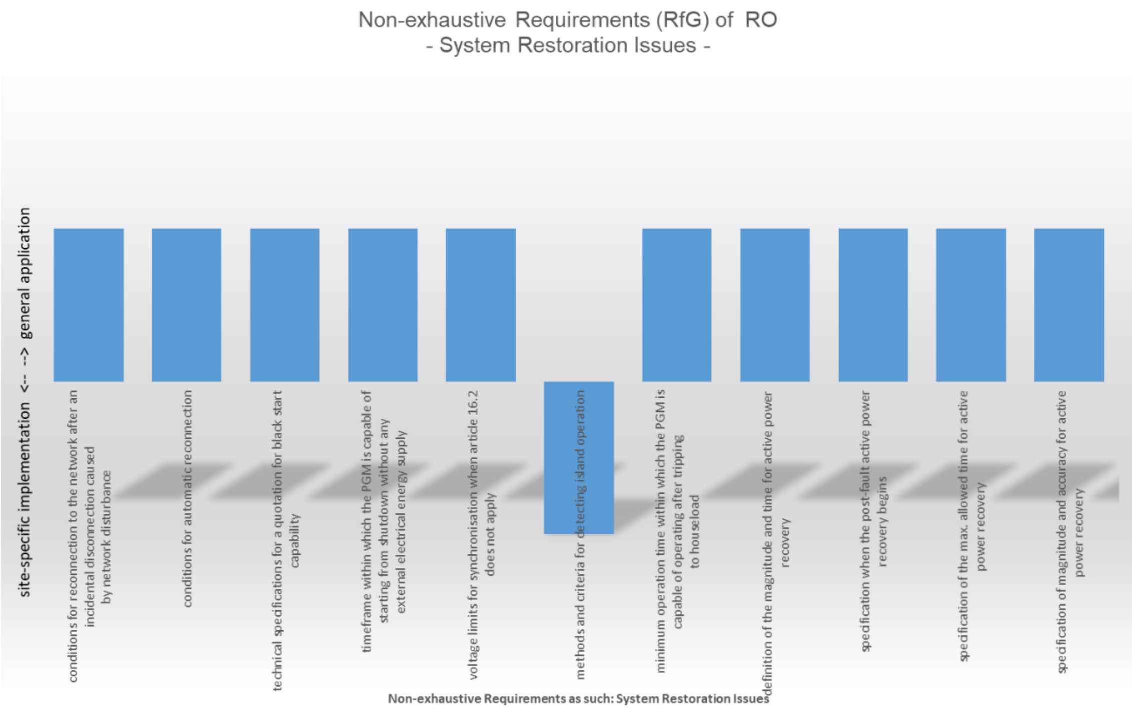


Figure 139: Romania (RO)

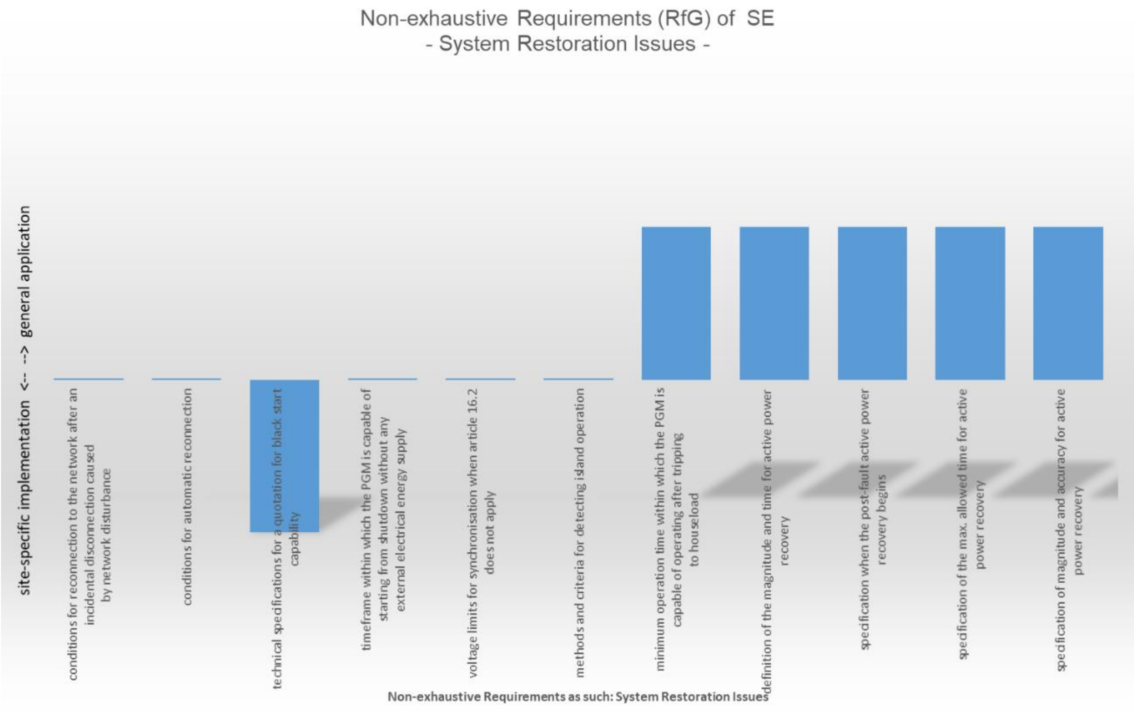


Figure 140: Sweden (SE)

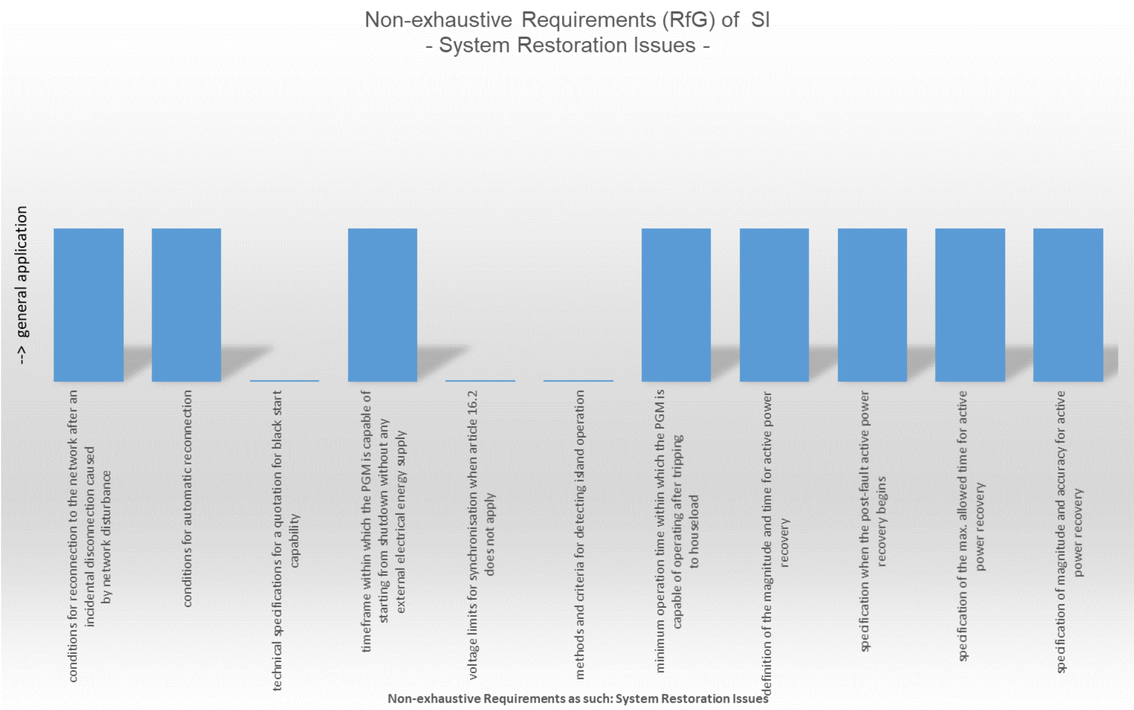


Figure 141: Slovenia (SI)

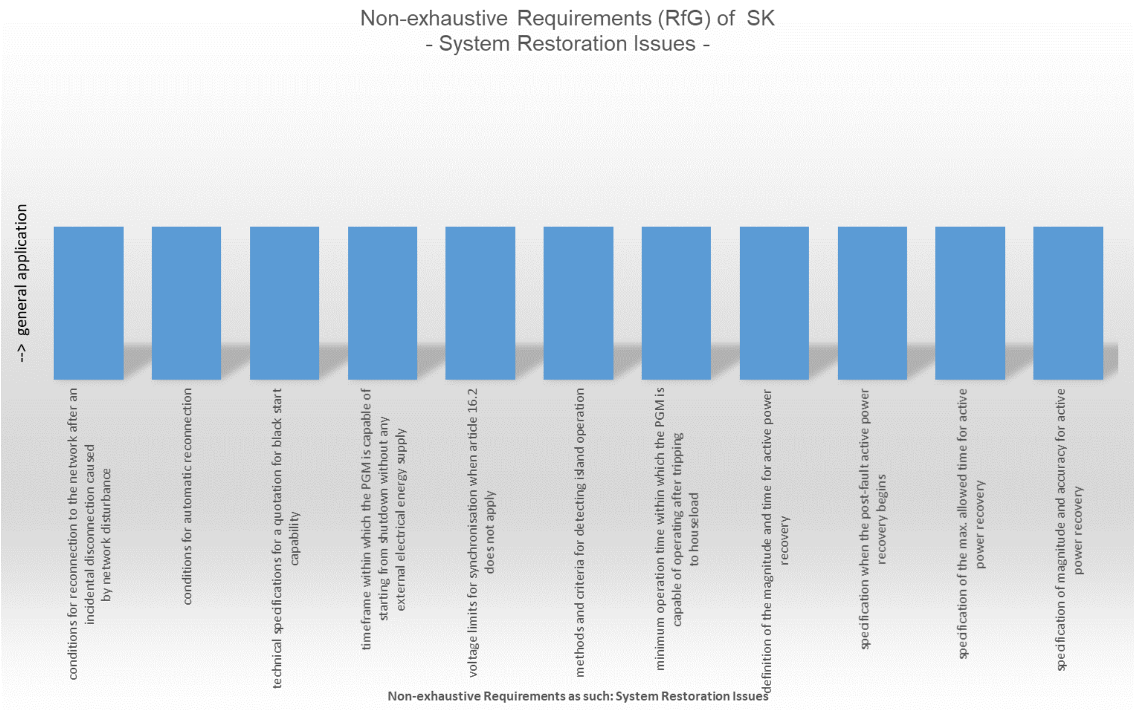


Figure 142: Slovakia (SK)

3.9 Instrumentation, Simulation Models and Protection Issues of NC RfG

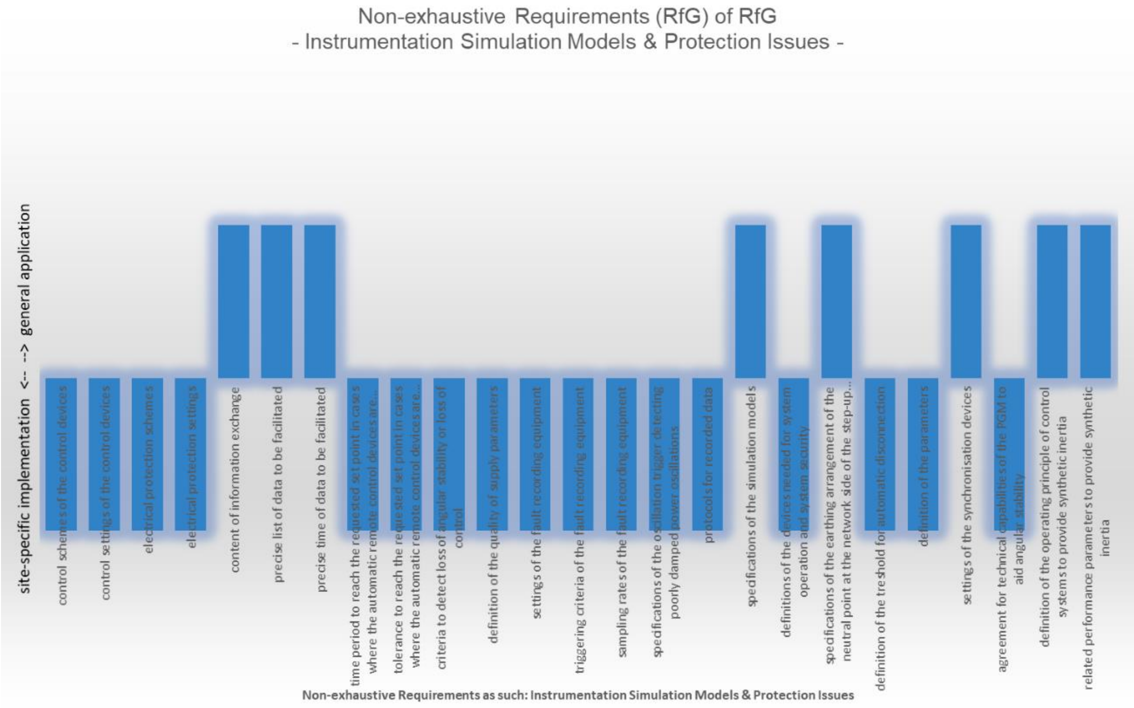


Figure 143: Reference values of non-exhaustive RfG – instrumentation, simulation ,models and protection issues

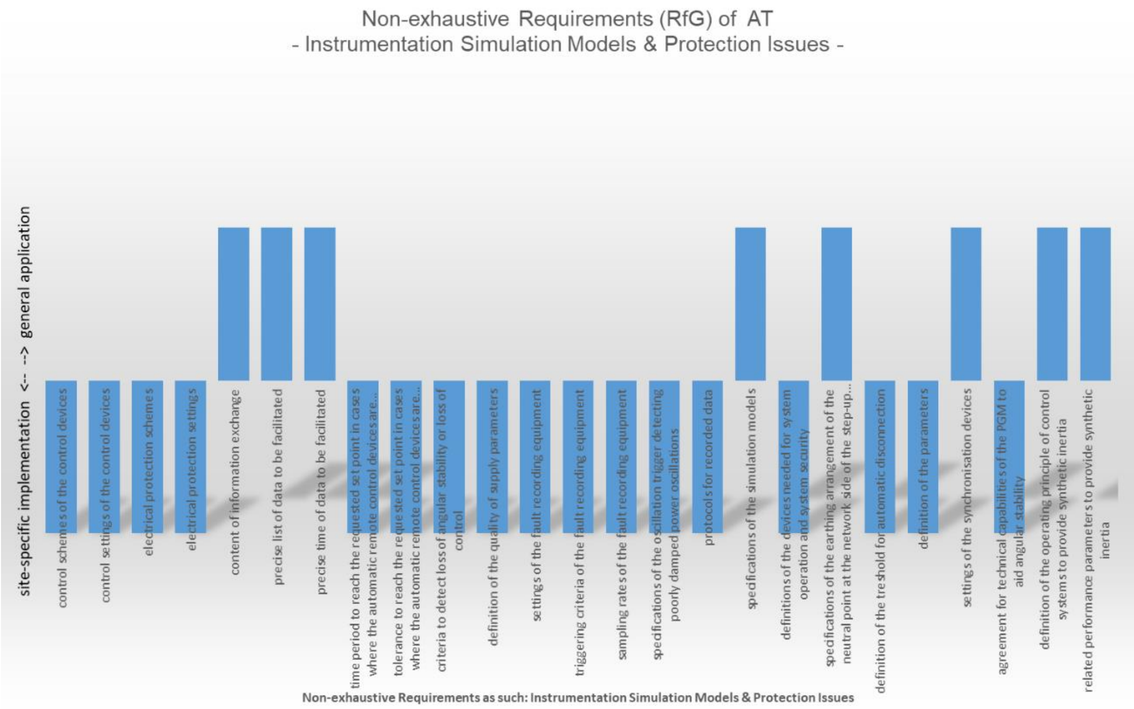


Figure 144: Austria (AT)

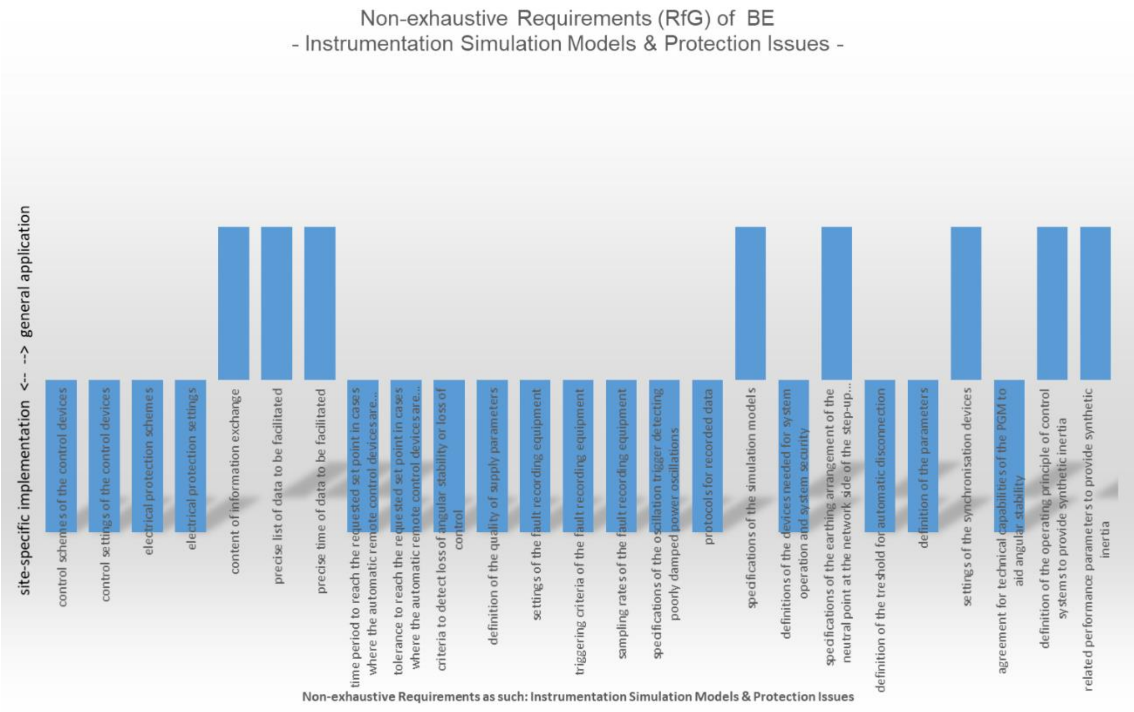


Figure 145: Belgium (BE)

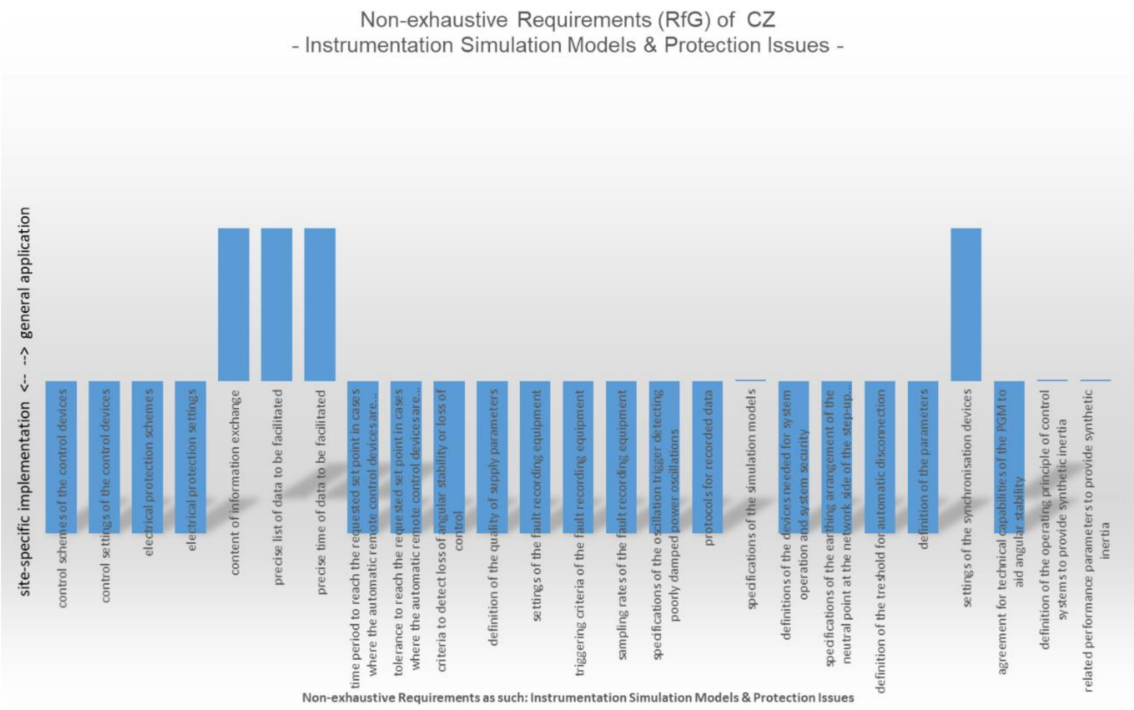


Figure 146: Czech Republic (CZ)

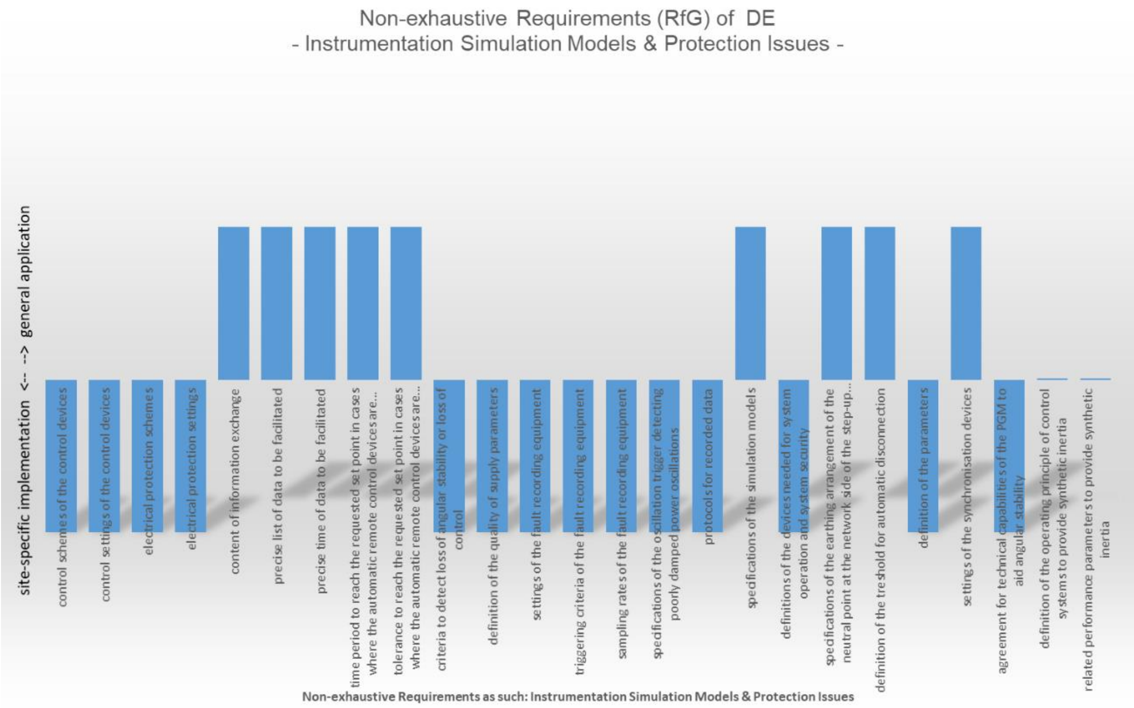


Figure 147: Germany (DE)

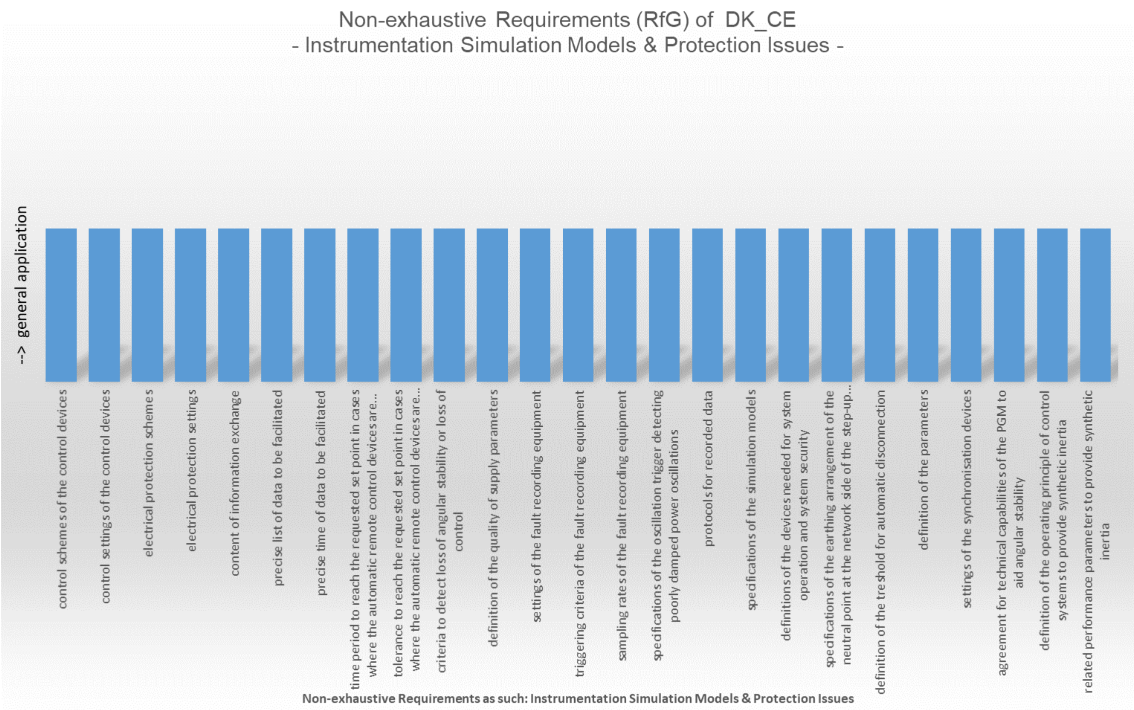


Figure 148: Denmark 1 (DK-CE)

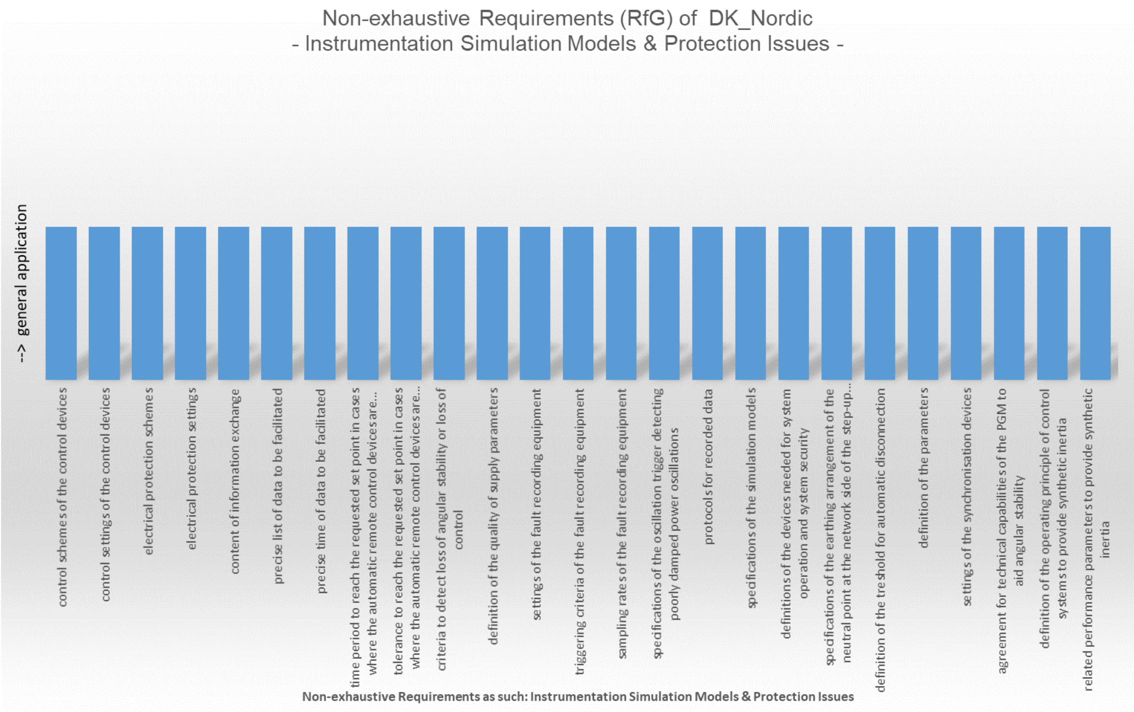


Figure 149: Denmark 2 (DK-Nordic)

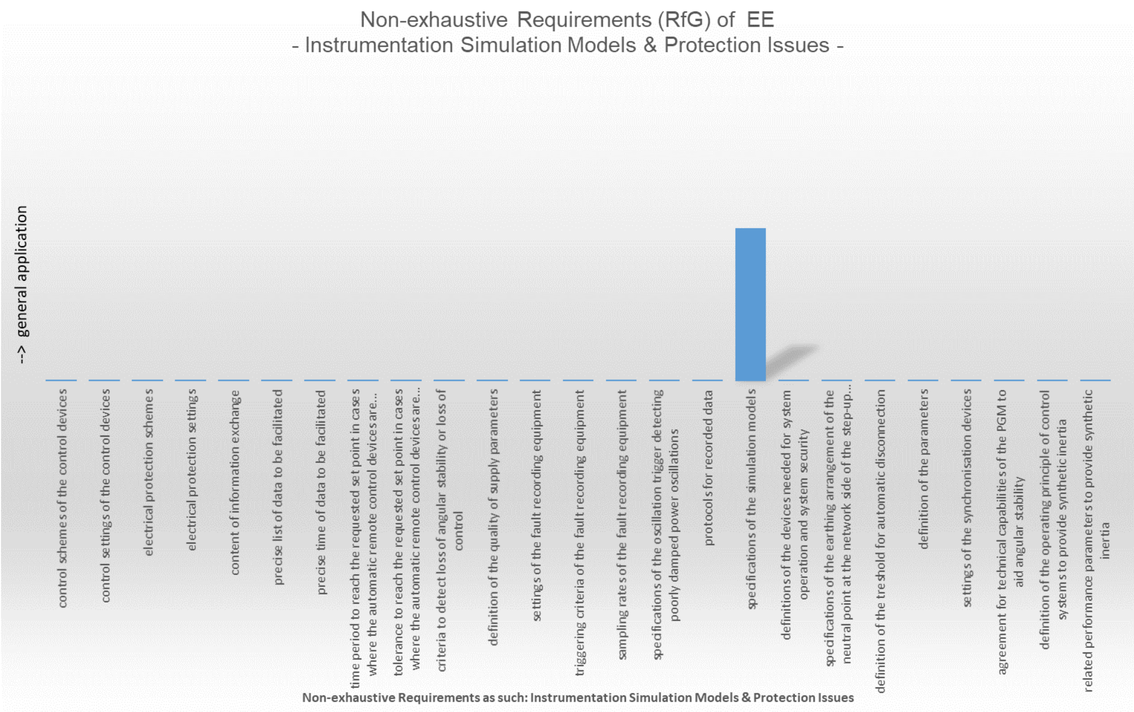


Figure 150: Estonia (EE)

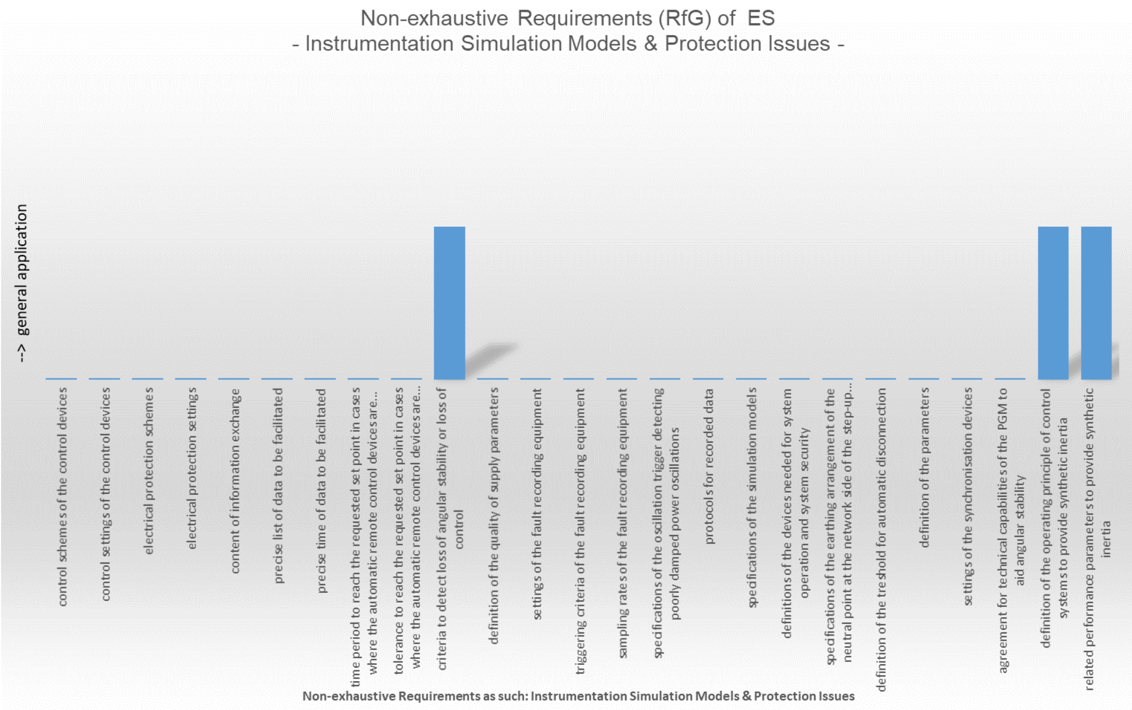


Figure 151: Spain (ES)

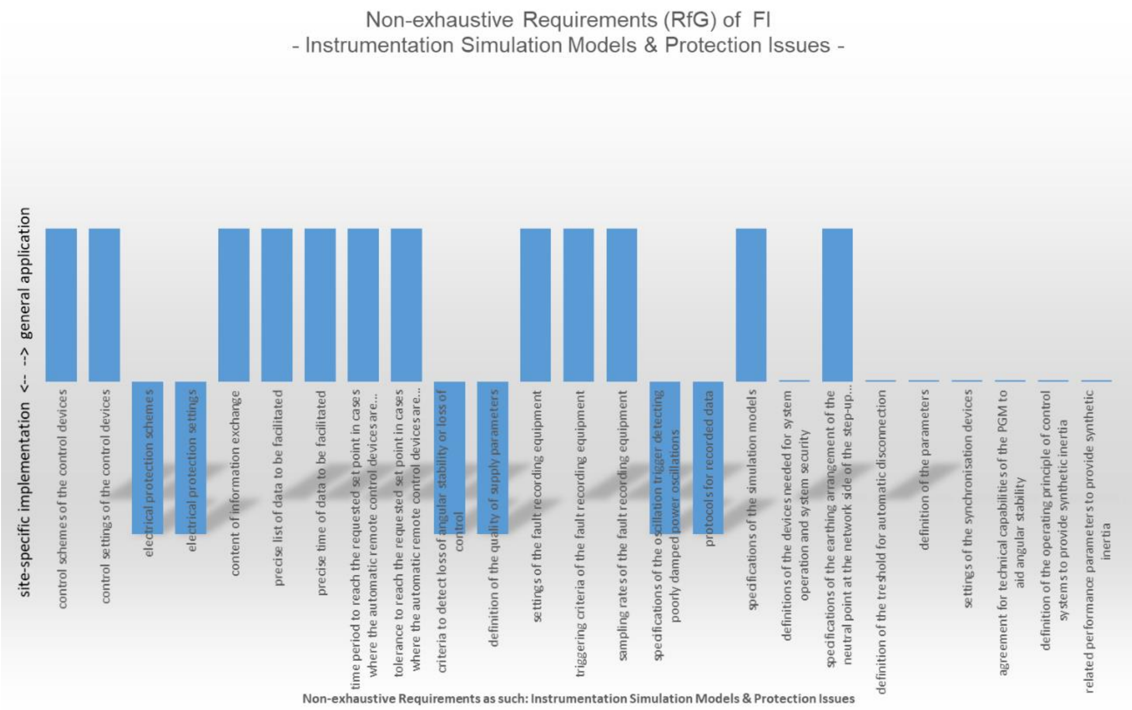


Figure 152: Finland (FI)

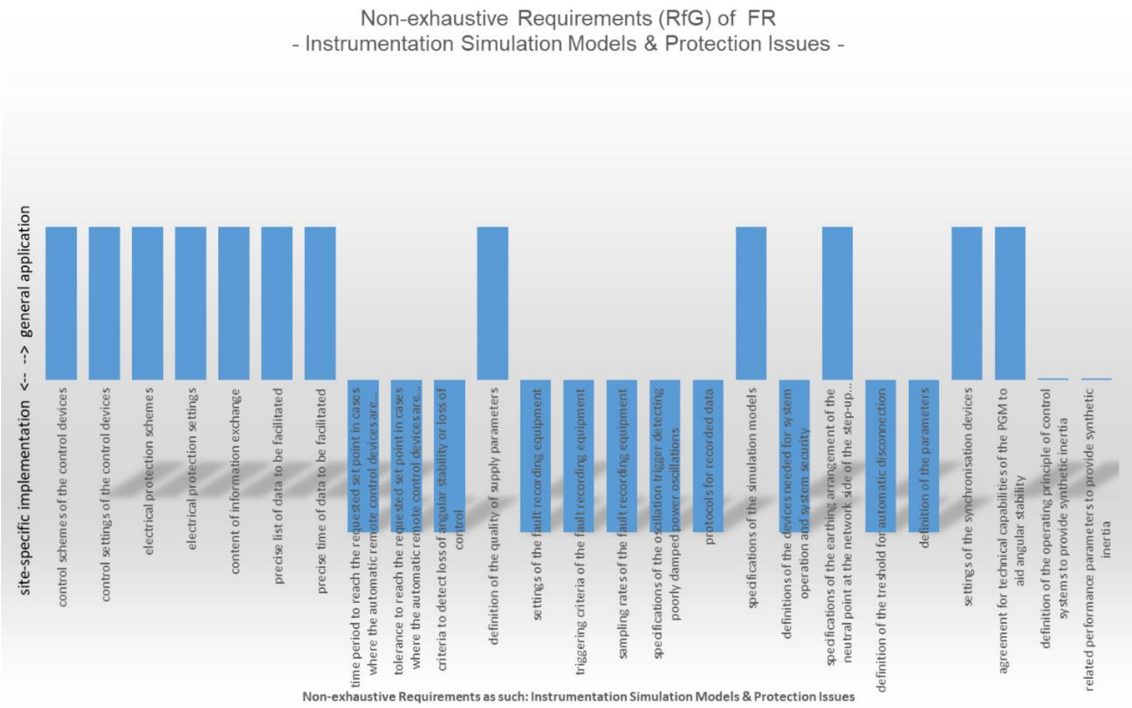


Figure 153: France (FR)

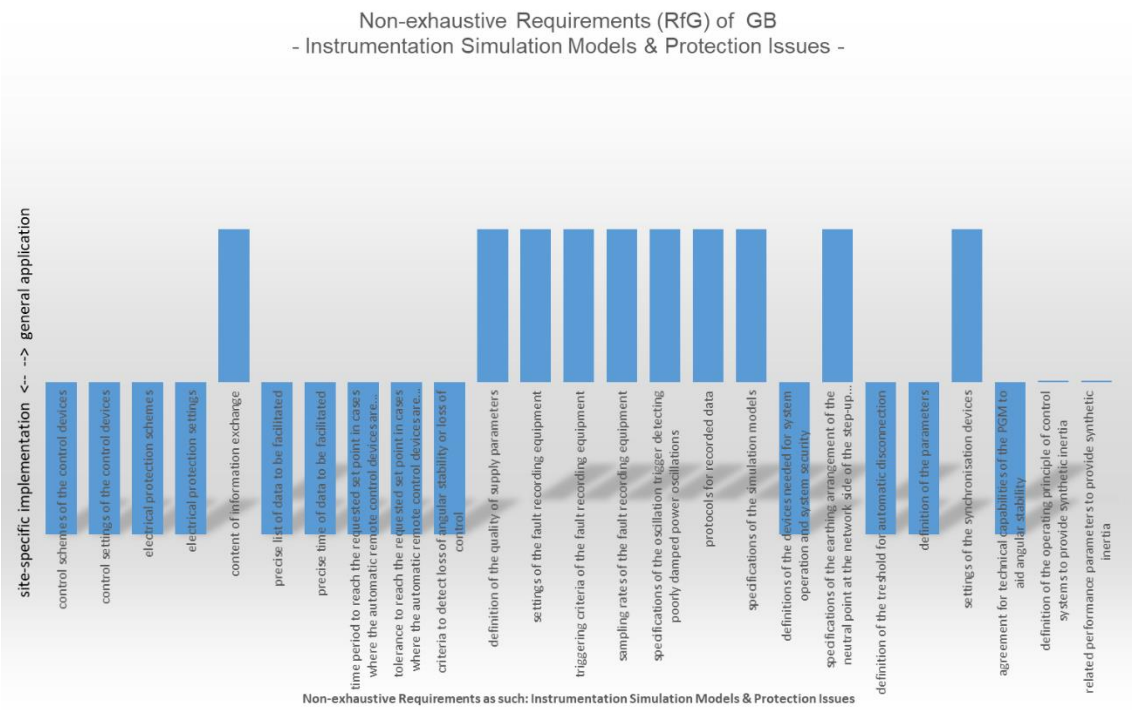


Figure 154: Great Britain (GB)

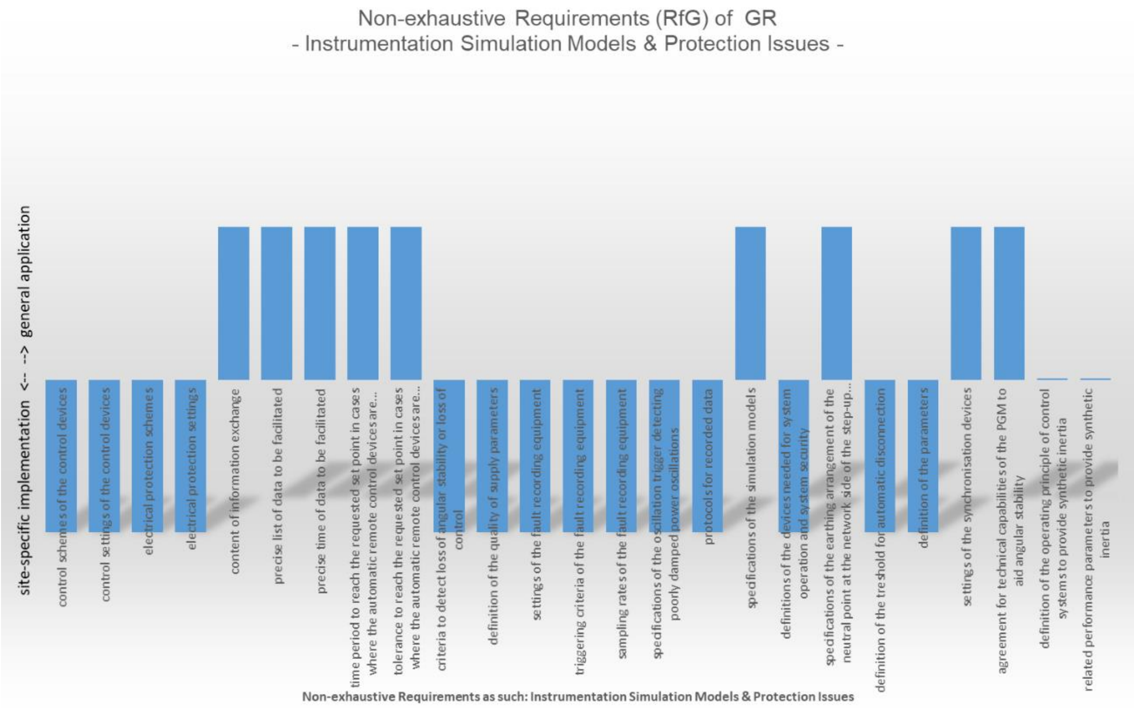


Figure 155: Greece (GR)

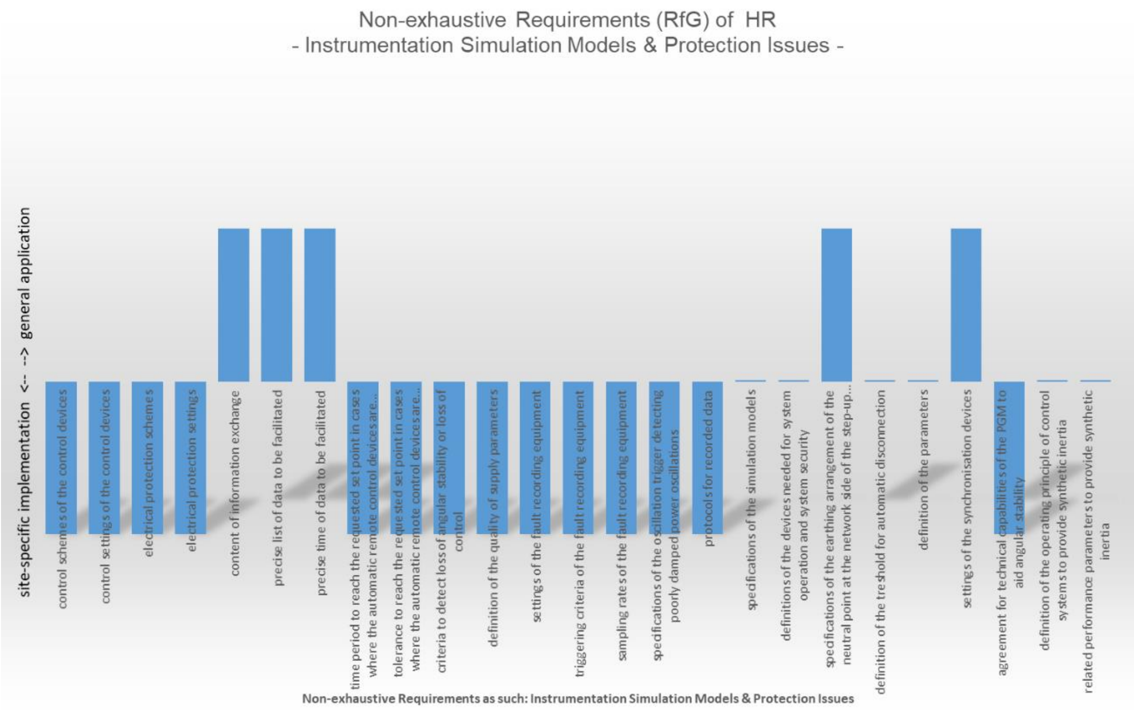


Figure 156: Croatia (HR)

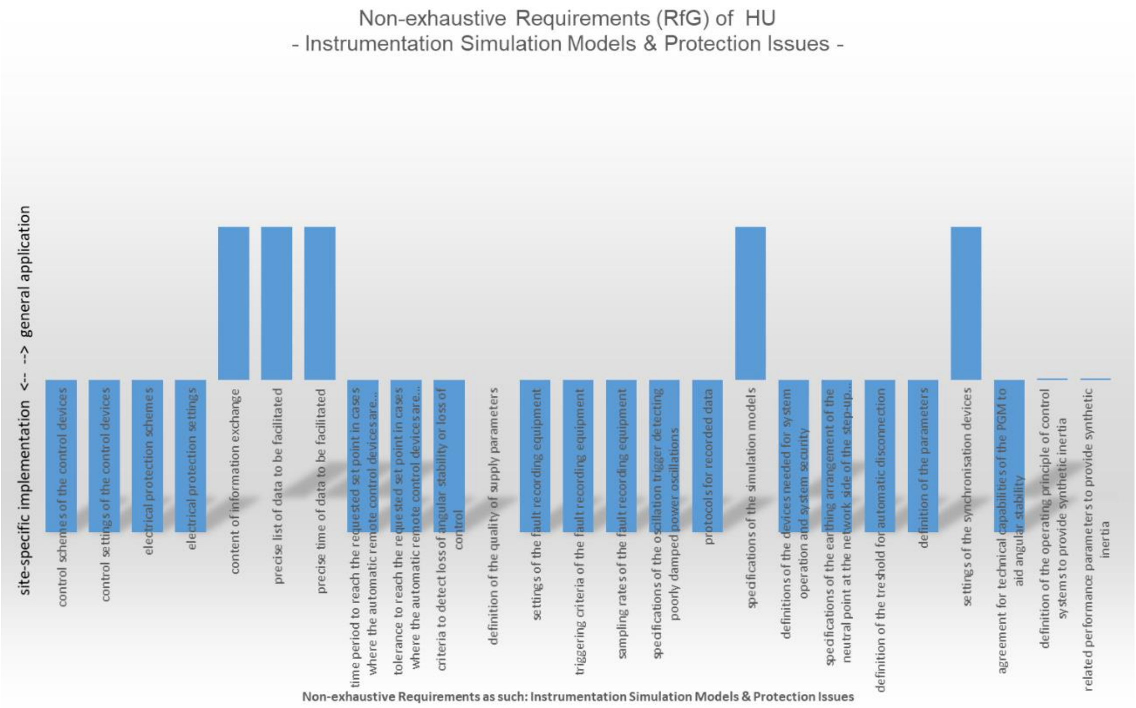


Figure 157: Hungary (HU)

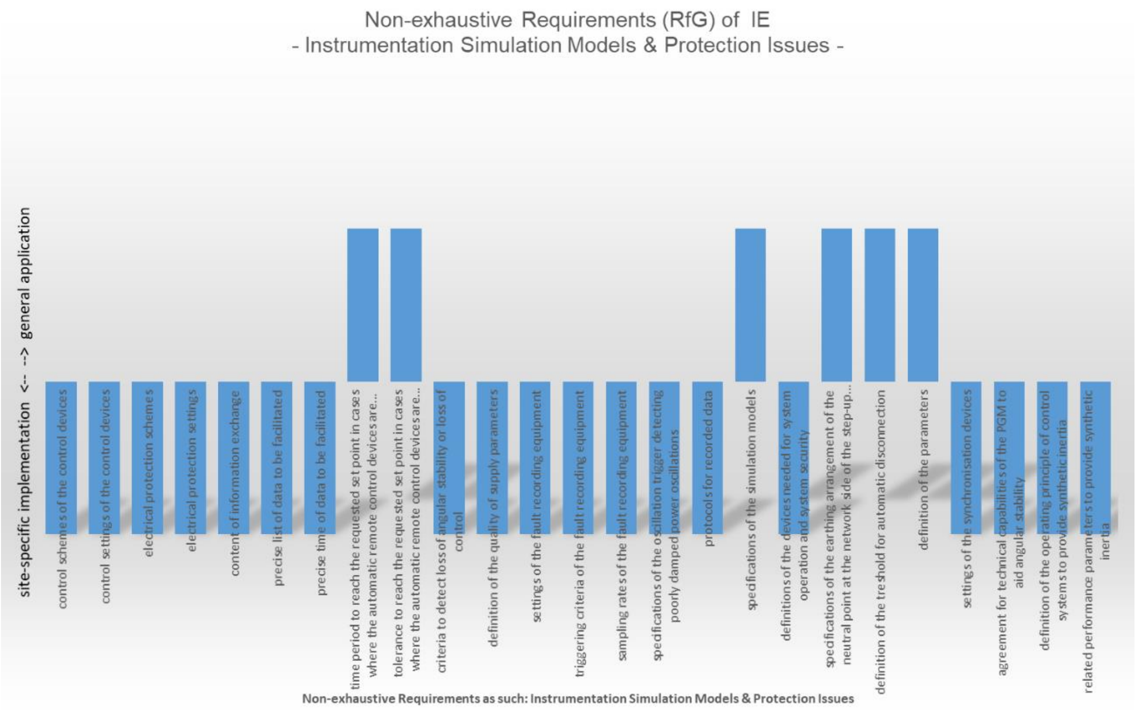


Figure 158: Ireland (IE)

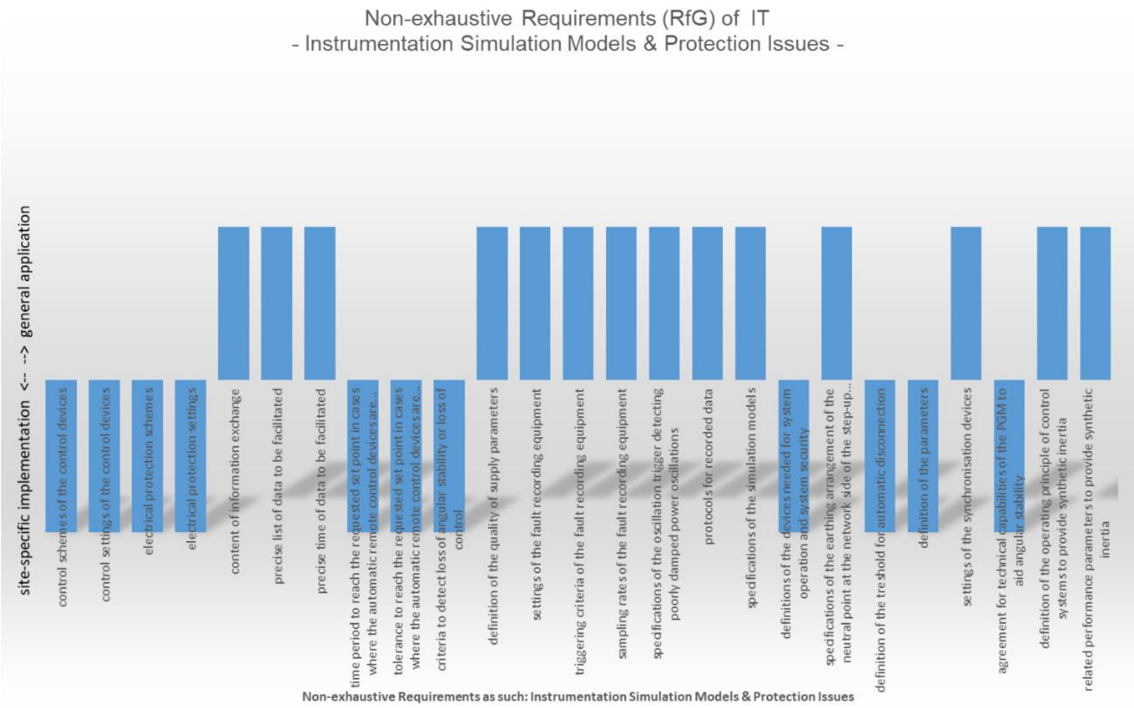


Figure 159: Italy (IT)

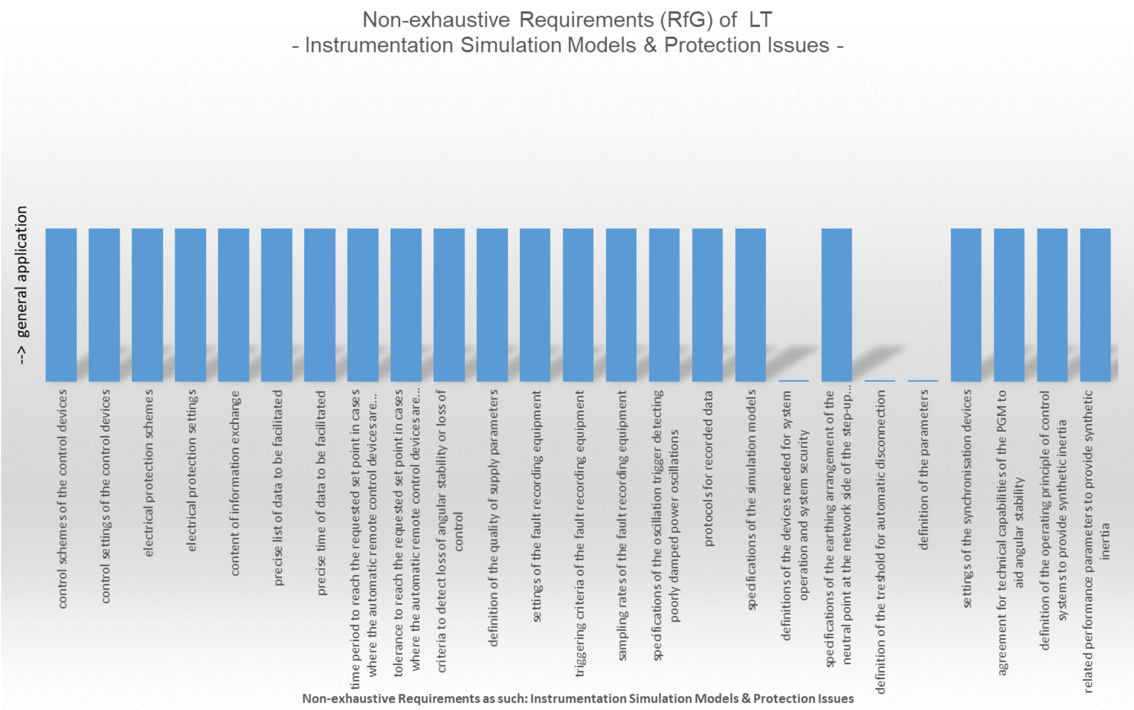


Figure 160: Lithuania (LT)

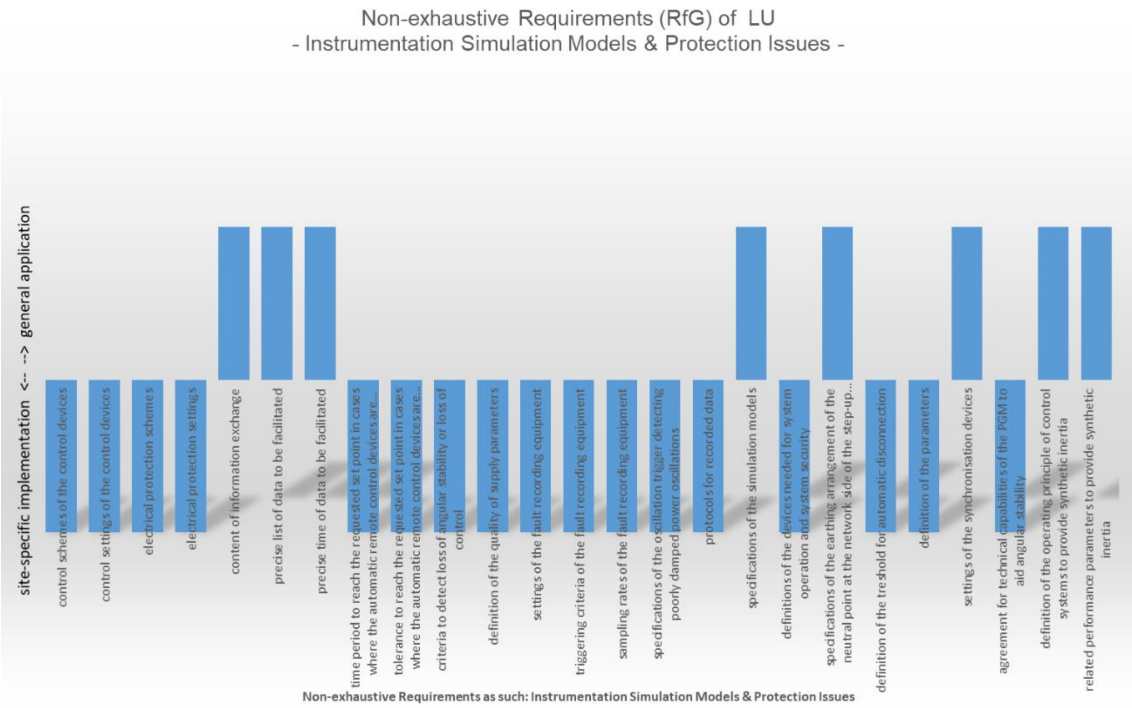


Figure 161: Luxembourg (LU)

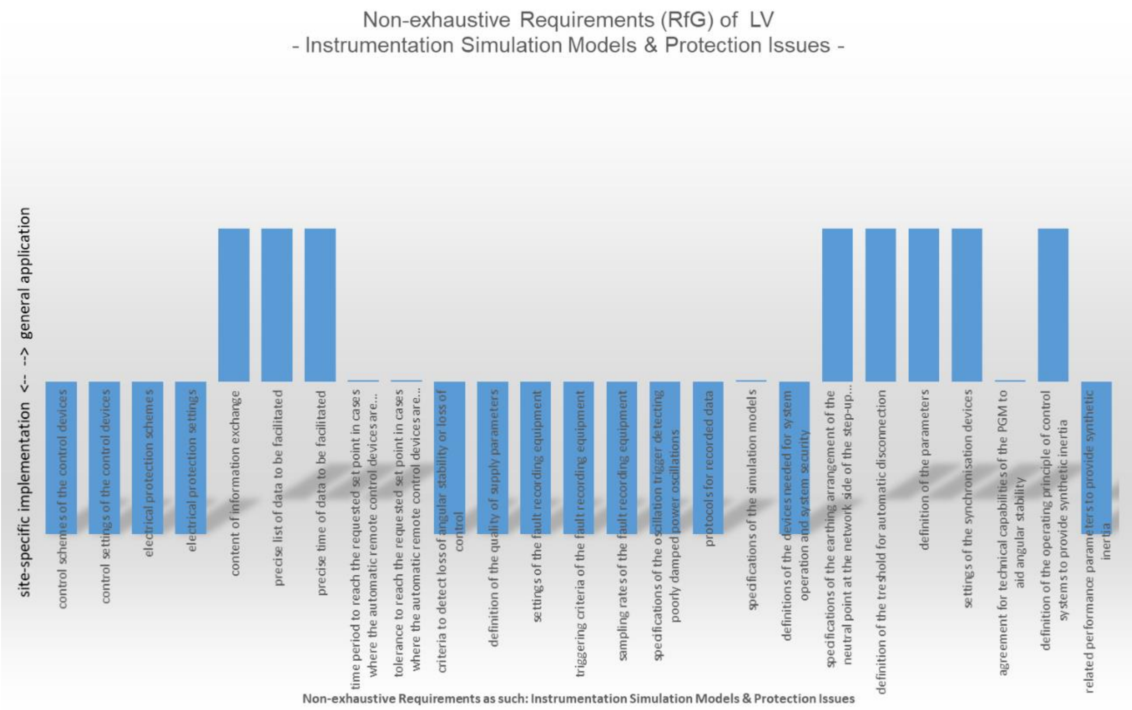


Figure 162: Latvia (LV)

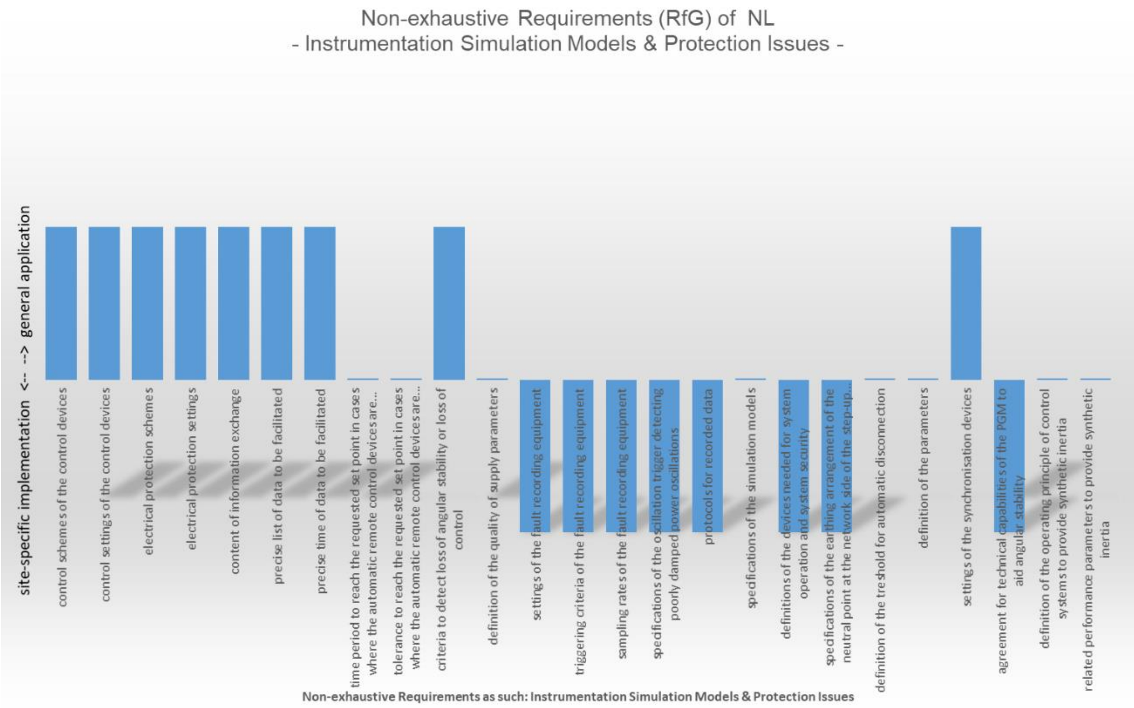


Figure 163: Netherlands (NL)

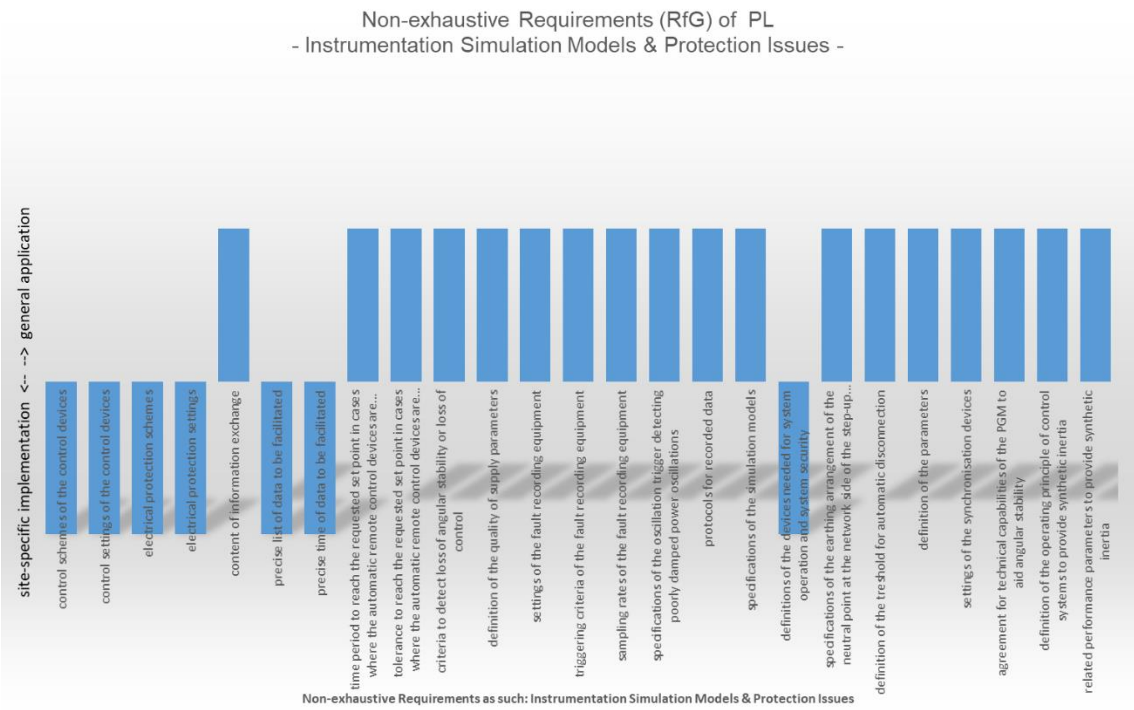


Figure 164: Poland (PL)

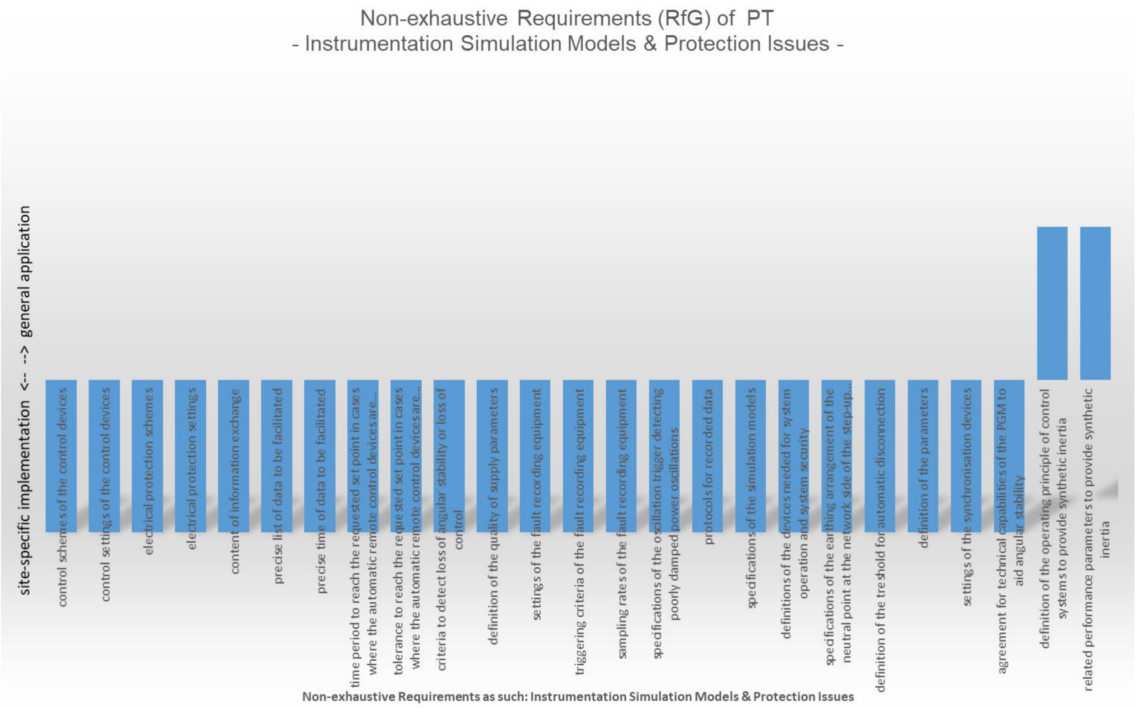


Figure 165: Portugal (PT)

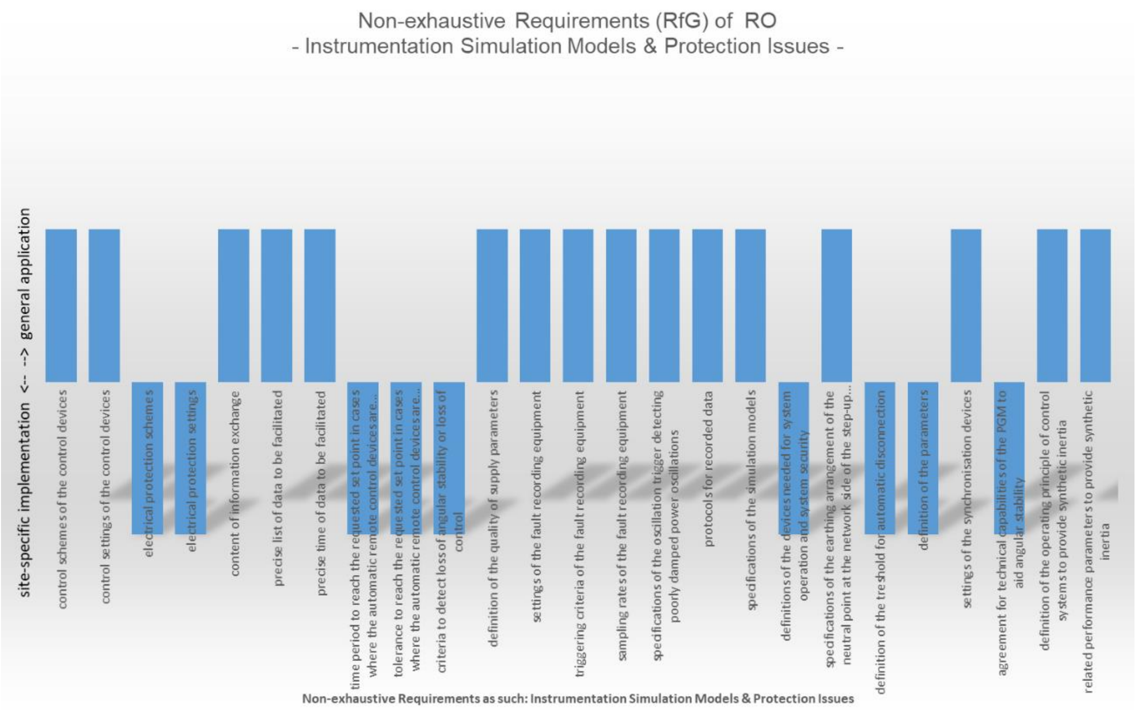


Figure 166: Romania (RO)

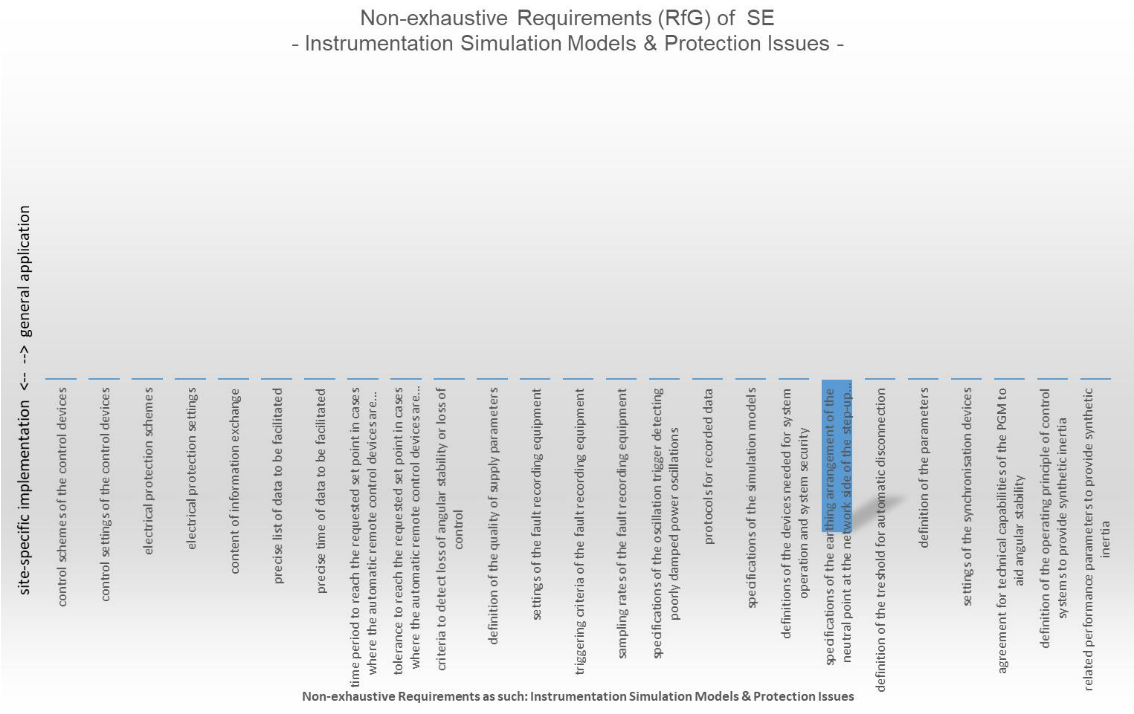


Figure 167: Sweden (SE)

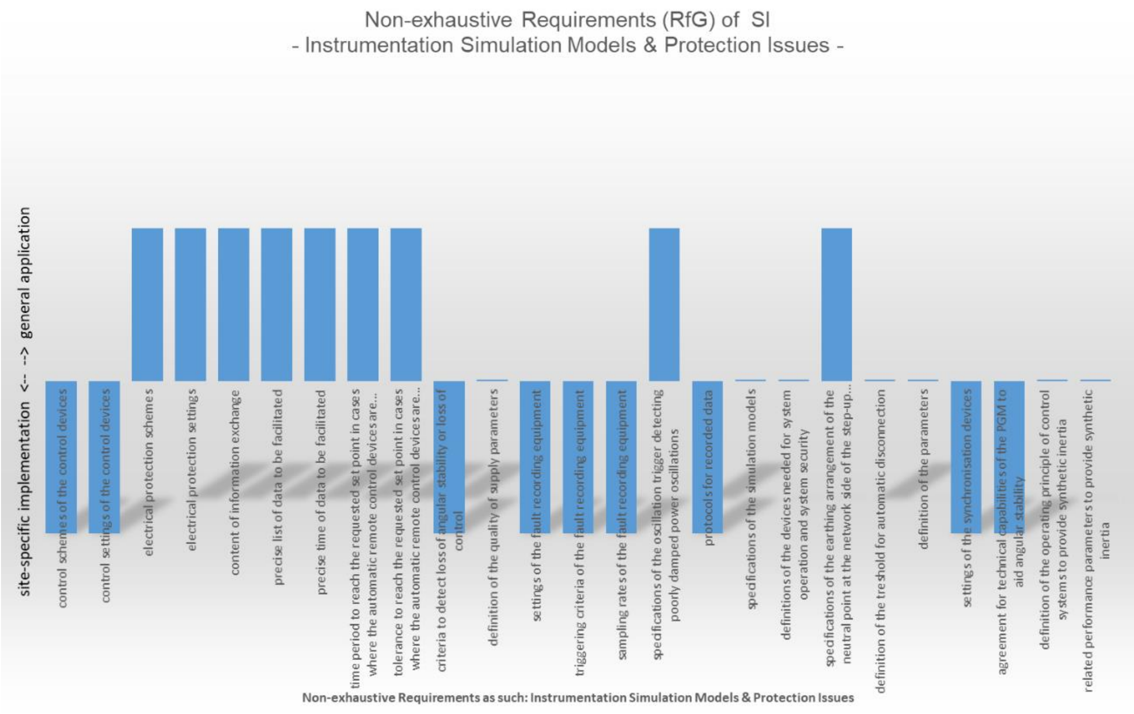


Figure 168: Slovenia (SI)

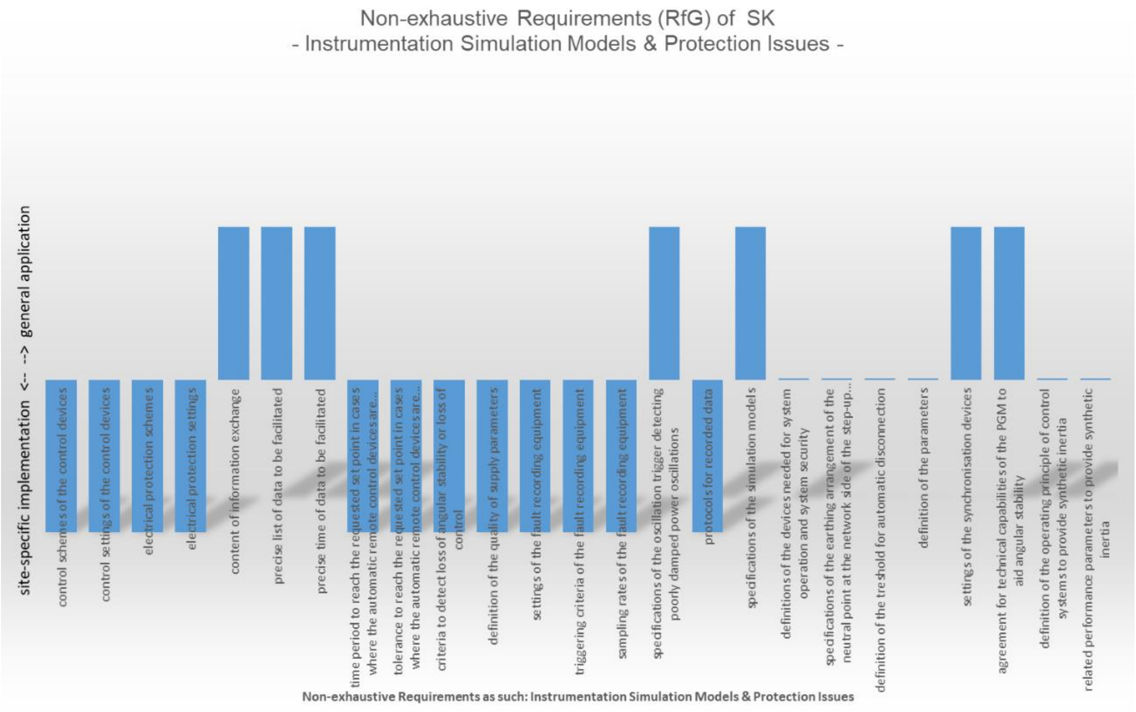


Figure 169: Slovakia (SK)

3.10 Specific statistical analysis of certain non-exhaustive requirements of NC RfG

The following subsections present statistical analysis of selected non-exhaustive requirements These results represent the current national implementation process of EU Member Countries.

3.10.1 Frequency ranges (article 13(1)(a)(ii))

From the NC RfG: *(ii) the relevant system operator, in coordination with the relevant TSO, and the power-generating facility owner may agree on wider frequency ranges, longer minimum times for operation or specific requirements for combined frequency and voltage deviations to ensure the best use of the technical capabilities of a power generating module, if it is required to preserve or to restore system security;*

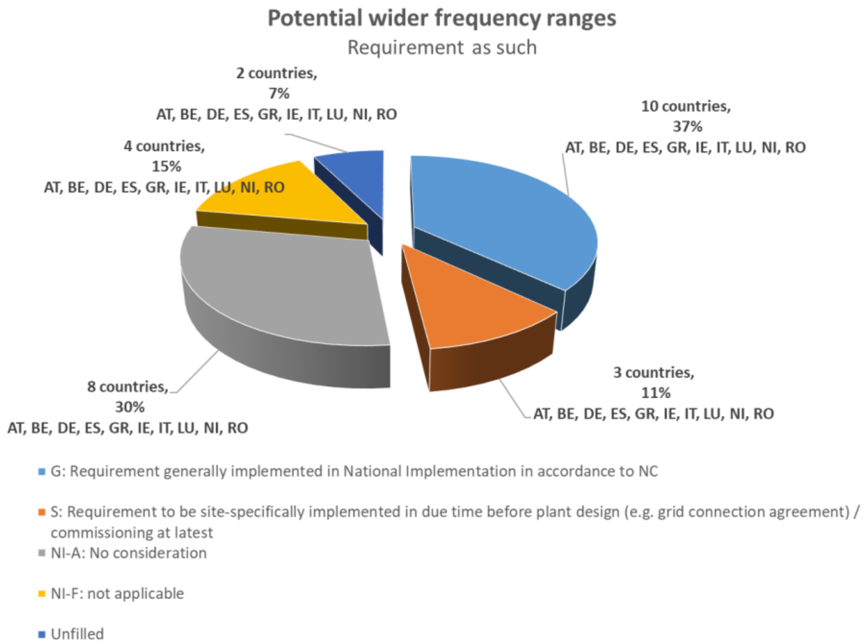


Figure 170: Potential wider frequency ranges

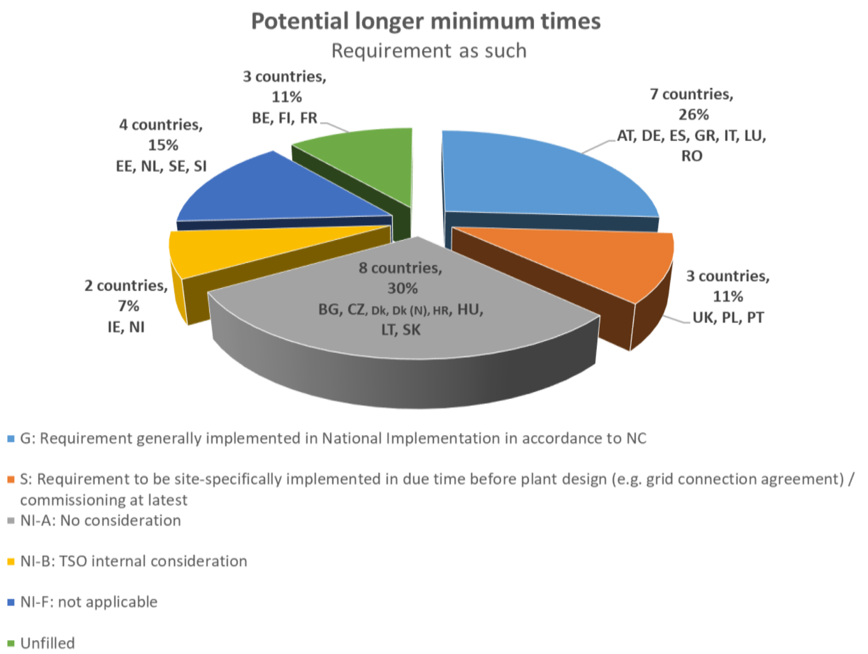


Figure 171: Potential longer minimum times

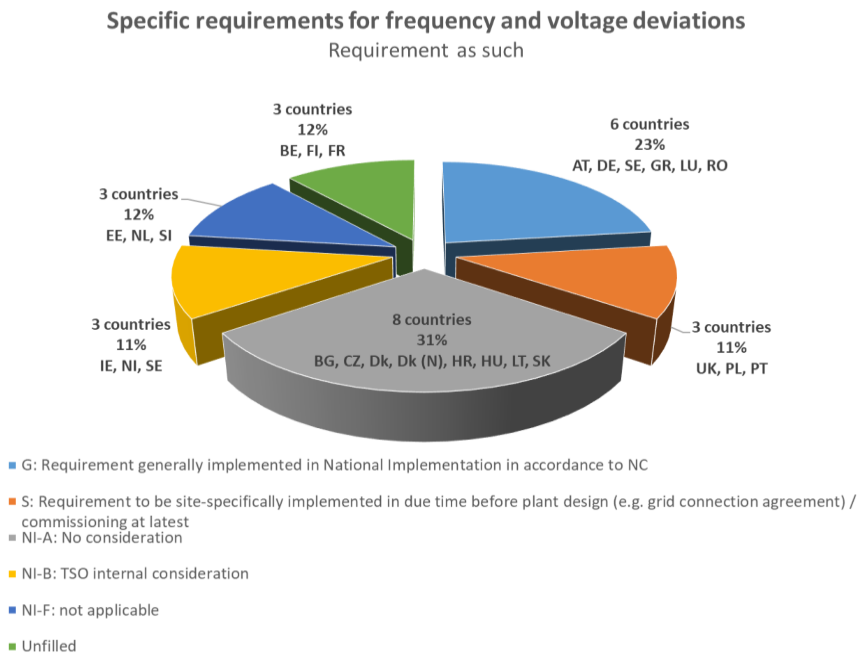


Figure 172: Specific requirements for frequency and voltage deviations

3.10.2 RoCoF (article 13(1)(b))

From the NC RfG: *With regard to the rate of change of frequency withstand capability, a power-generating module shall be capable of staying connected to the network and operate at rates of change of frequency up to a value specified by the relevant TSO, unless disconnection was triggered by rate-of-change-of-frequency-type loss of mains protection. The relevant system operator, in coordination with the relevant TSO, shall specify this rate-of-change-of-frequency-type loss of mains protection.*

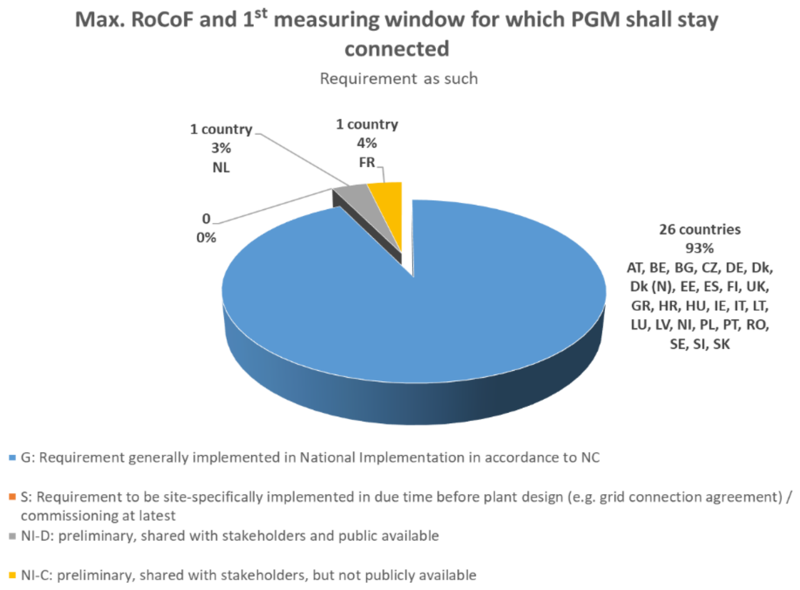


Figure 173: Max. RoCoF and 1st measuring window for which PGM shall stay connected

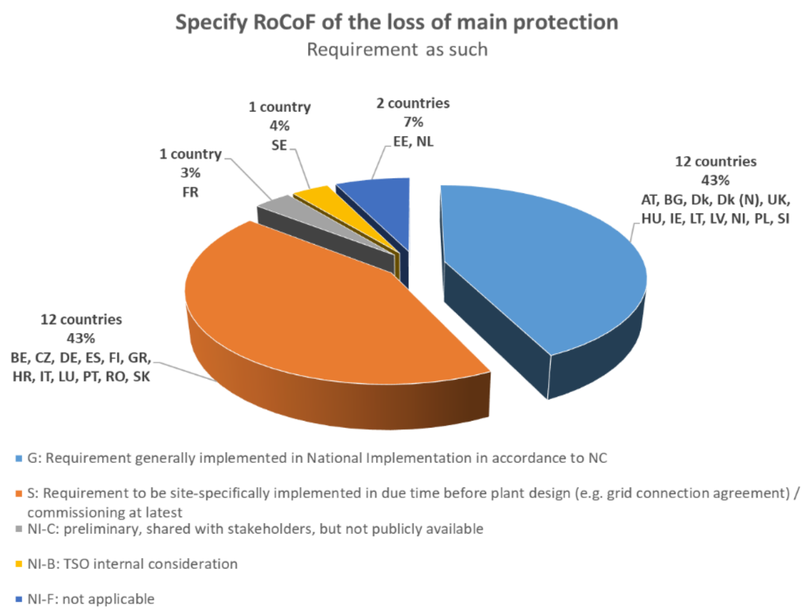


Figure 174: Specifiy RoCoF of the loss of main protection

3.10.3 LFSM-O (articles 13(2)(c), 13(2)(d))

From the NC RfG: *With regard to the limited frequency sensitive mode – overfrequency (LFSM-O), the following shall apply, as determined by the relevant TSO for its control area in coordination with the TSOs of the same synchronous area to ensure minimal impacts on neighbouring areas:*

(c) the frequency threshold shall be between 50,2 Hz and 50,5 Hz inclusive;

(d) the droop settings shall be between 2 % and 12 %;

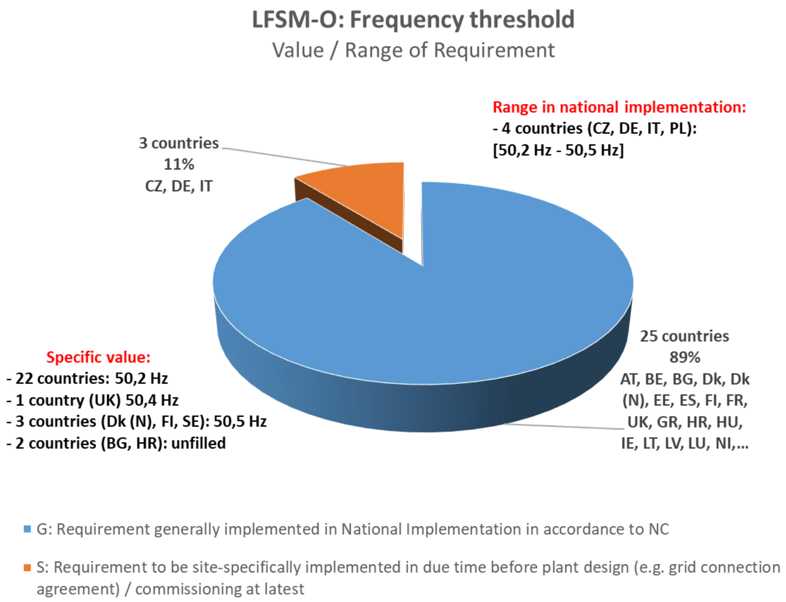


Figure 175: LFSM-O - Frequency threshold

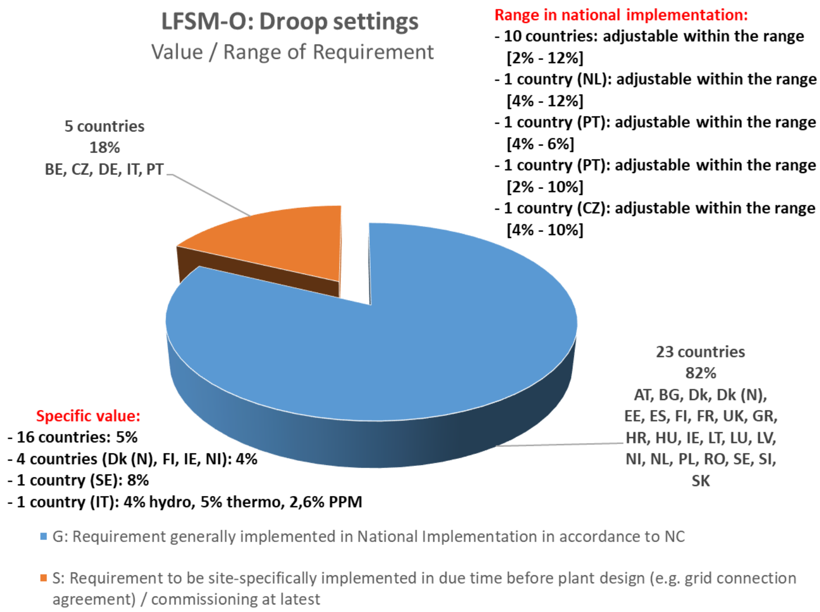


Figure 176: LFSM-O - Droop settings

3.10.4 LFSM-O (articles 13(2)(b), 13(2)(f))

From the NC RfG: *(b) instead of the capability referred to in paragraph (a), the relevant TSO may choose to allow within its control area automatic disconnection and reconnection of power-generating modules of Type A at randomised frequencies, ideally uniformly distributed, above a frequency threshold, as determined by the relevant TSO where it is able to demonstrate to the relevant regulatory authority, and with the cooperation of power-generating facility owners, that this has a limited cross-border impact and maintains the same level of operational security in all system states;*

(f) the relevant TSO may require that upon reaching minimum regulating level, the power-generating module be capable of either: (i) continuing operation at this level; or (ii) further decreasing active power output;

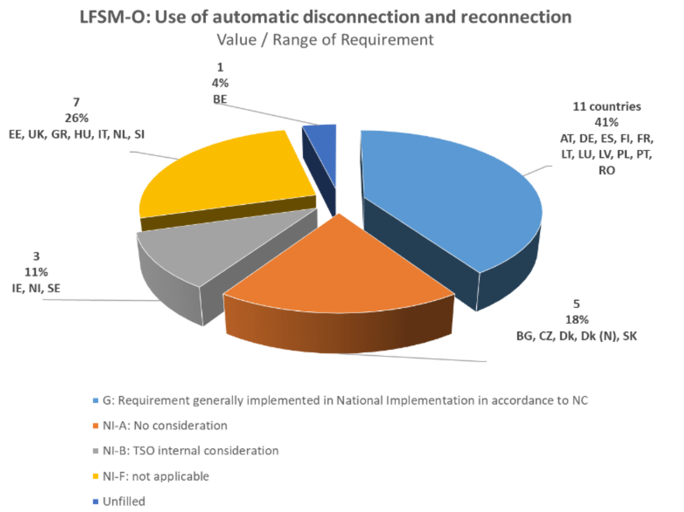


Figure 177: LFSM-O - Use of automatic disconnection and reconnection

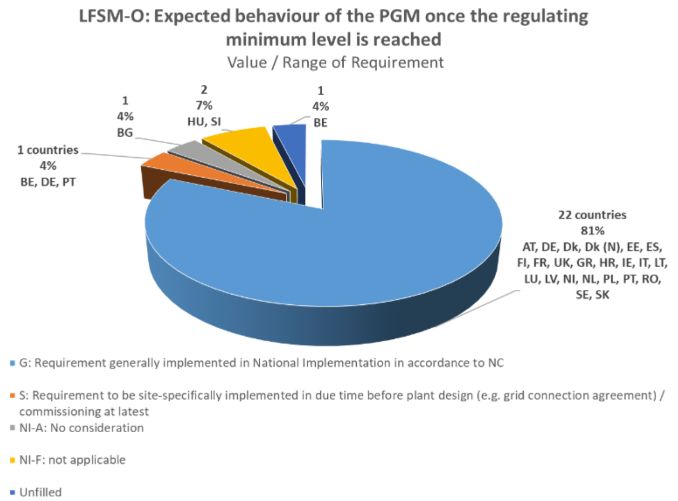


Figure 178: LFSM-O - Expected behaviour of the PGM once the regulating minimum level is reached

3.10.5 Admissible active power reduction (article 13(4))

From the NC RfG: *The relevant TSO shall specify admissible active power reduction from maximum output with falling frequency in its control area as a rate of reduction falling within the boundaries, illustrated by the full lines in Figure 2:*

(a) below 49 Hz falling by a reduction rate of 2 % of the maximum capacity at 50 Hz per 1 Hz frequency drop;

(b) below 49,5 Hz falling by a reduction rate of 10 % of the maximum capacity at 50 Hz per 1 Hz frequency drop.

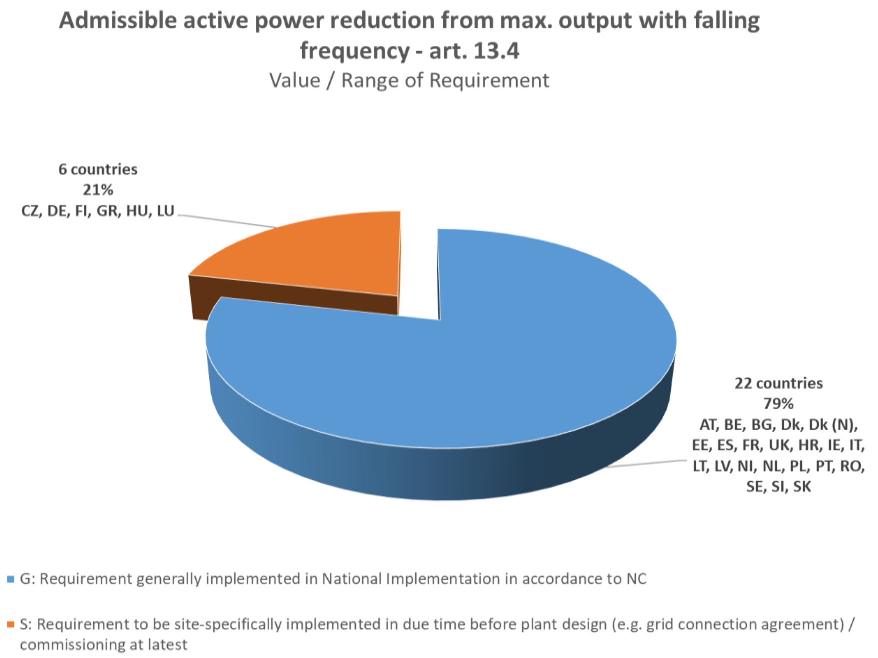


Figure 179: Admissible active power reduction from max. output with falling frequency

3.10.6 Admissible active power reduction (article 13(5))

From the NC RfG: *The admissible active power reduction from maximum output shall:*

(a) clearly specify the ambient conditions applicable;

(b) take account of the technical capabilities of power-generating modules.

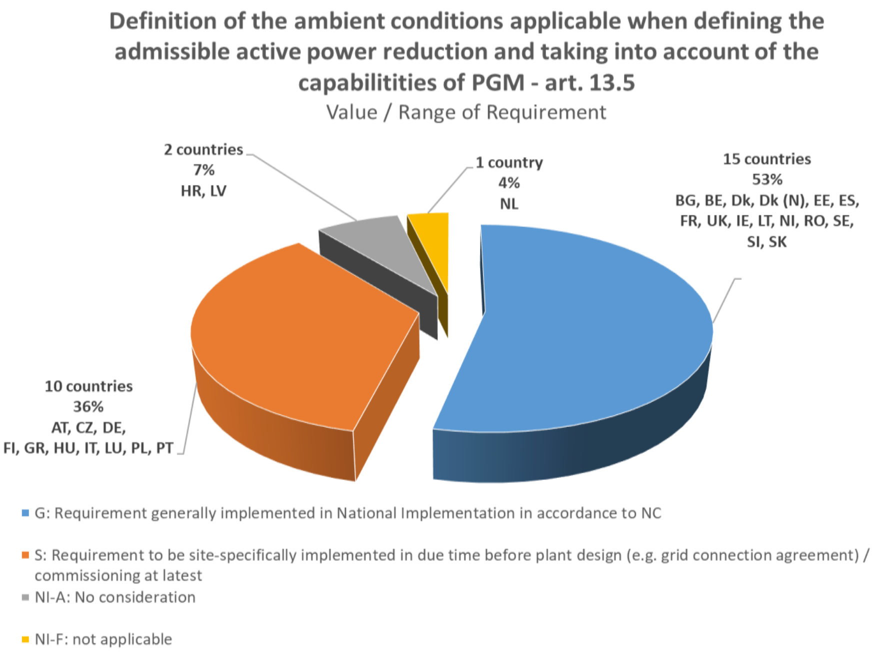


Figure 180: Definition of the ambient conditions

3.10.7 Automatic connection (article 13(7))

From the NC RfG: *The relevant TSO shall specify the conditions under which a power-generating module is capable of connecting automatically to the network. Those conditions shall include:*

(a) frequency ranges within which an automatic connection is admissible, and a corresponding delay time; and

(b) maximum admissible gradient of increase in active power output.

Automatic connection is allowed unless specified otherwise by the relevant system operator in coordination with the relevant TSO.

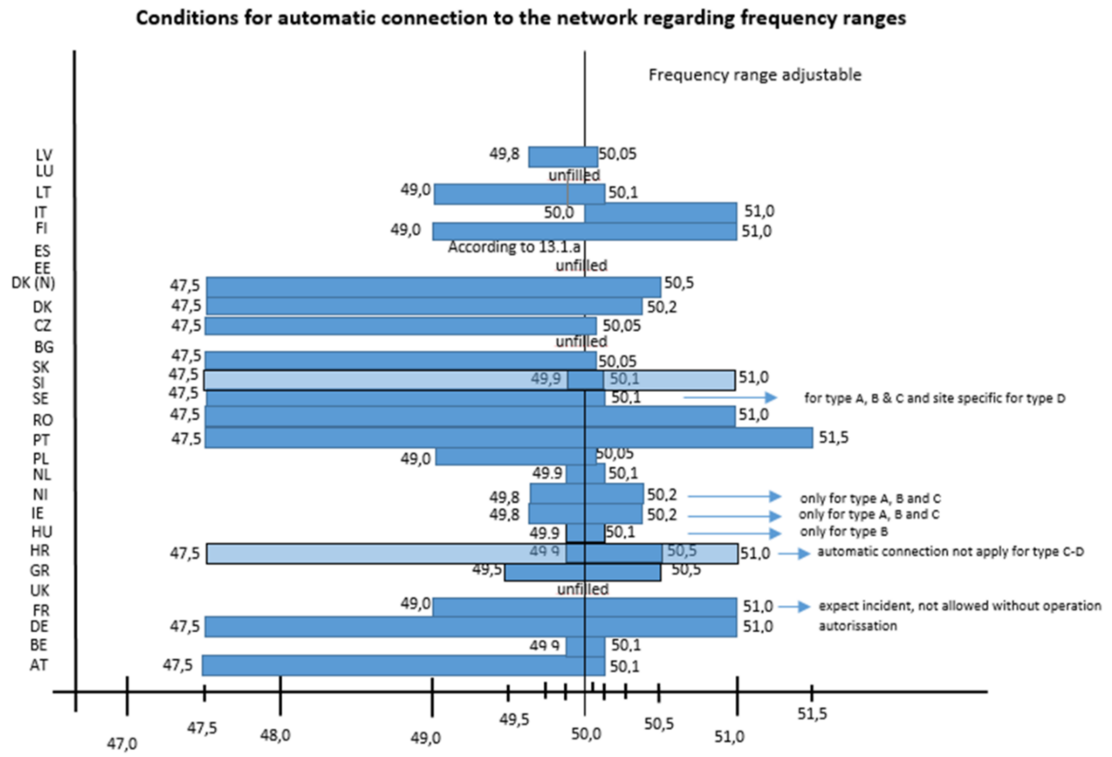


Figure 181: Conditions for automatic connection to the network regarding frequency ranges

3.10.8 Frequency sensitive mode – FSM (article 15(2)(c))

From the NC RfG: *In addition to Article 13(2), the following requirements shall apply to type C power-generating modules with regard to limited frequency sensitive mode — underfrequency (LFSM-U):*

(i) the power-generating module shall be capable of activating the provision of active power frequency response at a frequency threshold and with a droop specified by the relevant TSO in coordination with the TSOs of the same synchronous area as follows:

— the frequency threshold specified by the TSO shall be between 49,8 Hz and 49,5 Hz inclusive,

— the droop settings specified by the TSO shall be in the range 2-12 %.

