Implementation of the Network Code on Requirements for Grid Connection of Generators

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June – 2021

FGH GmbH

Mannheim - Aachen

Hamburg - Paris

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EUROPEAN COMMISSION

Directorate-General for Energy
Directorate B — Internal Energy Market
Unit B2 — Wholesale markets; electricity & gas

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PDF ISBN 978-92-76-39432-7 doi:10.2833/610006 MJ-09-21-258-EN-N

Luxembourg: Publications Office of the European Union, 2021

Document version history

Version	Date	Comment
01	12.02.2021	-
02	30.06.2021	- Phrase added on page 29 regarding the difference in the applicability of the requirements of RfG NC at the unit (or plant) level - Germany added to the countries fulfilling the implementation on loss of angular stability protection on page 111, table 71 - Note added regarding Belgium on page 126, table 94 - The word convergence changed to incidence on page 128, table 96 and table 97 - Phrase added on page 147 regarding the applicability of the requirements at the unit/plant level

Executive Summary

In May 2018, two years after the European Network Code Requirements for Generators (RfG NC) had been published, European Member States (MS) have been obliged to conclude the respective national implementations of their individual grid codes. Next to a set of binding grid connection requirements as so-called exhaustive requirements, fixed to all European member states, the RfG NC also introduced ranges on non-exhaustive requirements that had to be shaped by the member states in terms of their national implementations. Hence, in all over Europe, a full range of new grid codes is on stage, providing some challenges to all parties involved in the installation and operation of Power Generation Modules (PGMs), to manufacturers in terms of technology development and design of their equipment, to project developers in terms of electrical planning and grid code compliant commissioning processes and to system operators with respect to their newly defined obligations on ensuring grid code conformity.

In addition to the national definition of non-exhaustive requirements, European MS also had to define three thresholds in terms of installed capacity of PGMs to be connected to the power grid in order to distinguish between four different type of PGMs (A, B, C and D). For each type, additional and different grid connection requirements will apply.

Finally, in April 2019, the RfG NC entered into force – principally together with all national grid code implementations. However, delayed publication had to be encountered in some MS.

Given that baseline, the European Commission launched a tender document in late summer 2019 asking for a comprehensive survey of the national grid code implementations following the RfG NC in the European MS plus nine other European countries with additional focus on type A implementations:

- Bosnia and Herzegovina
- Switzerland
- Montenegro
- North Macedonia
- Serbia
- Great Britain
- Northern Ireland
- Iceland
- Norway

In addition, two separate grid areas have been introduced for England and Denmark, each, due to their assignment to different synchronous areas.

For simplicity reasons all countries in total are referred in the study report and this executive summary as MS+.

According to the requirements of the European commission, the basic objectives of the study are as follows:

- To identify and compare the national implementations of both exhaustive and non-exhaustive requirements of the RfG NC;
- To identify where non-mandatory requirements of RfG NC have been implemented
- To identify extended requirements that are not part of the RfG NC; here, especially with respect to type A PGMs
- To determine the extent to which the European Standards EN 50549-1/2 are taken into account in national implementations with respect to extended requirements not being part of the RfG NC

- To determine a degree of coherence for these grid code implementations among the MS+
- Taking into account the design of compliance schemes where defined on national MS+ level

Along these objectives the results of the survey are basically structured in two main sections, differentiating between type A PGMs on the one hand and those of type B, C and D on the other hand. Next to those requirements which are already addressed within the RfG NC as exhaustive and non-exhaustive requirements and, hence, had to be implemented in the national grid codes by any means, a further consideration is given to the introduction of additional requirements in the national implementations in both sections.

The explicit structure of the study is as follows:

Chapter 1 provides some basic definitions and terms essential for the study.

Chapter 2, then, introduces the background of RfG NC, the scope of the study in terms of countries under consideration by defining the MS+ set and explaining specialities in some synchronous areas.

Following these basic introductions chapter 3 summarizes some general information on the national implementation processes, i.e. the entities being involved in terms of elaboration and approval processes. An overview on the general status of the national implementation is given. Finally, the analysis on the national threshold definition in order to distinguish between the four types A-D of PGMs on national level is provided. For each type B, C and D MS+ had to determine the respective threshold in terms of a minimum PGM capacity (by means of total active and/or apparent power) within a range capped by a maximum capacity that has been fixed in the RfG NC for each synchronous area. Given that degree of freedom, naturally the national implementations provide a large variety in type definitions.

Chapter 4 is dedicated to the results of the survey on national RfG NC requirement implementations. The chapter starts with an overview on the different technical requirements as given in the RfG NC (both, exhaustive and non-exhaustive; for all types A-D). Then, a methodology to determine a degree of convergence is introduced to be applied throughout the following analyses for RfG NC requirements. For additional requirements outside the RfG NC regime an incidence level is provided.

Subsection 4.2 addresses the individual requirements to type A PGMs. First, with respect to those directly provided by the RfG NC, concluding with a degree of convergence for each requirement. Then, additional requirements are listed, that have been identified in the national implementations. Here, the incidence level is applied in a different way, as no reference to the RfG NC default can be given. A special consideration is given to references to the European Standards EN 50549-1/2.

Subsection 4.3 follows with the survey on type B, C and D requirements. First, an analysis on the implementation of the mandatory requirements is provided, followed by a respective analysis on the non-mandatory requirements inside the RfG NC. Then, an overview on additional requirements for type B, C and D PGMs is given that have been identified in the national grid code implementations. The subsection concludes with a summary on the convergence/incidence levels for each technical requirement and a detailed listing on deviations per country.

Chapter 5 provides an overview on the compliance schemes that have been introduced in the MS+ so far, following the – vague – provisions of RfG NC with respect to compliance testing and simulation within the operational notification process. Based on this quite heterogeneous fact finding some recommendations are given on how to establish a more uniform process throughout Europe as compliance requirements definitely pose a significant challenge for manufacturers with respect to market entrance.

Chapter 6 finally sums up the finding on the integration of the European Standards EN 50549-1/2 in the national grid code implementations of RfG NC.

Chapter 7 ends up with conclusions and recommendations.

The following essential conclusions are drawn from the findings of the study:

1. A high diversity is given with respect to the national definitions of thresholds for distinguishing between the PGM types (A-D) taking into account the installed capacity. Especially for the type A/B-threshold the survey has revealed differences in the national implementation by a factor of 150. This clearly contradicts any harmonisation of technical parameters on type level as manufacturers and PGM project developers are facing different type assignments along the European borders and, hence, market entrance barriers.
2. Though a high degree of convergence of in total 91% for the implementation of type A specific RfG NC requirements is found, this result is significantly contradicted by various additional requirements at the national level that are outside the scope of RfG NC for type A PGMs. For these additional requirements the incidence level goes down to below 10% in some cases. However, it must be noted that most of these additional provisions are also addressed by the European Standard EN 50549-1/2.
3. Also, for the mandatory requirements of the RfG NC for PGMs of type B, C and D the overall coherence level is quite high with a total of 84%. However, a total of 27 countries have at least one deviation in their RfG NC implementation compared to the defined European framework. With respect to the implementation of non-mandatory requirements for PGMs of type B, C and D the convergence level drops down to 68%. And, like for type A PGMs, some additional requirements for PGMs of type B, C and D are found in a number of national grid codes that have not been addressed by the RfG NC. Here, in general some type D requirements have been shifted down to type B and/or C PGMs as well, like reactive power supply. Moreover, totally new provisions have been introduced in some MS+, like Over Voltage Ride Through (OVRT) capabilities.
4. Compliance schemes, if addressed or implemented at all, show a very divergent picture in the MS+ to this date. A number of MS+ give references to the application of equipment certificates within the operational notification process and / or the compliance monitoring. But only two countries are, so far, providing respective certification schemes at the national level in order to prevent individual and diverging assessment schemes of each certification body which are difficult to qualify. Pan-European or even international standards on testing, modelling, model validation, simulation and conformity assessment are missing.
5. Storages – which are not in the scope of RfG NC but provide a significant asset to future power networks – are only addressed in two MS+ explicitly.