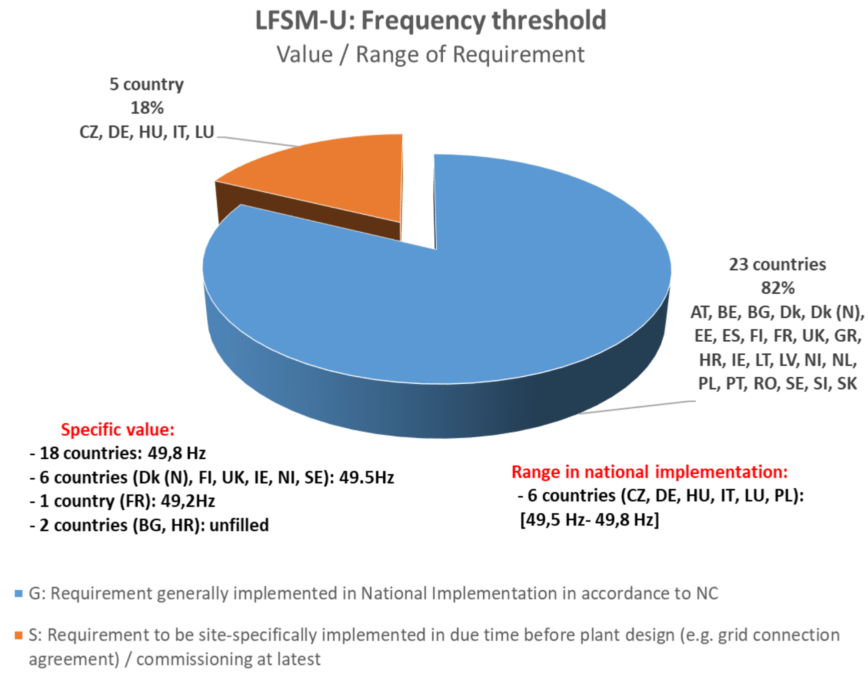


Figure 182: LFSM-U - Frequency threshold

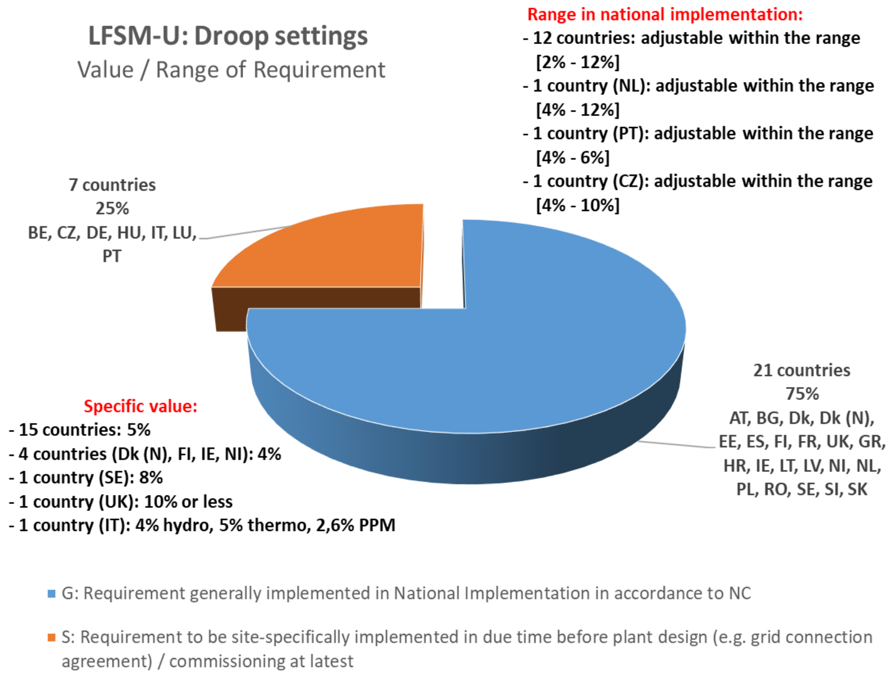


Figure 183: LFSM-U - Droop settings

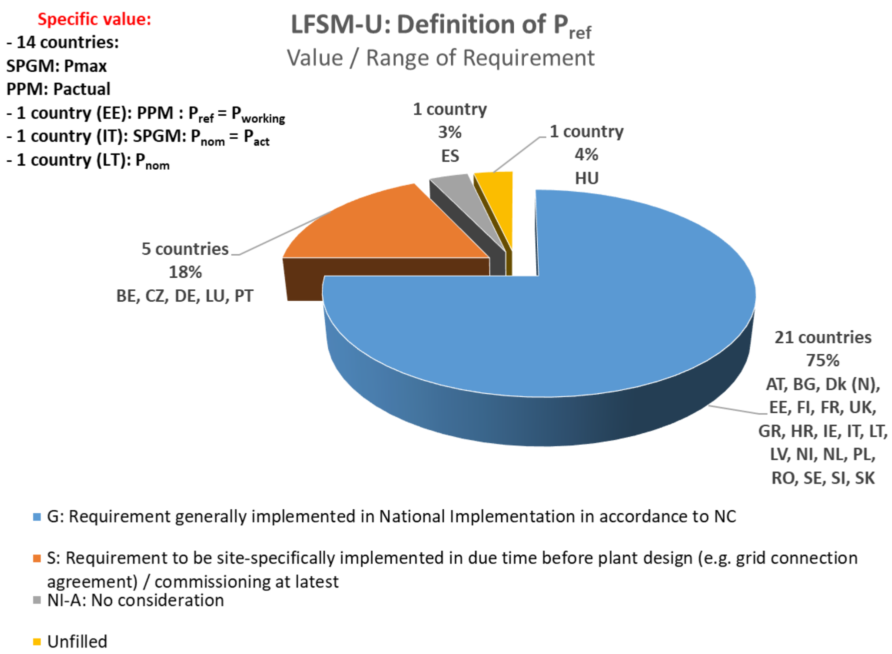


Figure 184: LFSM-U - Definition of P_{ref}

3.10.9 Frequency sensitive mode (article 15(2)(d)(i))

From the NC RfG: *in addition to point (c) of paragraph 2, the following shall apply cumulatively when frequency sensitive mode ('FSM') is operating:*

(i) the power-generating module shall be capable of providing active power frequency response in accordance with the parameters specified by each relevant TSO within the ranges shown in Table 4. In specifying those parameters, the relevant TSO shall take account of the following facts:

— in case of overfrequency, the active power frequency response is limited by the minimum regulating level,

— in case of underfrequency, the active power frequency response is limited by maximum capacity,

— the actual delivery of active power frequency response depends on the operating and ambient conditions of the power-generating module when this response is triggered, in particular limitations on operation near maximum capacity at low frequencies according to paragraphs 4 and 5 of Article 13 and available primary energy sources;

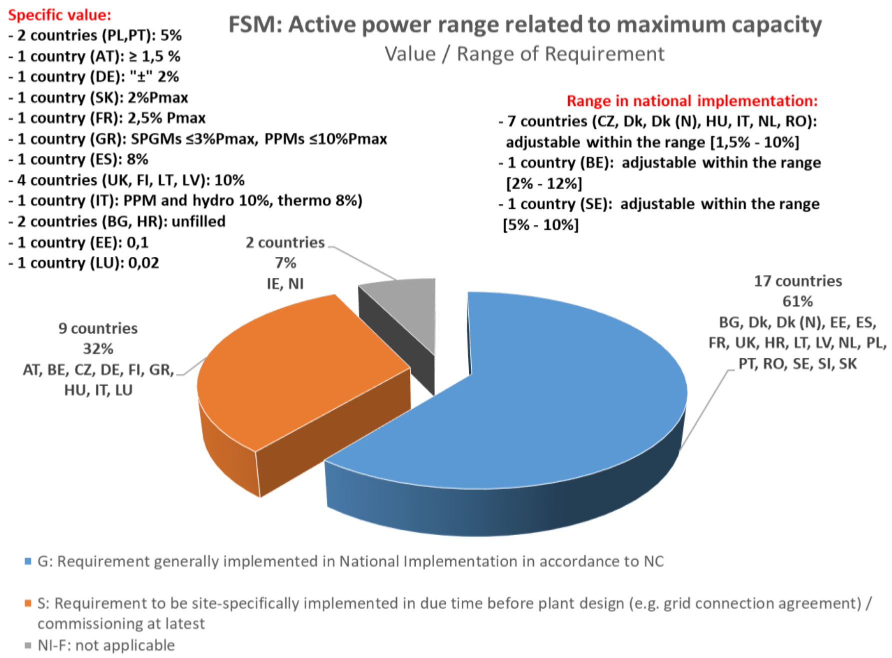


Figure 185: FSM - Active power range related to maximum capacity

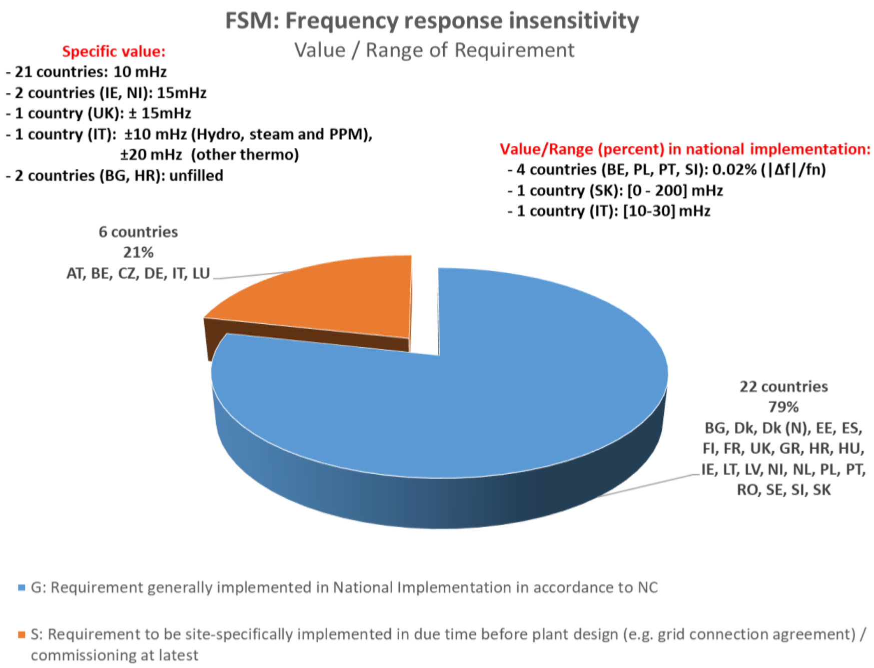


Figure 186: FSM - Frequency response insensitivity

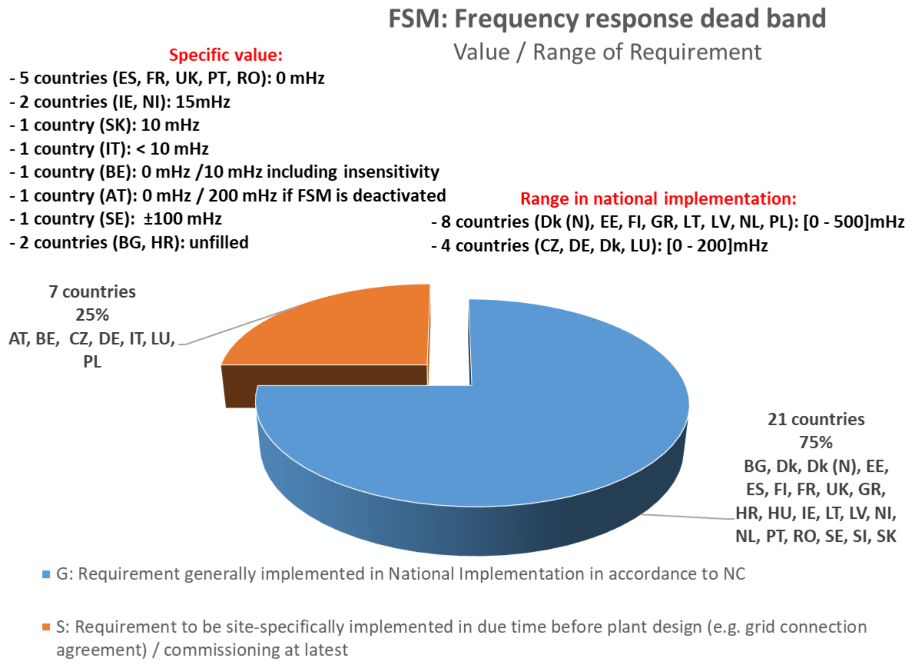


Figure 187: FSM - Frequency response dead band

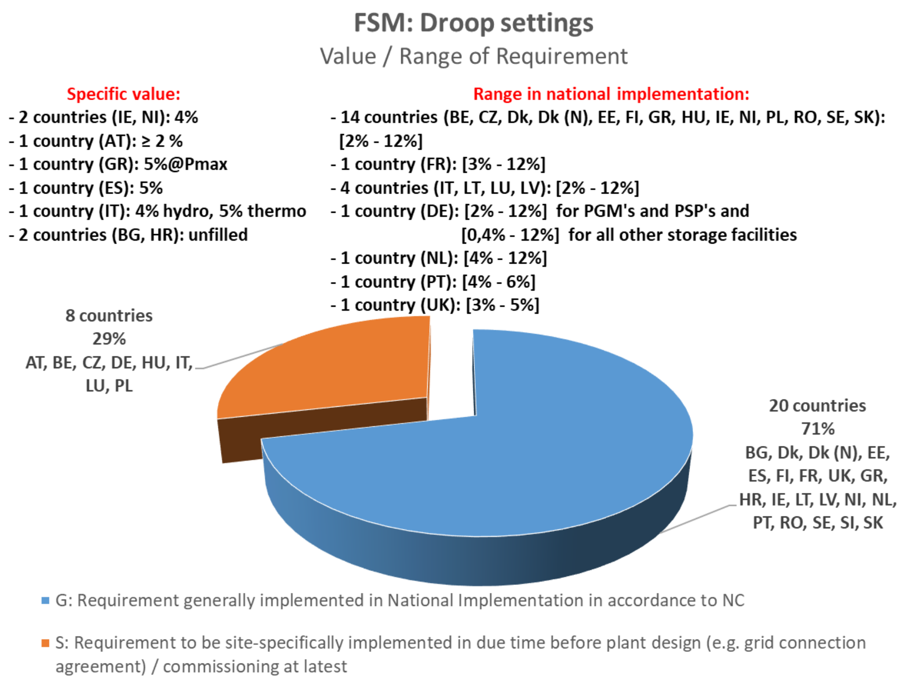


Figure 188: Droop settings

3.10.10 Frequency sensitive mode (article 15(2)(d)(iii))

From the NC RfG: *in the event of a frequency step change, the power-generating module shall be capable of activating full active power frequency response, at or above the full line shown in Figure 6 in accordance with the parameters specified by each TSO (which shall aim at avoiding active power oscillations for the power-generating module) within the ranges given in Table 5. The combination of choice of the parameters specified by the TSO shall take possible technology-dependent limitations into account;*

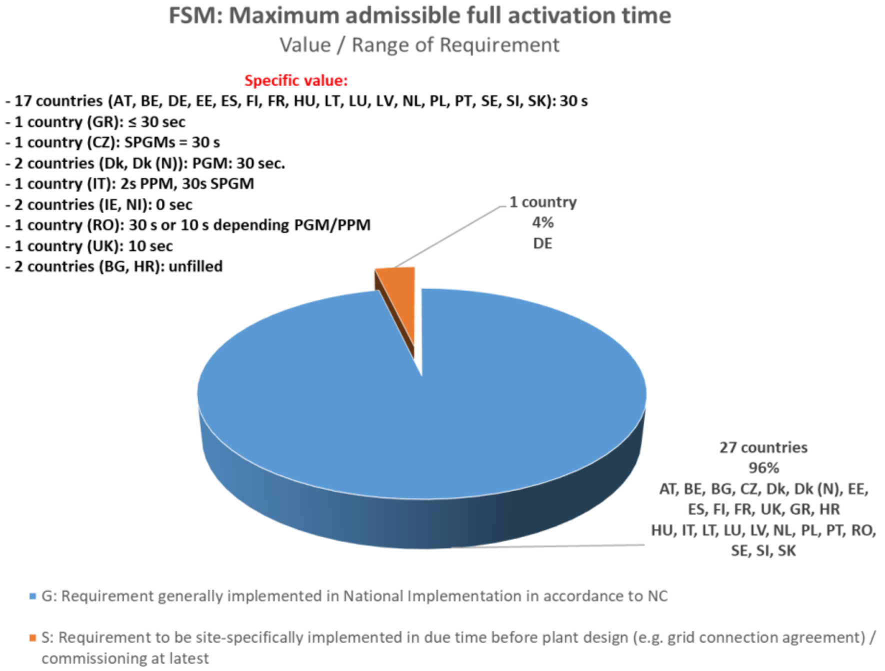


Figure 189: FSM - Maximum admissible full activation time

3.10.11 Frequency sensitive mode (article 15(2)(d)(iv))

From the NC RfG:

the initial activation of active power frequency response required shall not be unduly delayed.

If the delay in initial activation of active power frequency response is greater than two seconds, the power- generating facility owner shall provide technical evidence demonstrating why a longer time is needed.

For power-generating modules without inertia, the relevant TSO may specify a shorter time than two seconds. If the power-generating facility owner cannot meet this requirement they shall provide technical evidence demonstrating why a longer time is needed for the initial activation of active power frequency response;

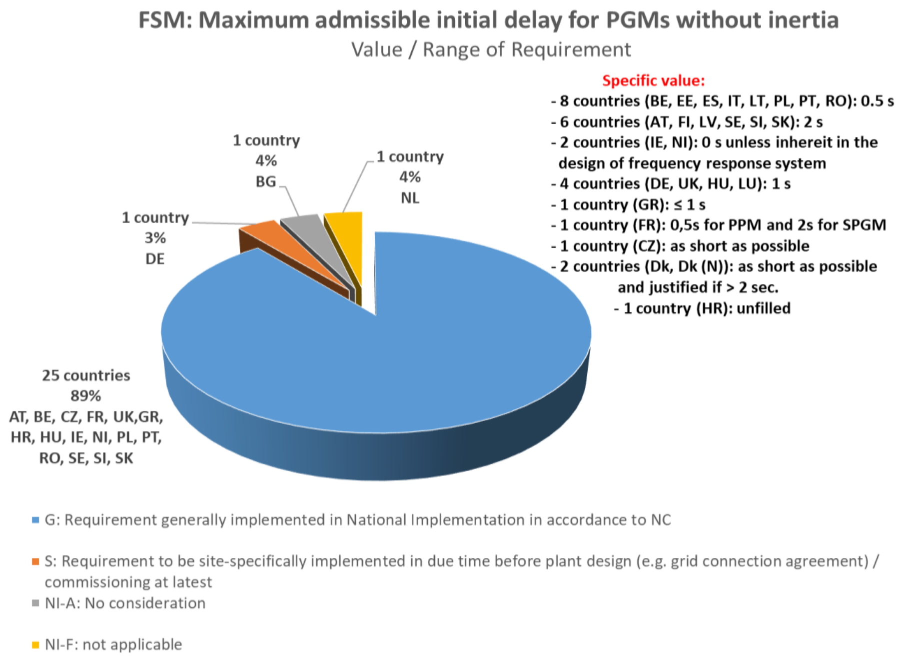


Figure 190: FSM - Maximum admissible initial delay for PGMs without inertia

3.10.12 Frequency sensitive mode (article 15(2)(d)(v))

From the NC RfG:

the power-generating module shall be capable of providing full active power frequency response for a period of between 15 and 30 minutes as specified by the relevant TSO. In specifying the period, the TSO shall have regard to active power headroom and primary energy source of the power-generating module;

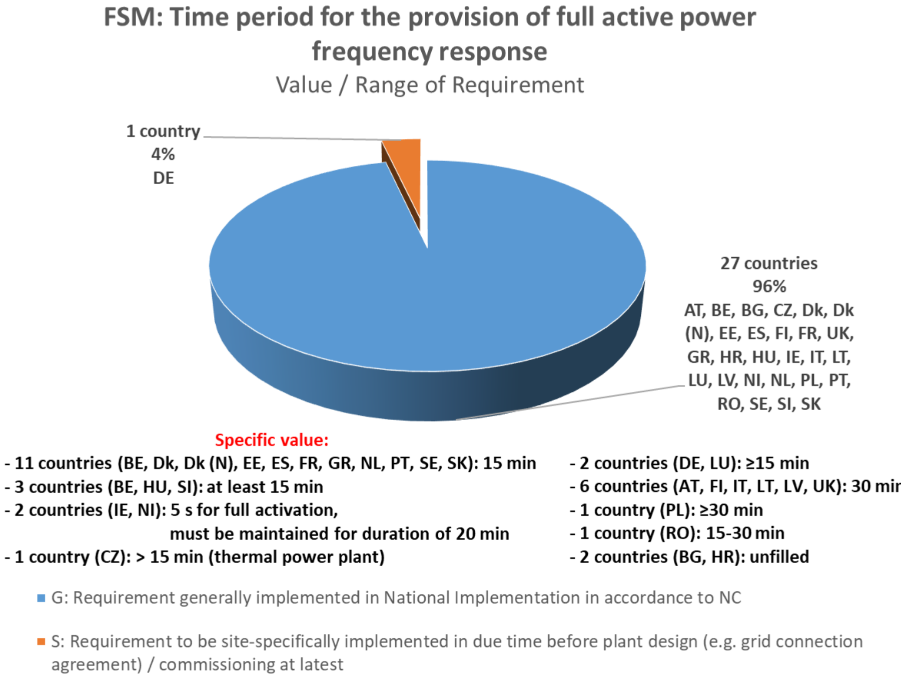


Figure 191: FSM - Time period for the provision of full active power frequency response

3.10.13 Frequency restoration control (article 15(2)(e))

From the NC RfG: *with regard to frequency restoration control, the power-generating module shall provide functionalities complying with specifications specified by the relevant TSO, aiming at restoring frequency to its nominal value or maintaining power exchange flows between control areas at their scheduled values;*

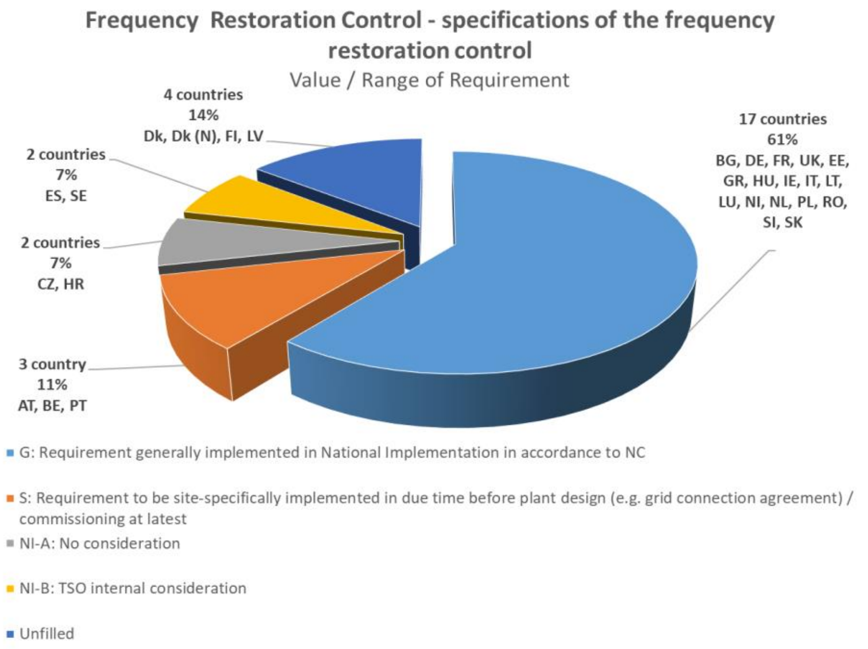


Figure 192: Frequency restoration control

3.10.14 Real time monitoring (article 15(2)(g))

From the NC RfG: *(i) to monitor the operation of active power frequency response, the communication interface shall be equipped to transfer in real time and in a secured manner from the power-generating facility to the network control centre of the relevant system operator or the relevant TSO, at the request of the relevant system operator or the relevant TSO, at least the following signals:*

(ii) the relevant system operator and the relevant TSO shall specify additional signals to be provided by the power- generating facility by monitoring and recording devices in order to verify the performance of the active power frequency response provision of participating power-generating modules.

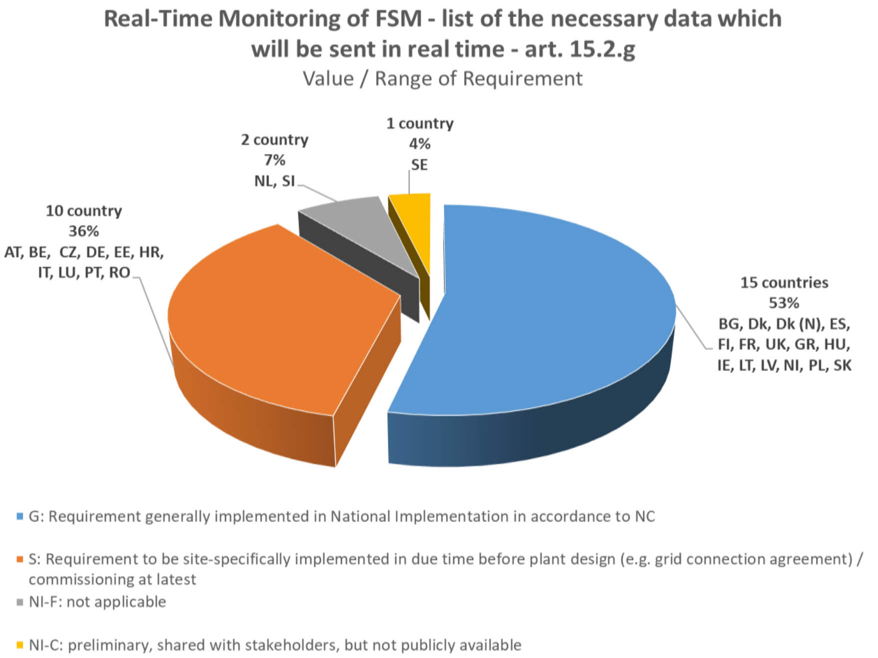


Figure 193: Real-time monitoring of FSM

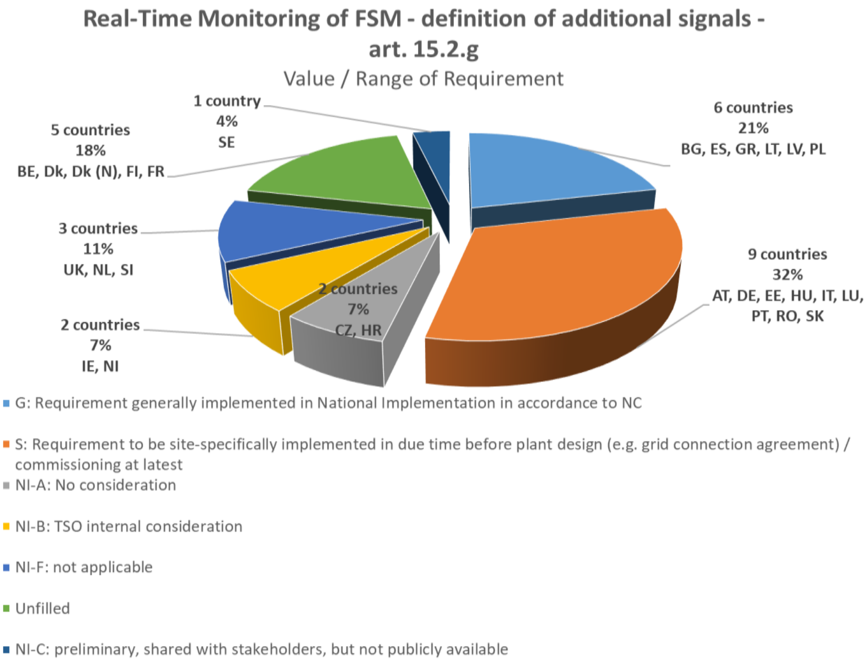


Figure 194: Real-time monitoring of FSM

3.10.15 Rates of change of active power output (article 15(6)(e))

From the NC RfG: *the relevant system operator shall specify, in coordination with the relevant TSO, minimum and maximum limits on rates of change of active power output (ramping limits) in both an up and down direction of change of active power output for a power-generating module, taking into consideration the specific characteristics of prime mover technology;*

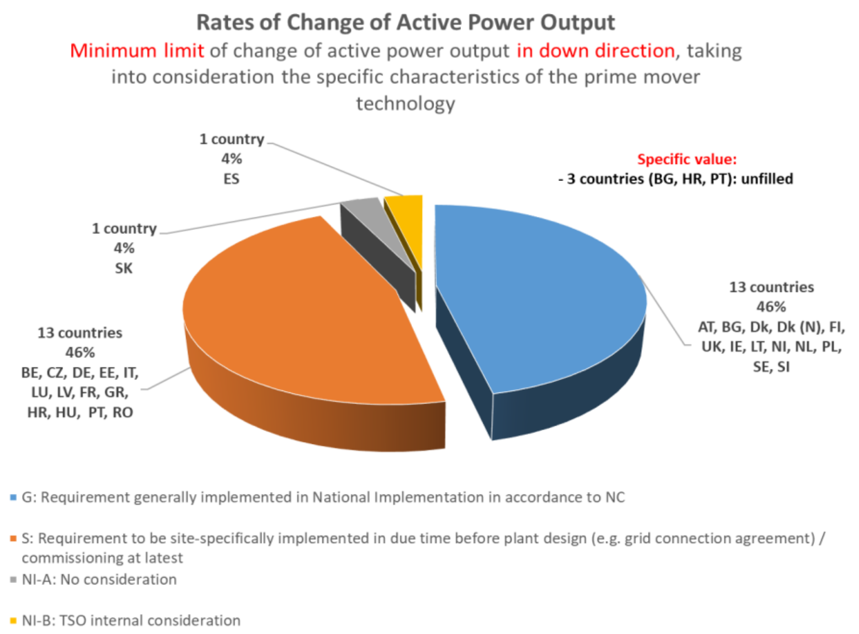


Figure 195: Minimum limit of change of active power output in down direction

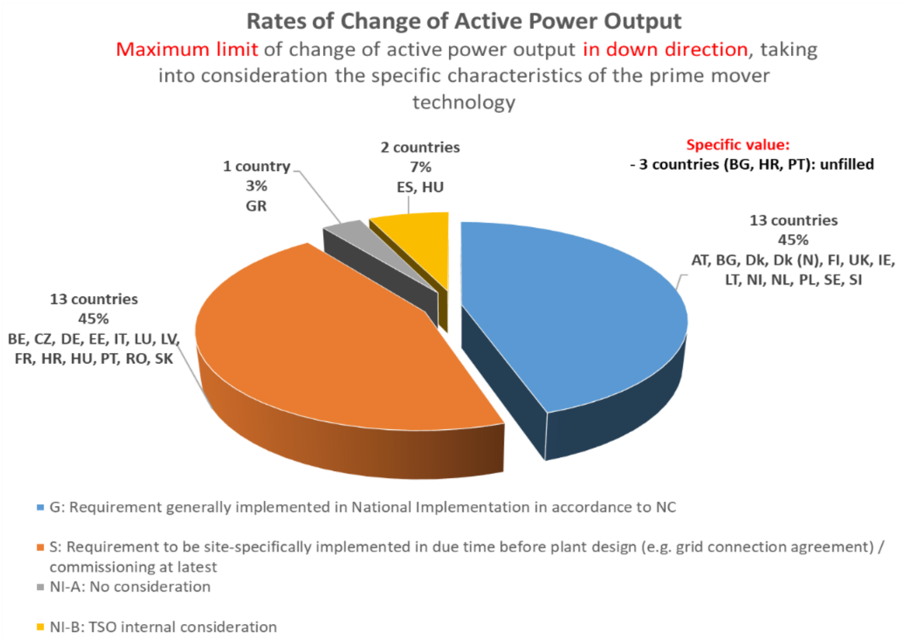


Figure 196: Maximum change of active power output in down direction

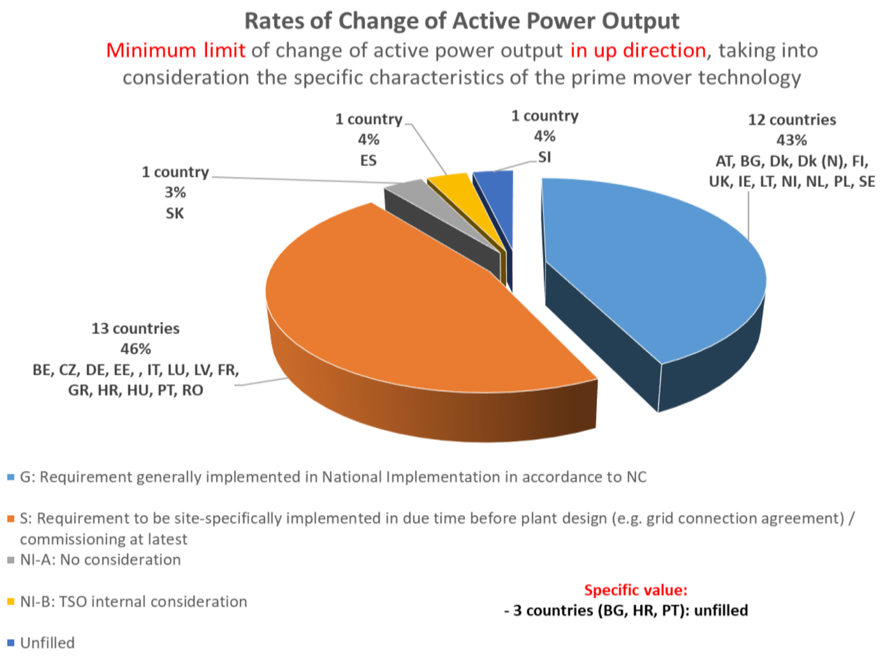


Figure 197: Minimum limit of change of active power output in up direction

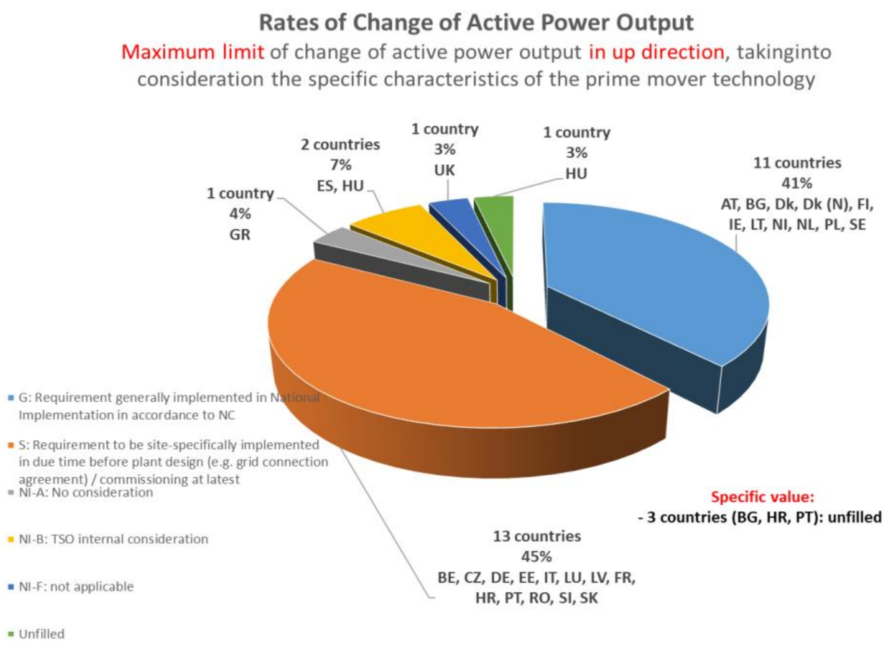


Figure 198: Maximum limit of change of active power output in up direction

4 NC DCC Implementation

4.1 Number of implemented non-exhaustive requirements in NC DCC

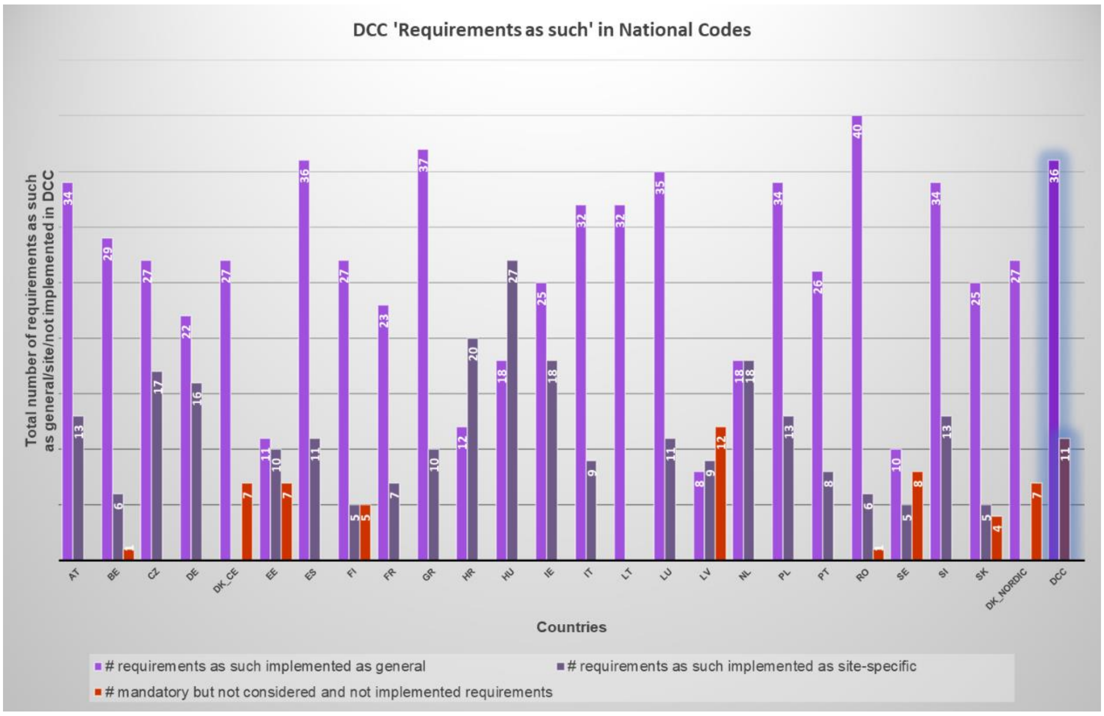


Figure 199: Reference total number of to be implemented DCC non-exhaustive requirements as such

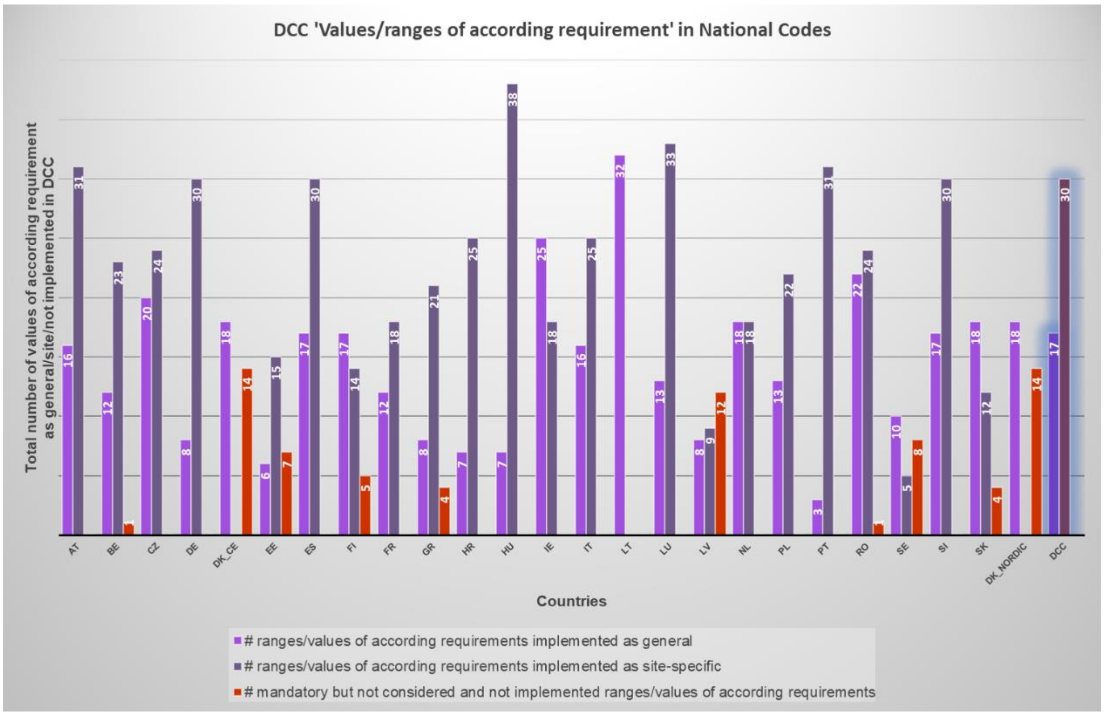


Figure 200: Reference total number of to be implemented values/ranges of regarding DCC non-exhaustive requirements

4.2 Frequency Issues of NC DCC

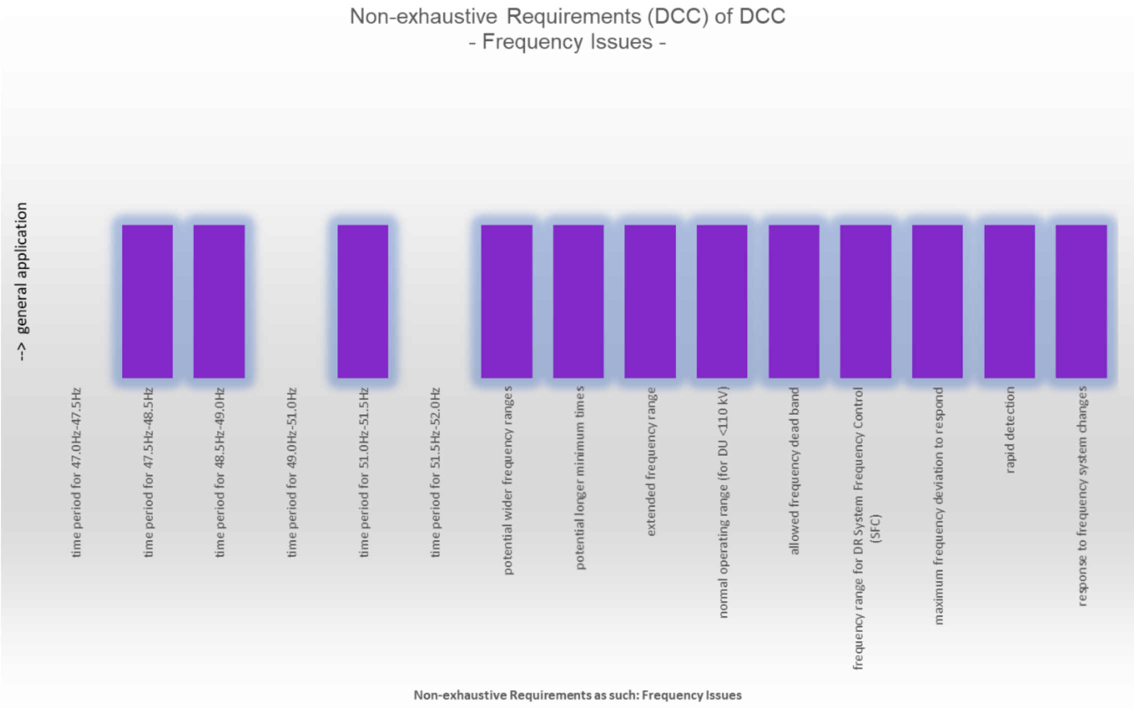


Figure 201: Reference values of non-exhaustive DCC frequency issues

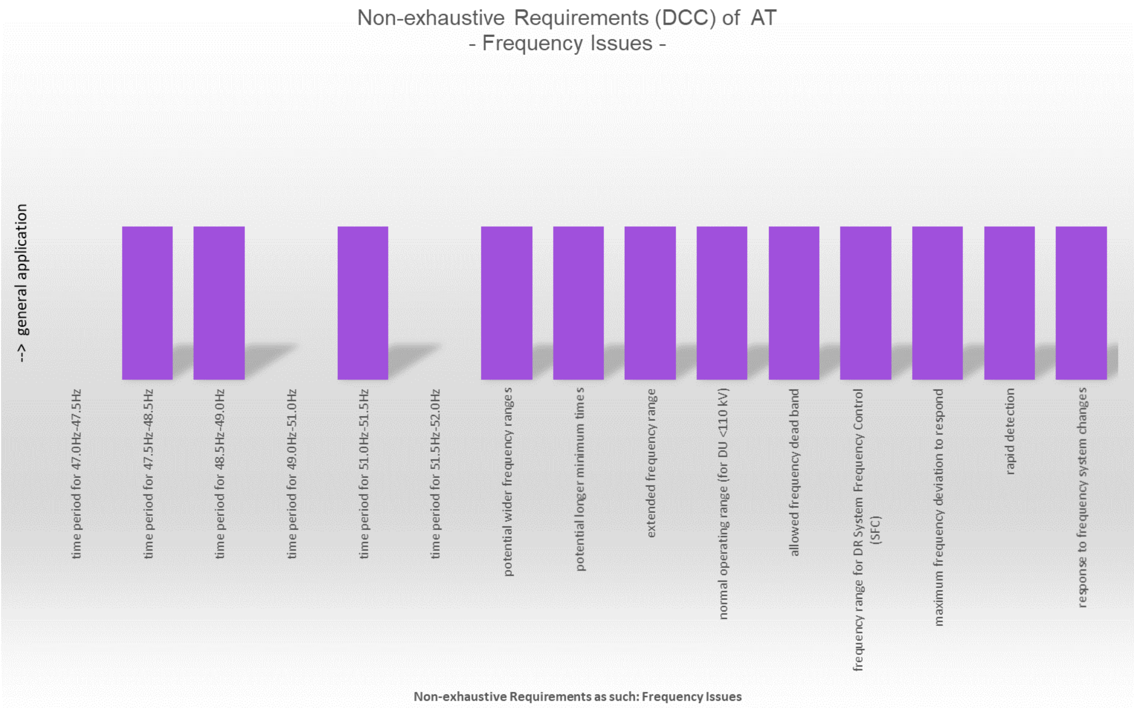


Figure 202: Austria (AT)

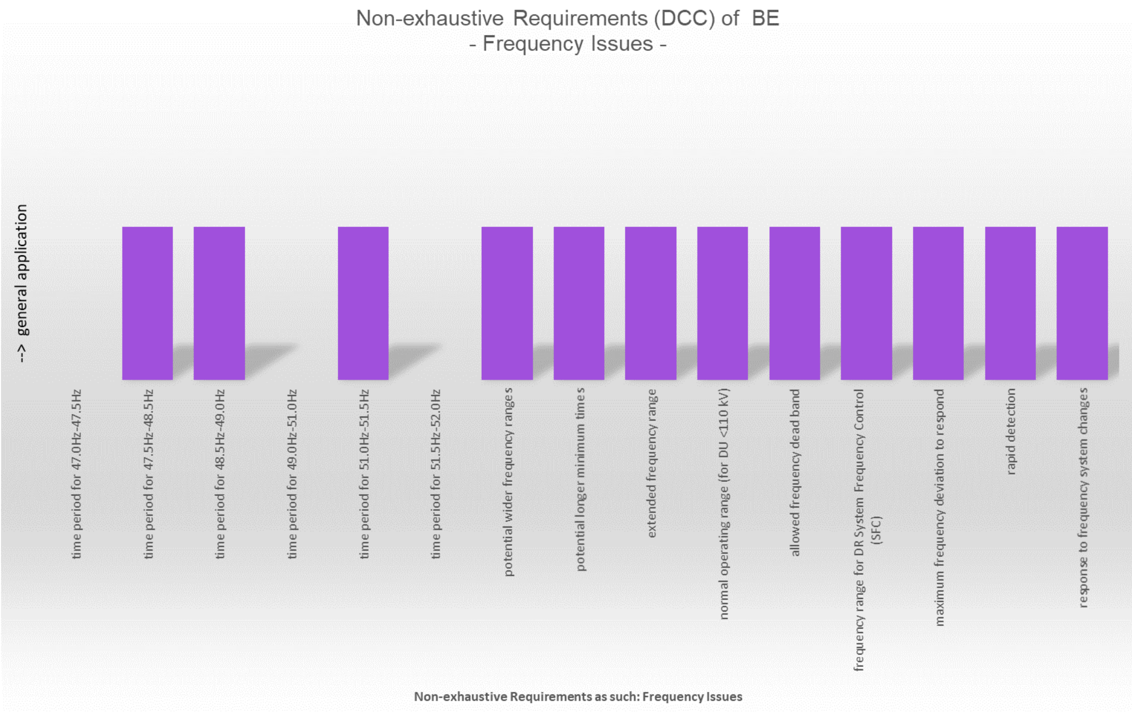


Figure 203: Belgium (BE)

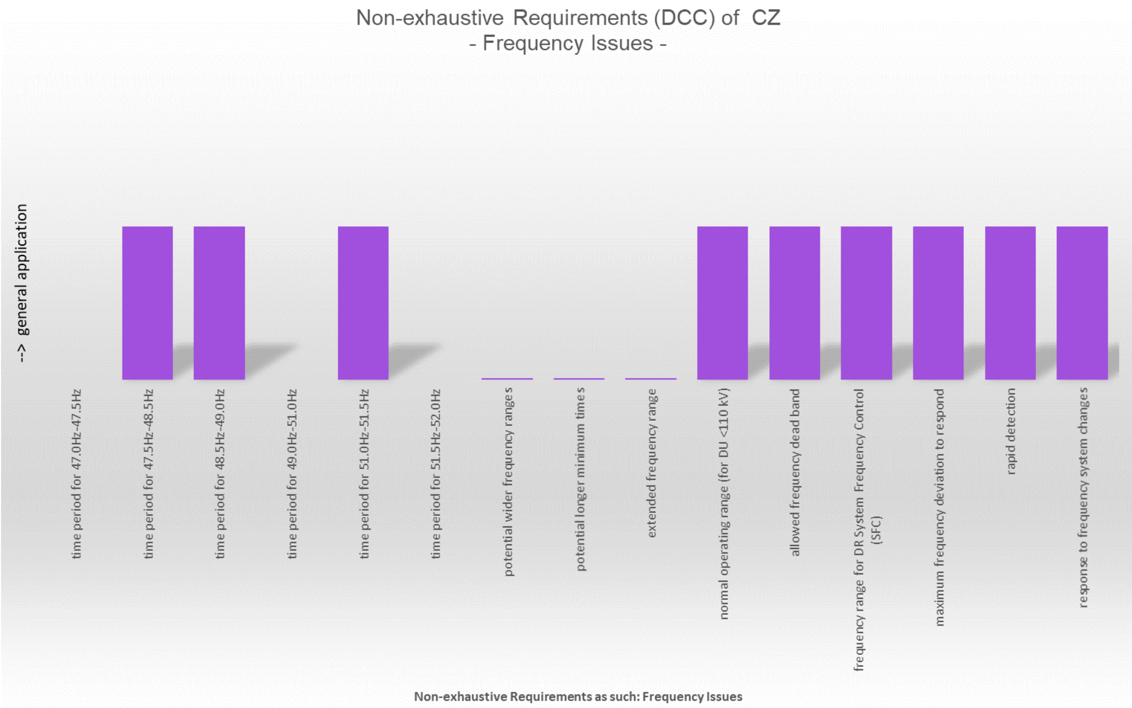


Figure 204: Czech Republic (CZ)

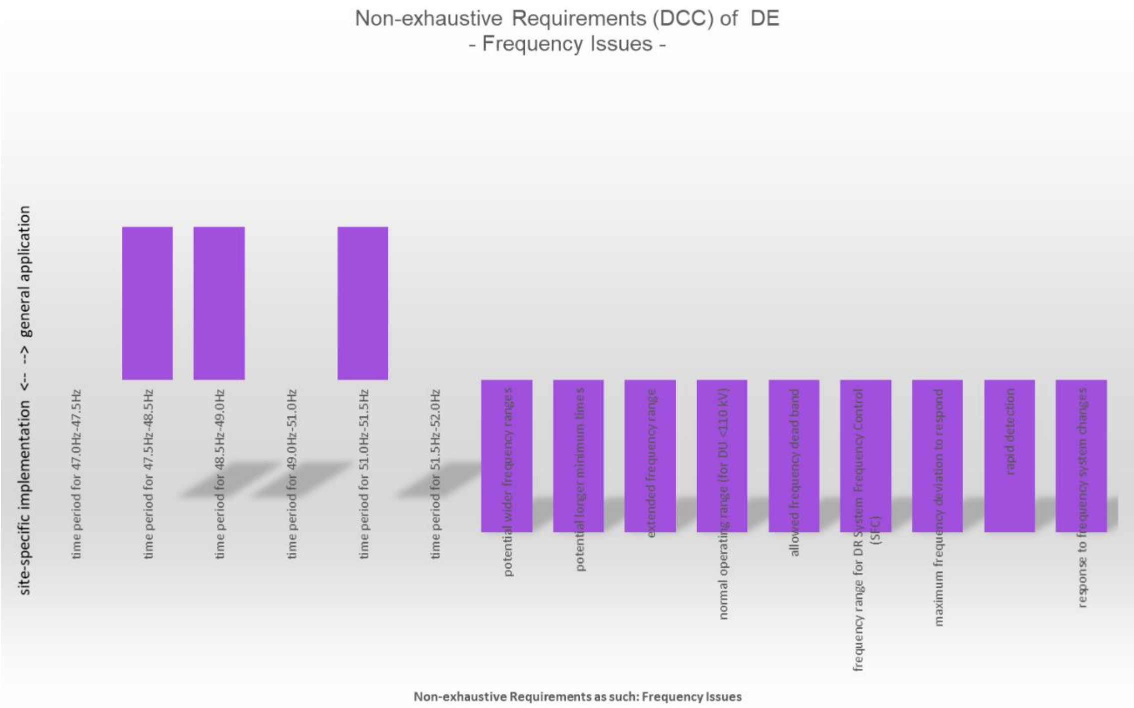


Figure 205: Germany (DE)

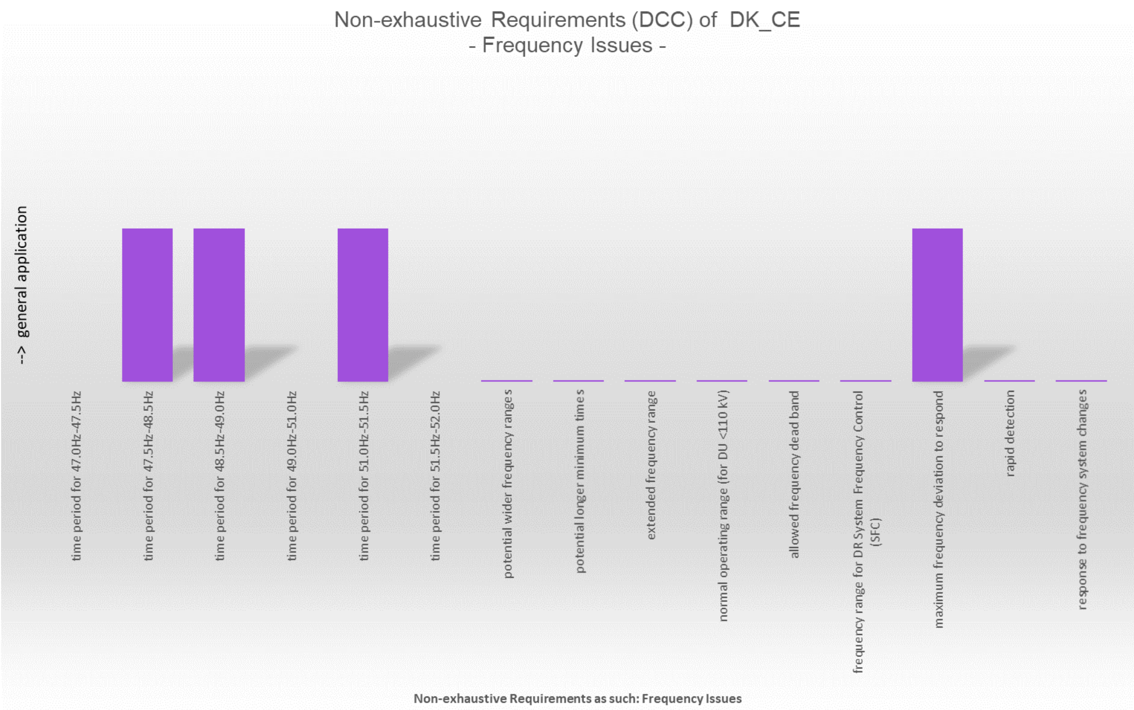


Figure 206: Denmark 1 (DK-CE)

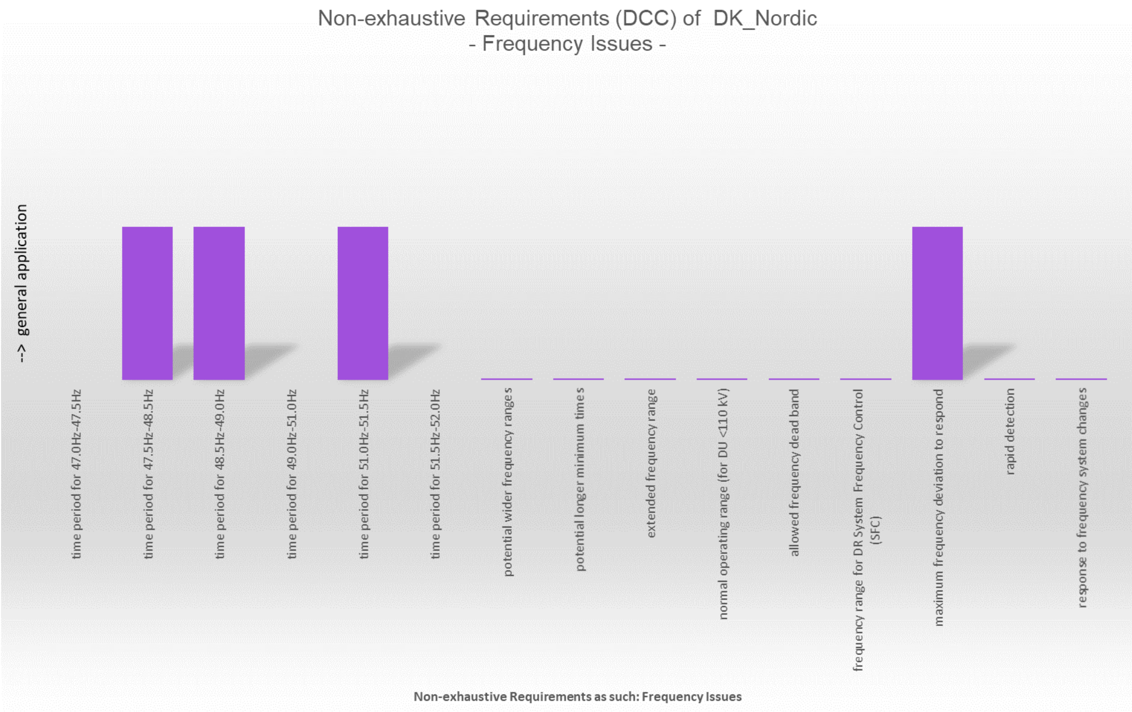


Figure 207: Denmark 2 (DK-Nordic)

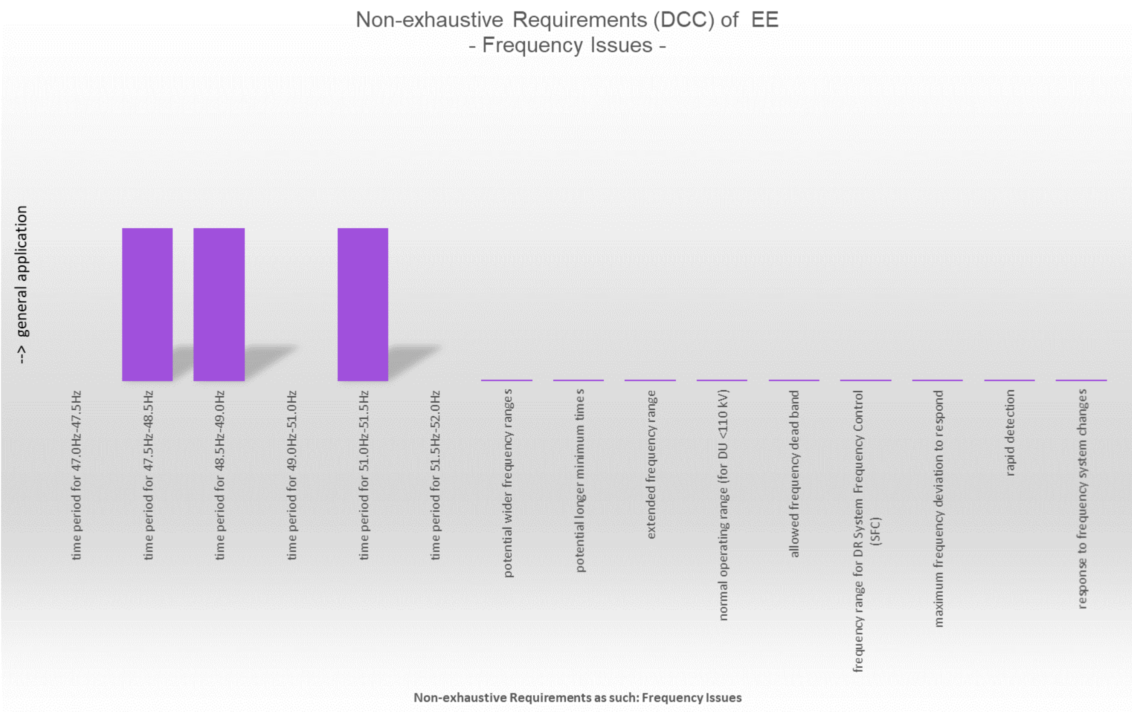


Figure 208: Estonia (EE)

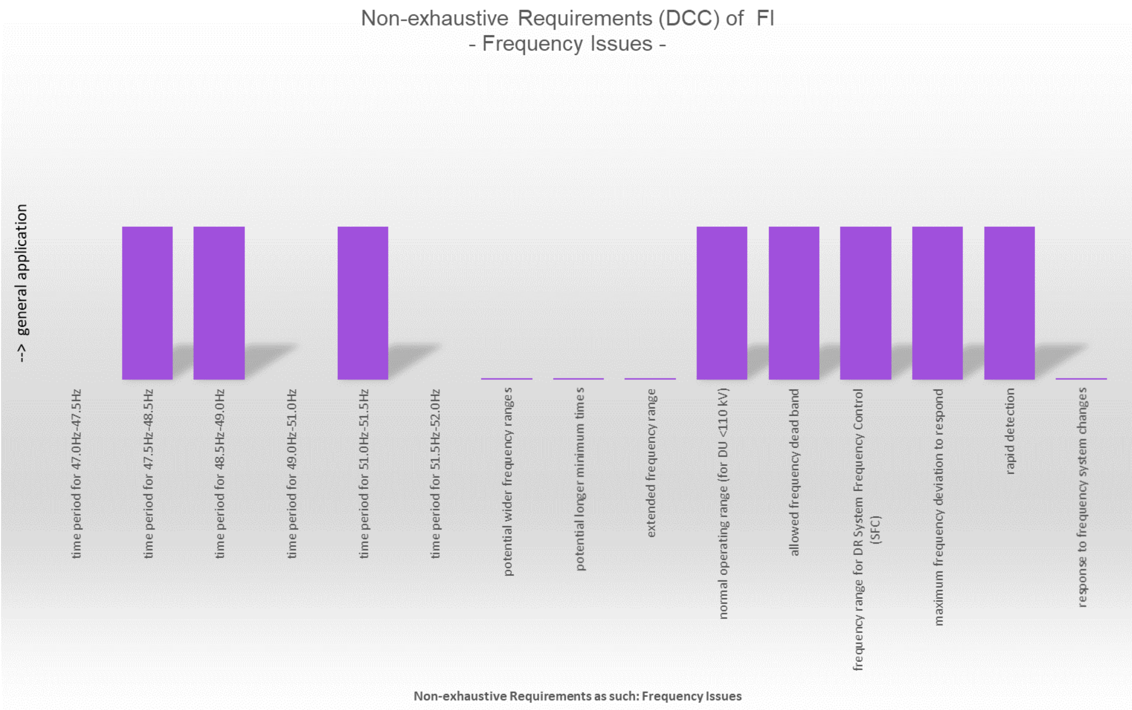


Figure 209: Finland (FI)

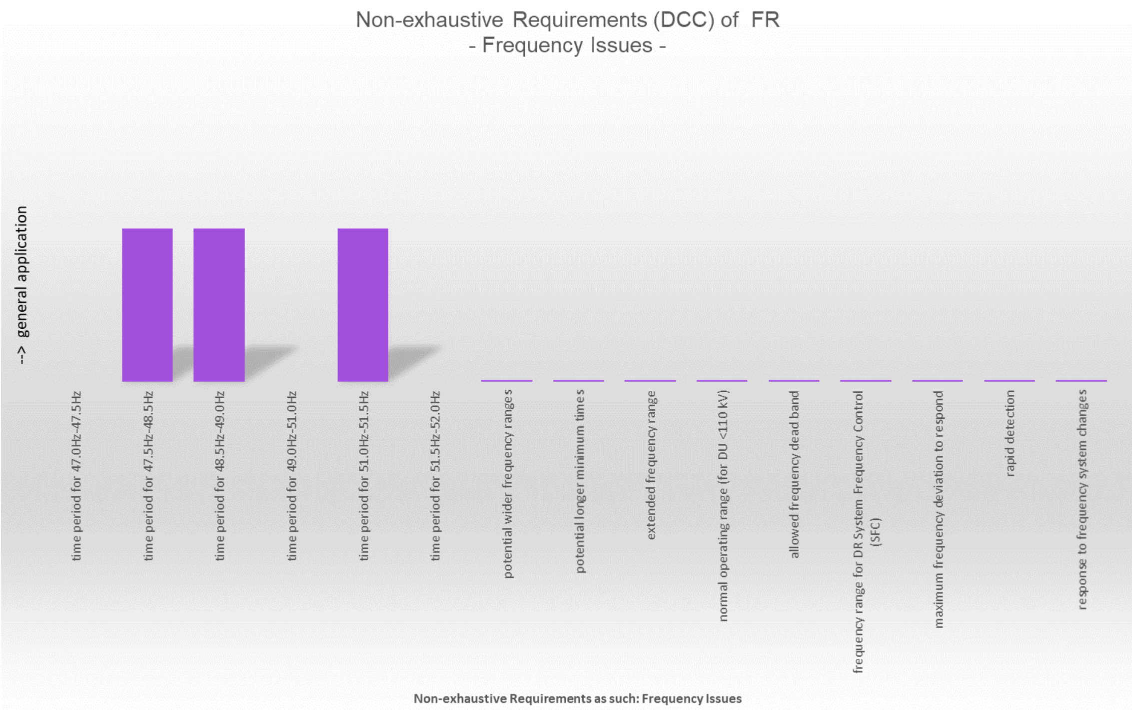


Figure 210: France (FR)

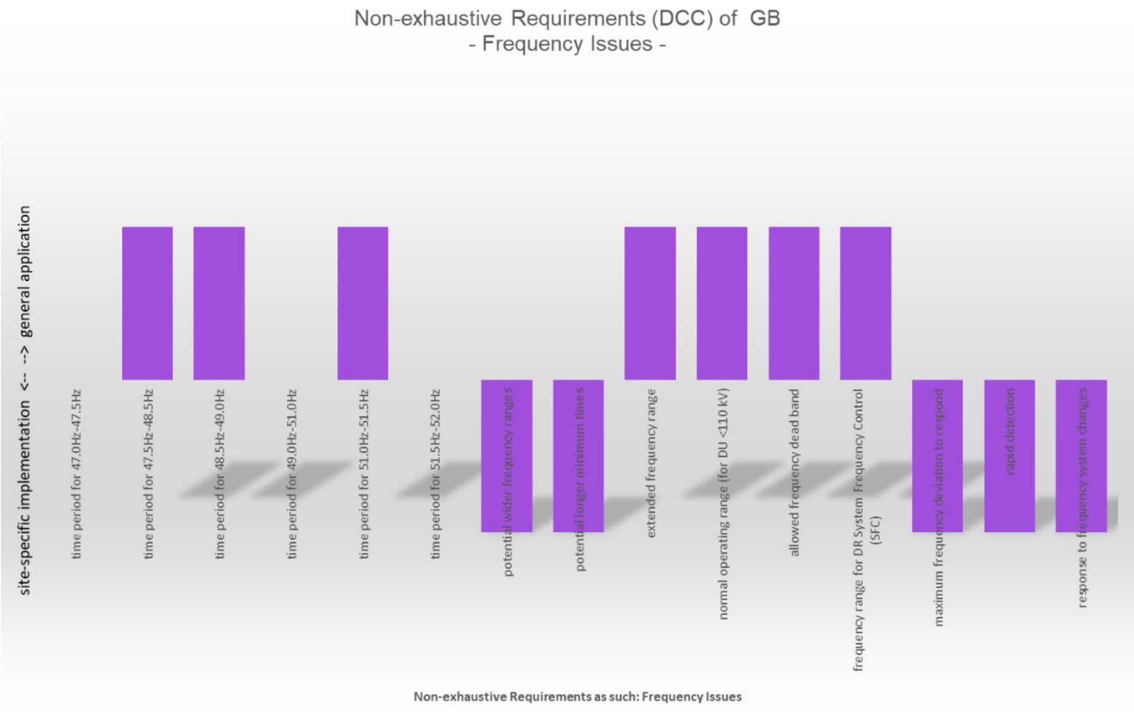


Figure 211: Great Britain (GB)

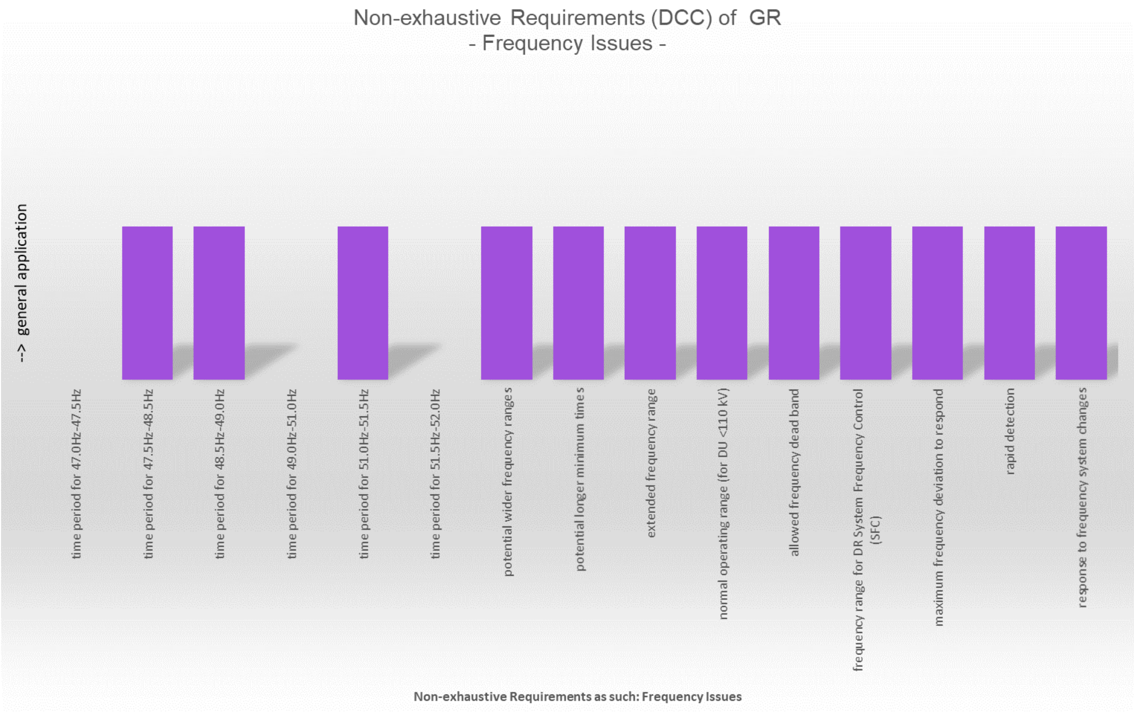


Figure 212: Greece (GR)

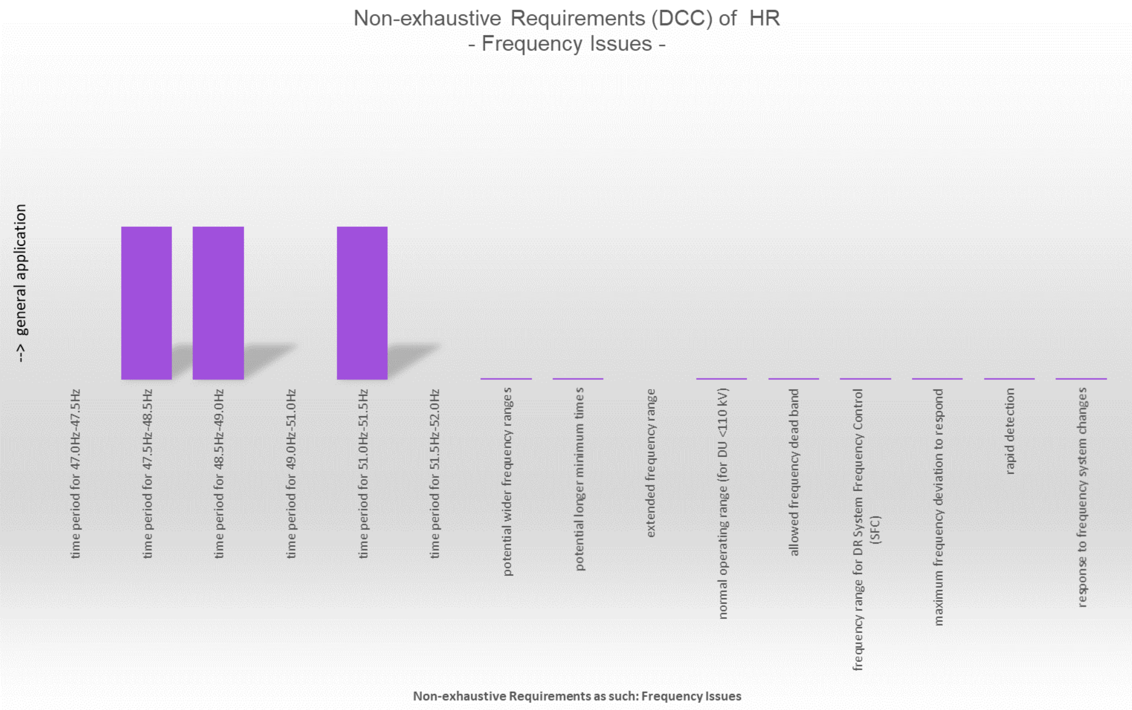


Figure 213: Croatia (HR)

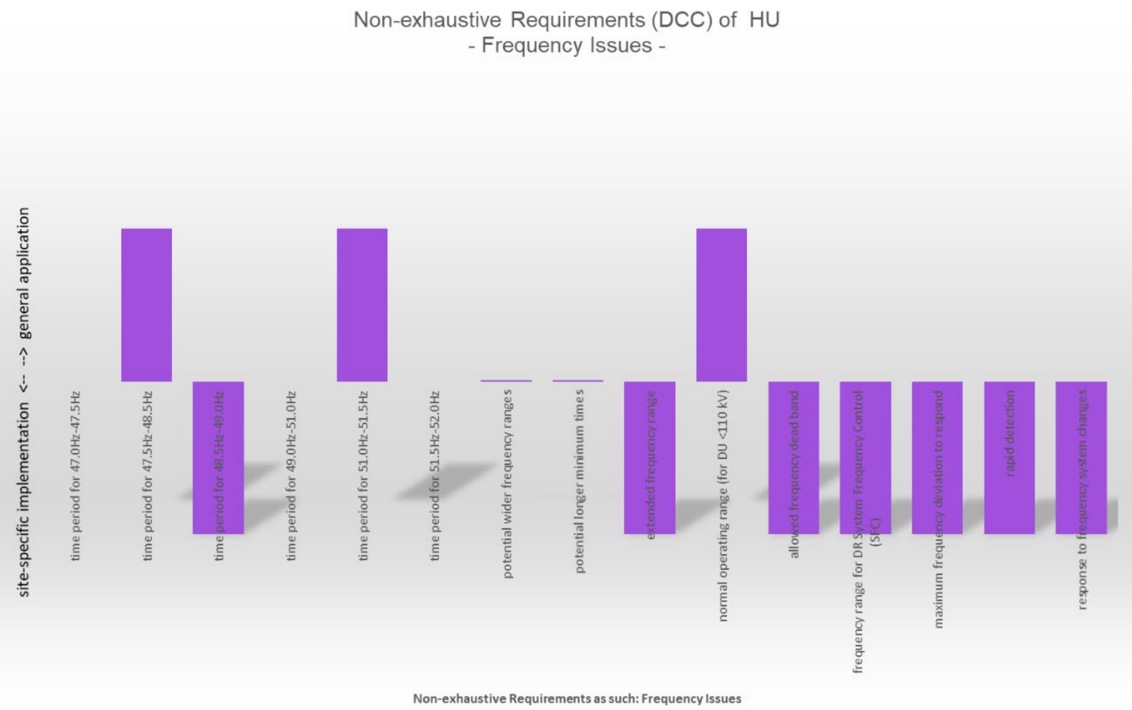


Figure 214: Hungary (HU)

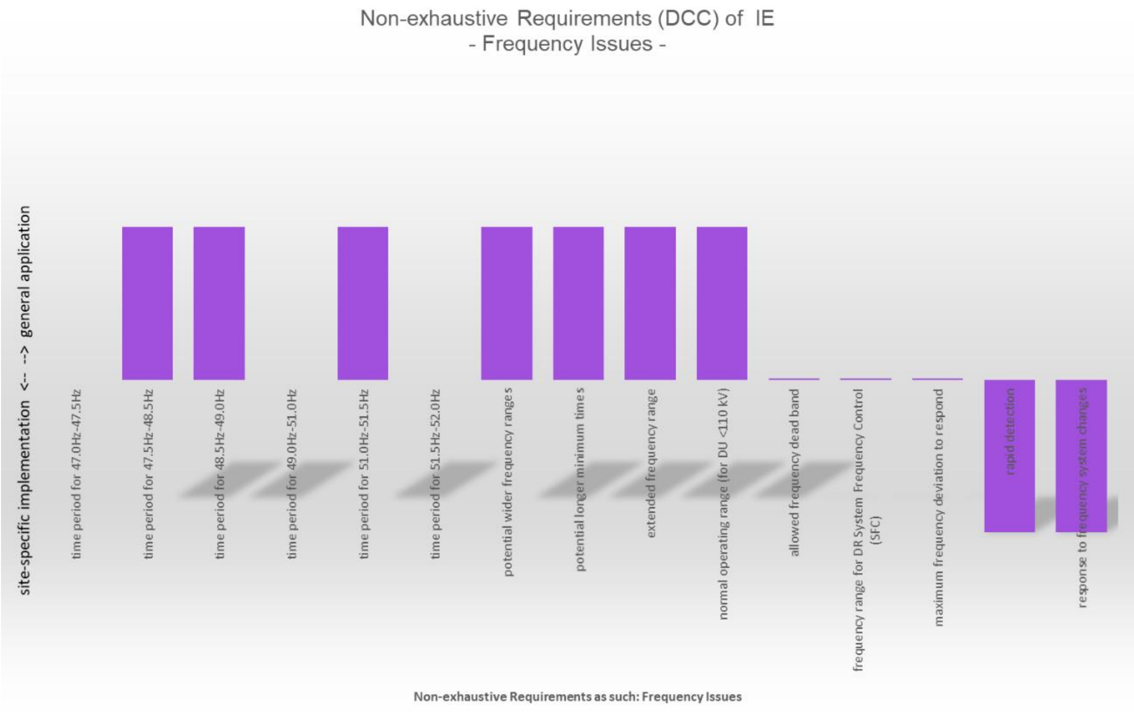


Figure 215: Ireland (IE)

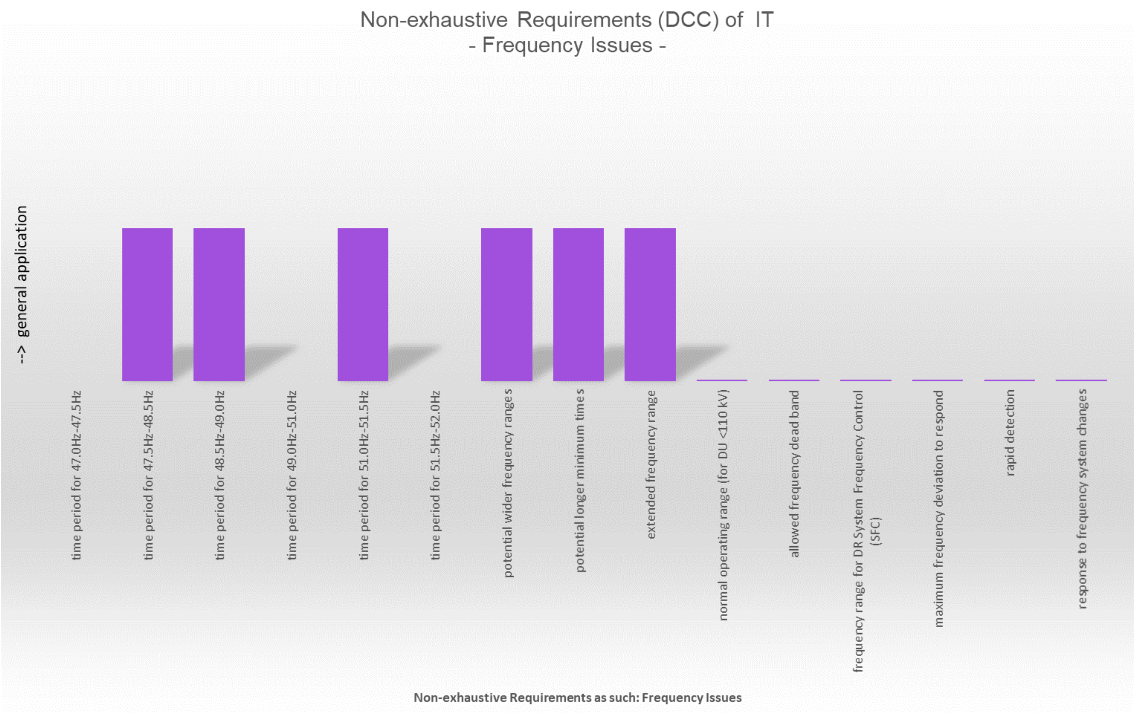


Figure 216: Italy (IT)

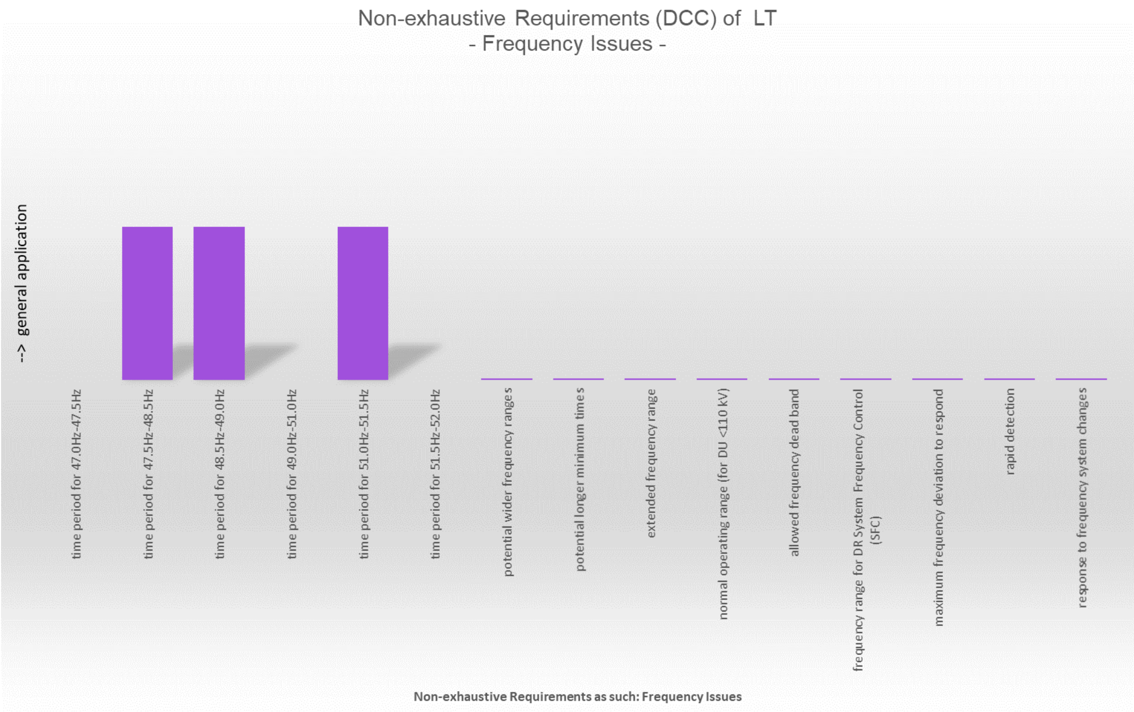


Figure 217: Lithuania (LT)

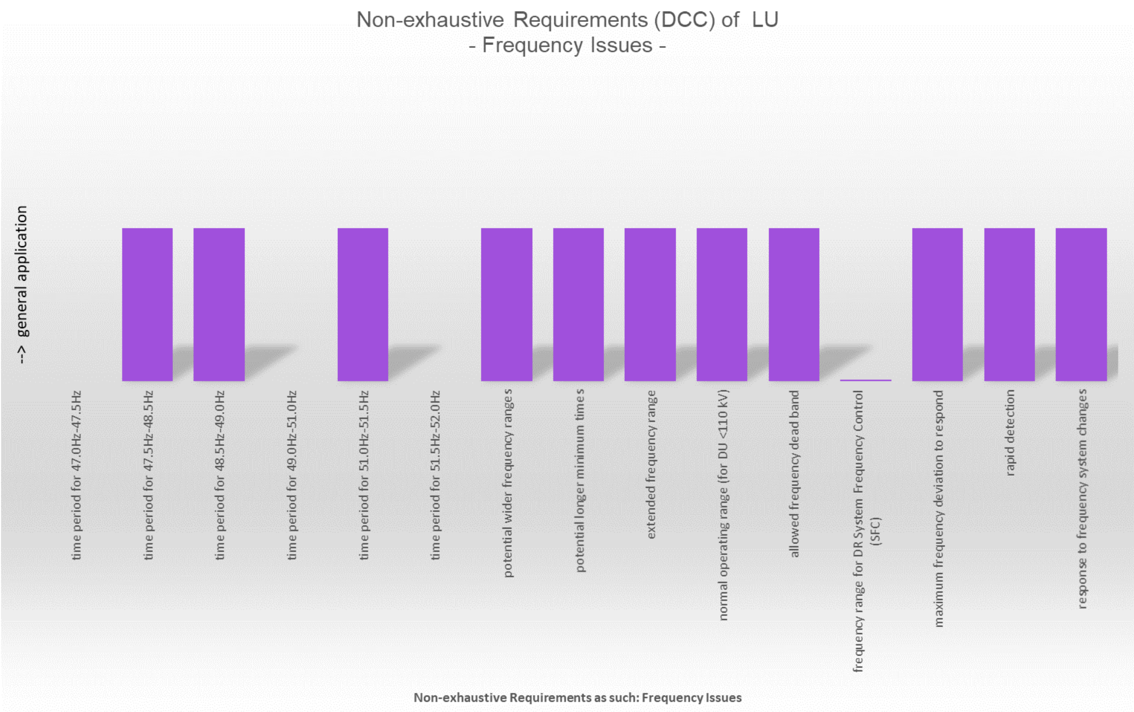


Figure 218: Luxembourg (LU)

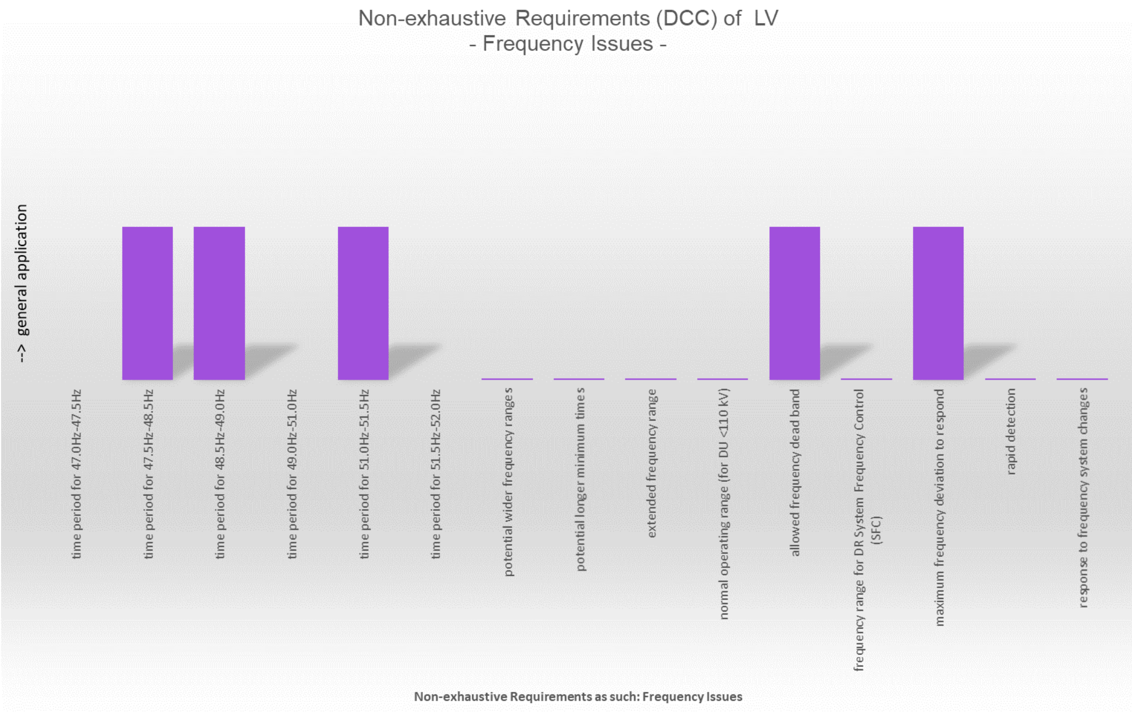


Figure 219: Latvia (LV)

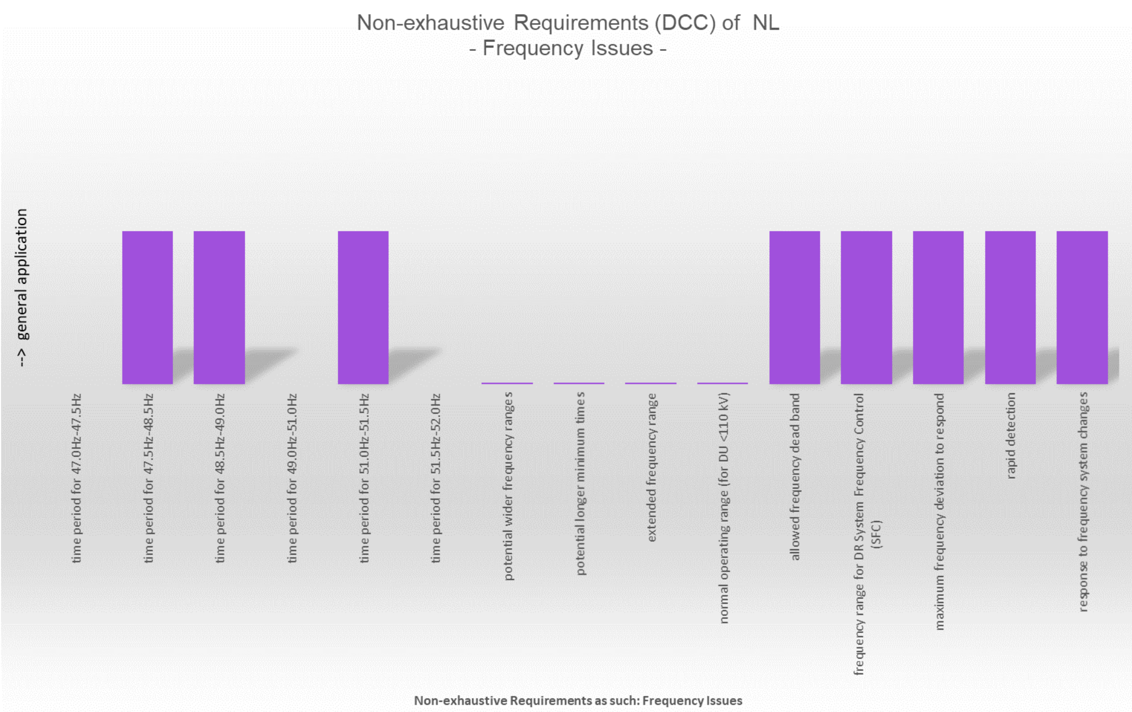


Figure 220: Netherlands (NL)

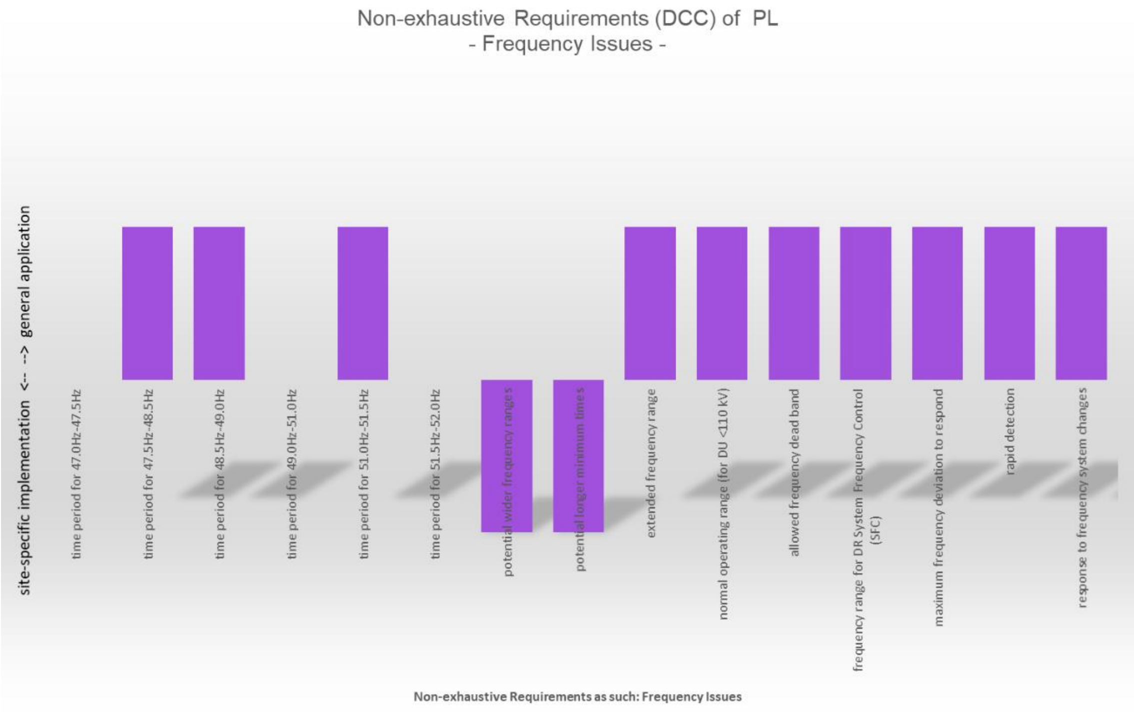


Figure 221: Poland (PL)

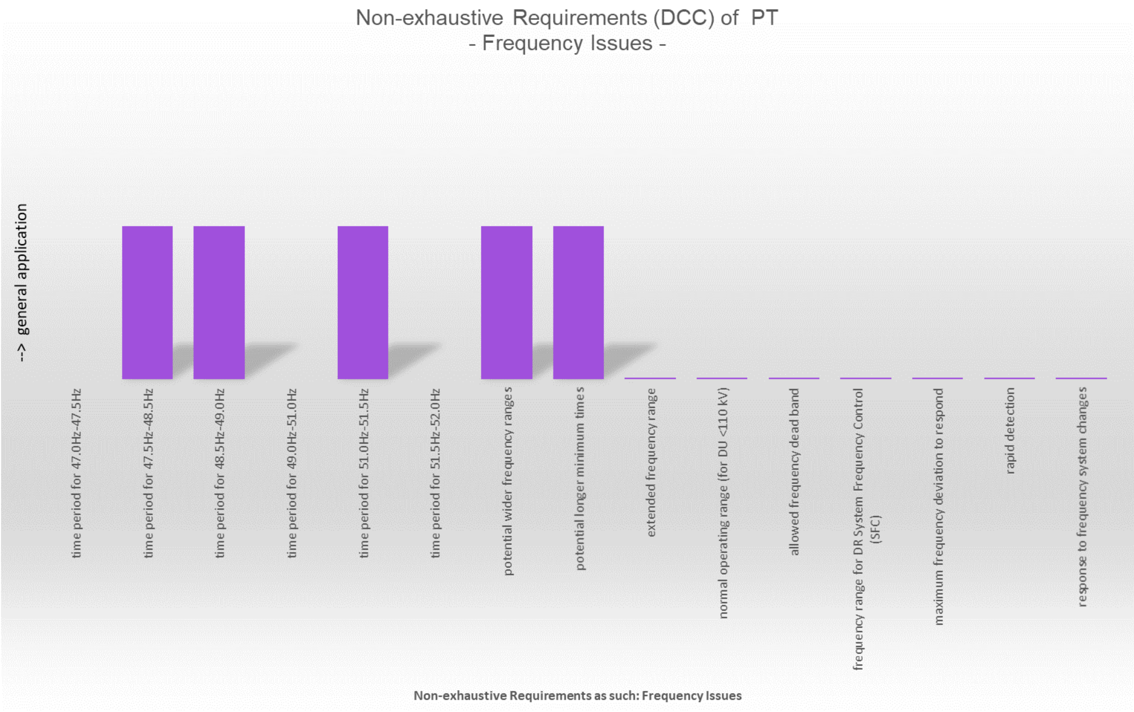


Figure 222: Portugal (PT)

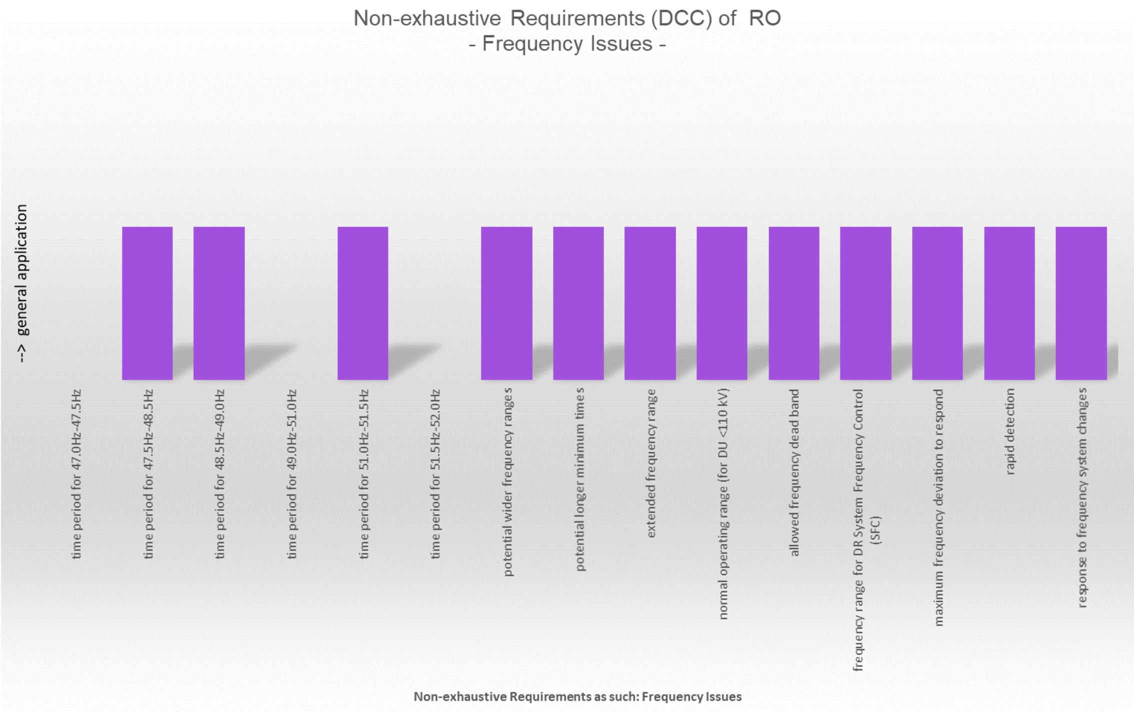


Figure 223: Romania (RO)

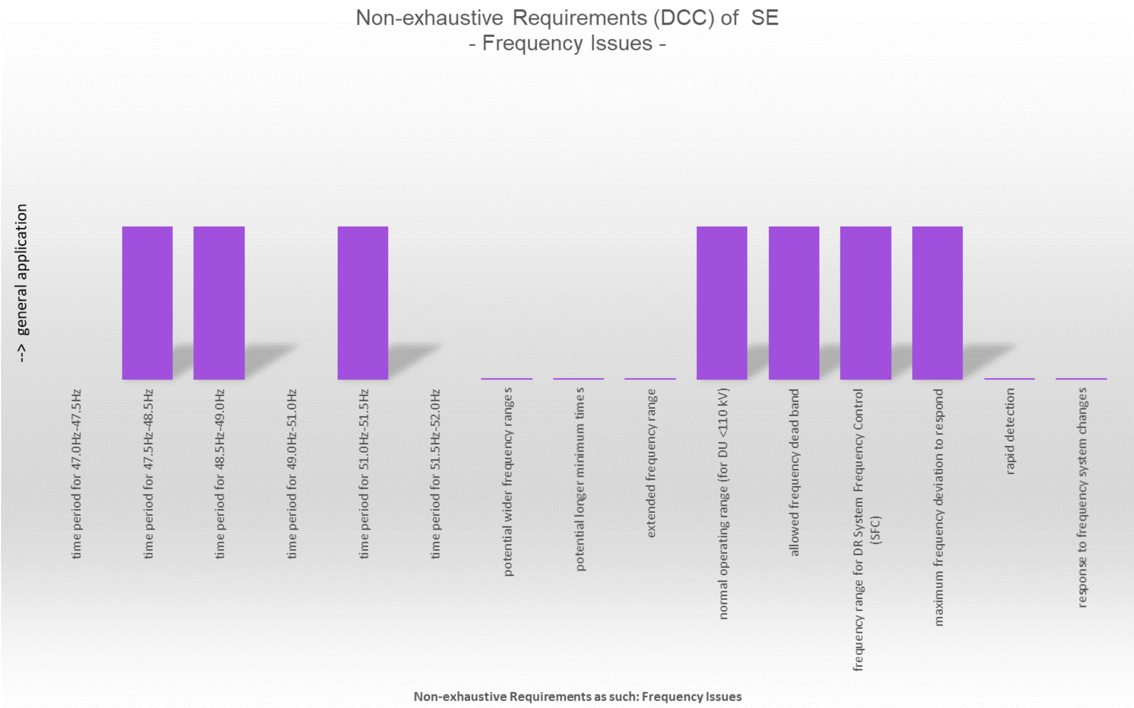


Figure 224: Sweden (SE)

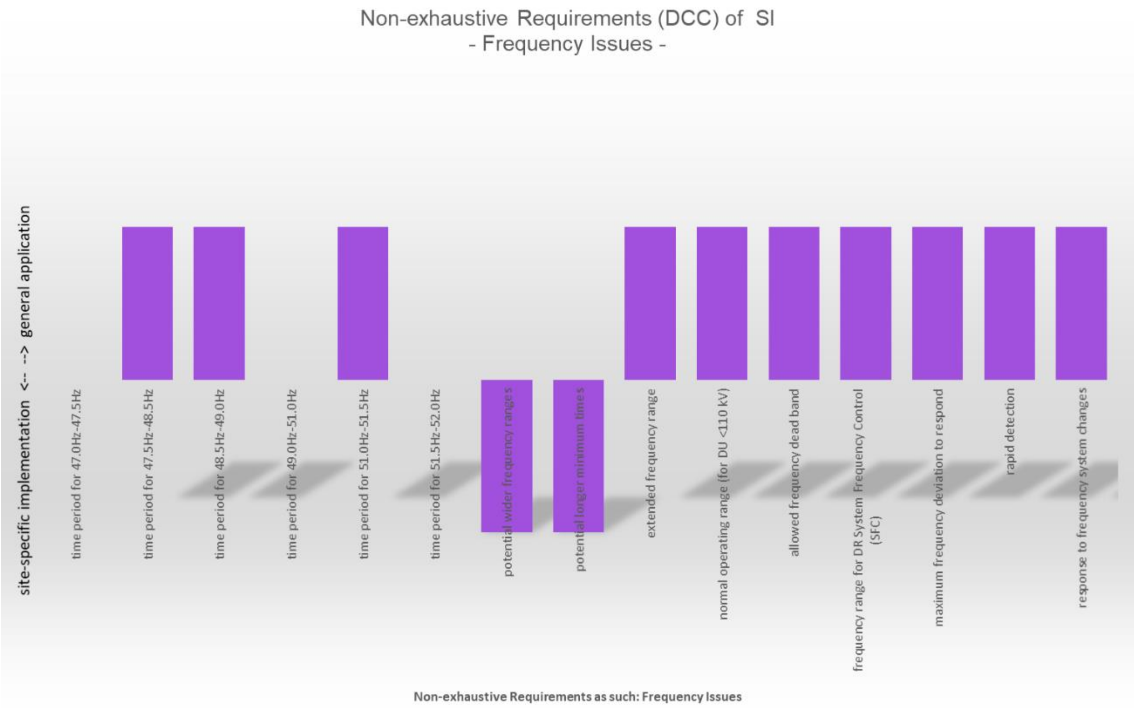


Figure 225: Slovenia (SI)

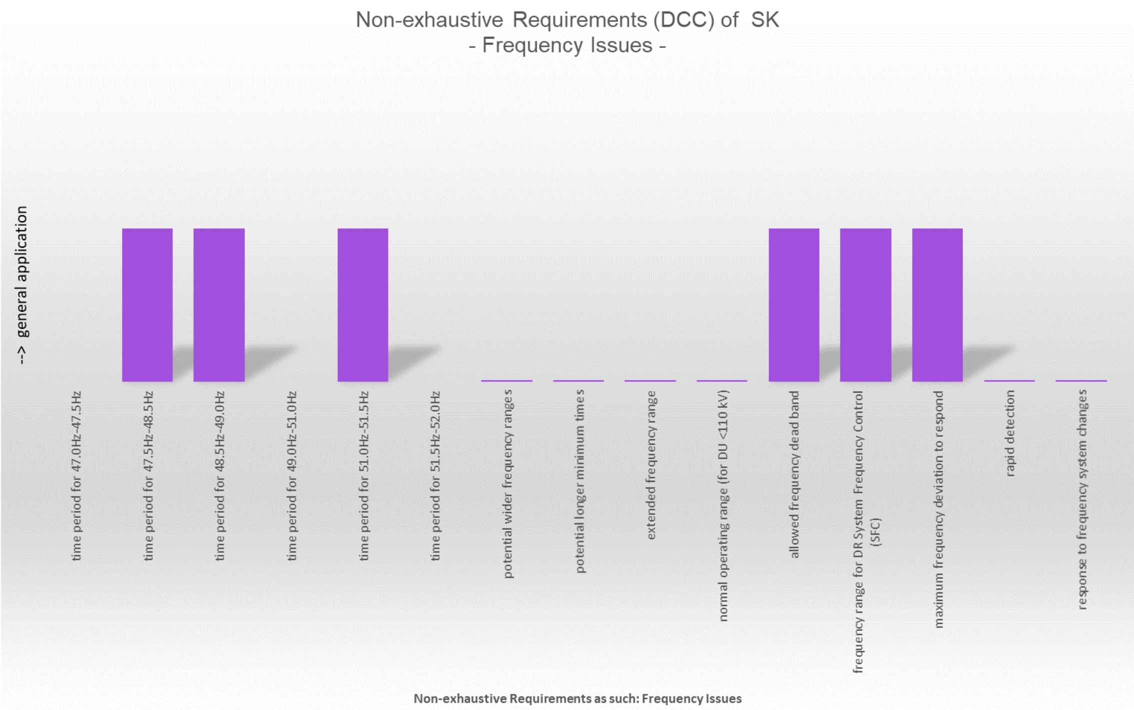


Figure 226: Slovakia (SK)

4.3 Voltage Issues of NC DCC

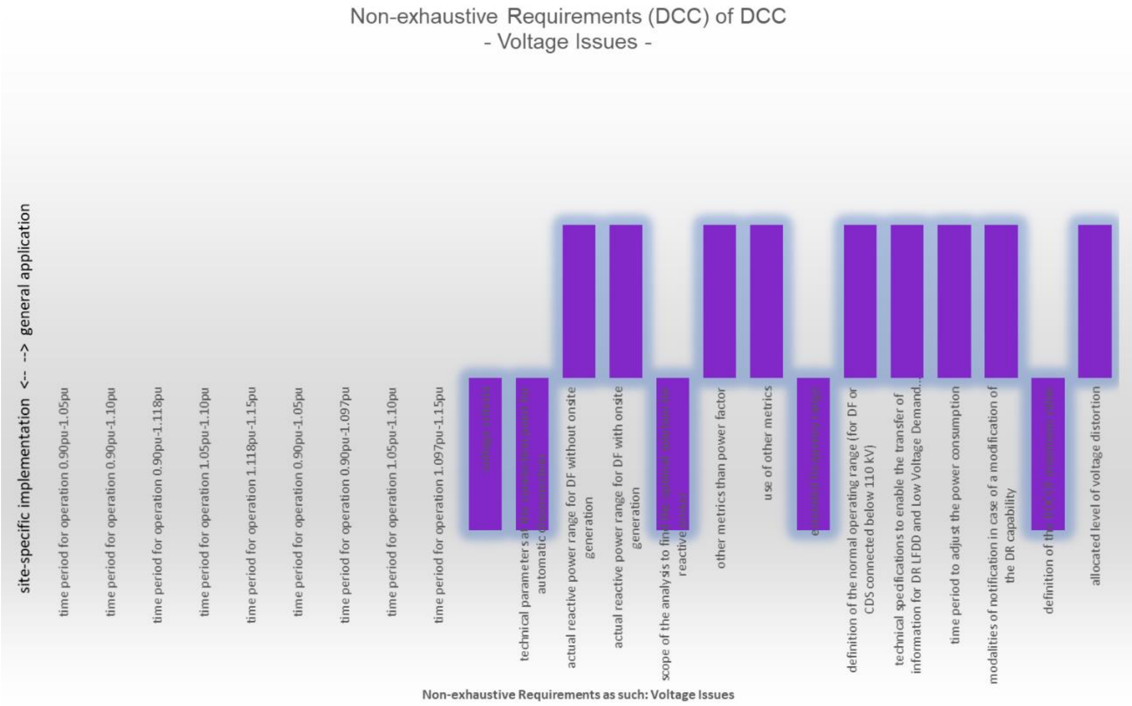


Figure 227: Reference values of non-exhaustive DCC – voltage issues

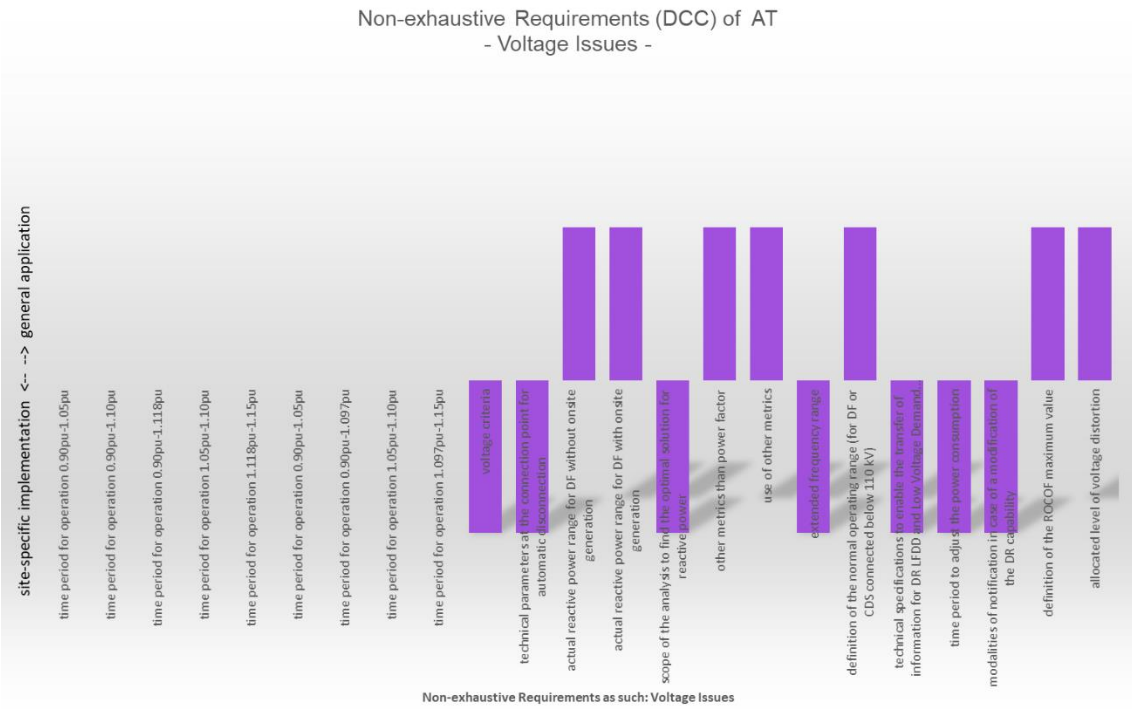


Figure 228: Austria (AT)

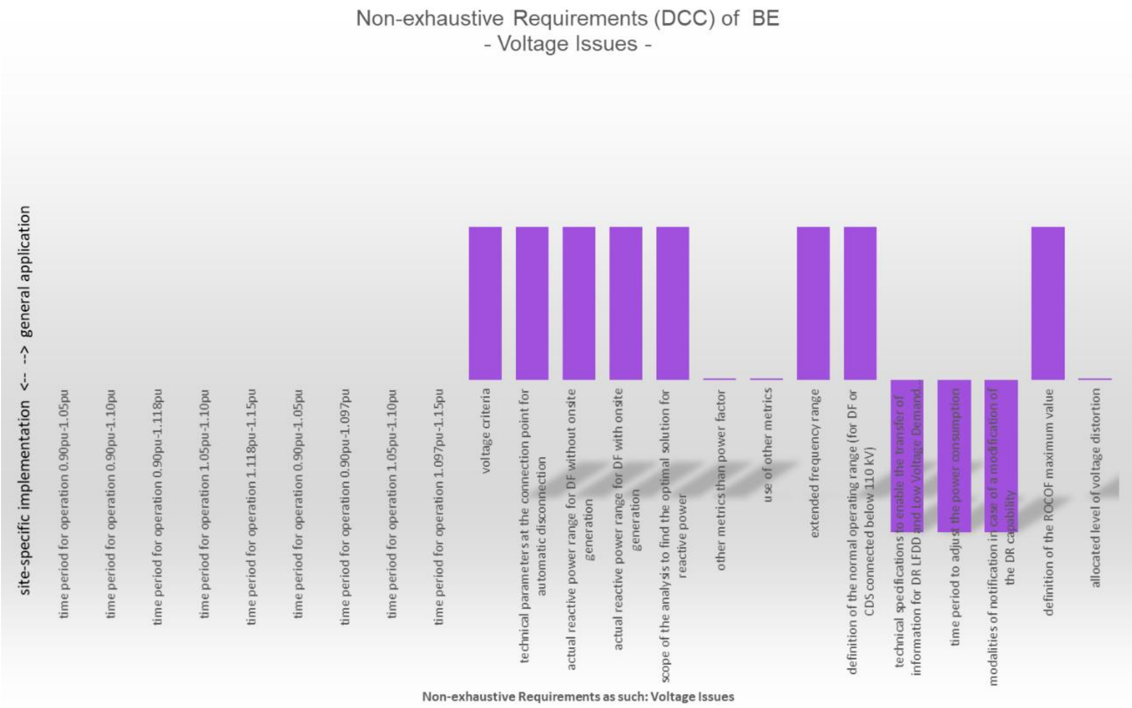


Figure 229: Belgium (BE)

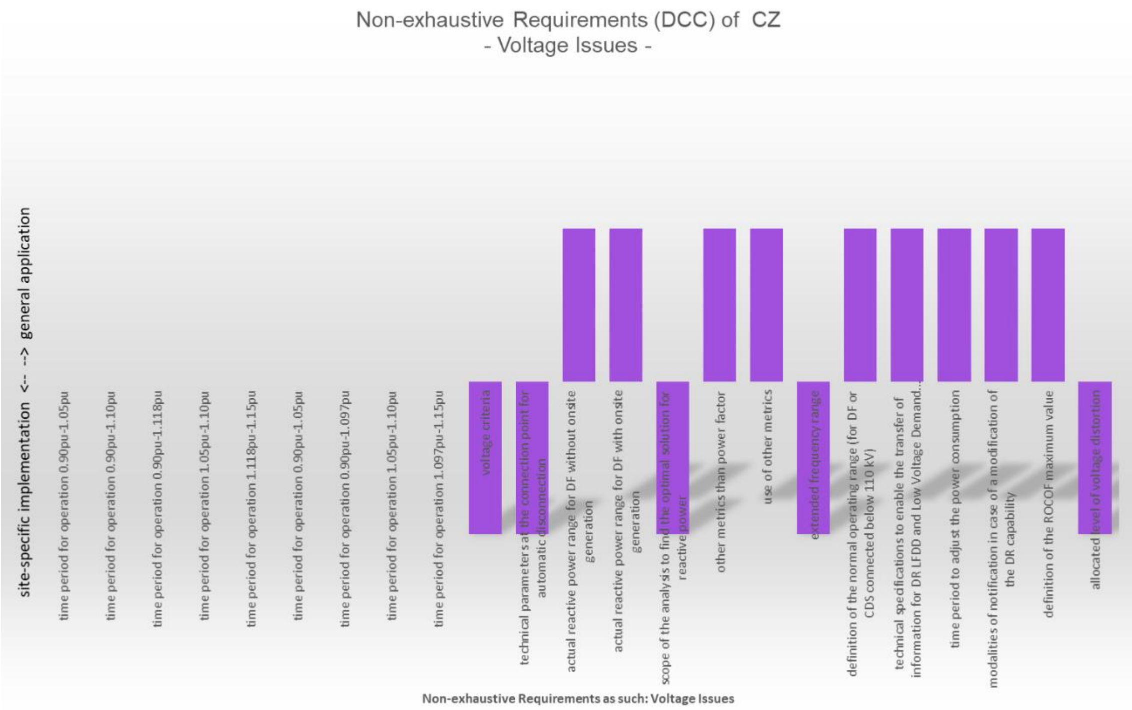


Figure 230: Czech Republic (CZ)

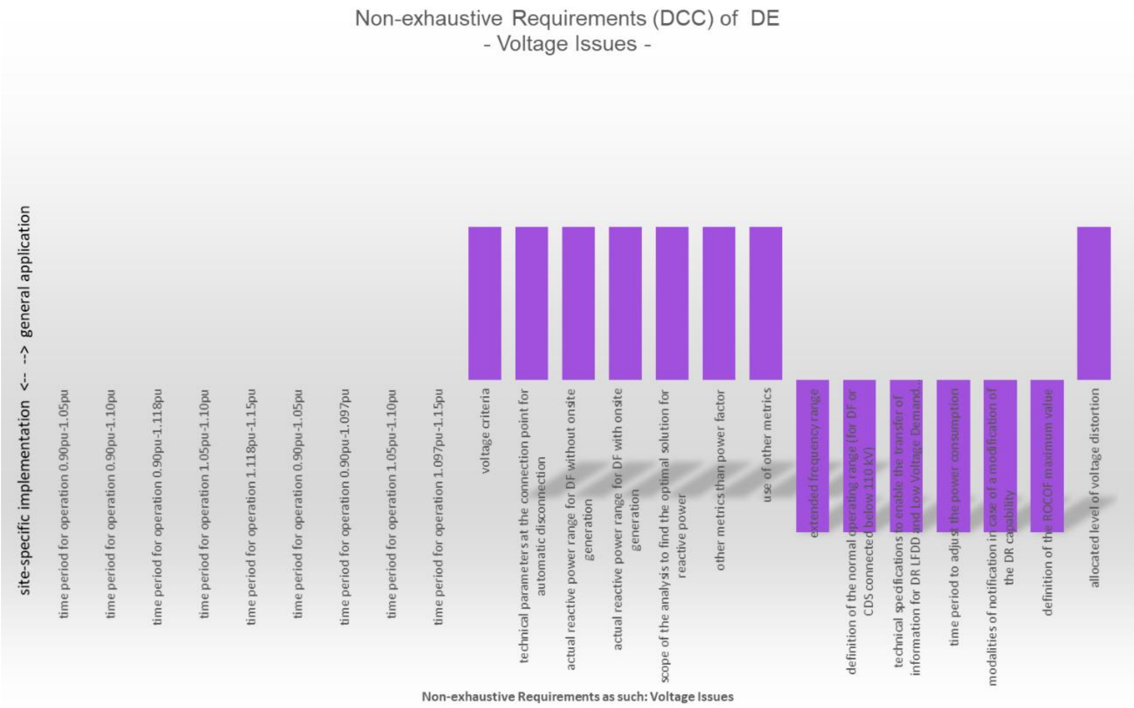


Figure 231: Germany (DE)

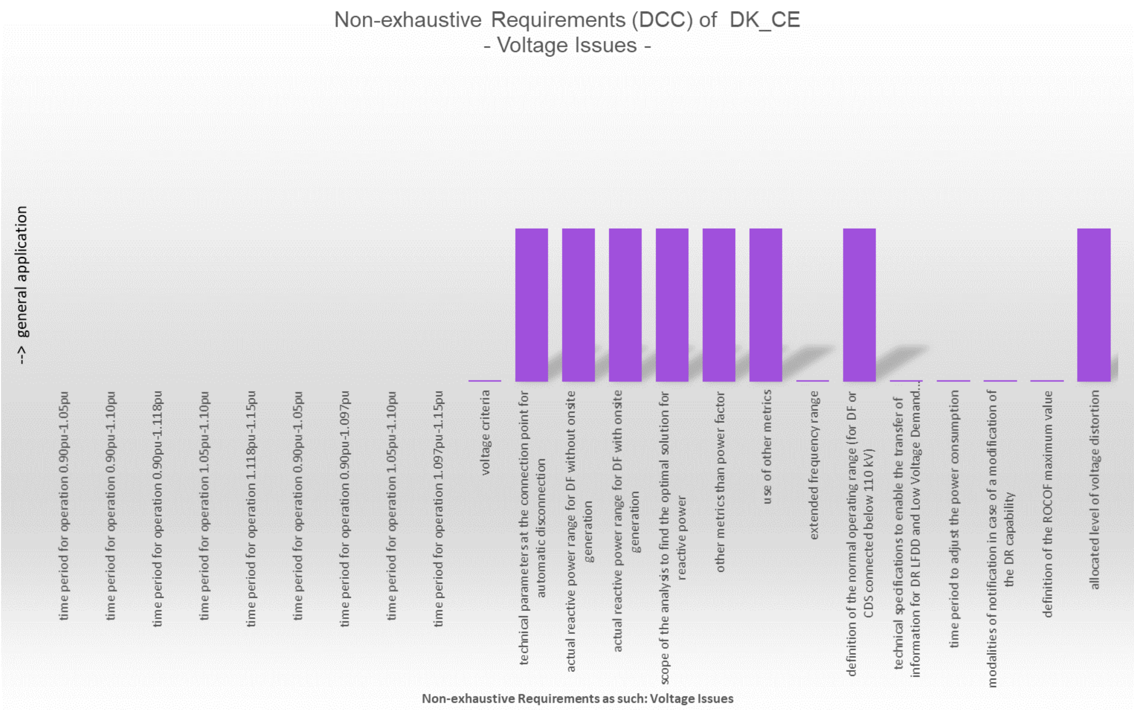


Figure 232: Denmark 1 (DK-CE)

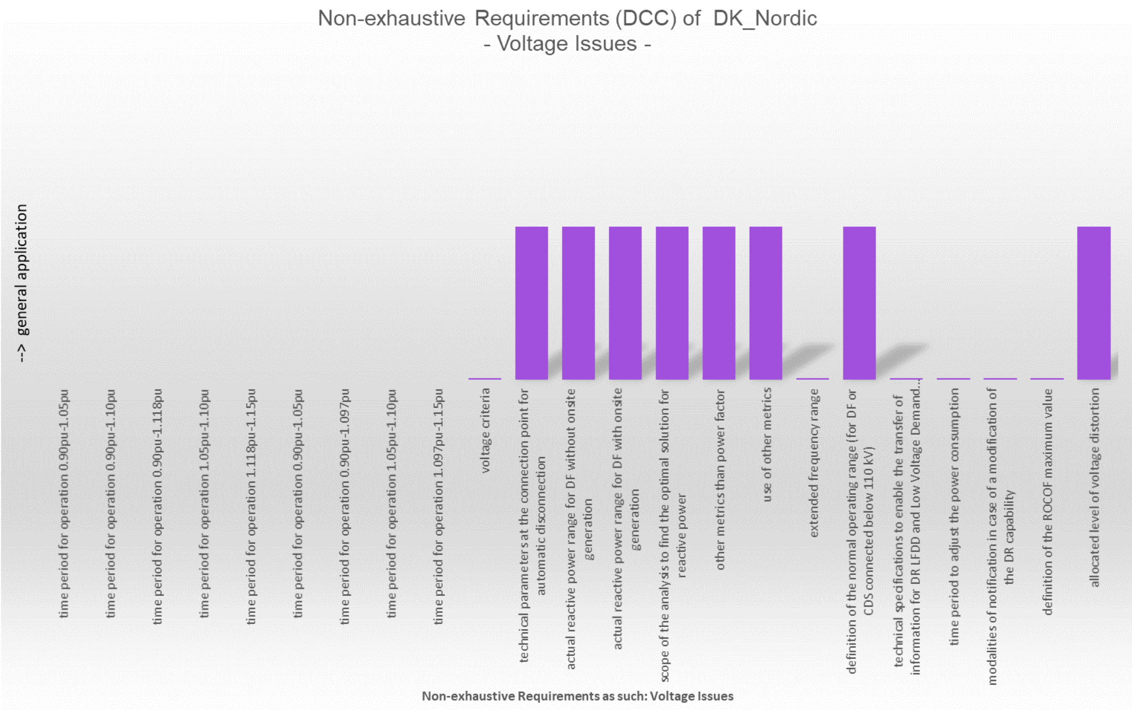


Figure 233: Denmark 2 (DK-Nordic)

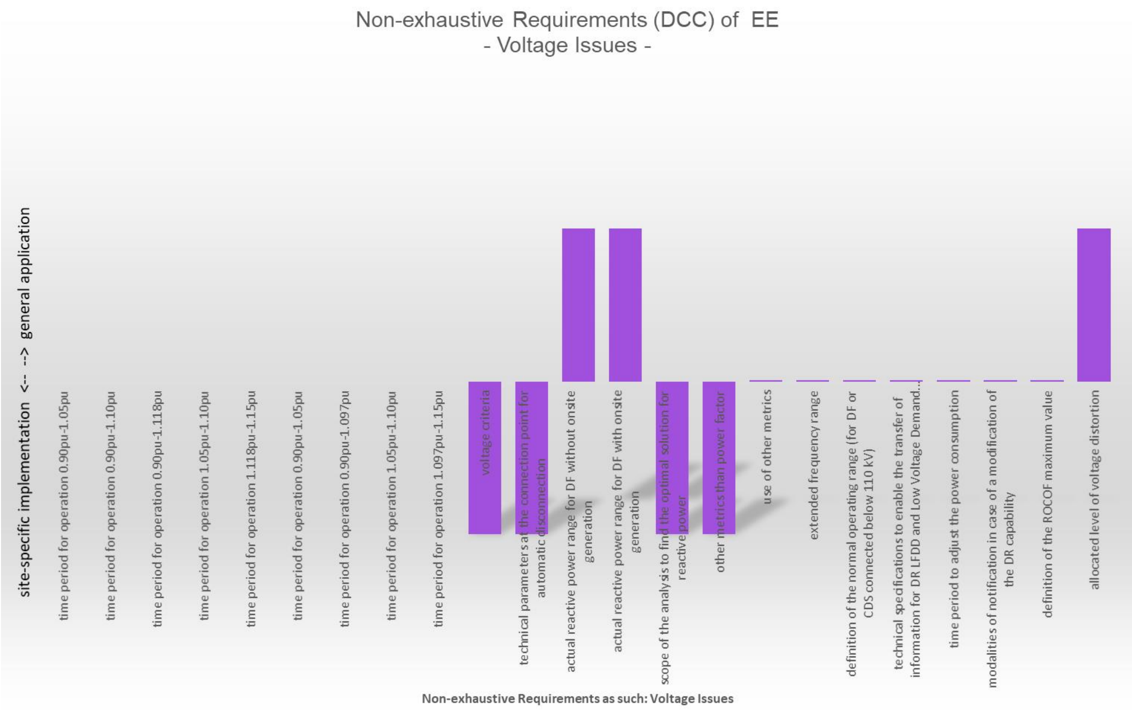


Figure 234: Estonia (EE)

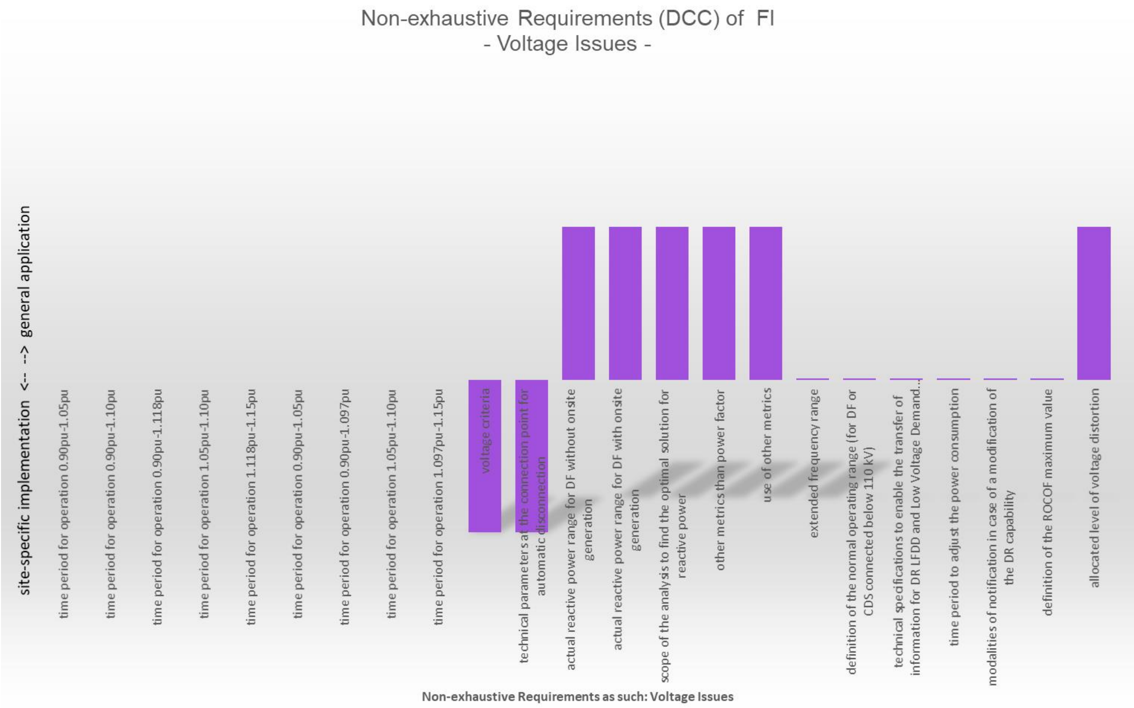


Figure 235: Finland (FI)

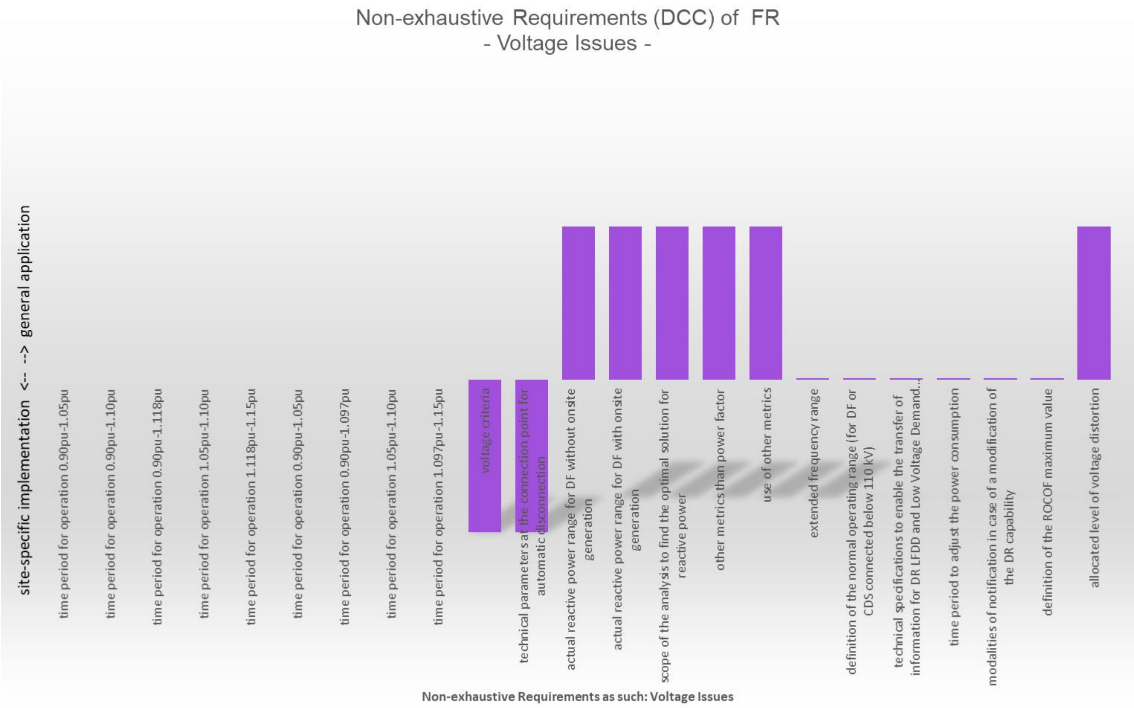


Figure 236: France (FR)

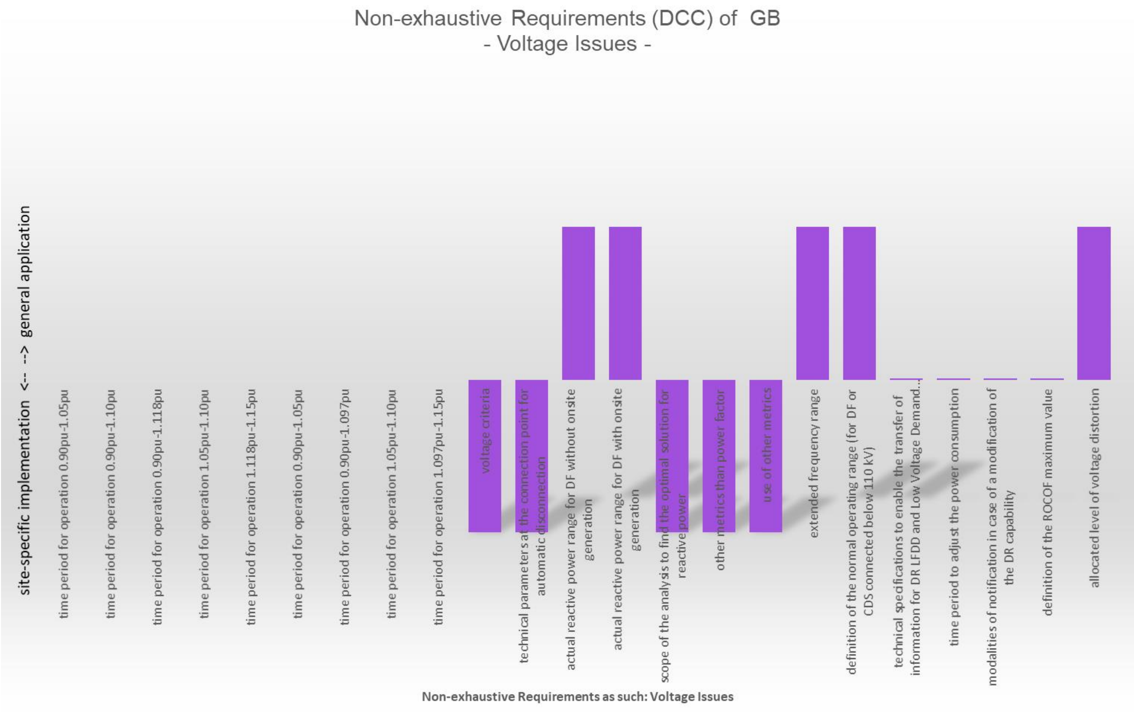


Figure 237: Great Britain (GB)

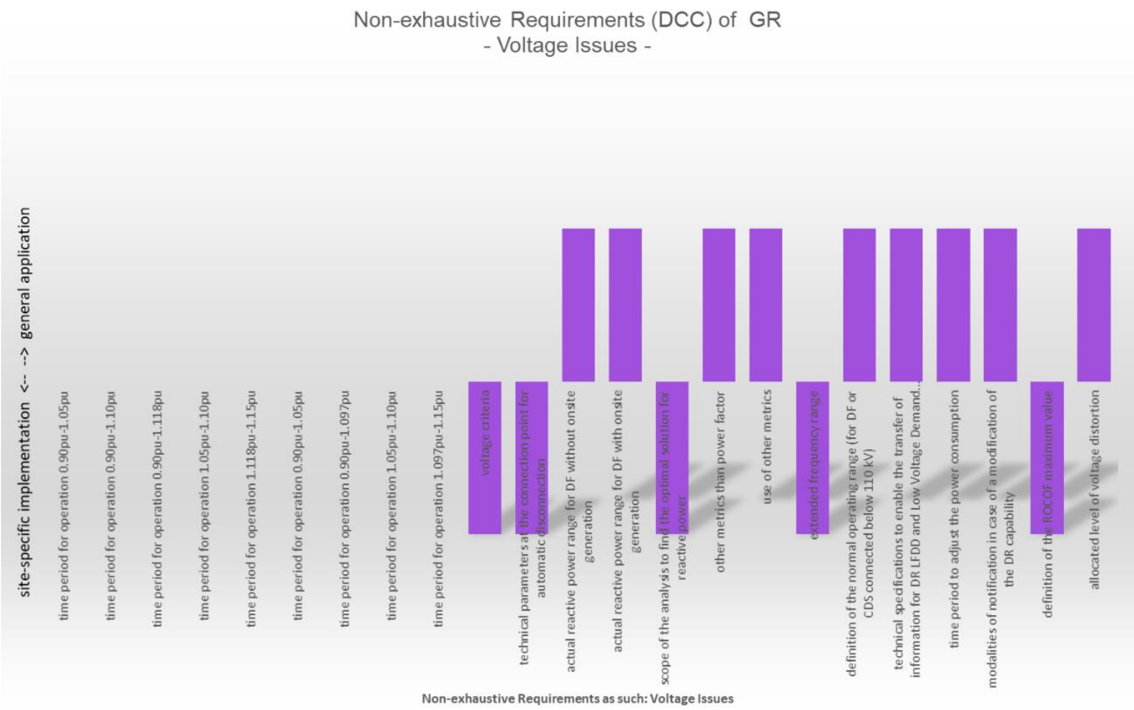


Figure 238: Greece (GR)

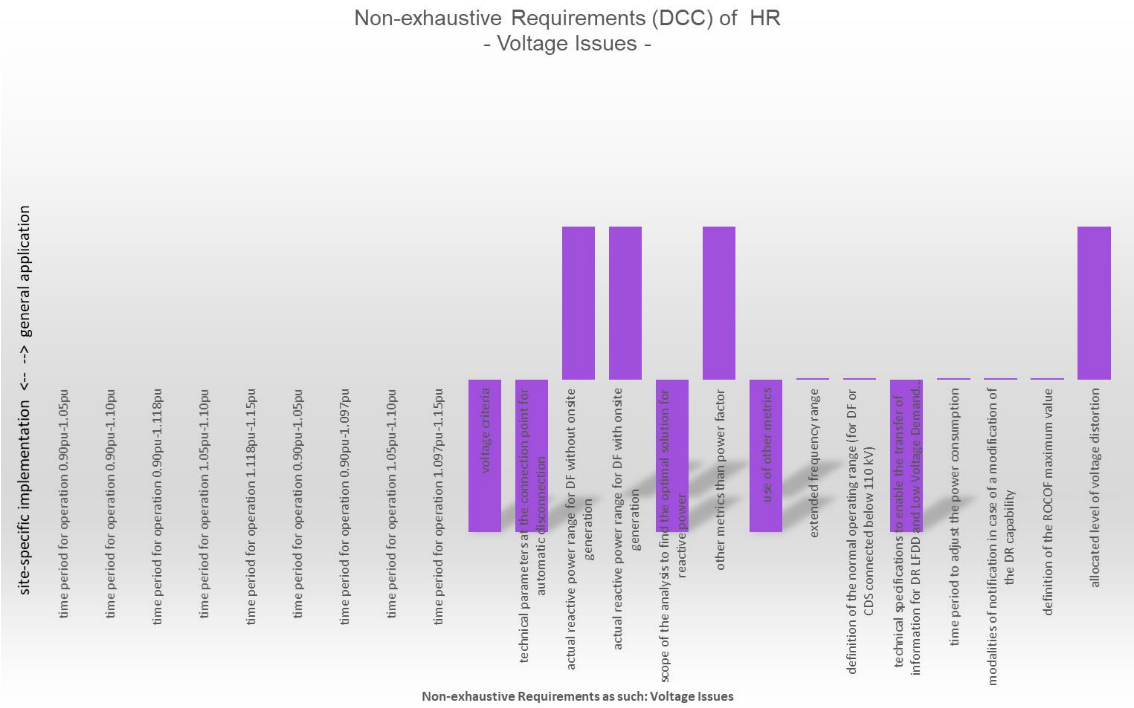


Figure 239: Croatia (HR)

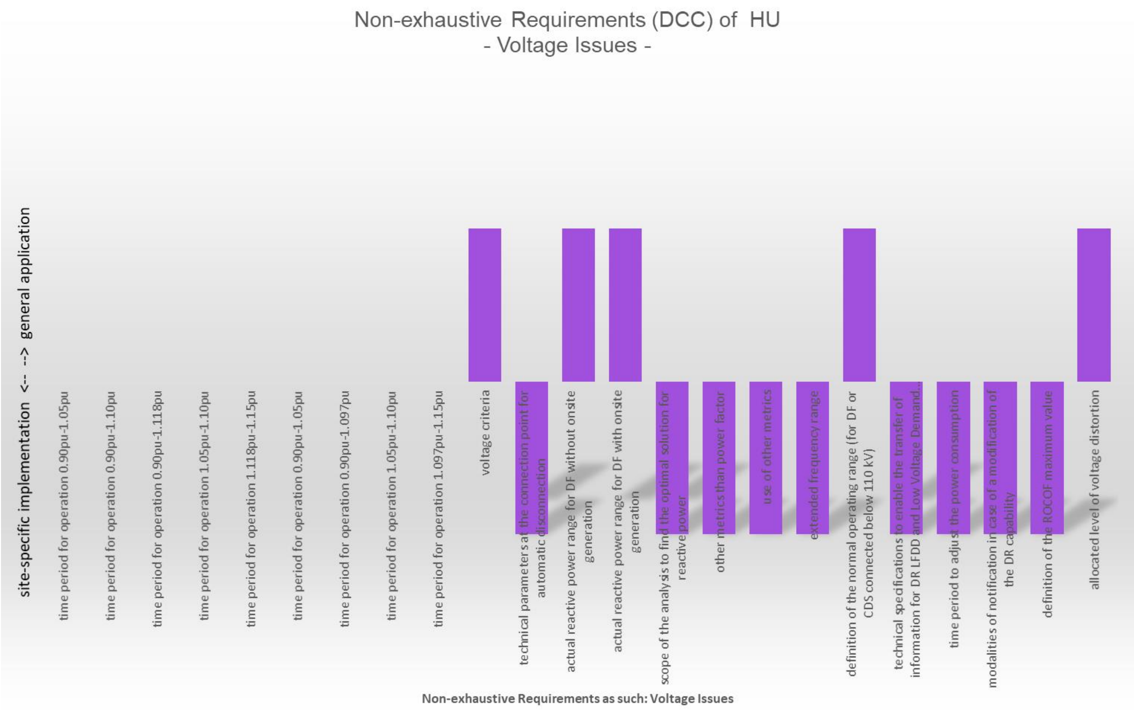


Figure 240: Hungary (HU)

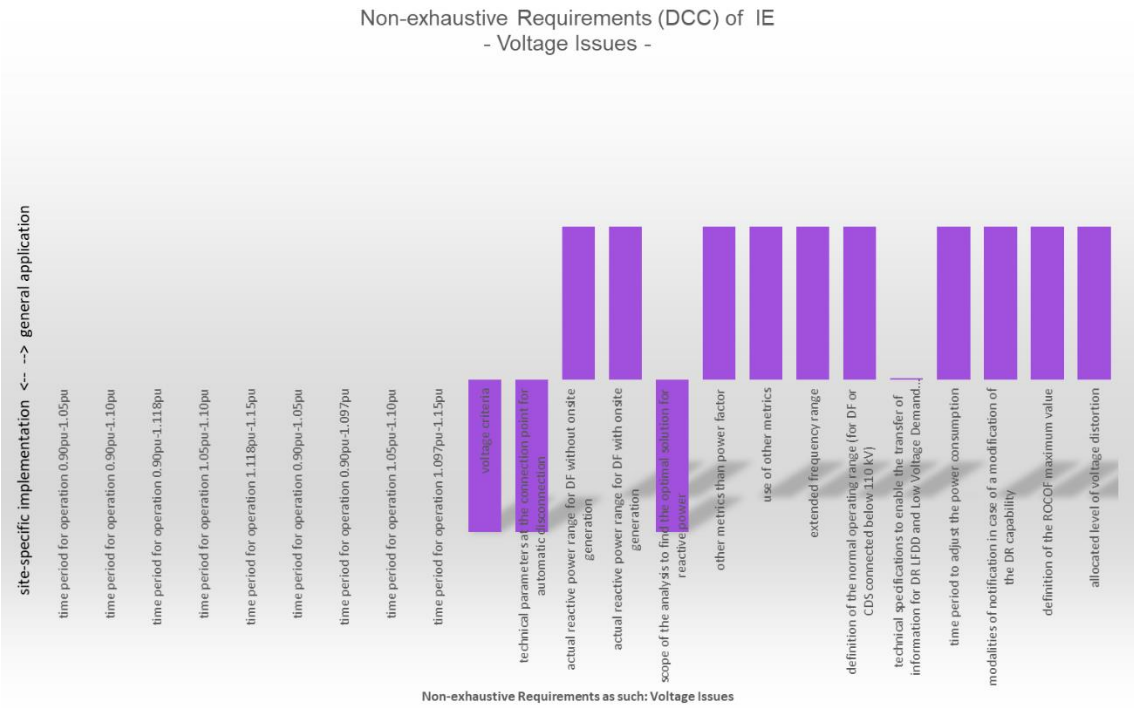


Figure 241: Ireland (IE)

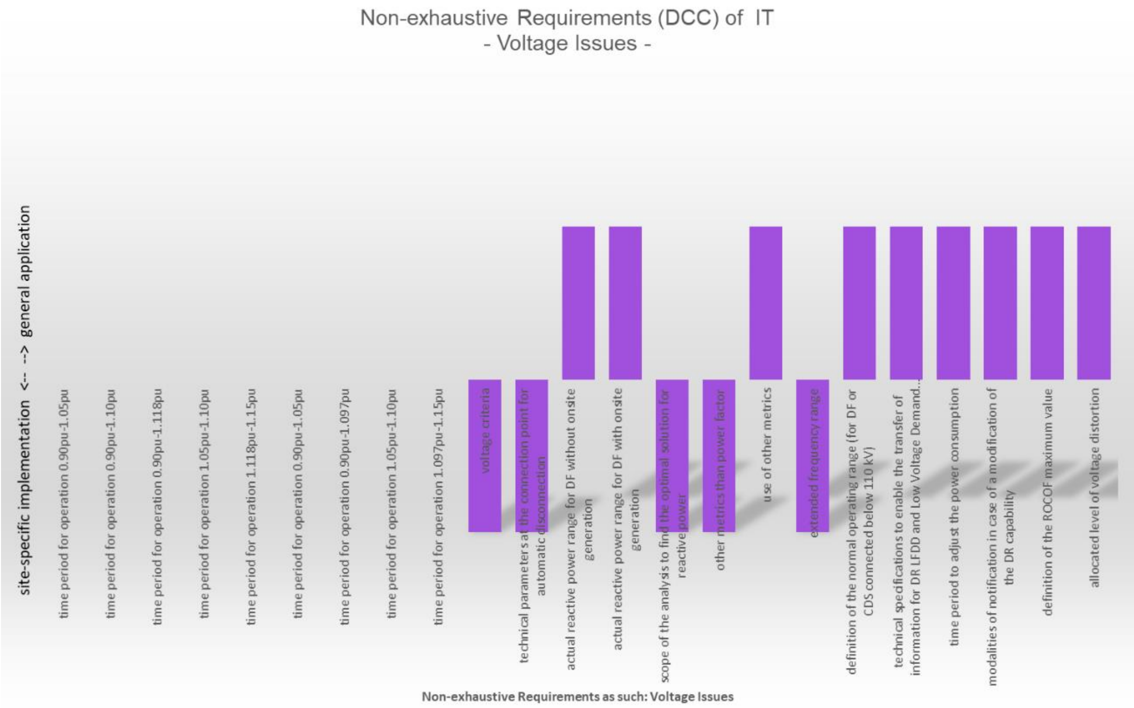


Figure 242: Italy (IT)

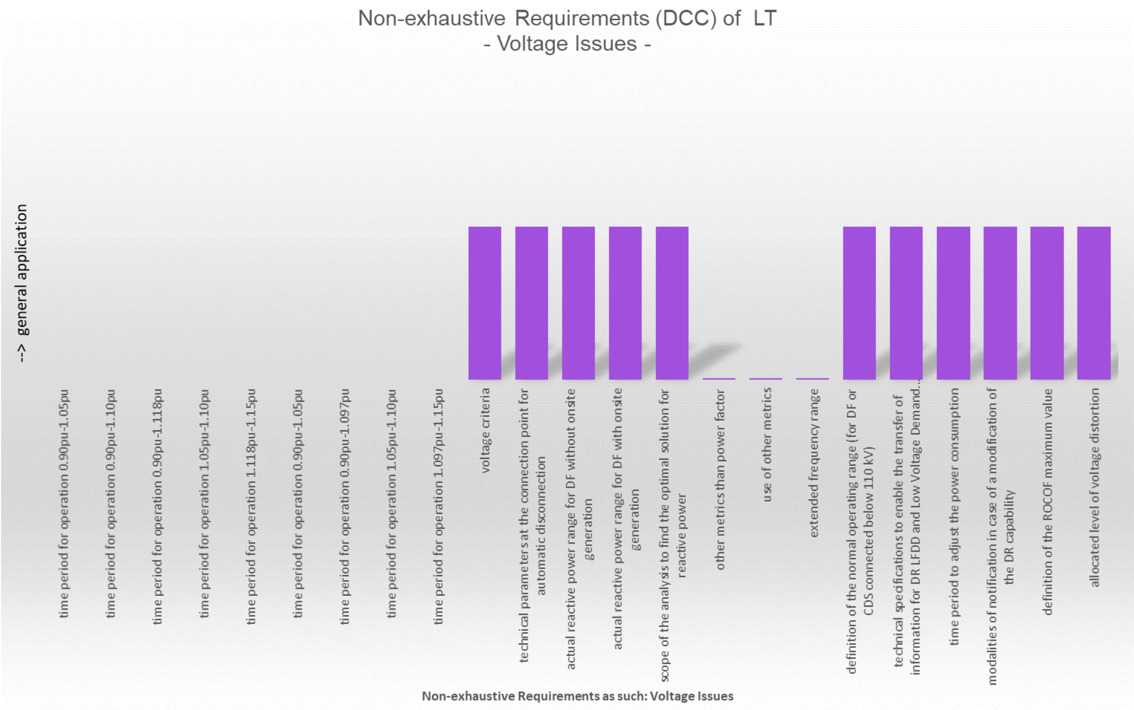


Figure 243: Lithuania (LT)

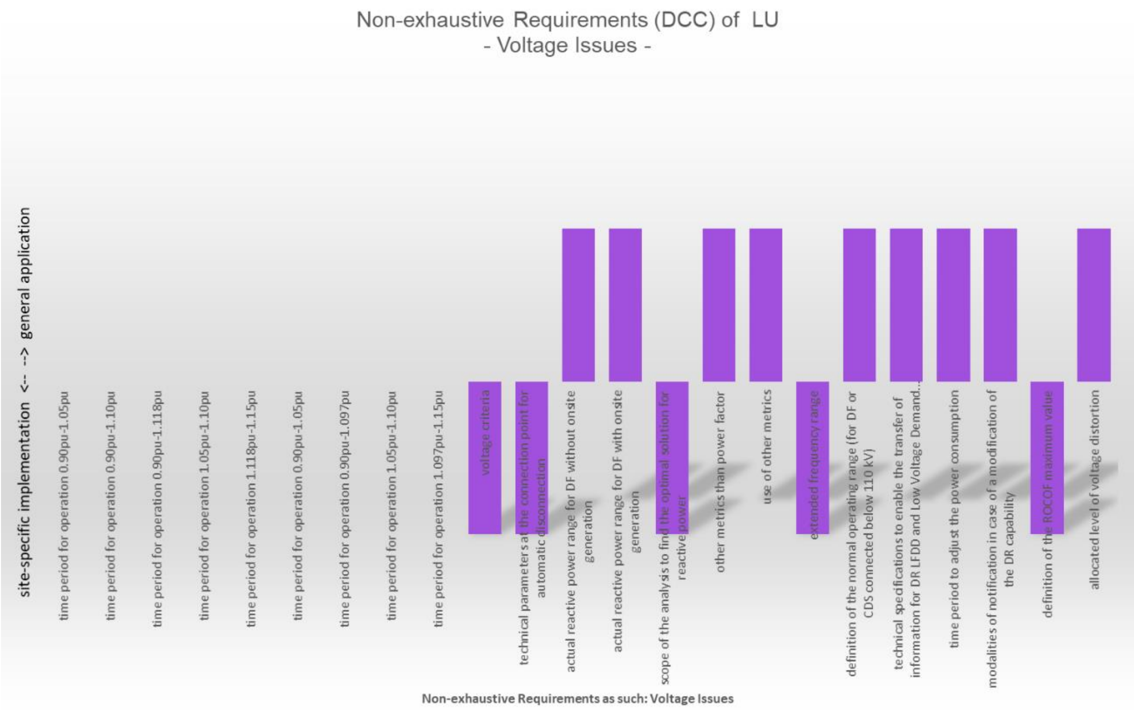


Figure 244: Luxembourg (LU)

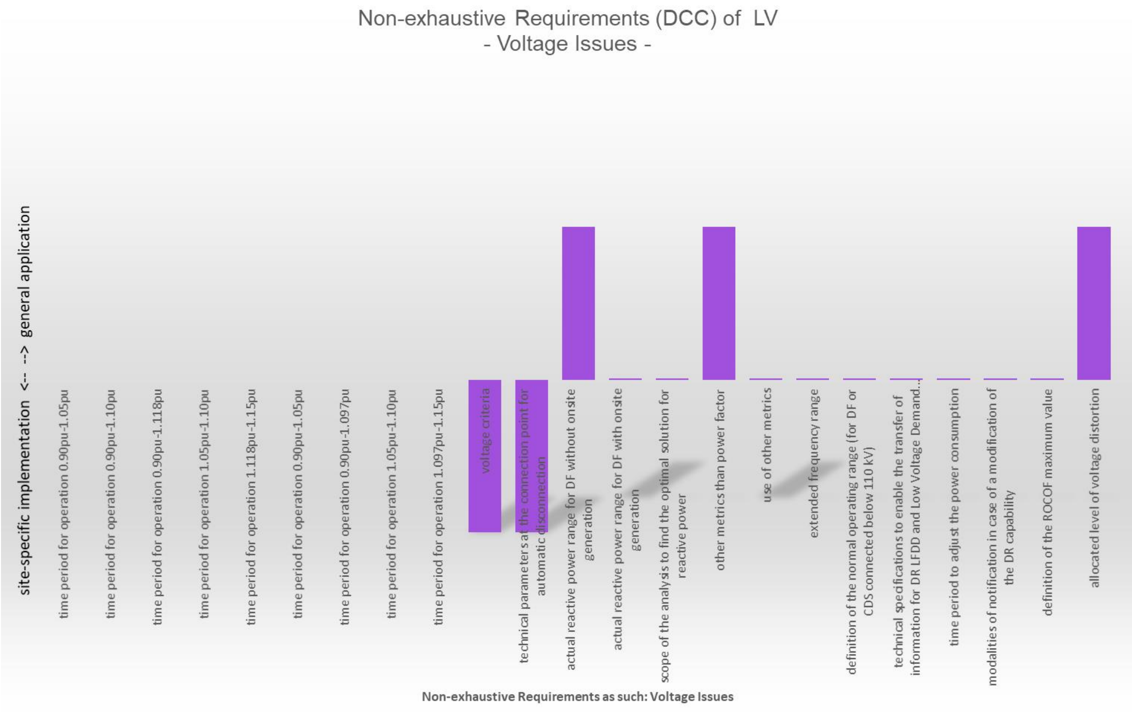


Figure 245: Latvia (LV)

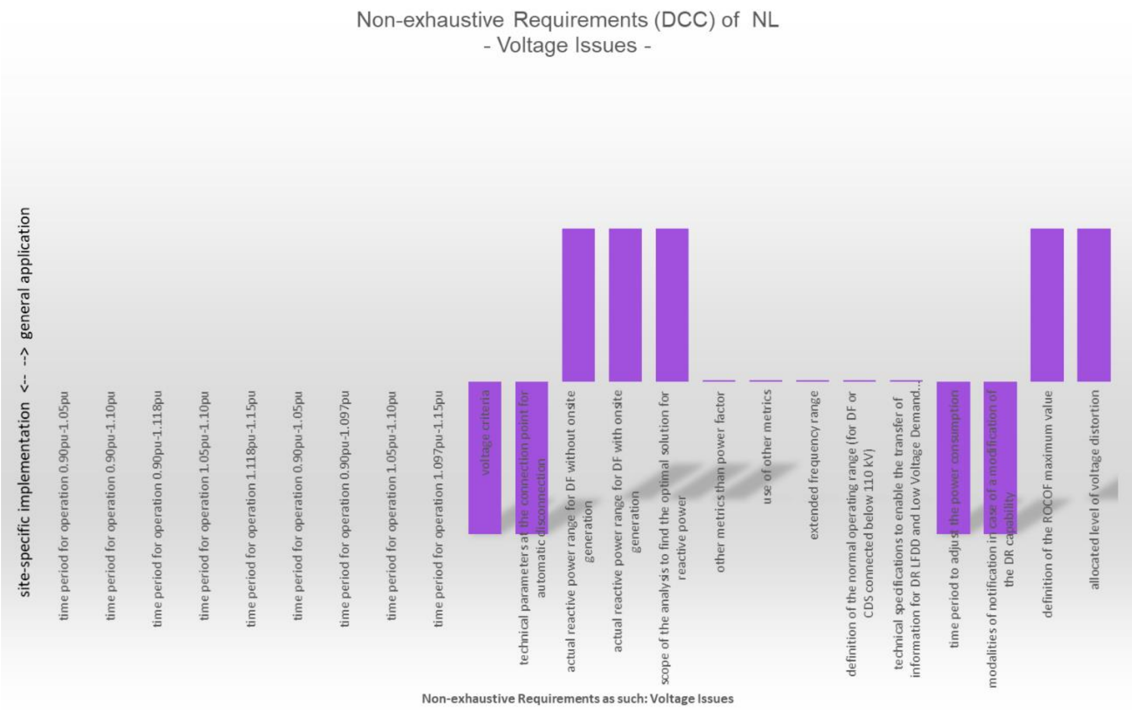


Figure 246: Netherlands (NL)

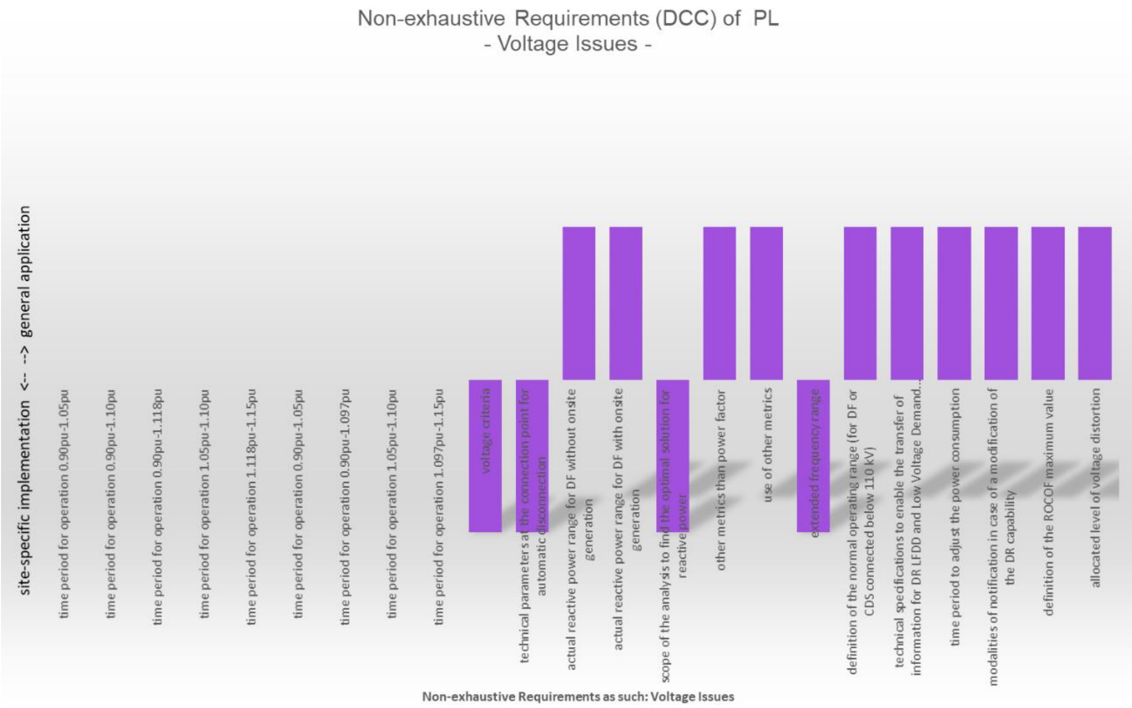


Figure 247: Poland (PL)

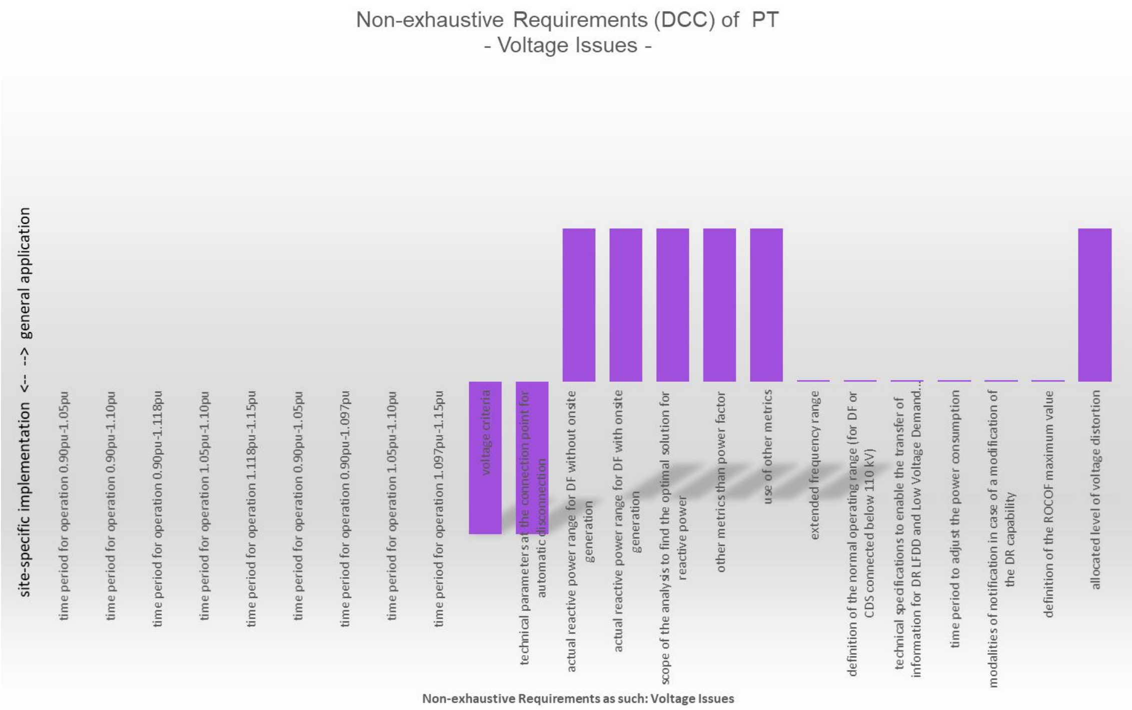


Figure 248: Portugal (PT)

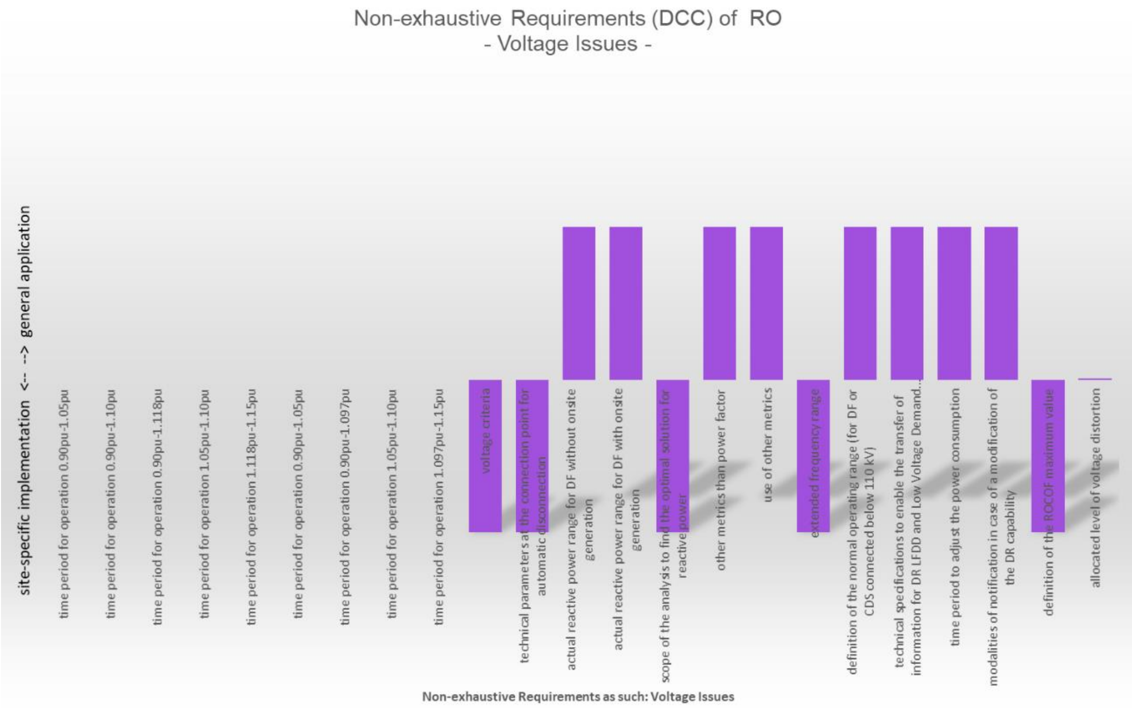


Figure 249: Romania (RO)

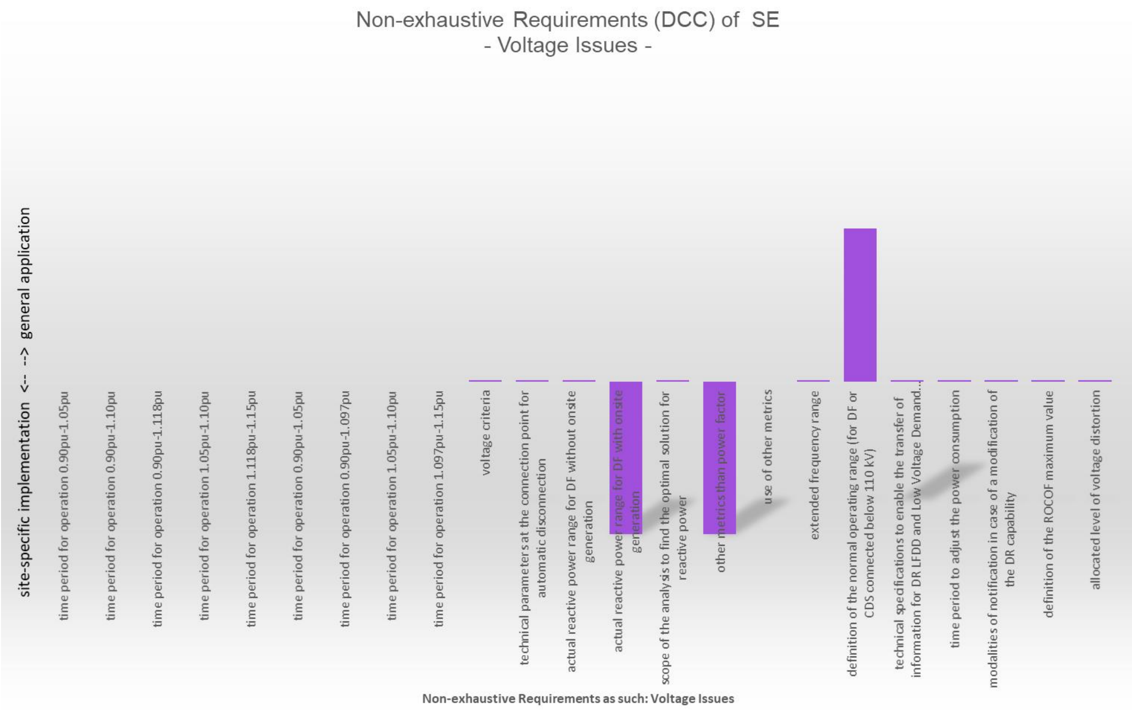


Figure 250: Sweden (SE)

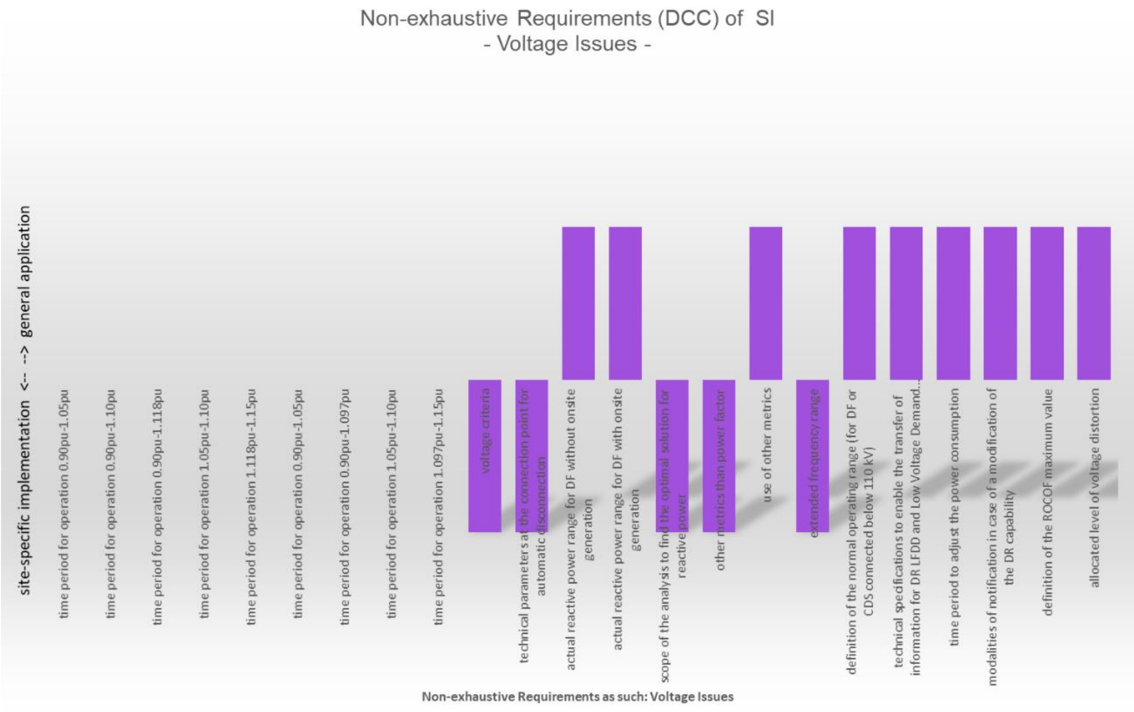


Figure 251: Slovenia (SI)

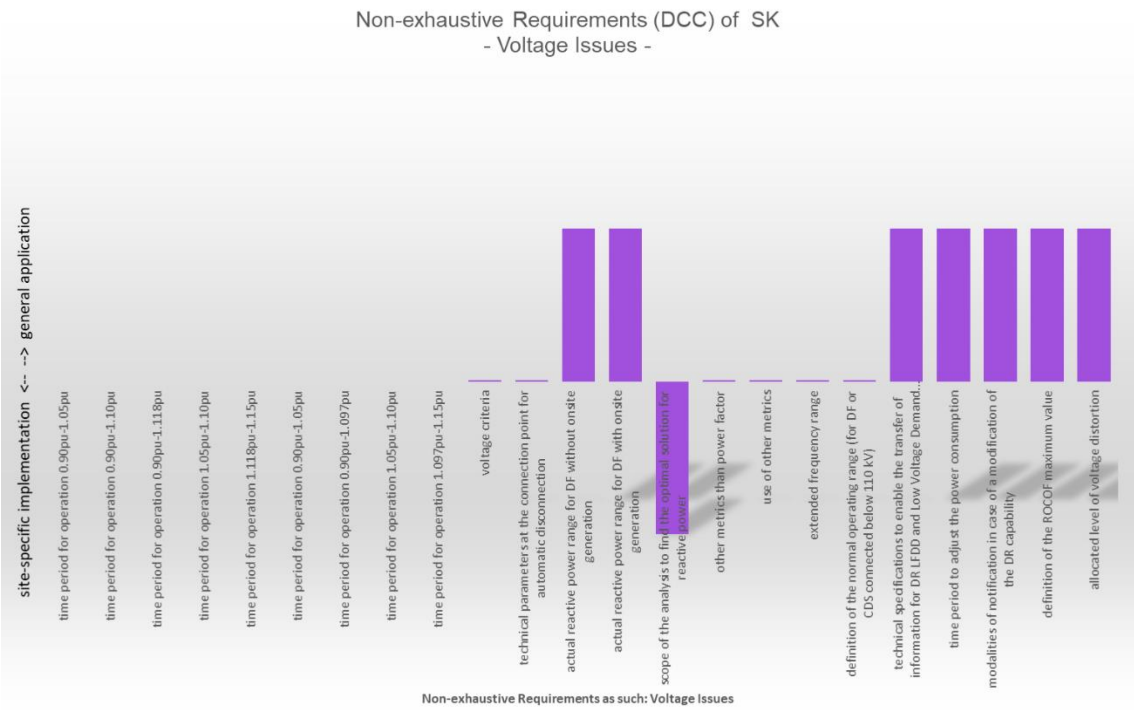


Figure 252: Slovakia (SK)

4.4 System Restoration Issues of NC DCC

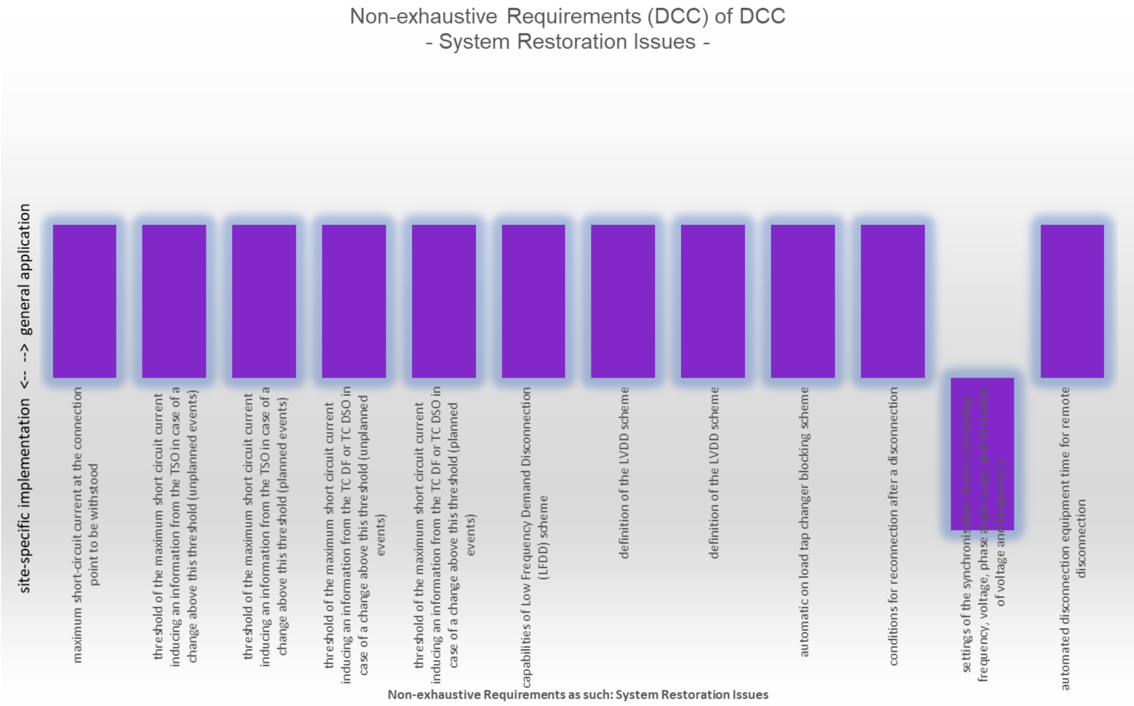


Figure 253: Reference values of non-exhaustive DCC – system restoration issues

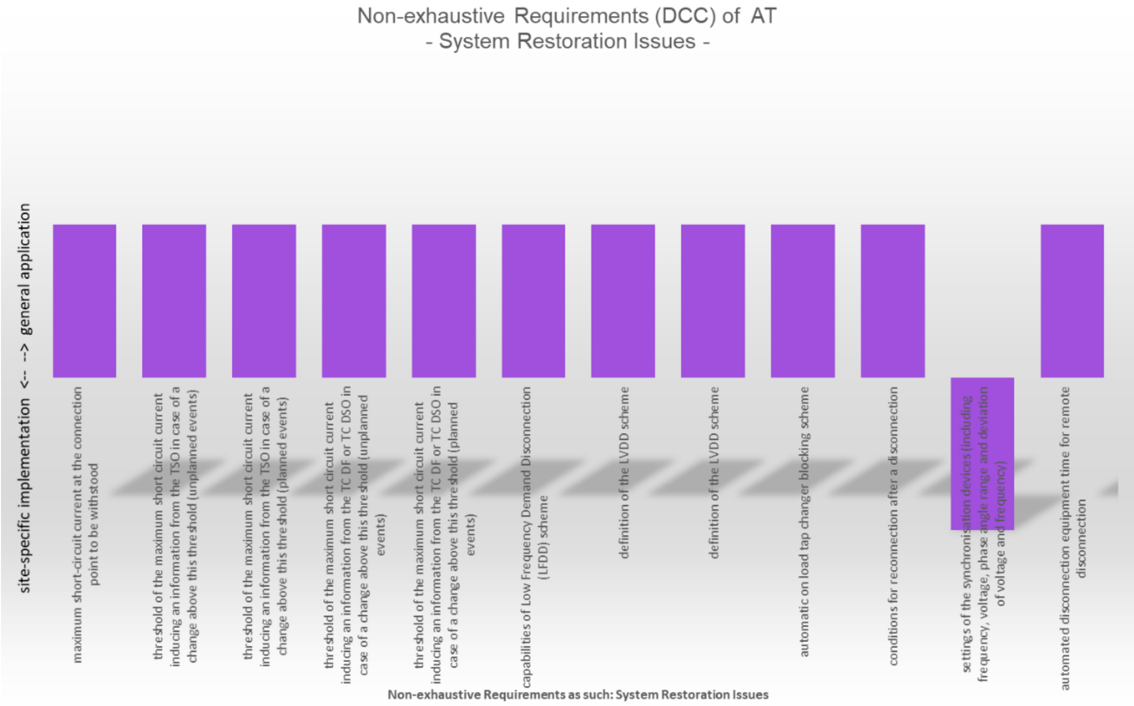


Figure 254: Austria (AT)

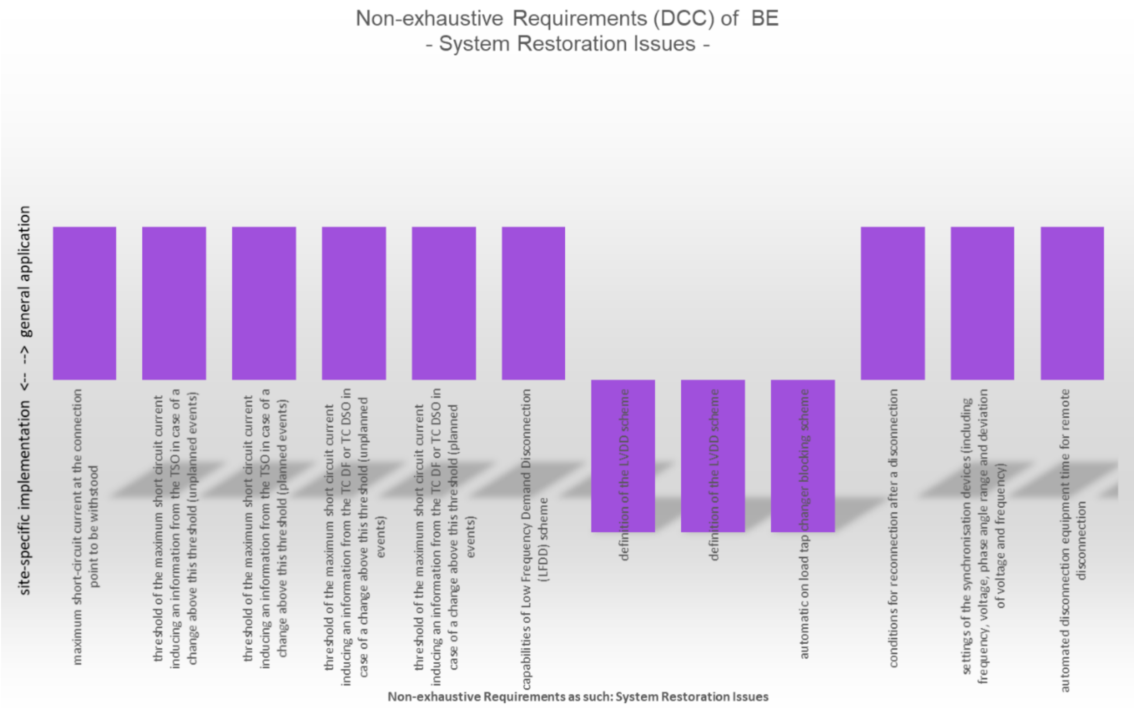


Figure 255: Belgium (BE)

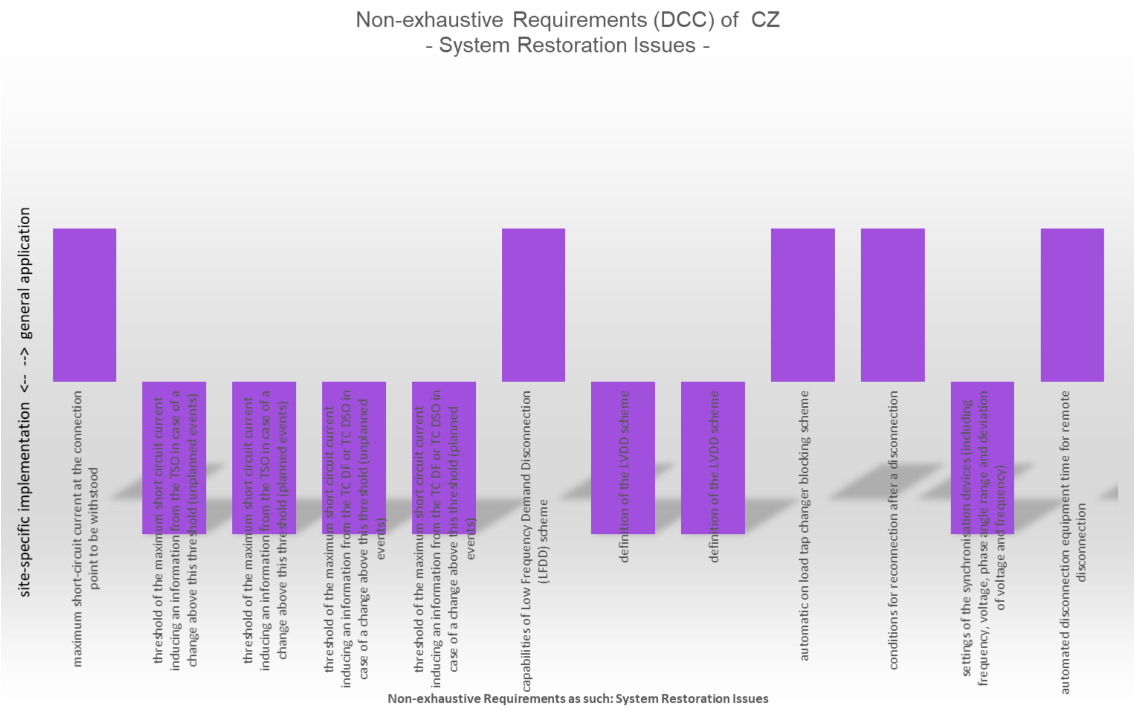


Figure 256: Czech Republic (CZ)

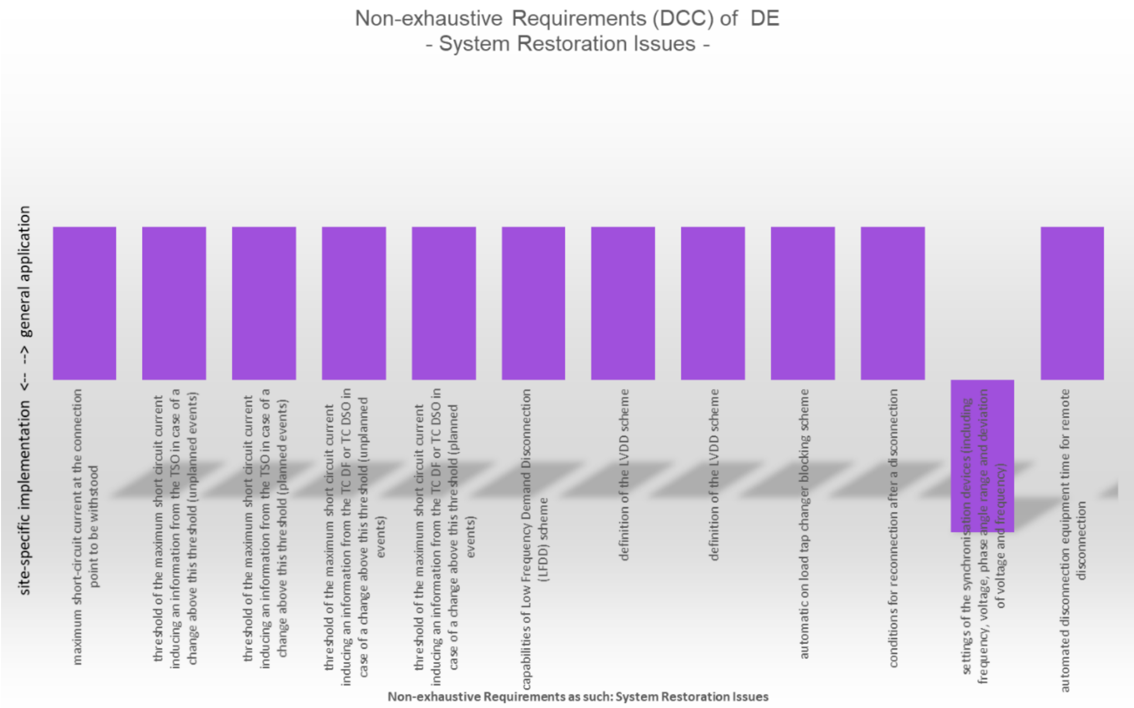


Figure 257: Germany (DE)

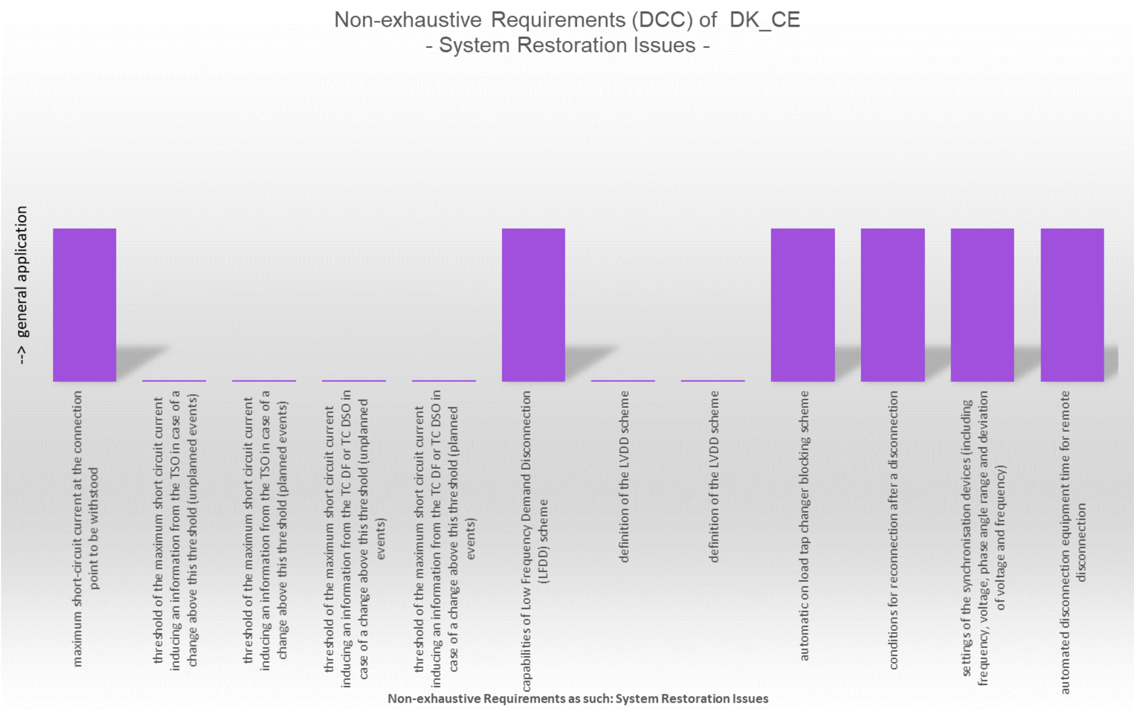


Figure 258: Denmark 1 (DK-CE)

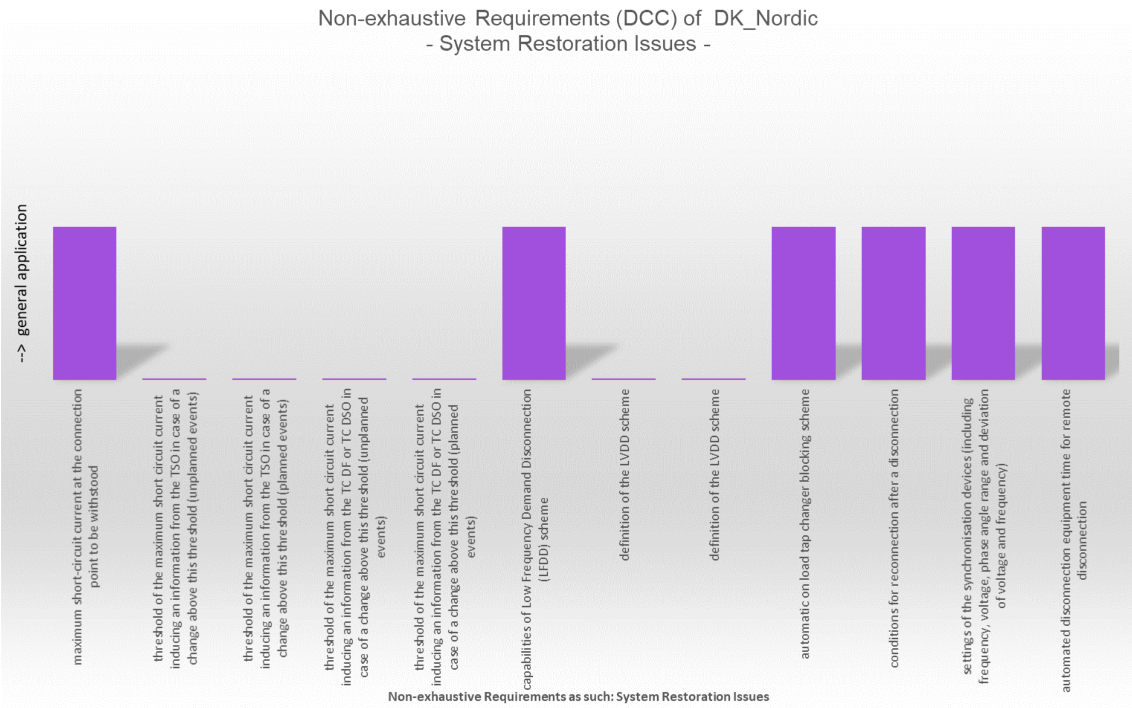


Figure 259: Denmark 2 (DK-Nordic)

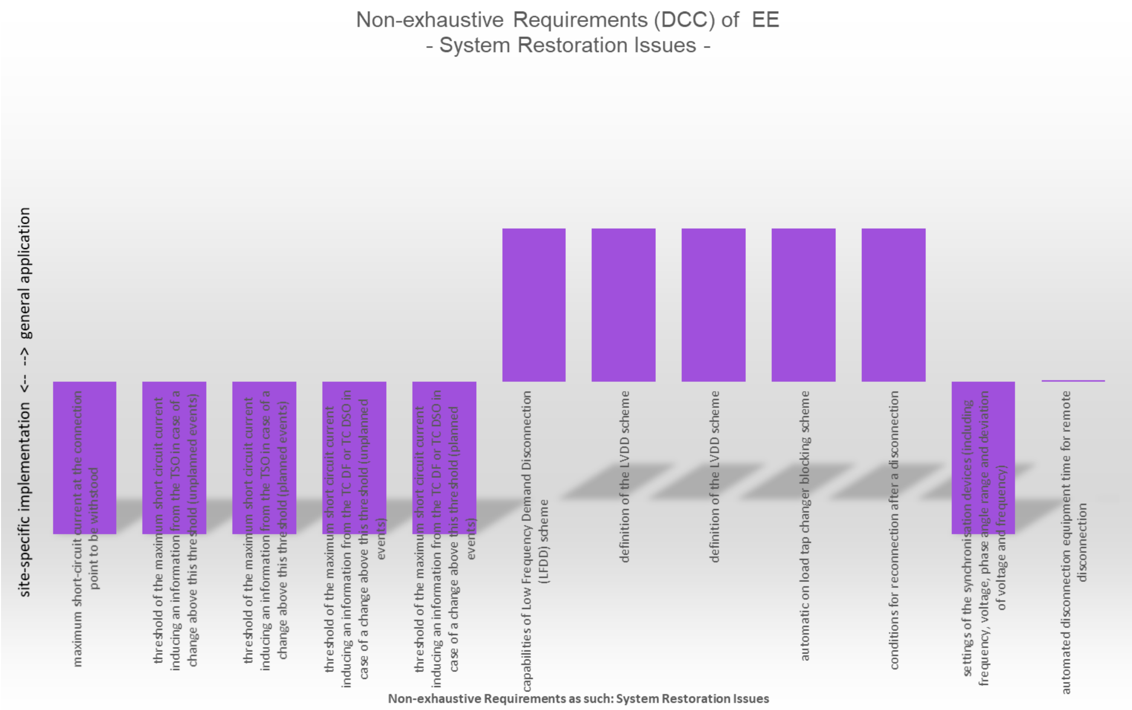


Figure 260: Estonia (EE)

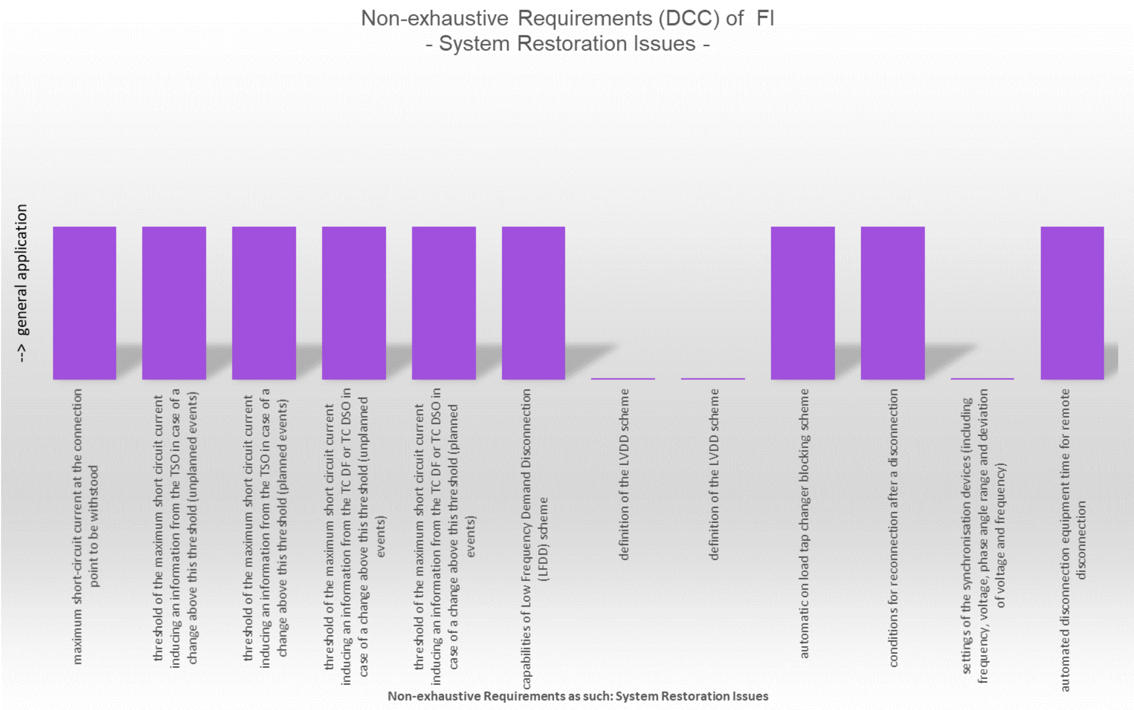


Figure 261: Finland (FI)

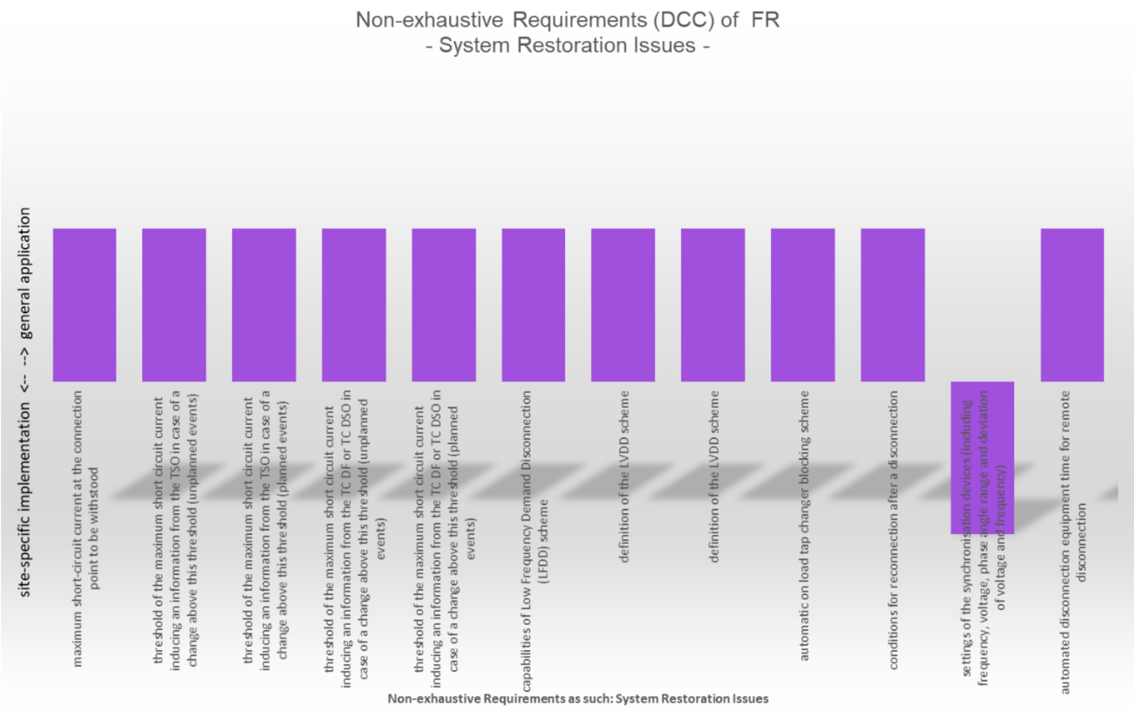


Figure 262: France (FR)

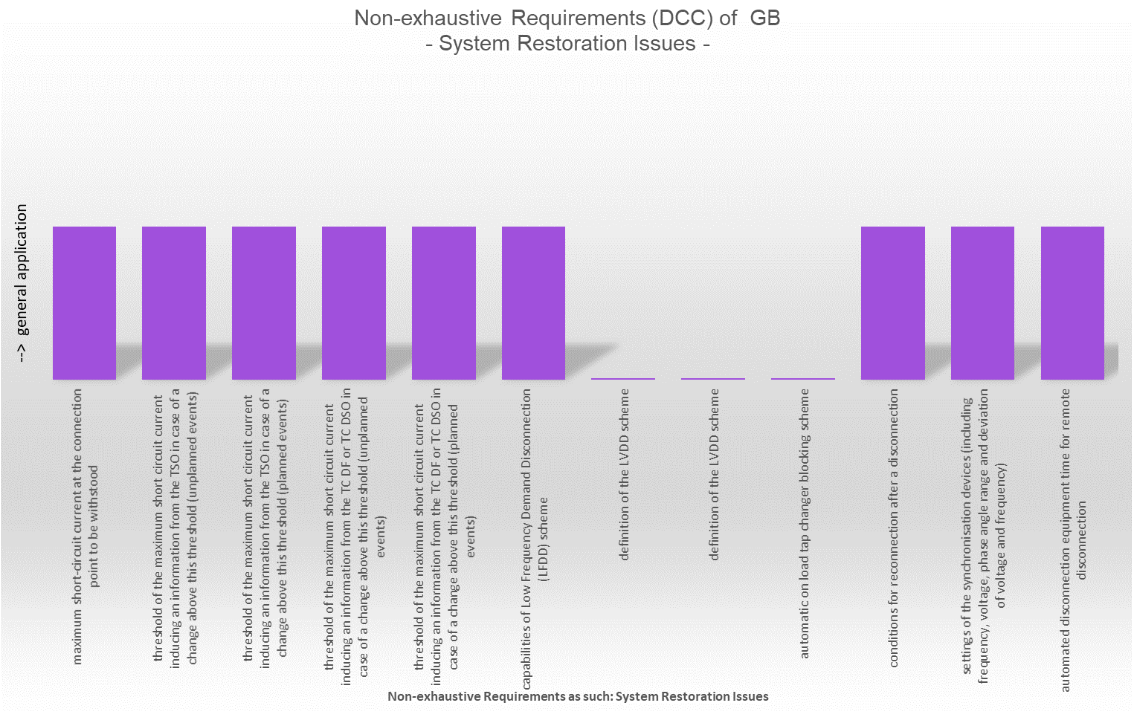


Figure 263: Great Britain (GB)

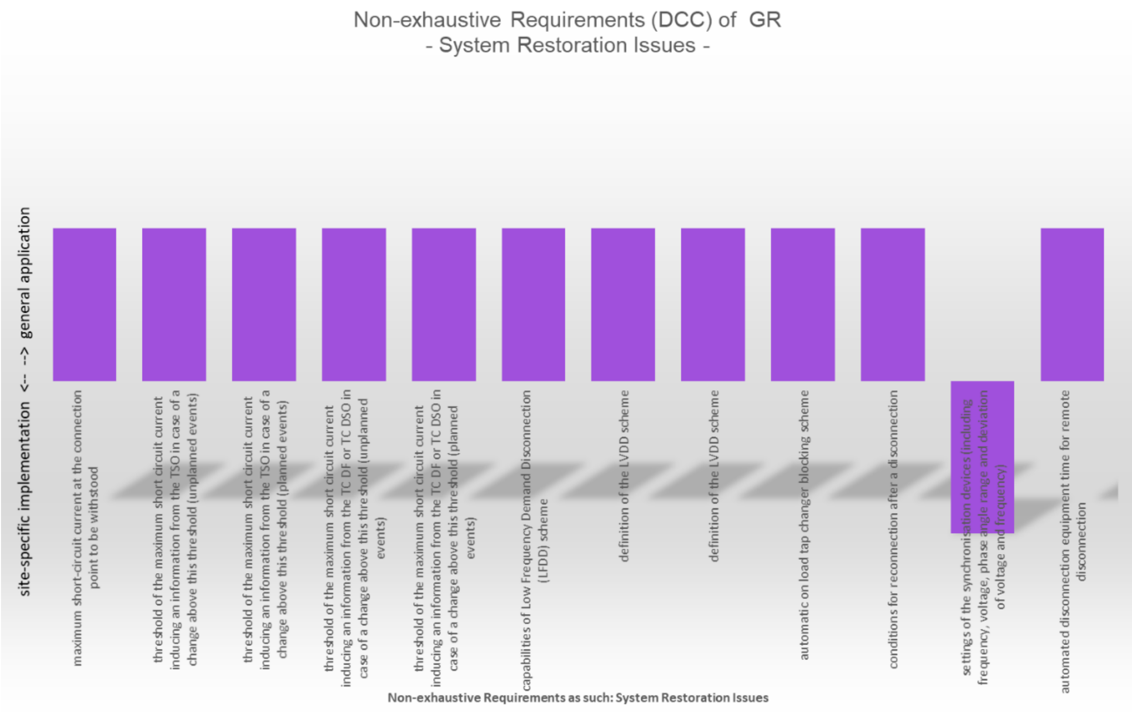


Figure 264: Greece (GR)

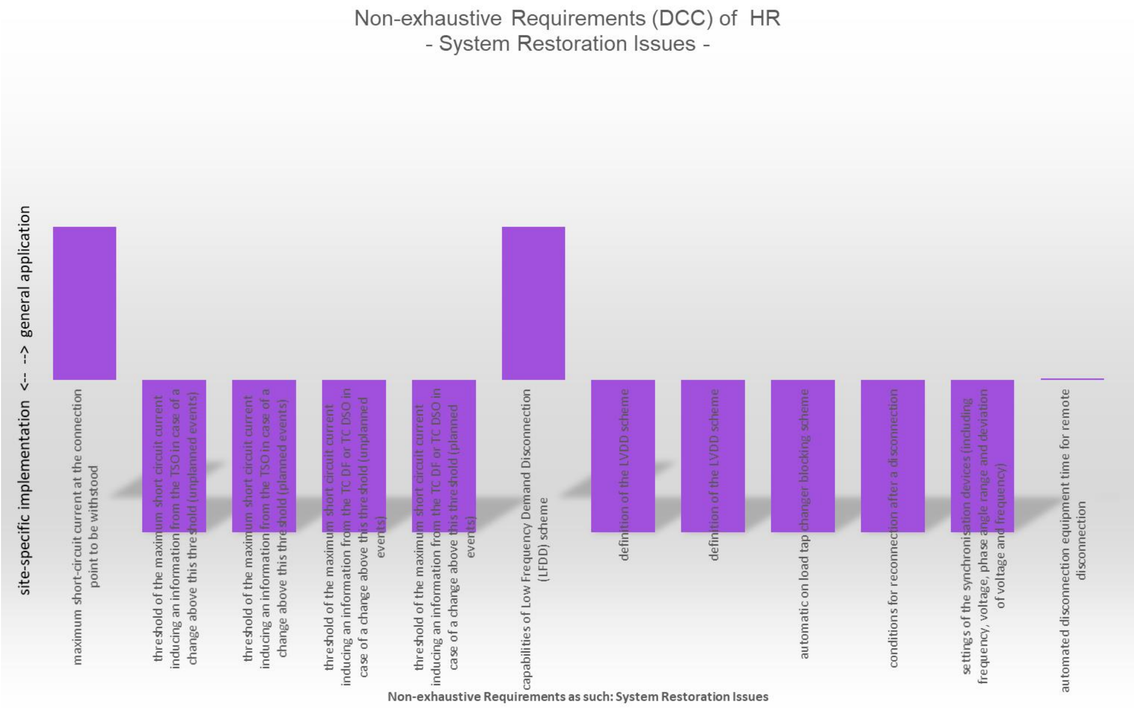


Figure 265: Croatia (HR)

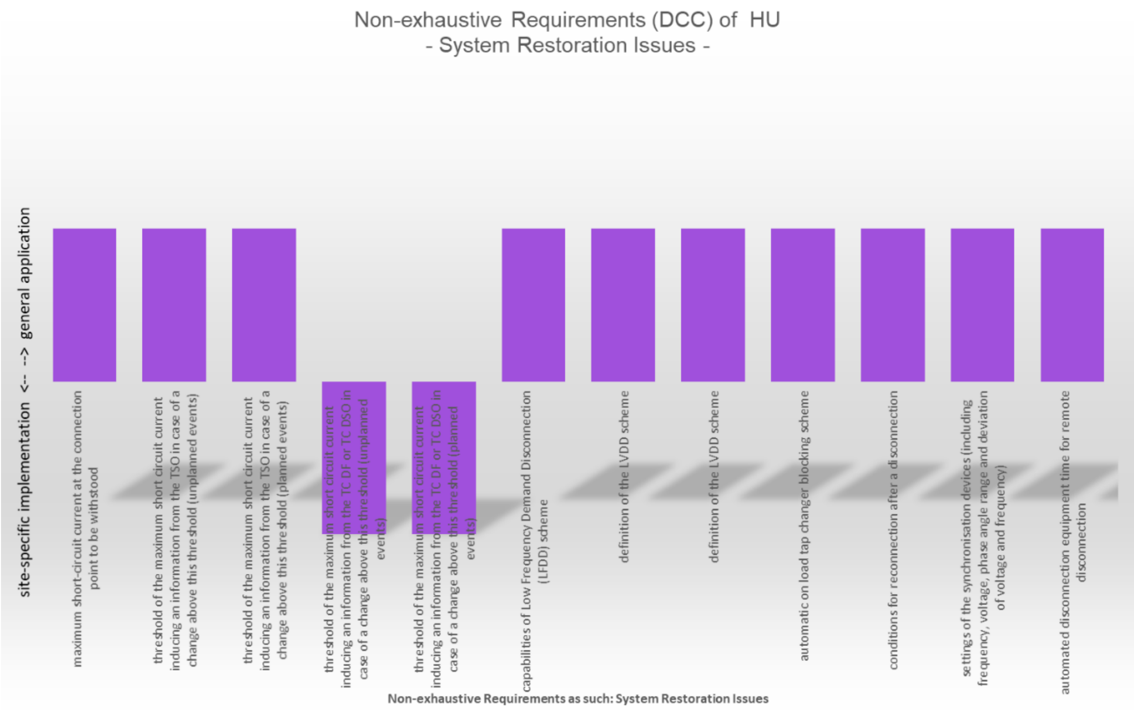


Figure 266: Hungary (HU)

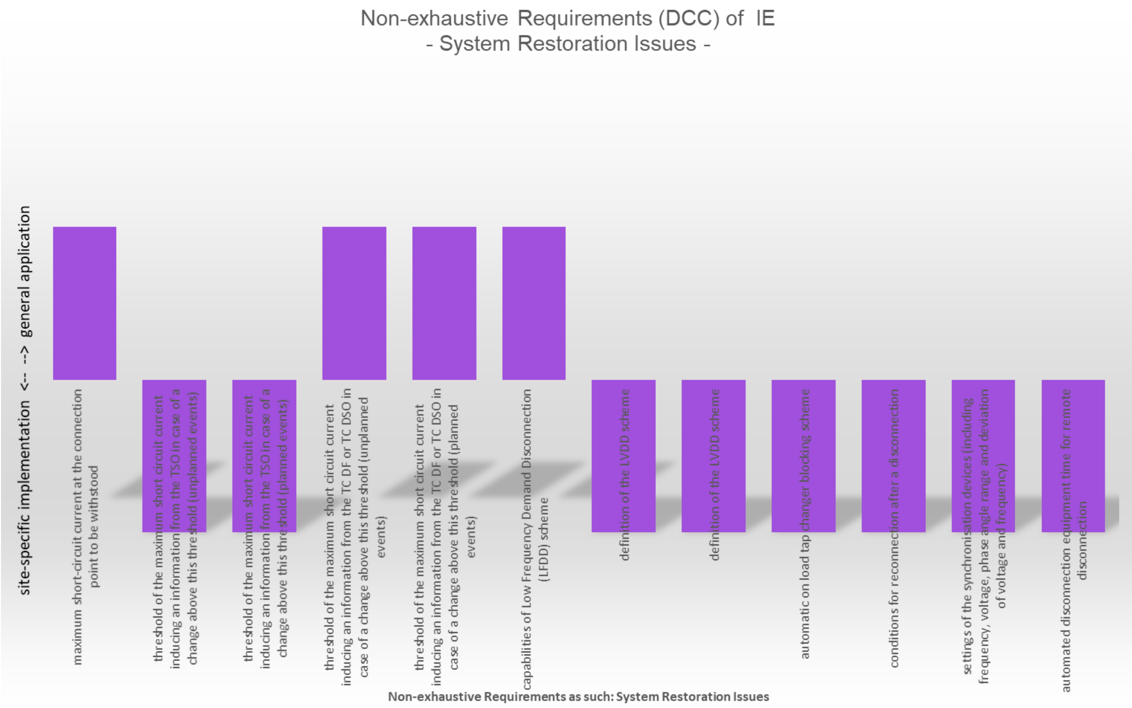


Figure 267: Ireland (IE)

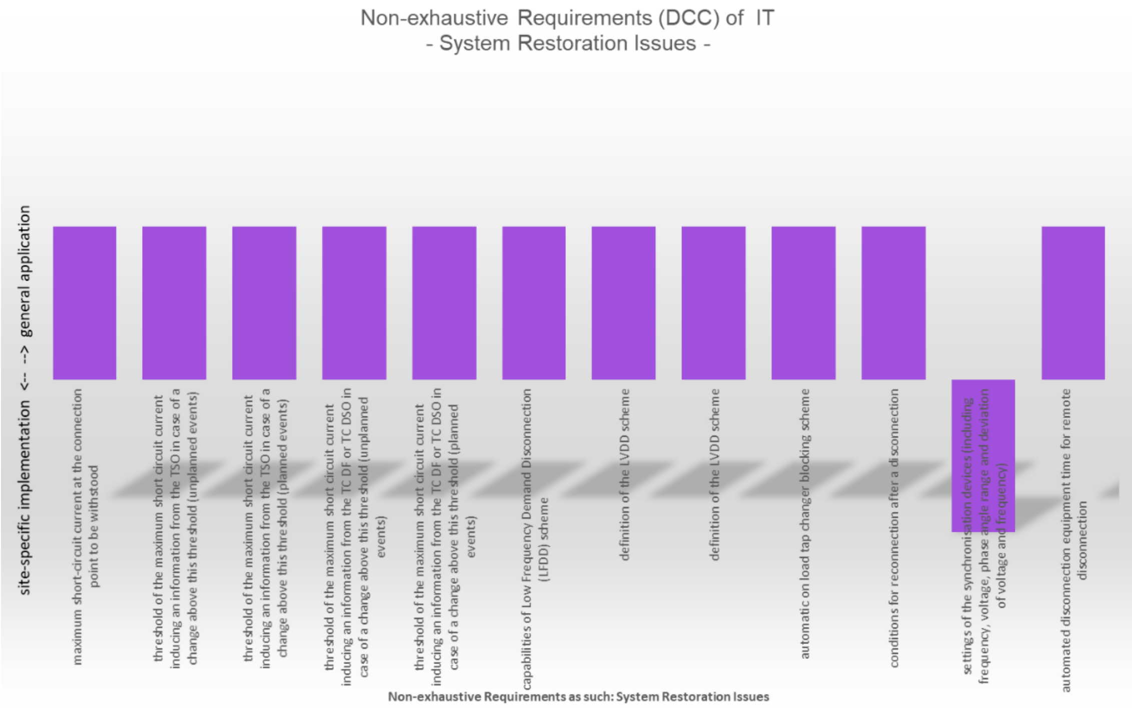


Figure 268: Italy (IT)

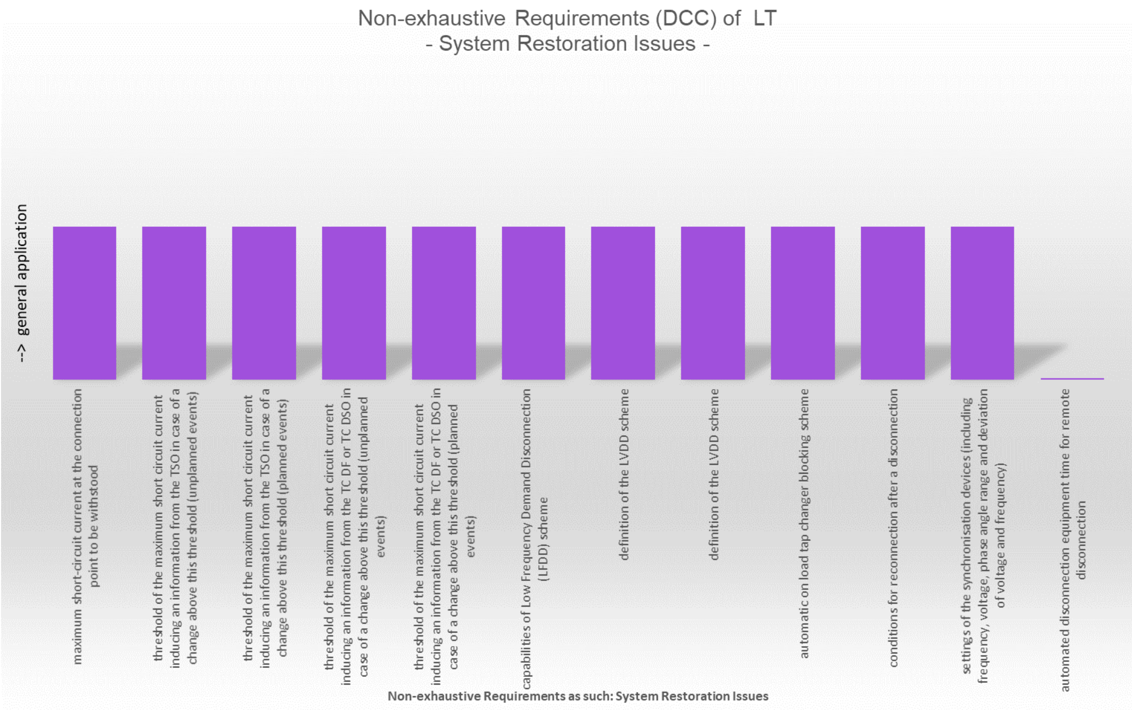


Figure 269: Lithuania (LT)