Based on these fact findings the following recommendations are made:

1. A more coherent scheme for type definitions (A-D) has to be elaborated in a future RfG NC.
2. Since there are many national implementations that have extended the ranges given by the non-exhaustive requirements of RfG NC, a future NC should either clearly restrict these extensions by a stringent negotiation beforehand or enlarge its own framework correspondingly. This will ensure a reliable framework and the avoidance of any member specific extensions in the implementations at national level.
3. Some of the additional requirements already implemented in the national grid codes, that, however, are not part of the RfG NC, should be addressed directly by a future RfG NC. This applies especially for provisions at type A level. Focus could be laid on requirements such as

OVRT, voltage or Q-control modes. The European Standard EN 50549-1/2 may provide a suitable framework.

4. The European commission should provide tenders for performing relevant studies on the impact of these additional requirements. These studies shall serve as a reliable technical basis to set the framework in the RfG NC with additional requirements.
5. Future NCs shall distinguish more precisely between the different compliance measures to be applied and provide more detailed and guiding information on respective procedures. Already existing schemes shall be analysed in detail, gathered and assembled into a common European standard. Benefit should be taken from the existing overall certification programmes in Spain and Germany and the ongoing standardisation initiatives at CENELEC and/or IEC RE level.
6. Considering the ongoing progress and increasing share of storage systems in power grids, it is recommended to include to the battery system within the scope of RfG NC.

Résumé

En mai 2018, deux ans après la publication des exigences du code de réseau sur les exigences applicables au raccordement au réseau des installations de production d'électricité (RfG NC), les États membres européens (EM) ont été obligés de conclure les mises en œuvre nationales respectives de leurs codes de réseau individuels. Outre un ensemble d'exigences contraignantes de connexion au réseau en tant qu'exigences dites exhaustives, fixées à tous les États membres européens, le RfG NC a également introduit des gammes d'exigences non exhaustives qui devaient être définies par les États membres en fonction de leurs mises en œuvre nationales. Par conséquent, dans toute l'Europe, une gamme complète de nouveaux codes de réseau est introduite, offrant des défis à toutes les parties impliquées dans l'installation et l'exploitation des unités de production d'électricité (UPE), aux fabricants en termes de développement technologique et de conception de leurs équipements, aux développeurs de projets en termes de planification électrique et de processus de mise en service conformes au code de réseau et aux gestionnaires de réseau en ce qui concerne leurs obligations nouvellement définies en matière de conformité au code de réseau.

Outre la définition des exigences non exhaustives au niveau national, les EM européens ont également dû définir trois seuils en termes de capacité installée de l'UPE à connecter au réseau électrique afin de distinguer quatre types différents d'UPE (A, B, C et D). Pour chaque type, des exigences supplémentaires et différentes de connexion au réseau s'appliqueront.

Enfin, en avril 2019, le RfG NC est entré en vigueur - principalement avec toutes les mises en œuvre nationales du code de réseau. Cependant, une publication tardive a dû être rencontrée dans certains États membres.

Compte tenu de cette base de référence, la Commission européenne a lancé un document d'appel d'offres à la fin de l'été 2019 demandant une enquête complète sur les mises en œuvre du code de réseau national à la suite du RfG NC dans les États membres européens ainsi que dans neuf autres pays européens en mettant un accent supplémentaire sur les mises en œuvre de type A:

- Bosnie-Herzégovine
- Suisse
- Monténégro
- Macédoine du Nord
- Serbie
- Grande-Bretagne
- Irlande du Nord
- Islande
- Norvège

En outre, deux zones de réseau distinctes ont été introduites pour l'Angleterre et le Danemark, chacune en raison de leur affectation à des zones synchrones différentes.

Pour des raisons de simplicité, tous les pays au total sont mentionnés dans le rapport d'étude et dans le présent résumé analytique en tant qu'États membres.

Selon les exigences de la Commission européenne, les objectifs de base de l'étude sont les suivants:

- Identifier et comparer les mises en œuvre nationales des exigences exhaustives et non exhaustives du RfG NC;
- Identifier où les exigences non obligatoires du RfG NC ont été mises en œuvre
- Identifier les exigences étendues qui ne font pas partie du RfG NC; ici, notamment en ce qui concerne les UPE de type A.

- Déterminer dans quelle mesure les normes européennes EN 50549-1 / 2 sont prises en compte dans les mises en œuvre nationales en ce qui concerne les exigences étendues ne faisant pas partie du RfG NC
- Déterminer un degré de cohérence pour ces mises en œuvre du code de réseau parmi les EM+
- Prise en compte de la conception des systèmes de conformité lorsqu'ils sont définis au niveau national des EM+.

Parallèlement à ces objectifs, les résultats de l'enquête sont essentiellement structurés en deux sections principales, différenciant les UPE de type A d'une part et ceux de type B, C et D d'autre part. Outre les exigences qui sont déjà traitées dans le RfG NC comme des exigences exhaustives et non exhaustives et, par conséquent, qui ont dû être mises en œuvre dans les codes de réseau nationaux par tous les moyens, une autre considération est donnée à l'introduction des exigences supplémentaires dans les mises en œuvre nationales dans les deux sections.

La structure explicite de l'étude est la suivante:

Le chapitre 1 fournit quelques définitions de base et des termes essentiels pour l'étude.

Le chapitre 2 présente ensuite le contexte du RfG NC, la portée de l'étude en termes de pays considérés en définissant l'ensemble des EM+ et en expliquant les particularités dans certaines zones synchrones.

Suite à ces introductions de base, le chapitre 3 résume quelques informations générales sur les processus nationaux de mise en œuvre, c'est-à-dire les entités impliquées en termes de processus d'élaboration et d'approbation. Un aperçu de l'état général de la mise en œuvre nationale est donné. Enfin, l'analyse de la définition du seuil national afin de distinguer les quatre types A-D des UPE au niveau national est fournie. Pour chaque type B, C et D, les EM+ devait déterminer le seuil respectif en termes de capacité de l'UPE minimale (au moyen de la puissance totale active et / ou apparente) dans une plage plafonnée par une capacité maximale qui a été fixée dans le RfG NC pour chaque zone synchrone. Compte tenu de ce degré de liberté, les mises en œuvre nationales offrent bien entendu une grande variété de définitions de types.

Le chapitre 4 est dédié aux résultats de l'enquête sur les mises en œuvre nationales des exigences du RfG NC. Le chapitre commence par un aperçu des différentes exigences techniques telles qu'indiquées dans le RfG NC (à la fois exhaustives et non exhaustives; pour tous les types A-D). Ensuite, une méthodologie pour déterminer un degré de convergence est introduite pour être appliquée tout au long des analyses suivantes pour les exigences RfG NC. Pour les exigences supplémentaires en dehors du régime RfG NC, un niveau d'incidence est fourni.

Le paragraphe 4.2 traite des exigences individuelles pour les UPE de type A. Premièrement, en ce qui concerne ceux directement fournis par le RfG NC, en concluant par un degré de convergence pour chaque exigence. Par la suite, les exigences supplémentaires, qui ont été identifiées dans les mises en œuvre nationales, sont répertoriées. Ici, le niveau d'incidence est appliqué d'une manière différente, car aucune référence aux valeurs par défaut du RfG NC ne peut être donnée. Une attention particulière est accordée aux références aux normes européennes EN 50549-1 / 2.