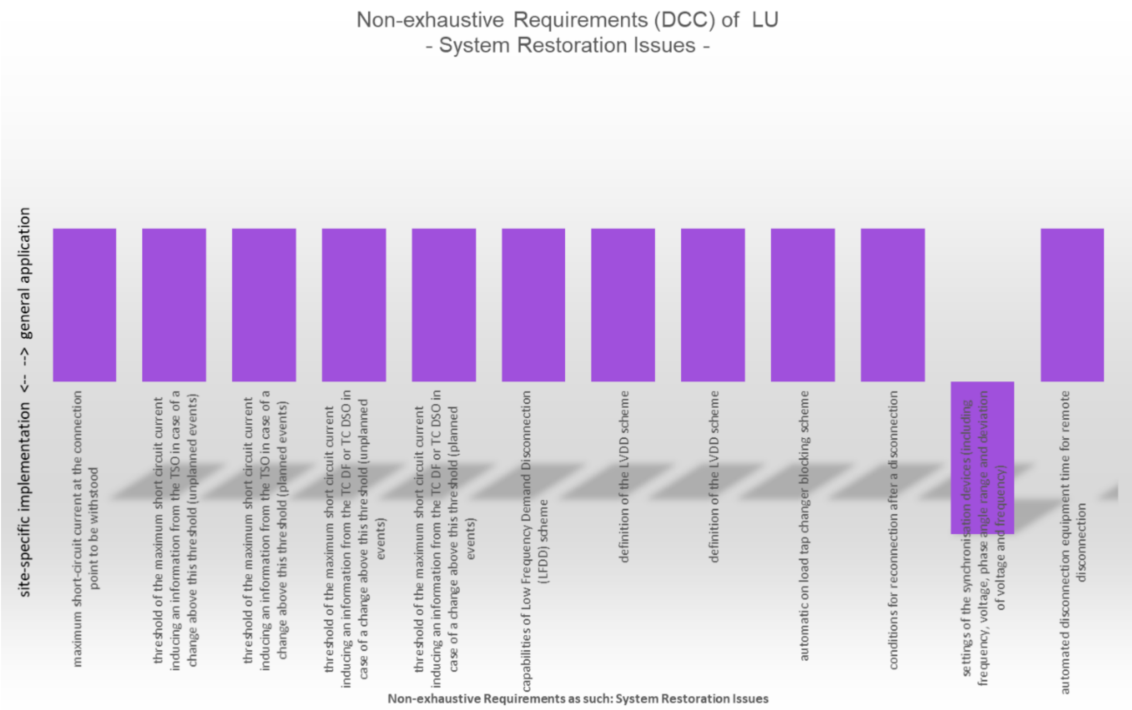


Figure 270: Luxembourg (LU)

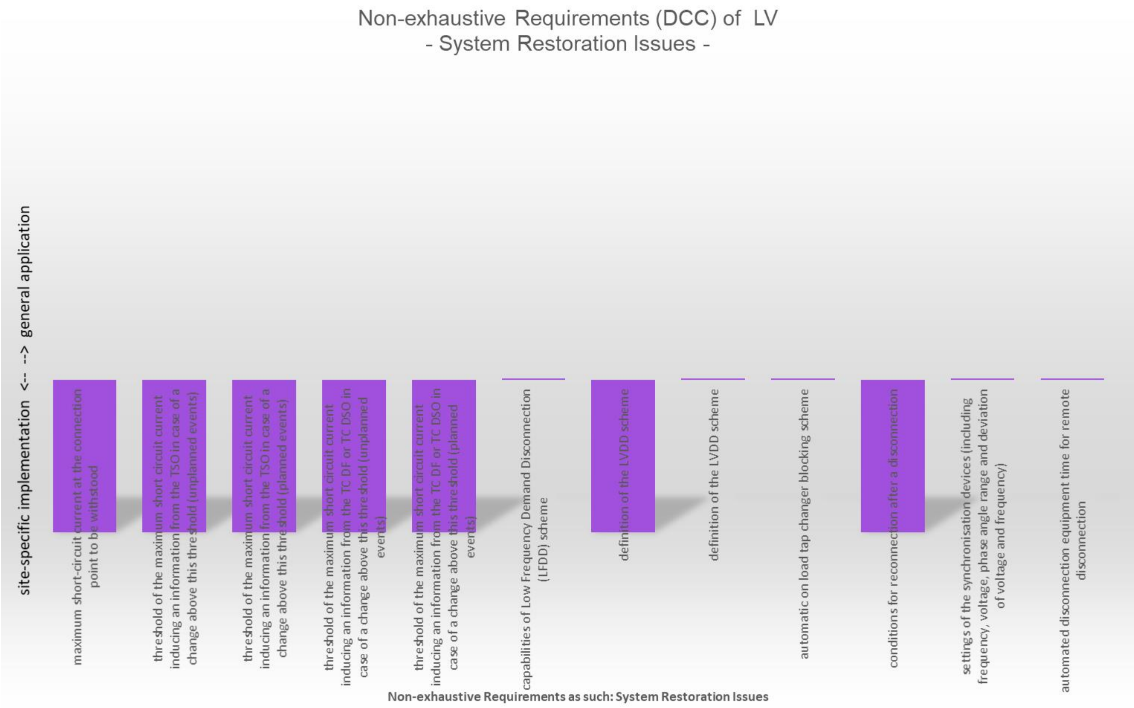


Figure 271: Latvia (LV)

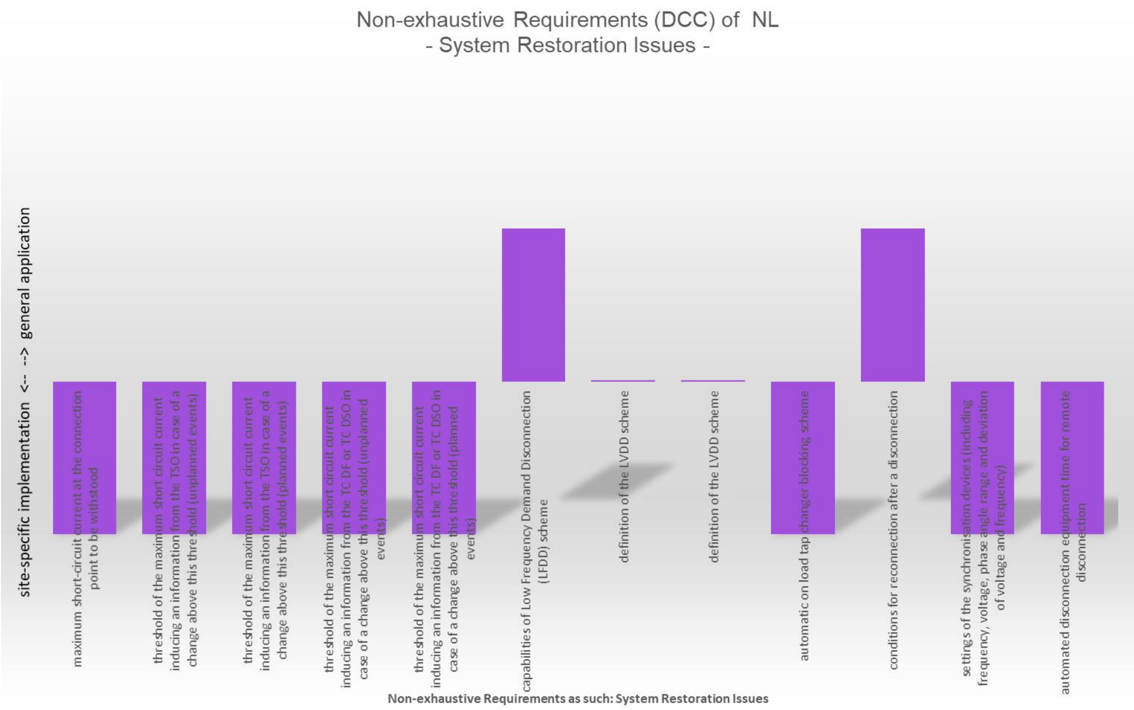


Figure 272: Netherlands (NL)

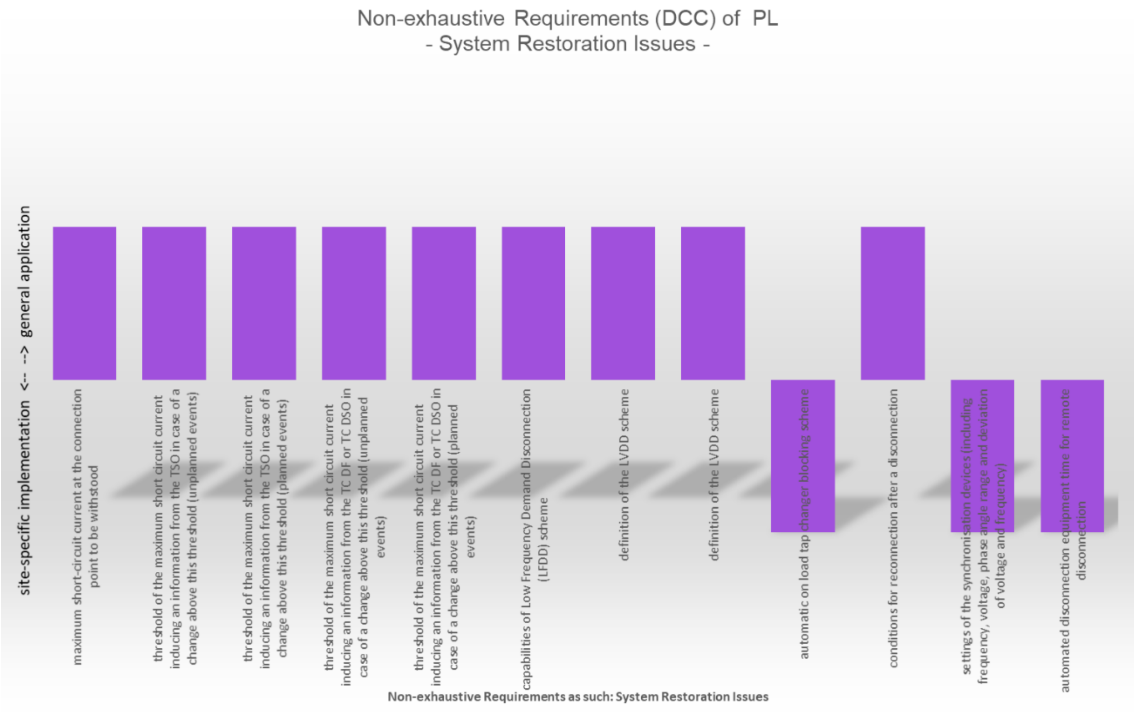


Figure 273: Poland (PL)

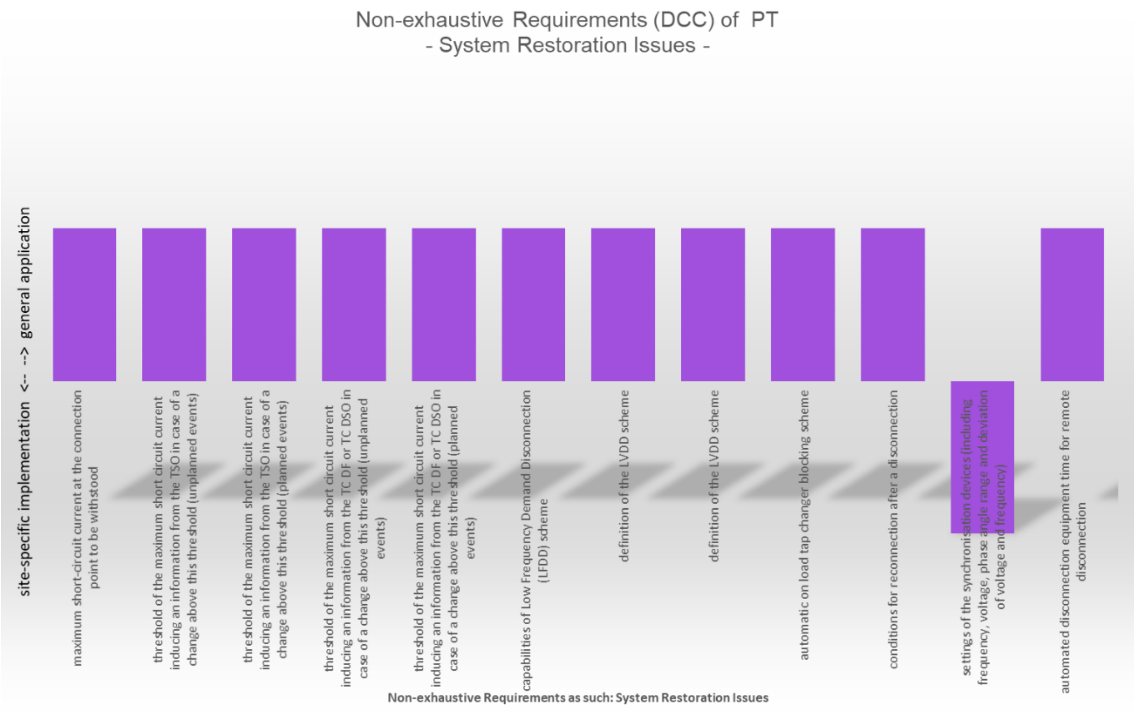


Figure 274: Portugal (PT)

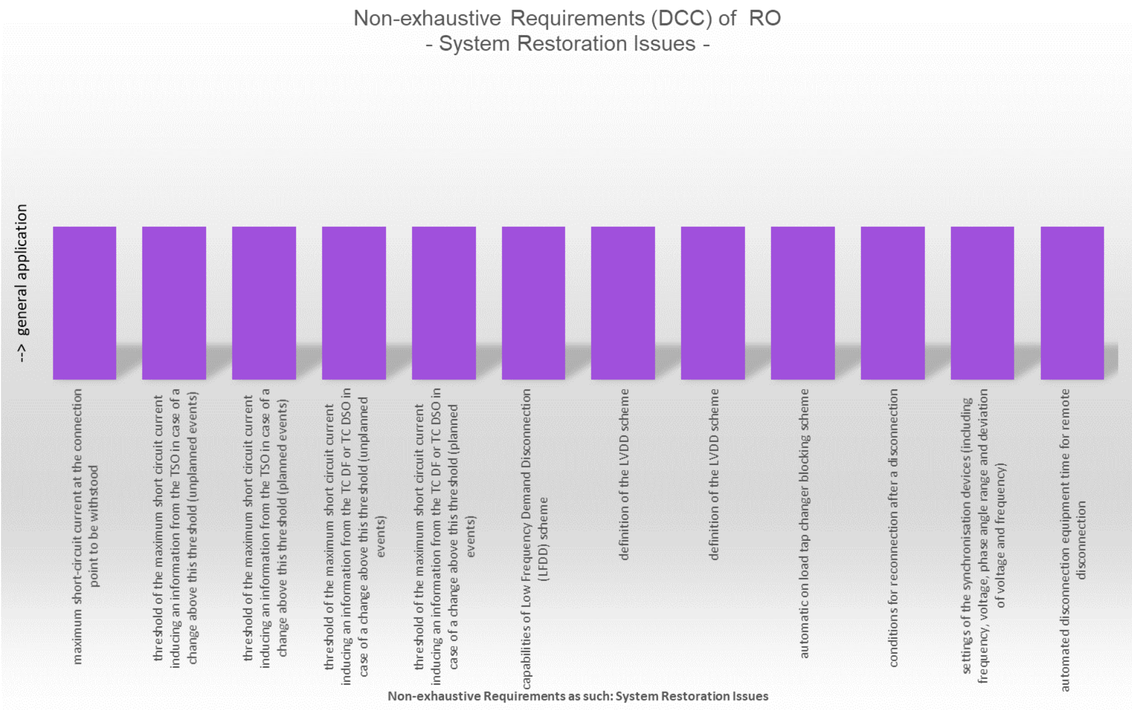


Figure 275: Romania (RO)

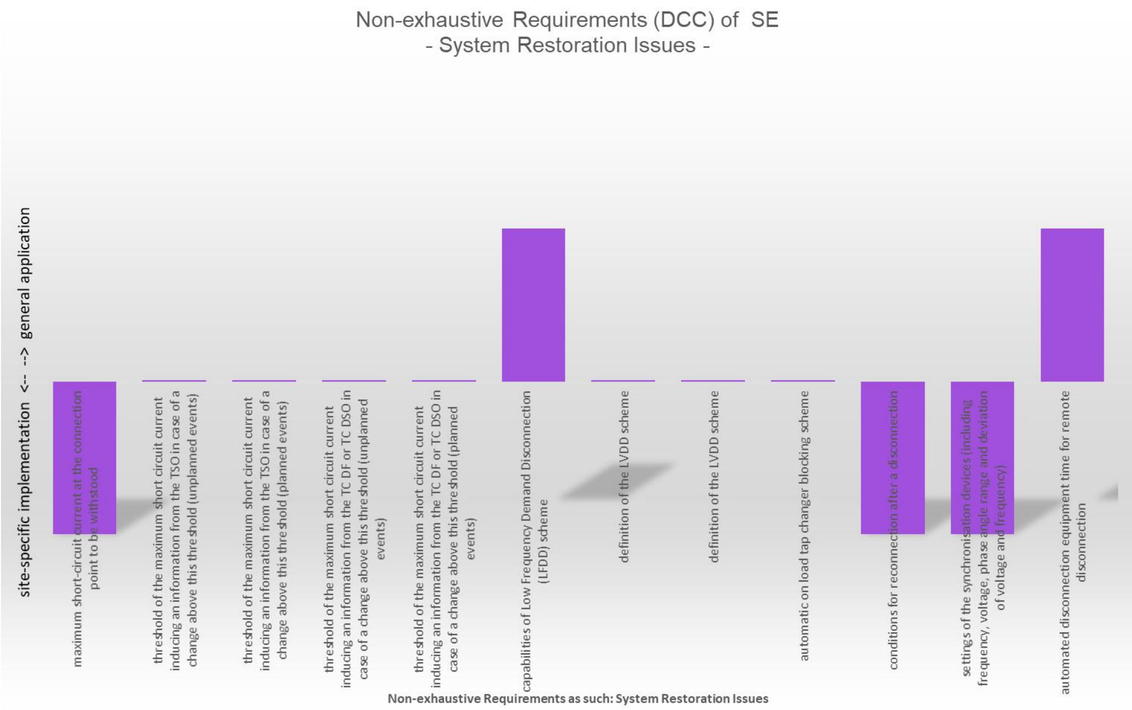


Figure 276: Sweden (SE)

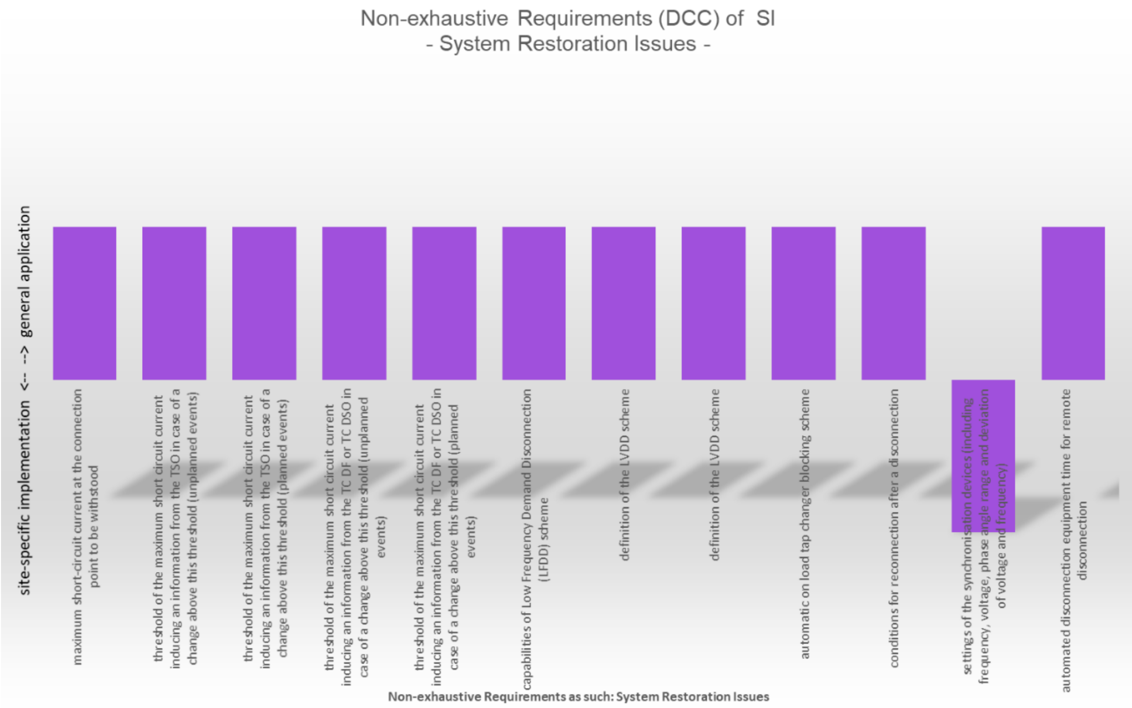


Figure 277: Slovenia (SI)

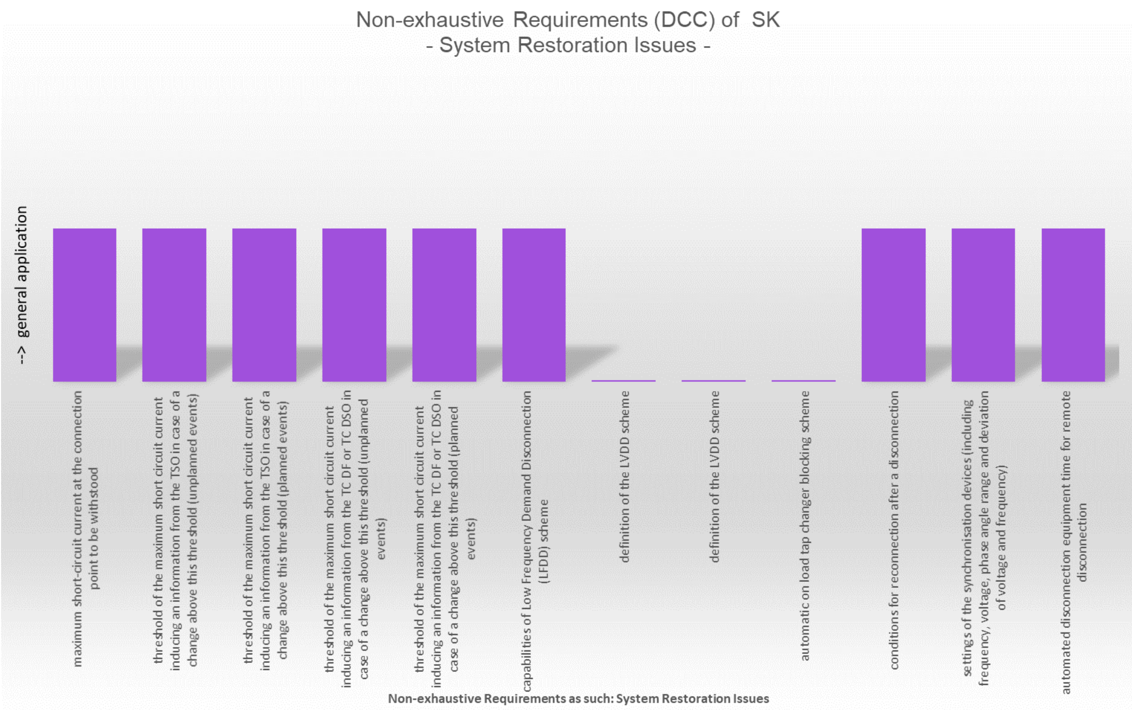


Figure 278: Slovakia (SK)

4.5 Instrumentation, Simulation Models and Protection Issues of NC DCC

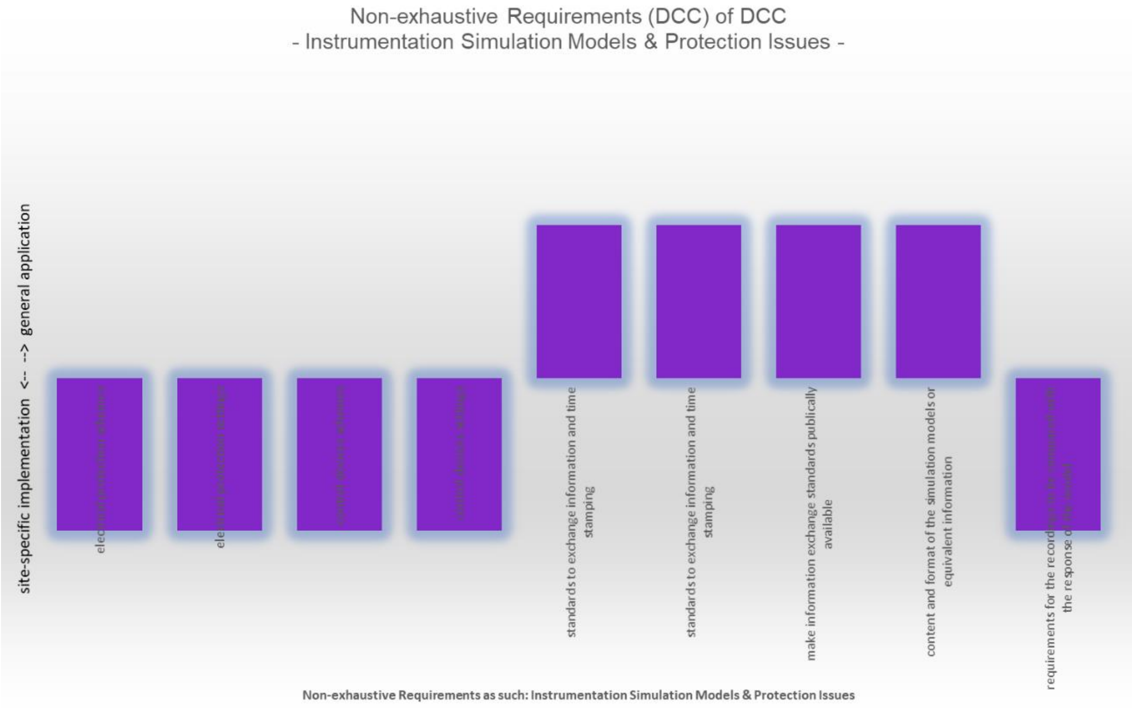


Figure 279: Reference values of non-exhaustive DCC – instrumentation, simulation ,models and protection issues

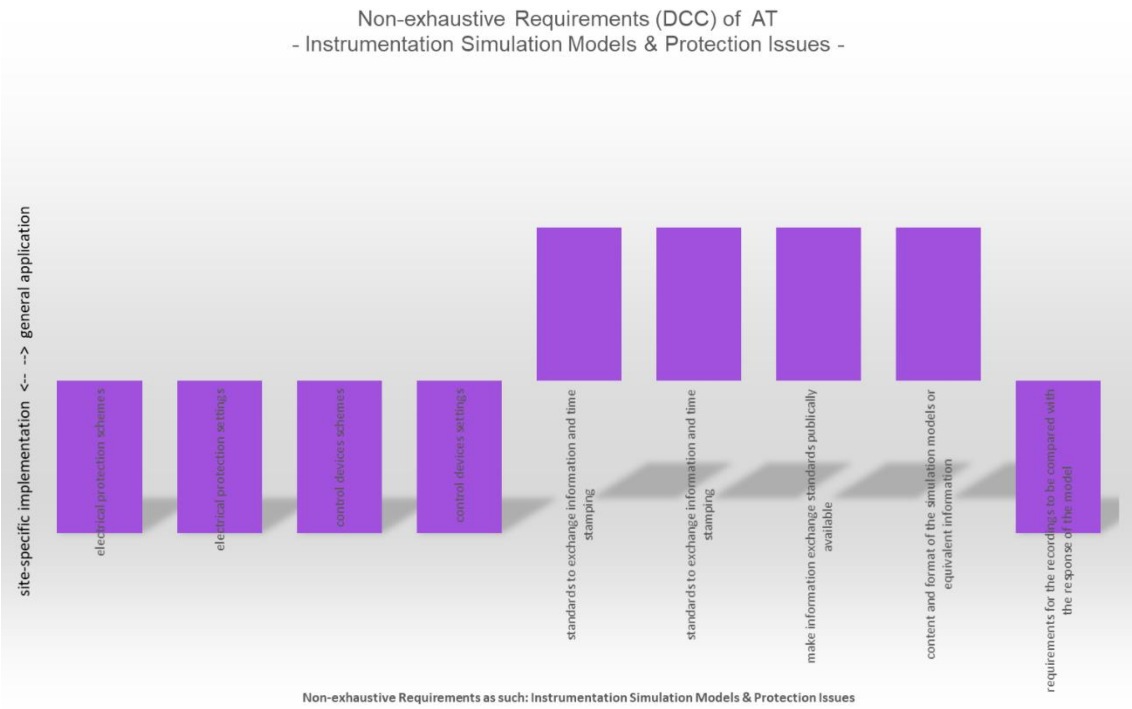


Figure 280: Austria (AT)

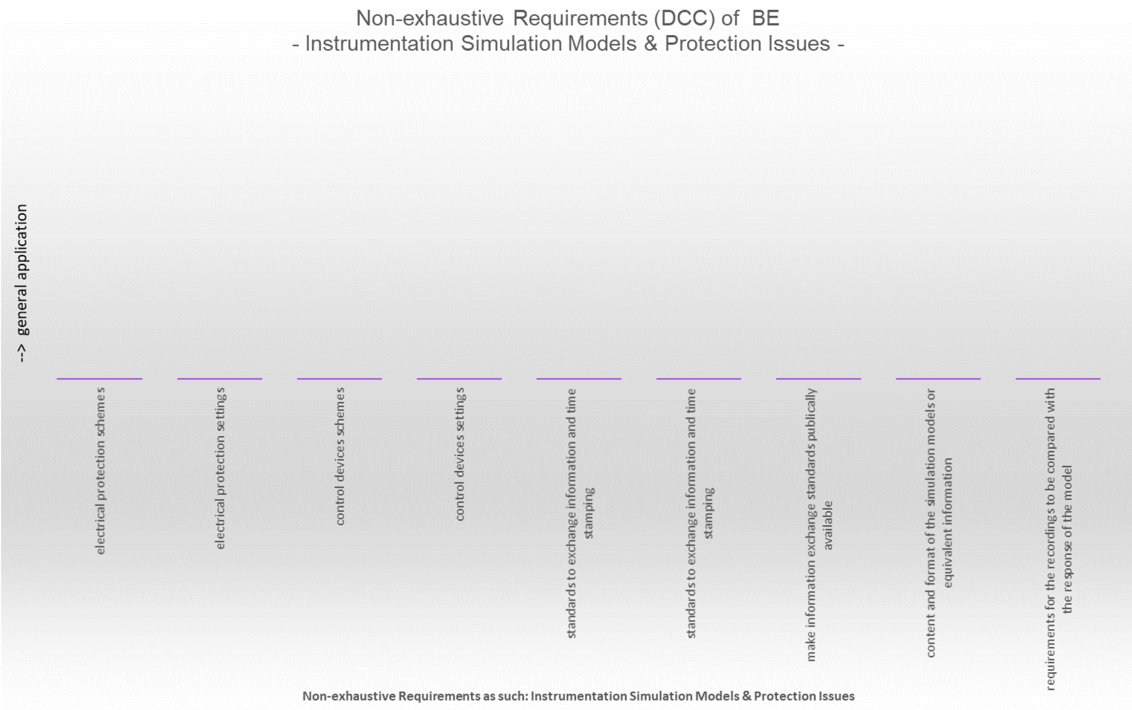


Figure 281: Belgium (BE)

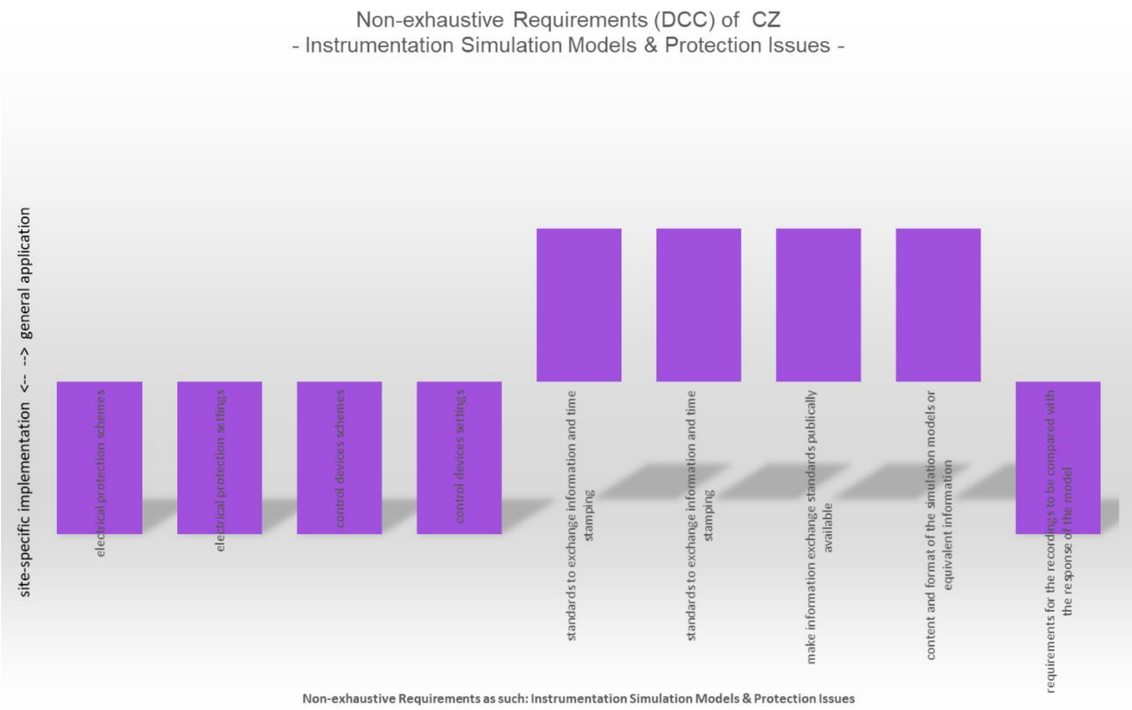


Figure 282: Czech Republic (CZ)

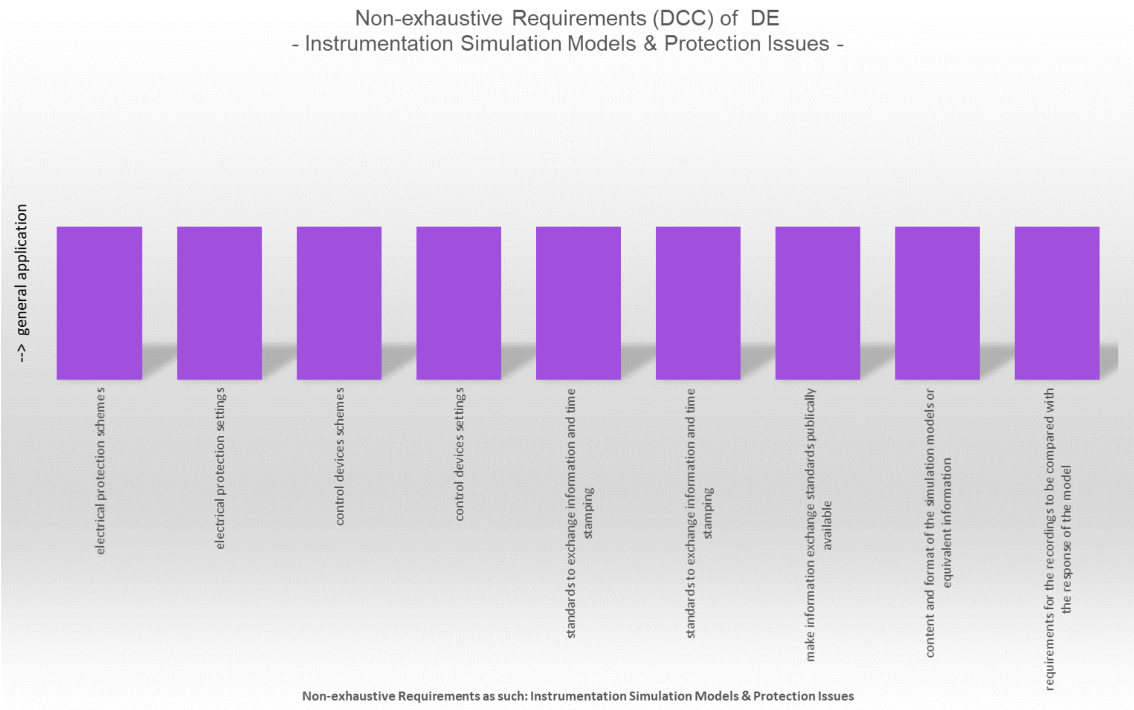


Figure 283: Germany (DE)

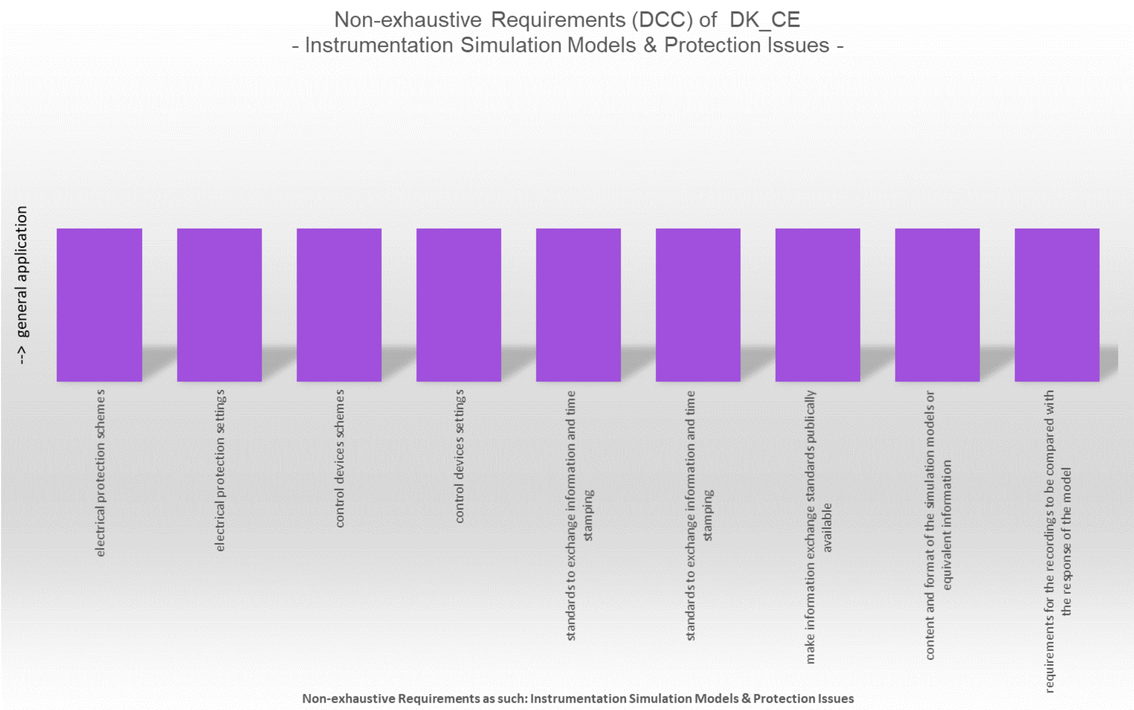


Figure 284: Denmark 1 (DK-CE)

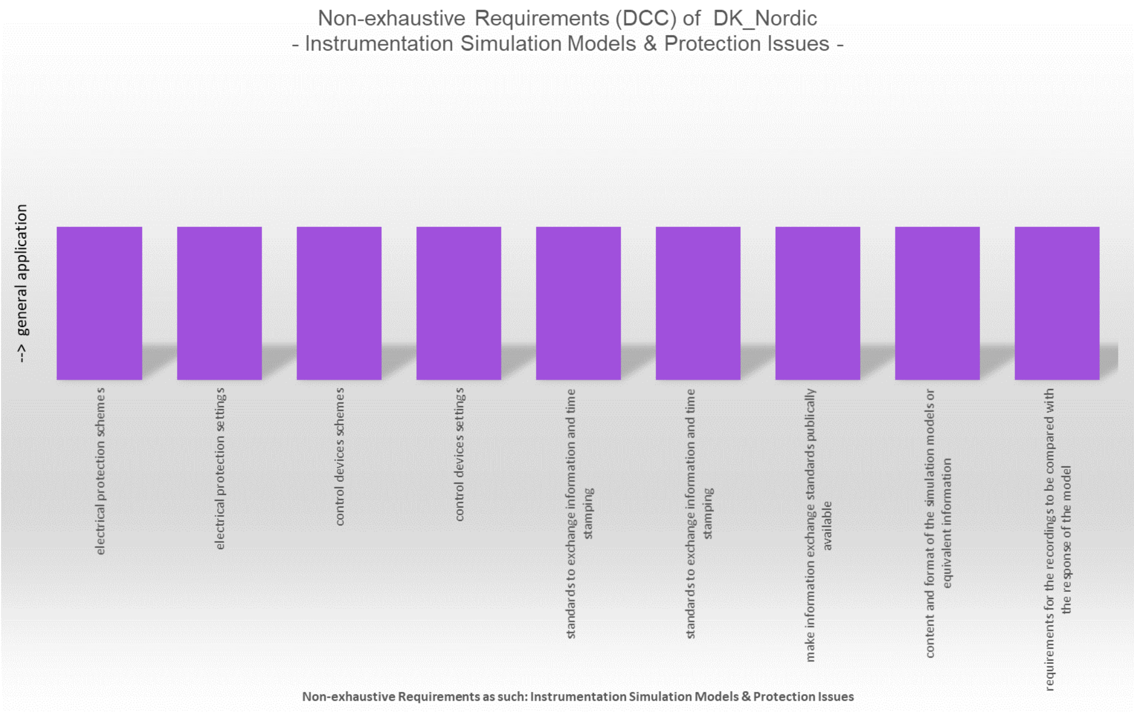


Figure 285: Denmark 2 (DK-Nordic)

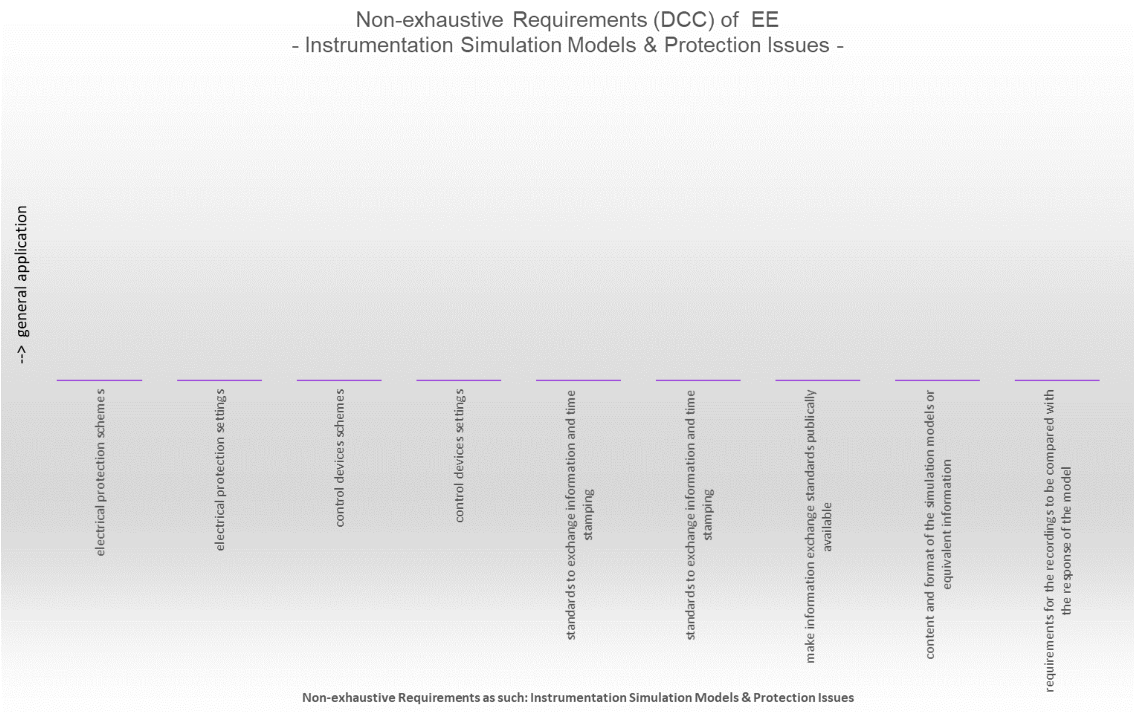


Figure 286: Estonia (EE)

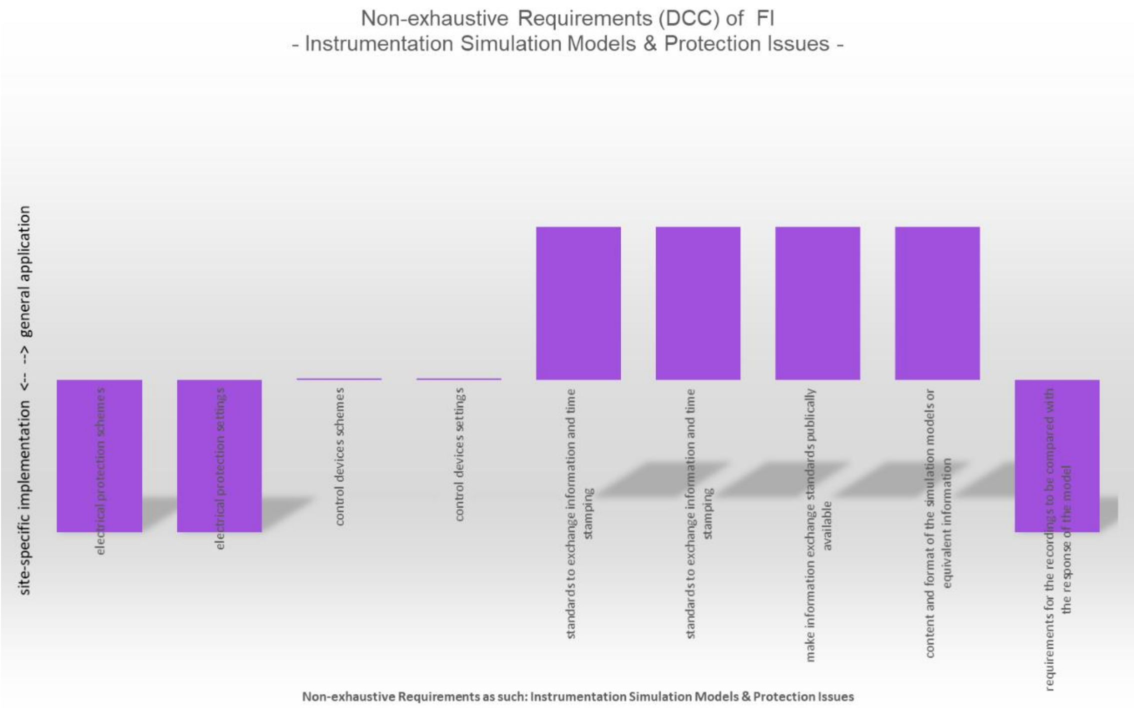


Figure 287: Finland (FI)

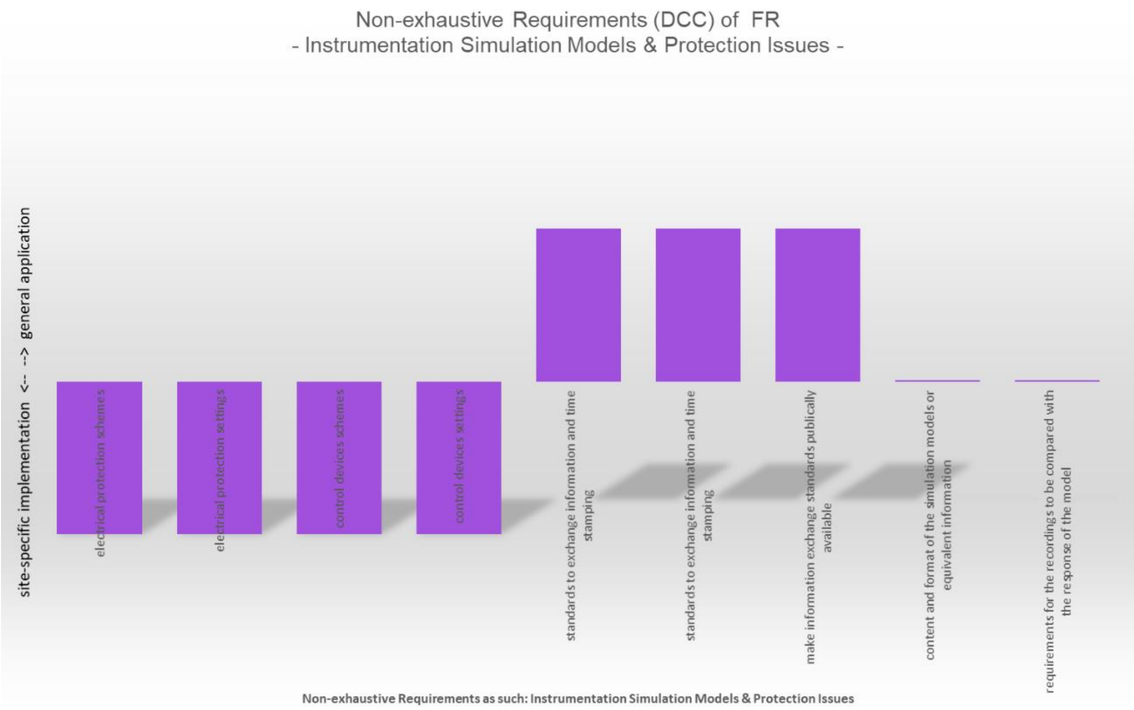


Figure 288: France (FR)

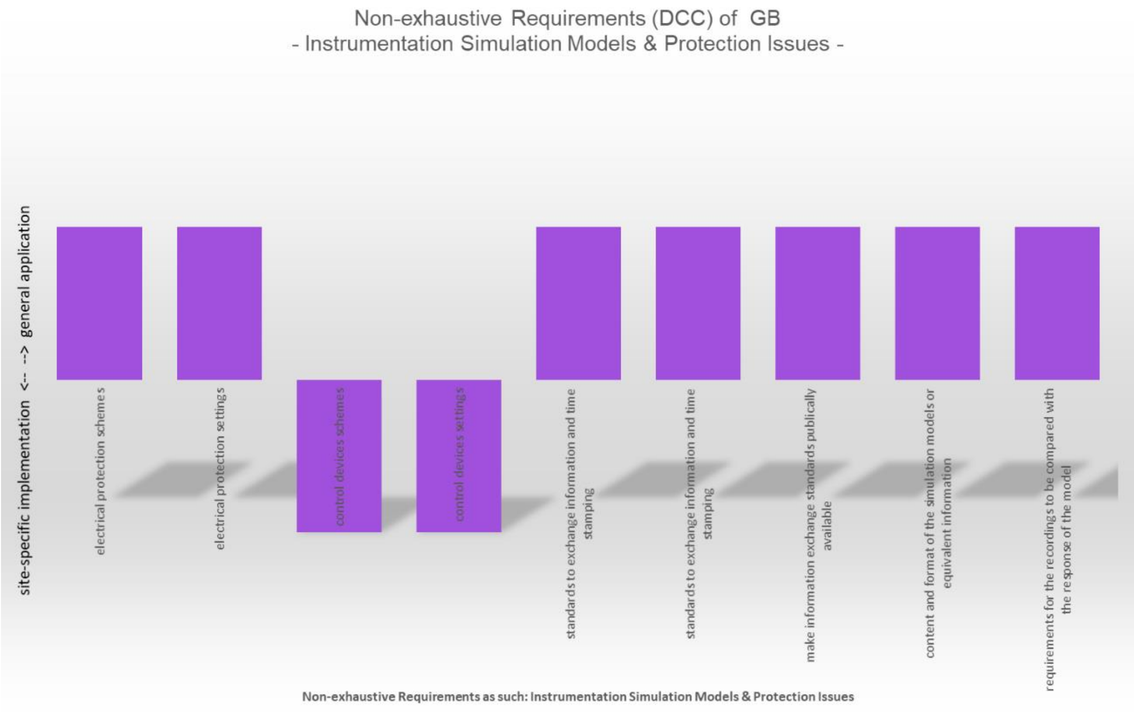


Figure 289: Great Britain (GB)

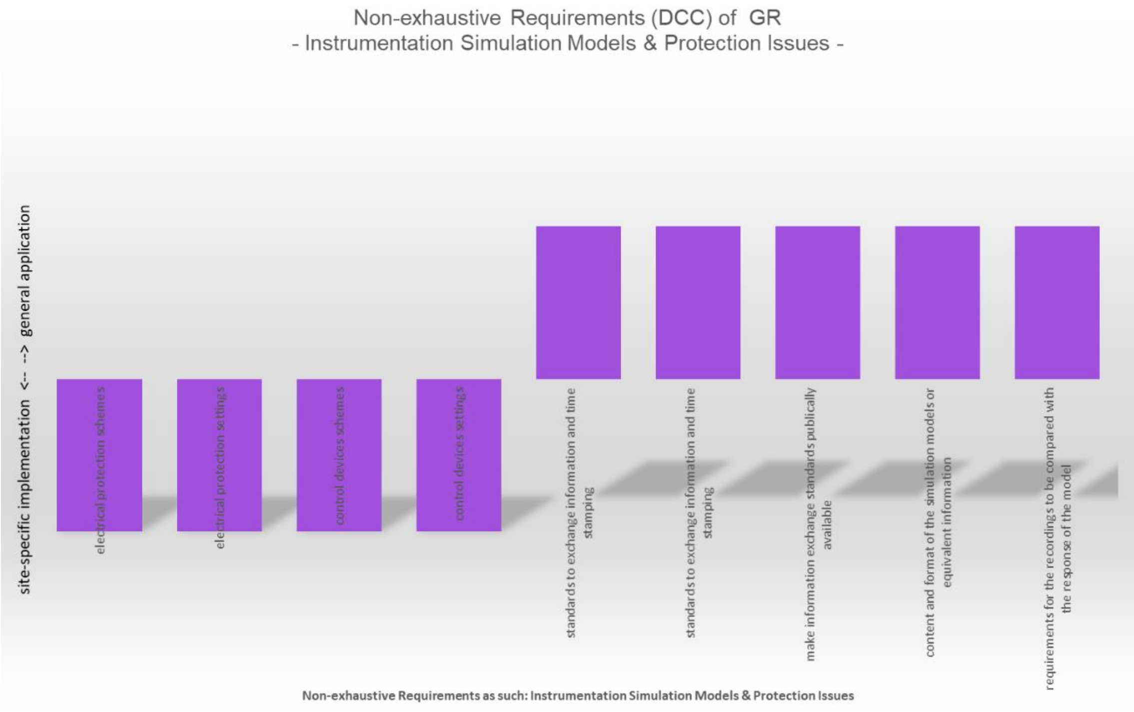


Figure 290: Greece (GR)

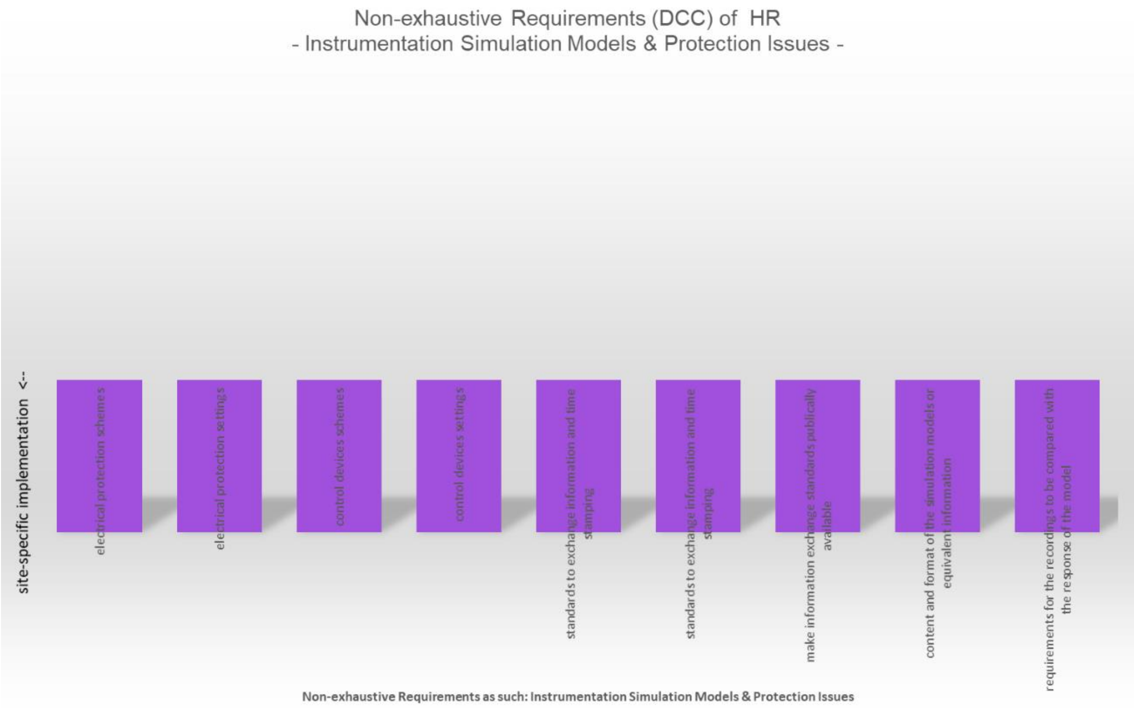


Figure 291: Croatia (HR)

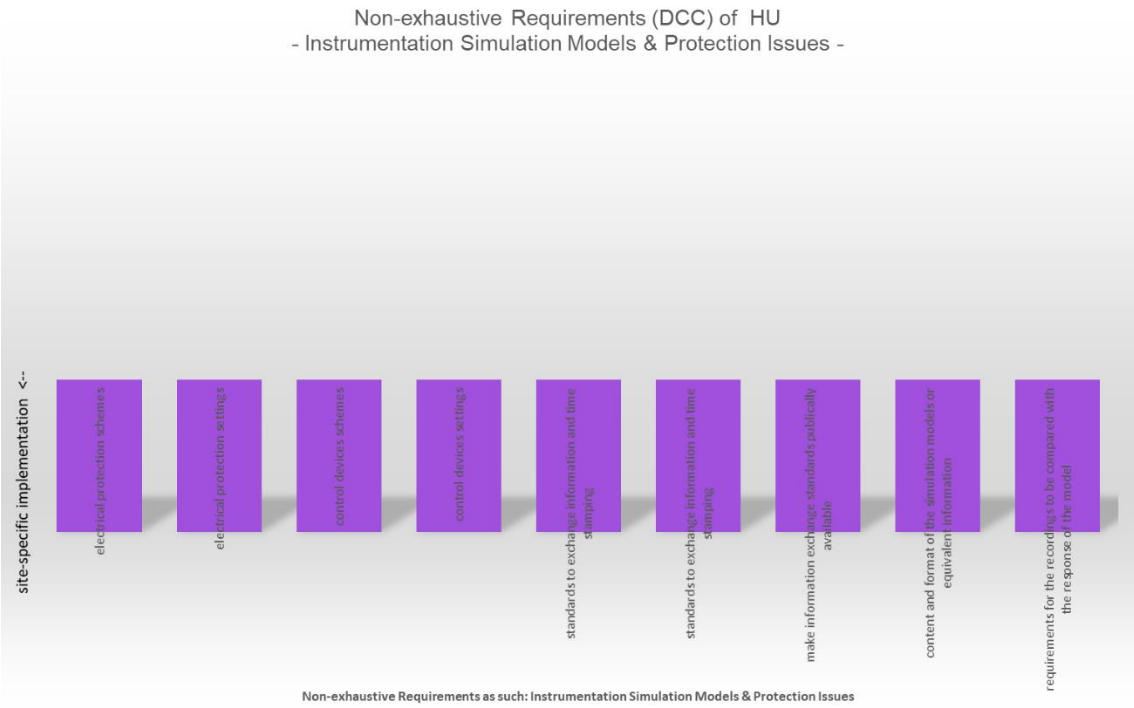


Figure 292: Hungary (HU)

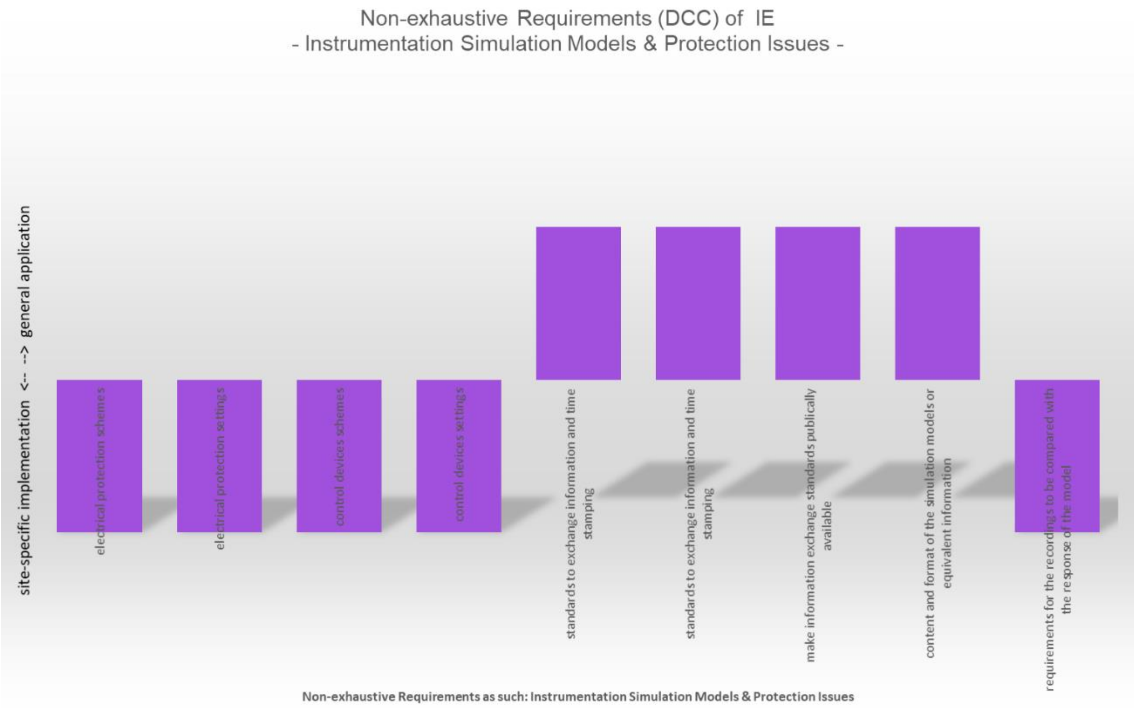


Figure 293: Ireland (IE)

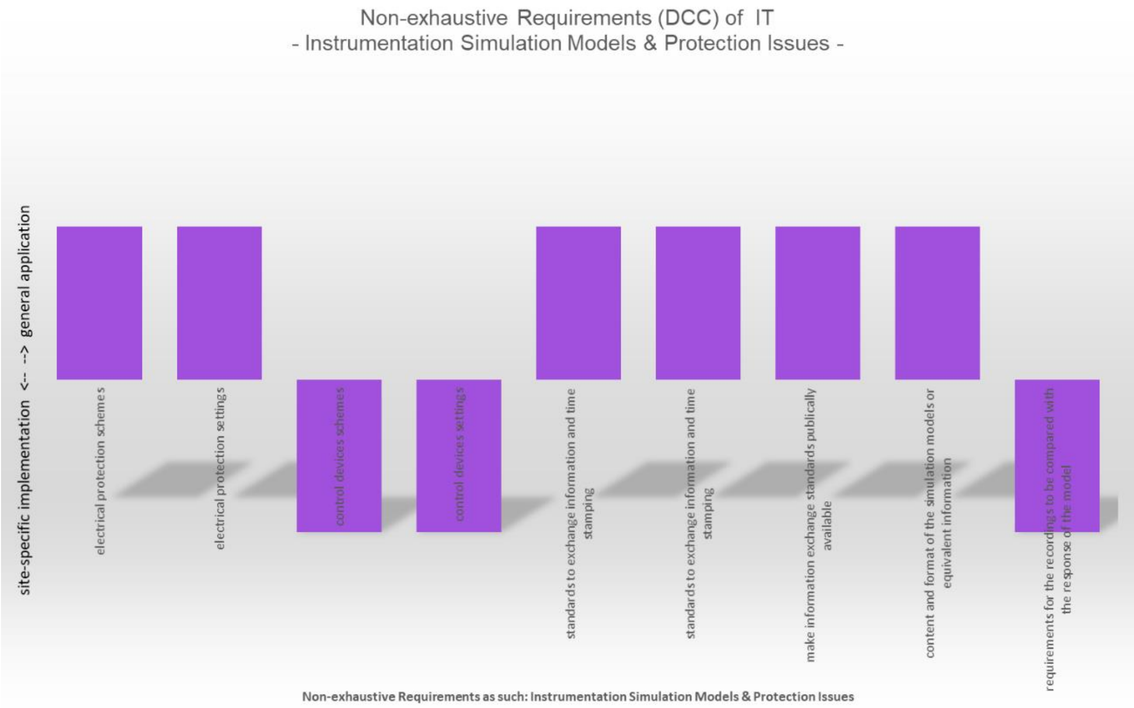


Figure 294: Italy (IT)

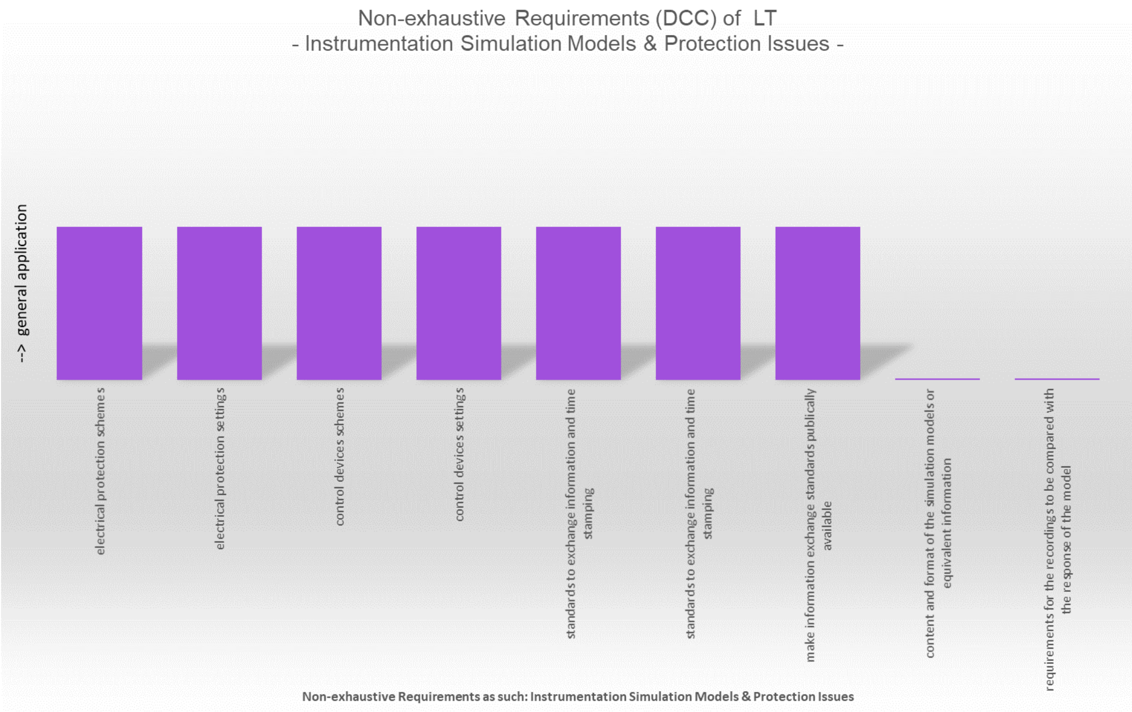


Figure 295: Lithuania (LT)

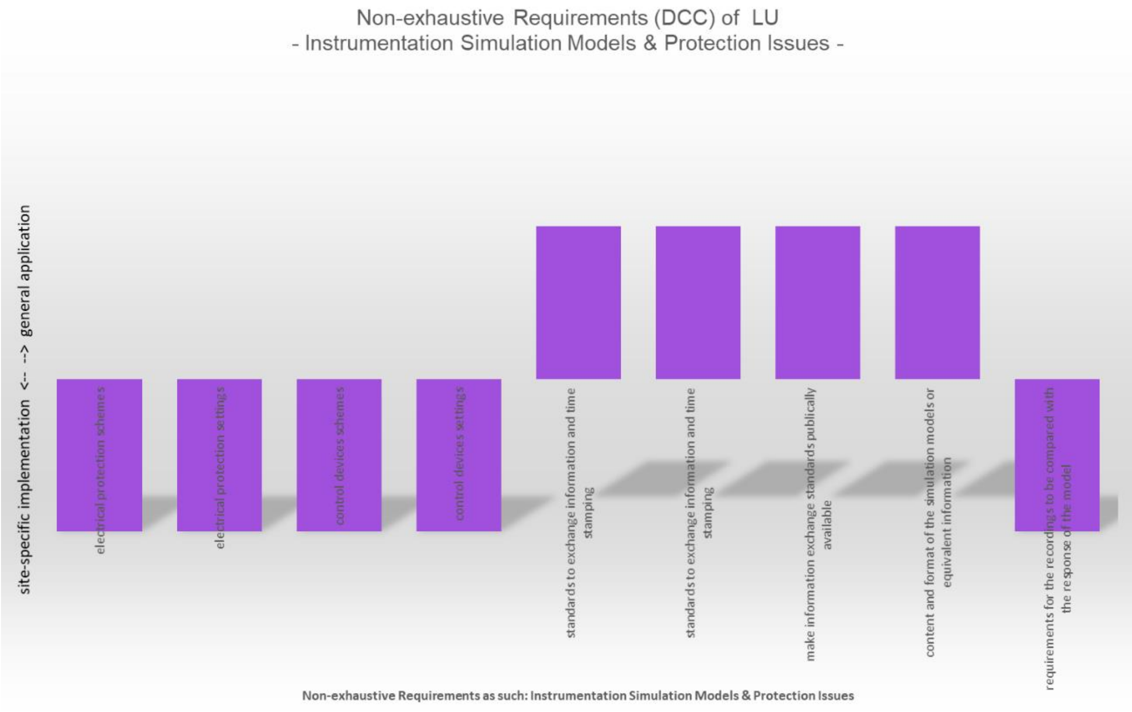


Figure 296: Luxembourg (LU)

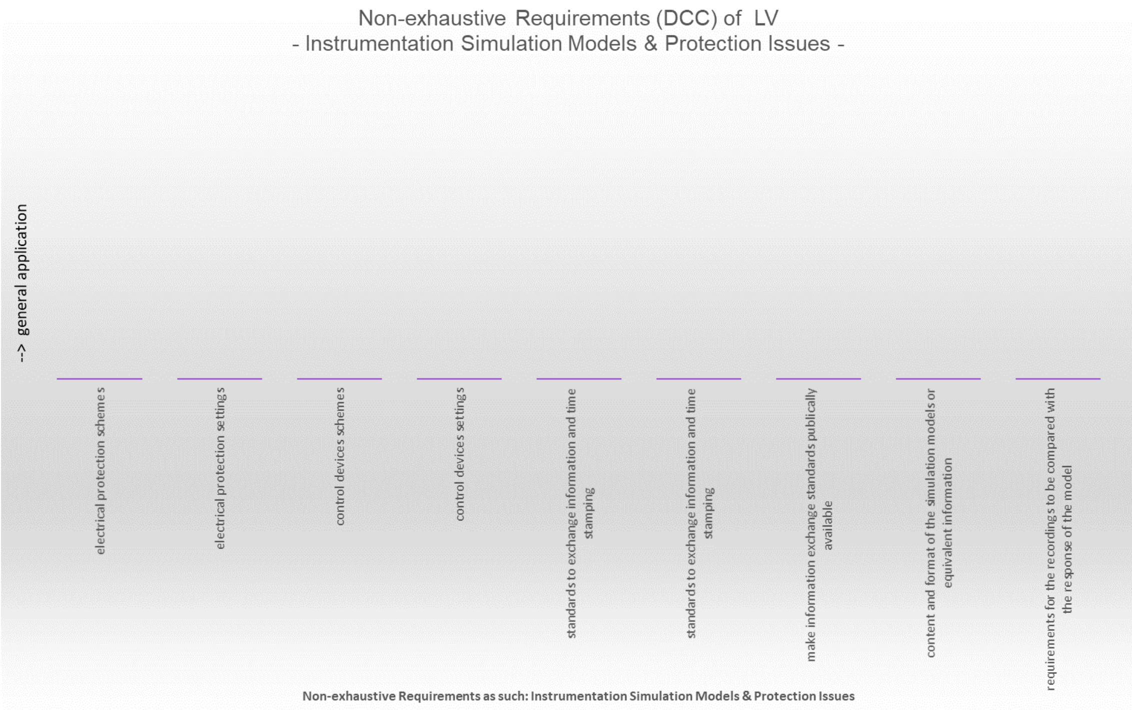


Figure 297: Latvia (LV)

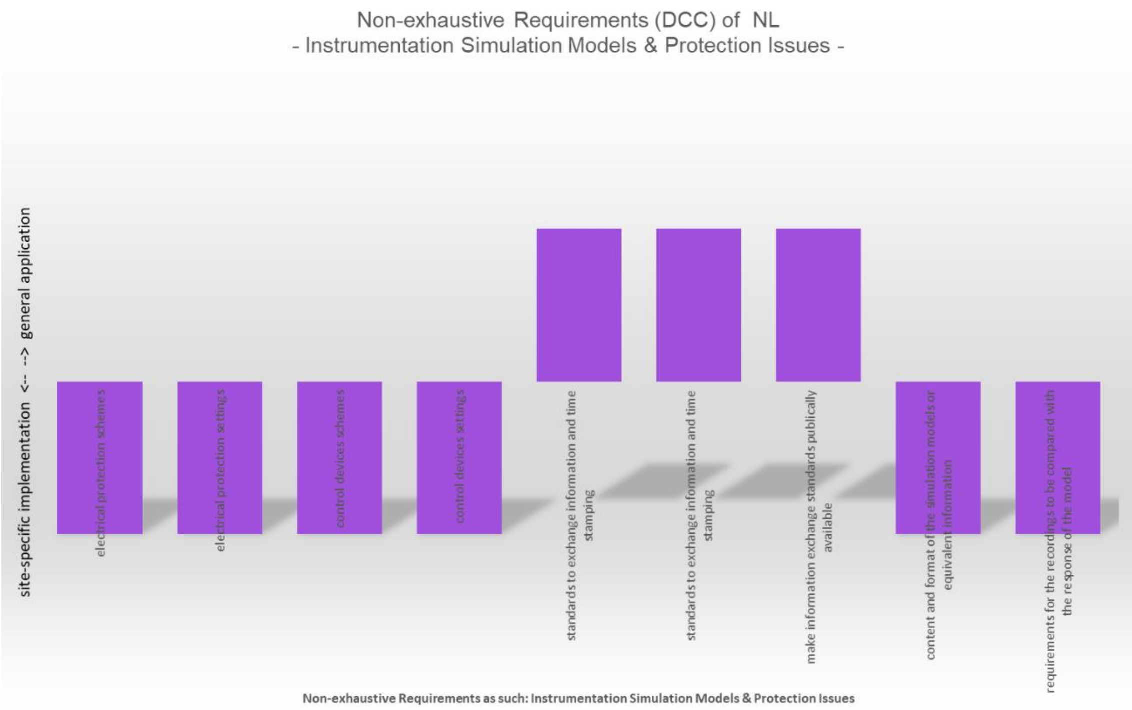


Figure 298: Netherlands (NL)

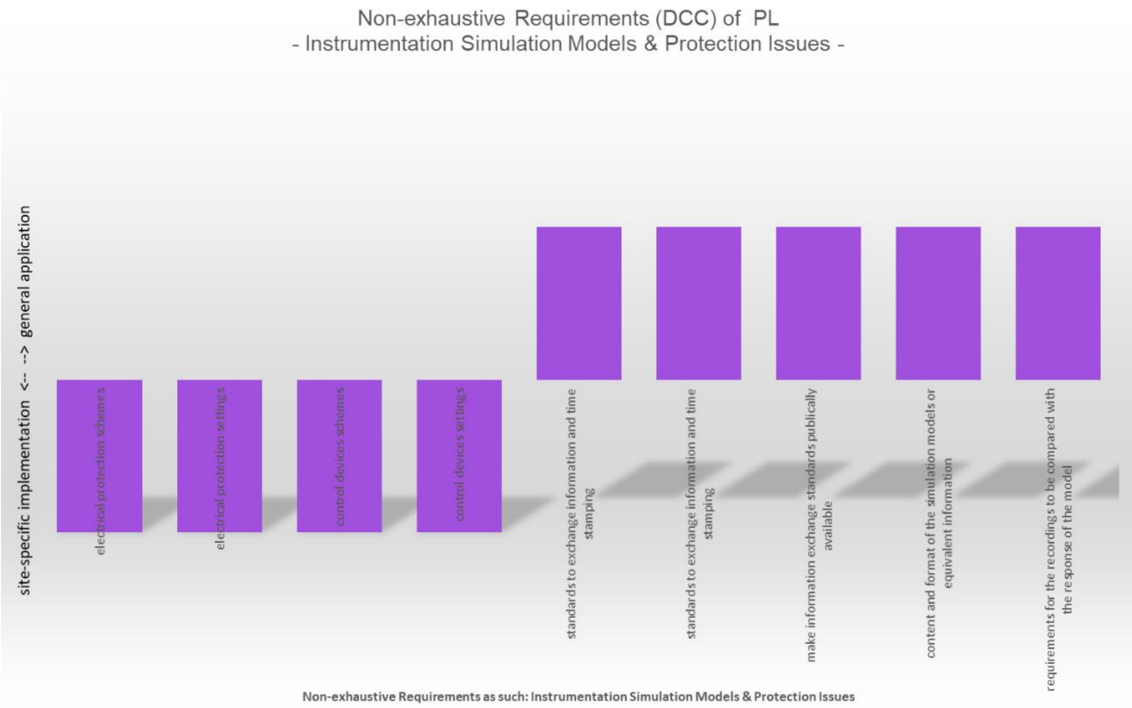


Figure 299: Poland (PL)

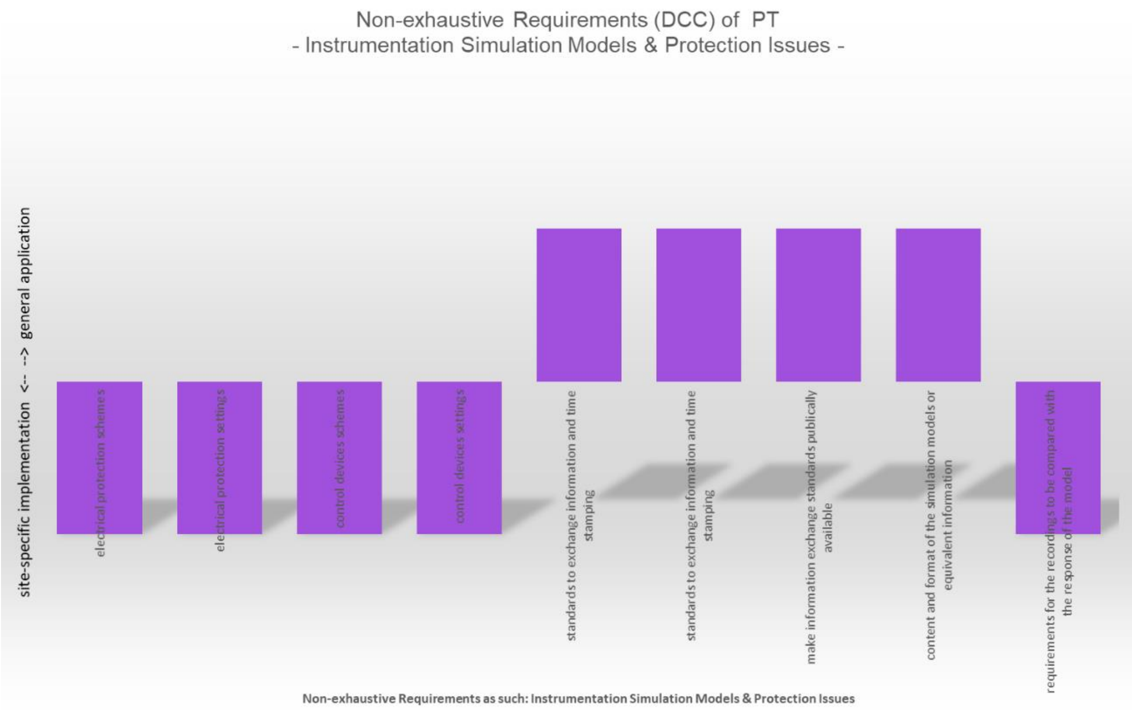


Figure 300: Portugal (PT)

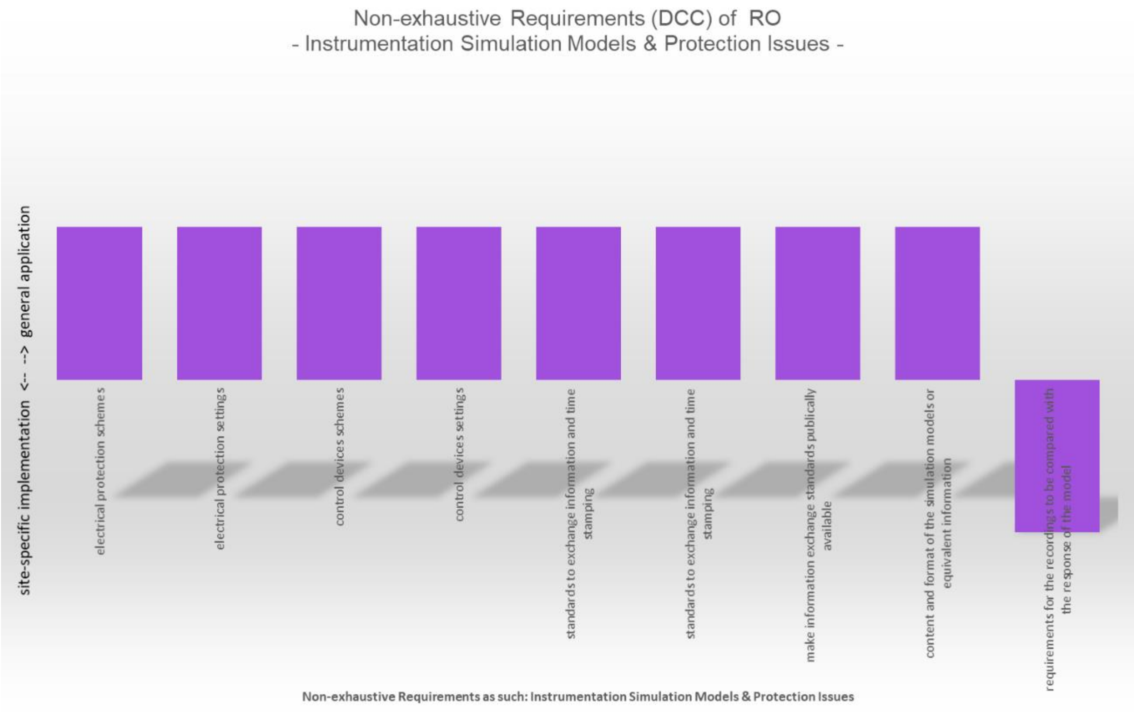


Figure 301: Romania (RO)

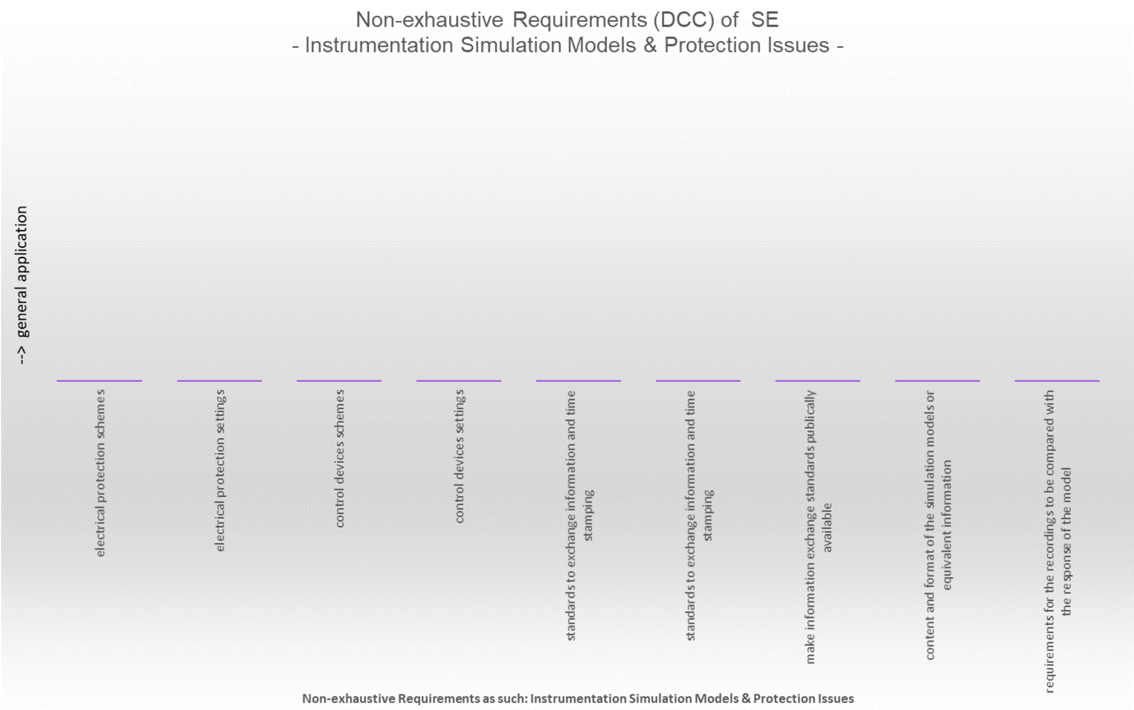


Figure 302: Sweden (SE)

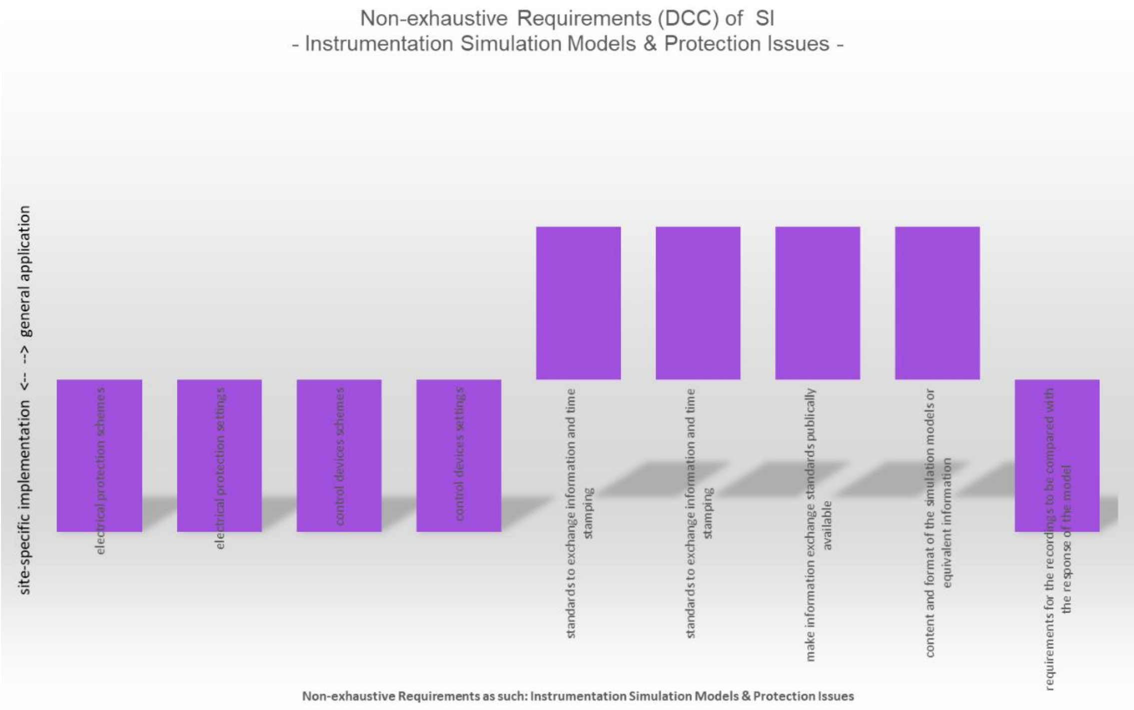


Figure 303: Slovenia (SI)

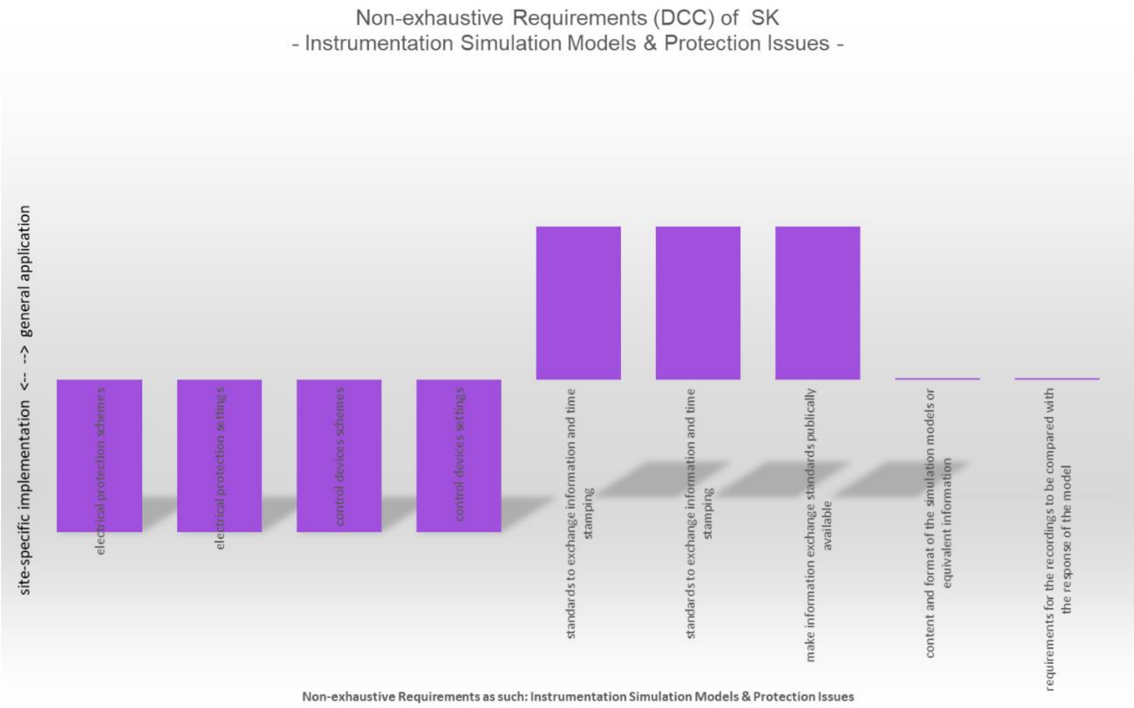


Figure 304: Slovakia (SK)

5 NC HVDC Implementation

5.1 Number of implemented non-exhaustive requirements in NC HVDC

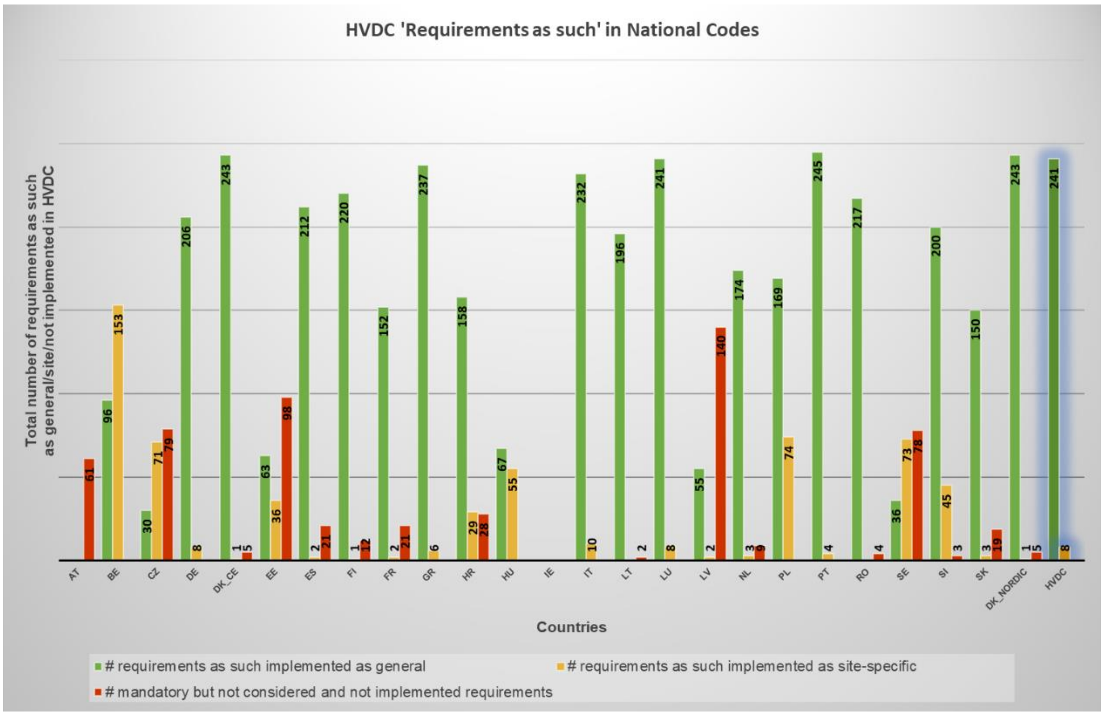


Figure 305: Reference total number of to be implemented HVDC non-exhaustive requirements as such

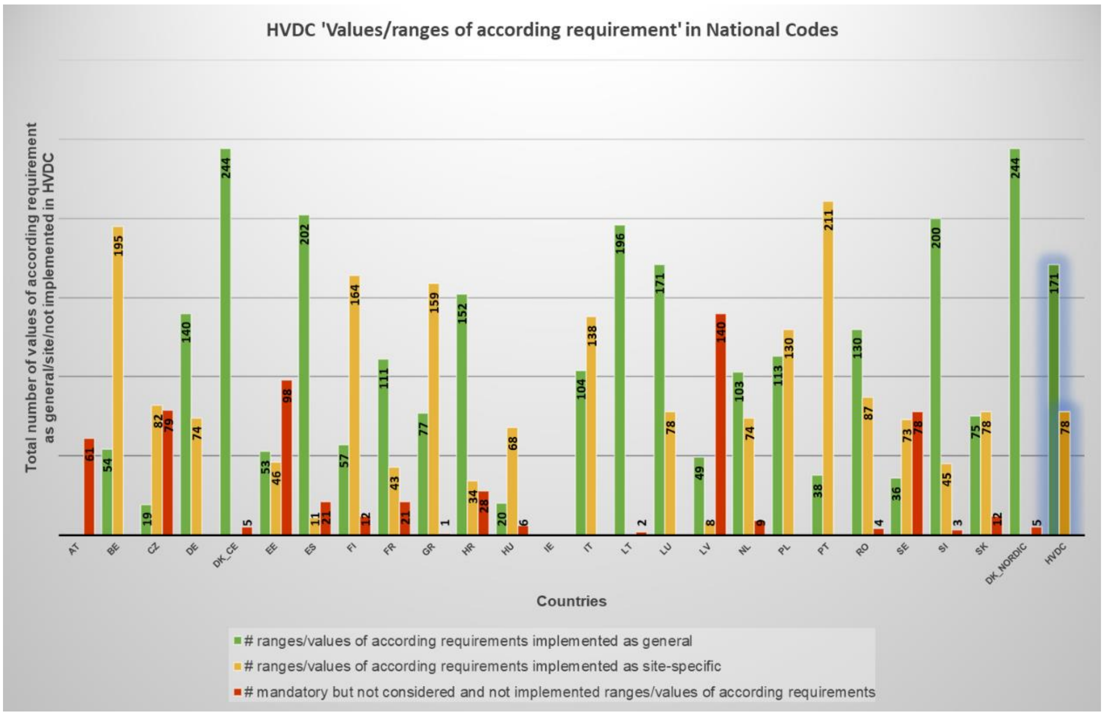


Figure 306: Reference total number of to be implemented values/ranges of regarding HVDC non-exhaustive requirements

5.2 Frequency Issues (1) of NC HVDC

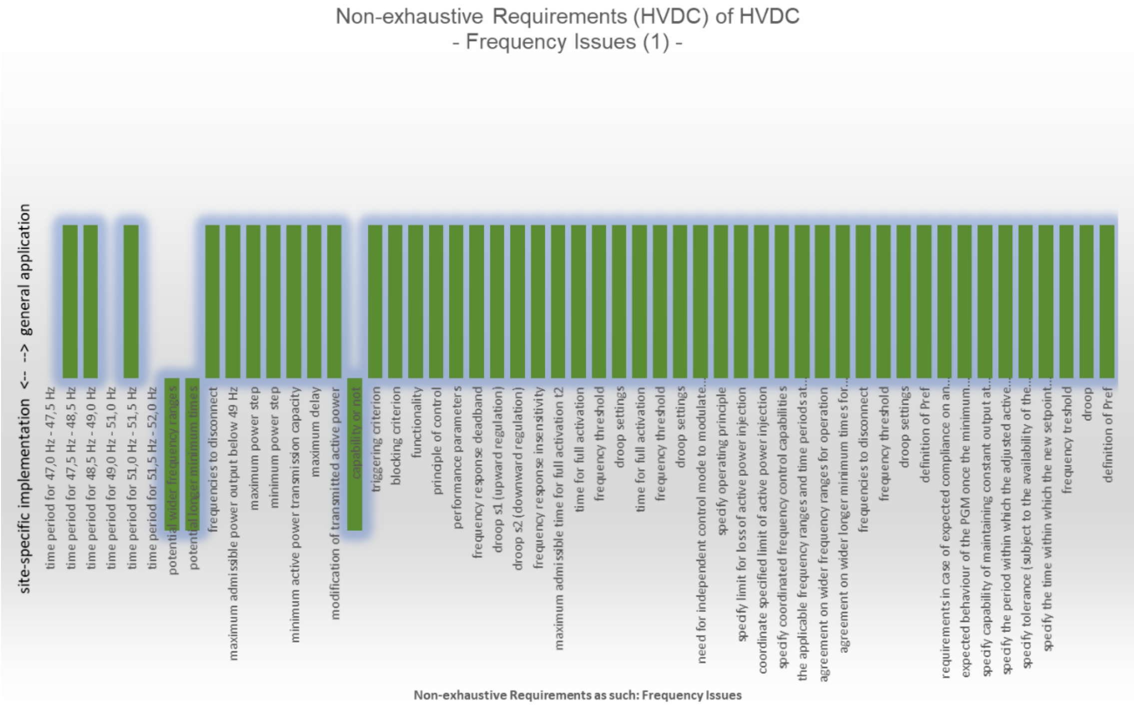


Figure 307: Reference values of non-exhaustive HVDC frequency issues (1)

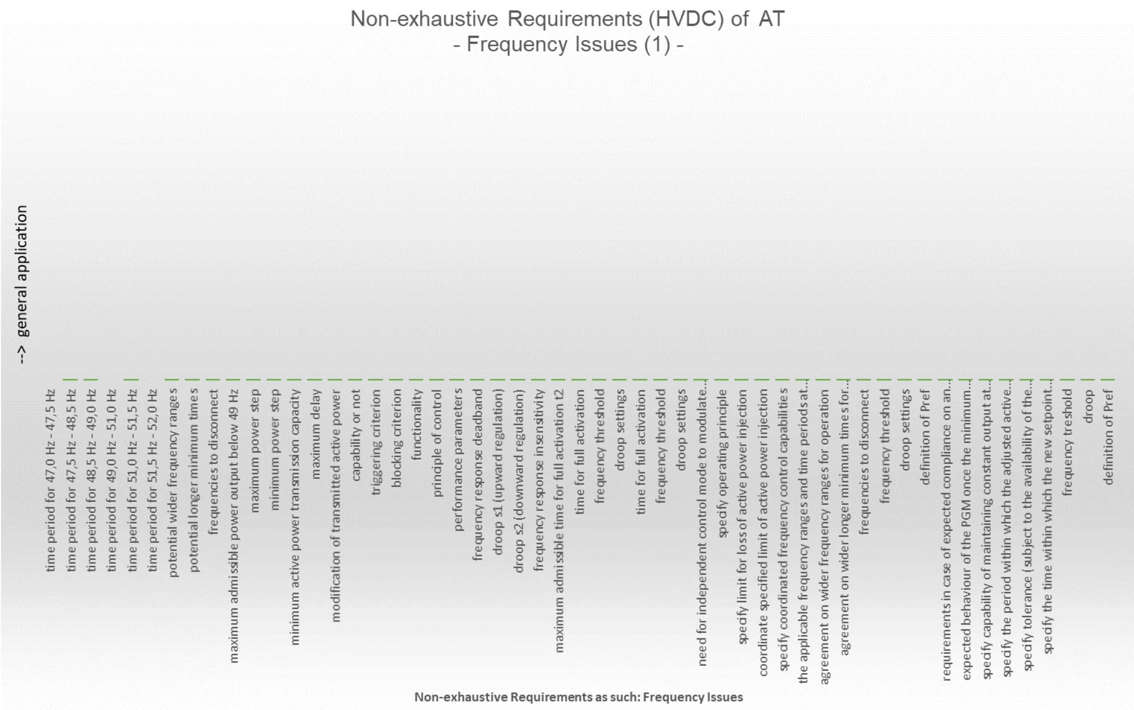


Figure 308: Austria (AT)

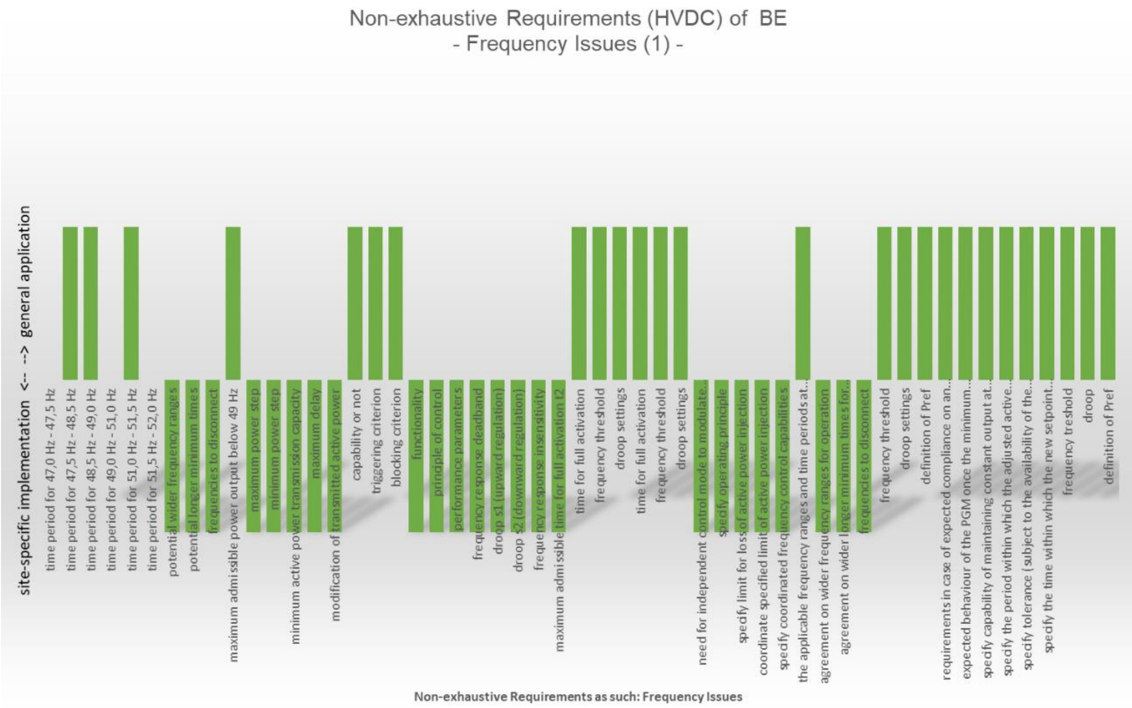


Figure 309: Belgium (BE)

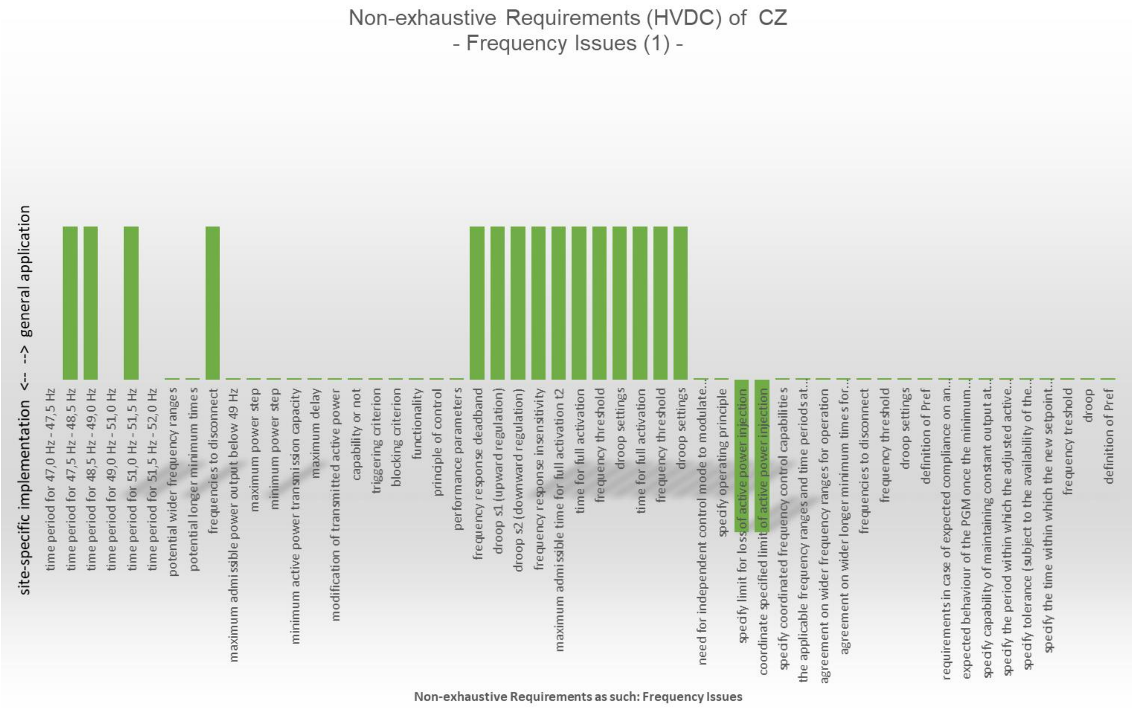


Figure 310: Czech Republic (CZ)

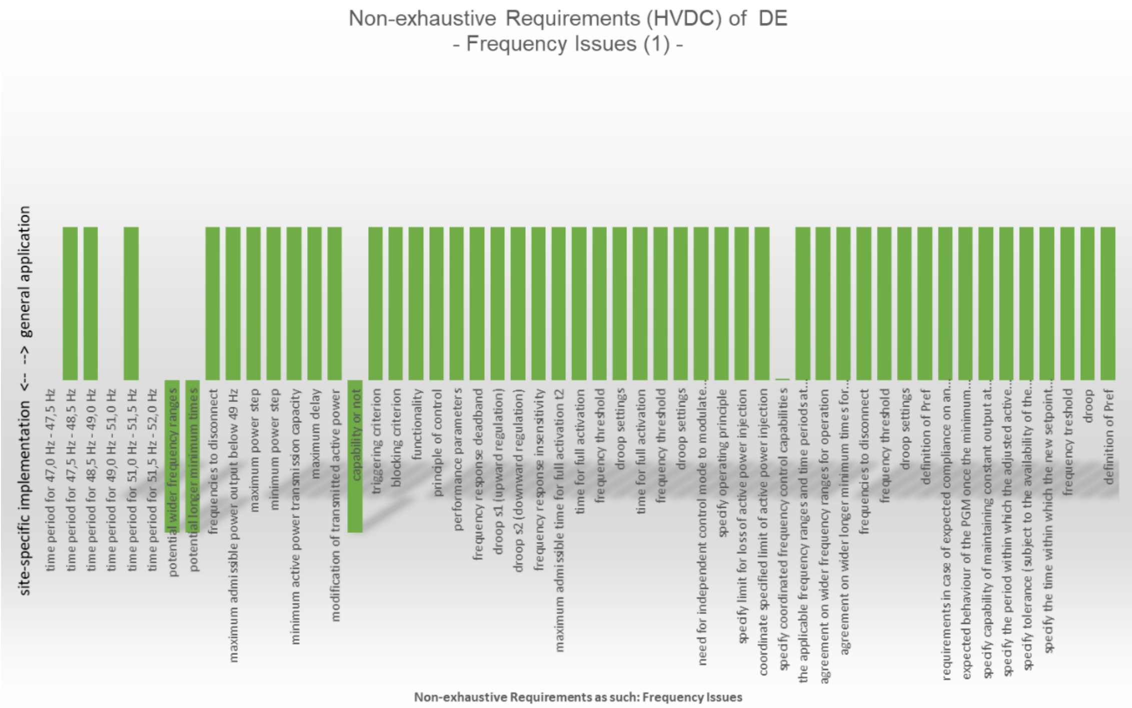


Figure 311: Germany (DE)

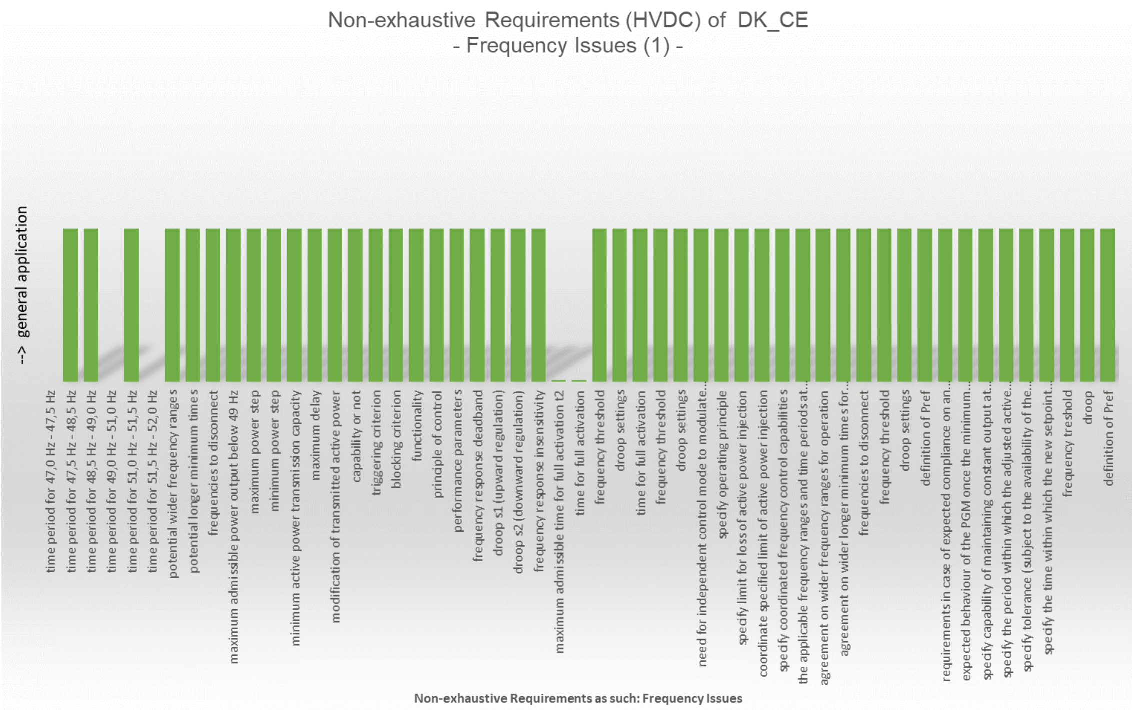


Figure 312: Denmark 1 (DK-CE)

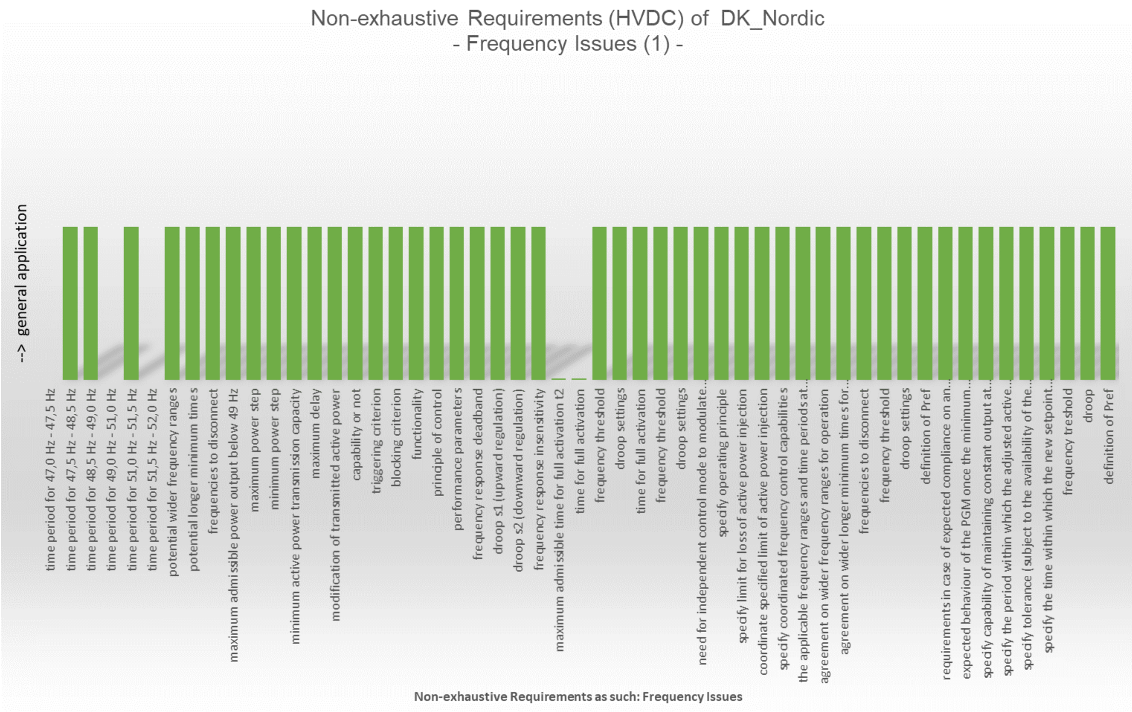


Figure 313: Denmark 2 (DK-Nordic)

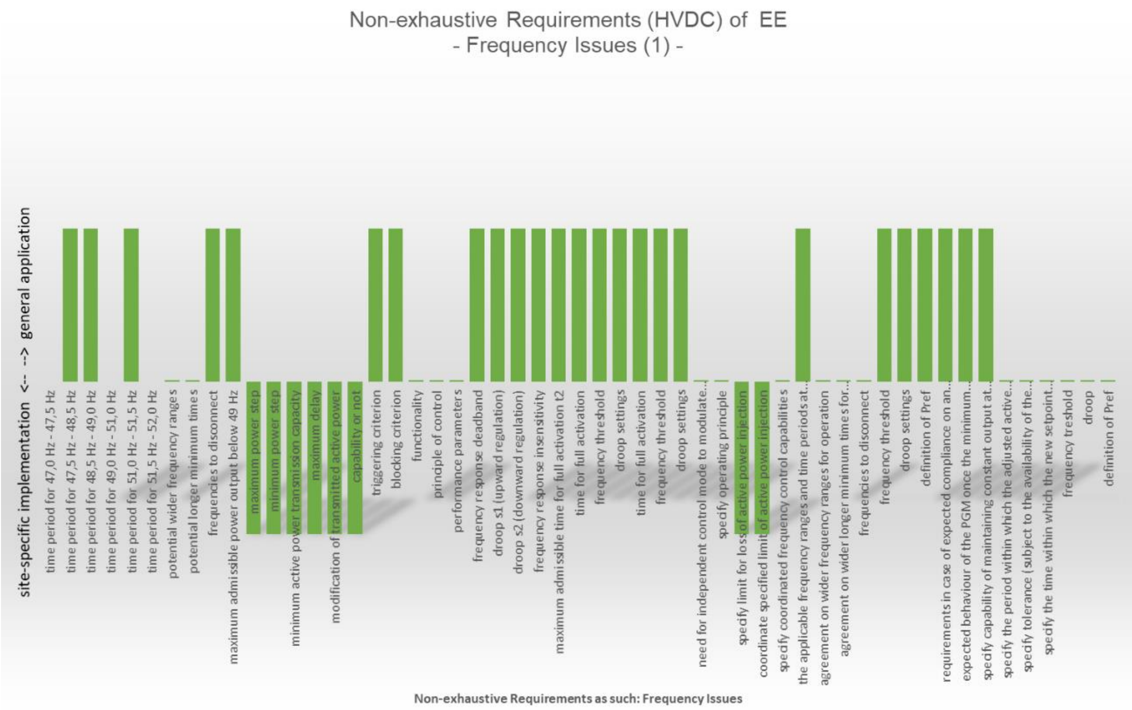


Figure 314: Estonia (EE)

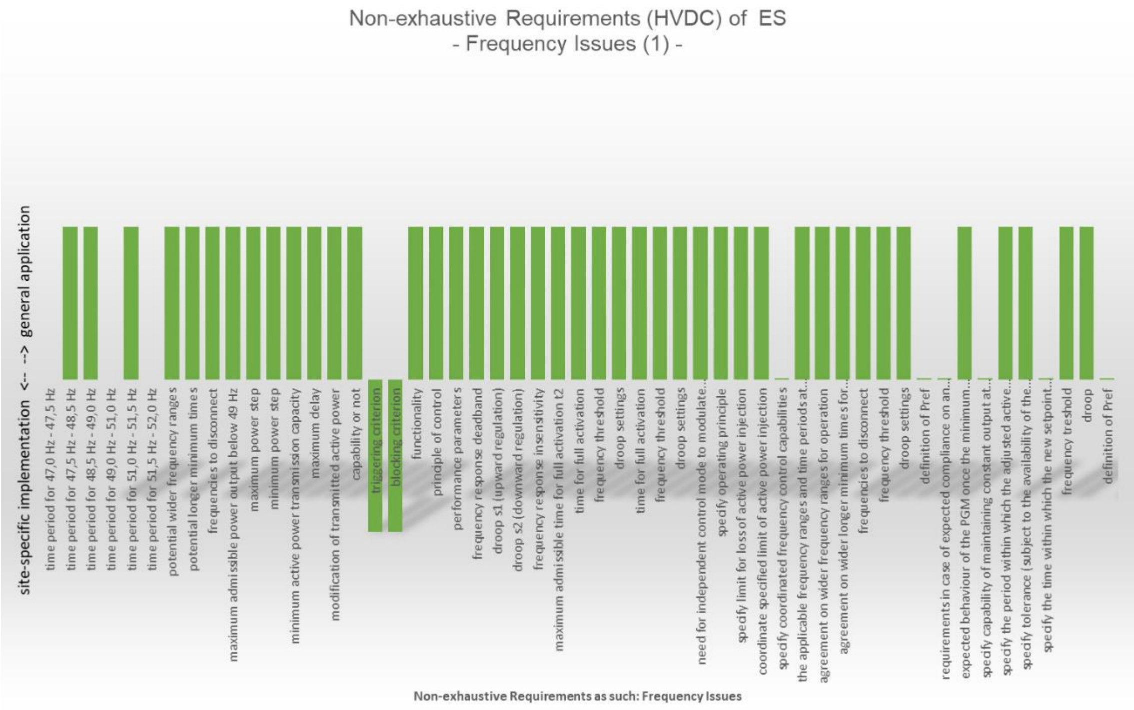


Figure 315: Spain (ES)

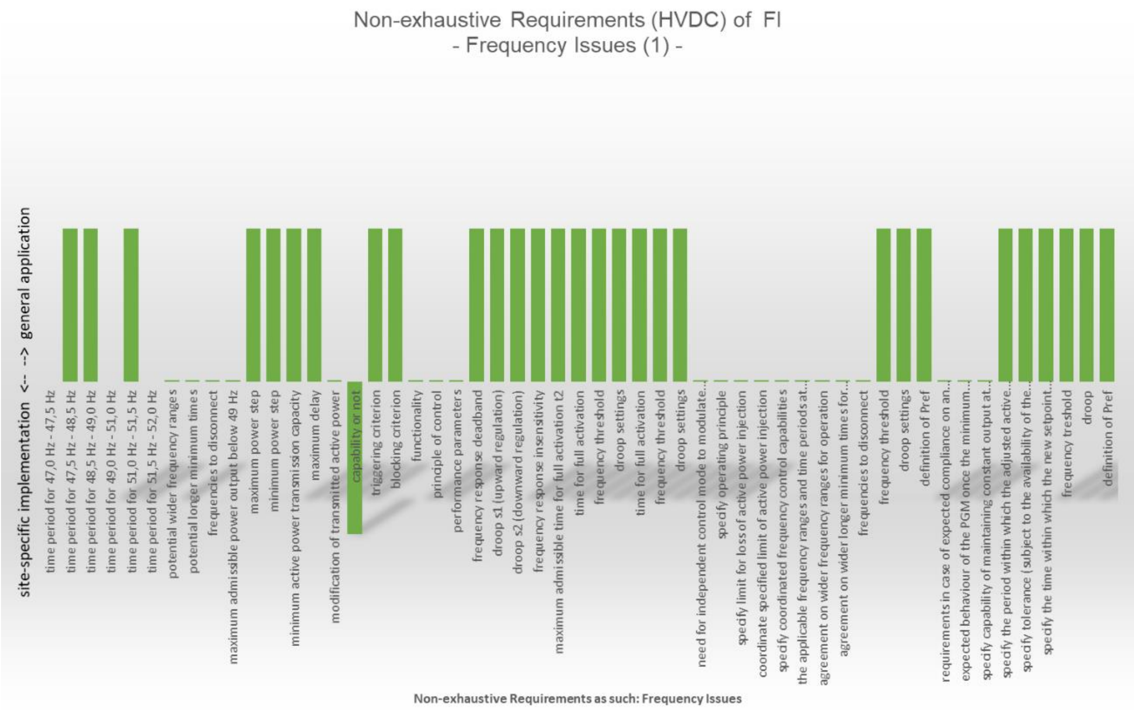


Figure 316: Finland (FI)

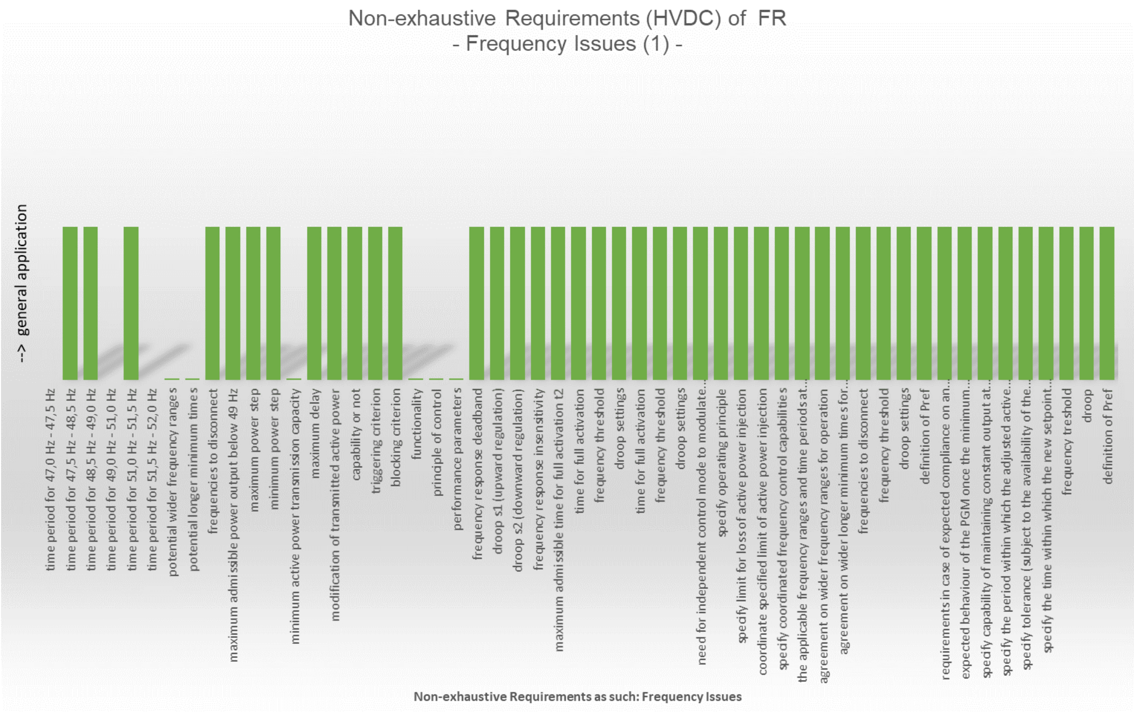


Figure 317: France (FR)

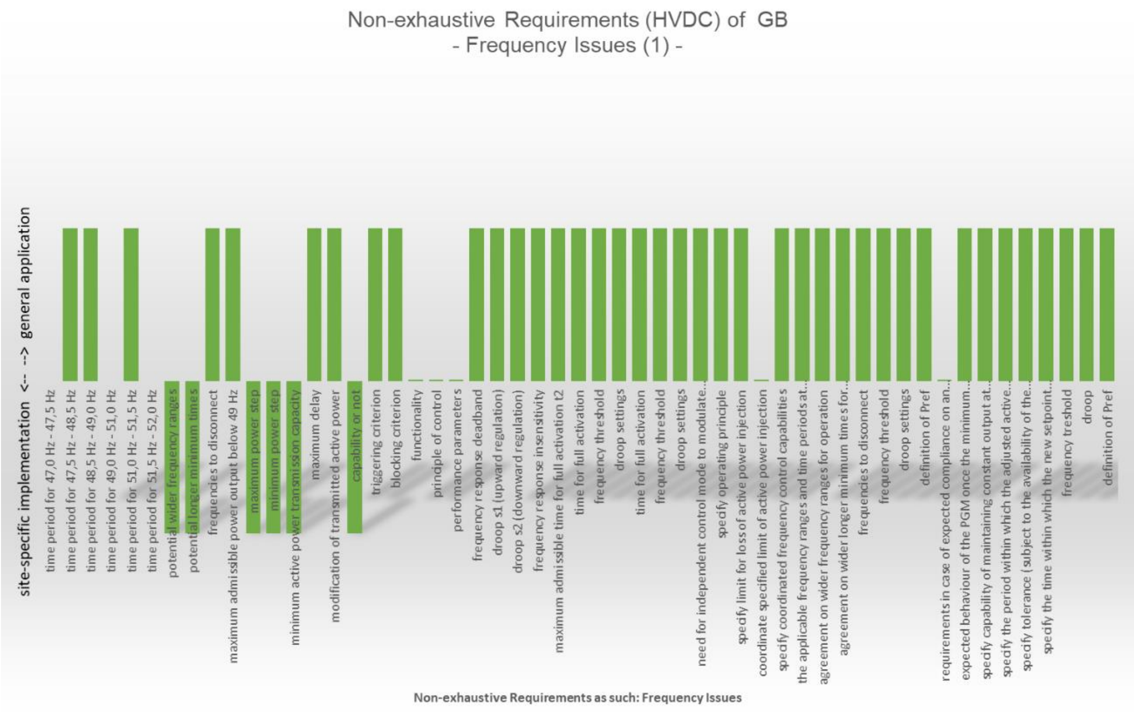


Figure 318: Great Britain (GB)

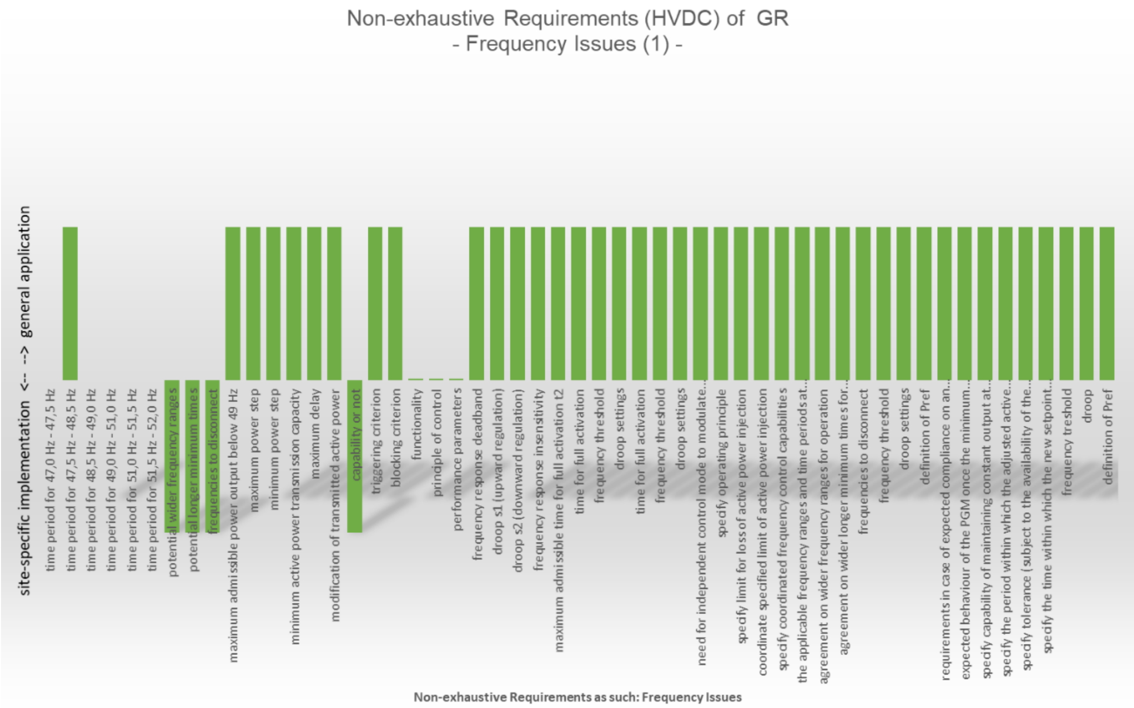


Figure 319: Greece (GR)

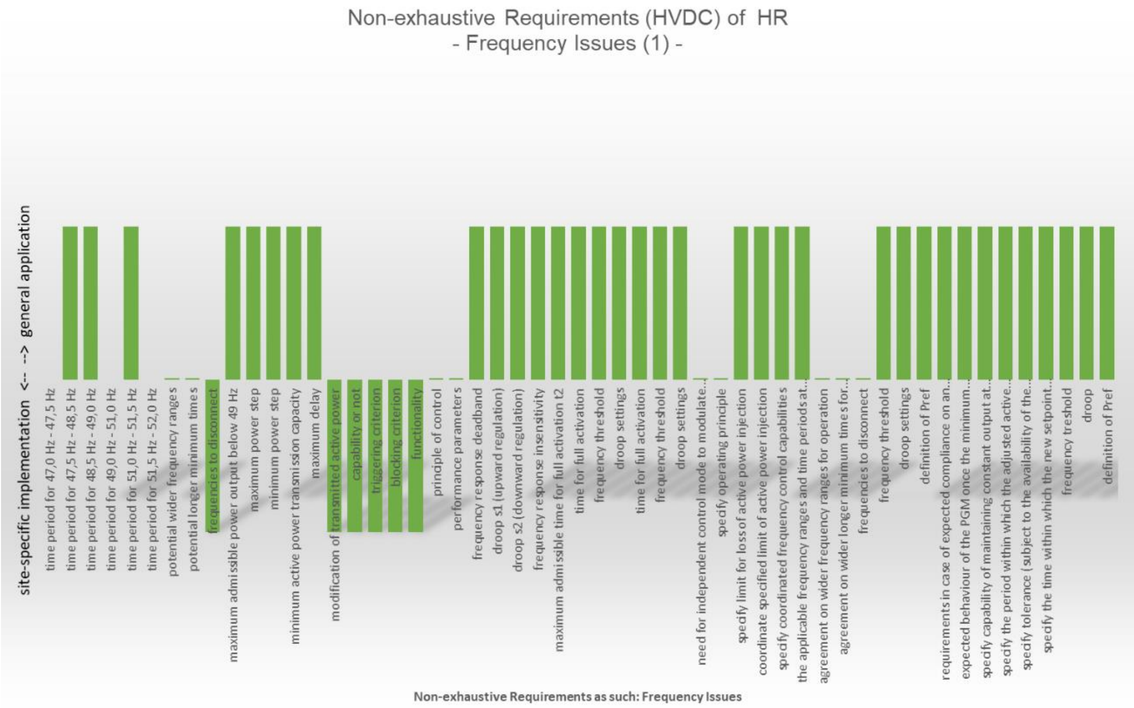


Figure 320: Croatia (HR)

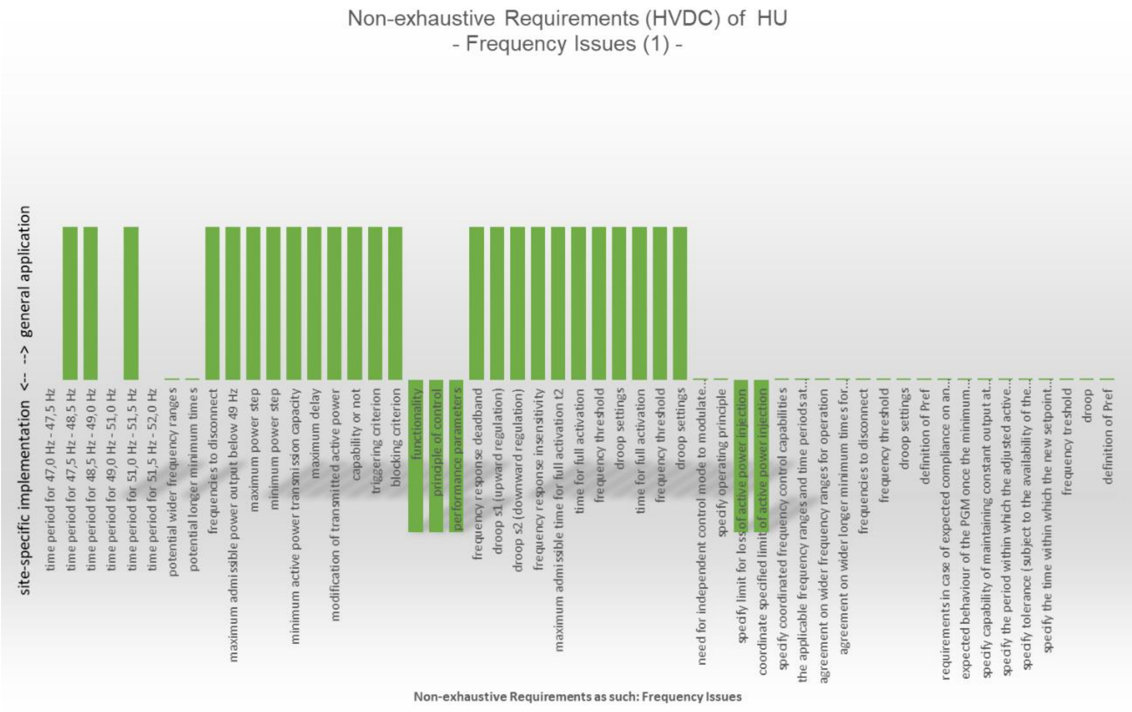


Figure 321: Hungary (HU)

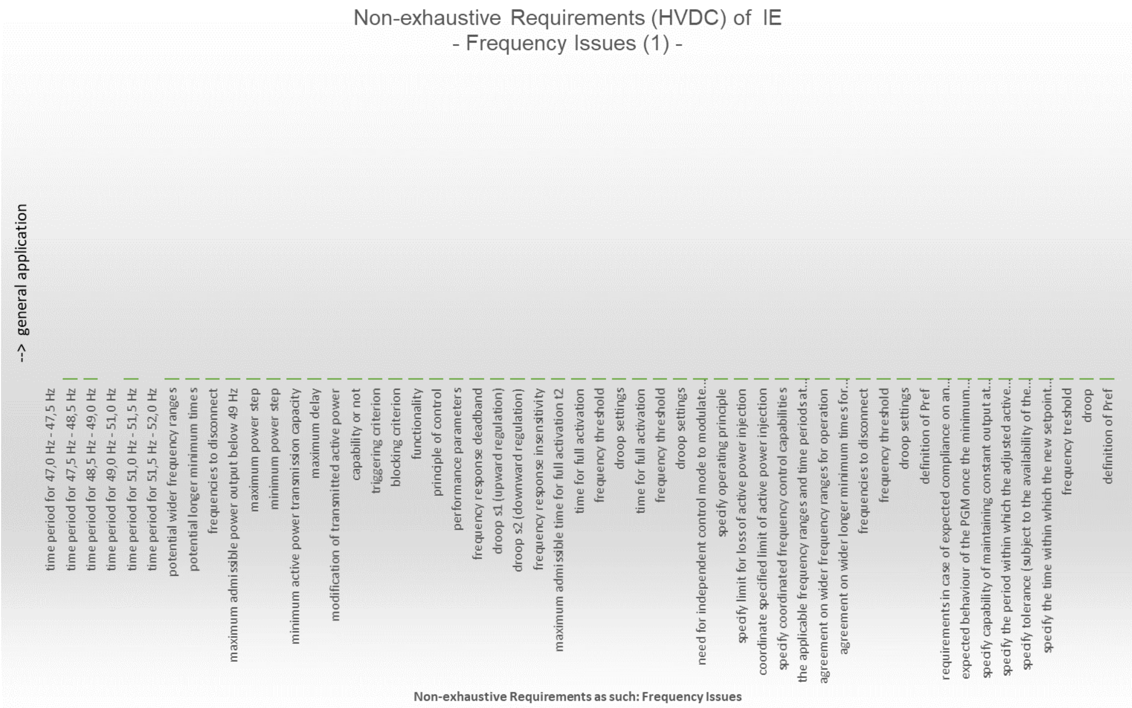


Figure 322: Ireland (IE)

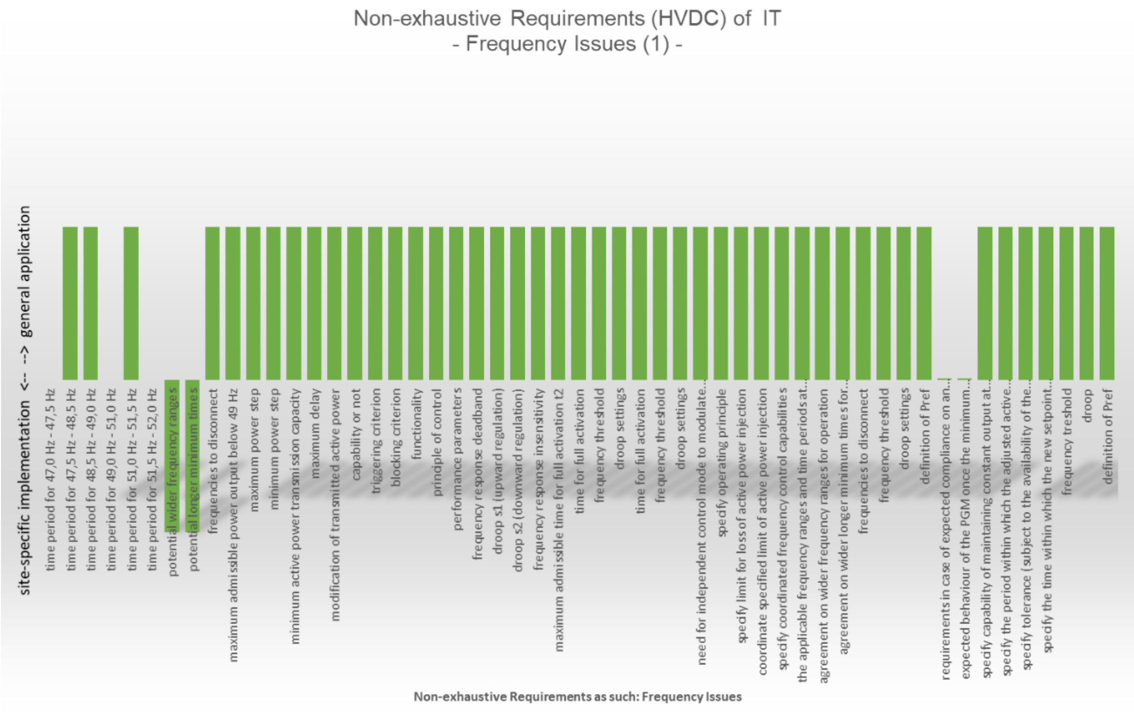


Figure 323: Italy (IT)

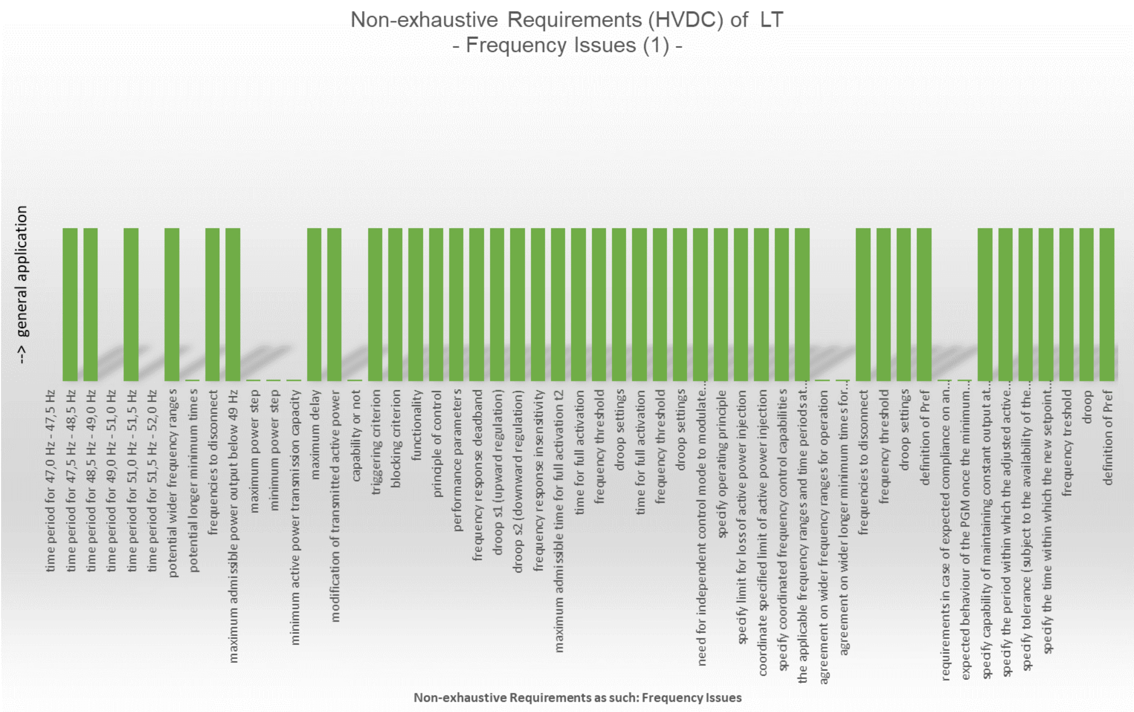


Figure 324: Lithuania (LT)

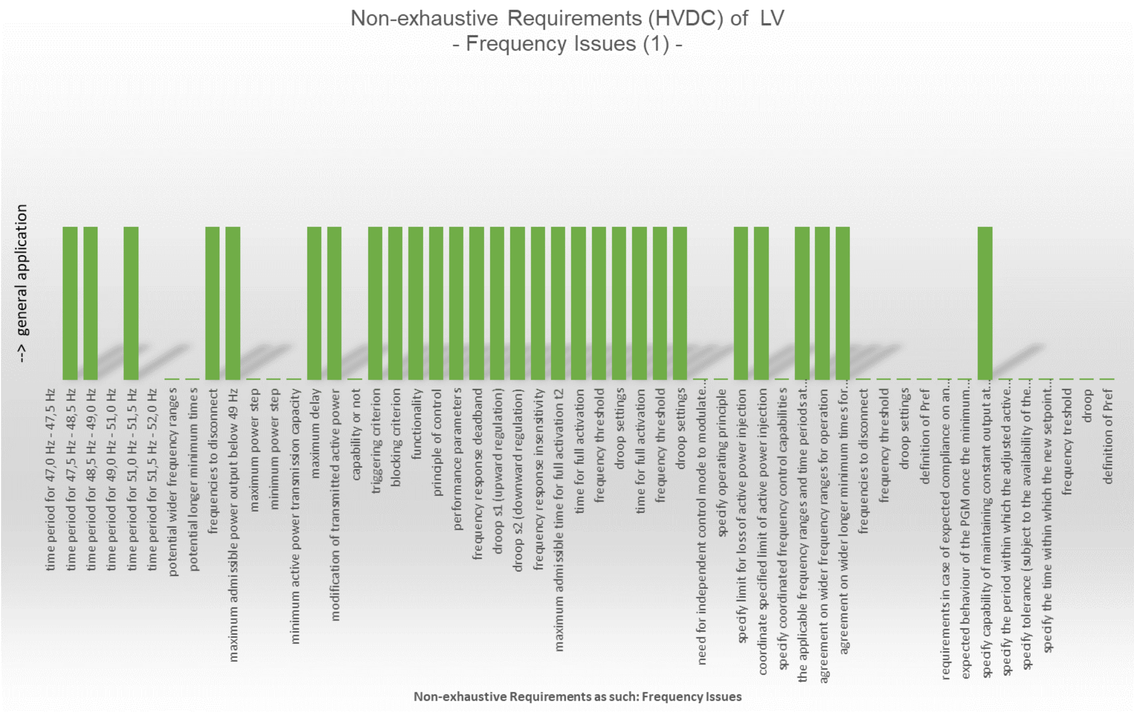


Figure 325: Latvia (LV)

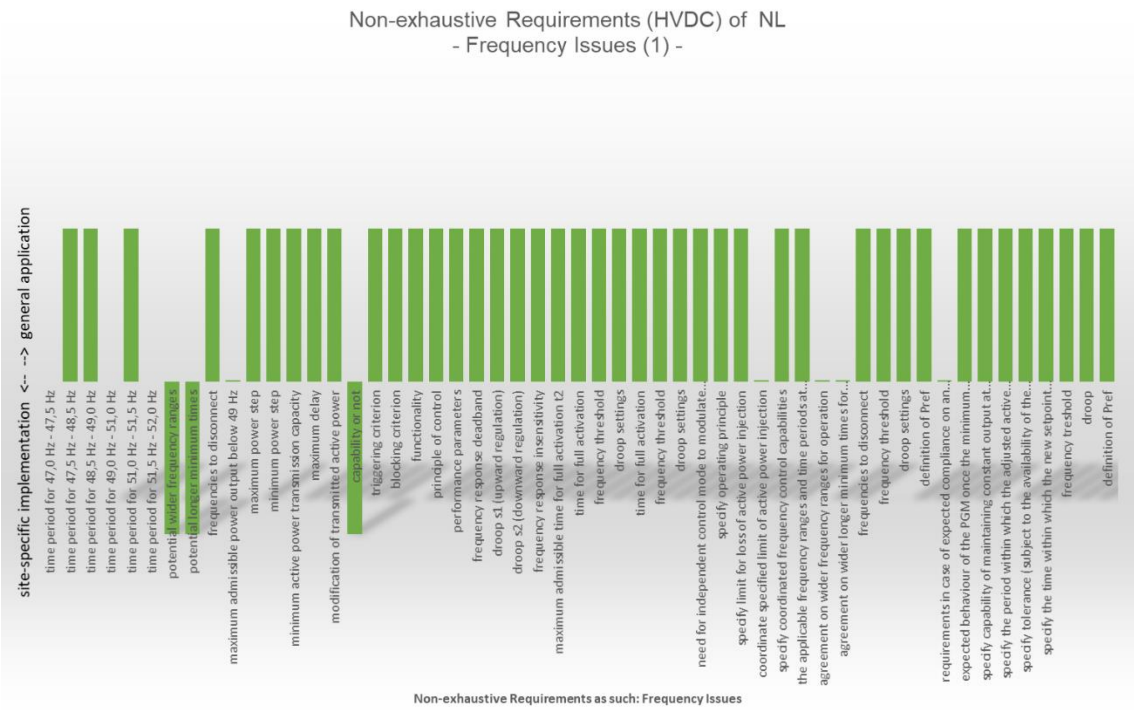


Figure 326: Netherlands (NL)

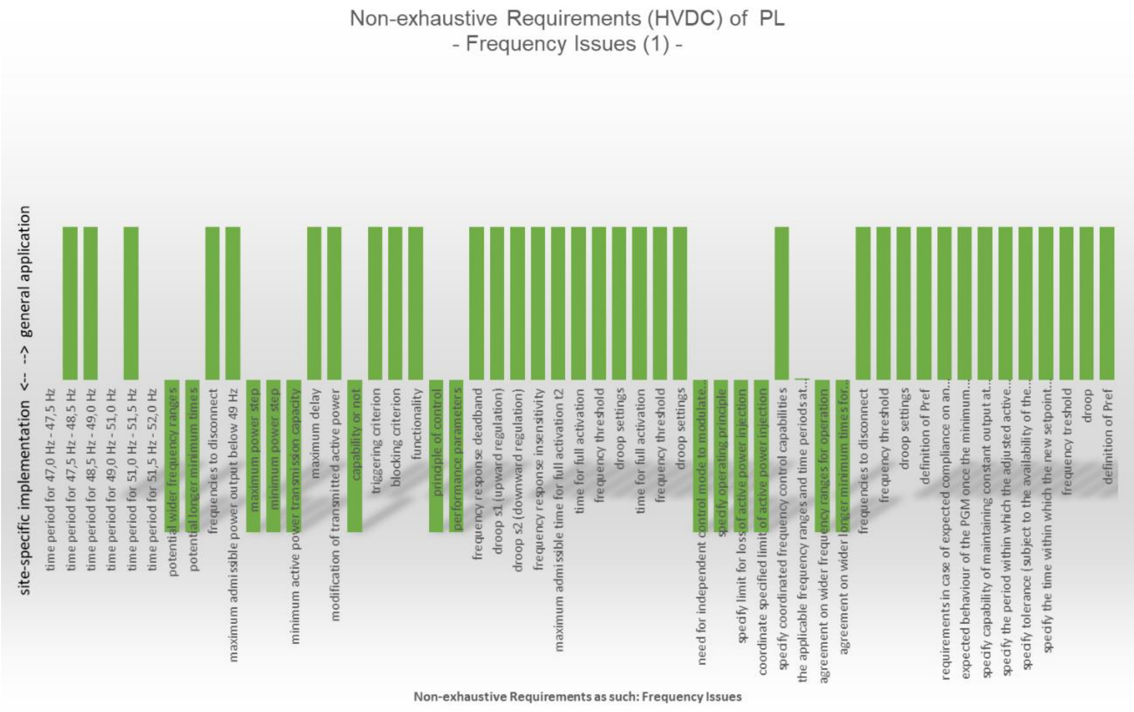


Figure 327: Poland (PL)

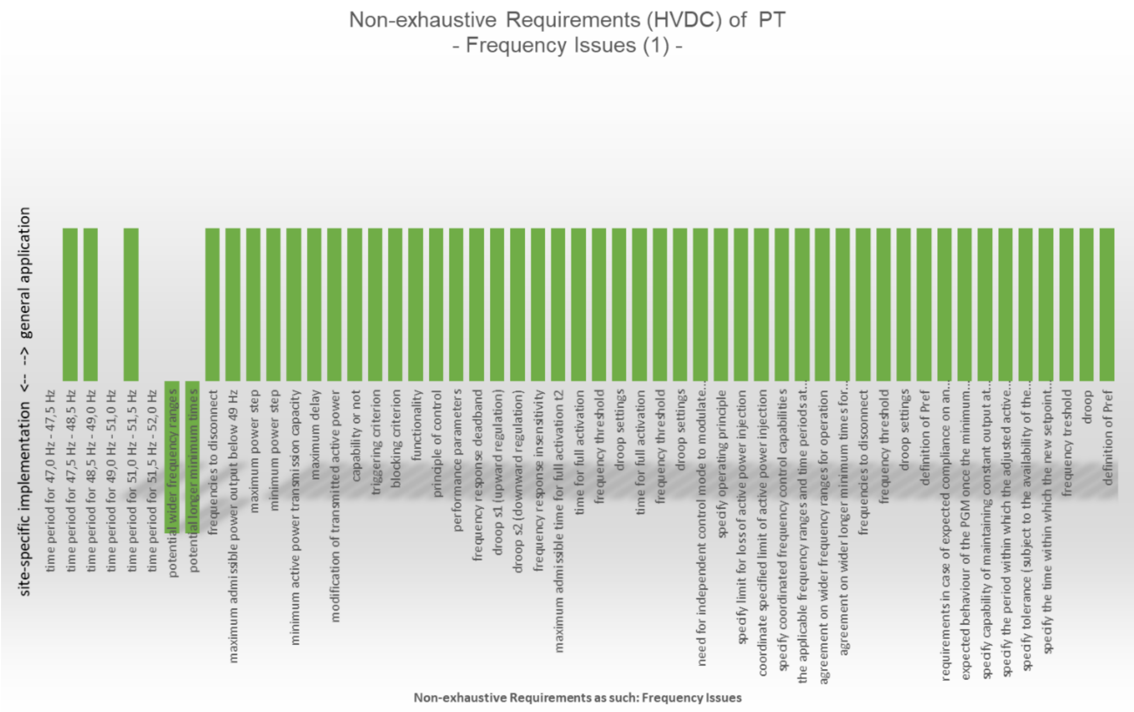


Figure 328: Portugal (PT)

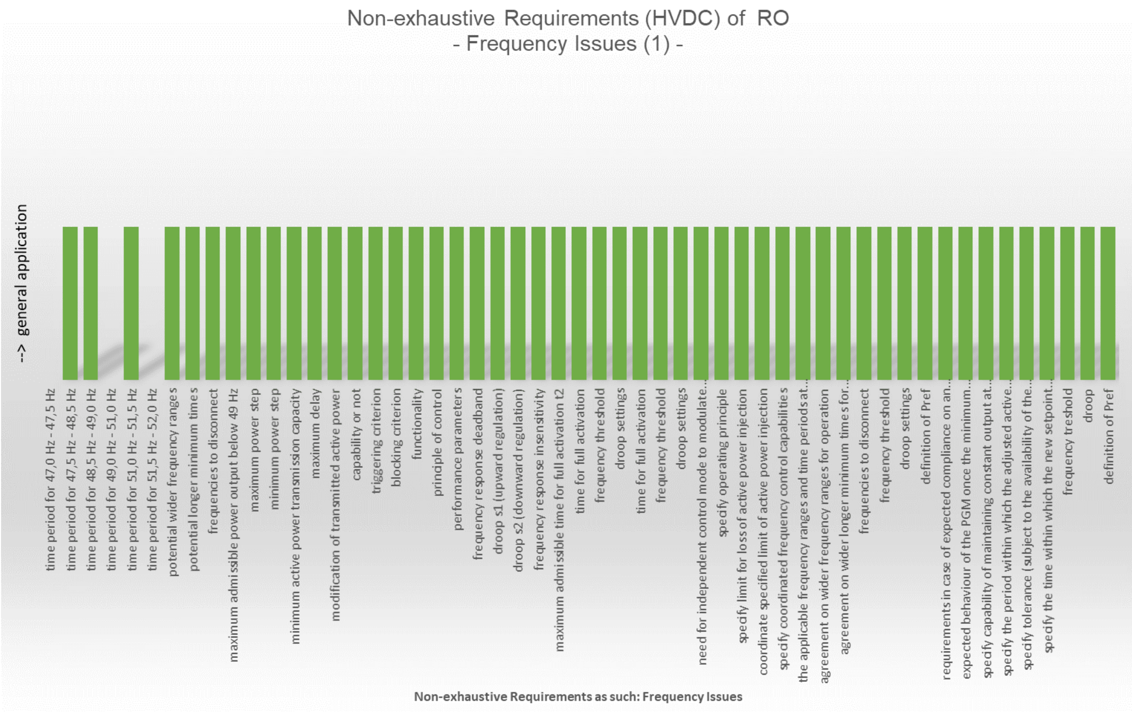


Figure 329: Romania (RO)

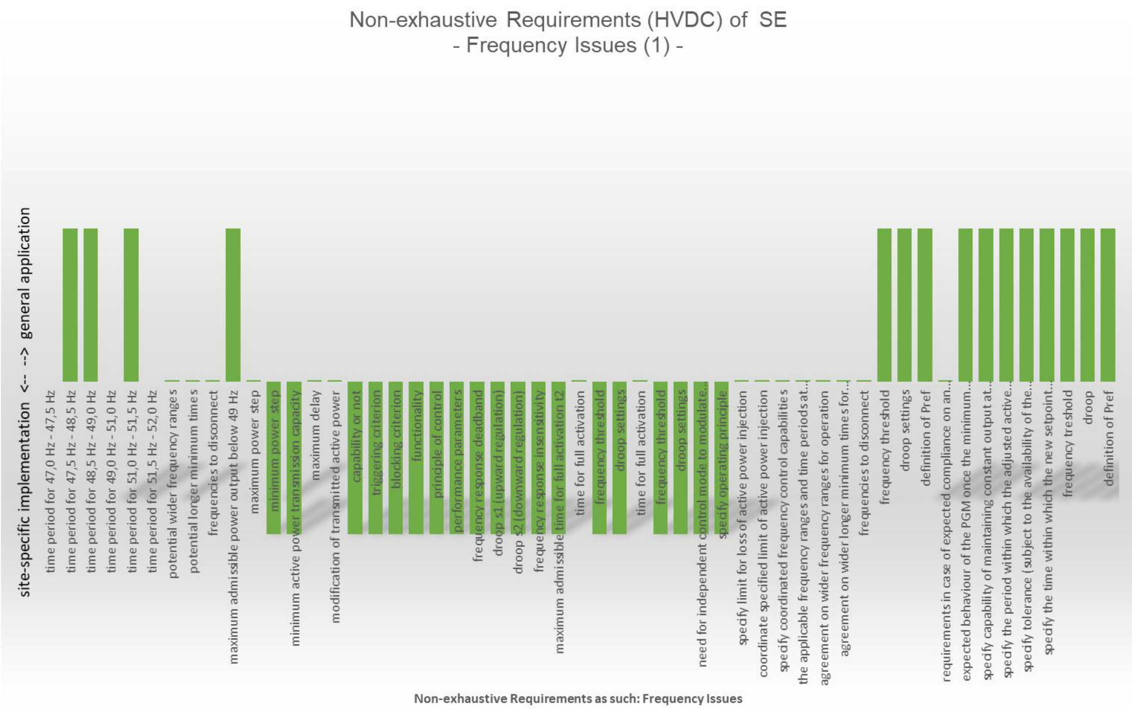


Figure 330: Sweden (SE)

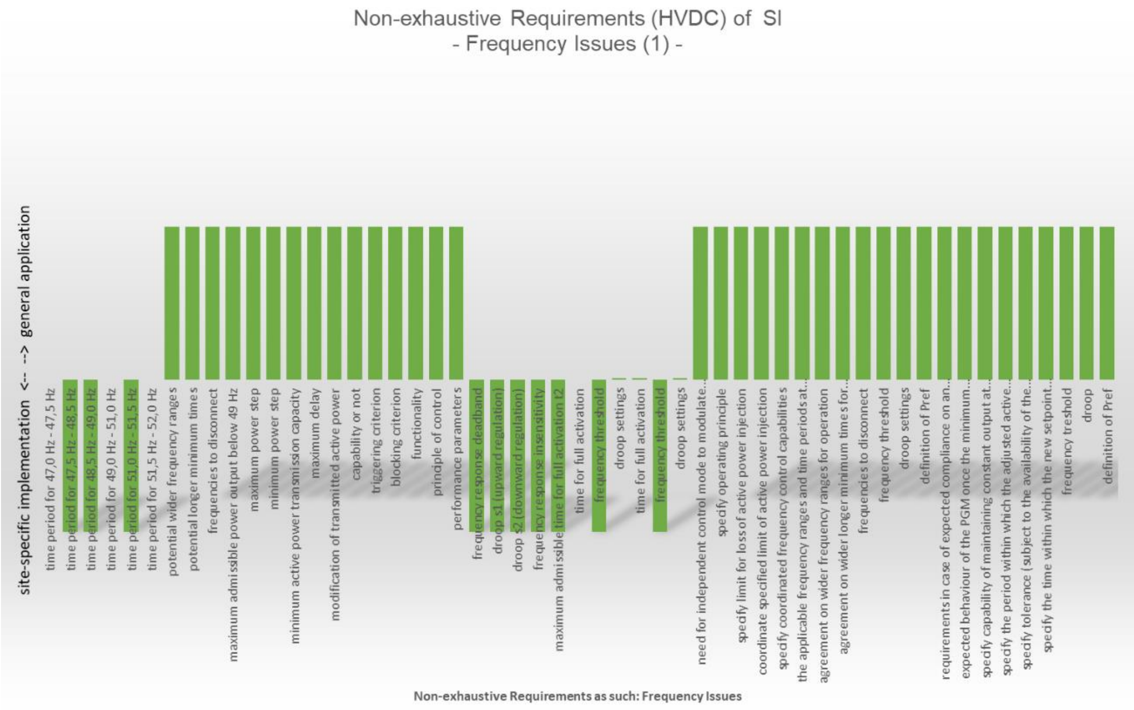


Figure 331: Slovenia (SI)

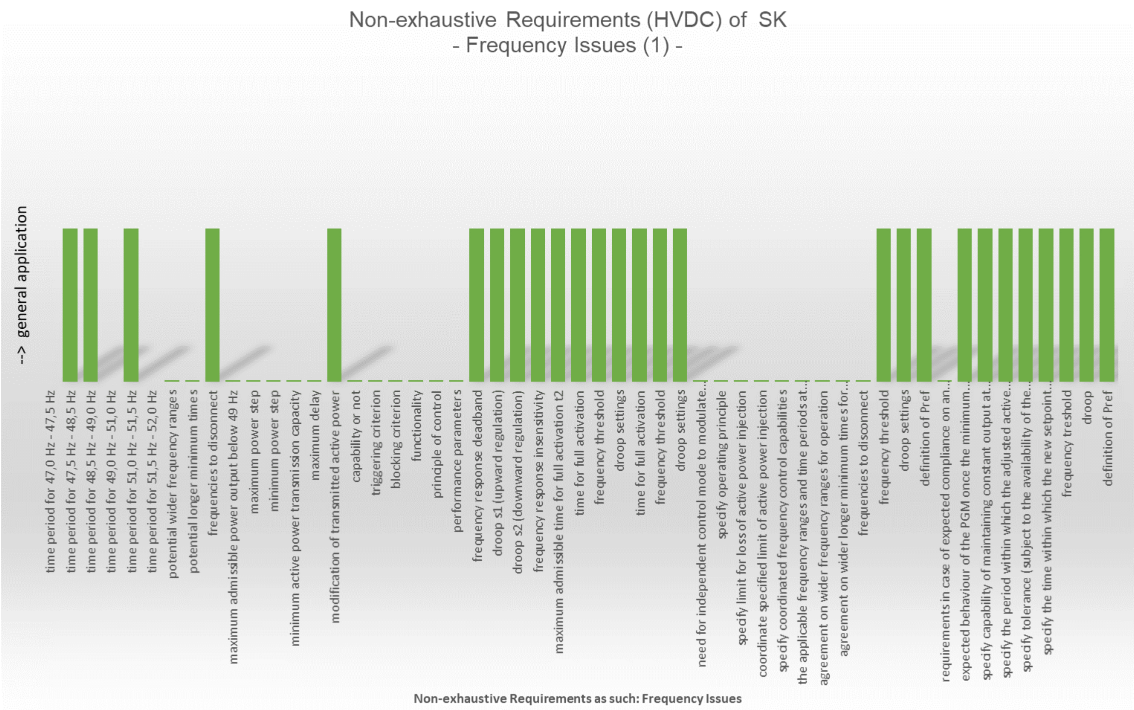


Figure 332: Slovakia (SK)

5.3 Frequency Issues (2) of NC HVDC

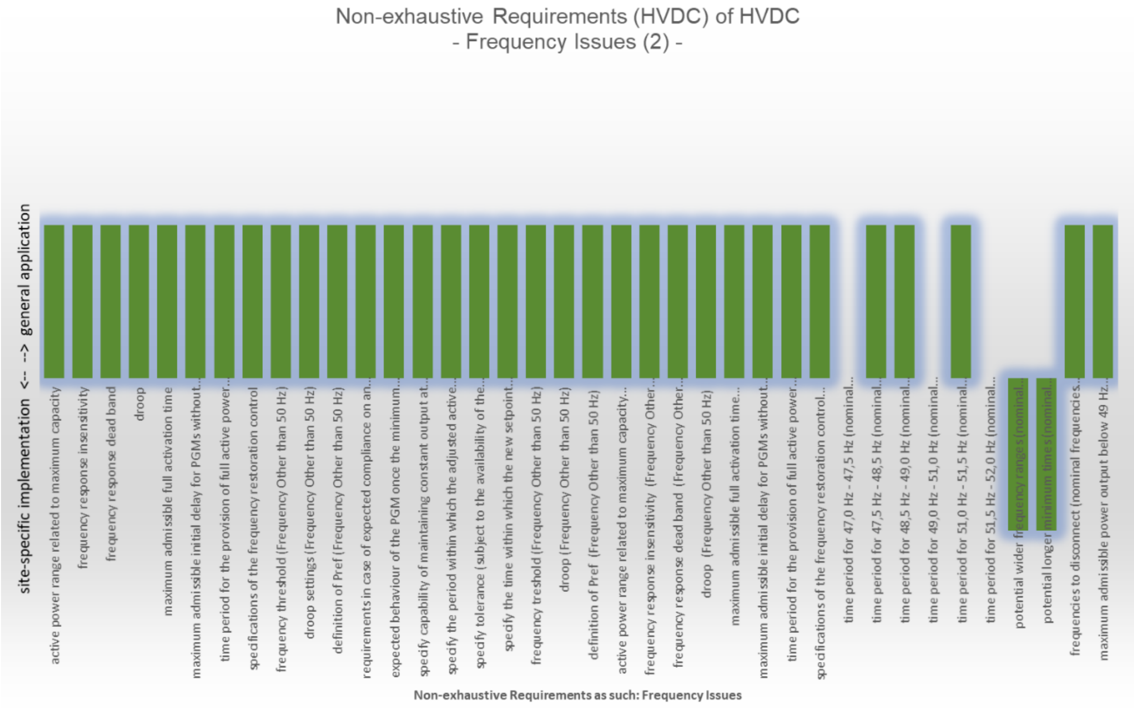


Figure 333: Reference values of non-exhaustive DCC – frequency issues (2)

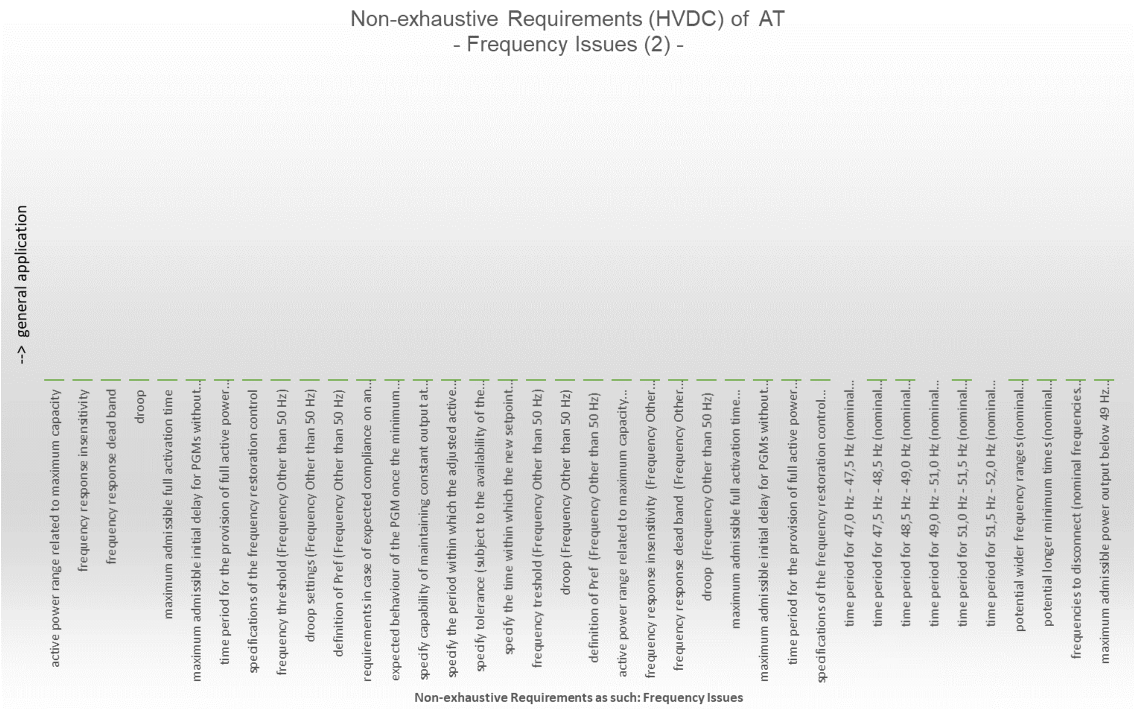


Figure 334: Austria (AT)

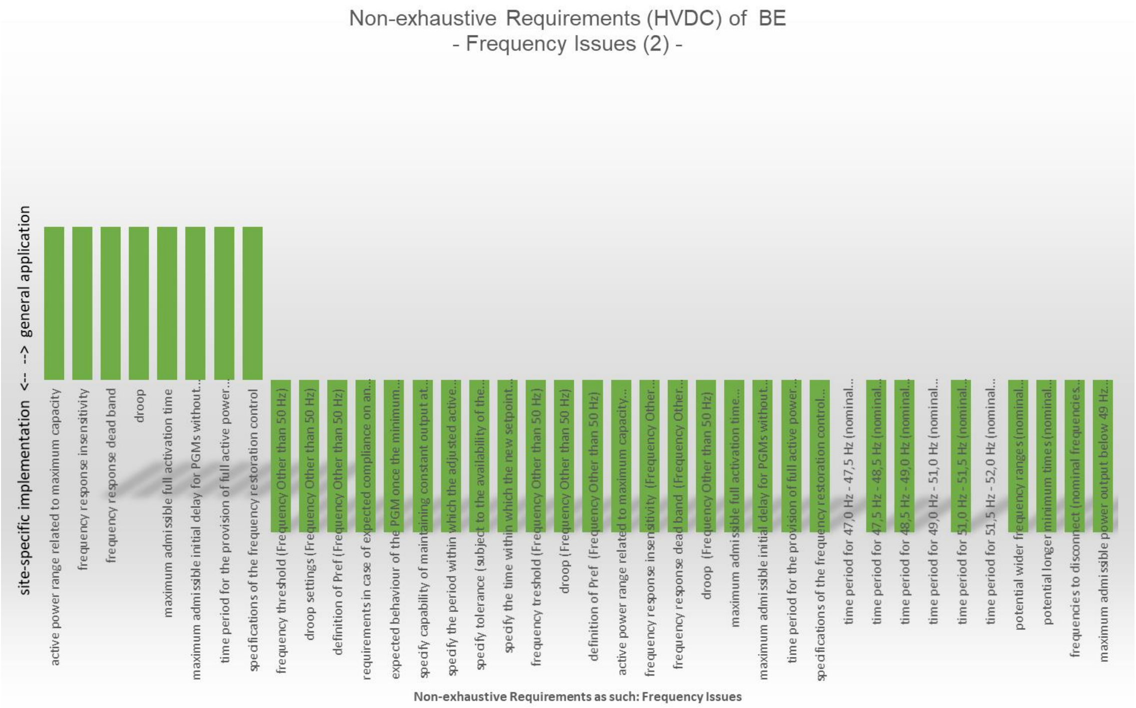


Figure 335: Belgium (BE)

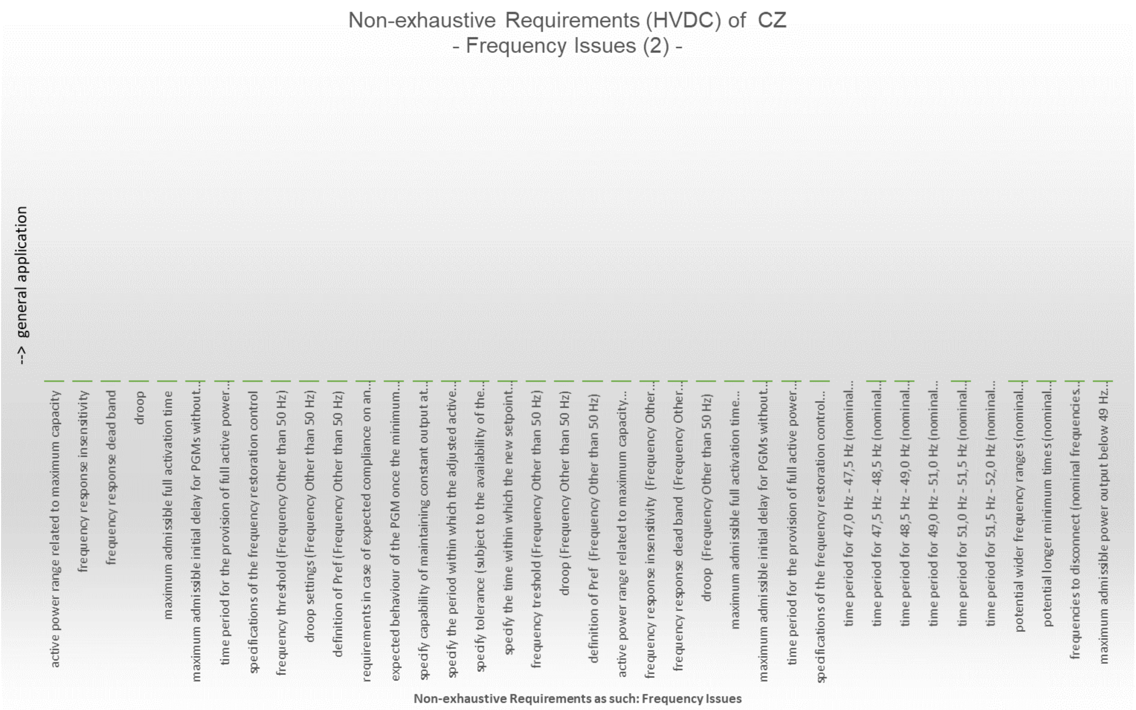


Figure 336: Czech Republic (CZ)

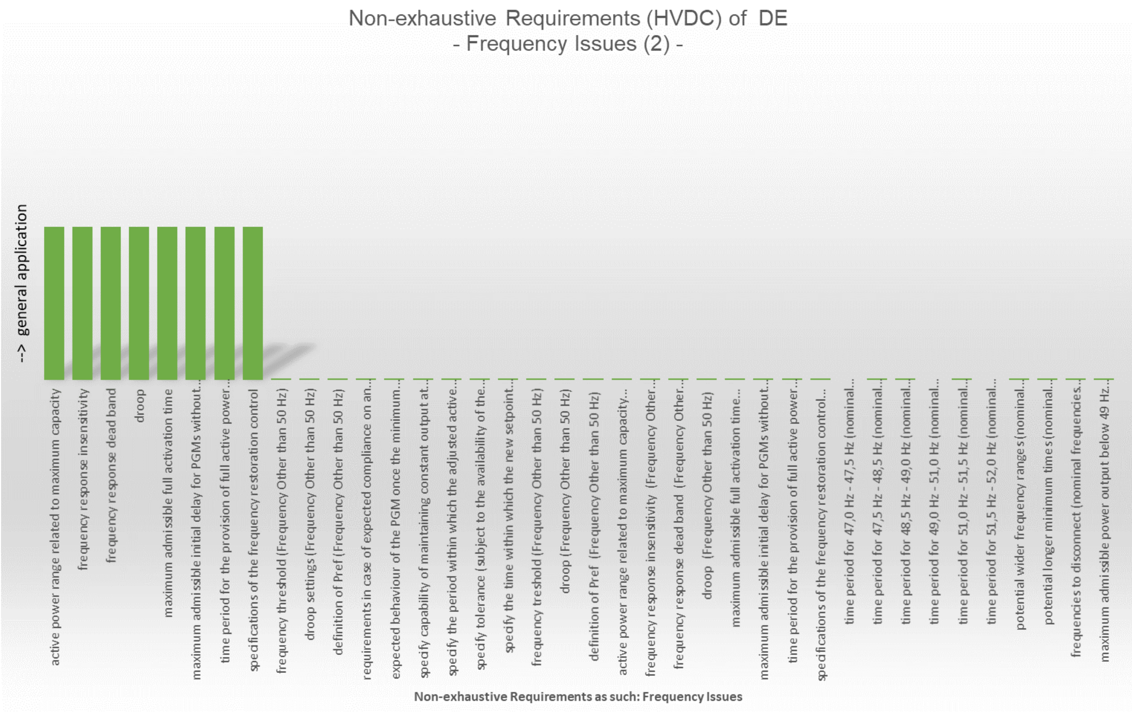


Figure 337: Germany (DE)

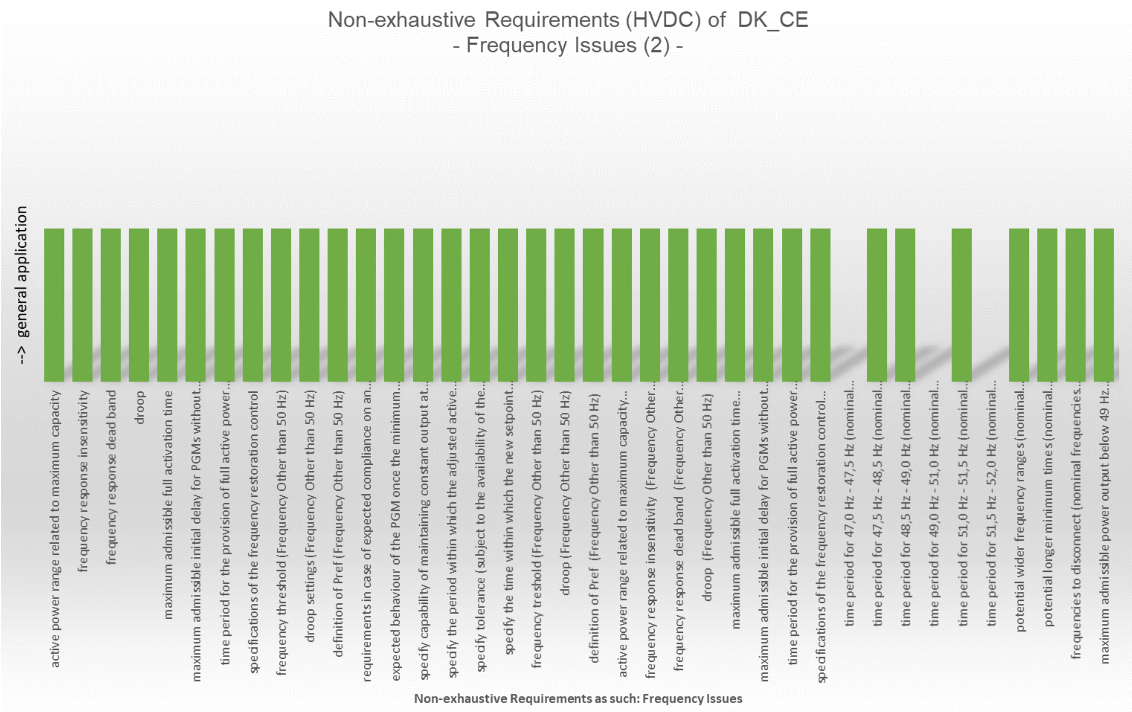


Figure 338: Denmark 1 (DK-CE)

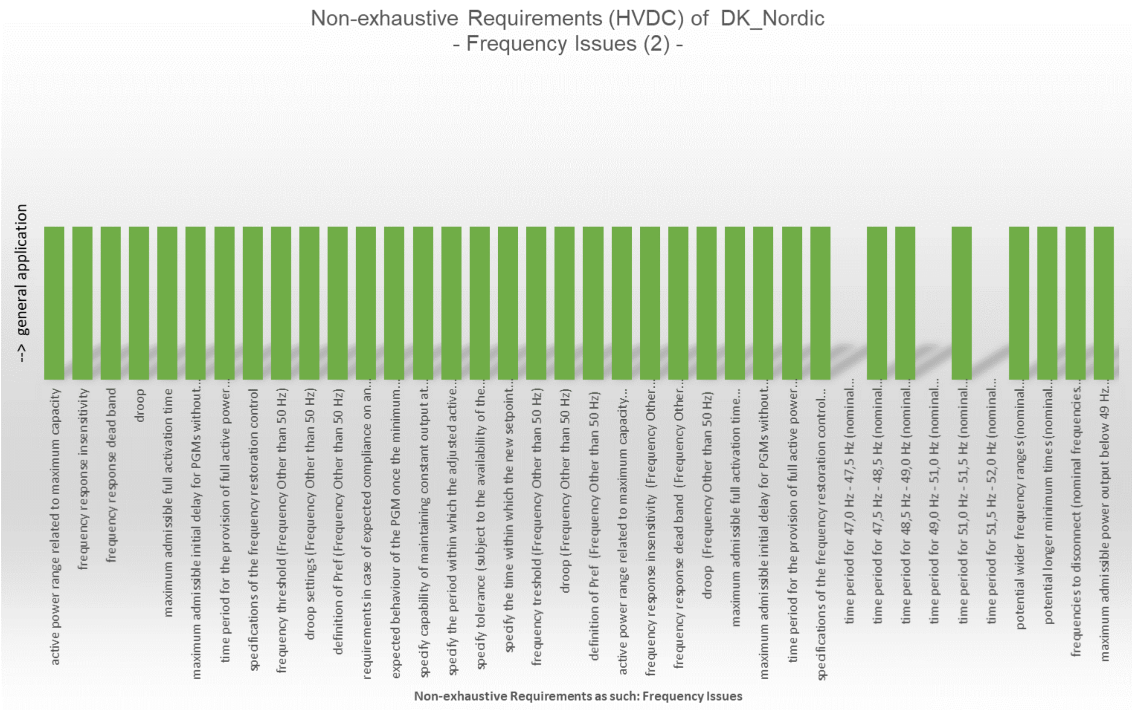


Figure 339: Denmark 2 (DK-Nordic)

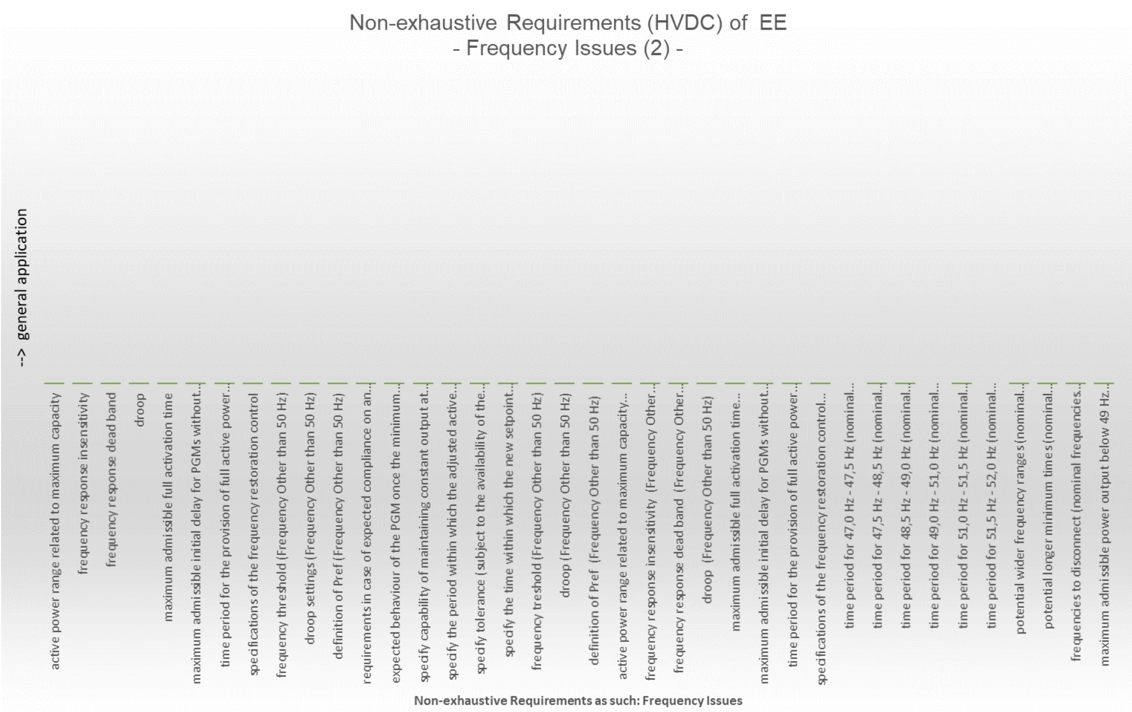


Figure 340: Estonia (EE)

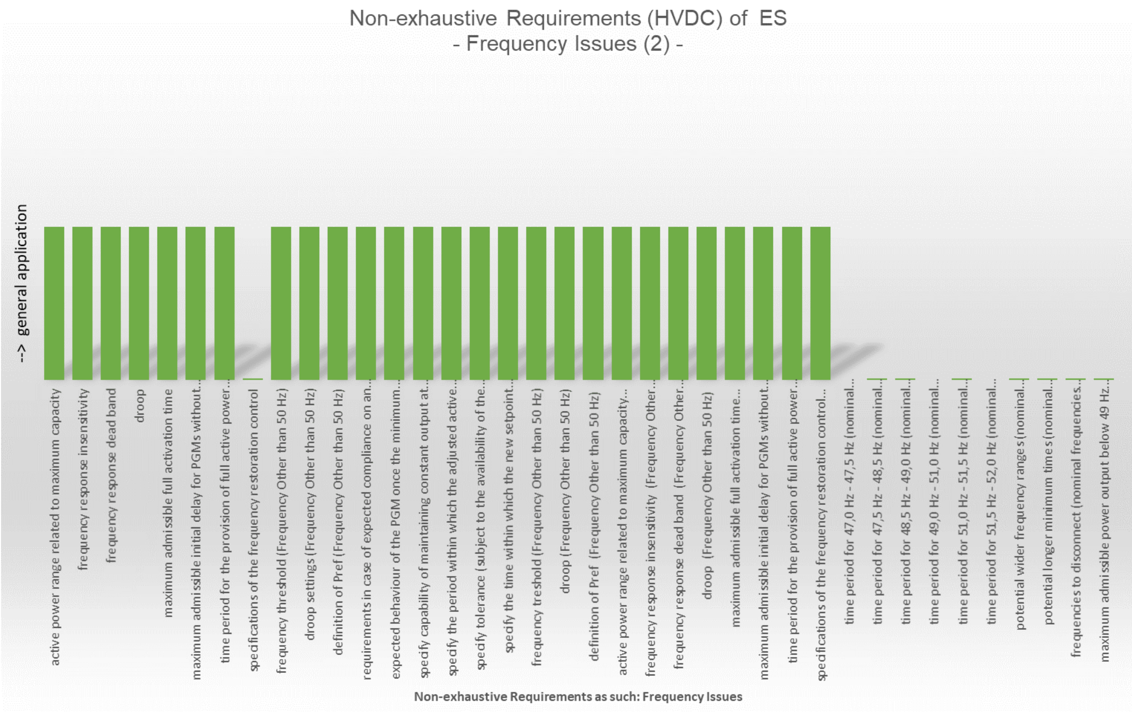


Figure 341: Spain (ES)

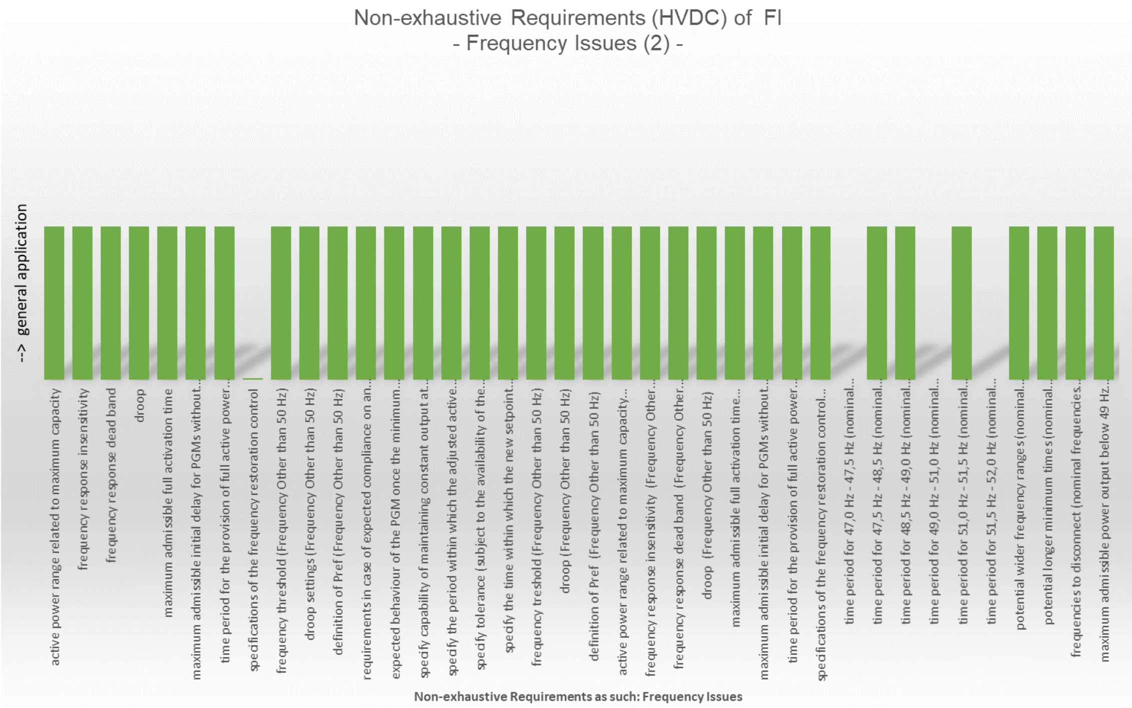


Figure 342: Finland (FI)

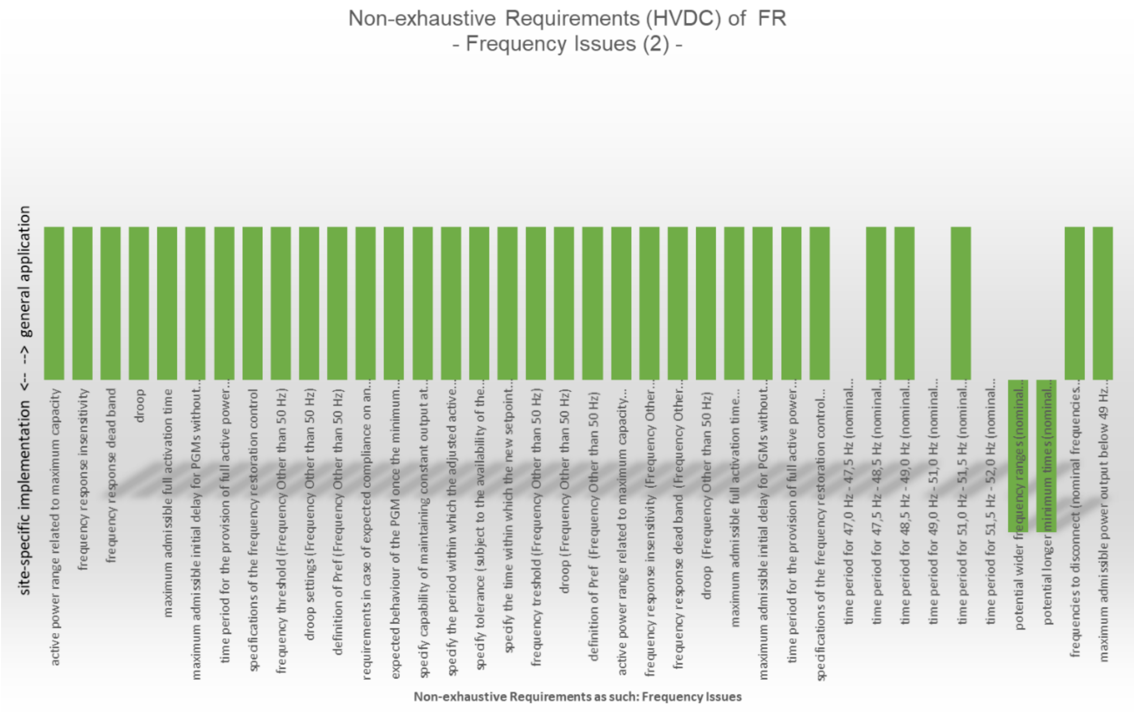


Figure 343: France (FR)

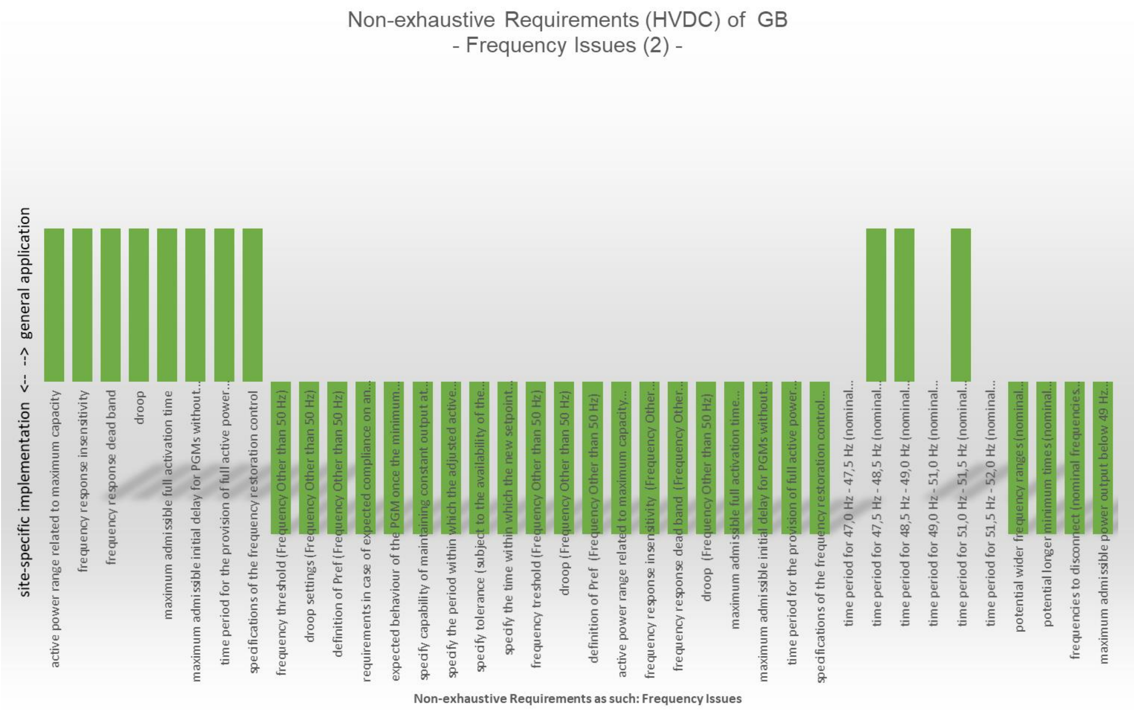


Figure 344: Great Britain (GB)

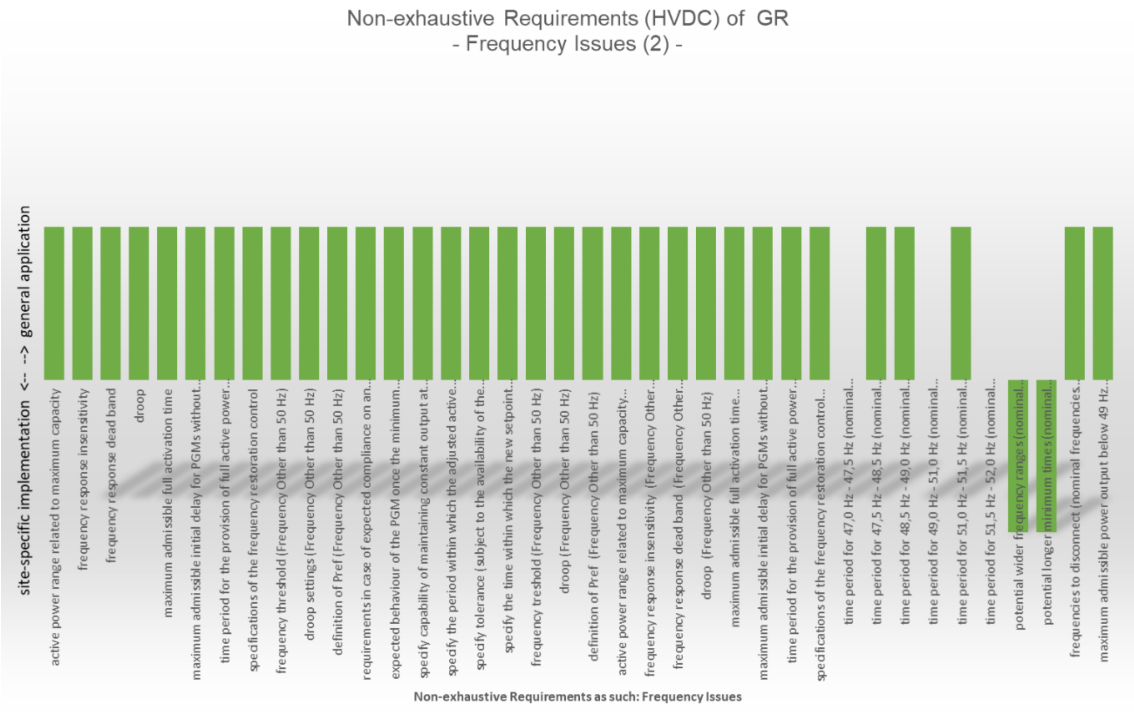


Figure 345: Greece (GR)

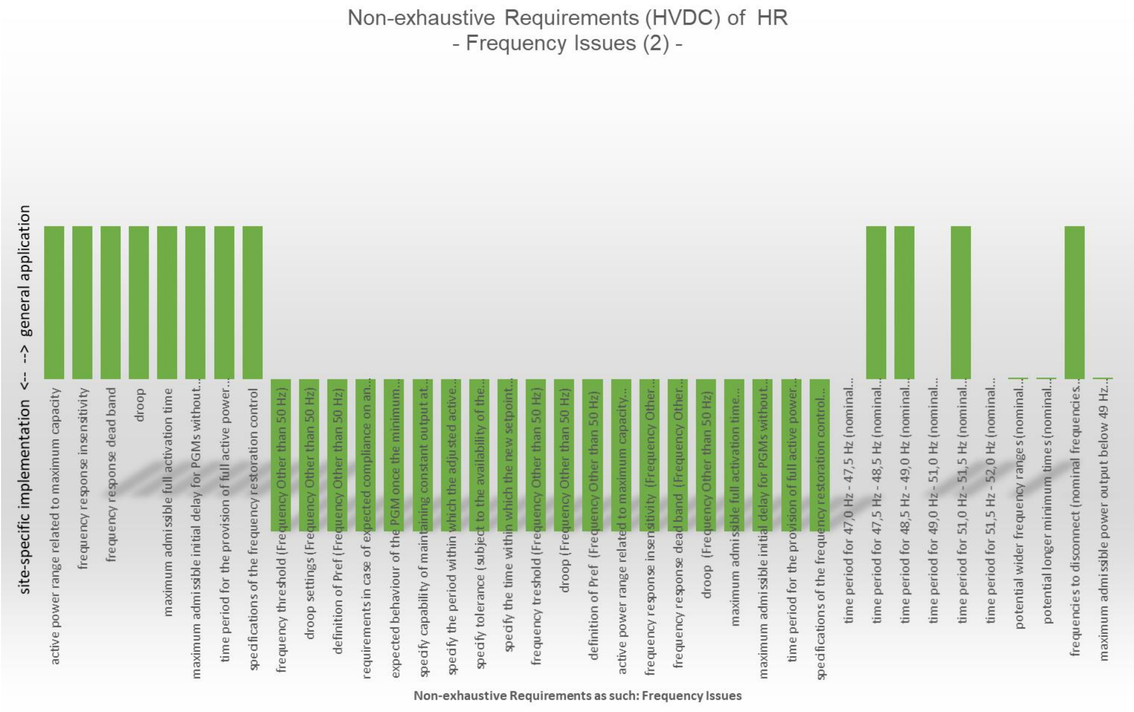


Figure 346: Croatia (HR)

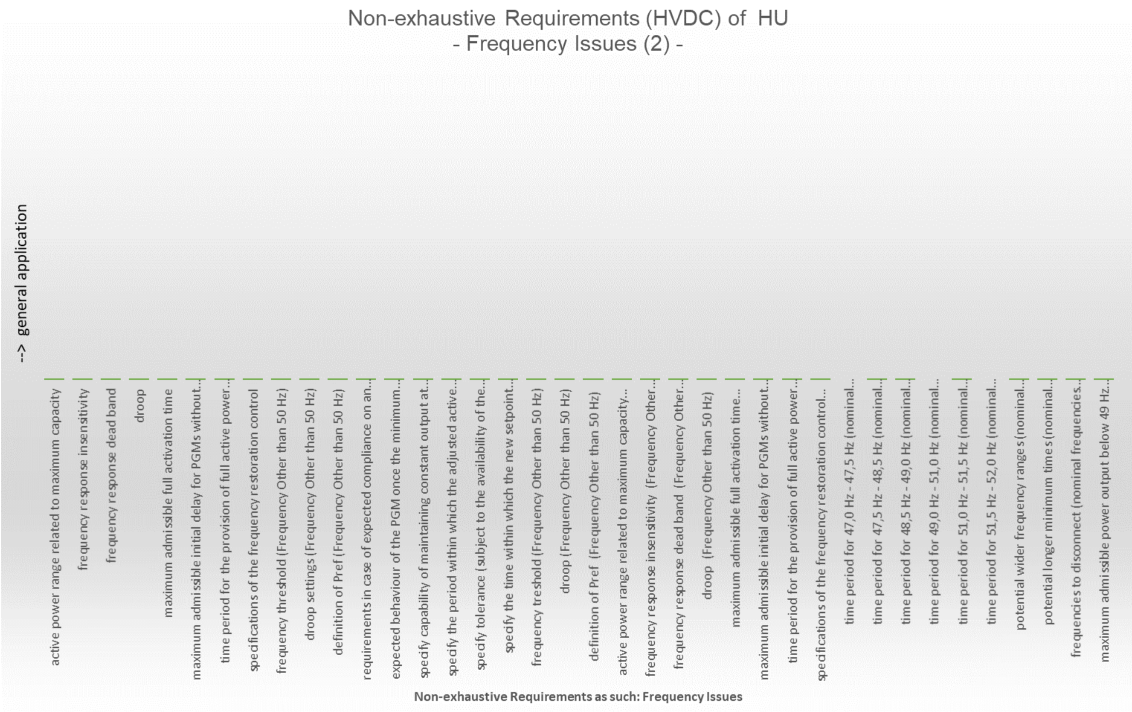


Figure 347: Hungary (HU)

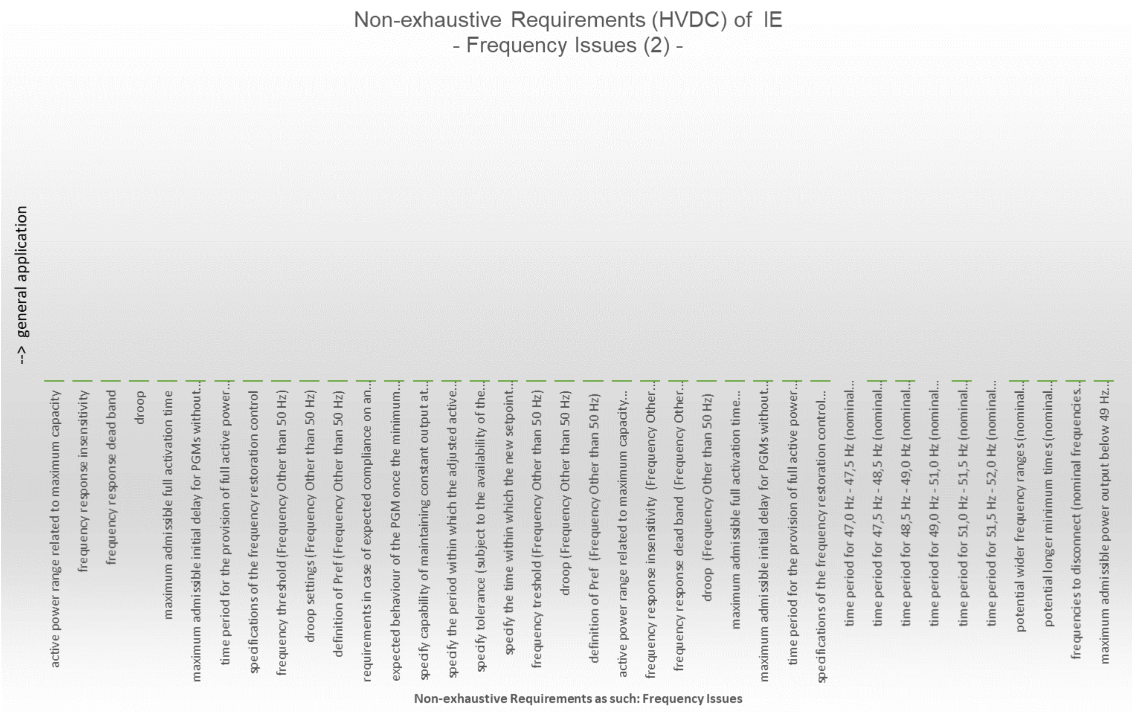


Figure 348: Ireland (IE)

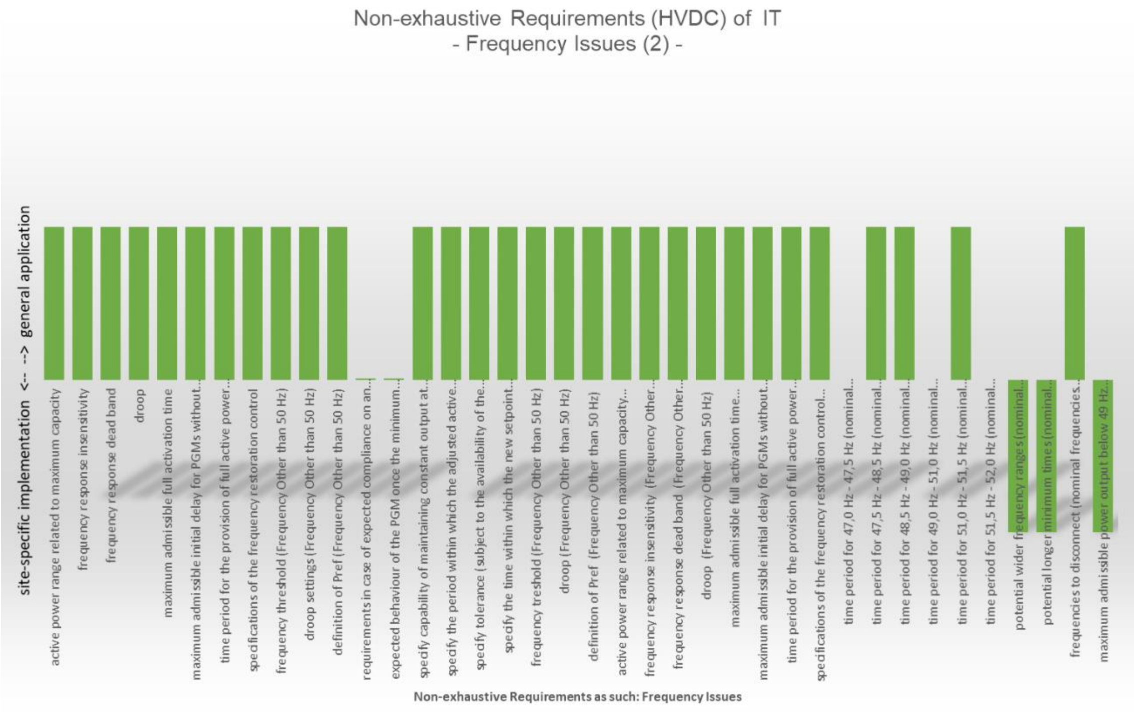


Figure 349: Italy (IT)

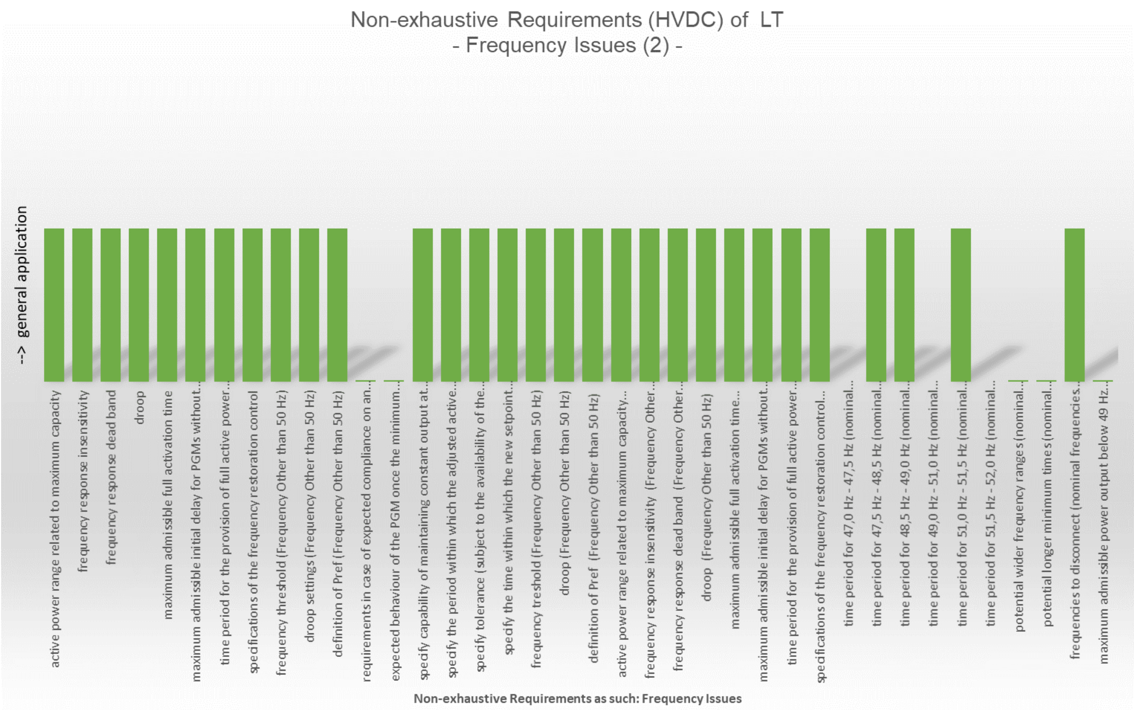


Figure 350: Lithuania (LT)

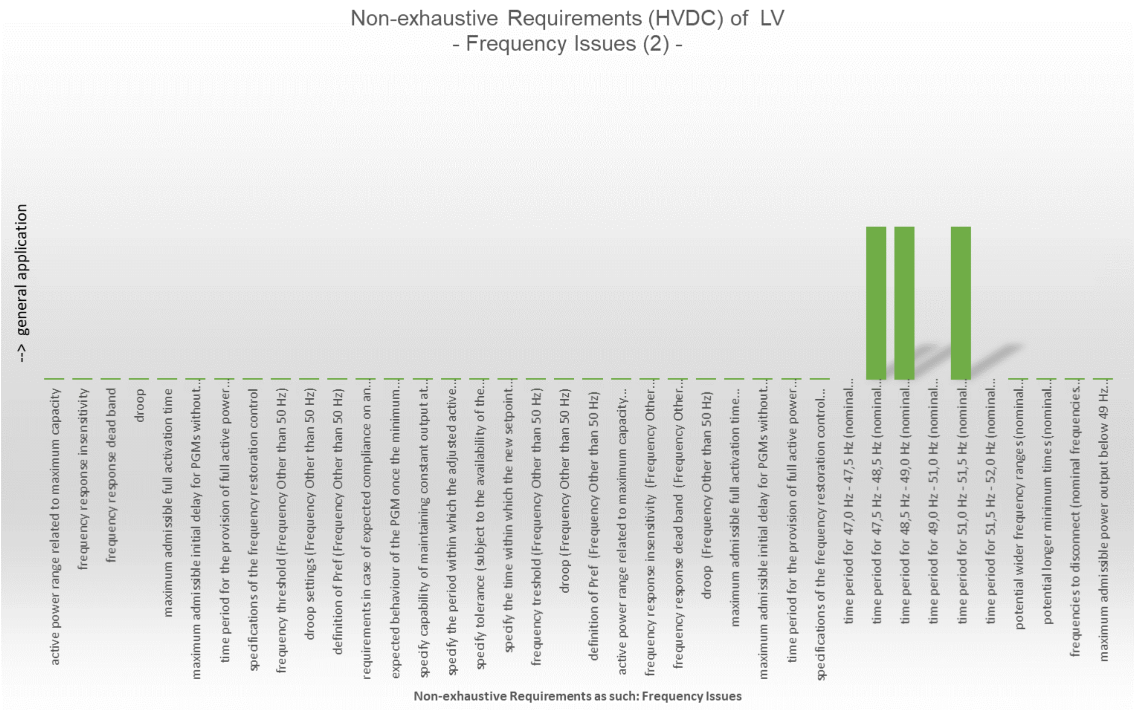


Figure 351: Latvia (LV)

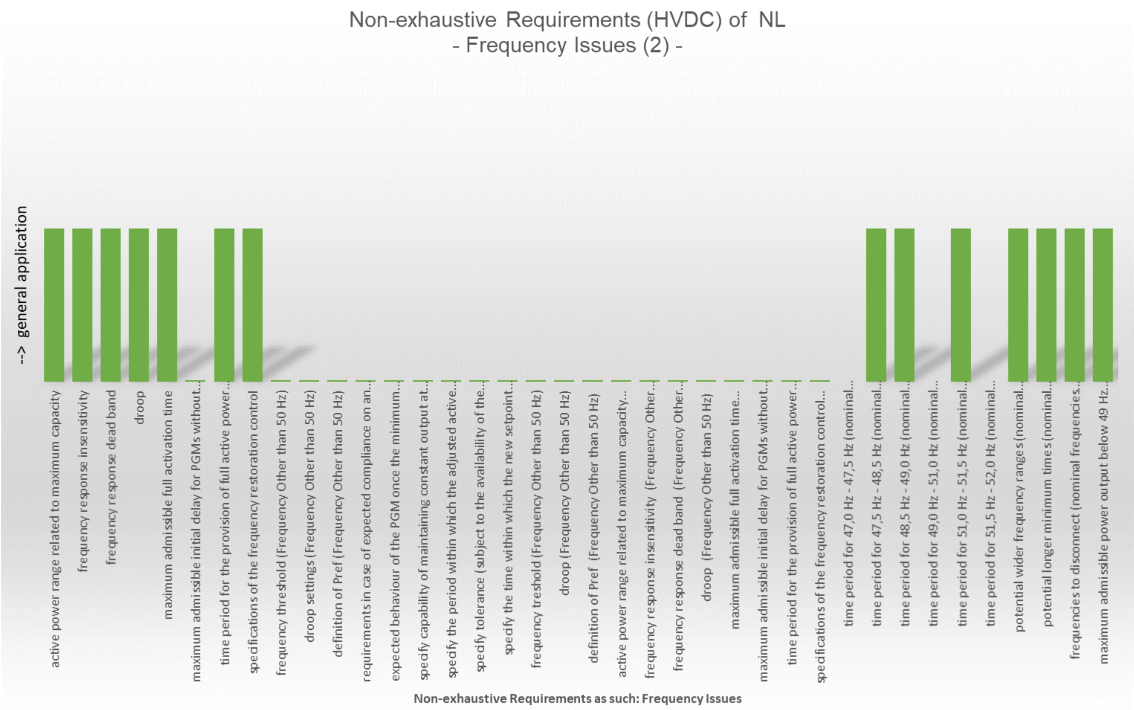


Figure 352: Netherlands (NL)

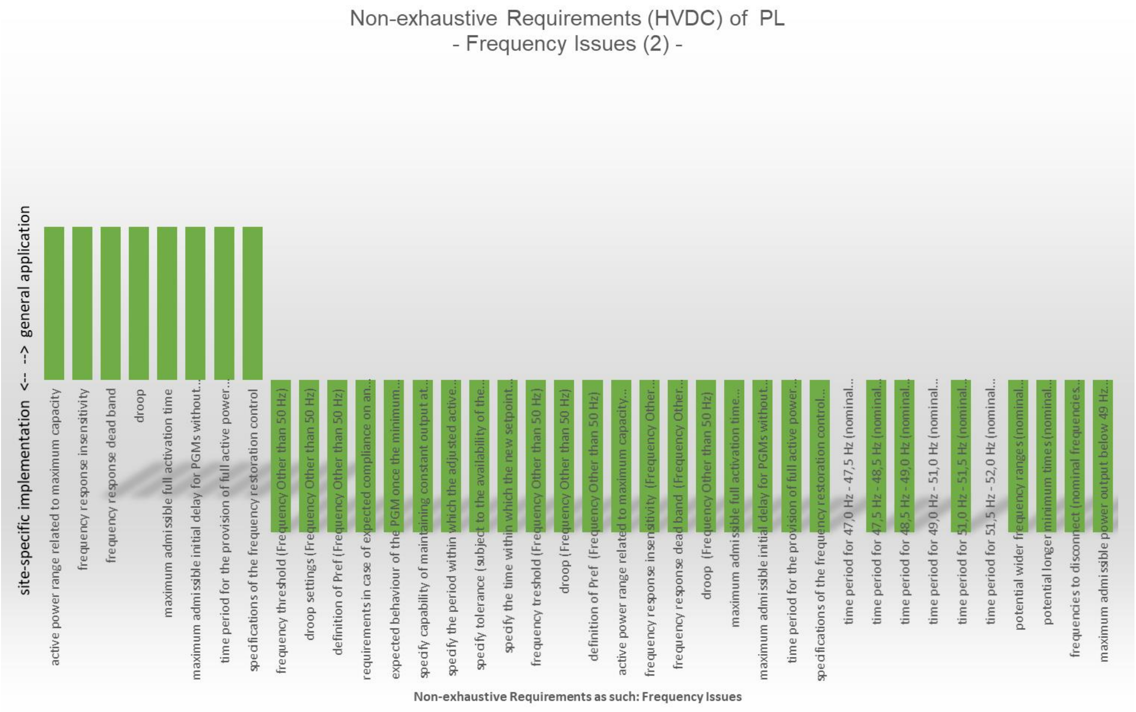


Figure 353: Poland (PL)

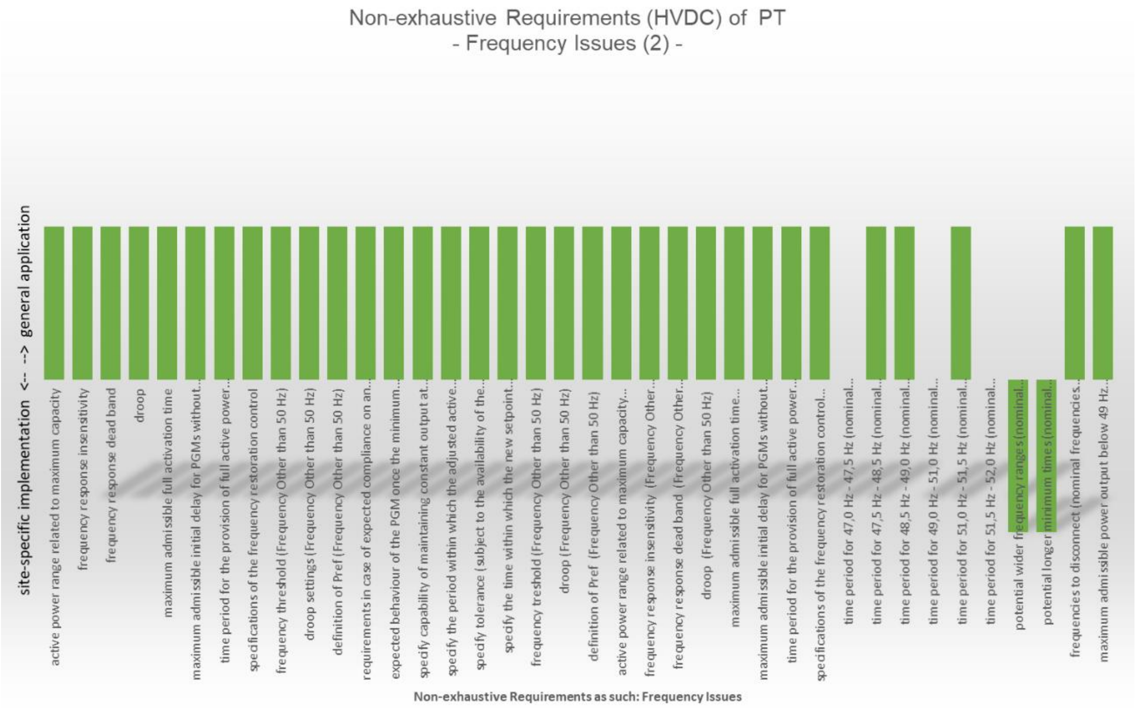


Figure 354: Portugal (PT)

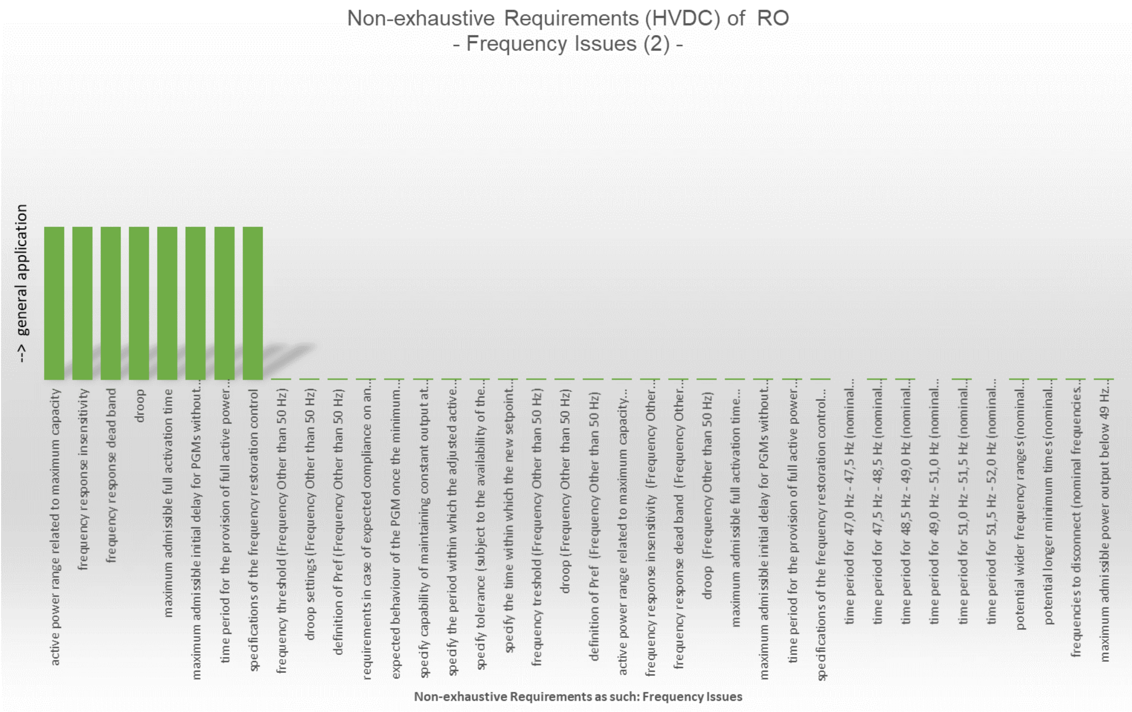


Figure 355: Romania (RO)

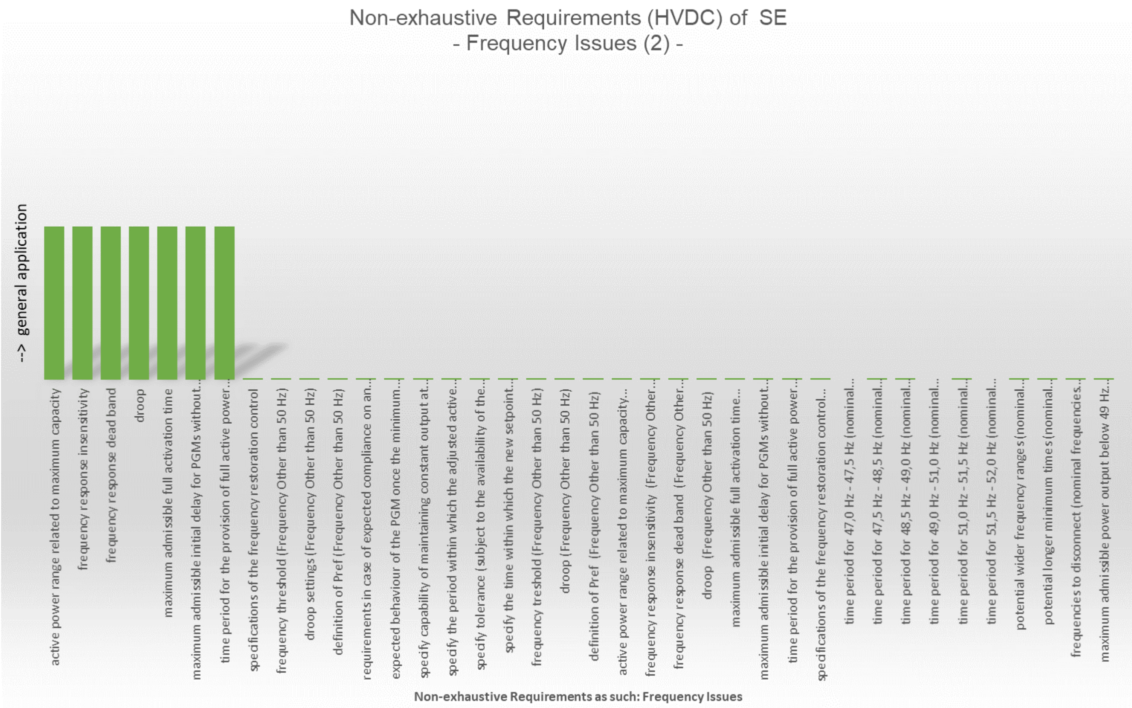


Figure 356: Sweden (SE)

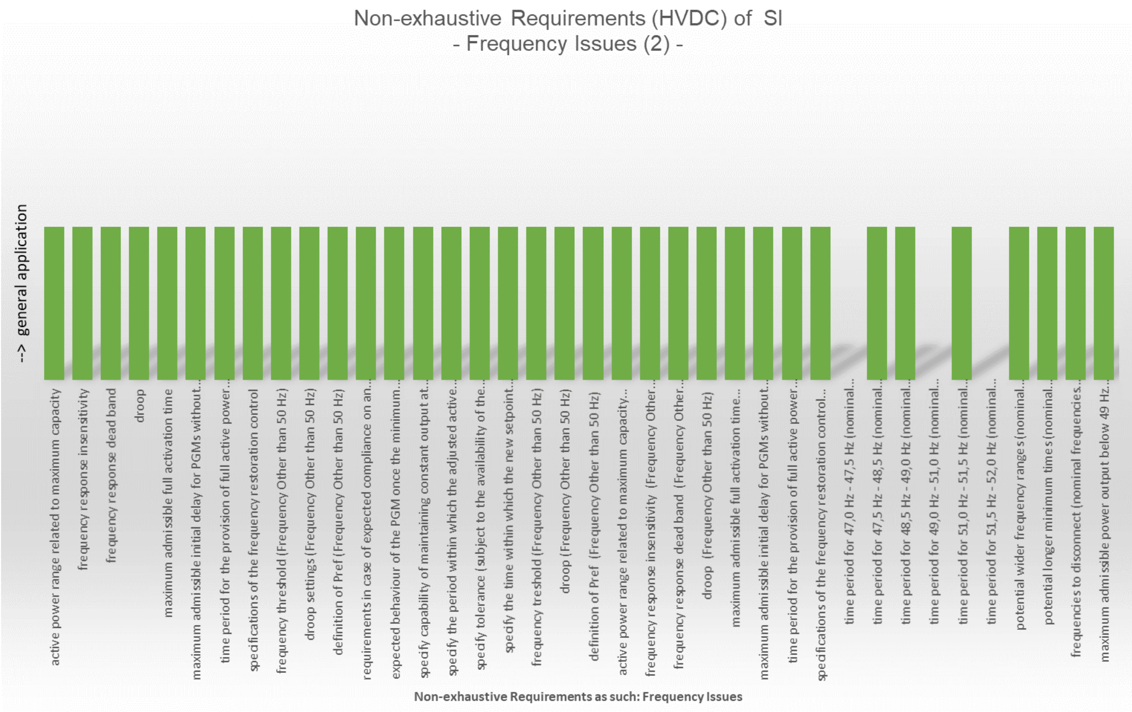


Figure 357: Slovenia (SI)

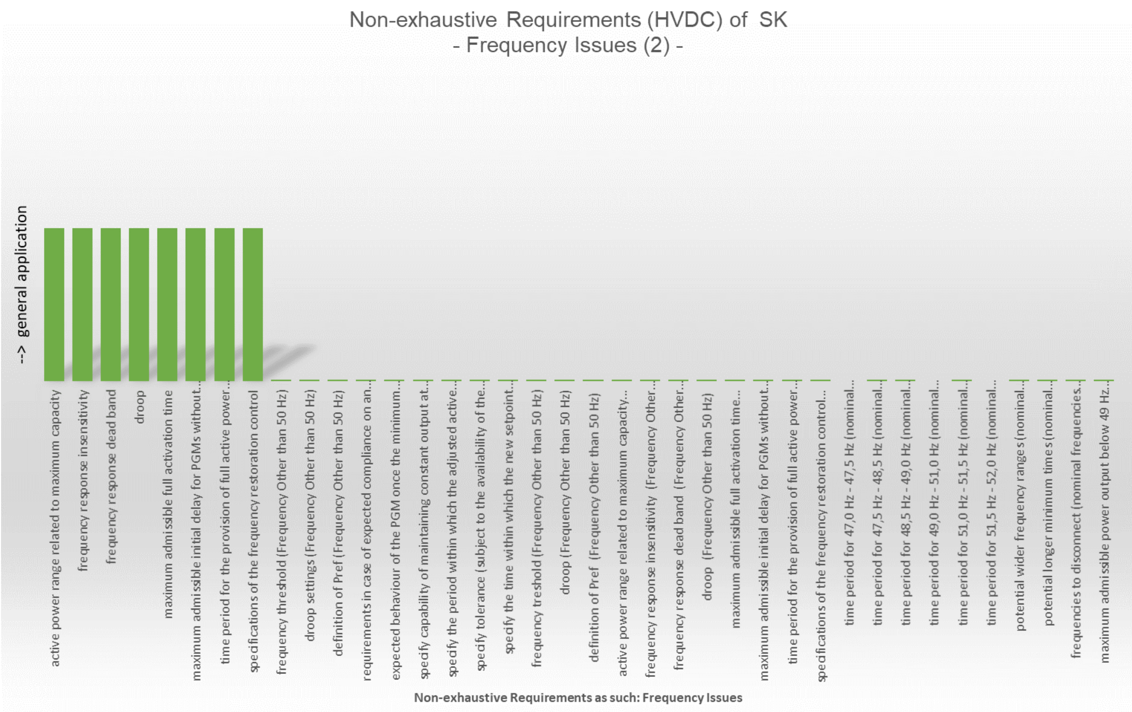


Figure 358: Slovakia (SK)

5.4 Voltage Issues of NC HVDC

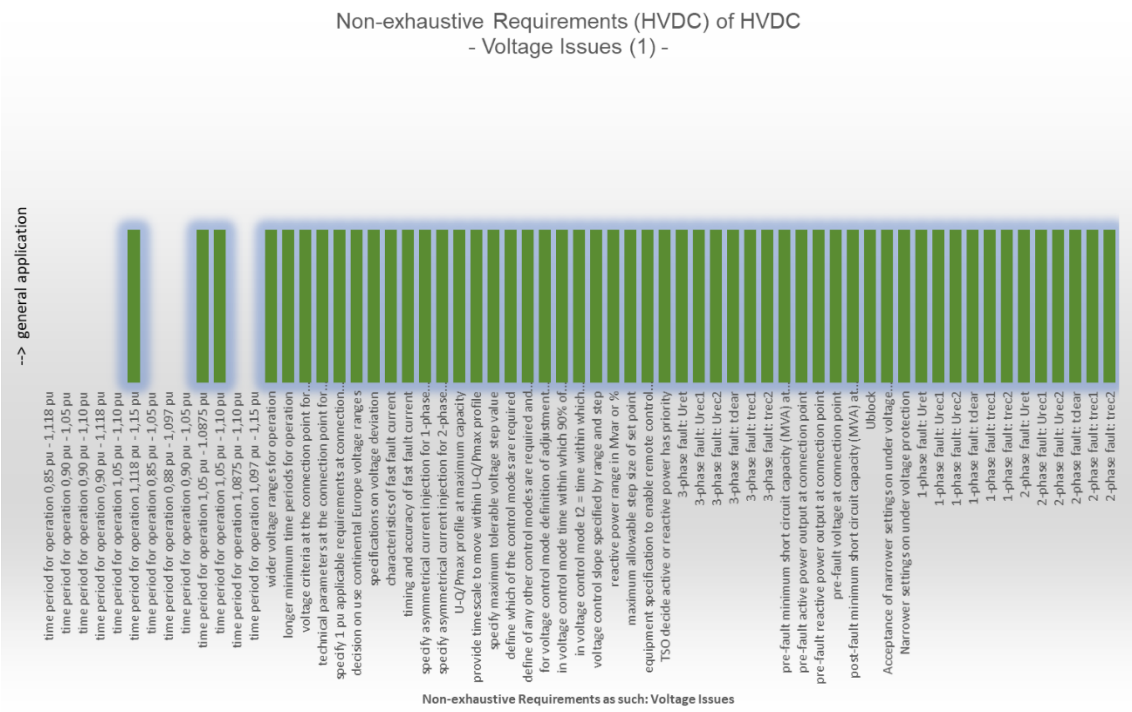


Figure 359: Reference values of non-exhaustive HVDC – voltage issues

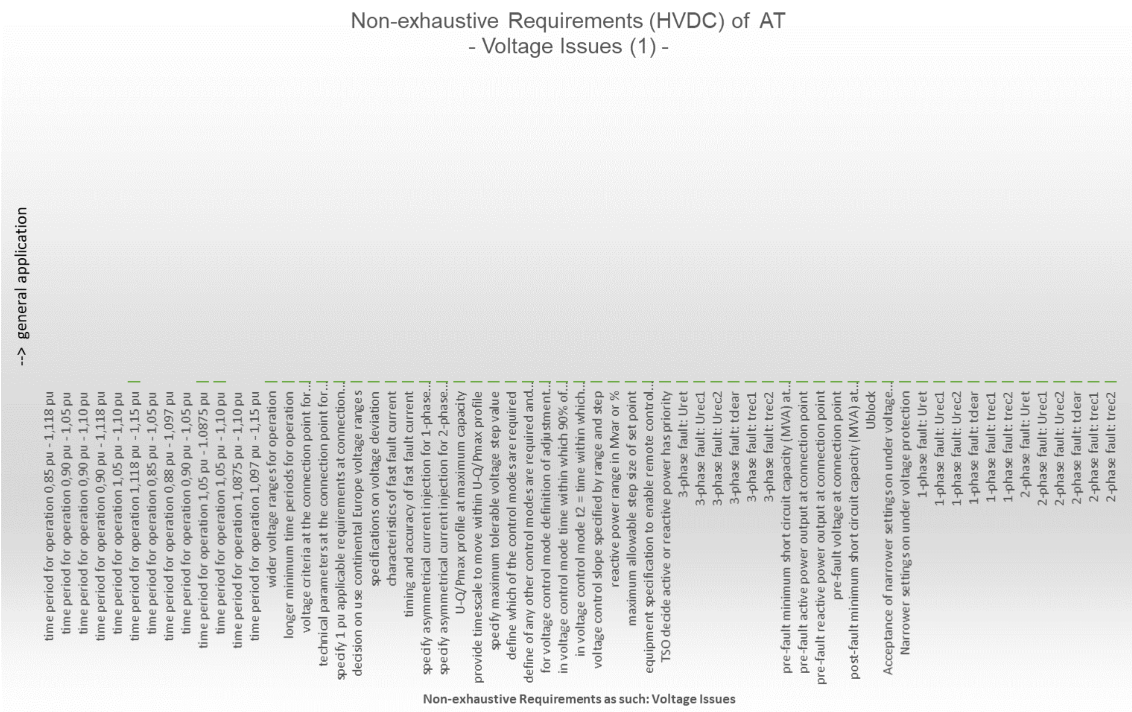


Figure 360: Austria (AT)

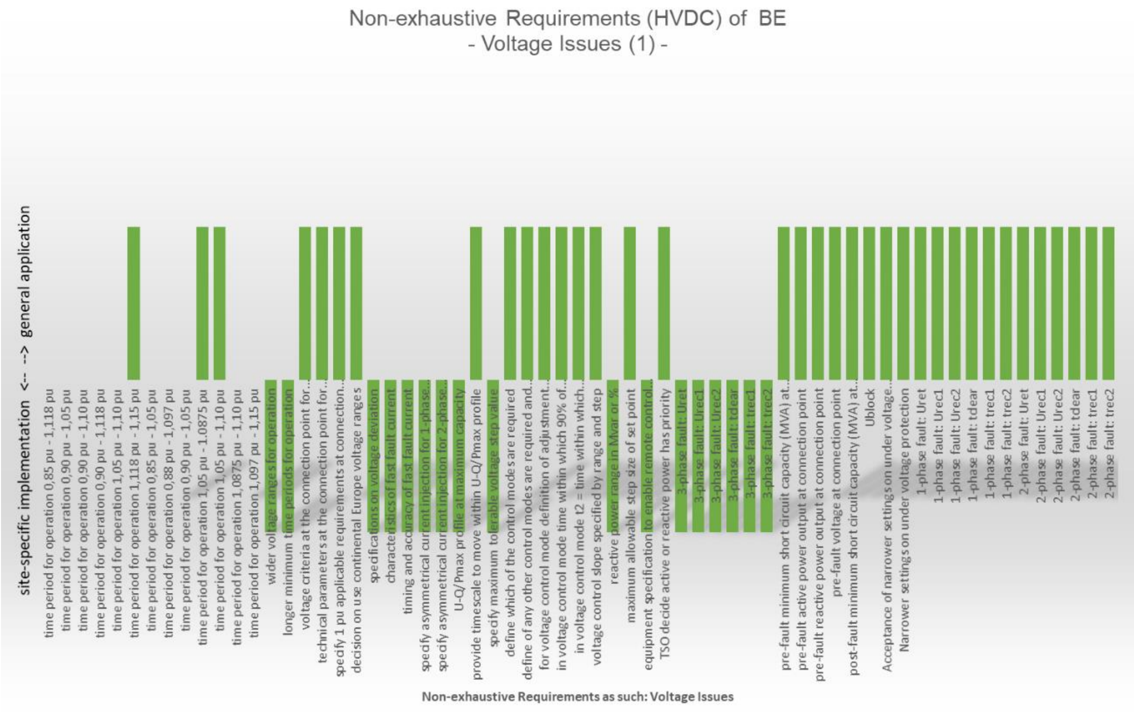


Figure 361: Belgium (BE)

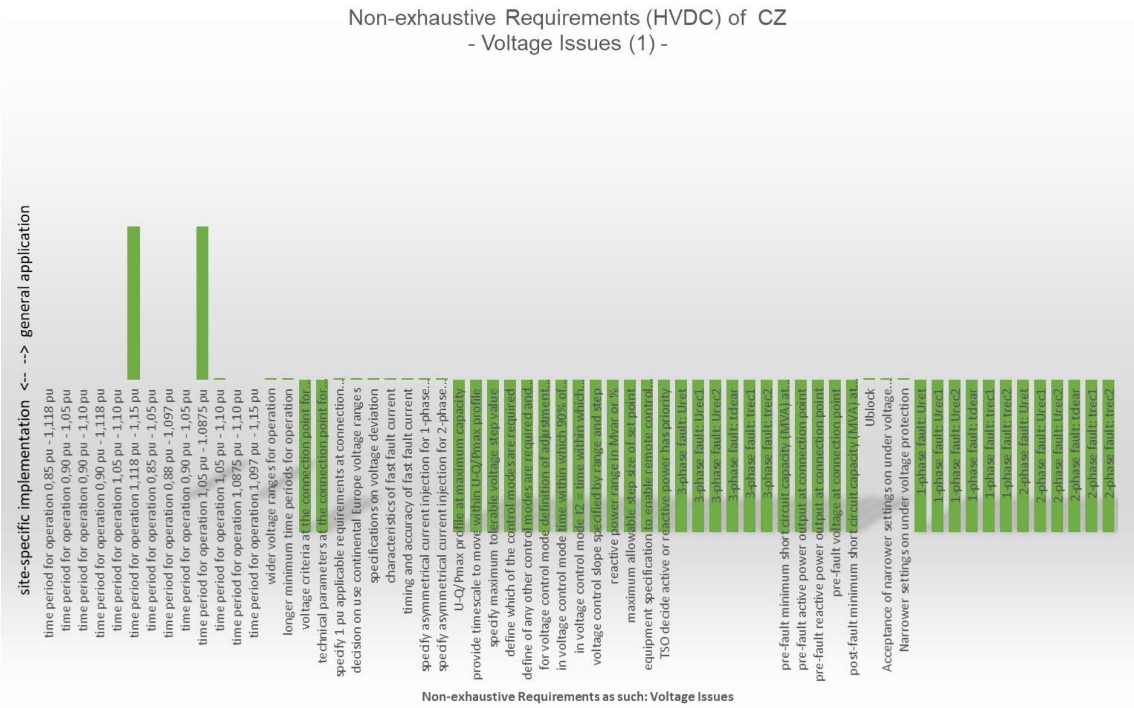


Figure 362: Czech Republic (CZ)

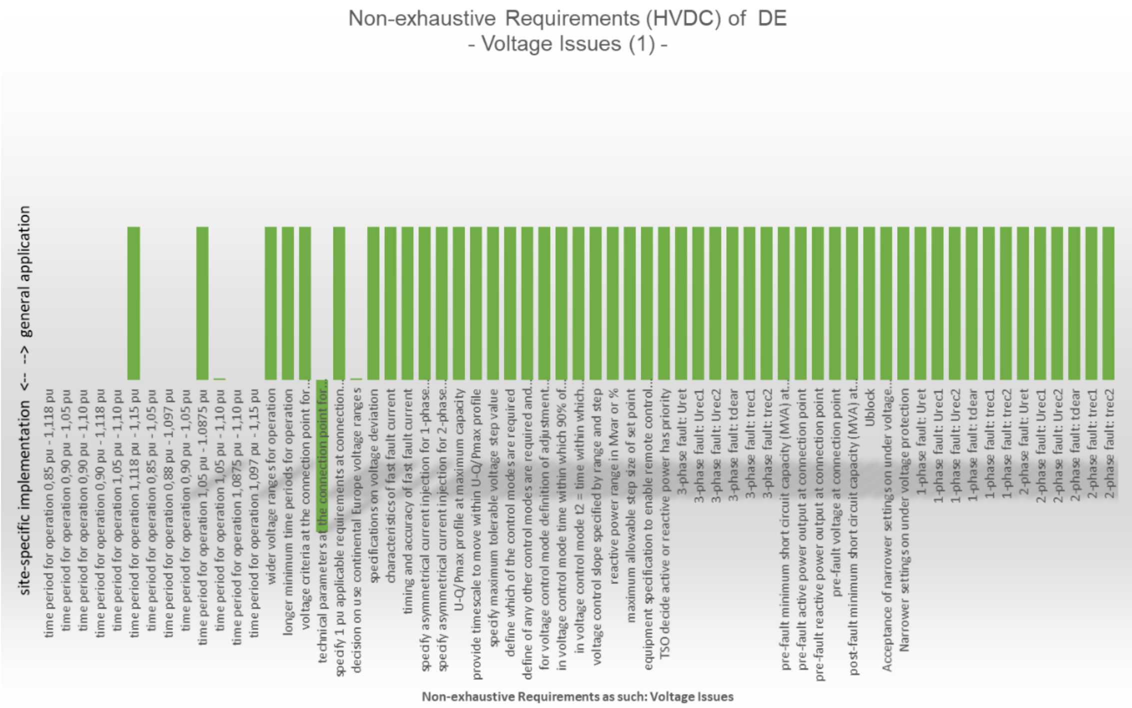


Figure 363: Germany (DE)

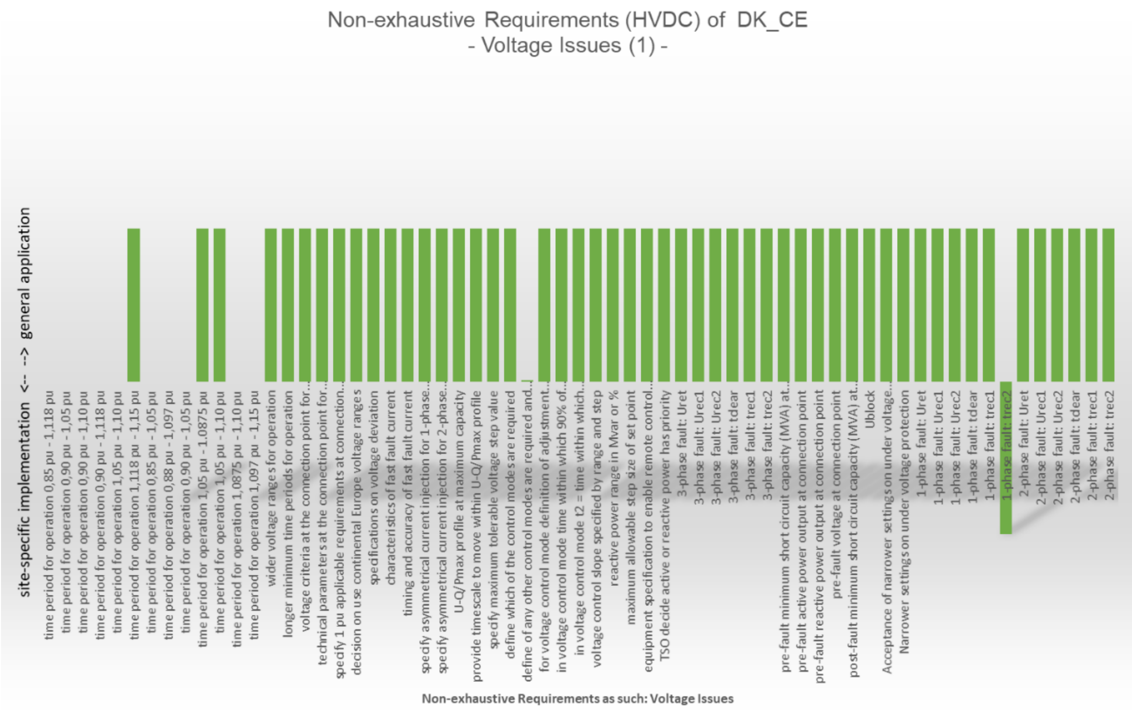


Figure 364: Denmark 1 (DK-CE)

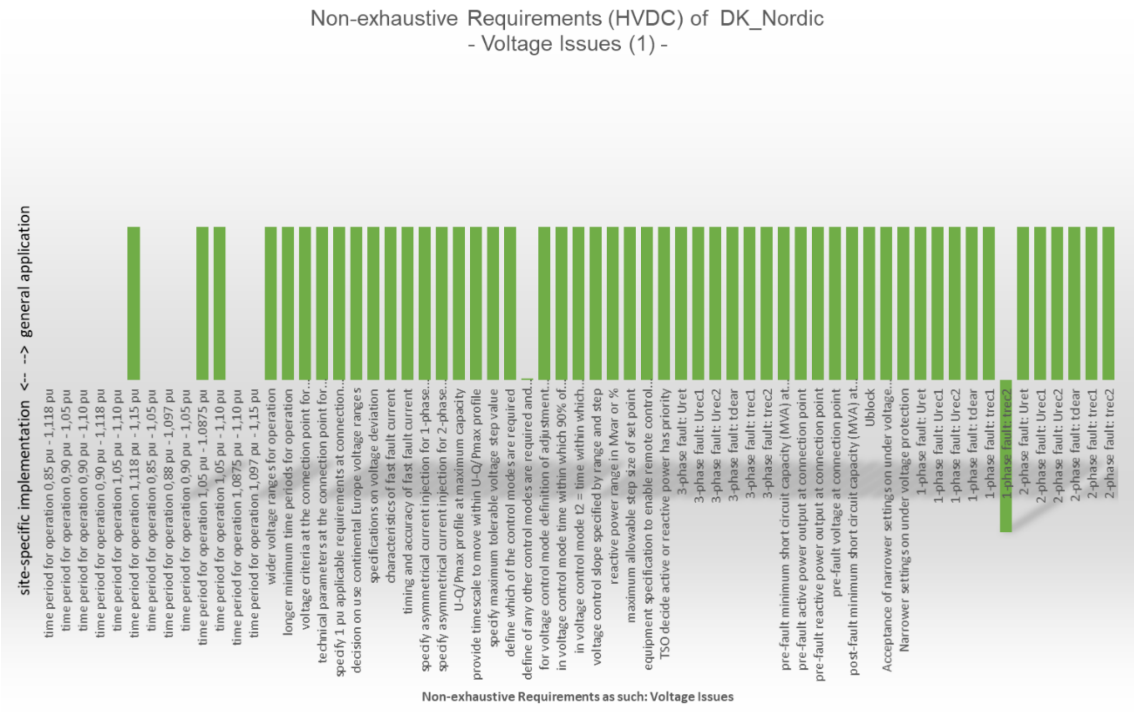


Figure 365: Denmark 2 (DK-Nordic)

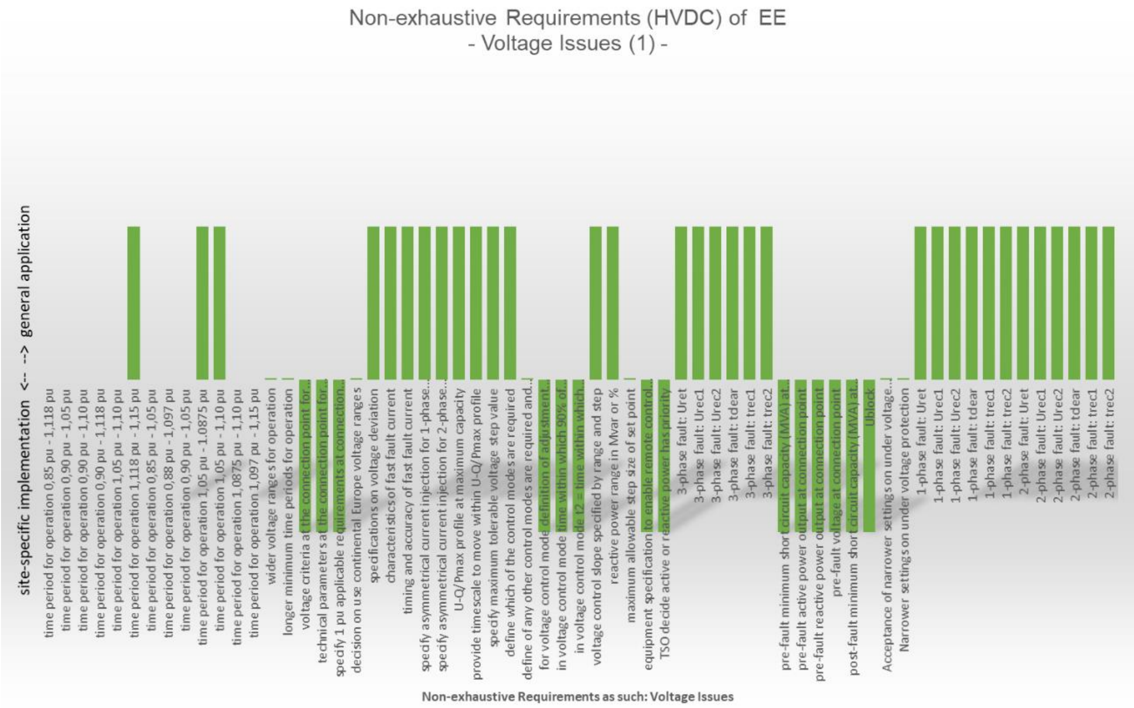


Figure 366: Estonia (EE)

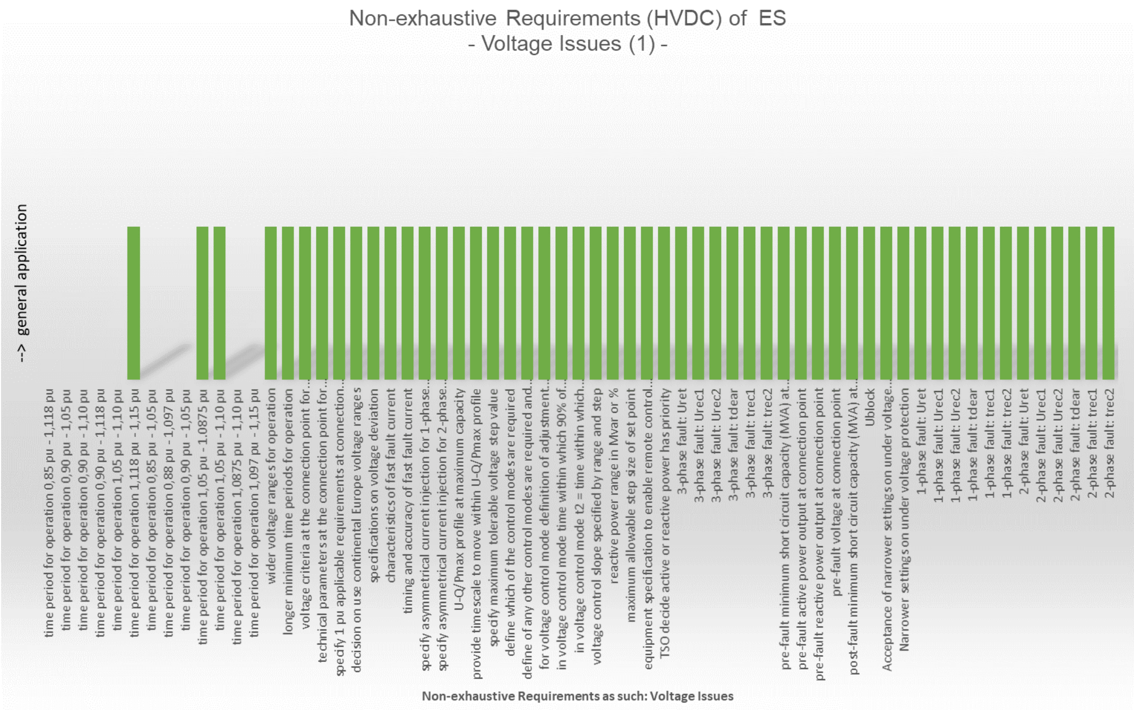


Figure 367: Spain (ES)

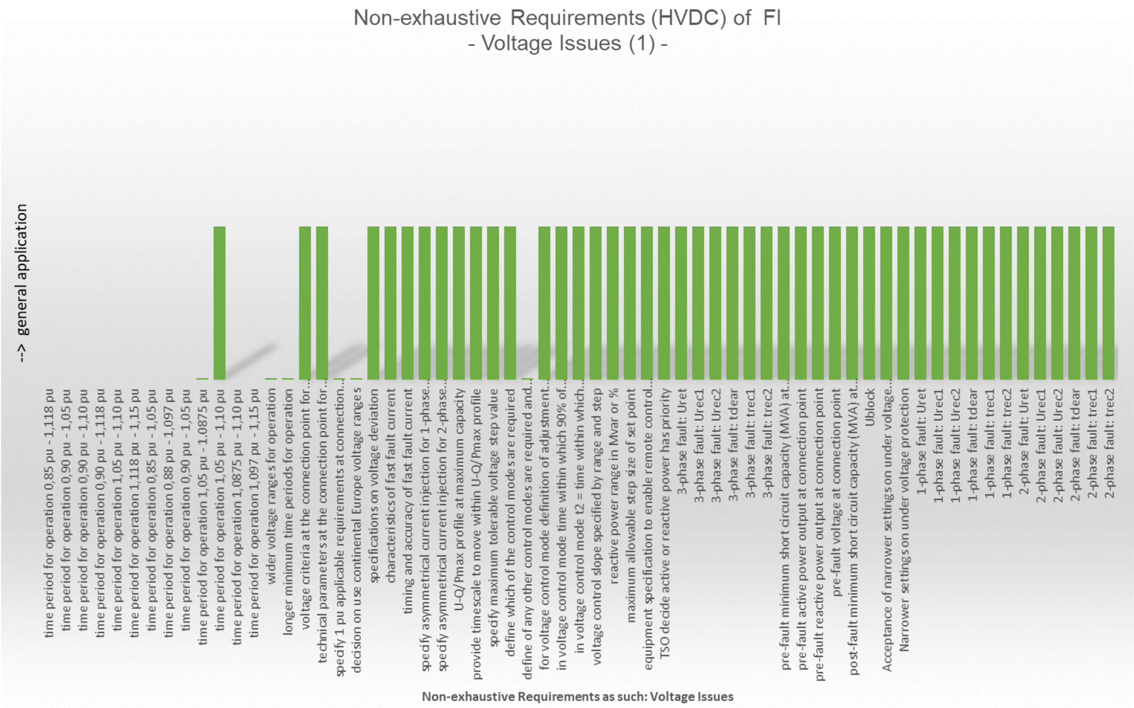


Figure 368: Finland (FI)

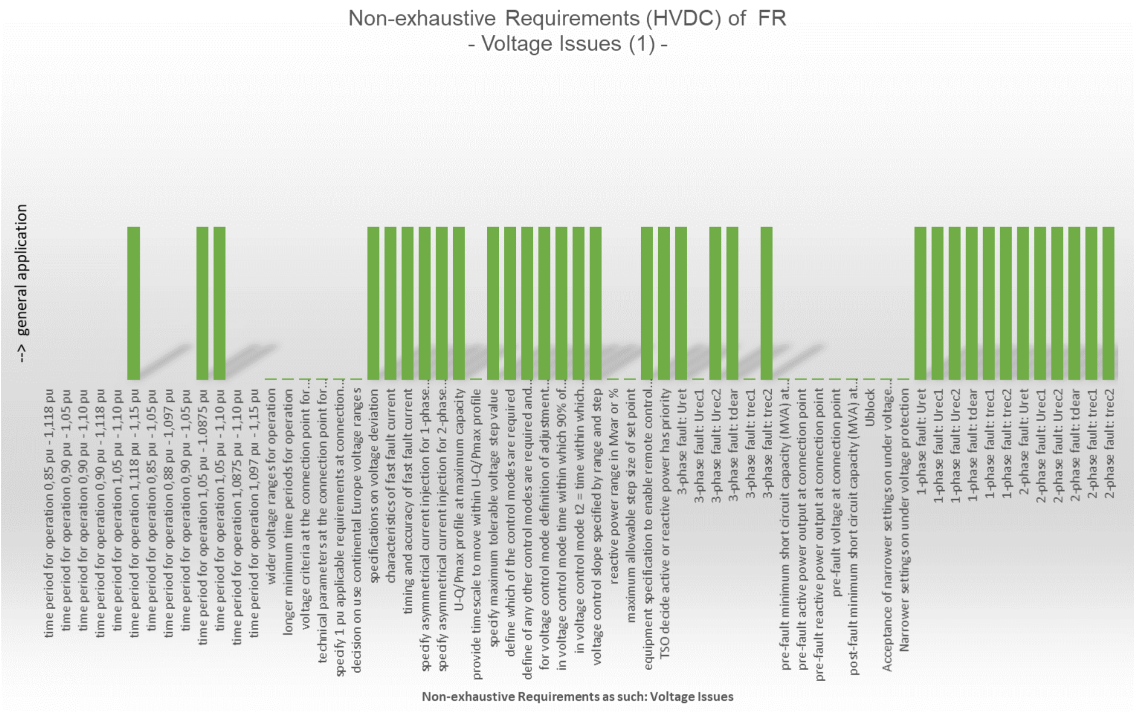


Figure 369: France (FR)

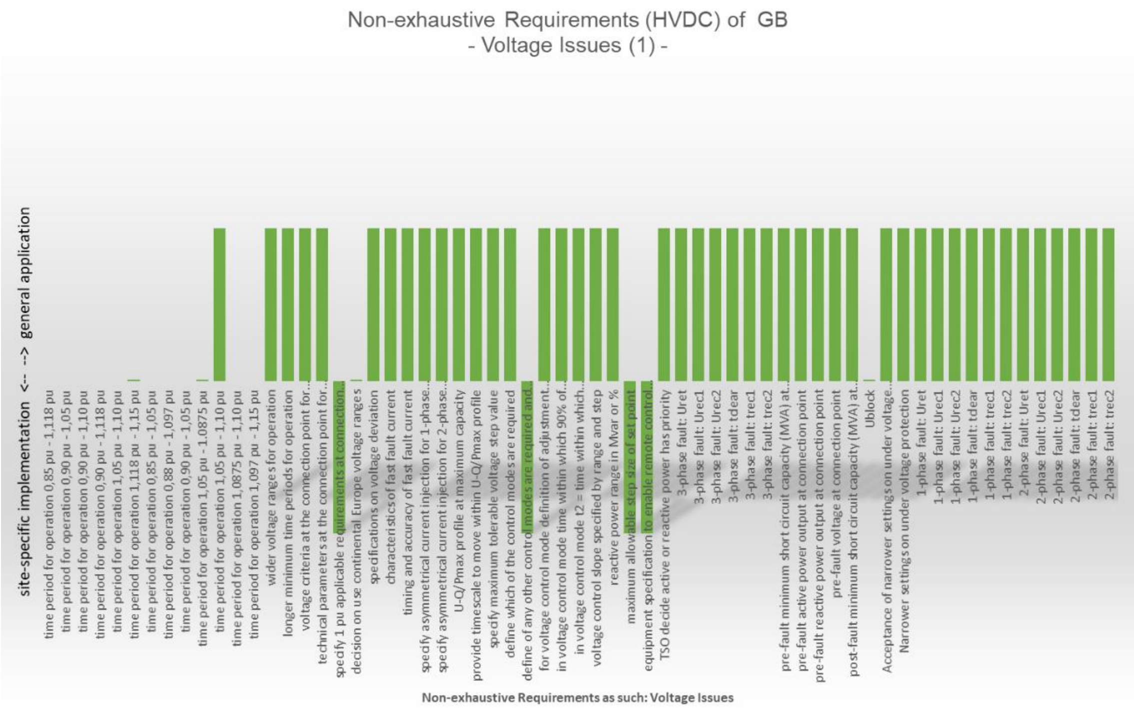


Figure 370: Great Britain (GB)

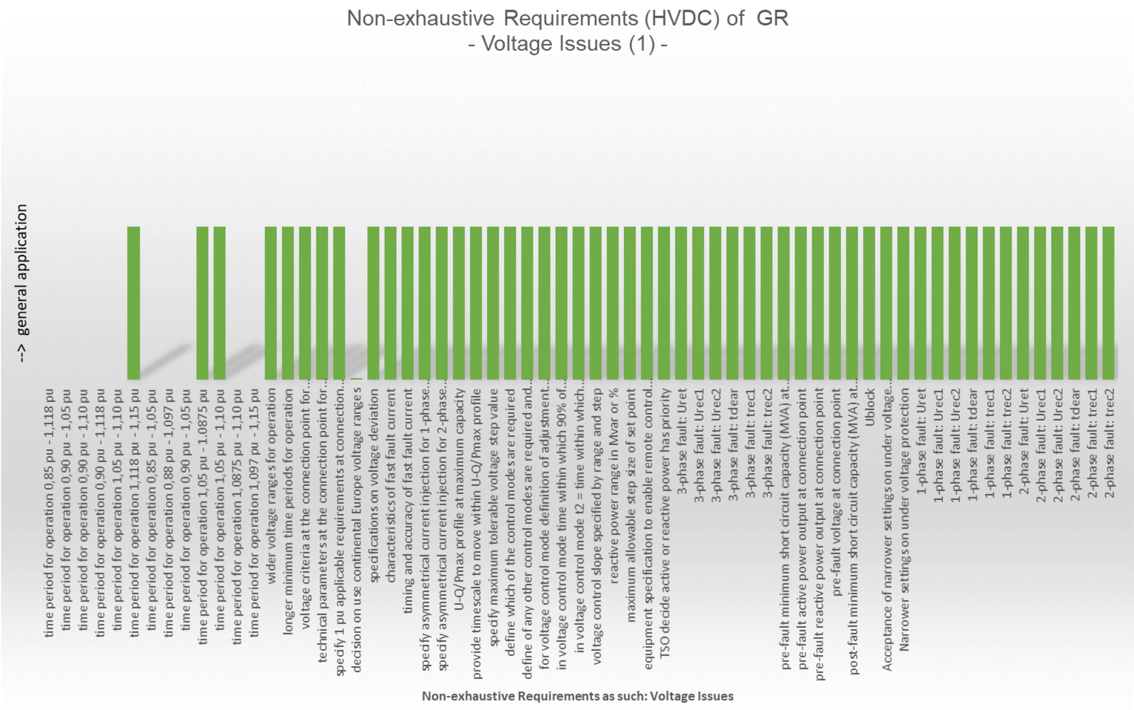


Figure 371: Greece (GR)

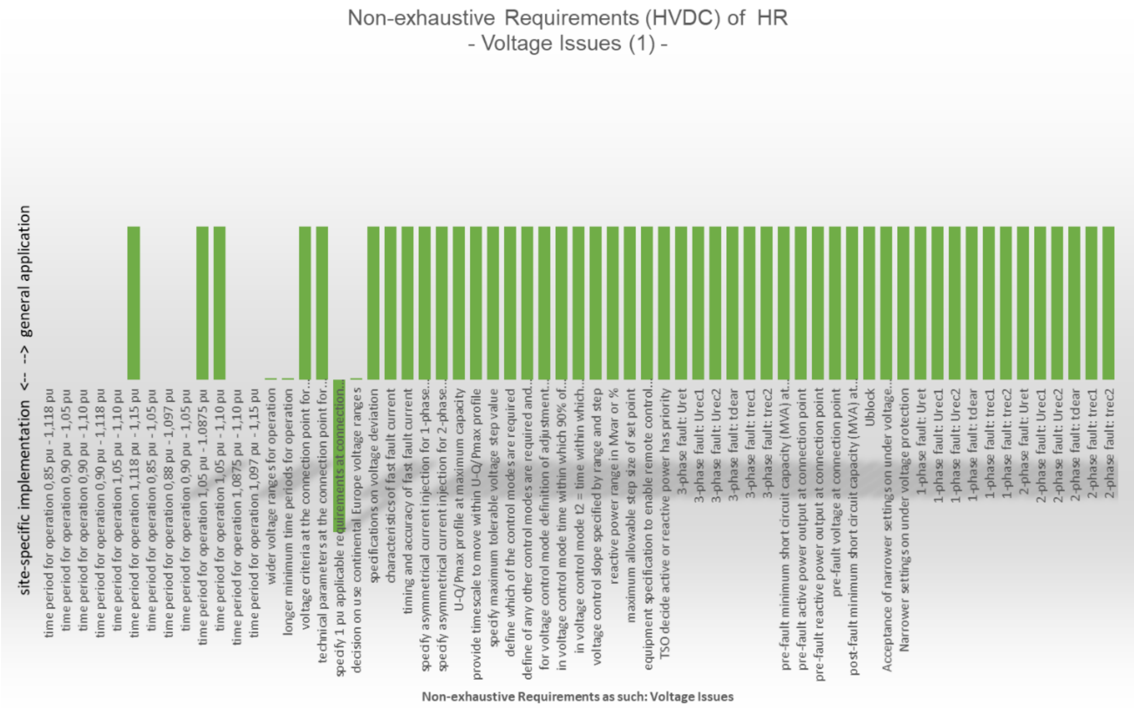


Figure 372: Croatia (HR)

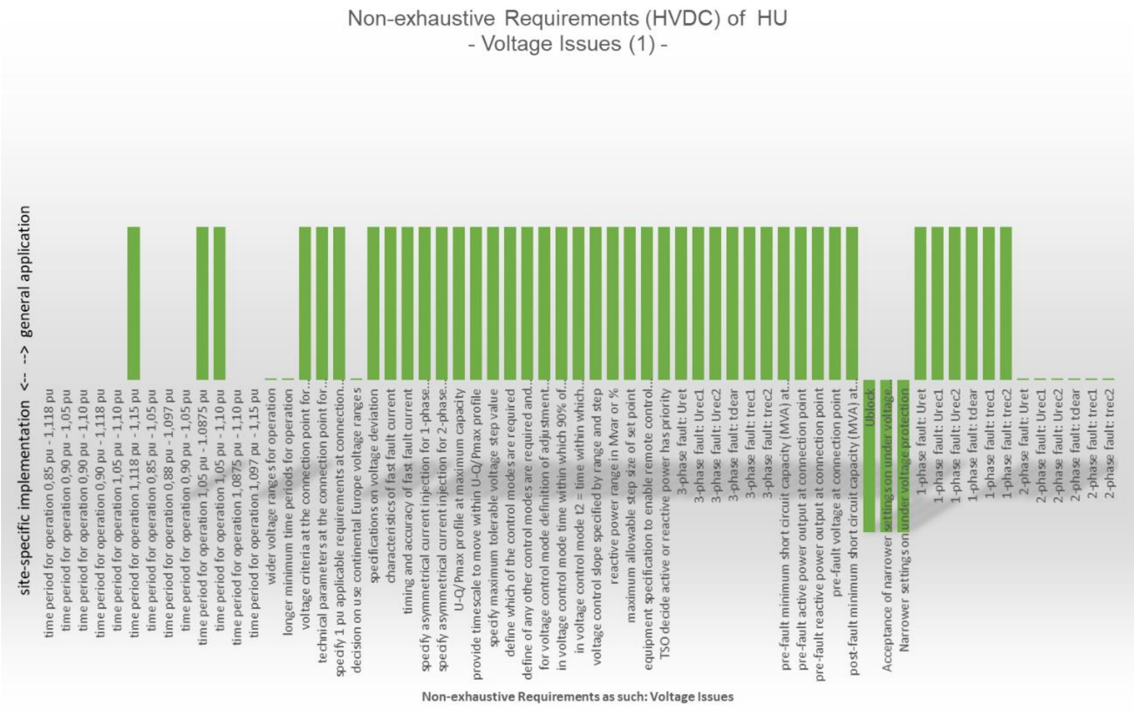


Figure 373: Hungary (HU)

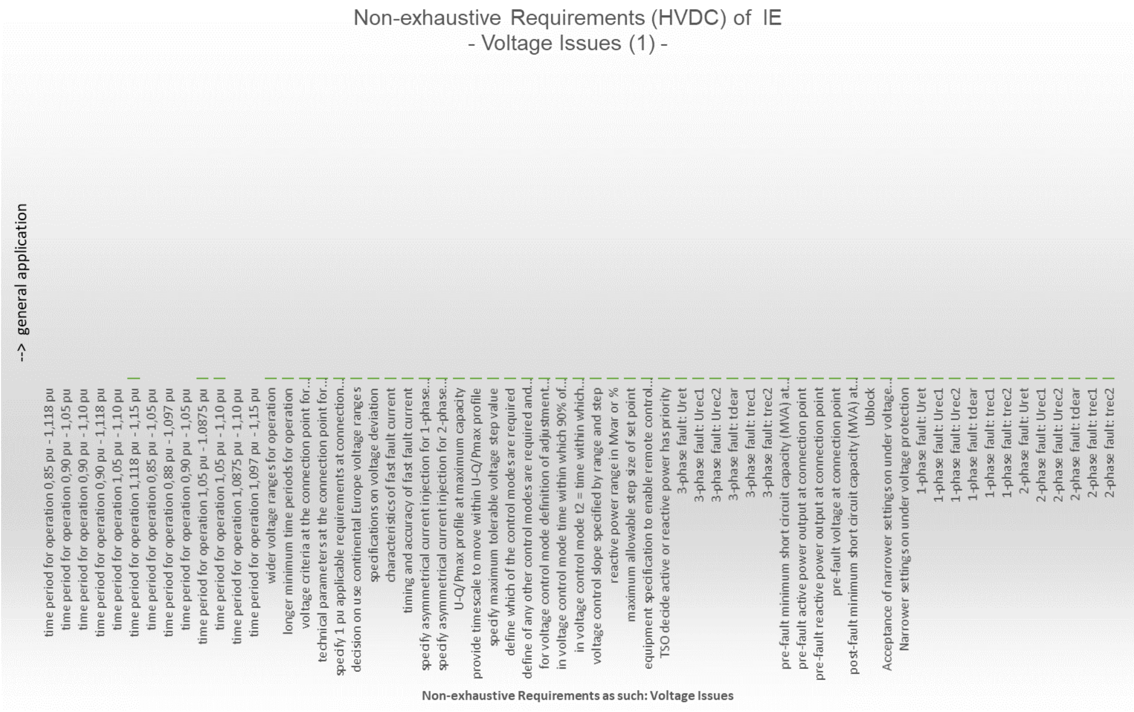


Figure 374: Ireland (IE)

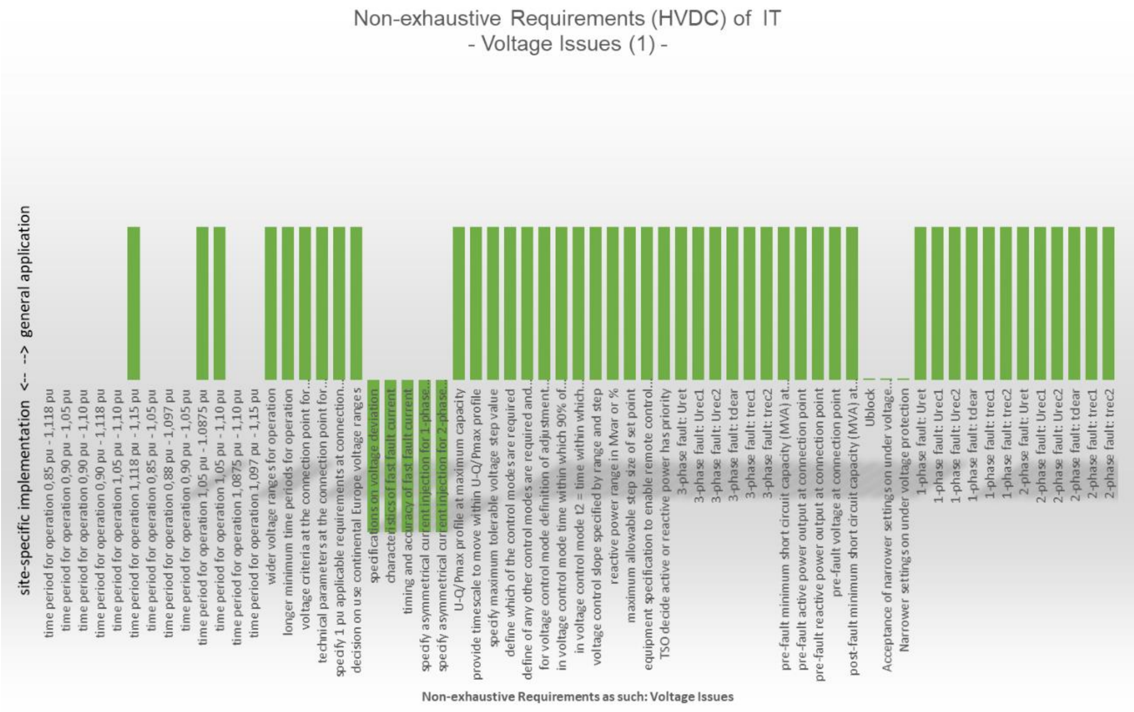


Figure 375: Italy (IT)

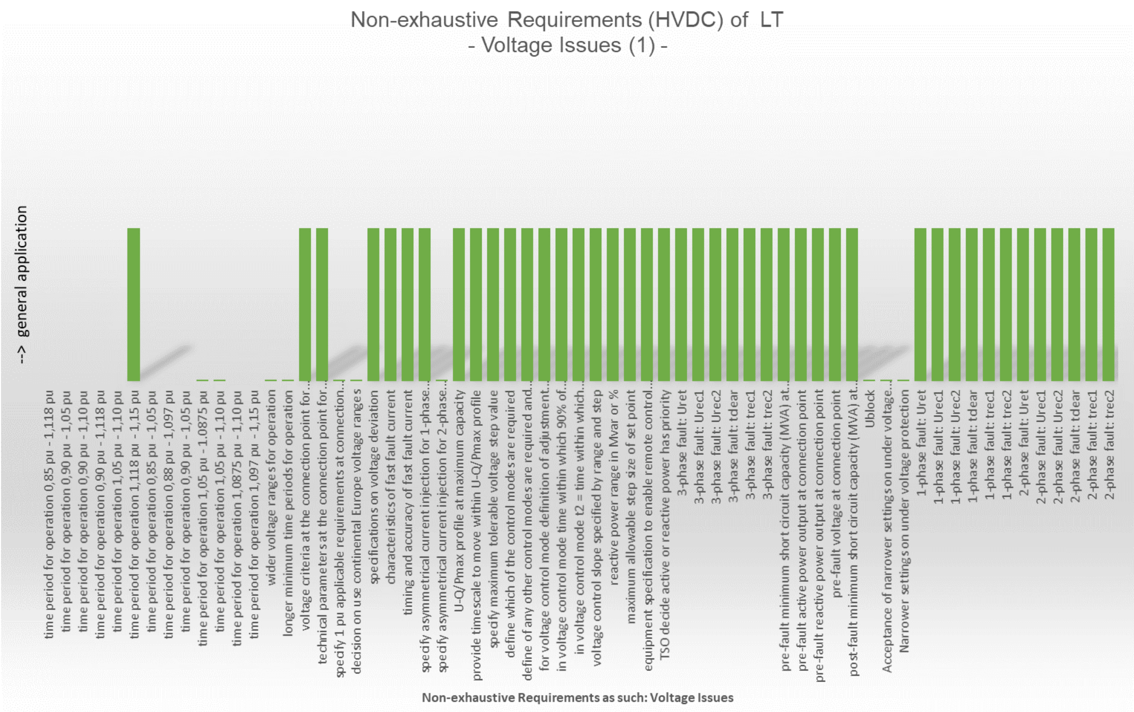


Figure 376: Lithuania (LT)

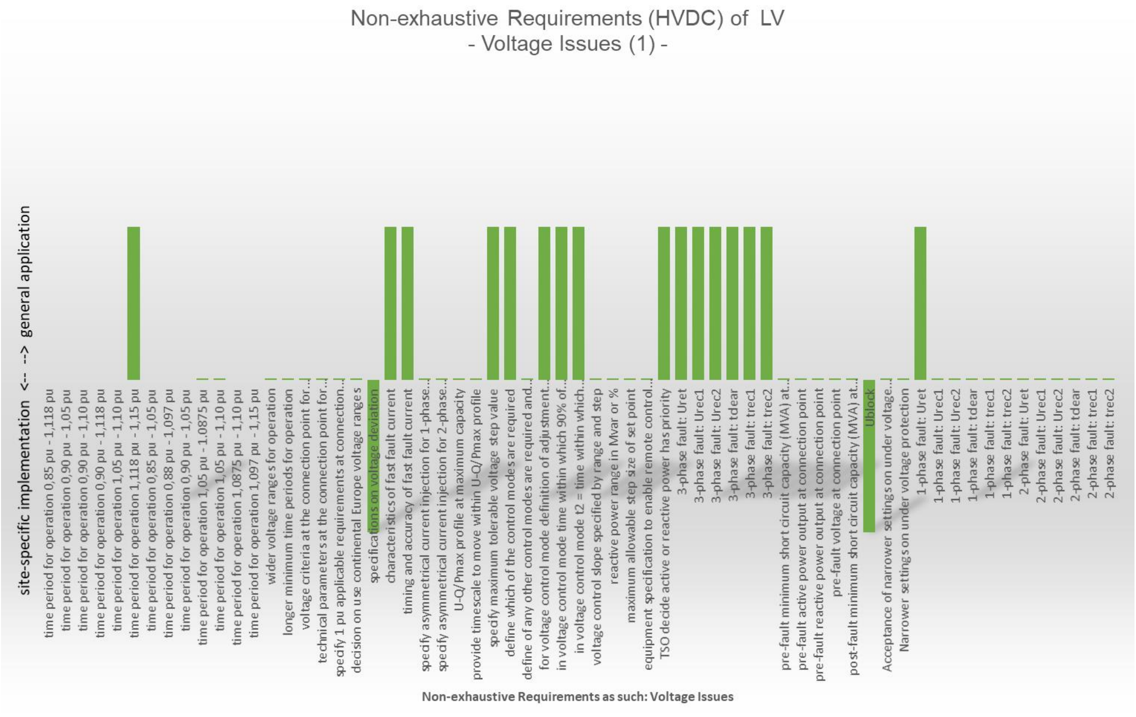


Figure 377: Latvia (LV)

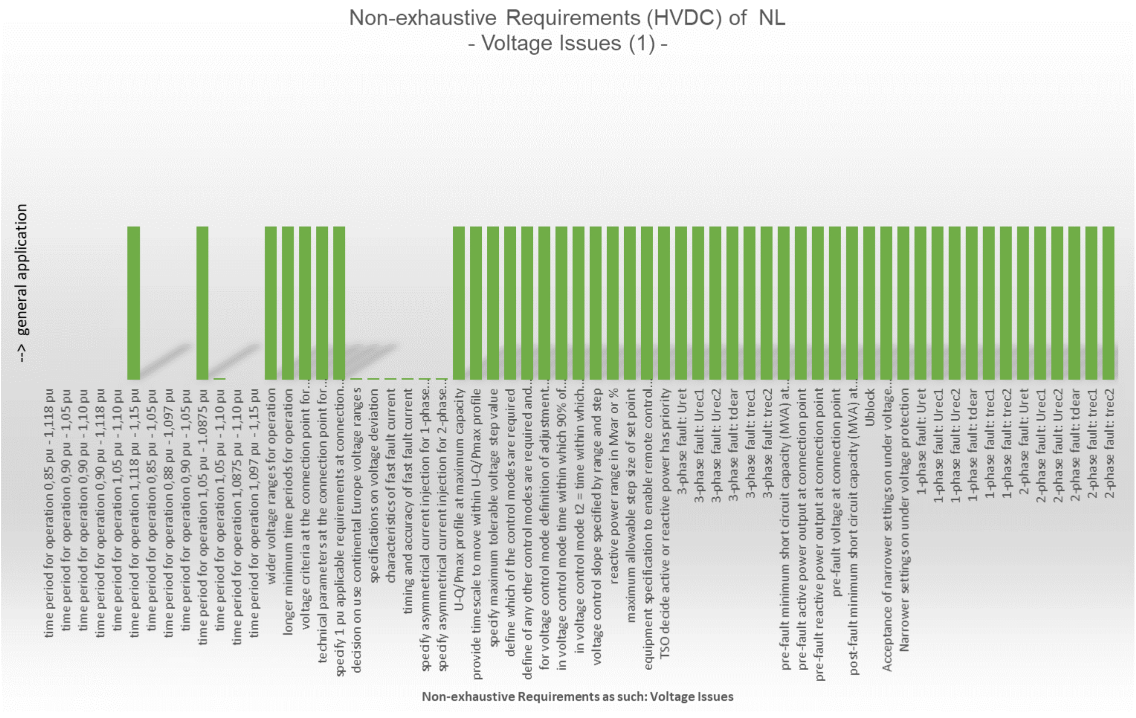


Figure 378: Netherlands (NL)

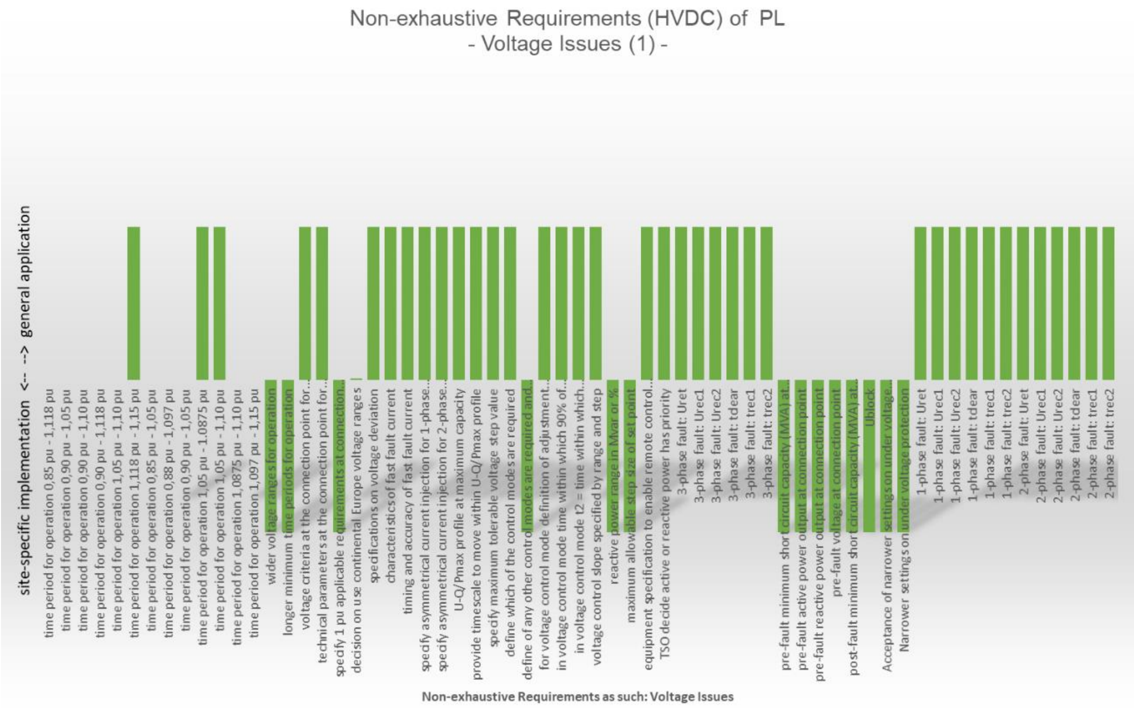


Figure 379: Poland (PL)

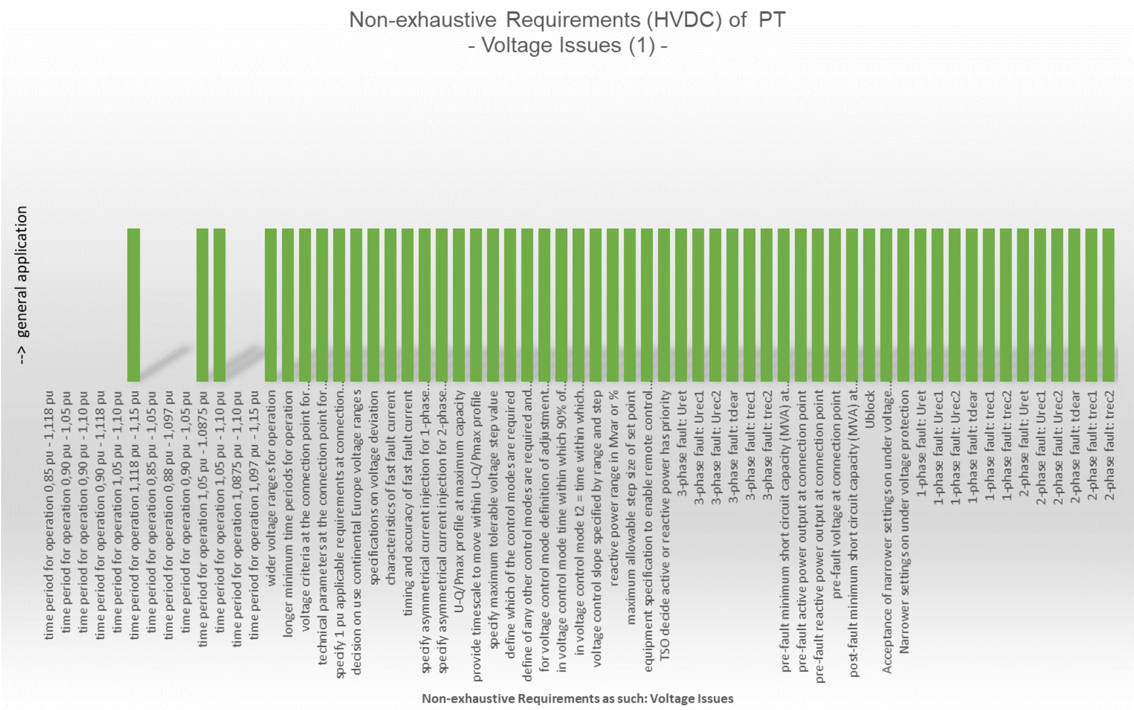


Figure 380: Portugal (PT)

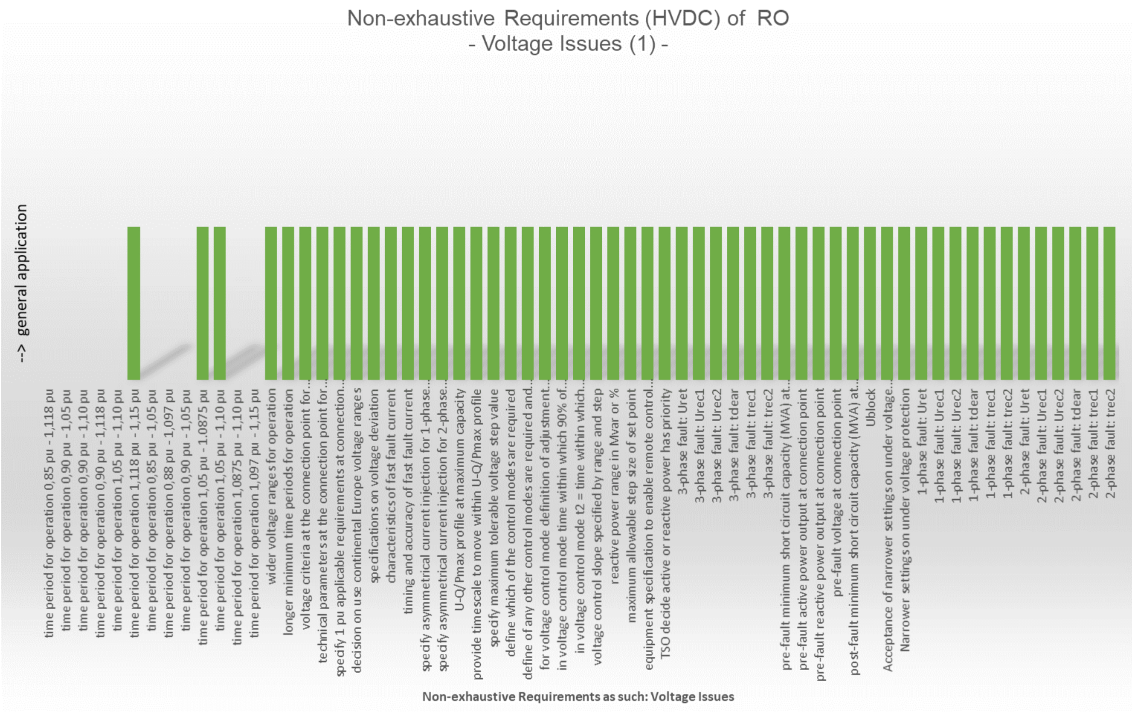


Figure 381: Romania (RO)

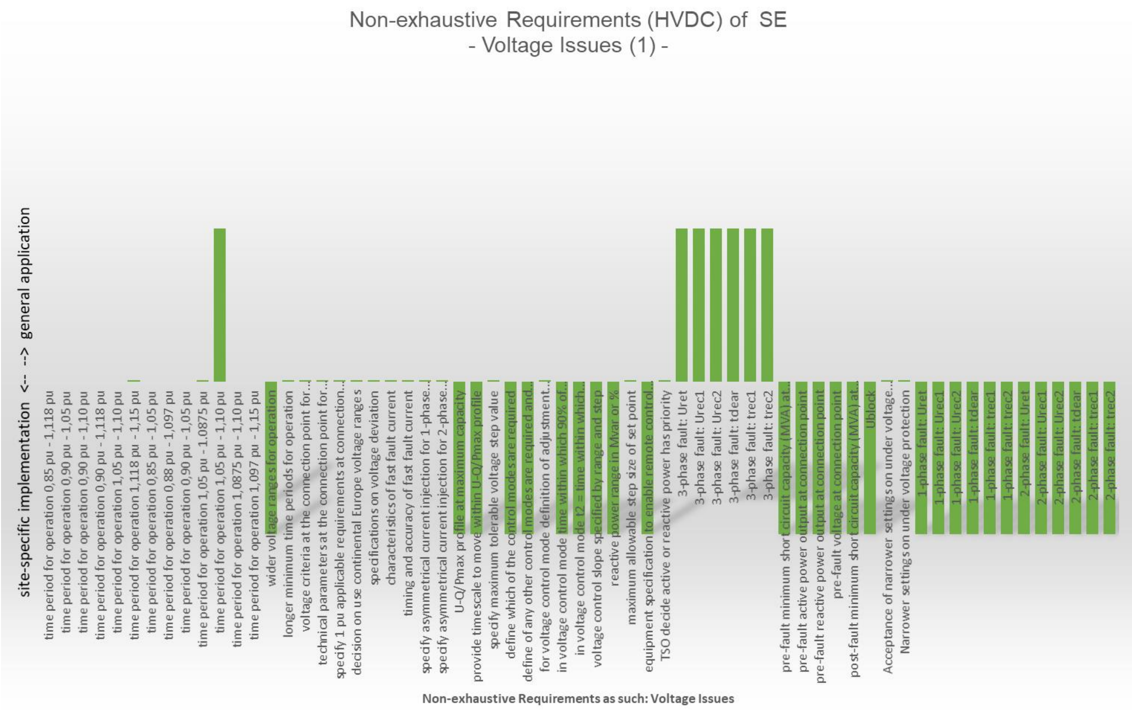


Figure 382: Sweden (SE)

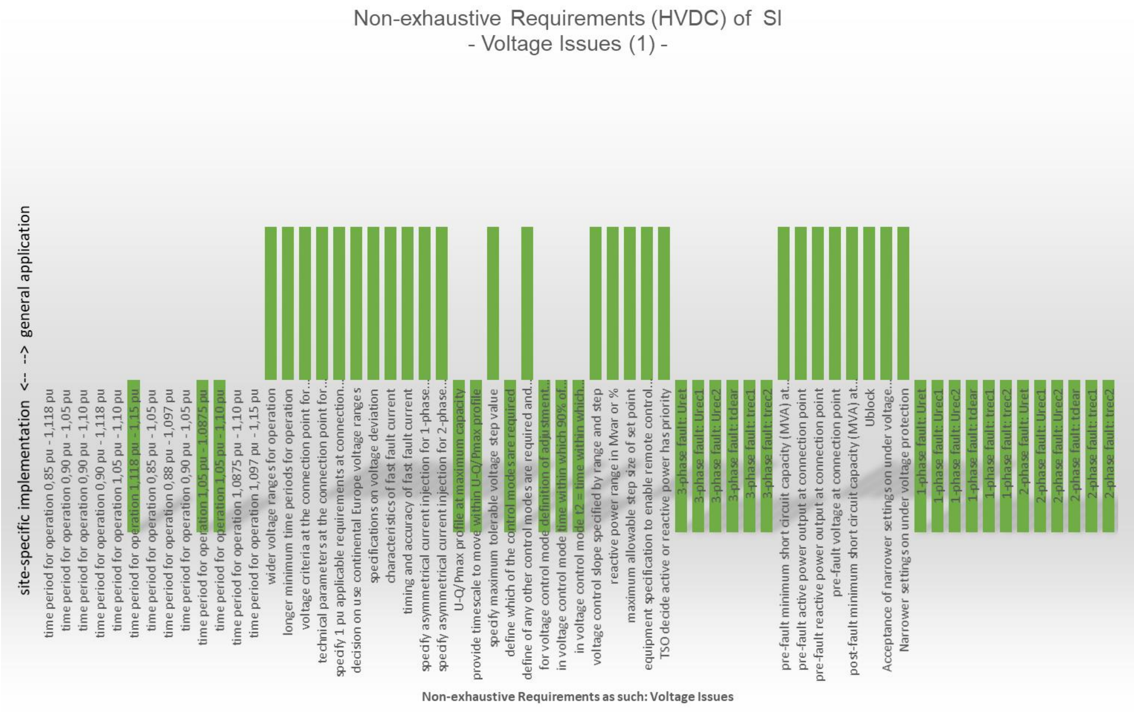


Figure 383: Slovenia (SI)

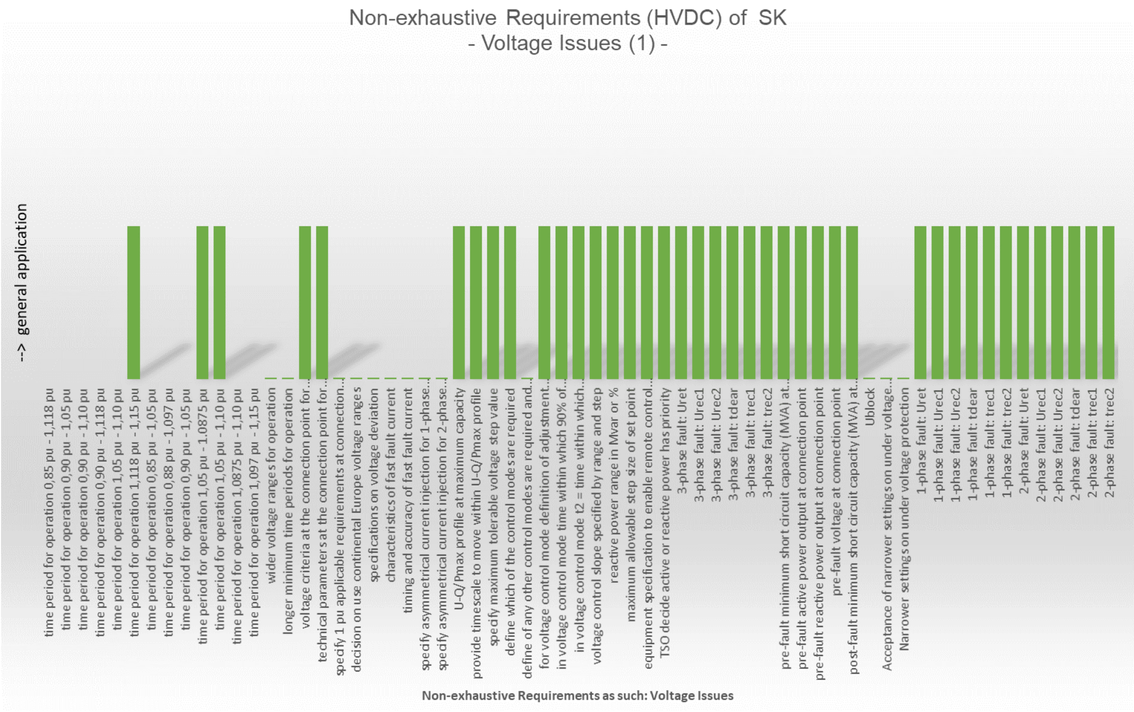


Figure 384: Slovakia (SK)

5.5 System Restoration Issues of NC HVDC

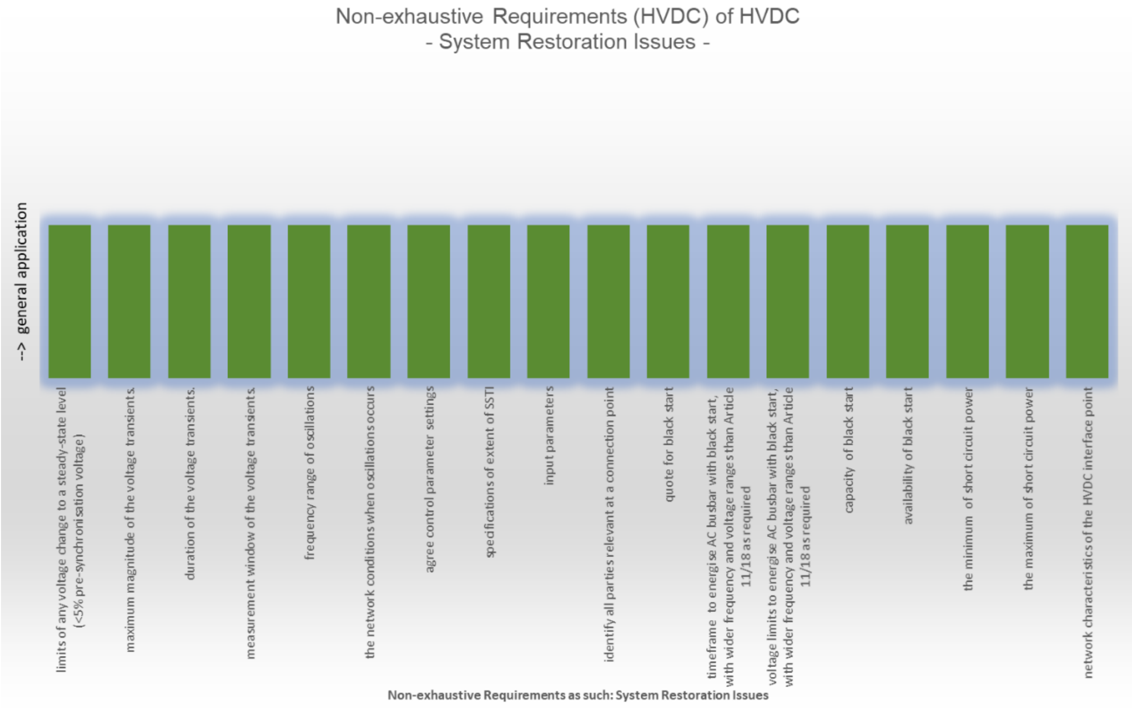


Figure 385: Reference values of non-exhaustive HVDC – system restoration issues

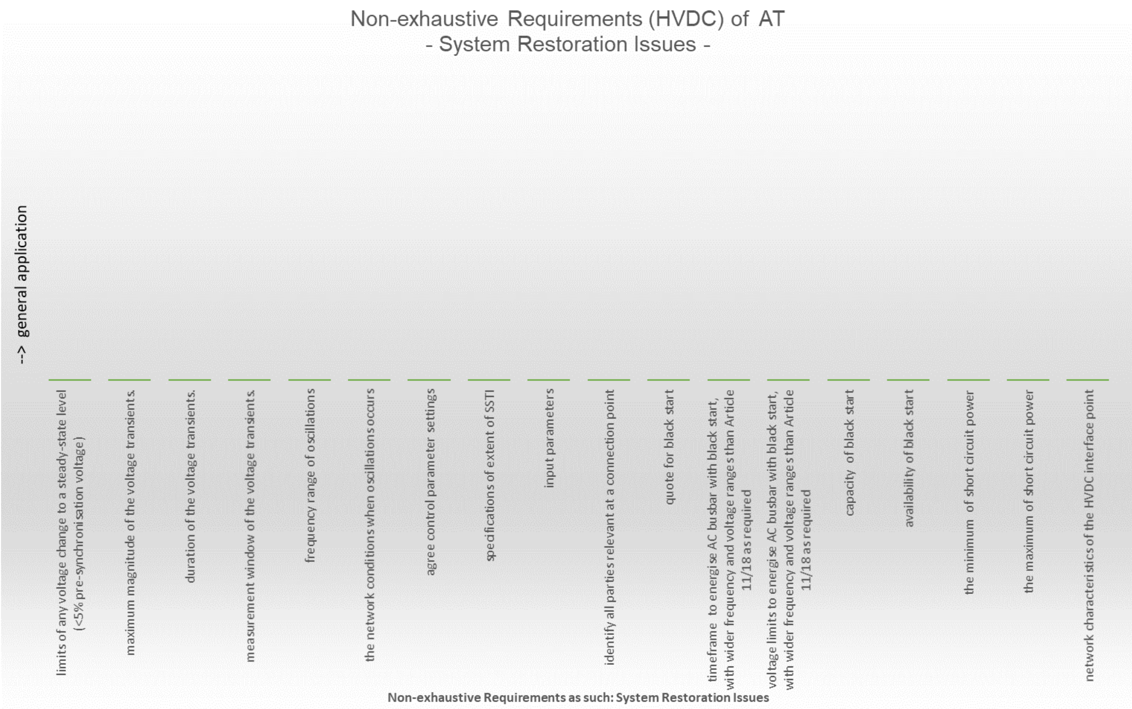


Figure 386: Austria (AT)

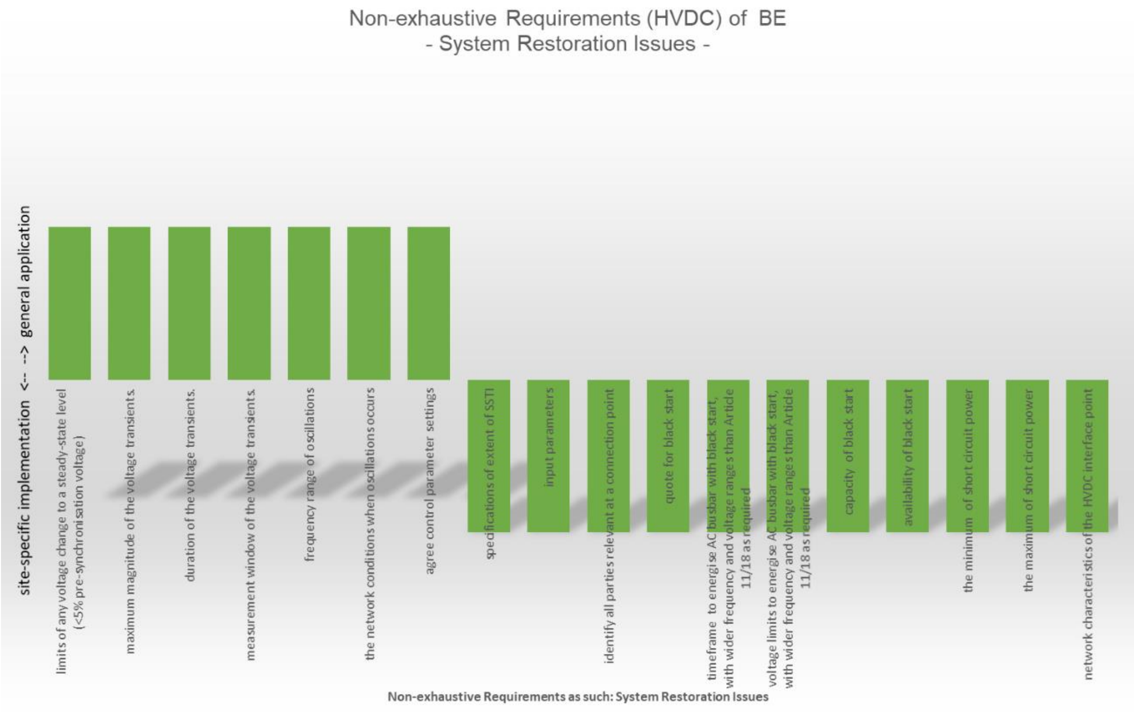


Figure 387: Belgium (BE)

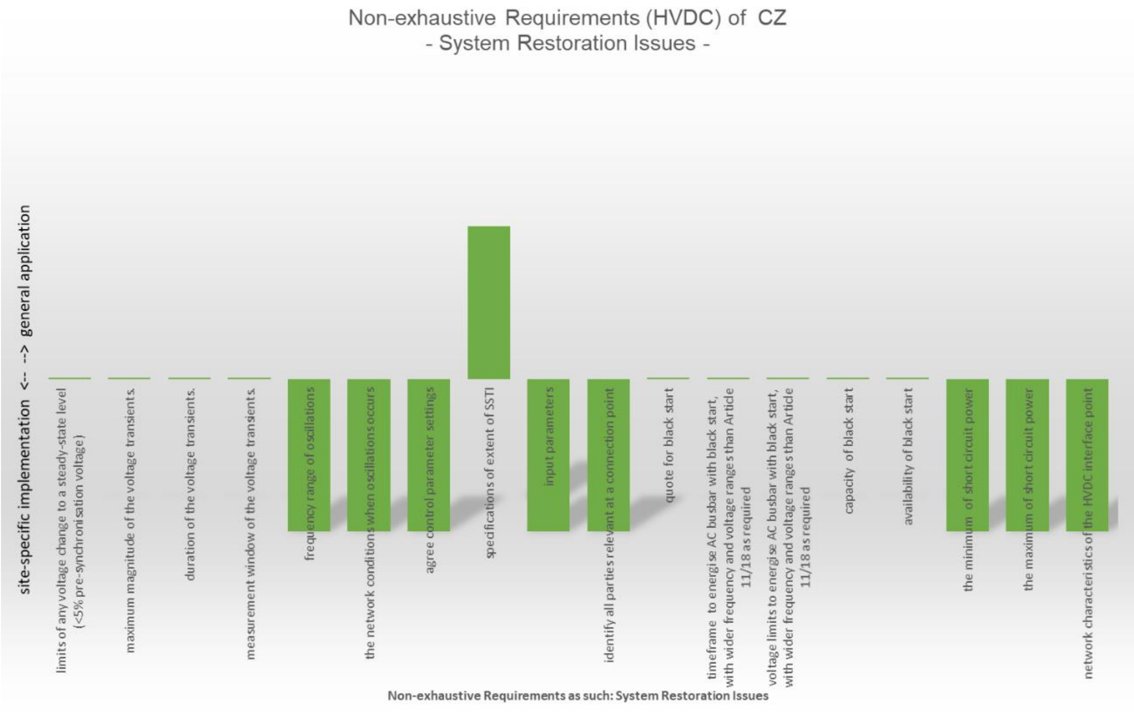


Figure 388: Czech Republic (CZ)

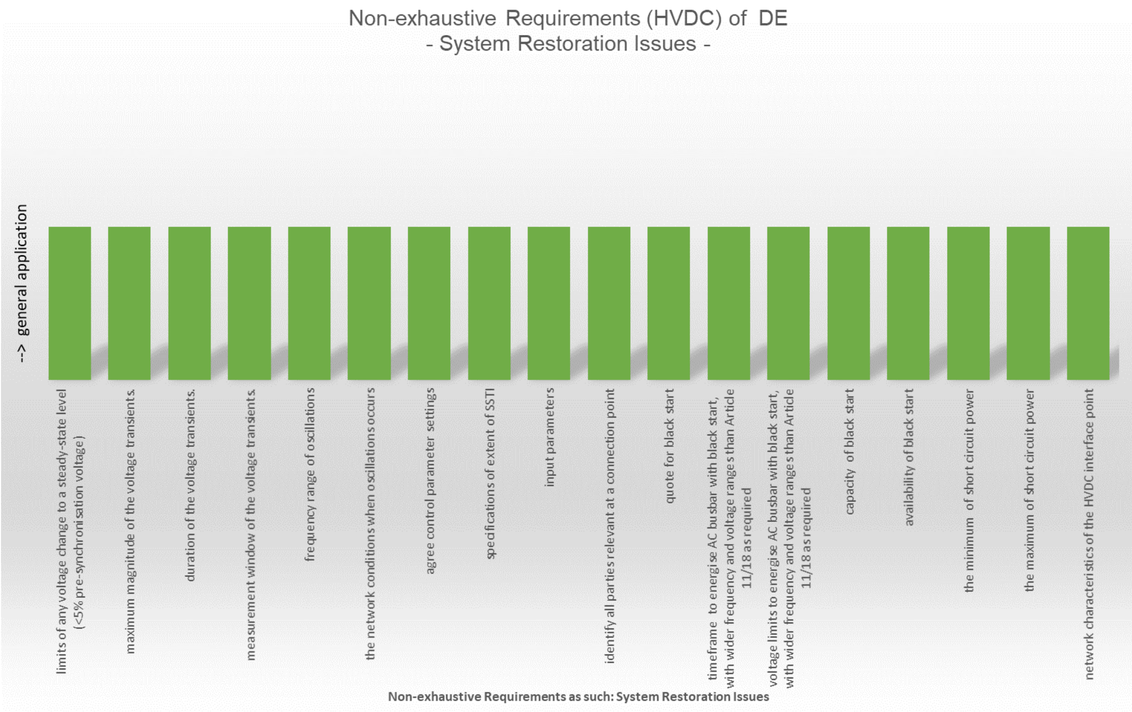


Figure 389: Germany (DE)

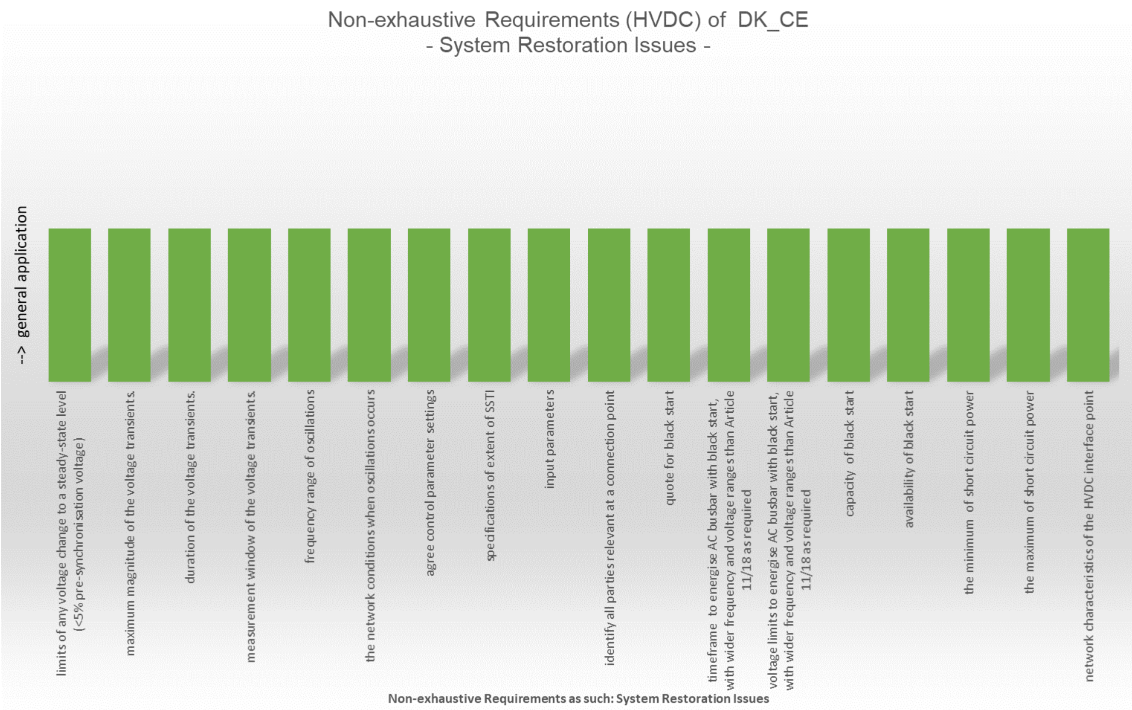


Figure 390: Denmark 1 (DK-CE)

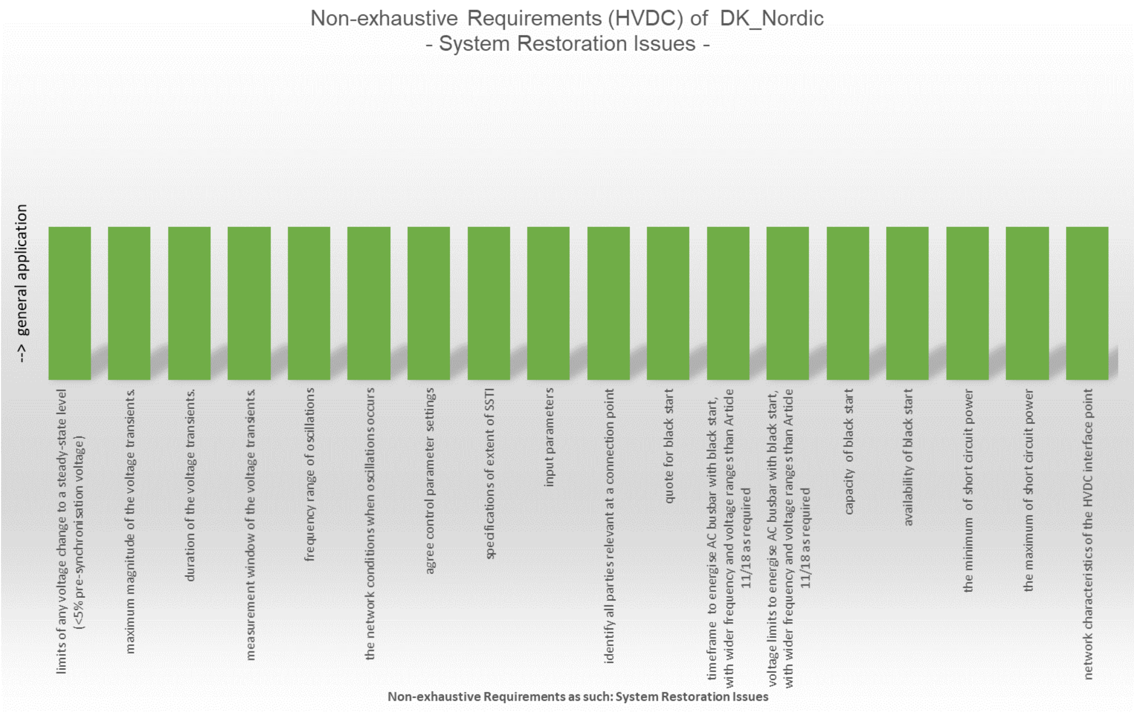


Figure 391: Denmark 2 (DK-Nordic)

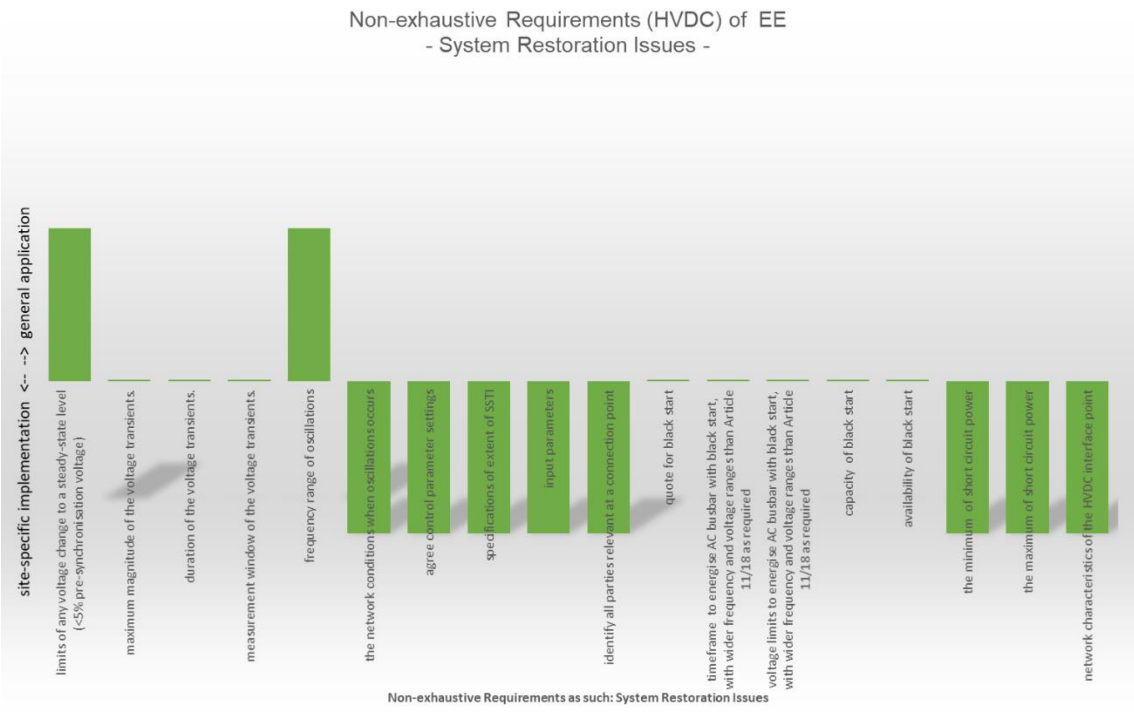


Figure 392: Estonia (EE)

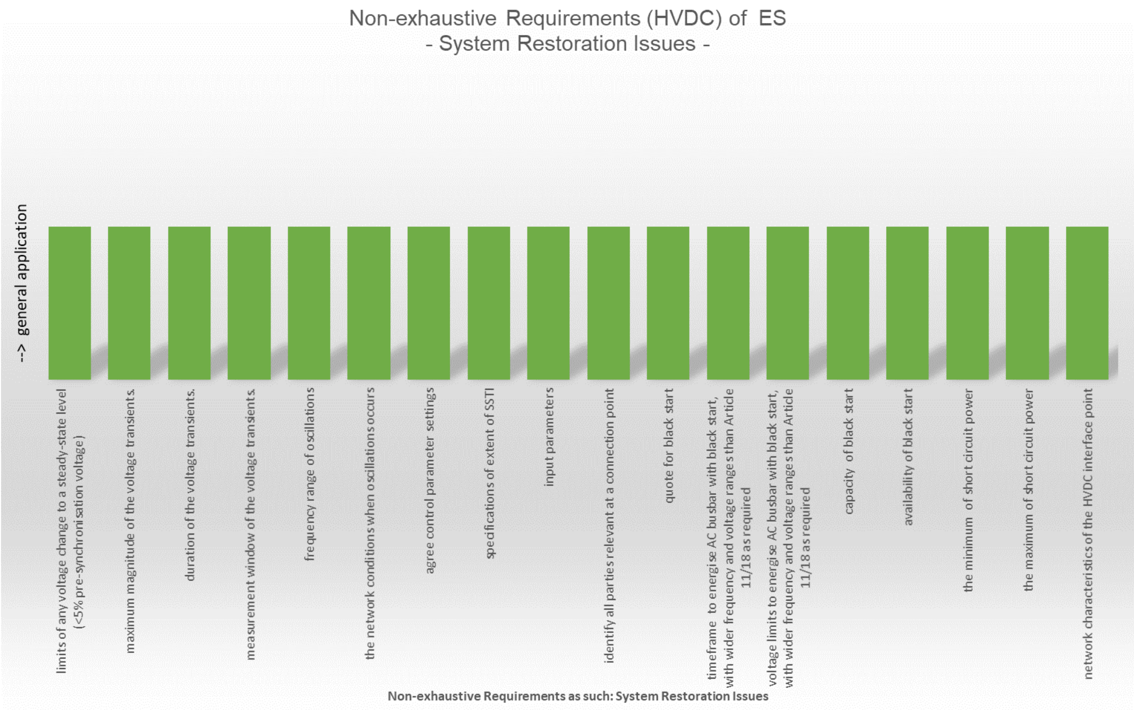


Figure 393: Spain (ES)

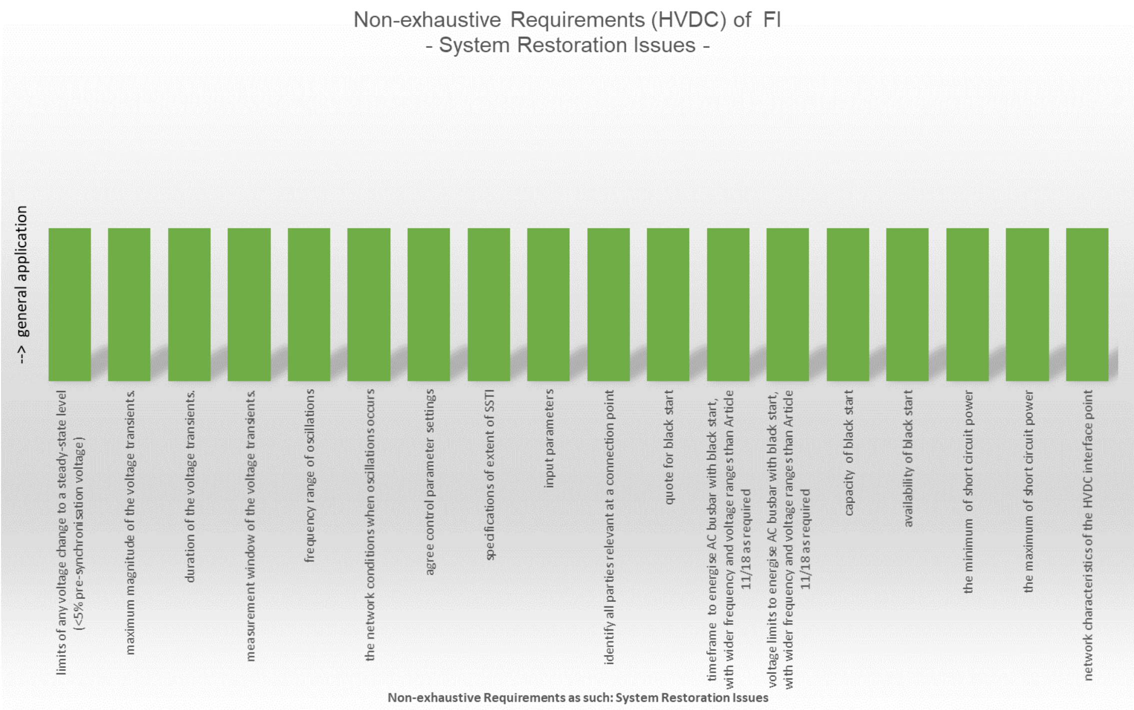


Figure 394: Finland (FI)

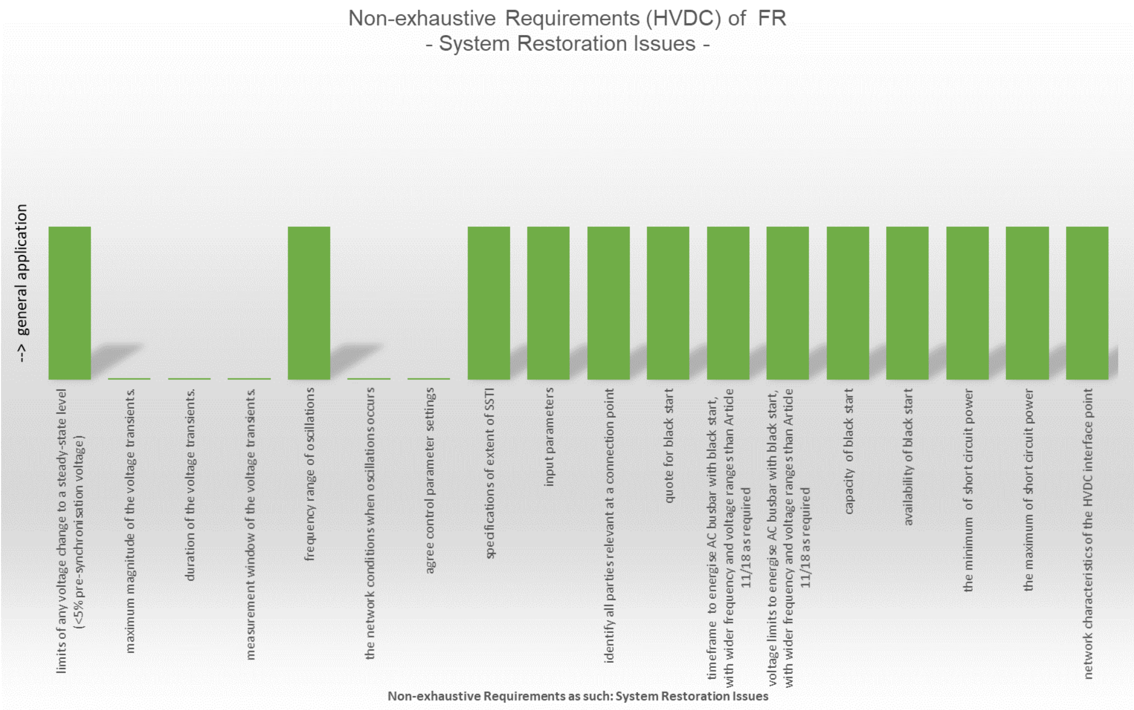


Figure 395: France (FR)

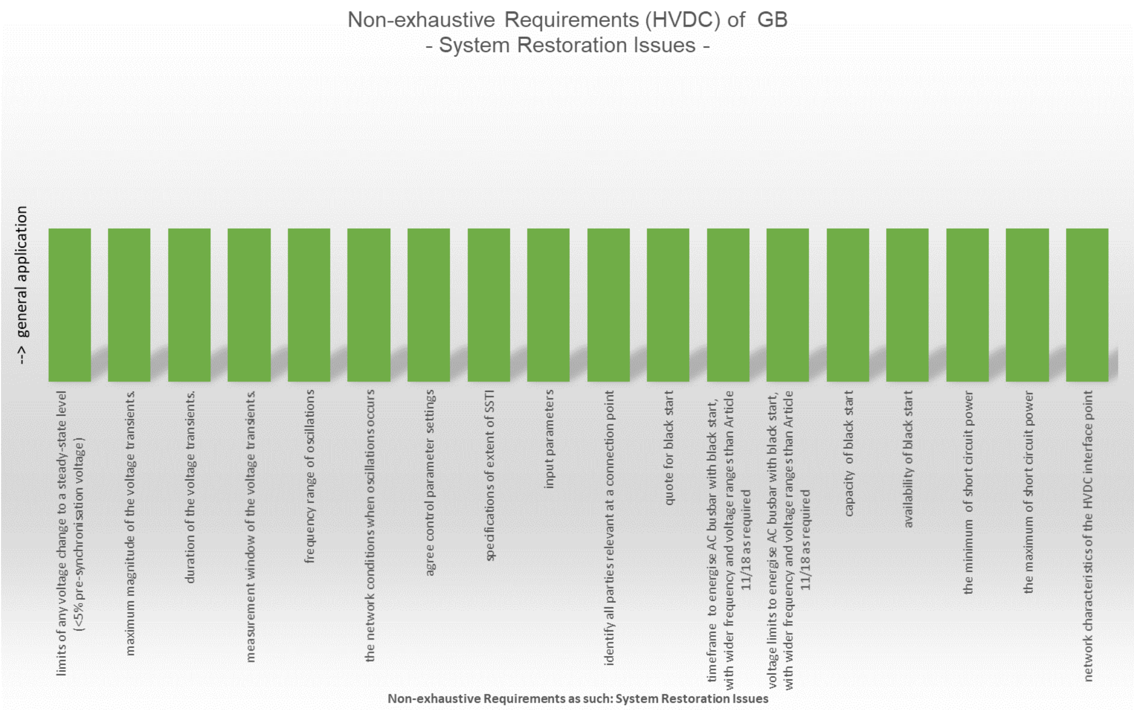


Figure 396: Great Britain (GB)

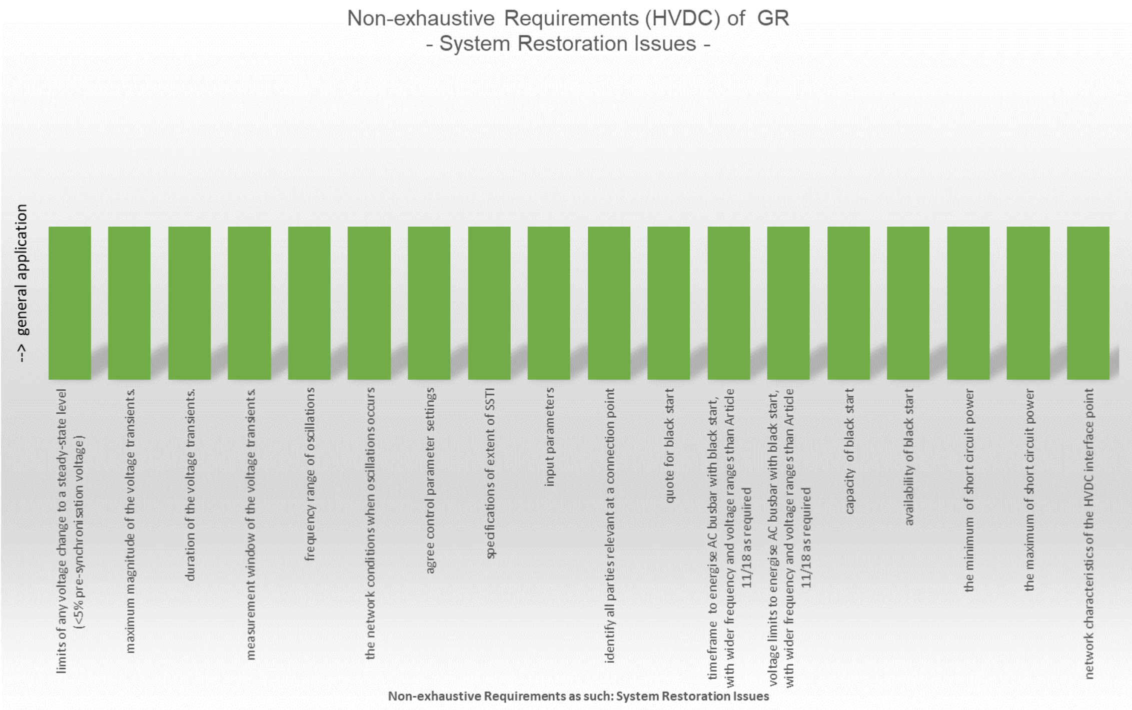


Figure 397: Greece (GR)

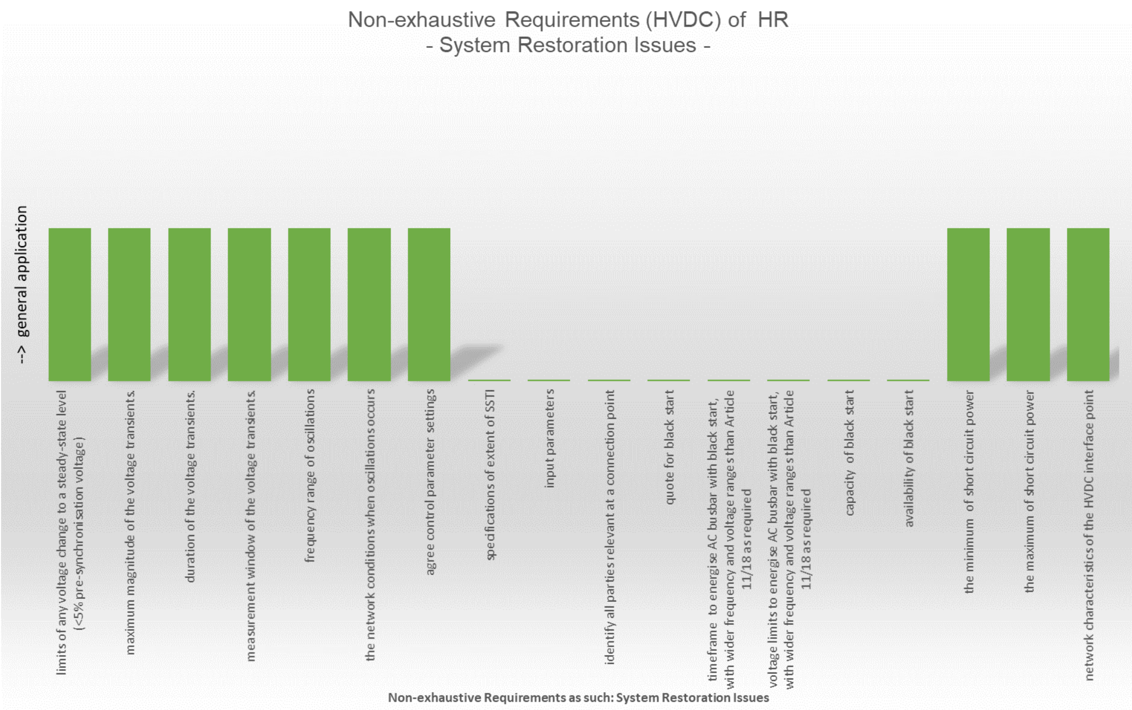


Figure 398: Croatia (HR)

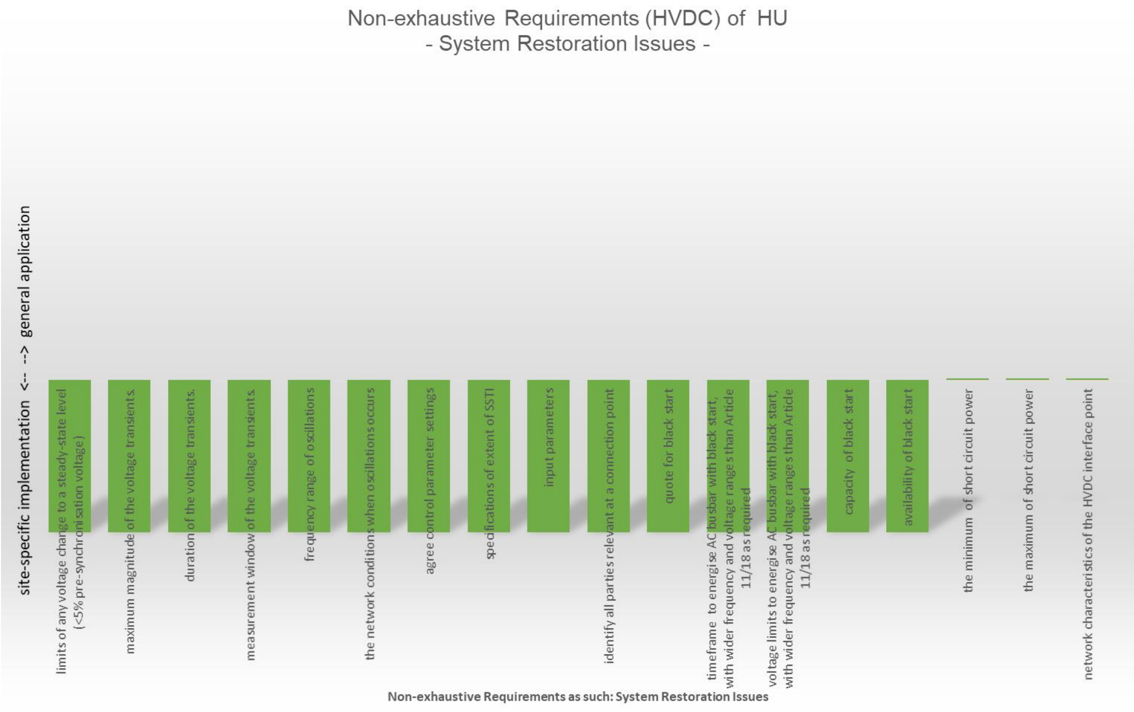


Figure 399: Hungary (HU)

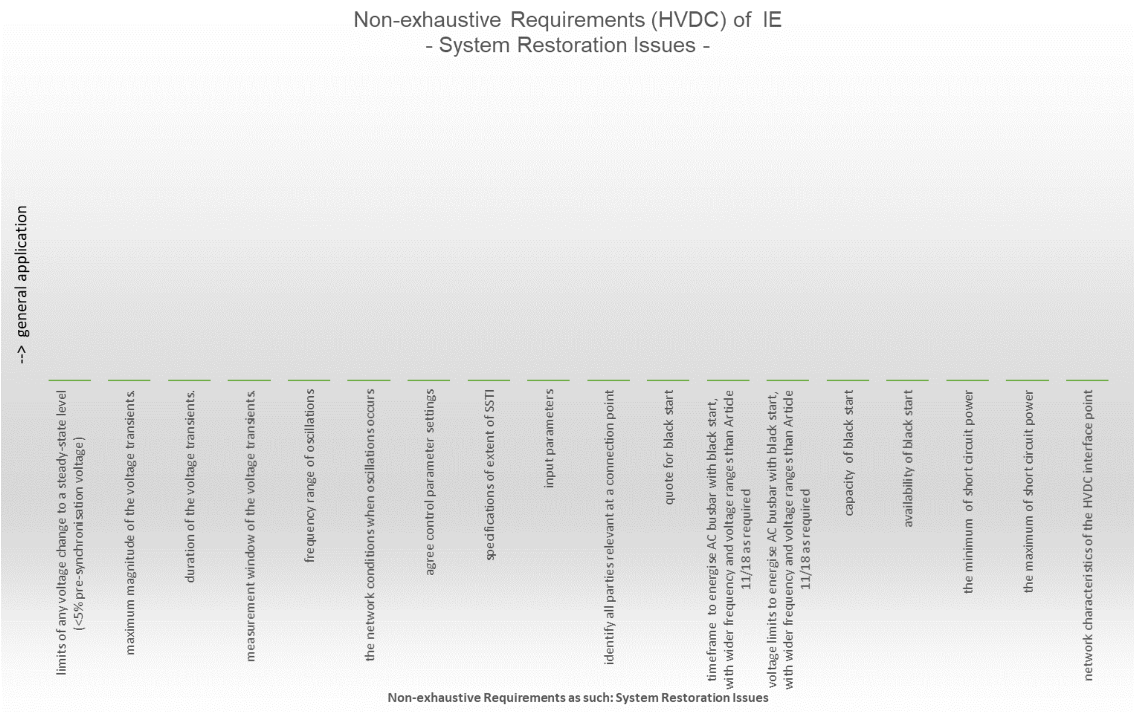


Figure 400: Ireland (IE)

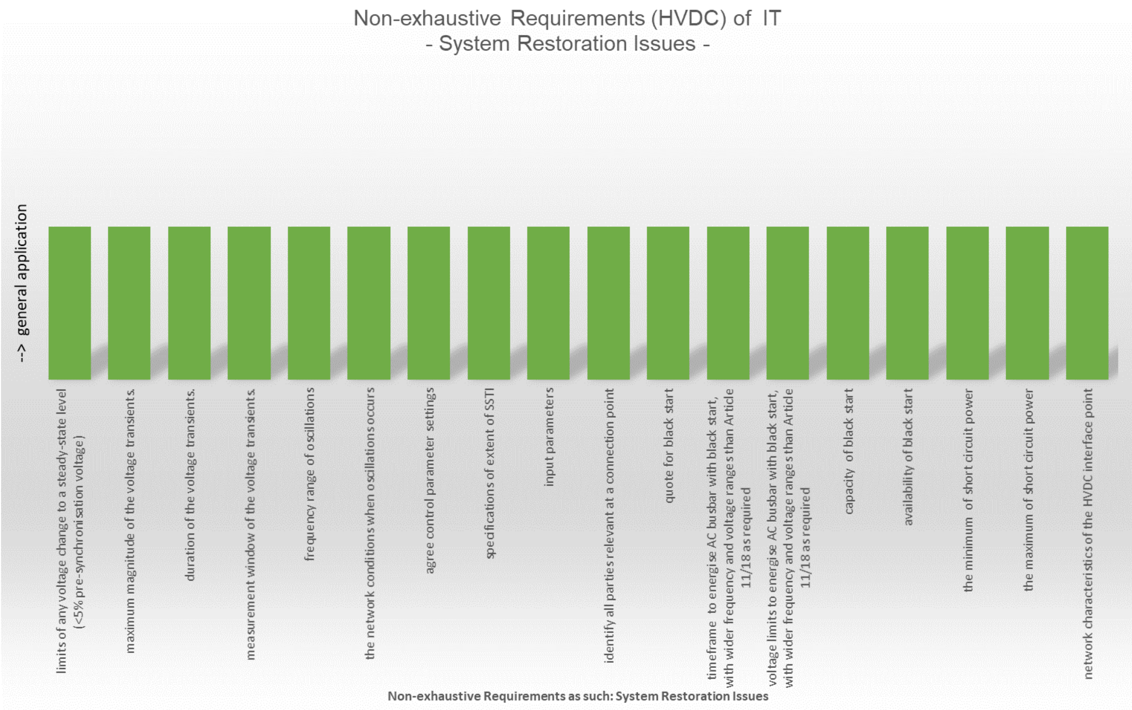


Figure 401: Italy (IT)

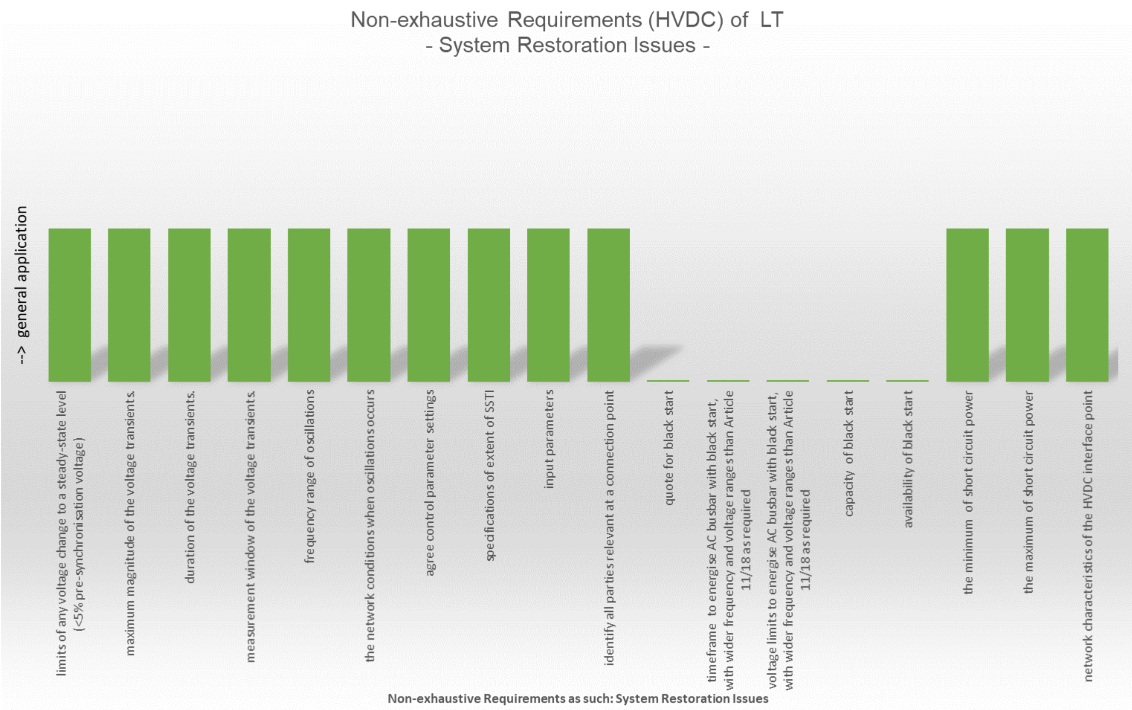


Figure 402: Lithuania (LT)

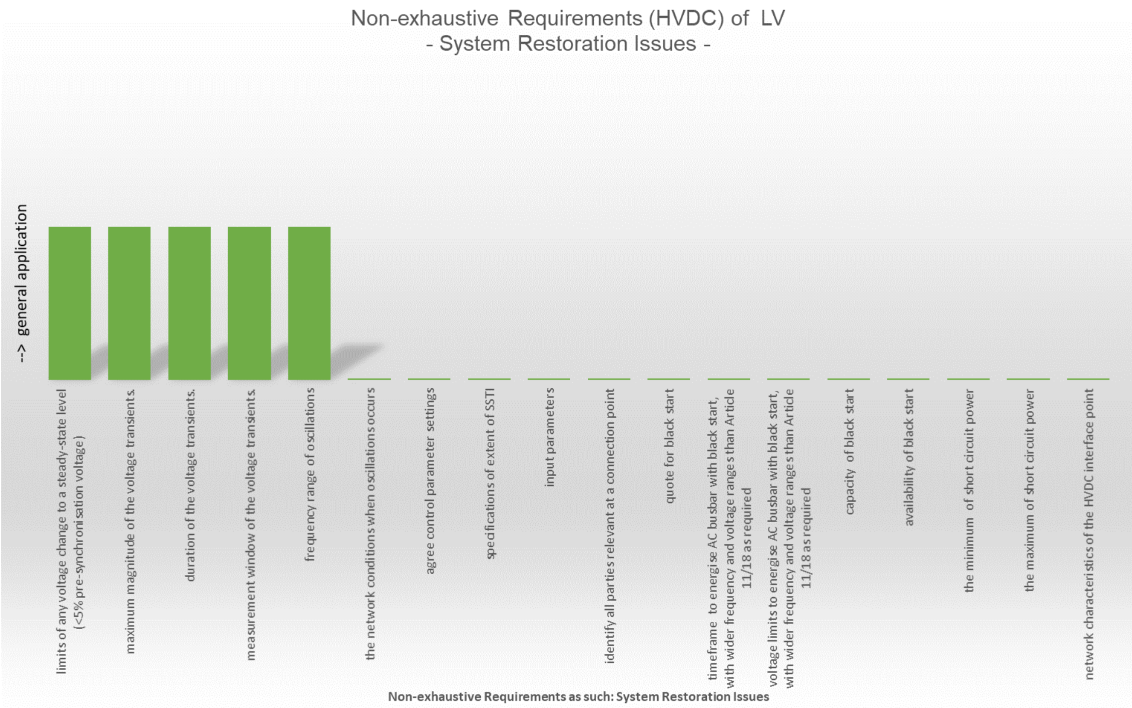


Figure 403: Latvia (LV)

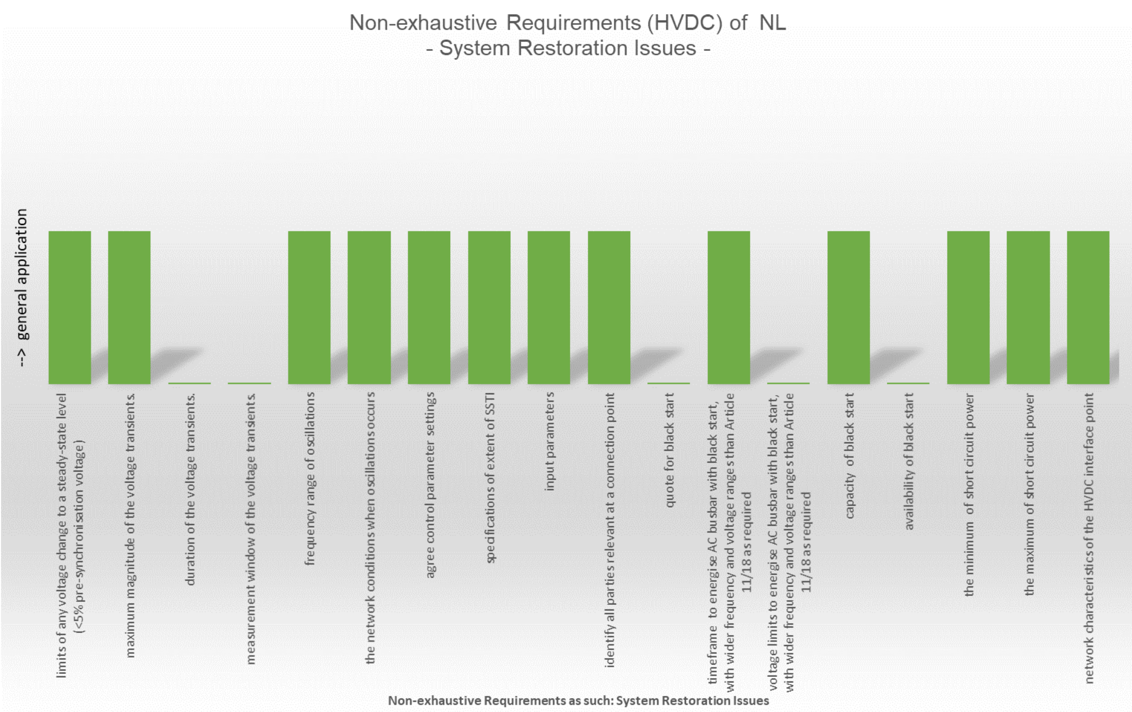


Figure 404: Netherlands (NL)

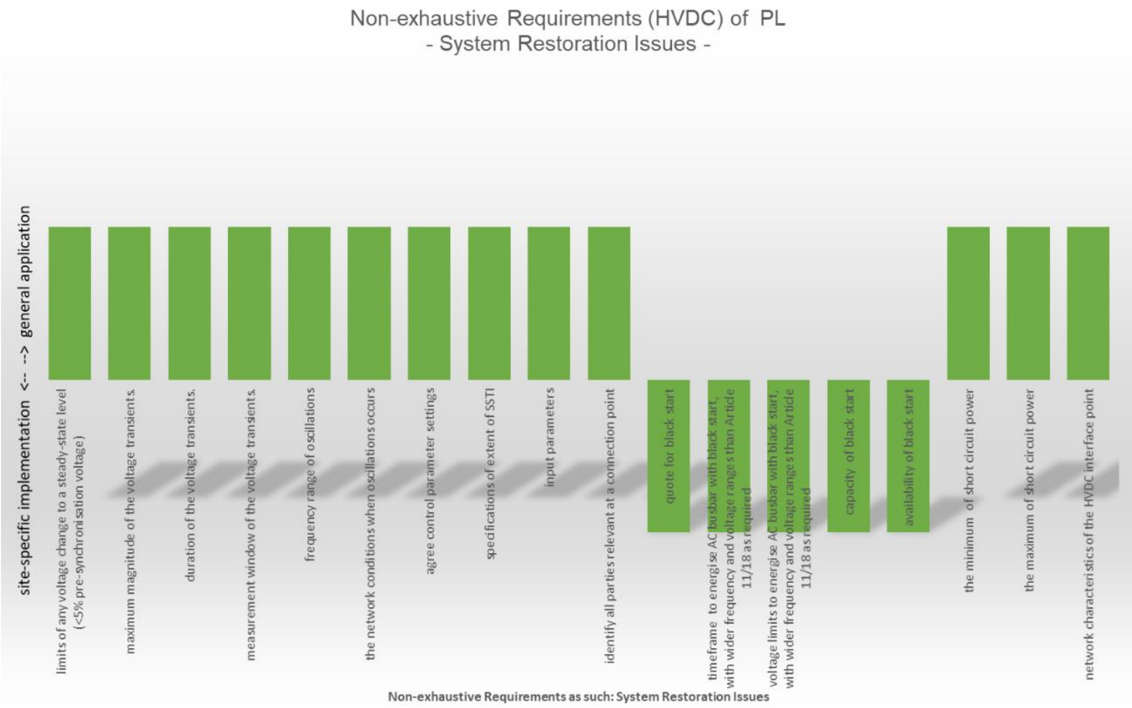


Figure 405: Poland (PL)

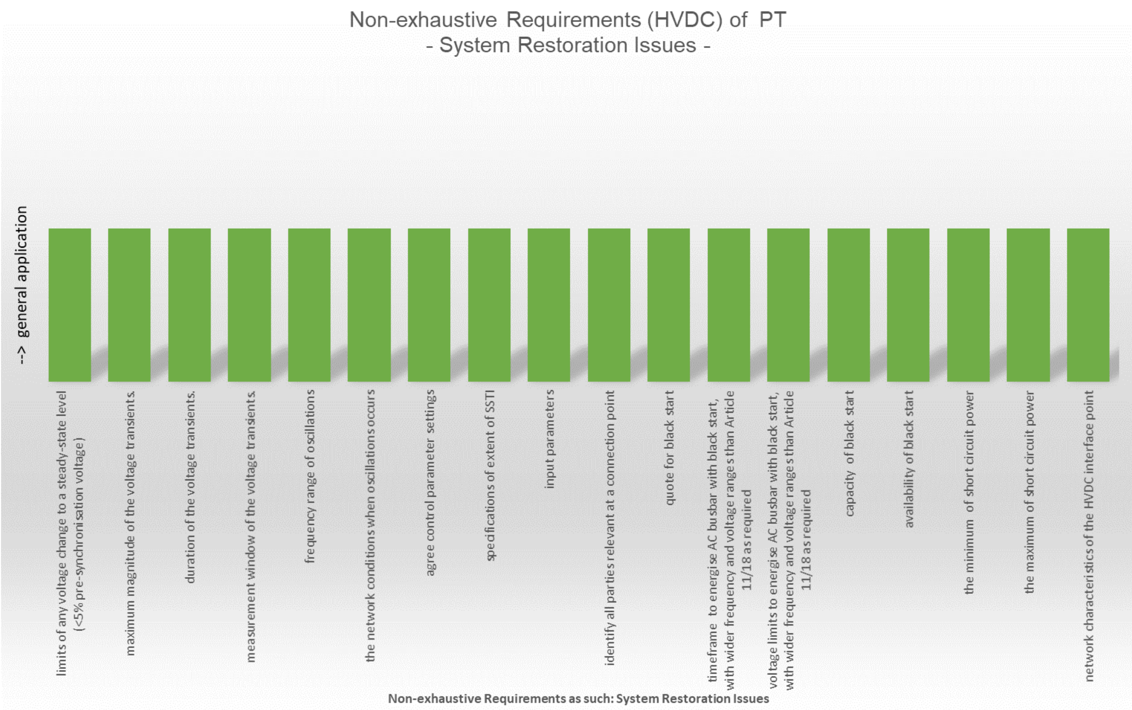


Figure 406: Portugal (PT)

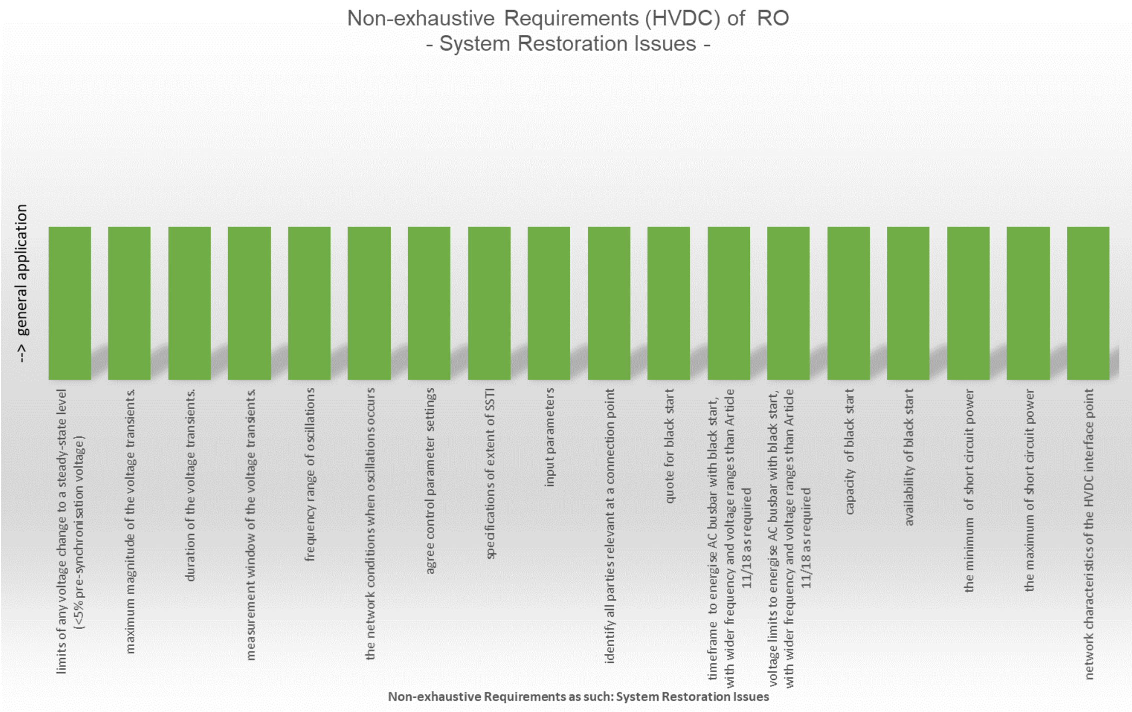


Figure 407: Romania (RO)

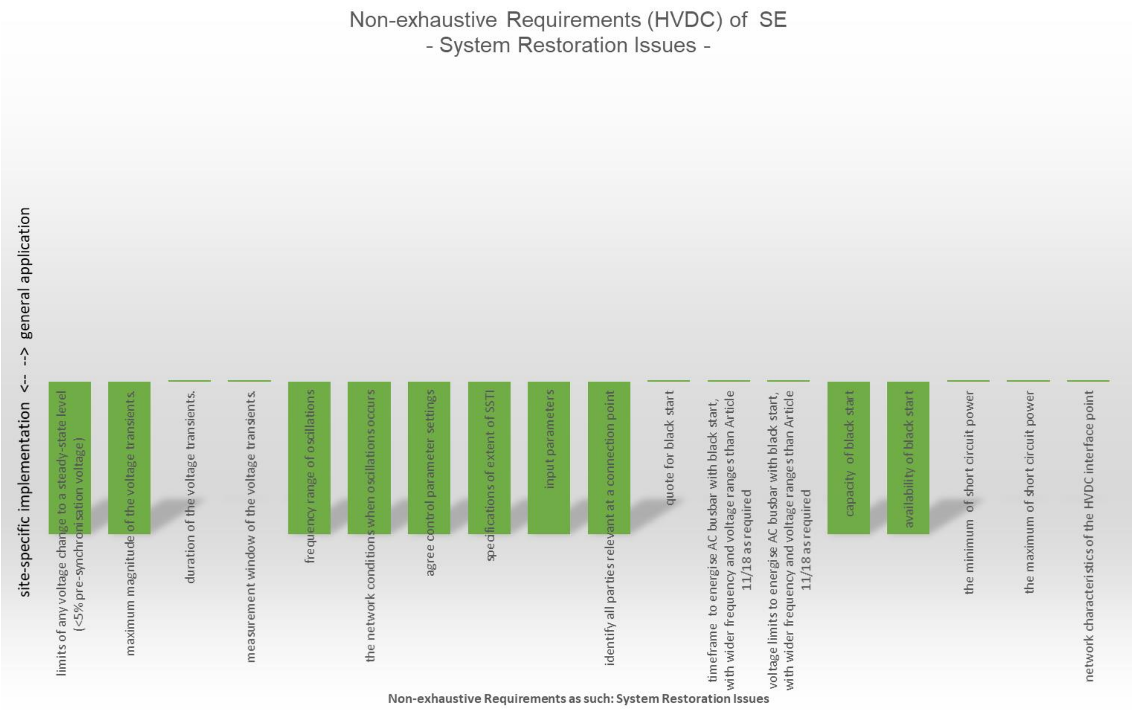


Figure 408: Sweden (SE)

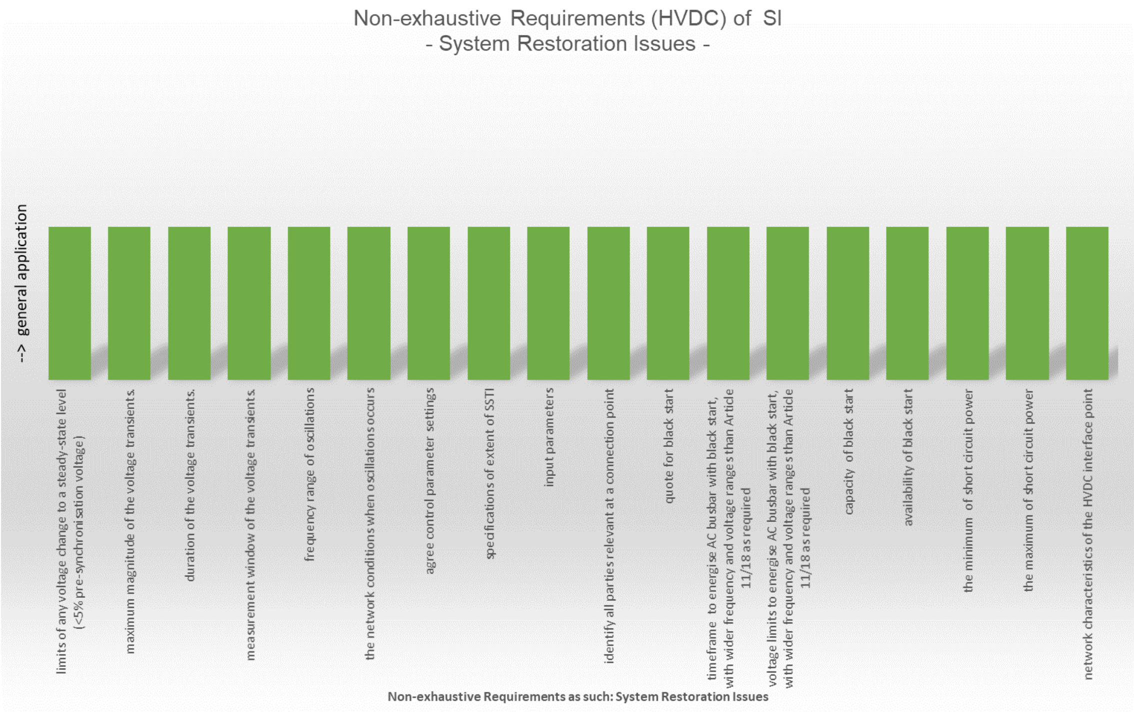


Figure 409: Slovenia (SI)

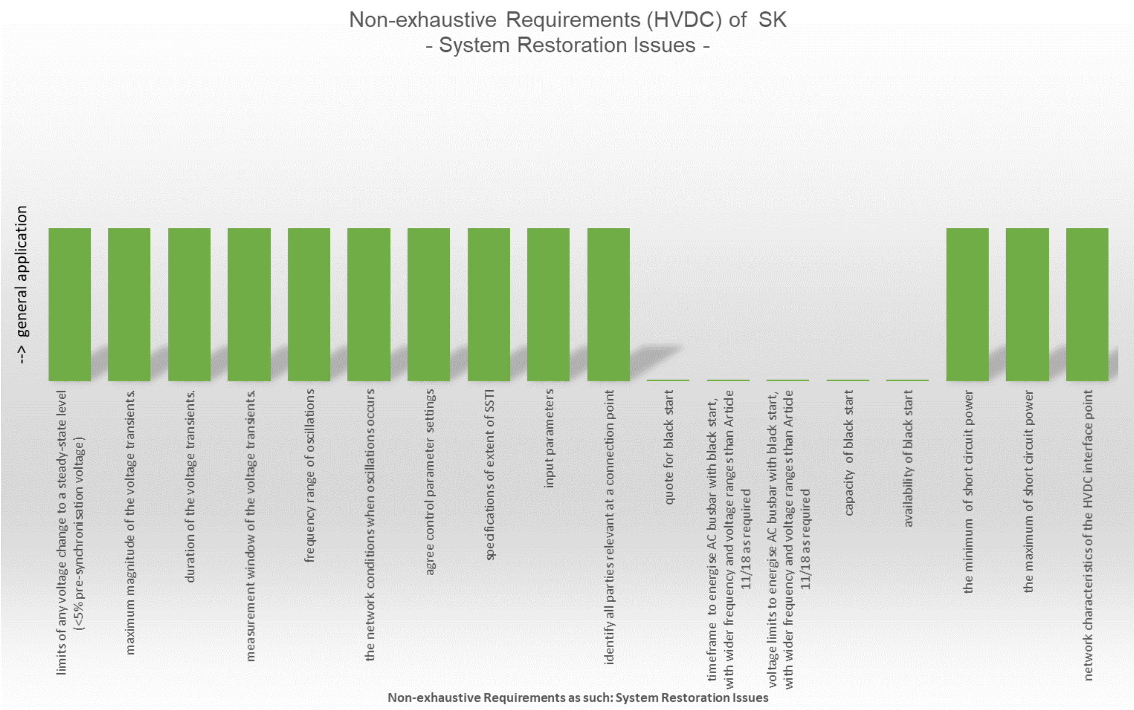


Figure 410: Slovakia (SK)

5.6 Instrumentation, Simulation Models and Protection Issues of NC HVDC

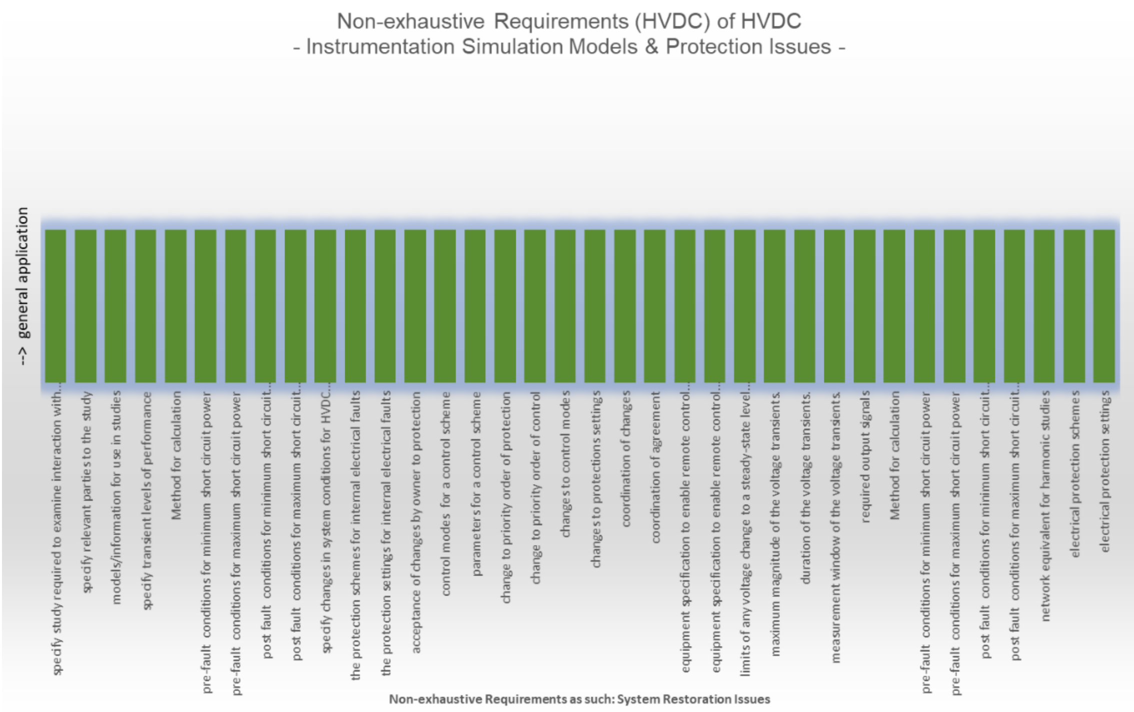


Figure 411: Reference values of non-exhaustive HVDC – instrumentation, simulation ,models and protection issues

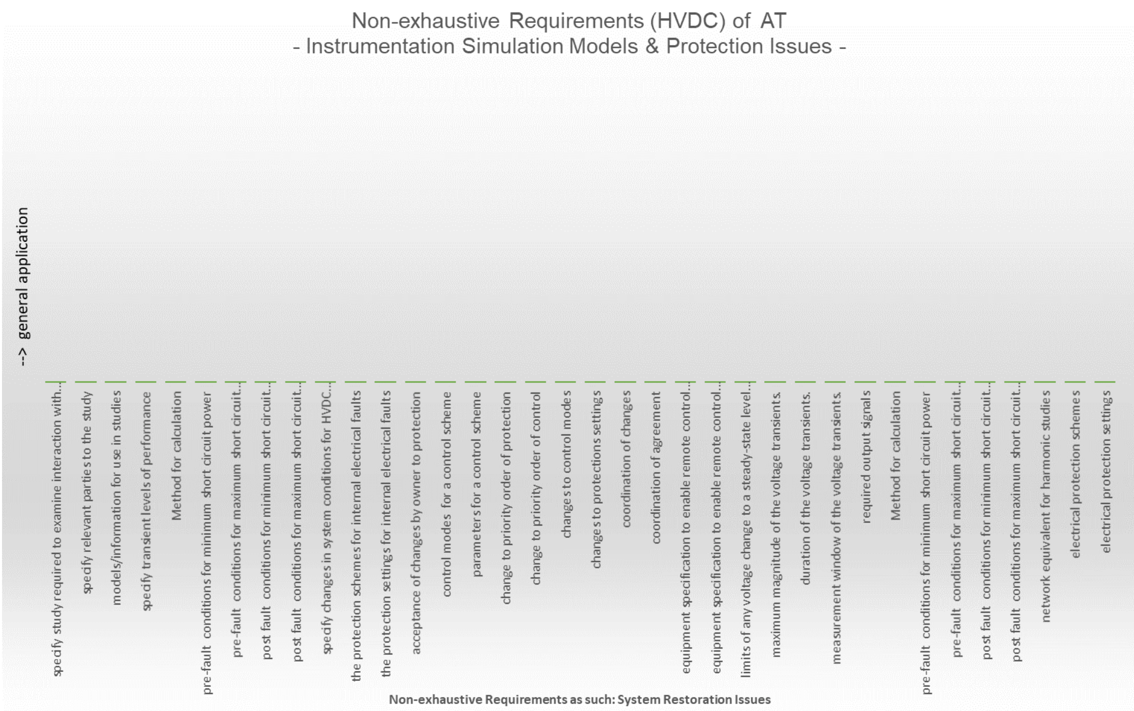


Figure 412: Austria (AT)

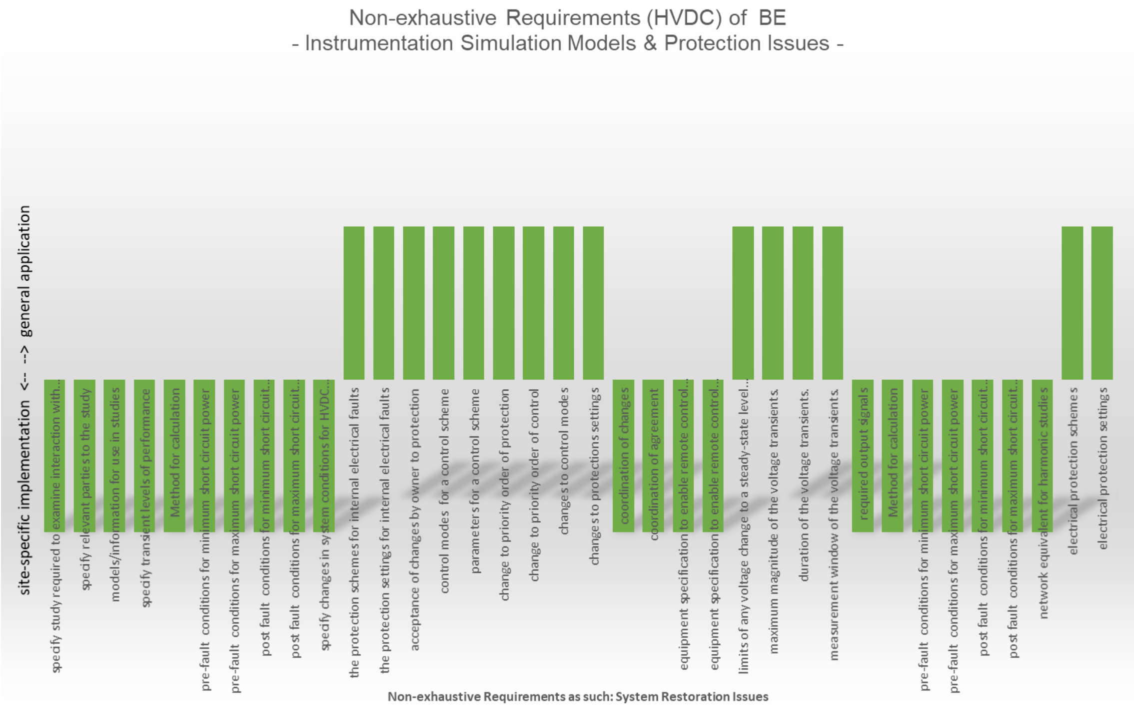


Figure 413: Belgium (BE)

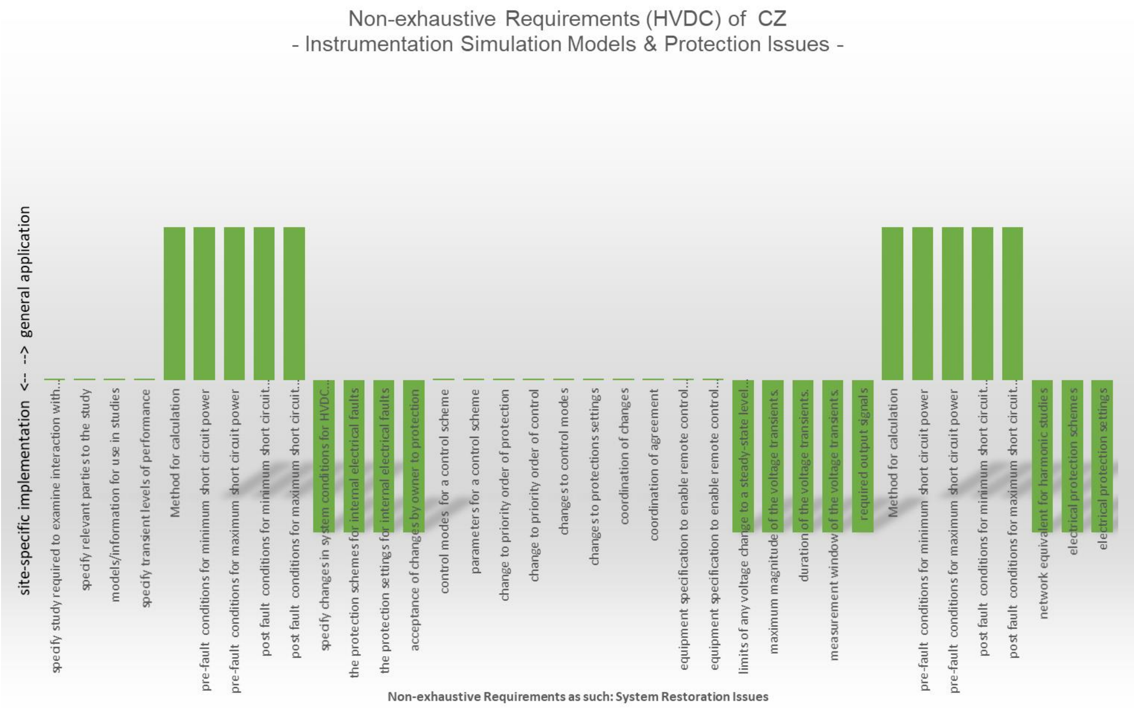


Figure 414: Czech Republic (CZ)

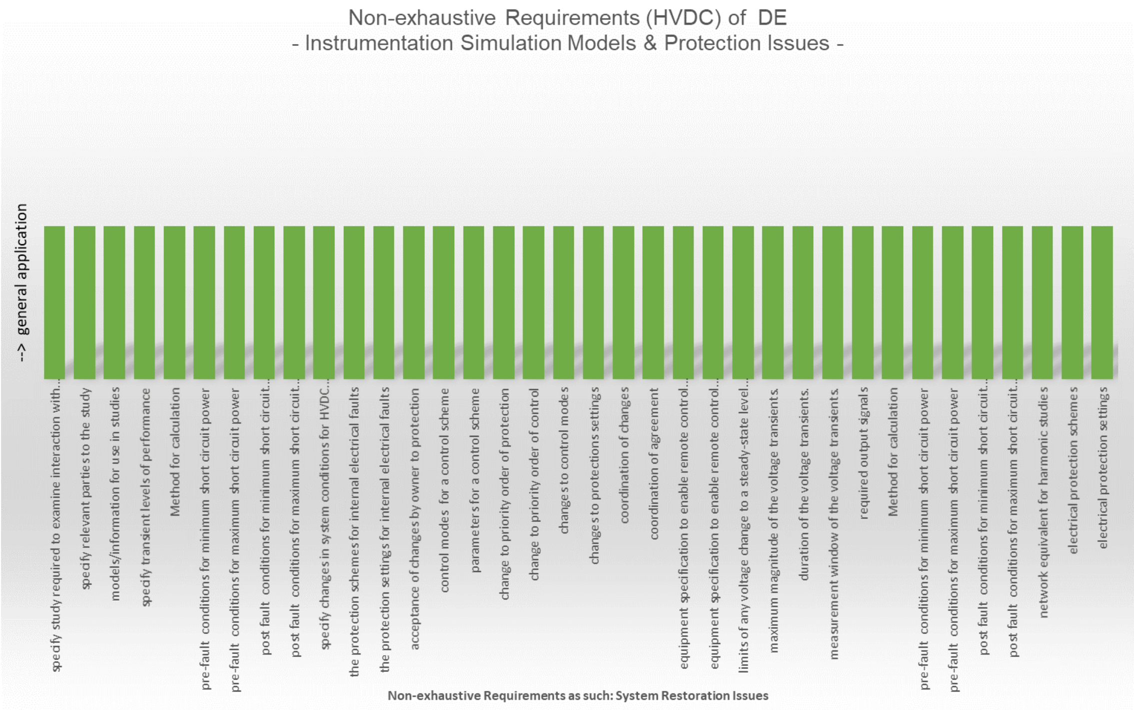


Figure 415: Germany (DE)

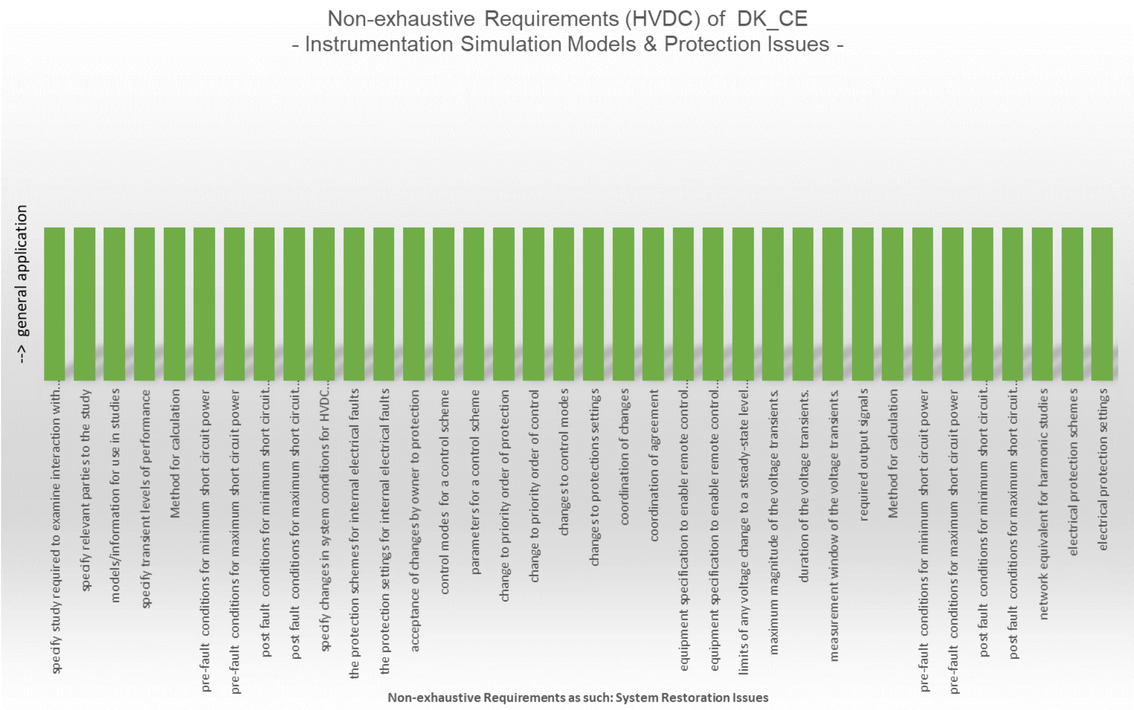


Figure 416: Denmark 1 (DK-CE)

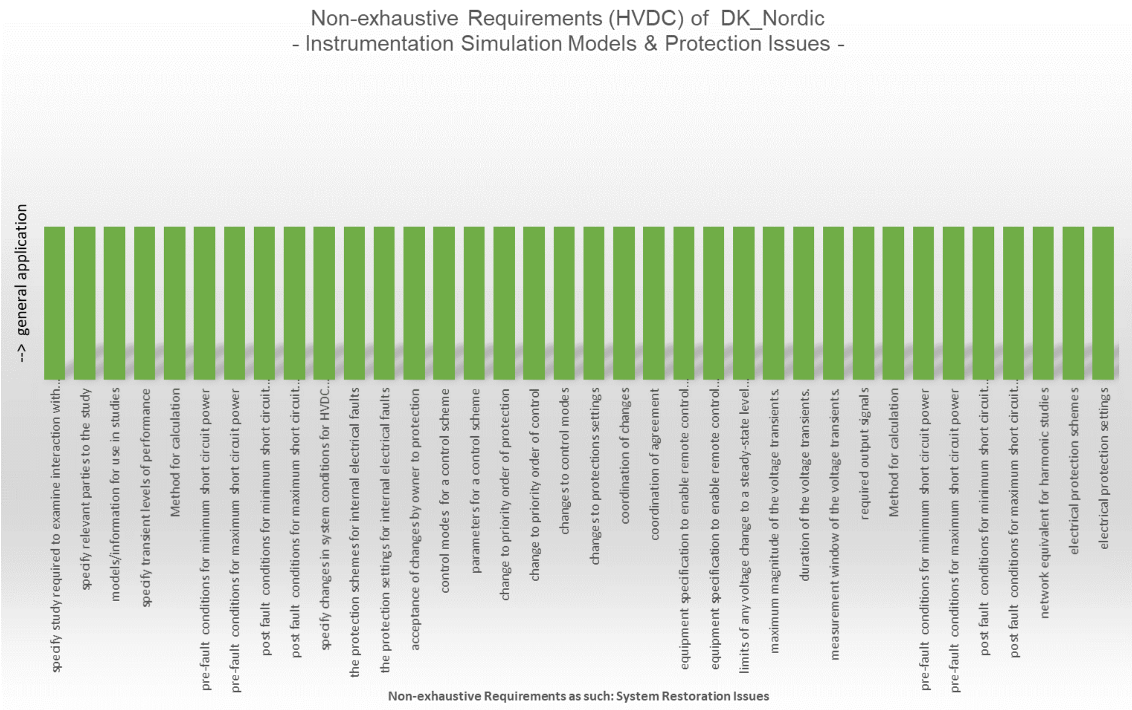


Figure 417: Denmark 2 (DK-Nordic)

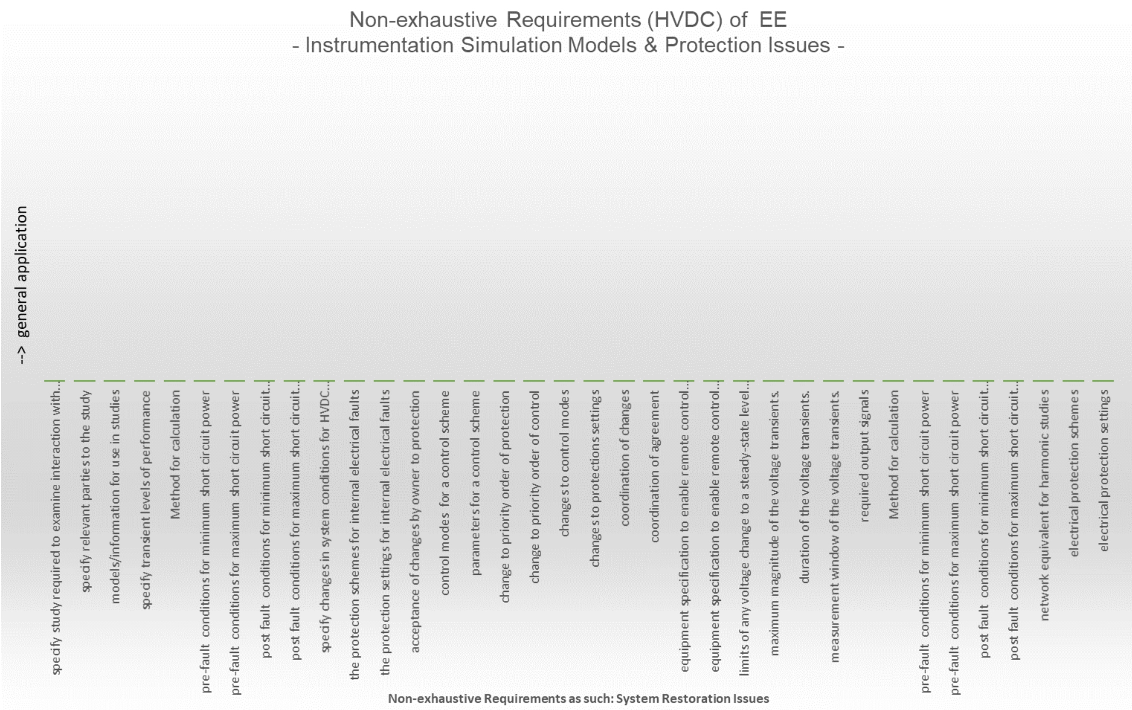


Figure 418: Estonia (EE)

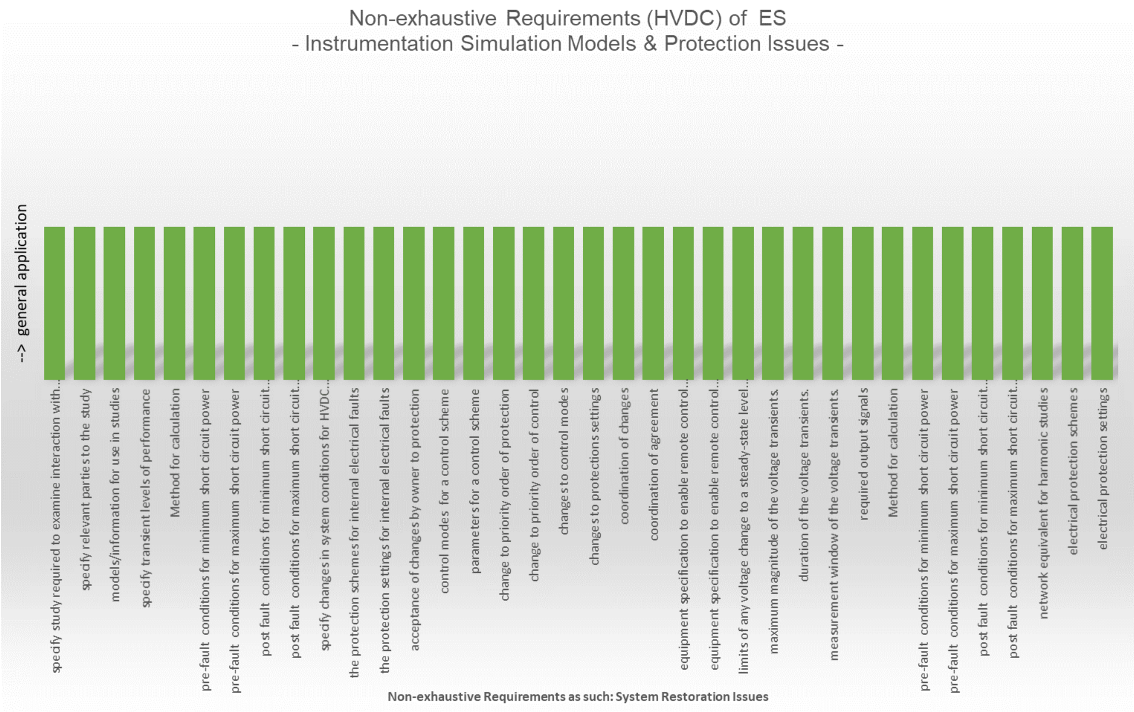


Figure 419: Spain (ES)

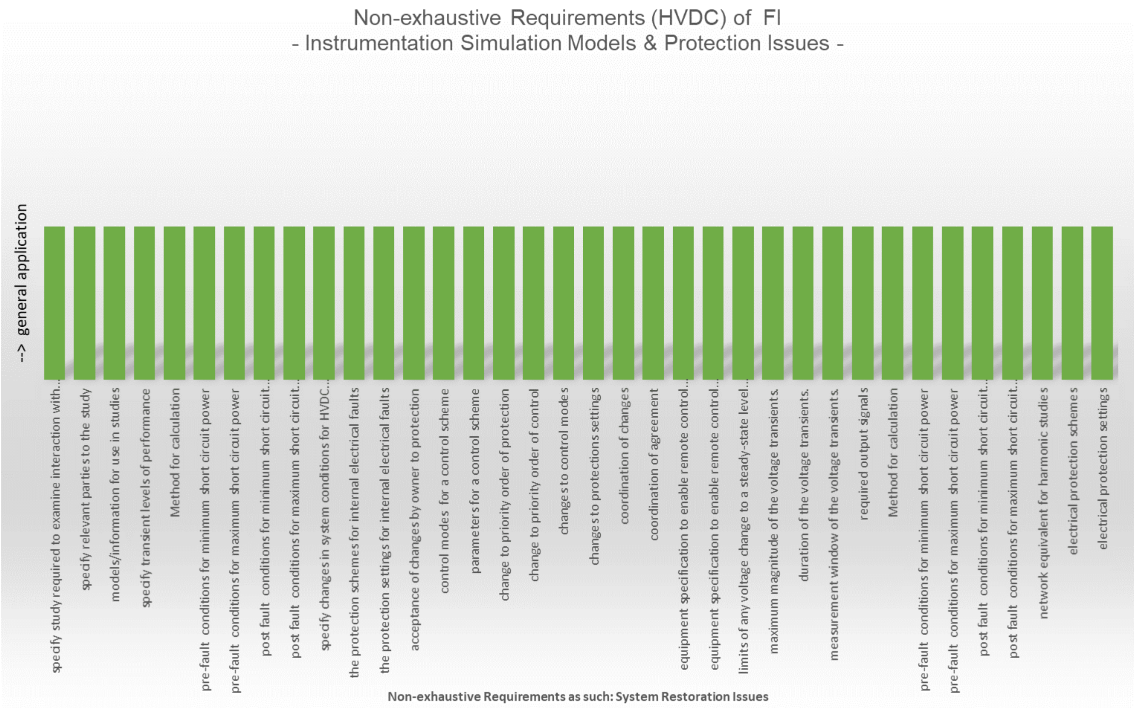


Figure 420: Finland (FI)

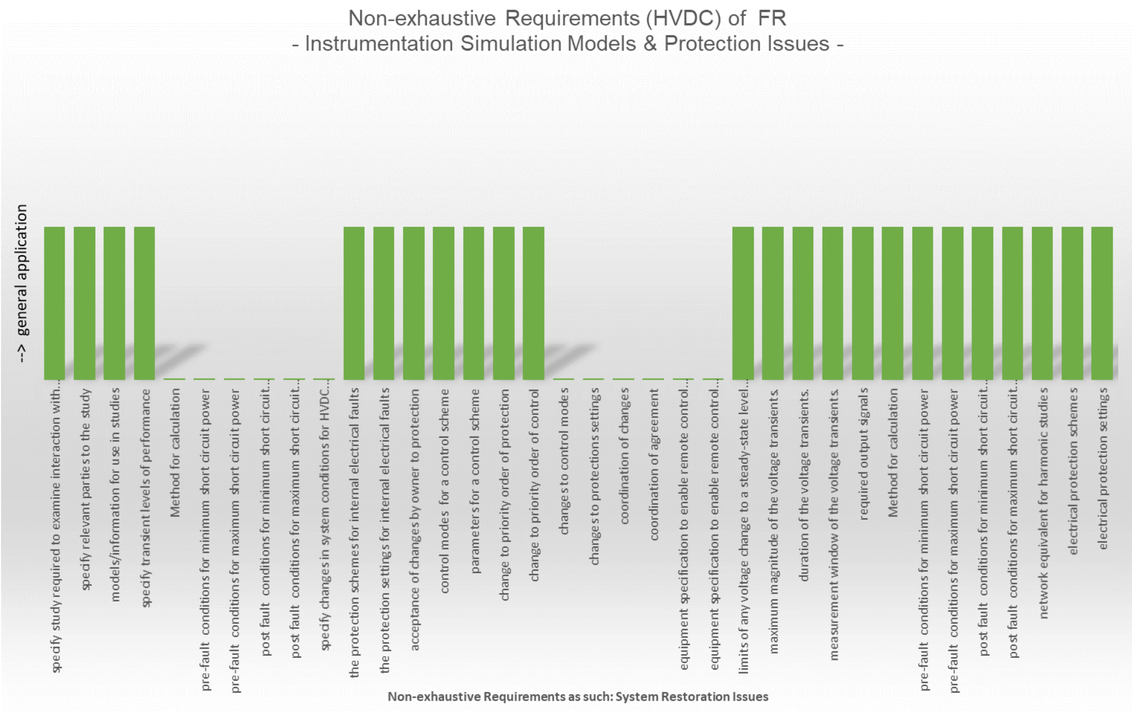


Figure 421: France (FR)

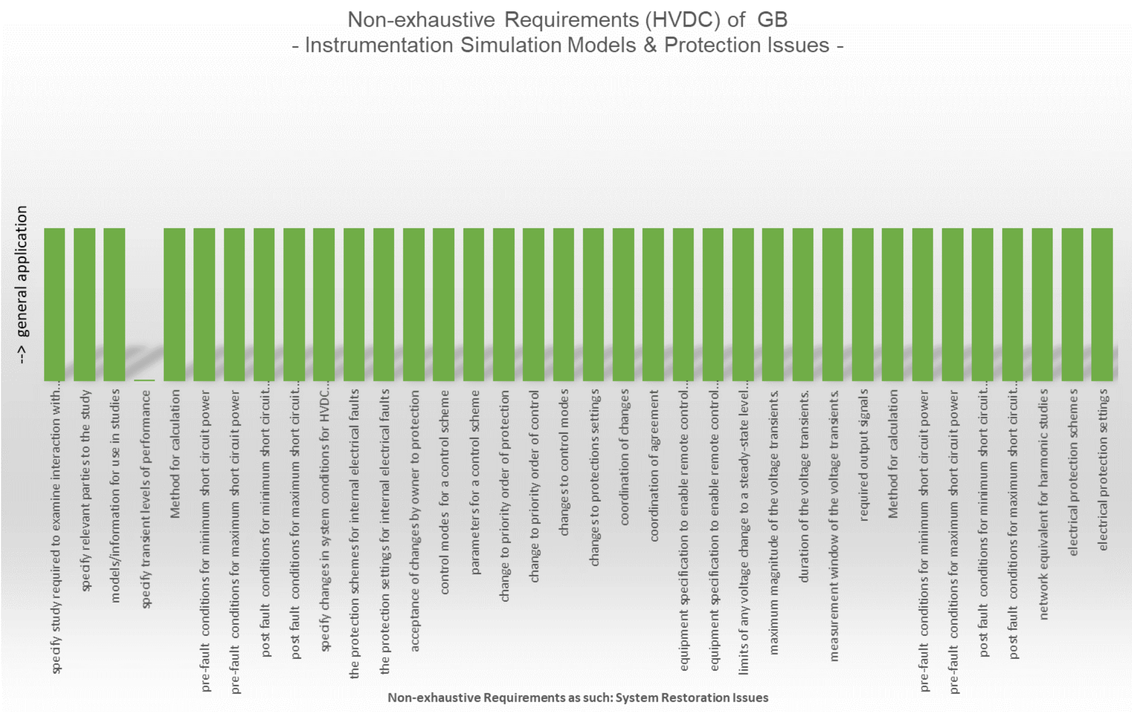


Figure 422: Great Britain (GB)

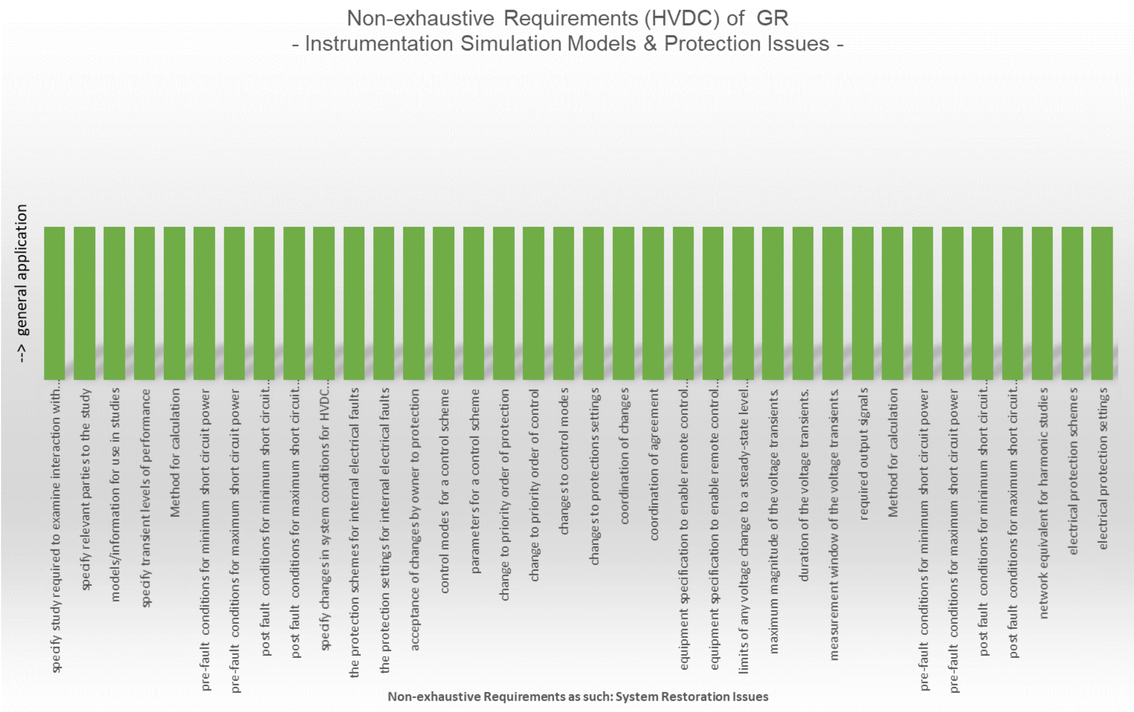


Figure 423: Greece (GR)

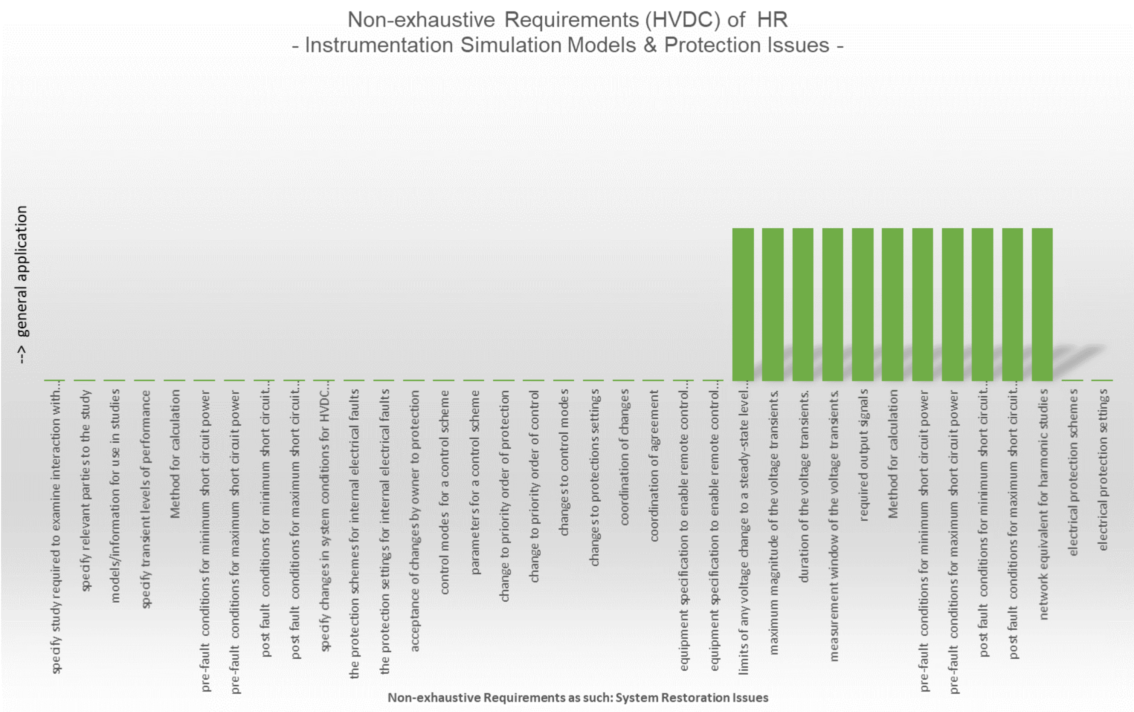


Figure 424: Croatia (HR)

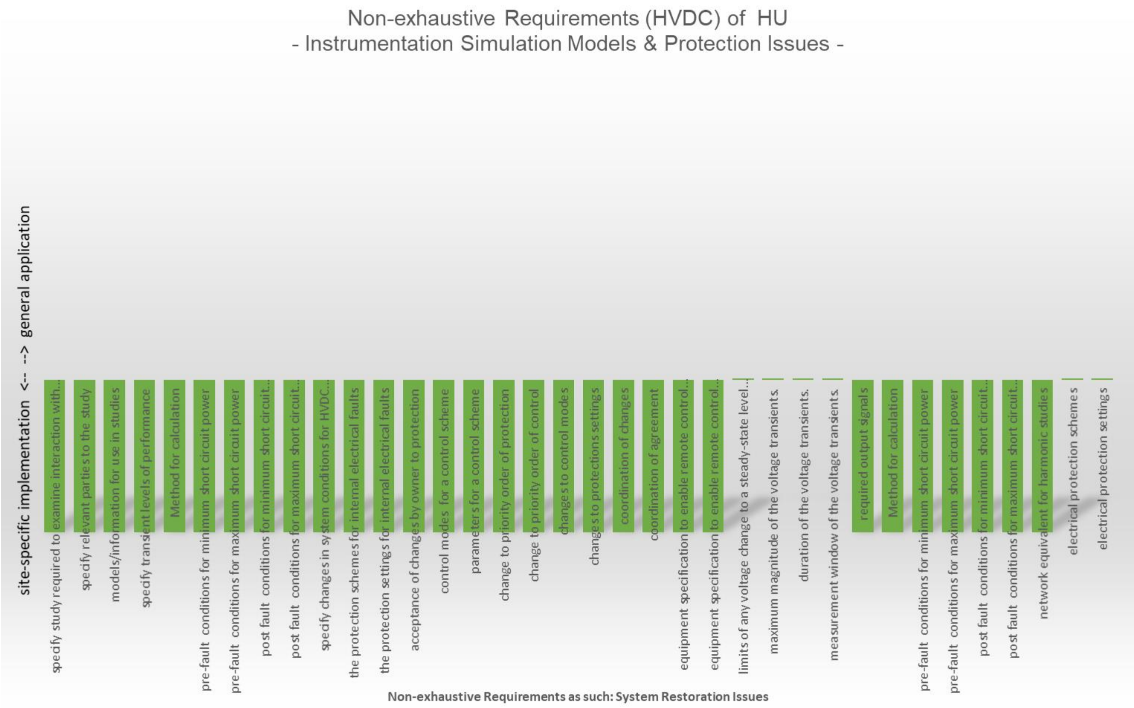


Figure 425: Hungary (HU)

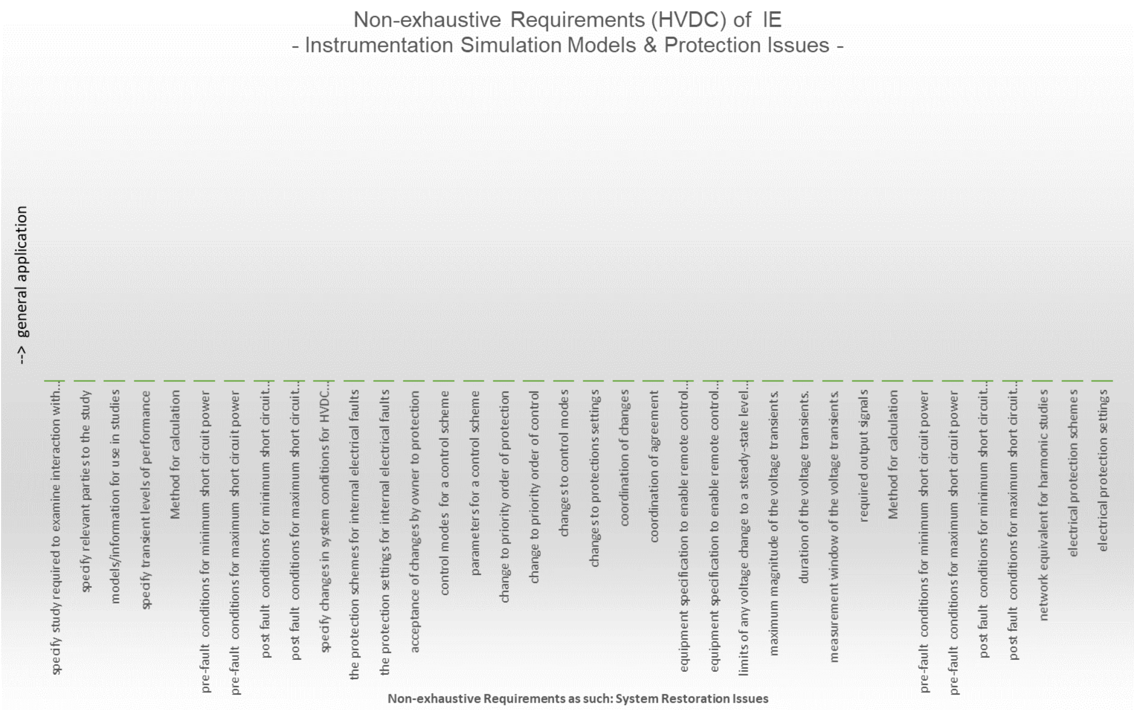


Figure 426: Ireland (IE)

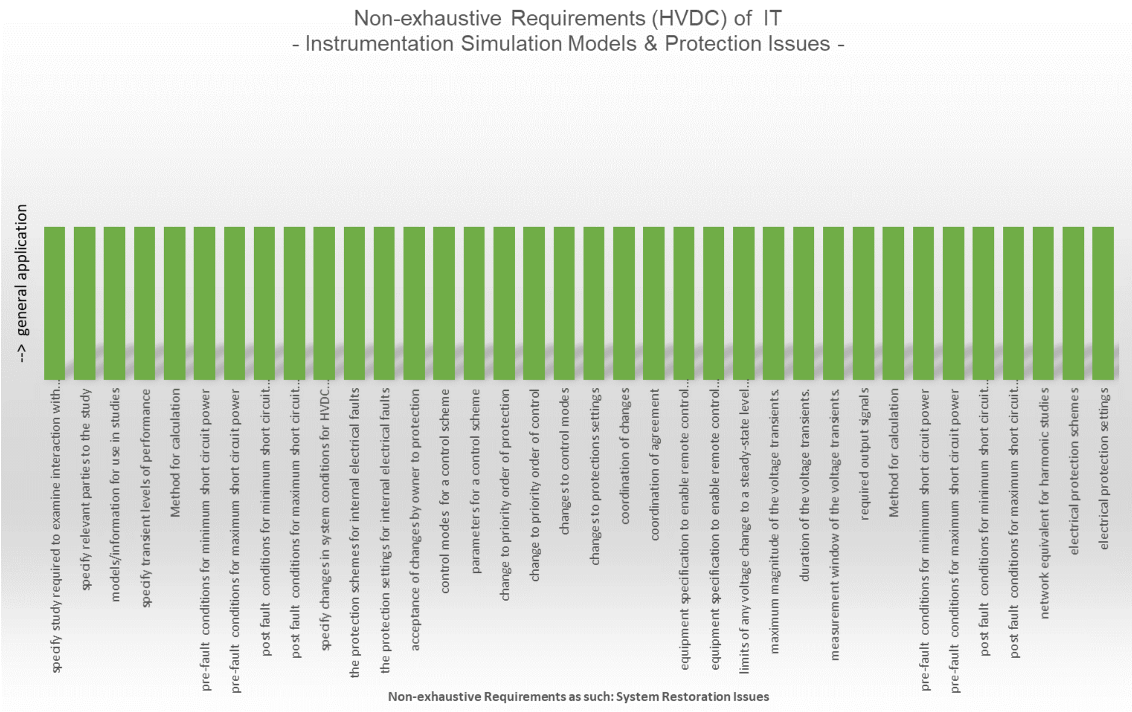


Figure 427: Italy (IT)

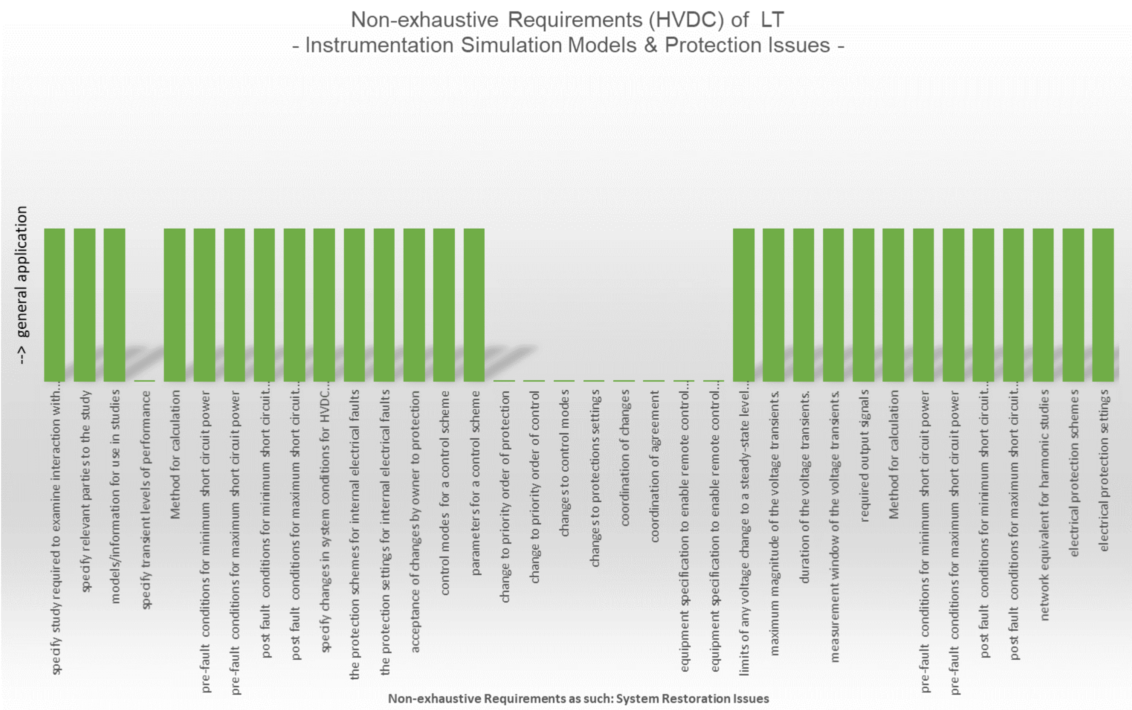


Figure 428: Lithuania (LT)

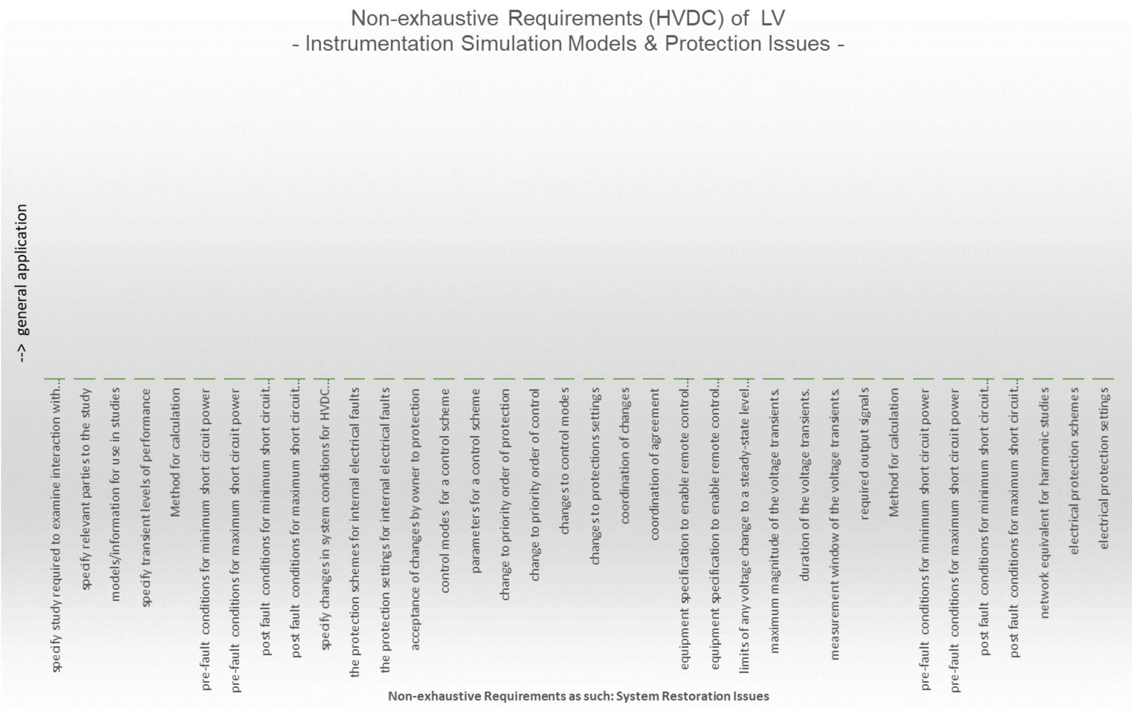


Figure 429: Latvia (LV)

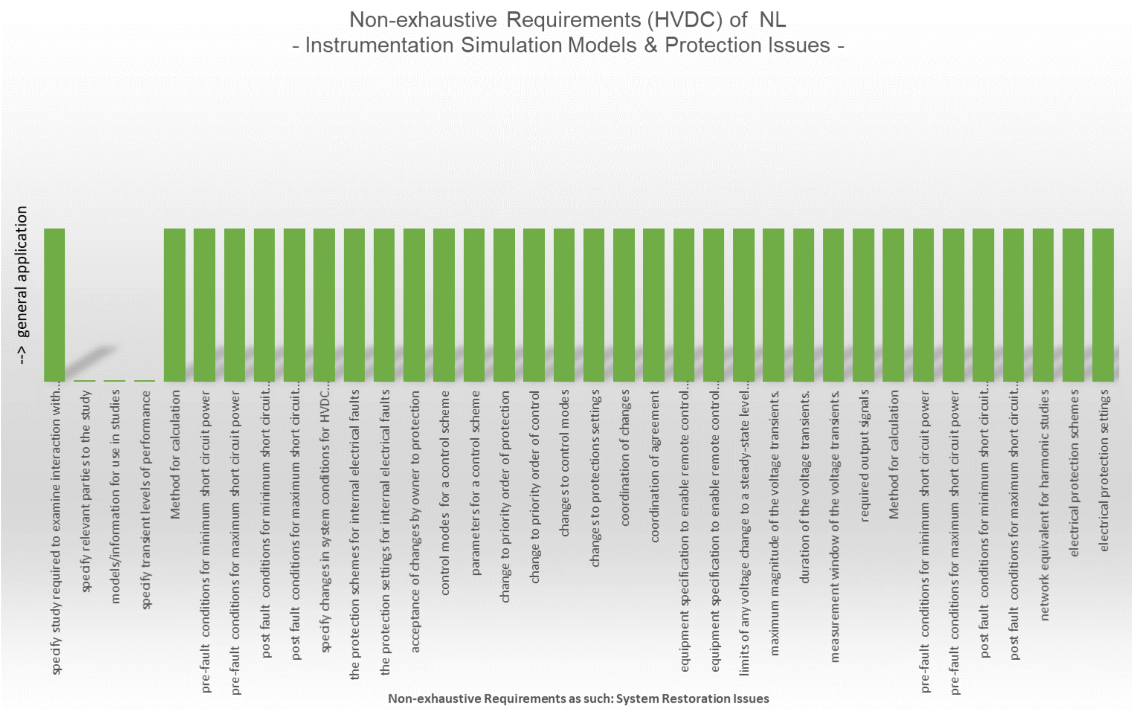


Figure 430: Netherlands (NL)

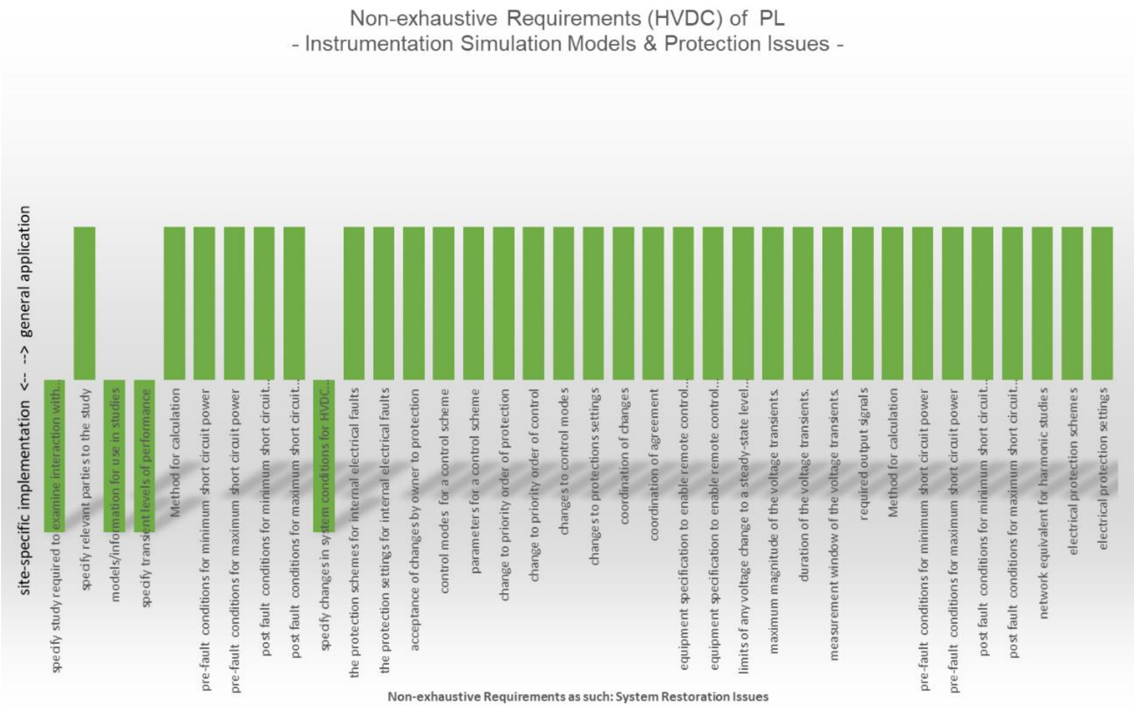


Figure 431: Poland (PL)

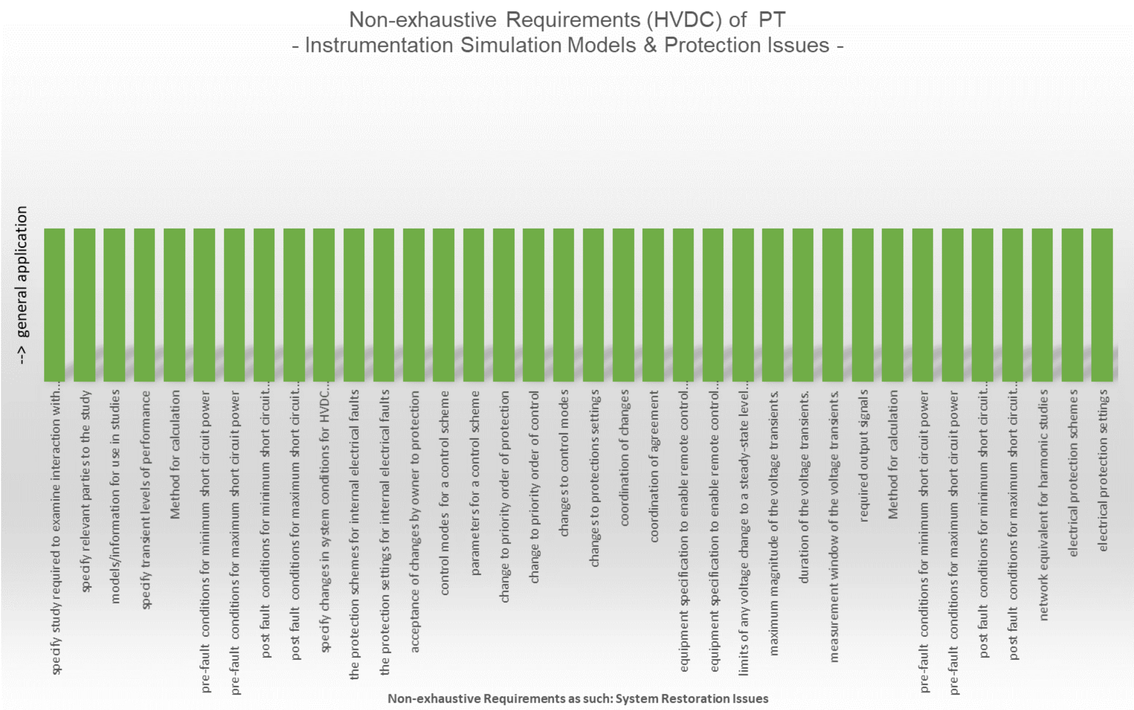


Figure 432: Portugal (PT)

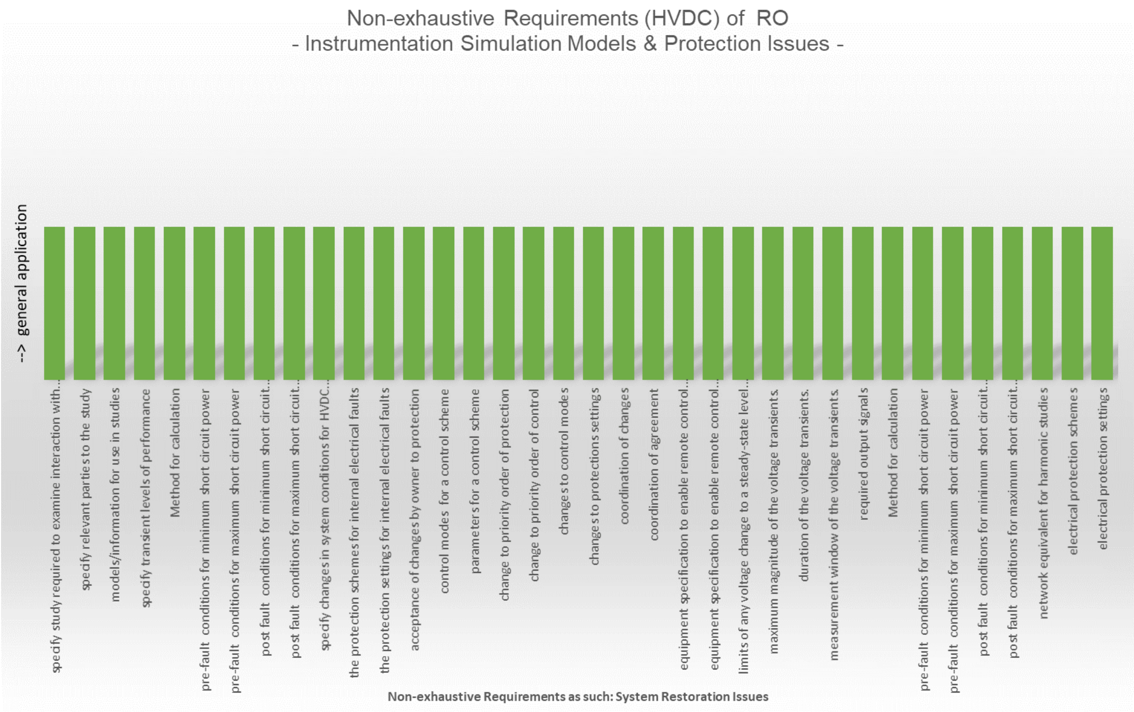


Figure 433: Romania (RO)

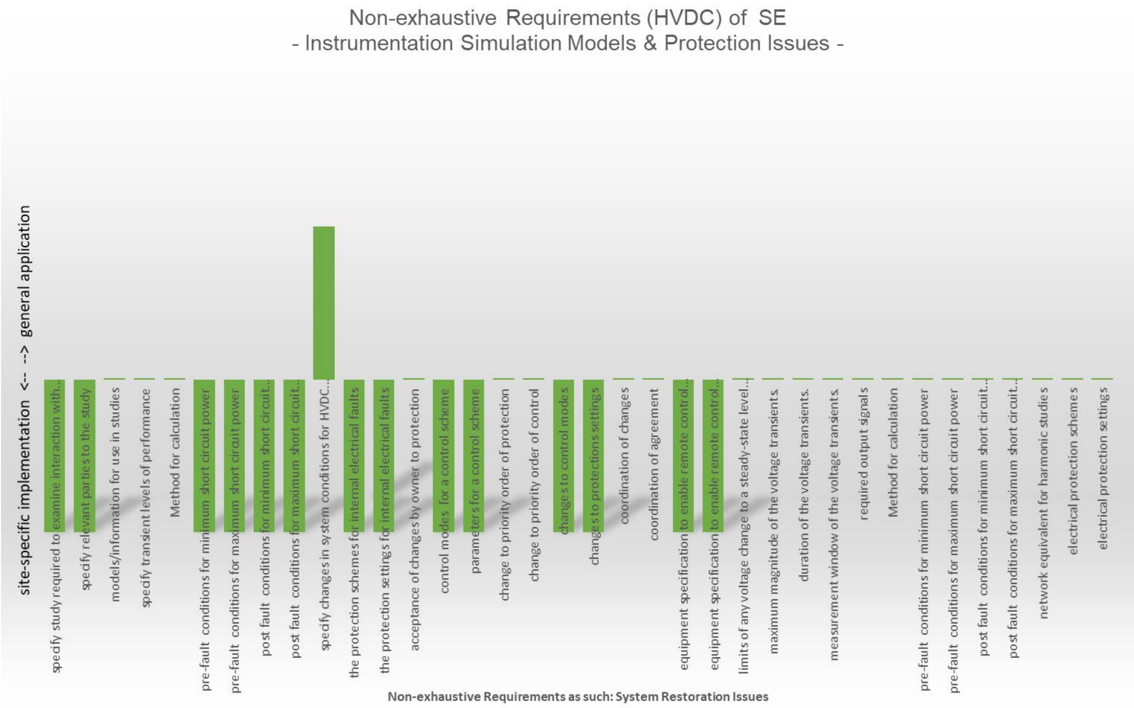


Figure 434: Sweden (SE)

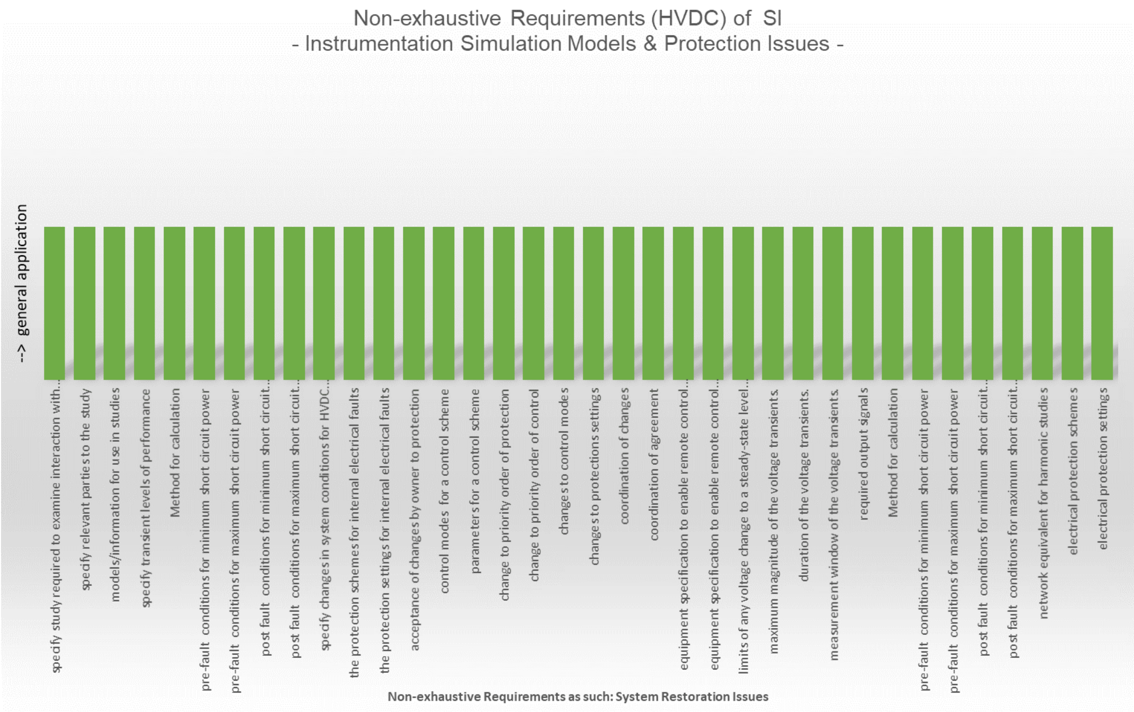


Figure 435: Slovenia (SI)

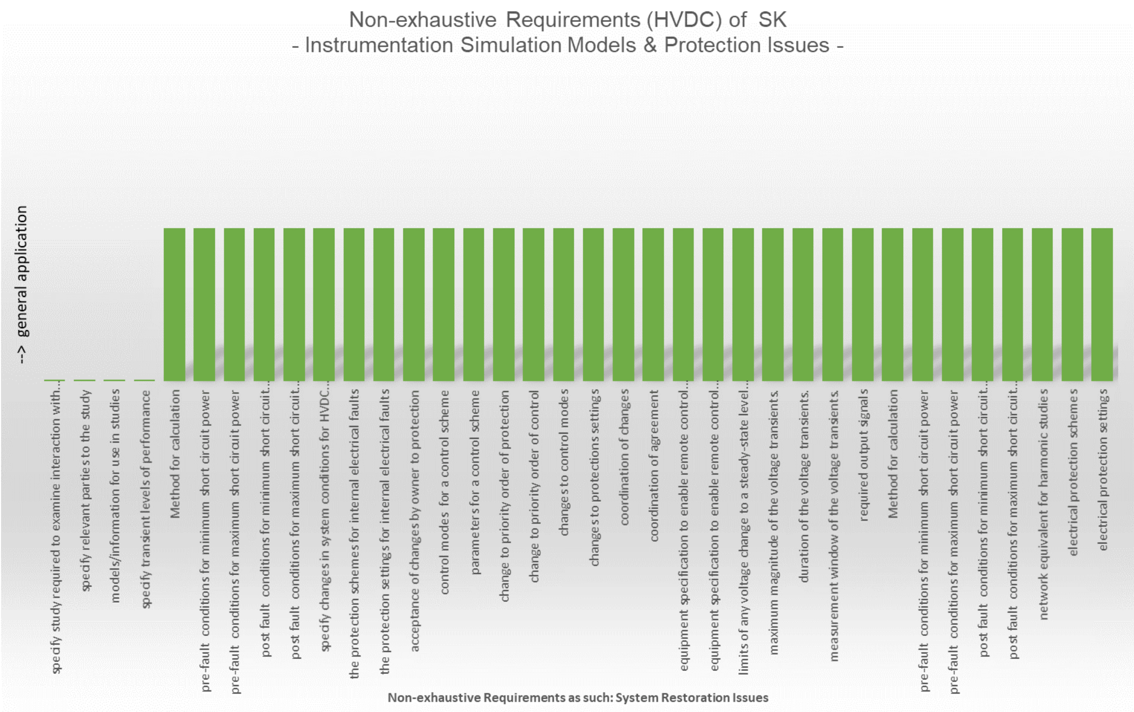


Figure 436: Slovakia (SK)

6 Annex

The following sections graphically present implemented Fault-Ride-Through capabilities in the NCNCs. For the reason of readability and easy interpretation the FRT implementation curves of two countries at a time are grouped in one diagram in alphabetic order. This means no direct comparison of the pairwise presented countries' graphs but only enhances readability. Any numerical values of FRT curves can be found in the consolidated Implementation Monitoring Excel File on the ENTSO-E website (for RfG FRT data and HVDC FRT data).

6.1 Findings on Fault-Ride-Through Capability according to NC RfG article 14(3)(a)(i)

6.1.1 FRT criteria for SPGMs of type B/C

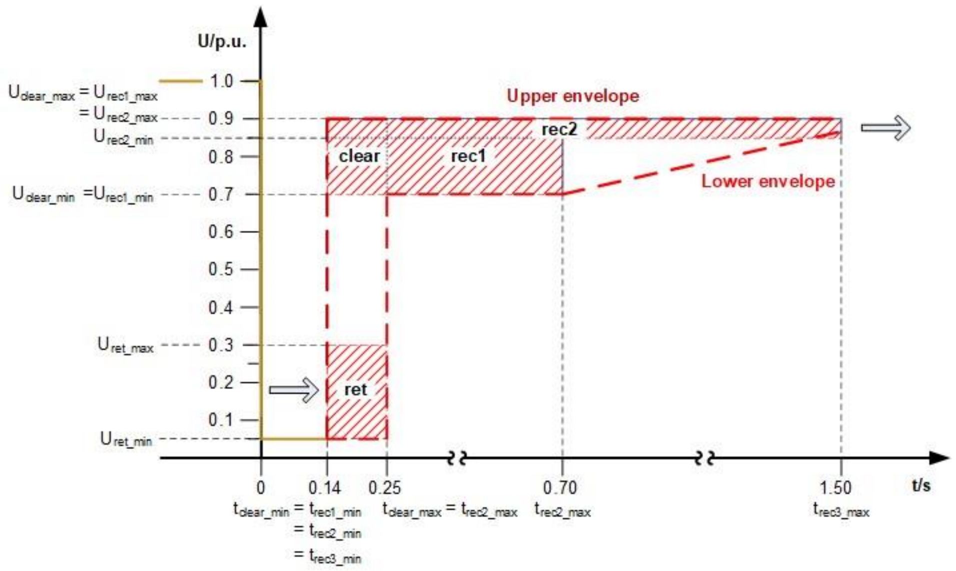
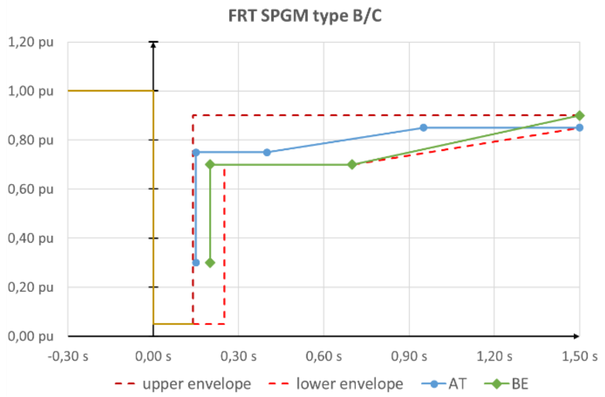
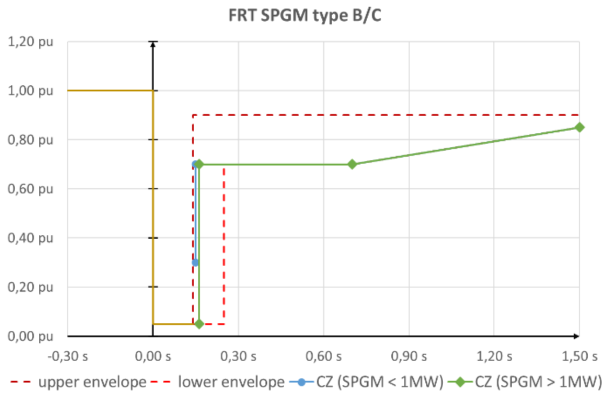


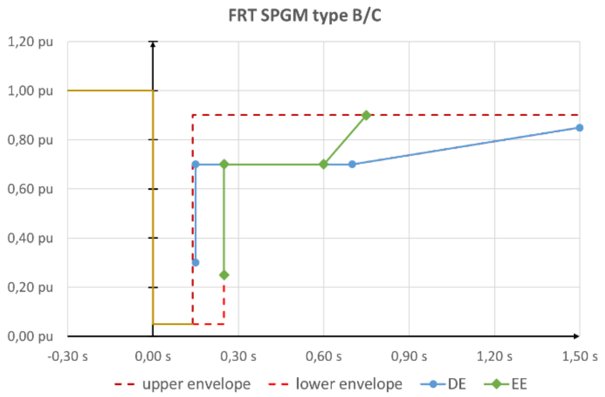
Figure 437: Fault-ride-through profile a SPGM type B/C, FRT curve should be inside defined area limited by the red upper and lower boundary conditions in the figure.

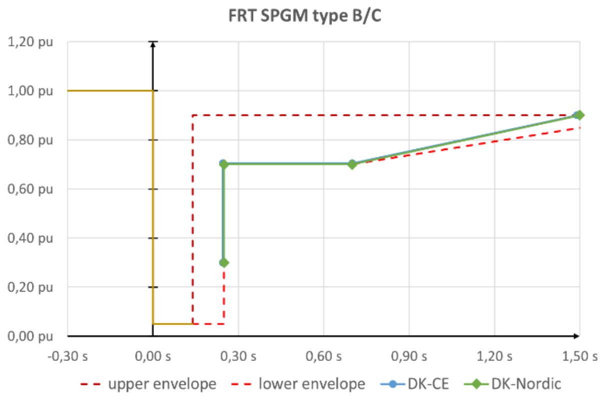
Voltage parameters (p.u.)		Time parameters (s)	
U_{ret}	0,05 – 0,30	t_{clear}	0,14 – 0,15 (0,14 – 0,25)
U_{clear}	0,70 – 0,90	t_{rec1}	t_{clear}
U_{rec1}	U_{clear}	t_{rec2}	t_{rec1} – 0,70
U_{rec2}	0,85 – 0,90 and ≥ U_{clear}	t_{rec3}	t_{rec2} – 1,50

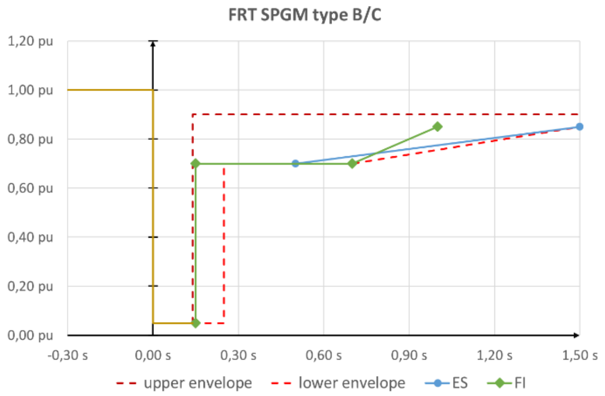
Table 2: Parameters for fault-ride-through capability of SPGMs type B/C

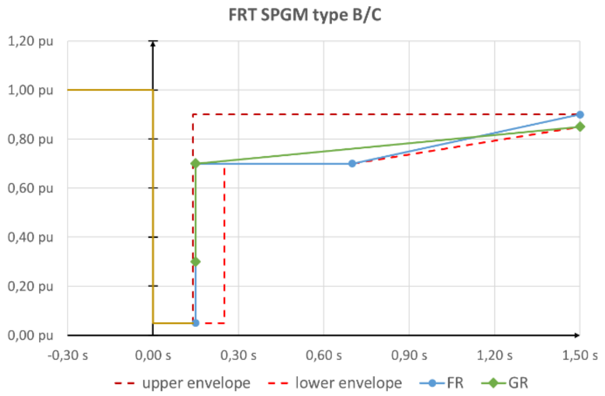

FRT SPGM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s
0,00 s
0,30 s
0,60 s
0,90 s
1,20 s
1,50 s
upper envelope
lower envelope
AT
BE

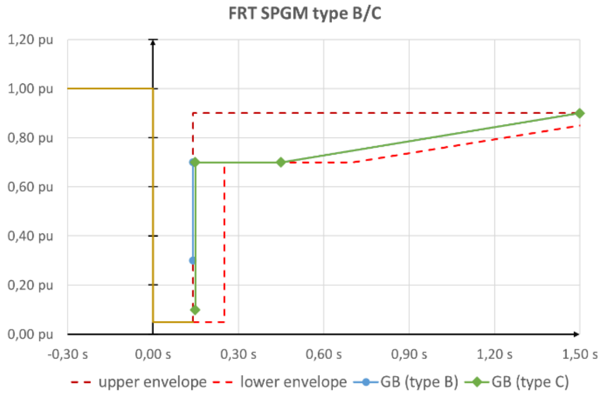

FRT SPGM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s
0,00 s
0,30 s
0,60 s
0,90 s
1,20 s
1,50 s
upper envelope
lower envelope
CZ (SPGM < 1MW)
CZ (SPGM > 1MW)

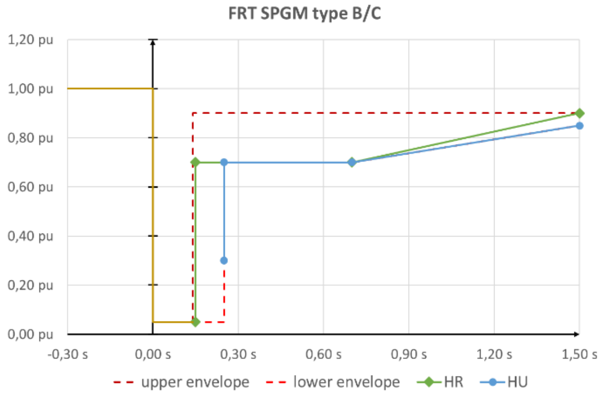

FRT SPGM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s
0,00 s
0,30 s
0,60 s
0,90 s
1,20 s
1,50 s
upper envelope
lower envelope
DE
EE

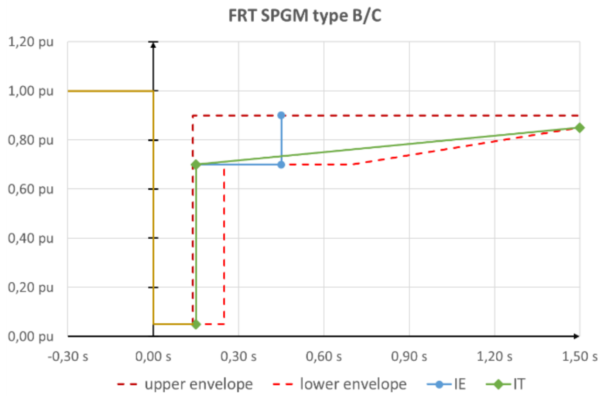

FRT SPGM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s
0,00 s
0,30 s
0,60 s
0,90 s
1,20 s
1,50 s
upper envelope
lower envelope
DK-CE
DK-Nordic

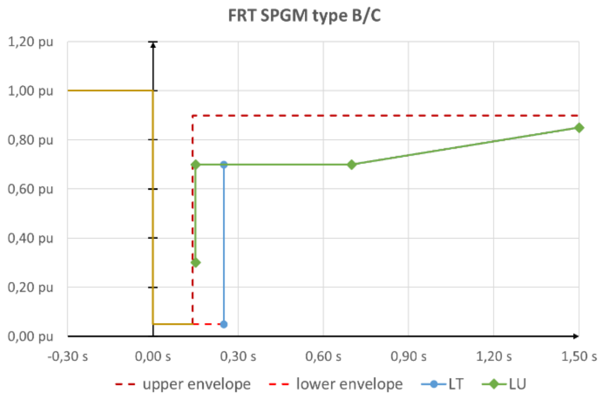

FRT SPGM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s
0,00 s
0,30 s
0,60 s
0,90 s
1,20 s
1,50 s
upper envelope
lower envelope
ES
FI

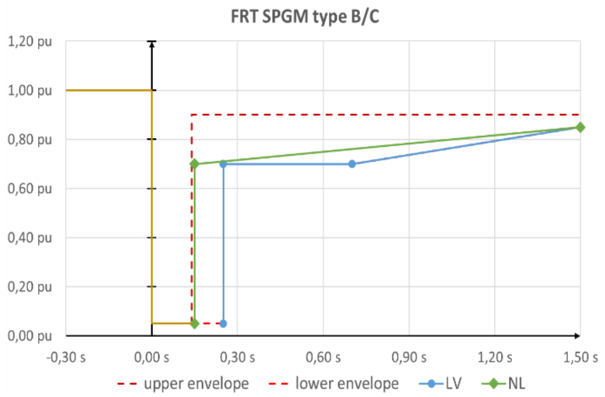

FRT SPGM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s
0,00 s
0,30 s
0,60 s
0,90 s
1,20 s
1,50 s
upper envelope
lower envelope
FR
GR

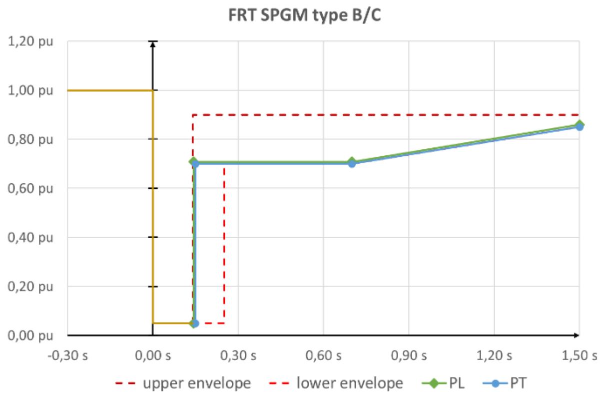

FRT SPGM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s
0,00 s
0,30 s
0,60 s
0,90 s
1,20 s
1,50 s
upper envelope
lower envelope
GB (type B)
GB (type C)

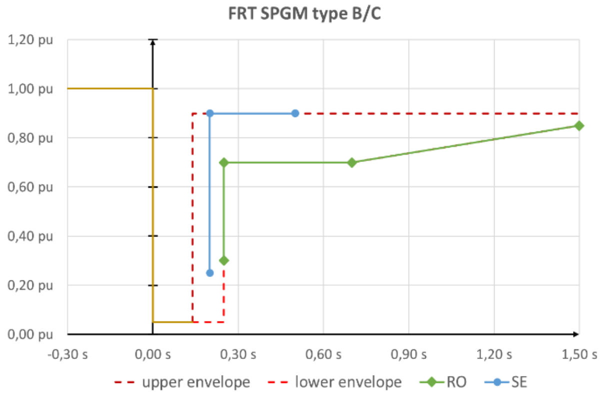

FRT SPGM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s
0,00 s
0,30 s
0,60 s
0,90 s
1,20 s
1,50 s
upper envelope
lower envelope
HR
HU

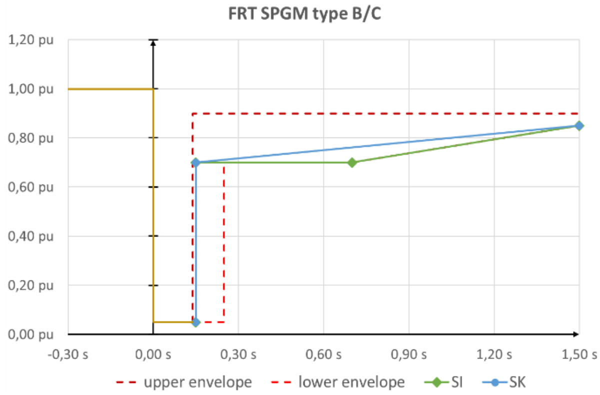

FRT SPGM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s
0,00 s
0,30 s
0,60 s
0,90 s
1,20 s
1,50 s
upper envelope
lower envelope
IE
IT


FRT SPGM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s
0,00 s
0,30 s
0,60 s
0,90 s
1,20 s
1,50 s
upper envelope
lower envelope
LT
LU


FRT SPGM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s
0,00 s
0,30 s
0,60 s
0,90 s
1,20 s
1,50 s
upper envelope
lower envelope
LV
NL


FRT SPGM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s
0,00 s
0,30 s
0,60 s
0,90 s
1,20 s
1,50 s
upper envelope
lower envelope
PL
PT





6.1.2 FRT criteria for PPMs of type B/C

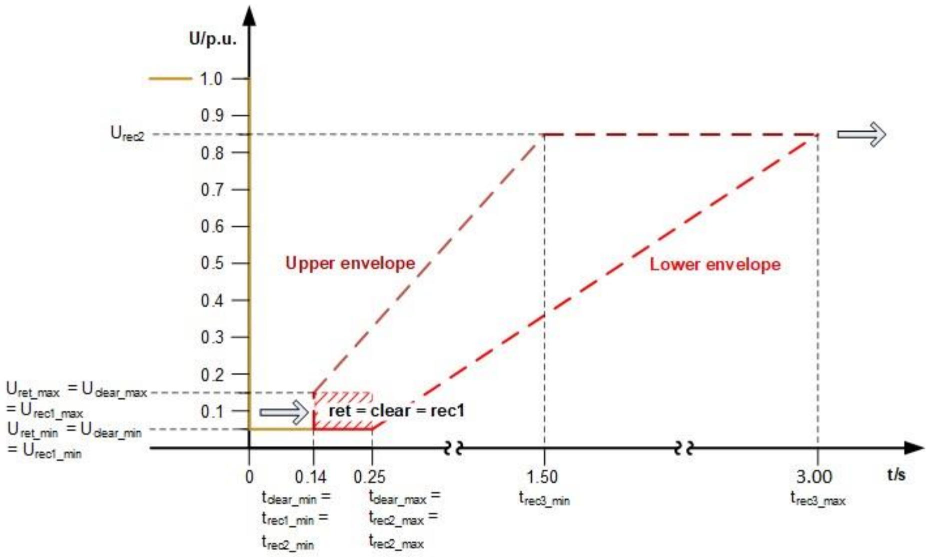
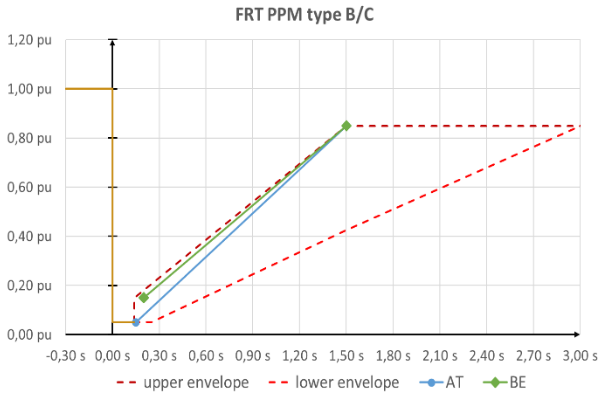
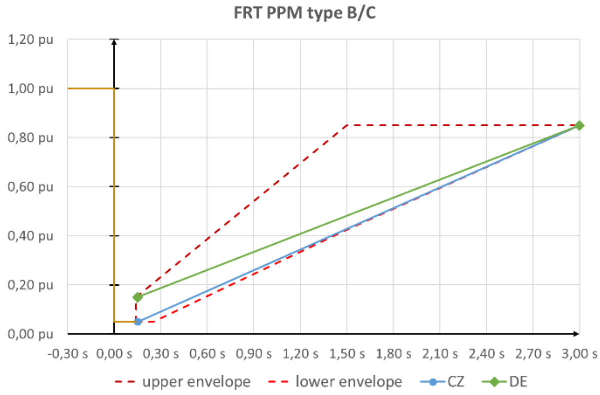


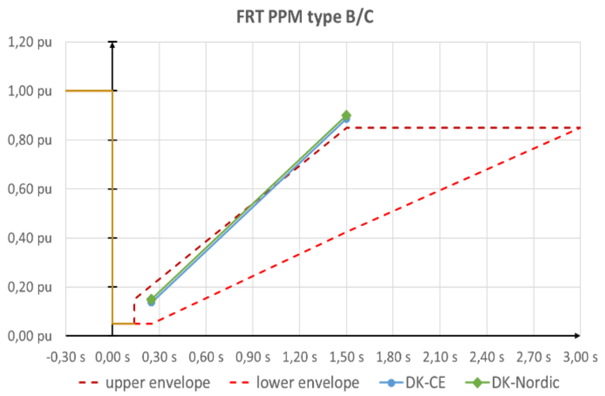
Figure 438: Fault-ride-through profile a PPM type B/C, FRT curve should be inside defined area limited by the red upper and lower boundary conditions in the figure.

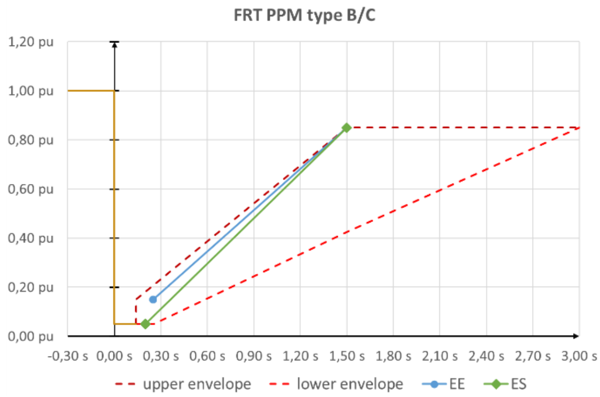
Voltage parameters (p.u.)		Time parameters (s)	
U_{ret}	0,05 – 0,15	t_{clear}	0,14 – 0,15 (0,14 – 0,25)
U_{clear}	U_{ret} – 0,15	t_{rec1}	t_{clear}
U_{rec1}	U_{clear}	t_{rec2}	t_{rec1}
U_{rec2}	0,85	t_{rec3}	1,50 – 3,00

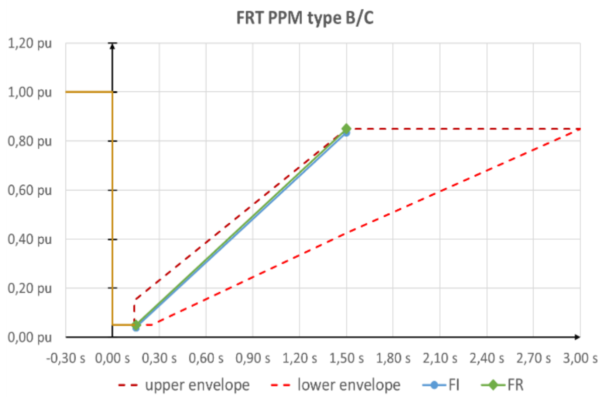
Table 3: Parameters for fault-ride-through capability of PPMs type B/C

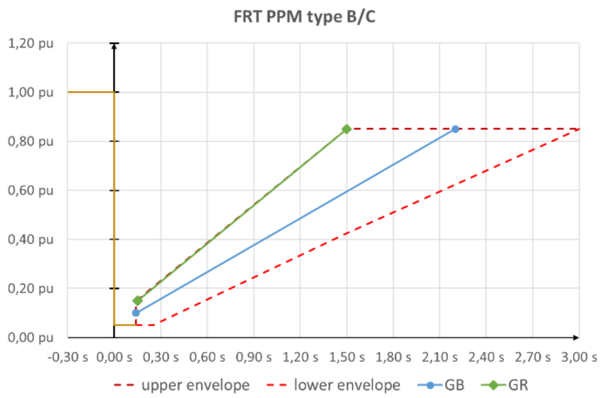

FRT PPM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
AT
BE

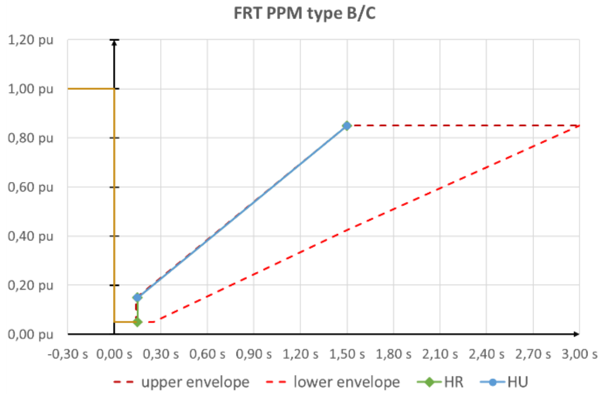

FRT PPM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
CZ
DE

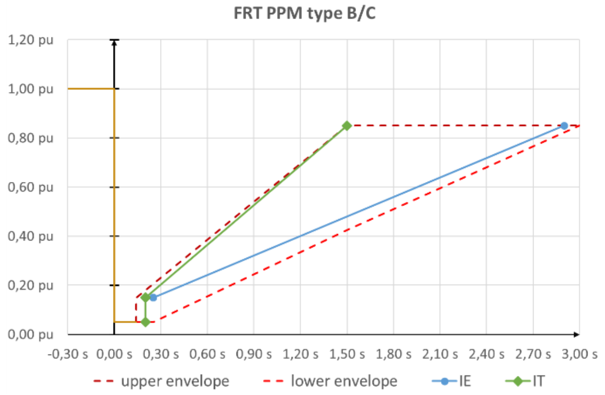

FRT PPM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
DK-CE
DK-Nordic

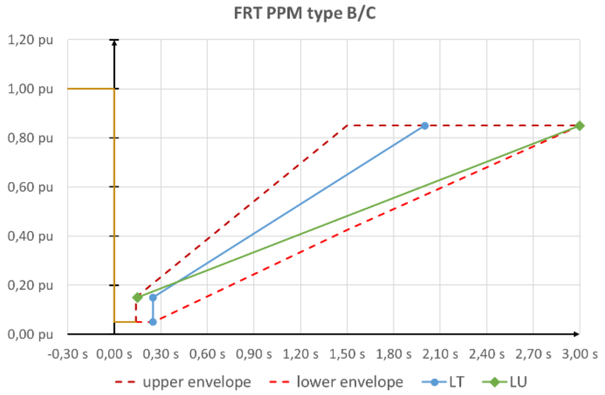

FRT PPM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
EE
ES

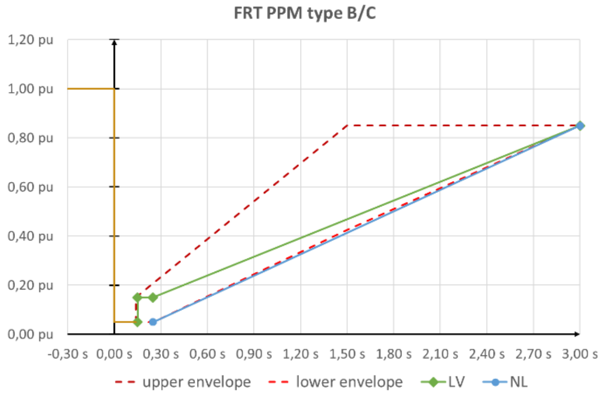

FRT PPM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
FI
FR

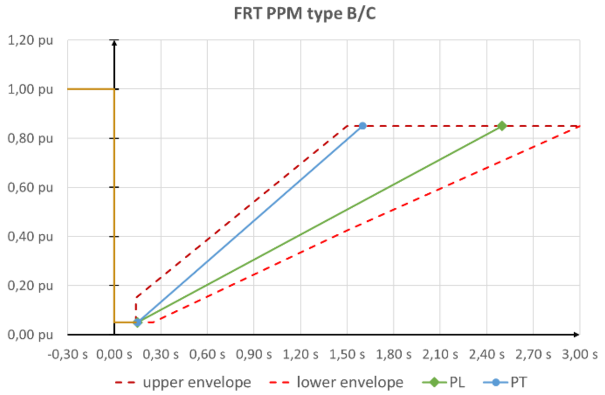

FRT PPM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
GB
GR

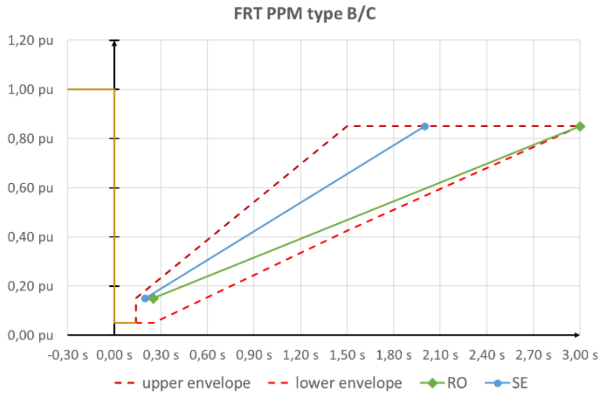

FRT PPM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
HR
HU

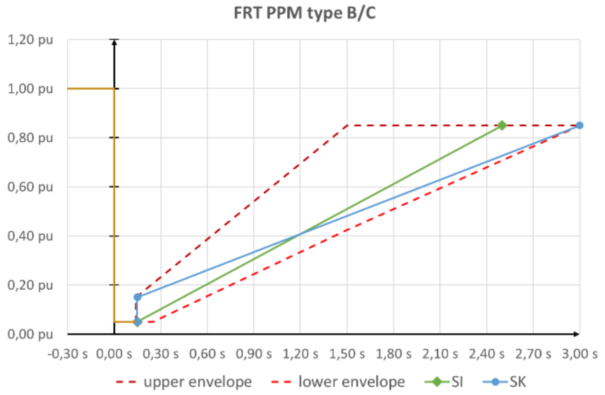

FRT PPM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
IE
IT


FRT PPM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
LT
LU


FRT PPM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
LV
NL


FRT PPM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
PL
PT


FRT PPM type B/C
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
RO
SE



6.2 Findings on Fault-Ride-Through Capability according to NC RfG article 16(3)(a)(i)

6.2.1 FRT criteria for SPGMs of type D

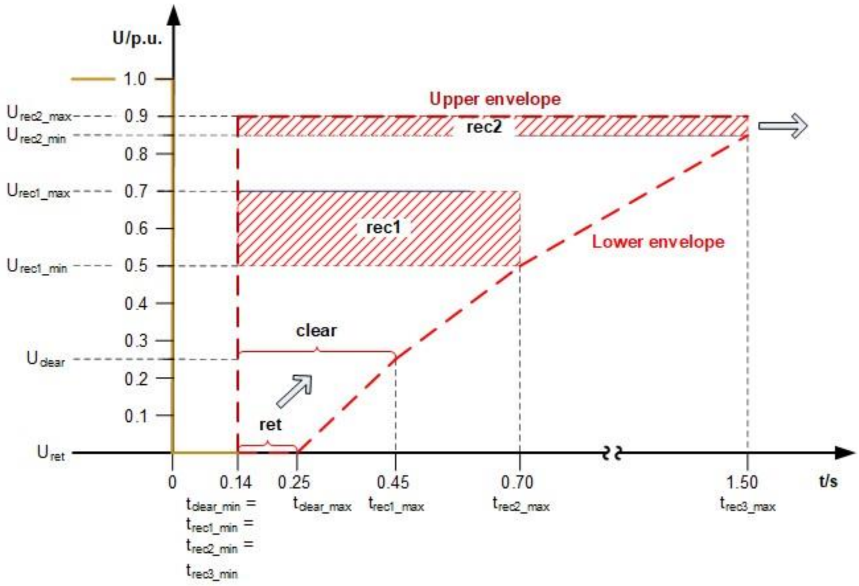
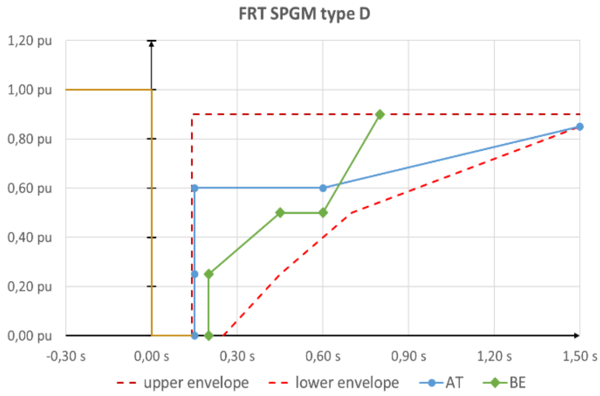
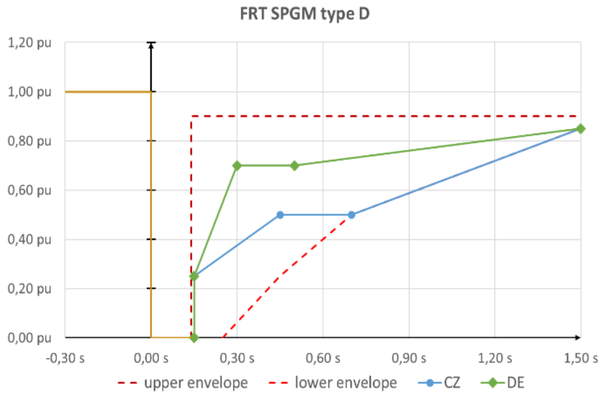


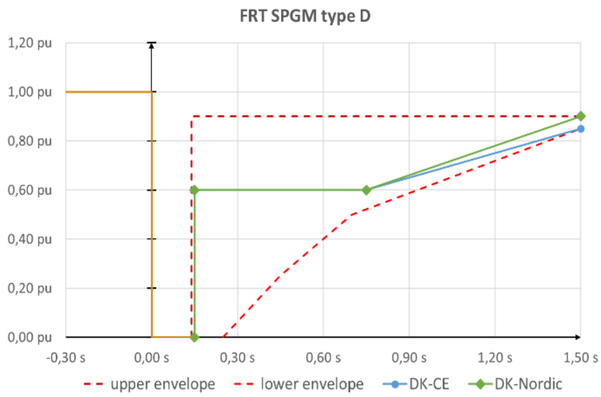
Figure 439: Fault-ride-through profile a SPGM type D, FRT curve should be inside defined area limited by the red upper and lower boundary conditions in the figure.

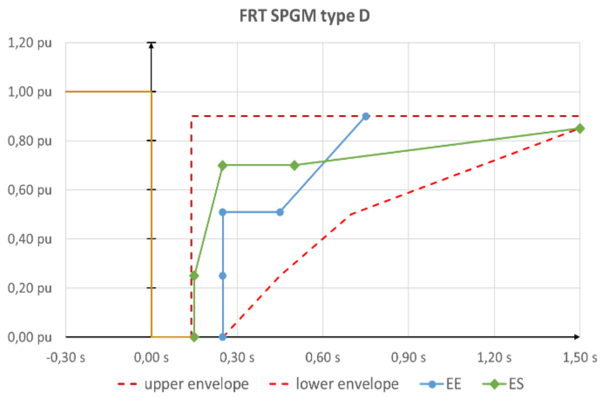
Voltage parameters (p.u.)		Time parameters (s)	
U_{ret}	0,00	t_{clear}	0,14 – 0,15 (0,14 – 0,25)
U_{clear}	0,25	t_{rec1}	t_{clear} – 0,45
U_{rec1}	0,50 – 0,70	t_{rec2}	t_{rec1} – 0,70
U_{rec2}	0,85 – 0,90	t_{rec3}	t_{rec2} – 1,50

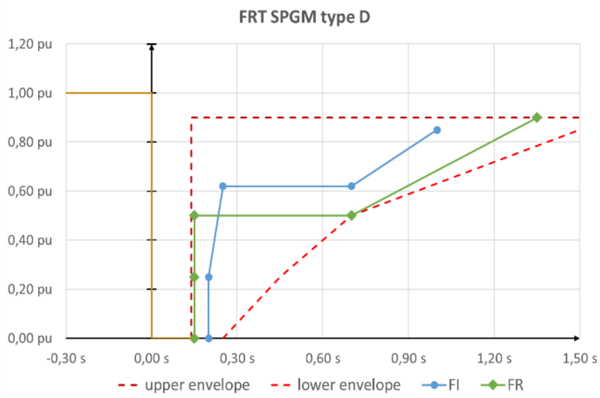
Table 4: Parameters for fault-ride-through capability of SPGMs type D

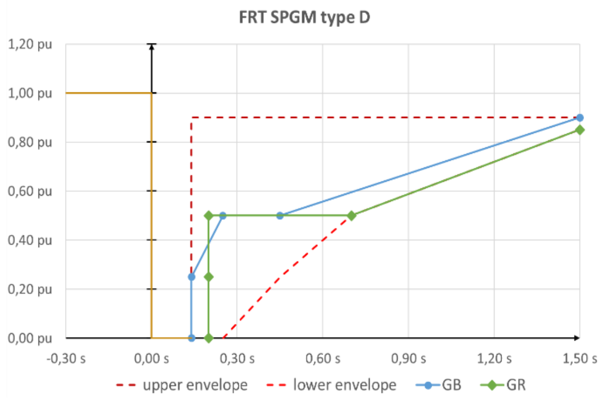

FRT SPGM type D
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s
0,00 s
0,30 s
0,60 s
0,90 s
1,20 s
1,50 s
upper envelope
lower envelope
AT
BE

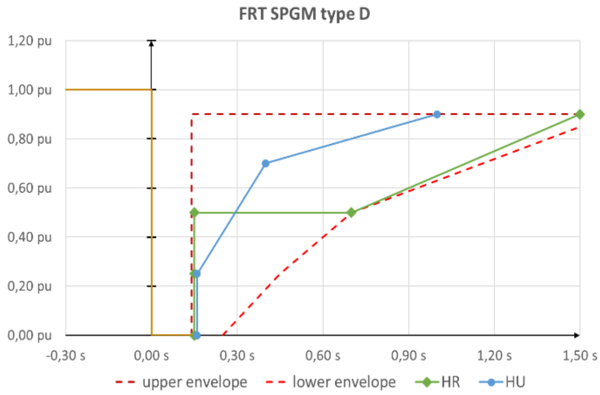

FRT SPGM type D
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s
0,00 s
0,30 s
0,60 s
0,90 s
1,20 s
1,50 s
upper envelope
lower envelope
CZ
DE

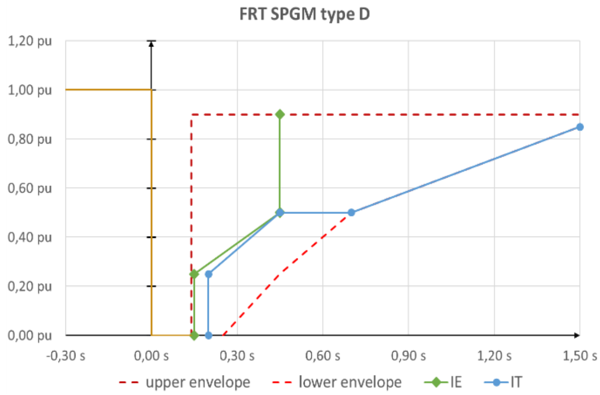

FRT SPGM type D
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s
0,00 s
0,30 s
0,60 s
0,90 s
1,20 s
1,50 s
upper envelope
lower envelope
DK-CE
DK-Nordic

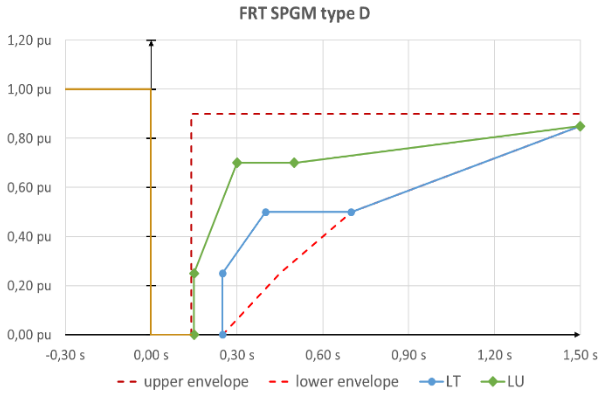

FRT SPGM type D
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s
0,00 s
0,30 s
0,60 s
0,90 s
1,20 s
1,50 s
upper envelope
lower envelope
EE
ES

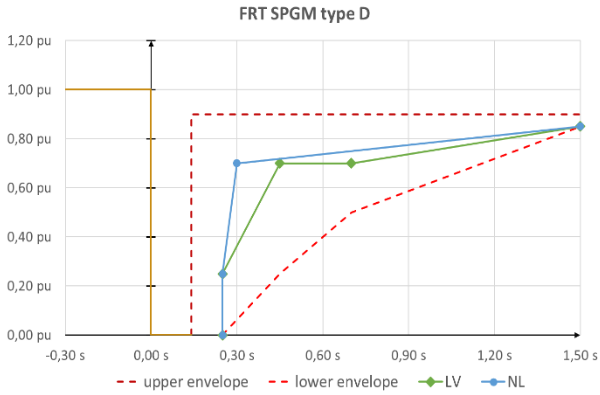

FRT SPGM type D
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s
0,00 s
0,30 s
0,60 s
0,90 s
1,20 s
1,50 s
upper envelope
lower envelope
FI
FR

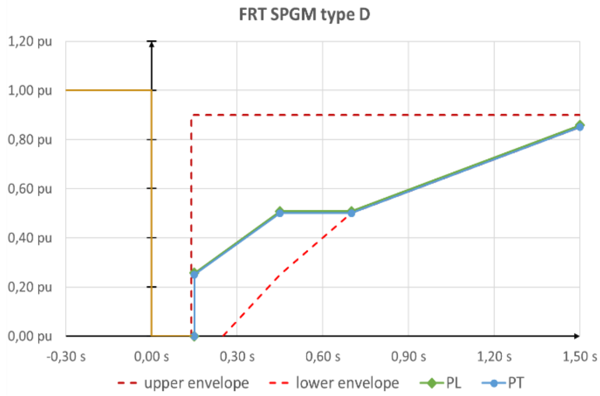

FRT SPGM type D
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s
0,00 s
0,30 s
0,60 s
0,90 s
1,20 s
1,50 s
upper envelope
lower envelope
GB
GR

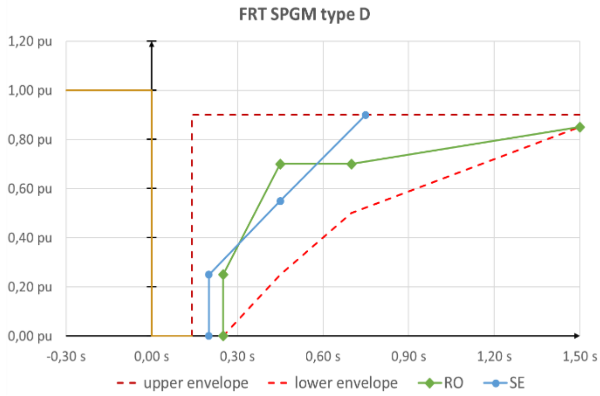

FRT SPGM type D
upper envelope
lower envelope
HR
HU

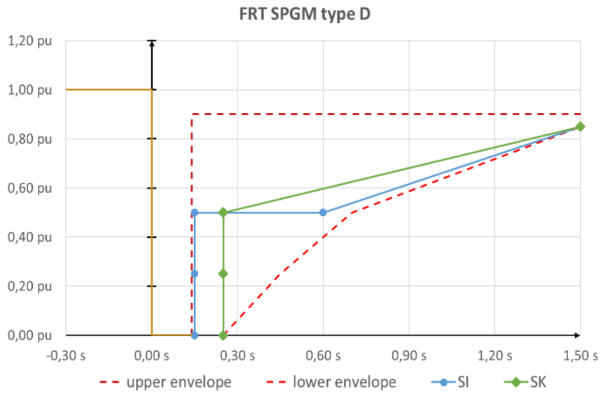

FRT SPGM type D
upper envelope
lower envelope
IE
IT


FRT SPGM type D
upper envelope
lower envelope
LT
LU


FRT SPGM type D
upper envelope
lower envelope
LV
NL


FRT SPGM type D
upper envelope
lower envelope
PL
PT


FRT SPGM type D
upper envelope
lower envelope
RO
SE



6.2.2 FRT criteria for PPMs of type D

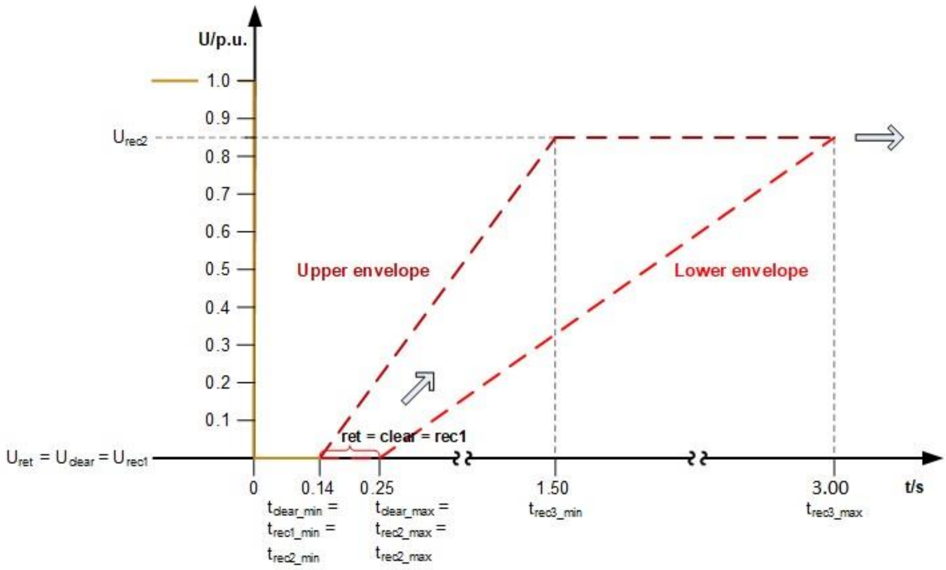
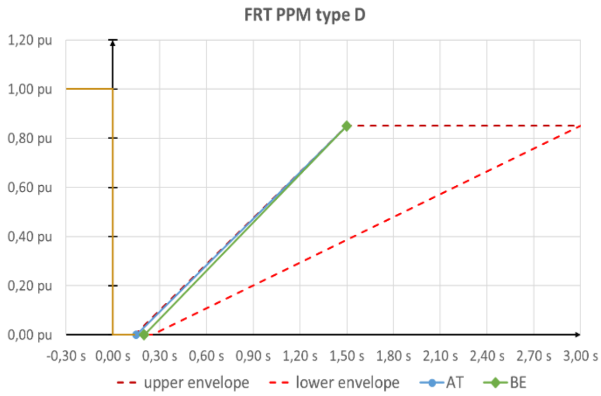
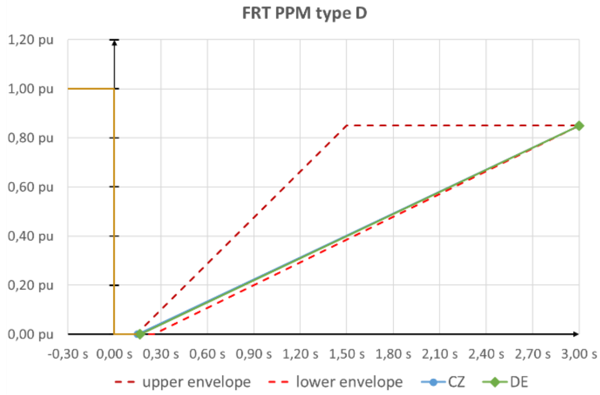


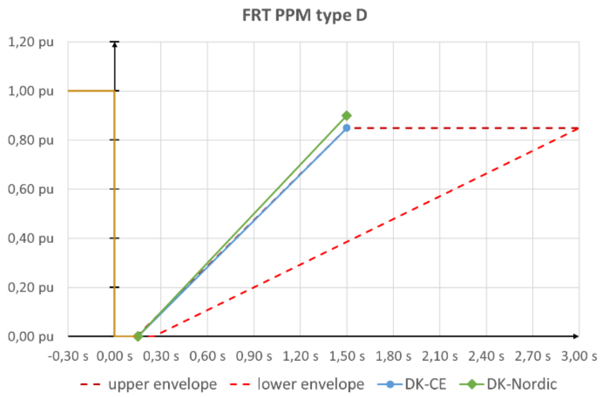
Figure 440: Fault-ride-through profile a PPM type D, FRT curve should be inside defined area limited by the red upper and lower boundary conditions in the figure.

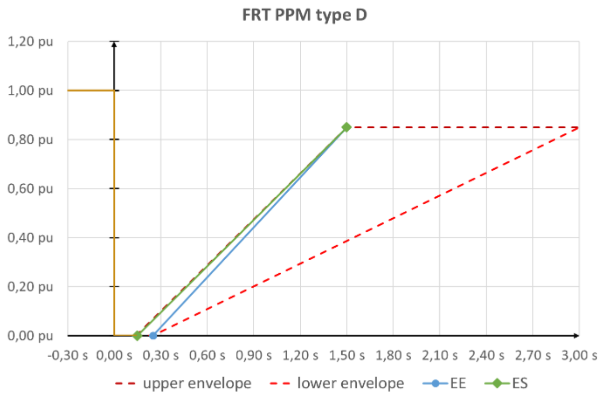
Voltage Parameters (pu)		Time parameters (s)	
U_{ret}	0,00	t_{clear}	0,14 – 0,15 (0,14 – 0,25)
U_{clear}	U_{ret}	t_{rec1}	t_{clear}
U_{rec1}	U_{clear}	t_{rec2}	t_{rec1}
U_{rec2}	0,85	t_{rec3}	1,50 – 3,00

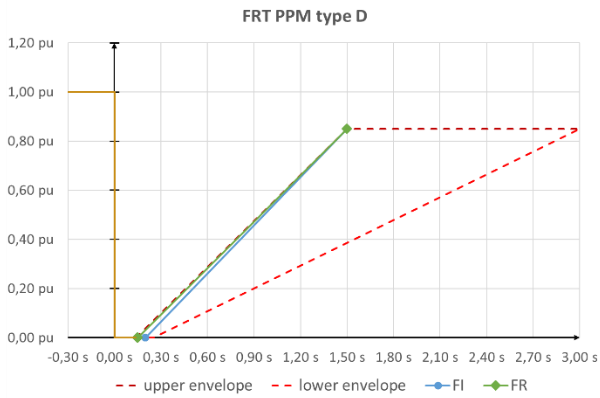
Table 5: Parameters for fault-ride-through capability of PPMs type D

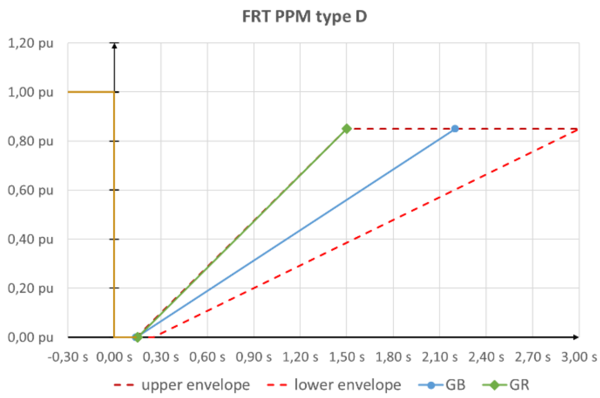

FRT PPM type D
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
AT
BE

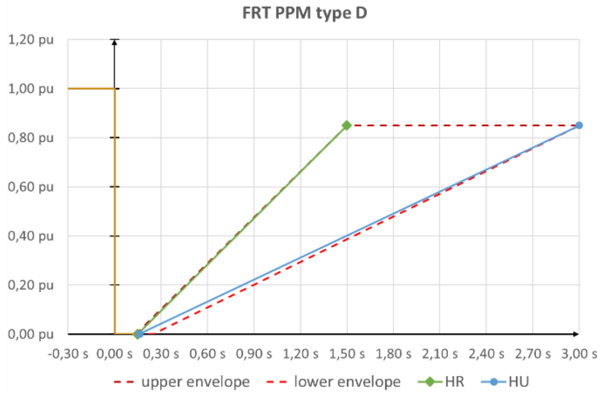

FRT PPM type D
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
CZ
DE

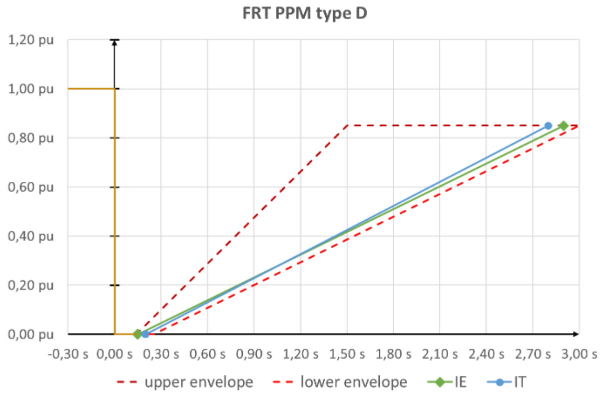

FRT PPM type D
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
DK-CE
DK-Nordic

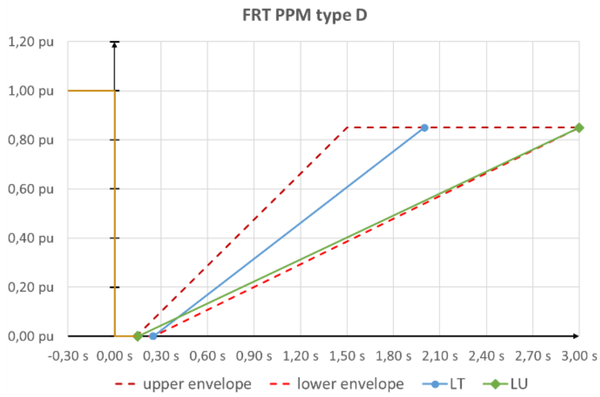

FRT PPM type D
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
EE
ES

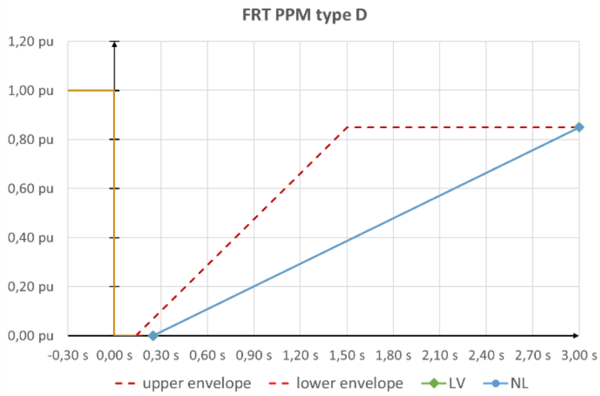

FRT PPM type D
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
FI
FR

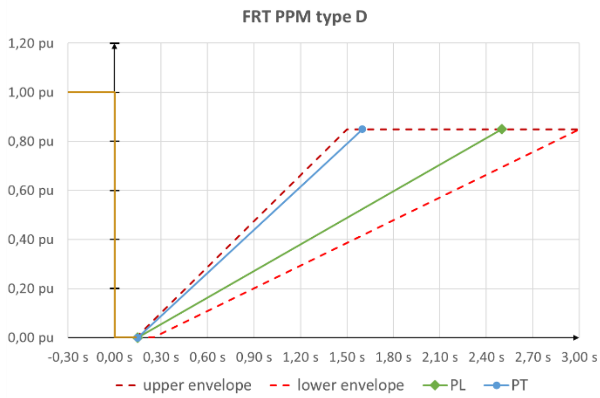

FRT PPM type D
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
GB
GR

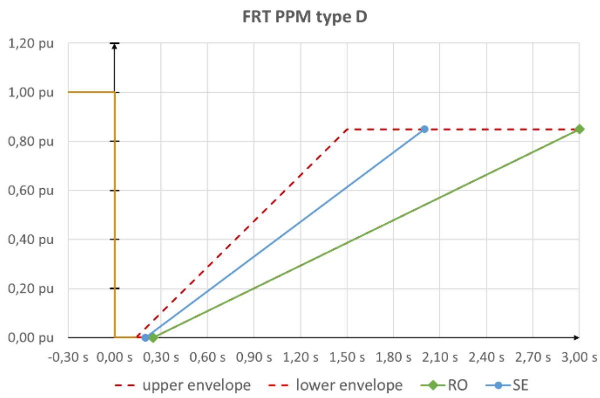

FRT PPM type D
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
HR
HU

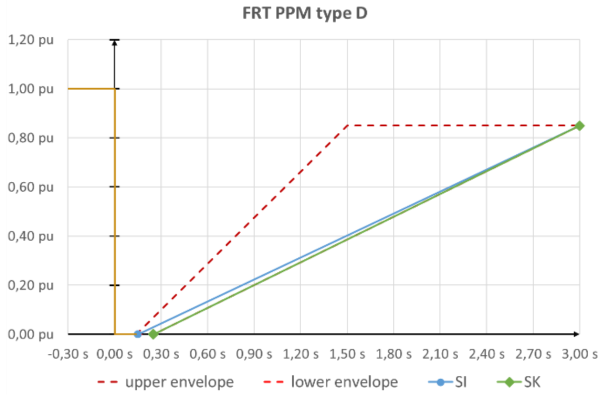

FRT PPM type D
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
IE
IT


FRT PPM type D
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
LT
LU


FRT PPM type D
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
LV
NL


FRT PPM type D
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
PL
PT


FRT PPM type D
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-0,30 s 0,00 s 0,30 s 0,60 s 0,90 s 1,20 s 1,50 s 1,80 s 2,10 s 2,40 s 2,70 s 3,00 s
upper envelope
lower envelope
RO
SE



6.3 Conclusions on implementation status of RfG FRT capabilities of type B/C/D

Country	Data provision	Implementation pursuant to article 14.3.a.(i) – SPGMs	Implementation pursuant to article 14.3.a.(i) – PPMs	Implementation pursuant to article 16.3.a.(i) – SPGMs	Implementation pursuant to article 16.3.a.(i) – PPMs	Remarks
AT	Yes	Yes	Yes	Yes	Yes	-
BE	Yes	Yes	Yes	Yes	Yes	-
BG	No	No	No	No	No	Lack of numerical data
CZ	Yes	Yes	Yes	Yes	Yes	-
DE	Yes	Yes	Yes	Yes	Yes	-
DK-CE	Yes	Yes	No	No	Yes	Out of NC RfG ranges
DK-Nordic	Yes	Yes	No	No	No	Out of NC RfG ranges
EE	Yes	Yes	Yes	Yes	Yes	-
ES	Yes	Yes	Yes	Yes	Yes	-
FI	Yes	Yes	Yes	Yes	Yes	-
FR	Yes	Yes	Yes	Yes	Yes	-
GB	Yes	Yes	Yes	Yes	Yes	-
GR	Yes	Yes	Yes	Yes	Yes	-
HR	Yes	Yes	Yes	Yes	Yes	-
HU	Yes	Yes	Yes	Yes	Yes	-
IE	Yes	Yes	Yes	Yes	Yes	-
IT	Yes	Yes	Yes	Yes	Yes	-
LT	Yes	Yes	Yes	Yes	Yes	-
LU	Yes	Yes	Yes	Yes	Yes	-
LV	Yes	Yes	Yes	Yes	Yes	-
NL	Yes	Yes	Yes	Yes	Yes	-
PL	Yes	Yes	Yes	Yes	Yes	-
PT	Yes	Yes	Yes	Yes	Yes	-
RO	Yes	Yes	Yes	Yes	Yes	-
SE	Yes	Yes	Yes	Yes	Yes	-
SI	Yes	Yes	Yes	Yes	Yes	-
SK	Yes	Yes	Yes	Yes	Yes	-

Table 6: Implementation status of FRT capabilities pursuant to RfG article 14.3.a.(i) / 16.3.a.(i)

6.4 Findings on Fault-Ride-Through Capability according to NC HVDC article 25(1)(a)(i)

6.4.1 FRT criteria for HVDC converter stations

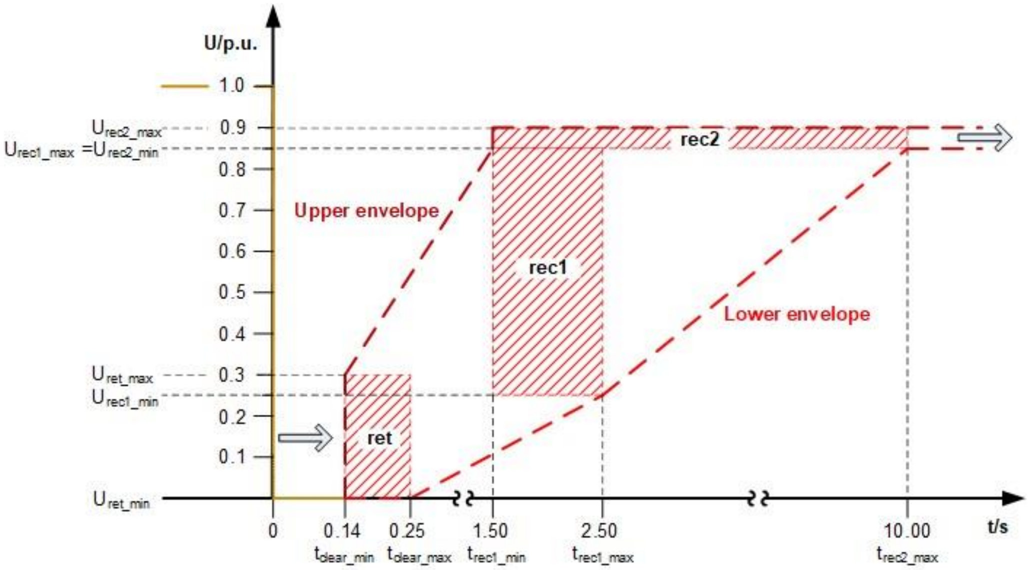
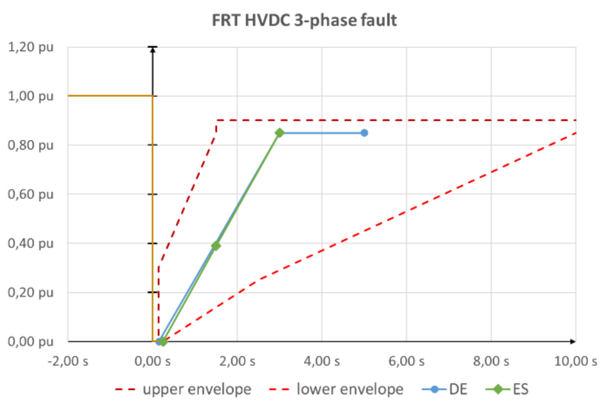
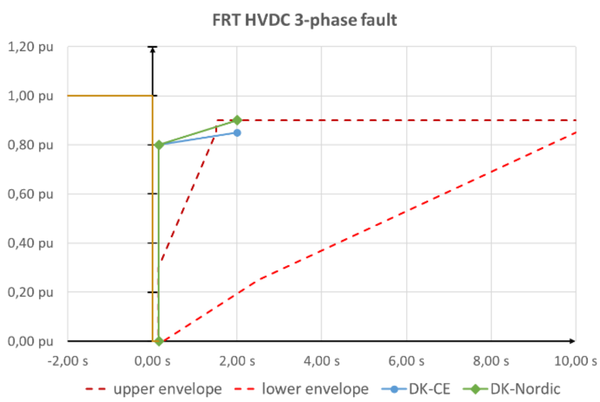


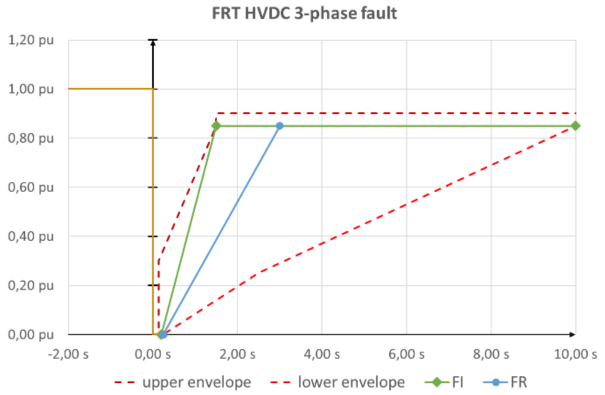
Figure 441: Fault-ride-through profile a HVDC converter station, FRT curve should be inside defined area limited by the red upper and lower boundary conditions in the figure.

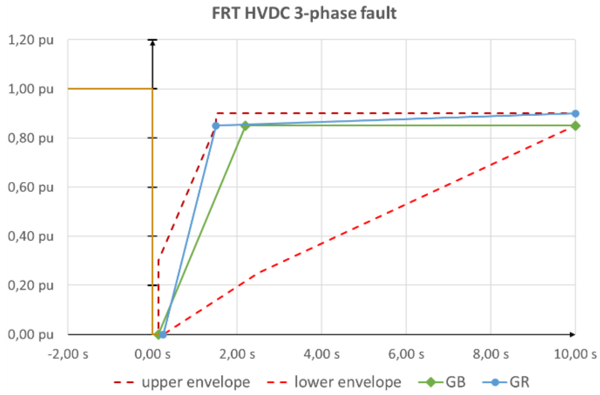
Voltage parameters (p.u.)		Time parameters (s)	
U_{ret}	0,00 – 0,30	t_{clear}	0,14 – 0,15
U_{rec1}	0,25 – 0,85	t_{rec1}	1,50 – 2,50
U_{rec2}	0,85 – 0,90	t_{rec2}	t_{rec1} – 10,00

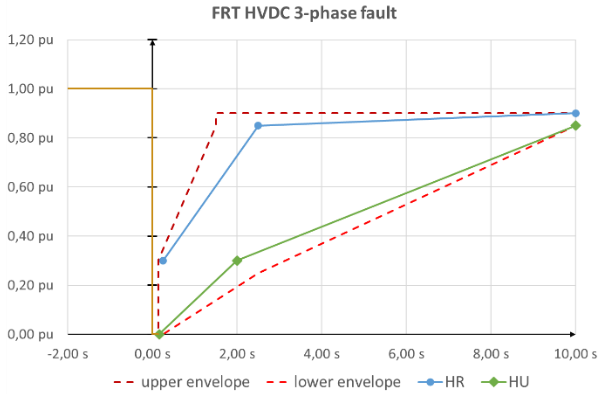
Table 7: Parameters for fault-ride-through capability of HVDC converter stations

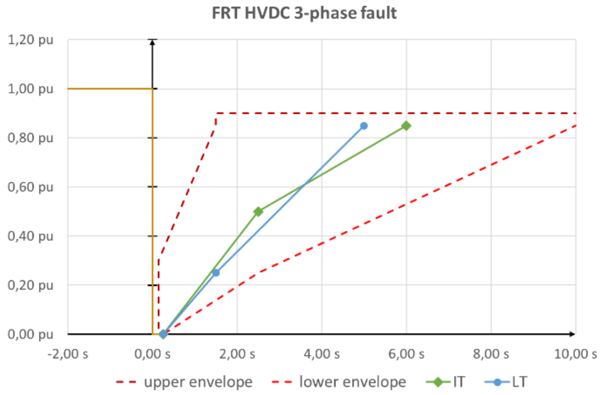


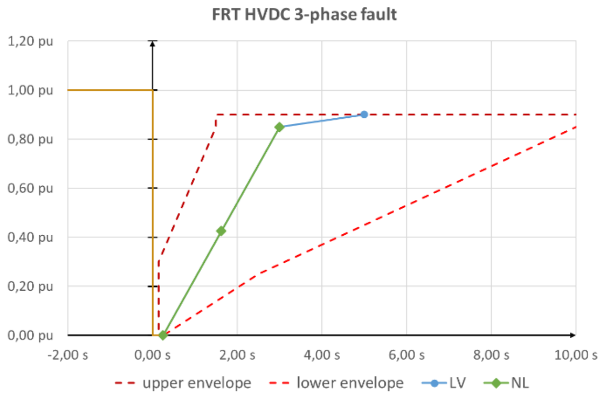


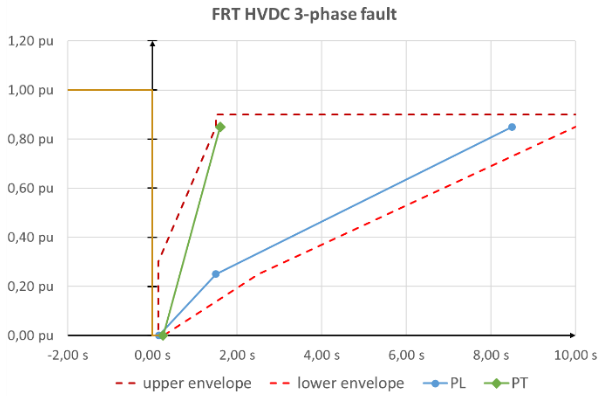

FRT HVDC 3-phase fault
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-2,00 s
0,00 s
2,00 s
4,00 s
6,00 s
8,00 s
10,00 s
upper envelope
lower envelope
FI
FR

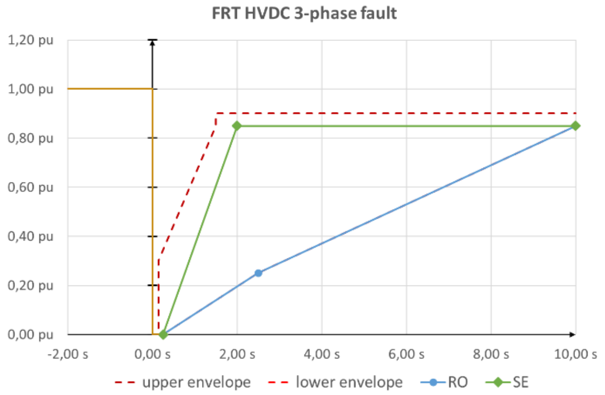

FRT HVDC 3-phase fault
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-2,00 s
0,00 s
2,00 s
4,00 s
6,00 s
8,00 s
10,00 s
upper envelope
lower envelope
GB
GR

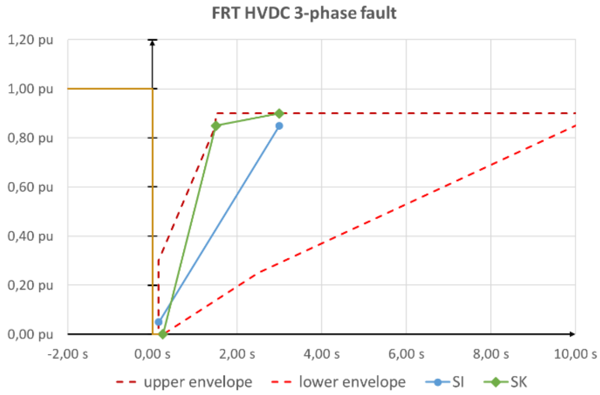

FRT HVDC 3-phase fault
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-2,00 s
0,00 s
2,00 s
4,00 s
6,00 s
8,00 s
10,00 s
upper envelope
lower envelope
HR
HU


FRT HVDC 3-phase fault
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-2,00 s
0,00 s
2,00 s
4,00 s
6,00 s
8,00 s
10,00 s
upper envelope
lower envelope
IT
LT


FRT HVDC 3-phase fault
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-2,00 s
0,00 s
2,00 s
4,00 s
6,00 s
8,00 s
10,00 s
upper envelope
lower envelope
LV
NL


FRT HVDC 3-phase fault
1,20 pu
1,00 pu
0,80 pu
0,60 pu
0,40 pu
0,20 pu
0,00 pu
-2,00 s
0,00 s
2,00 s
4,00 s
6,00 s
8,00 s
10,00 s
upper envelope
lower envelope
PL
PT





6.5 Conclusions on implementation status of HVDC converter stations' FRT capabilities

Country	Data provision	Implementation pursuant to article 25.1	Remarks
AT	Yes	–	No installations
BE	Yes	–	Minimum is specified
BG	No	–	Lack of numerical data
CZ	Yes	–	Site specific
DE	Yes	Yes	–
DK-CE	Yes	No	Out of NC HVDC ranges
DK-Nordic	Yes	No	Out of NC HVDC ranges
EE	Yes	Yes	–
ES	Yes	Yes	–
FI	Yes	Yes	–
FR	Yes	No	No U_{re1}, t_{rec1}
GB	Yes	Yes	–
GR	Yes	Yes	–
HR	Yes	Yes	–
HU	Yes	Yes	–
IE&NI	Yes	Yes (only NI)	–
IT	Yes	Yes	–
LT	Yes	Yes	–
LU	No	–	No installations
LV	Yes	Yes	–
NL	Yes	Yes	–
PL	Yes	Yes	–
PT	Yes	Yes	–
RO	Yes	Yes	–
SE	Yes	Yes	–
SI	Yes	Yes	–
SK	Yes	Yes	–s

Table 8: Implementation status of HVDC converter stations' FRT capabilities pursuant to HVDC article 25.1

6.6 References of examined non-exhaustive requirements linked to CNC articles

6.6.1 NC RfG non-exhaustive requirements – Frequency Issues

Issue	RfG Article No.	Non-exhaustive Requirement
Frequency Ranges	13(1)(a)(i)	Time period for: ▪ 47.5Hz-48.5Hz (SAs: CE, Baltic) ▪ 48.5Hz-49.0Hz (SAs: CE, Nordic, GB, IR, Baltic) ▪ 51.0Hz-51.5Hz (SAs: Baltic)
Frequency Ranges	13(1)(a)(ii)	▪ Potential wider frequency ranges ▪ Potential longer minimum times ▪ Specific requirements for frequency and voltage deviations
RoCoF	13(1)(b)	Max. RoCoF and measuring window for which PGM shall stay connected
RoCoF	13(1)(b)	Specify RoCoF of the loss of main protection
LFSM-O	13(2)(a)	▪ Frequency threshold ▪ Droop settings
LFSM-O	13(2)(b)	Use of automatic disconnection and reconnection
LFSM-O	13(2)(f)	Expected behaviour of the PGM once the regulating minimum level is reached
Admissible Active Power Reduction	13(4)	Admissible active power reduction from max. output with falling frequency
Admissible Active Power Reduction from maximum Output with falling Frequency	13(5)	Definition of the ambient conditions applicable when defining the admissible active power reduction and take into account of the capabilities of PGM
Logic Interface (1)	13(6)	Requirements for the additional equipment necessary to allow active power output to be remotely operable
Automatic Connection to the Network	13(7)	Conditions for automatic connection to the network regarding ▪ Frequency ranges ▪ Corresponding delay time ▪ Maximum admissible gradient of increase in active power output
Logic Interface (2)	14(2)(b)	Requirements for the equipment necessary to make the logic interface remotely operable (to cease active power output)
Frequency Stability	15(2)(a)	▪ Time period to reach the adjusted active power set point ▪ Tolerance applying to the new set point ▪ Time period to reach tolerance applying to the new set point
LFSM-U	15(2)	▪ Frequency threshold ▪ Droop ▪ Definition of P_{ref}
Frequency Sensitive Mode	15(2)(d)(i)	▪ Active power range related to maximum capacity ▪ Frequency response insensitivity ▪ Frequency response dead band ▪ Droop
Frequency Sensitive Mode (FSM)	15(2)(d)(iii)	Maximum admissible full activation time

Issue	RfG Article No.	Non-exhaustive Requirement
Frequency Sensitive Mode (FSM)	15(2)(d)(iv)	Maximum admissible initial delay for PGMs without inertia
Frequency Sensitive Mode (FSM)	15(2)(d)(v)	Time period for the provision of full active power frequency response
Frequency Restoration Control	15(2)(e)	Specifications of the frequency restoration control
Real-Time Monitoring of FSM	15(2)(g)	▪ List of the necessary data which will be sent in real time ▪ Definition of additional signals
Rates of Change of Active Power Output	15(6)	Taking into consideration the specific characteristics of the prime mover technology: ▪ Minimum limit of change of active power output in down direction ▪ Maximum limit of change of active power output in down direction ▪ Minimum limit of change of active power output in up direction ▪ Maximum limit of change of active power output in up direction

Table 9: NC RfG non-exhaustive requirements – Frequency Issues

6.6.2 NC RfG non-exhaustive requirements – Voltage Issues

Issue	RfG Article No.	Non-exhaustive Requirement
Fault Ride Through Capability	14(3)(a)(i) (Voltage-against-time profile)	SPGM: ▪ U_{ret}, U_{clear}, U_{rec1}, U_{rec2} ▪ t_{ret}, t_{clear}, t_{rec1}, t_{rec2}, t_{rec3}
Fault Ride Through Capability	14(3)(a)(i) (Voltage-against-time profile)	PPM: ▪ U_{ret}, U_{clear}, U_{rec1}, U_{rec2} ▪ t_{ret}, t_{clear}, t_{rec1}, t_{rec2}, t_{rec3}
Fault Ride Through Capability	14(3)(a)(iv)	▪ Pre-fault minimum short circuit capacity (MVA) at connection point ▪ Pre-fault active power output at connection point ▪ Pre-fault reactive power output at connection point ▪ Pre-fault voltage at connection point ▪ Post-fault minimum short circuit capacity (MVA) at connection point (only type D)
Fault Ride Through Capability	14(3)(b) (Voltage-against-time profile for asymmetric faults)	SPGM: ▪ U_{ret}, U_{clear}, U_{rec1}, U_{rec2} ▪ t_{ret}, t_{clear}, t_{rec1}, t_{rec2}, t_{rec3}
Fault Ride Through Capability	14(3)(b) (Voltage-against-time profile for asymmetric faults)	PPM: ▪ U_{ret}, U_{clear}, U_{rec1}, U_{rec2} ▪ t_{ret}, t_{clear}, t_{rec1}, t_{rec2}, t_{rec3}
Fault Ride Through Capability	16(3)(a)(i) (Voltage-against-time profile)	SPGM: ▪ U_{ret}, U_{clear}, U_{rec1}, U_{rec2} ▪ t_{ret}, t_{clear}, t_{rec1}, t_{rec2}, t_{rec3}

Issue	RfG Article No.	Non-exhaustive Requirement
Fault Ride Through Capability	16(3)(a)(i) (Voltage-against-time profile)	PPM: ▪ U_{ret}, U_{clear}, U_{rec1}, U_{rec2} ▪ t_{ret}, t_{clear}, t_{rec1}, t_{rec2}, t_{rec3}
Fault Ride Through Capability	16(3)(c) (Voltage-against-time profile for asymmetric faults)	SPGM: ▪ U_{ret}, U_{clear}, U_{rec1}, U_{rec2} ▪ t_{ret}, t_{clear}, t_{rec1}, t_{rec2}, t_{rec3}
Fault Ride Through Capability	16(3)(c) (Voltage-against-time profile for asymmetric faults)	PPM: ▪ U_{ret}, U_{clear}, U_{rec1}, U_{rec2} t_{ret}, t_{clear}, t_{rec1}, t_{rec2}, t_{rec3}
Fault Ride Through Capability	16(3)(b)(i)	▪ Pre-fault minimum short circuit capacity (MVA) at connection point
Fault Ride Through Capability	16(3)(b)(ii)	▪ Pre-fault active power output at connection point ▪ Pre-fault reactive power output at connection point ▪ Pre-fault voltage at connection point
Fault Ride Through Capability	16(3)(b)(iii)	▪ Post-fault minimum short circuit capacity (MVA) at connection point
Automatic Disconnection due to Voltage Level	15(3)	▪ Voltage criteria for automatic disconnection ▪ Settings for automatic disconnection
Voltage Ranges PGM U<300kV	16(2)(a)(i)	Time period for operation: ▪ 1.118pu-1.15pu (SAs: CE)
Voltage Ranges PGM U<300kV	16(2)(a)(ii)	▪ Shorter time period in the event of simultaneous overvoltage and under frequency ▪ Shorter time period in the event of simultaneous undervoltage and over frequency
Voltage Ranges PGM U<300kV	16(2)(b)	▪ Wider voltage ranges for operation may be agreed by RSO, PGFO and TSO ▪ Longer minimum time periods for operation may be agreed by RSO, PGFO and TSO
Voltage Ranges PGM 300kV < U <400kV	16()(a)(i)	Time period for operation ▪ 1.05pu-1.10pu (SAs: CE; Nordic)
Voltage Ranges PGM 300kV < U <400kV	16(2)(a)(iii)	Time period for operation ▪ 1.05pu-1.0875pu in Spain may be specified as unlimited
Voltage Ranges PGM 300kV < U <400kV	16(2)(a)(v)	For Baltic voltage ranges and time period for operation may be in line with Continental Europe for facilities connected to the 400kV network.
Voltage Ranges PGM 300kV < U <400kV	16(2)(a)(ii)	▪ Shorter time period in the event of simultaneous overvoltage and under frequency ▪ Shorter time period in the event of simultaneous undervoltage and over frequency
Voltage Ranges PGM 300kV < U <400kV	16(2)(b)	▪ Wider voltage ranges for operation may be agreed by RSO, PGFO and TSO ▪ Longer minimum time periods for operation may be agreed by RSO, PGFO and TSO
Reactive Power Capability SPGM	17(2)(a)	Capability to supply or absorb reactive power

Issue	RfG Article No.	Non-exhaustive Requirement
Supplementary Reactive Power SPGM	18(2)(a)	Definition of supplementary reactive power to compensate reactive power demand of the HV line or cable when connection point is not located at the HV side of the step-up transformer
Reactive Power Capability SPGM at max. Capacity	18(2)(b)(i)	U-Q/P_{max}-profile at maximum capacity
Reactive Power Capability SPGM at max. Capacity	18(2)(b)(iv)	Appropriate timescale to reach any operating point within U-Q/P_{max}-profile
Voltage Control SPGM	19(2)(a)	▪ Parameters and settings of the components of the voltage control system ▪ Specifications of the automatic voltage regulator (AVR)
Voltage Stability SPGM	19(2)(b)(v)	Power threshold above which PSS function must be specified
Reactive Power Capability PPM	20(2)(a)	Capability to supply or absorb reactive power
Fast Fault Current PPM	20(2)(b)(ii)	▪ How the voltage deviation is determined? ▪ When the voltage deviation is determined? ▪ Characteristics of fast fault current injection ▪ Timing of fast fault current injection which may include several stages ▪ Accuracy of fast fault current injection which may include several stages ▪ The end of the voltage deviation
Fast Fault Current PPM	20(2)(c)	▪ Specification for asymmetrical current injection (in case of asymmetrical faults 1-phase/2-phase faults)
Supplementary Reactive Power PPM	21(3)(a)	▪ Definition of supplementary reactive power to compensate reactive power demand of the HV line or cable when connection point is not located at the HV side of the step-up transformer
Reactive Power PPM at max. Capacity	21(3)(b)	▪ U-Q/P_{max}-profile at maximum capacity
Reactive Power PPM below max. Capacity	21(3)(c)(i)	▪ U-Q/P_{max}-profile below maximum capacity
Reactive Power PPM below max. Capacity	21(3)(c)(iv)	▪ Appropriate timescale to reach any operating point within U-Q/P_{max}-profile
Reactive Power Control Modes PPM	21(3)(d)(iv) (Voltage control mode)	▪ t_1: time within which 90% of the change in reactive power is reached ▪ t_2: time within which 100% of the change in reactive power is reached
Reactive Power Control Modes PPM	21(3)(d)(vi) (Power factor control mode)	▪ Target power factor ▪ Time period to reach the set point ▪ Tolerance
Reactive Power Modes PPM	21(3)(d)(vii) (Specifications of the two reactive power control mode options)	▪ Which reactive power control mode is chosen? ▪ Which associated set points are applied? ▪ Which further equipment is needed to make the relevant set point operable?

Table 10: NC RfG non-exhaustive requirements – Voltage Issues

6.6.3 NC RfG non-exhaustive requirements – System Restoration Issues

Issue	RfG Article No.	Non-exhaustive Requirement
Reconnection Capability	14(4)(a)	Conditions for reconnection to the network after an incidental disconnection caused by network disturbance
Reconnection Capability	14(4)(b)	Conditions for automatic reconnection
Blackstart Capability	15(5)(a)(ii)	Technical specifications for a quotation for black start capability
Blackstart Capability	15(5)(a)(iii)	Timeframe within which the PGM is capable of starting from shutdown without any external electrical energy supply
Blackstart Capability	15(5)(a)(iv)	Voltage limits for synchronisation when article 16.2 does not apply
Capability of Island Operation	15(5)(b)(iii)	Methods and criteria for detecting island operation
Operation following Tripping to Houseload	15(5)(c)(iii)	Minimum operation time within which the PGM is capable of operating after tripping
Active Power Recovery SPGM	17(3)	Definition of the magnitude and time for active power recovery
Post Fault Active Power Recovery PPM	20(3)(a)	▪ Specification when the post-fault active power recovery begins ▪ Specification of the max. allowed time for active power recovery ▪ Specification of magnitude and accuracy for active power recovery

Table 11: NC RfG non-exhaustive requirements – System Restoration Issues

6.6.4 NC RfG non-exhaustive requirements – Instrumentation, Simulation Models and Protections Issues

Issue	RfG Article No.	Non-exhaustive Requirement
Control Scheme and Settings	14(5)(a)	▪ Control schemes of the control devices ▪ Control settings of the control devices
Electrical Protection Schemes and Settings	14(5)(b)	▪ Electrical protection schemes ▪ Electrical protection settings
Information Exchanges	14(5)(d)	▪ Content of information exchange ▪ Precise list of data to be facilitated ▪ Precise time of data to be facilitated
Manual, local Measures where the Automatic Remote Devices are out of Order	15(2)(b)	▪ Time period to reach the requested set point in cases where the automatic remote control devices are out of service ▪ Tolerance to reach the requested set point in cases where the automatic remote control devices are out of service
Loss of Angular Stability or Loss of Control	15(6)(a)	Criteria to detect loss of angular stability or loss of control
Instrumentation	15(6)(b)(i)	Definition of the quality of supply parameters
Instrumentation	15(6)(b)(ii)	▪ Settings of the fault recording equipment ▪ Triggering criteria of the fault recording equipment ▪ Sampling rates of the fault recording equipment

Issue	RfG Article No.	Non-exhaustive Requirement
Instrumentation	15(6)(b)(iii)	Specifications of the oscillation trigger detecting poorly damped power oscillations
Instrumentation	15(6)(b)(iv)	Protocols for recorded data
Simulation Models	15(6)(c)(iii)	Specifications of the simulation models
Installation of Devices for System Operations and Security	15(6)(d)	Definitions of the devices needed for system operation and system security
Neutral Point at the Network Side of Step-Up Transformers	15(6)(f)	Specifications of the earthing arrangement of the neutral point at the network side of the step-up transfomers
Automatic Disconnection	16(2)(c)	▪ Definition of the threshold for automatic disconnection ▪ Definition of the parameters
Synchronisation	16(4)	Settings of the synchronisation devices
Angular Stability	19(3)	Agreement for technical capabilities of the PGM to aid angular stability
Synthetic Inertia	21(2)	▪ Definition of the operating principle of control systems to provide synthetic inertia ▪ Related performance parameters to provide synthetic inertia

Table 12: NC RfG non-exhaustive requirements – Instrumentation, Simulation Models and Protection Issues

6.6.5 NC DCC non-exhaustive requirements – Frequency Issues

Issue	DCC Article No.	Non-exhaustive Requirement
Frequency Ranges	12(1) and Annex I	Time period for: ▪ 47.5Hz-48.5Hz (SAs: CE, Baltic) ▪ 48.5Hz-49.0Hz (SAs: CE, Nordic, GB, IR, Baltic) ▪ 51.0Hz-51.5Hz (SAs: Baltic)
Frequency Ranges	12(2) and Annex I	▪ Potential wider frequency ranges ▪ Potential longer minimum times ▪ Specific requirements for frequency and voltage deviations
Frequency Ranges	29.(2)(a)	Extended frequency range
DRS	29.(2)(c)	for DU connected below 110 kV: definition of the normal operating range
DRS	29(2)(d)	definition of the allowed frequency dead band
DRS	29(2)(e)	▪ Definition of the frequency ranges for DRS System Frequency Control (SFC) ▪ Definition of the maximum frequency deviation to respond
DRS	29(2)(g)	▪ Definition of the rapid detection of frequency system changes ▪ Definition of the response to frequency system changes

Table 13: NC DCC non-exhaustive requirements – Frequency Issues

6.6.6 NC DCC non-exhaustive requirements – Voltage Issues

Issue	DCC Article No.	Non-exhaustive Requirement
Voltage Ranges	13(1) and Annex II	Time period for: ▪ 1,05 pu – 1,10 pu (SAs: Nordic) ▪ 1,118 pu – 1,15 pu (SAs: CE, Baltic)
Voltage Ranges	13(1) and Annex II	Time period for: ▪ 1,05 pu – 1,10 pu (SAs: CE, Nordic, GB) ▪ 1,097 pu – 1,15 pu (SAs: Baltic)
Automatic disconnection due to voltage level	13(6)	▪ Voltage criteria parameters at the connection point for automatic disconnection ▪ Technical parameters at the connection point for automatic disconnection
Reactive power capability for TC DF and TC DS	15(1)(a)	Definition of the actual reactive power range for DF without onsite generation
Reactive power capability for TC DF and TC DS	15(1)(b)	Definition of the actual reactive power range for DF with onsite generation
Reactive power capability for TC DF and TC DS	15(1)(c)	Definition of the scope of the analysis to find the optimal solution for reactive power
Reactive power capability for TC DF and TC DS	15(1)(d)	Definition of other metrics than power factor
Reactive power capability for TC DF and TC DS	15(1)(e)(e)	Use of other metrics
Reactive power capability for TC DF and TC DS	15(3)	Method to carry out active control the exchange of reactive power at the connection point
DRS	28(2)(a)	Extended frequency range
DRS	28(2)(c)	For DF or CDS connected below 110 kV: definition of the normal operating range
DRS	28(2)(e)	Technical specifications to enable the transfer of information for DR LFDD and Low Voltage Demand Disconnection (LVDD), for DR Active Power Control (APC) and DR Reactive Power Control
DRS	28(2)(f)	Definition of the time period to adjust the power consumption
DRS	28(2)(i)	Definition of the modalities of notification in case of a modification of the DR capability
DRS	28(2)(k)	Definition of the ROCOF maximum value
Power quality	20	Allocated level of voltage distortion

Table 14: NC DCC non-exhaustive requirements – Voltage Issues

6.6.7 NC DCC non-exhaustive requirements – System Restoration Issues

Issue	DCC Article No.	Non-exhaustive Requirement
Short circuit requirements	14(1)	Maximum short-circuit current at the connection point to be withstood
Short circuit requirements	14(3)	Unplanned events: threshold of the maximum short circuit current inducing an information from the TSO in case of a change above this threshold
Short circuit requirement	14(5)	Planned events: threshold of the maximum short circuit current inducing an information from the TSO in case of a change above this threshold
Short circuit requirement	14(8)	Unplanned events: threshold of the maximum short circuit current inducing an information from the; TC DF or TC DSO in case of a change above this threshold
Short circuit requirements	14(9)	Planned events: threshold of the maximum short circuit current inducing an information from the TC DF or TC DSO in case of a change above this threshold
Demand disconnection for system defence	19(1)(a)	Definition the capabilities of Low Frequency Demand Disconnection (LFDD) scheme
Demand disconnection for system defence	19(2)(a)	Definition of the LVDD scheme
Demand disconnection for system defence	19(2)(b)	Definition of the LVDD scheme
Demand disconnection for system defence	19(3)(b)	Definition of the automatic on load tap changer blocking scheme
Demand disconnection for system defence	19(4)(a)	Definition of the conditions for reconnection after a disconnection
Demand disconnection for system defence	19(4)(b)	Settings of the synchronisation devices (including frequency, voltage, phase angle range and deviation of voltage and frequency)
Demand disconnection for system defence	19(4)(c)	Definition of the automated disconnection equipment time for remote disconnection

Table 15: NC DCC non-exhaustive requirements – System Restoration Issues

6.6.8 NC DCC non-exhaustive requirements – Instrumentation, Simulation Models and Protections Issues

Issue	DCC Article No.	Non-exhaustive Requirement
Electrical Protection Scheme and settings	16(1)	▪ Electrical protection schemes ▪ Electrical protection settings
Control Requirements	17(1)	▪ Control devices schemes ▪ Control devices settings
Information Exchanges	18(1)	Standards to exchange information and time stamping
Information Exchanges	18(2)	Standards to exchange information and time stamping
Information Exchanges	18(3)	Make information exchange standards publically available
Simulation Models	21(3)	Content and format of the simulation models or equivalent information
Simulation Models	21(5)	Requirements for the recordings to be compared with the response of the model

Table 16: NC DCC non-exhaustive requirements – Instrumentation, Simulation Models and Protection Issues

6.6.9 NC HVDC non-exhaustive requirements – Frequency Issues

Issue	HVDC Article No.	Non-exhaustive Requirement
Frequency Ranges	11(1)	Time period for: ▪ 47,5 Hz-48,5 Hz (SAs: CE, Baltic) ▪ 48,5 Hz-49,0 Hz (SAs: CE, Nordic, GB, IR, Baltic) ▪ 51,0 Hz-51,5 Hz (SAs: Baltic) ▪ 51,5 Hz-52,0 Hz (SAs: CE, Nordic, GB, IR, Baltic)
Wider Frequency Ranges	11(2)	▪ Potential wider frequency ranges ▪ Potential longer minimum times
Automatic Disconnection	11(3)	▪ Frequencies to disconnect
Maximum Admissible Power Output	11(4)	▪ Maximum admissible power output reduction below 49 Hz
Active Power Controllability	13(1)(a)(i)	▪ Maximum power step ▪ Minimum power step
Active Power Controllability	13(1)(a)(ii)	▪ Minimum active power transmission capacity
Active Power Controllability	13(1)(a)(iii)	▪ Maximum delay
Active Power Controllability	13(1)(b)	▪ Modification of transmitted active power
Fast Active Power Reversal	13(1)(c)	▪ Capability or not fast active power reversal
Automatic Remedial Action	13(3)	▪ Triggering criterion ▪ Blocking criterion
Synthetic Inertia	14(1)	▪ Functionality
Synthetic Inertia	14(2)	▪ Principle of control ▪ Performance parameters
Frequency Sensitive Mode	Annex II A(1)(a)	▪ Frequency response dead band ▪ Droop s1 (upward regulation) ▪ Droop s2 (downward regulation) ▪ Frequency response insensitivity
Frequency Sensitive Mode	Annex II A(1)(d)(ii)	▪ Initial delay t1 ▪ Time for full activation t2
LFSM-O	Annex II B(1)(c)	▪ Initial delay ▪ Time for full activation
LFSM-O	Annex II B(2)	▪ Frequency threshold ▪ Droop s3
LFSM-U	Annex II C(1)(c)	▪ Initial delay
LFSM-U	Annex II C(2)	▪ Time for full activation ▪ Frequency threshold ▪ Droop s4
Frequency Control Mode	16(1)	▪ Need for independent control mode to modulate active power output
Frequency Control Mode	16(2)	▪ Specify operating principle

Issue	HVDC Article No.	Non-exhaustive Requirement
Max. Loss of Active Power	17(1)	▪ Specify limit for loss of active power injection
Max. Loss of Active Power	17(2)	▪ Coordinate specified limit of active power injection
Frequency Stability Requirements	39(1)(b)	▪ Specify coordinated frequency control capabilities
Frequency Ranges	39(2)(a)	▪ The applicable frequency ranges and time periods at nominal frequencies other than 50 Hz
Wider Frequency Ranges	39(2)(b)	▪ Agreement on wider frequency ranges for operation ▪ Agreement on wider longer minimum times for operation
Automatic Disconnection	39(2)(c)	▪ Frequencies for automatic disconnection
LFSM-O	39(4)	▪ Frequency threshold ▪ Droop settings
LFSM-O	39(4)	▪ Definition of P_{ref}
LFSM-O	39(4)	▪ Expected behaviour of the PGM once the minimum regulating level is reached
Constant Power	39(5)	▪ Specify capability of maintaining constant output at PPM target active power value regardless of changes in frequency
Active Power Controllability	39(6)	▪ Specify tolerance (subject to the availability of the prime mover resource) applying to the new set point ▪ Specify the time within which the new set point must be reached
LFSM-U	39(7)	▪ Frequency threshold ▪ Droop
LFSM-U	39(7)	▪ Definition of P_{ref}
FSM with Subject to a Fast Signal Response	39(8)	▪ Active power range related to maximum capacity ▪ Frequency response insensitivity ▪ Frequency response dead band ▪ Droop ▪ Maximum admissible full activation time ▪ Maximum admissible initial delay for PGMs without inertia ▪ Time period for the provision of full active power frequency response
Frequency Restoration	39(9)	▪ Specifications of the frequency restoration control
For Frequencies other than 50 Hz	39(10)	▪ Frequency threshold, droop (Frequency other than 50 Hz) ▪ Frequency response dead band (Frequency other than 50 Hz) ▪ Definition of P_{ref} (Frequency other than 50 Hz)
Wider frequency ranges (nominal frequencies other than 50 Hz	47(1)	▪ Potential wider frequency ranges (nominal frequencies other than 50 Hz) ▪ Potential longer minimum times (nominal frequencies other than 50 Hz)
Automatic Disconnection (for frequencies other than 50 Hz)	47(1)	▪ Frequencies to disconnect (nominal frequencies other than 50 Hz)
Maximum Admissible Power Output (for frequencies other than 50 Hz)	47(2)	▪ Maximum admissible power output below 49 Hz (nominal frequencies other than 50 Hz

Table 17: NC HVDC non-exhaustive requirements – Frequency Issues

6.6.10 NC HVDC non-exhaustive requirements – Voltage Issues

Issue	HVDC Article No.	Non-exhaustive Requirement
Voltage Ranges 110 kV ≤ U < 300 kV	Annex III Table 4	Time period for: ▪ 1,118 pu - 1,15 pu (SAs: CE)
Voltage Ranges 300 kV < U ≤ 400 kV	Annex III Table 5	Time period for: ▪ 1,05 pu - 1,0875 pu (SAs: CE) ▪ 1,05 pu - 1,10 pu (SAs: Nordic)
Agreement on Wider Voltage Ranges or Longer Min. Times	18(2)	▪ Wider voltage ranges for operation ▪ Longer minimum time periods for operation
Automatic Disconnection	18(3)	▪ Voltage criteria at the connection point for automatic disconnection ▪ Technical parameters at the connection point for automatic disconnection
Voltage Ranges	18(4)	▪ Specify 1 pu applicable requirements at connection points
Voltage Ranges	18(5)	▪ Decision on use continental Europe voltage ranges
Short Circuit Contribution during Faults	19(2)(a)	▪ Specifications on voltage deviation
Short Circuit Contribution during Faults	19(2)(b)	▪ Characteristics of fast fault current
Short Circuit Contribution during Faults	19(2)(c)	▪ Timing and accuracy of fast fault current
Short Circuit Contribution during Faults	19(3)	▪ Specify asymmetrical current injection for 1-phase faults ▪ Specify asymmetrical current injection for 2-phase faults
Reactive Power Capability	20(1)	▪ U-Q/P_{max} profile at maximum capacity
Reactive Power Capability	20(3)	▪ Provide timescale to move within U-Q/P_{max} profile
Reactive Power Exchanged with the Network	21(2)	▪ Specify maximum tolerable voltage step value
Reactive Power Control Mode	22(1)	▪ Define which of the control modes are required
Reactive Power Control Mode	22(2)	▪ Define of any other control modes are required and if so what are they
Reactive Power Control Mode	22(3)(b)	▪ For voltage control mode definition of adjustment steps required for dead band
Reactive Power Control Mode	22(3)(c)	▪ In voltage control mode time within which 90% of the change in reactive power is reached within 0,1 seconds -10,0 seconds ▪ In voltage control mode t_2 = time within which 100% of the change in reactive power is reached within 1 seconds - 60 seconds
Reactive Power Control Mode	22(3)(d)	▪ Voltage control slope specified by range and step
Reactive Power Control Mode	22(4)	▪ Reactive power range in Mvar or %
Reactive Power Control Mode	22(5)	▪ Maximum allowable step size of set point

Issue	HVDC Article No.	Non-exhaustive Requirement
Reactive Power Control Mode	22(6)	▪ Equipment specification to enable remote control of control modes and set points
Priority to Active or Reactive Power Contribution	23	▪ TSO decide active or reactive power has priority during low and high voltage operation and during faults
Fault Ride Through	25(1)	Specify: ▪ 3-phase fault: U_{ret} ▪ 3-phase fault: U_{rec1} ▪ 3-phase fault: U_{rec2} ▪ 3-phase fault: t_{clear} ▪ 3-phase fault: t_{rec1} ▪ 3-phase fault: t_{rec2}
Fault Ride Through	25(2)(a)	▪ Pre-fault minimum short circuit capacity (MVA) at connection point
Fault Ride Through	25(2)(b)	▪ Pre-fault voltage at connection point
Fault Ride Through	25(2)(c)	▪ Post-fault minimum short circuit capacity (MVA) at connection point
Fault Ride Through	25(4)	▪ Voltages where HVDC system can block, U_{block}
Fault Ride Through	25(5)	▪ Acceptance of narrower settings on under voltage protection ▪ Narrower settings on under voltage protection
Fault Ride Through	25(6)	Specify: ▪ 1-phase fault: U_{ret} ▪ 1-phase fault: U_{rec1} ▪ 1-phase fault: U_{rec2} ▪ 1-phase fault: t_{clear} ▪ 1-phase fault: t_{rec1} ▪ 1-phase fault: t_{rec2} ▪ 2-phase fault: U_{ret} ▪ 2-phase fault: U_{rec1} ▪ 2-phase fault: U_{rec2} ▪ 2-phase fault: t_{clear} ▪ 2-phase fault: t_{rec1} ▪ 2-phase fault: t_{rec2}

Table 18: NC HVDC non-exhaustive requirements – Voltage Issues

6.6.11 NC HVDC non-exhaustive requirements – System Restoration Issues

Issue	HVDC Article No.	Non-exhaustive Requirement
Energisation and Synchronisation of HVDC Converter Stations	28	▪ Limits of any voltage change to a steady-state level (<5% pre-synchronisation voltage) ▪ Maximum magnitude of the voltage transients ▪ Duration of the voltage transients ▪ Measurement window of the voltage transients

Issue	HVDC Article No.	Non-exhaustive Requirement
Power Oscillation Damping Capability	30	▪ Frequency range of oscillations ▪ The network conditions when oscillations occur ▪ Agree control parameter settings
Power Oscillation Damping Capability	31(2)	▪ Specifications of extent of SSTI ▪ Input parameters
Power Oscillation Damping Capability	31(3)	▪ Identify all parties relevant at a connection point
Black Starts	37(1)	▪ Obtain quote for black start
Black Starts	37(2)	▪ Specify timeframe after shut down of the HVDC system ▪ Wider frequency ranges than Article 11 as required ▪ Wider voltage ranges than Article 18 as required
Black Starts	37(3)	▪ Capacity of black start ▪ Availability of black start
Stable Operation with Min & Max SC Power	42(b)	▪ The minimum of short circuit power ▪ The maximum of short circuit power ▪ Network characteristics of the HVDC interface point

Table 19: NC HVDC non-exhaustive requirements – System Restoration Issues

6.6.12 NC HVDC non-exhaustive requirements – Simulation Issues

Issue	HVDC Article No.	Non-exhaustive Requirement
Interaction Between HVDC and Other Plants/Equipment	29(2)	▪ Specify study required to examine interaction with adjacent equipment
Interaction Between HVDC and Other Plants/Equipment	29(3)	▪ Specify all other relevant parties to the study
Interaction Between HVDC and Other Plants/Equipment	29(5)	▪ Models/information for use in studies
Interaction Between HVDC and Other Plants/Equipment	29(7)	▪ Specify transient levels of performance
Network Characteristics	32(1)	▪ Method for calculation ▪ Pre-fault conditions for minimum short circuit power ▪ Pre-fault conditions for maximum short circuit power ▪ Post fault conditions for minimum short circuit power ▪ Post fault conditions for maximum short circuit power
HVDC System Robustness	33(1)	▪ Specify changes in system conditions for HVDC system to remain stable
Electrical Protection Schemes and Settings	34(1)	▪ The protection schemes for internal electrical faults ▪ The protection settings for internal electrical faults
Electrical Protection Schemes and Settings	34(3)	▪ Acceptance of changes by owner to protection

Issue	HVDC Article No.	Non-exhaustive Requirement
Electrical Protection Schemes and Settings	35(1)	▪ Control modes for a control scheme ▪ Parameters for a control scheme
Electrical Protection Schemes and Settings	35(2)	▪ Specify priority order of protection and control devices
Changes to Protection and Control Schemes and Settings	36(1)	▪ Changes to control modes ▪ Changes to protections settings
Changes to Protection and Control Schemes and Settings	36(2)	▪ Coordination of changes and agreement
Changes to Protection and Control Schemes and Settings	36(3)	▪ Equipment specification to enable remote control of control modes and associated set points
Synchronization	41(1)	▪ Limits of any voltage change to a steady-state level (<5% pre-synchronisation voltage) ▪ Maximum magnitude of the voltage transients ▪ Duration of the voltage transients
Output Signals	41(2)	▪ Specify required output signals
Method of Pre-Fault and Post-Fault Conditions	42(a)	▪ Method for calculation ▪ Pre-fault conditions for minimum short circuit power ▪ Pre-fault conditions for maximum short circuit power ▪ Post fault conditions for minimum short circuit power ▪ Post fault conditions for maximum short circuit power
Equivalents Representing the Collection Grid	42(c)	▪ Provide network equivalent for harmonic studies
Electrical Protection Schemes	43(1)	▪ Electrical protection schemes ▪ Electrical protection settings

Table 20: NC HVDC non-exhaustive requirements – Instrumentation, Simulation Models and Protection Issues

7 Conclusion

The 2020 data reflects the implementation status of National Connection Network Codes in comparison to the three Connection Network Codes. The data was received from Member States during 2020 data monitoring and was then used to assimilate the results presented in this report.

7.1 Conclusion on implementation status of NC RfG capabilities

Section 3 details the results from the implementation of RfG.

For RfG there are two key conclusions, these being:

- The Capacity Thresholds between Type B, C and D Power Generating Modules are reflected in Figure 2, Figure 3 and Figure 4 with details of variations from RfG on a country by country basis being summarised in section 3.2.
- The number of implemented non-exhaustive requirements in RfG (Figure 5) and the RfG Values / Ranges according to the requirements in the National Codes (Figure 6).

The Capacity Thresholds on a country by country basis are well documented in section 3.1 and 3.2 of this report. If the reader is interested in the detailed findings of the Capacity Thresholds on a country by country basis, they are encouraged to read these sections of the report.

So far as the number of implemented non-exhaustive requirements in RfG and the RfG Values / Ranges it is worth providing a brief conclusion.

Figure 5 details the number of implemented requirements in RfG. The more detailed data relating to Frequency Issues, Fault Ride Through Issues, Voltage & Reactive Power, System Restoration Issues & Instrumentation, Simulation Models & Protection are presented in Figure 7 to Figure 169 on a country by country basis.

Based on Figure 5 (Implemented requirements in RfG) across all countries, a total of 3776 are general requirements, 486 are site specific requirements and 203 are mandatory requirements but have not been considered and therefore not implemented yet. These figures have been derived by adding each category in Figure 5 (i.e. general requirements, site specific requirements and non-implemented values) which gives an indication of how the requirements across the whole of Europe have been implemented.

As a benchmark (from Figure 5) it is noted that under RfG there are 168 general requirements and 28 requirements which can be agreed on a site specific basis.

Based on Figure 6 (RfG Values / Ranges according to the requirements in the National Codes) across all countries, a total of 3223 were based on general ranges / values which were implemented in National Codes, 1015 are based on site specific requirements and 203 are mandatory requirements but have not been considered and therefore not implemented yet. These figures have been derived by adding each category in Figure 6 (i.e. general requirements, site specific requirements and non-implemented values) which gives an indication of the wide variation of values across Europe.

As a benchmark (from Figure 6), it is noted that under RfG, there are 139 values which can be specified at a general level in National Codes and 57 values which can be agreed on a site specific basis.

7.2 Conclusion on implementation status of NC DCC capabilities

Section 4 details the results from the implementation of DCC.

An overview of the results is shown in Section 4.1 (Number of Implemented non-exhaustive requirements in DCC which are represented in Figure 199 and Figure 200). The more detailed data relating to Frequency Issues, Voltage Issues, System Restoration Issues & Instrumentation, Simulation Models & Protection are presented in Figure 201 to Figure 304 on a country by country basis.

Based on Figure 199 (DCC requirements as such in National Codes) across all countries, a total of 649 are general requirements, 257 are site specific requirements and 52 are mandatory requirements but have not been considered and therefore not implemented yet. These figures have been derived by adding each category in Figure 199 (i.e. general requirements, site specific requirements and non-implemented values) which gives an indication of how the requirements across the whole of Europe have been implemented.

As a benchmark (from Figure 199) it is noted that under DCC, there are 36 general requirements and 11 requirements which can be agreed on a site specific basis.

Based on Figure 200 (DCC Values / Ranges according to the requirements in the National Codes) across all countries, a total of 361 were based on general ranges / values which were implemented in National Codes, 496 are based on site specific requirements and 70 are mandatory requirements but have not been considered and therefore not implemented yet. These figures have been derived by adding each category in Figure 200 (i.e. general requirements, site specific requirements and non-implemented values) which gives an indication of the wide variation of values across Europe.

As a benchmark (from Figure 200), it is noted that under DCC, there are 17 values which can be specified at a general level in National Codes and 30 values which can be agreed on a site specific basis.

7.3 Conclusion on implementation status of NC HVDC capabilities

Section 5 details the results from the implementation of HVDC.

An overview of the results are shown in Section 5.1 (Number of Implemented non-exhaustive requirements in HVDC which are represented in Figure 305 and Figure 306). The more detailed data relating to Frequency Issues, Voltage Issues, System Restoration Issues & Instrumentation, Simulation Models & Protection are presented in Figure 307 to Figure 436 on a country by country basis.

Based on Figure 305 (HVDC requirements as such in National Codes) across all countries, a total of 3842 are general requirements, 587 are site specific requirements and 585 are mandatory requirements but have not been considered and therefore not implemented yet. These figures have been derived by adding each category in Figure 305 (i.e. general requirements, site specific requirements and non-implemented values) which gives an indication of how the requirements across the whole of Europe have been implemented.

As a benchmark (from Figure 305) it is noted that under the HVDC Code there are 241 general requirements and 8 requirements which can be agreed on a site specific basis.

Based on Figure 306 (HVDC Values / Ranges according to the requirements in the National Codes) across all countries, a total of 2588 were based on general ranges / values which were implemented in National Codes, 1798 are based on site specific requirements and 585 are mandatory requirements but have not been considered and therefore not implemented yet. These figures have been derived by adding each category in Figure 306 (i.e. general requirements, site specific requirements and non-implemented values) which gives an indication of the wide variation of values across Europe. As a benchmark (from Figure 306), it is noted that under HVDC, there are 171 values which can be specified at a general level in National Codes and 78 values which can be agreed on a site specific basis.