Le paragraphe 4.3 suit avec l'enquête sur les exigences de type B, C et D. Tout d'abord, une analyse de la mise en œuvre des exigences obligatoires est fournie, suivie d'une analyse respective des exigences non obligatoires à l'intérieur du RfG NC. Ensuite, un aperçu des exigences supplémentaires pour les UPE de type B, C et D est donné qui ont été identifiées dans les mises en œuvre nationales du code de réseau. Le paragraphe se termine par un résumé des niveaux de convergence / d'incidence pour chaque exigence technique et une liste détaillée des écarts par pays.

Le chapitre 5 donne un aperçu des systèmes de conformité qui ont été introduits dans les États membres jusqu'à présent, à la suite des dispositions - vagues - du RfG NC concernant les tests de conformité et la simulation dans le cadre du processus de notification opérationnelle. Sur la base de ces constatations assez hétérogènes, certaines recommandations sont données sur la manière d'établir un processus plus uniforme dans toute l'Europe, car les exigences de conformité posent définitivement un défi important aux fabricants en ce qui concerne l'entrée sur le marché.

Le chapitre 6 résume enfin les conclusions sur l'intégration des normes européennes EN 50549-1 / 2 dans les mises en œuvre nationales du RfG NC.

Le chapitre 7 se termine par des conclusions et des recommandations.

Les conclusions essentielles suivantes sont tirées des résultats de l'étude:

1. Une grande diversité est donnée en ce qui concerne les définitions nationales des seuils pour distinguer les types des UPE (A-D) en tenant compte de la capacité installée. En particulier pour le seuil de type A / B, l'enquête a révélé des différences dans la mise en œuvre nationale d'un facteur 150. Cela contredit clairement toute harmonisation des paramètres techniques au niveau d’un type, car les fabricants et les développeurs de projets UPE sont confrontés à des attributions de type différentes le long des frontières européennes, et par conséquent, des barrières à l'entrée du marché.
2. Bien qu'un degré élevé de convergence de 91% au total pour la mise en œuvre des exigences RfG NC spécifiques de type A soit observé, ce résultat est considérablement contredit par diverses exigences supplémentaires au niveau national qui ne relèvent pas du champ d'application du RfG NC pour l’UPE de type A. Pour ces exigences supplémentaires, le niveau d'incidence descend à moins de 10% dans certains cas. Cependant, il convient de noter que la plupart de ces dispositions supplémentaires sont également traitées par la norme européenne EN 50549-1 / 2.
3. En outre, pour les exigences obligatoires du RfG NC pour les UPE de type B, C et D, le niveau de cohérence global est assez élevé avec un total de 84%. Cependant, un total de 27 pays ont au moins un écart dans leur mise en œuvre RfG NC par rapport au cadre européen défini. En ce qui concerne la mise en œuvre d'exigences non obligatoires pour les UPE de type B, C et D, le niveau de convergence tombe à 68%. Comme pour les UPE de type A, certaines exigences supplémentaires pour les UPE de type B, C et D se trouvent dans un certain nombre de codes de réseau nationaux qui n'ont pas été traités par le RfG NC. Ici, en général, certaines exigences de type D ont également été généralisées pour les UPE de type B et / ou C, comme la fourniture de puissance réactive. De plus, des dispositions totalement nouvelles ont été introduites dans certains EM+, comme les capacités de surtension (OVRT).
4. Les schémas de conformité, s'ils sont abordés ou mis en œuvre, montrent une image très divergente dans les États membres à ce jour. Un certain nombre de EM+ font référence à l'application de certificats d'équipement dans le cadre du processus de notification opérationnelle et / ou du contrôle de conformité. Mais seuls deux pays proposent, à ce jour, des systèmes de certification respectifs au niveau national afin d'éviter des systèmes d'évaluation individuels et divergents de chaque organisme de certification qui sont difficiles à qualifier. Il manque des normes paneuropéennes ou même internationales sur les essais, la modélisation, la validation des modèles, la simulation et l'évaluation de la conformité.
5. Les systèmes de stockage - qui n'entrent pas dans le champ d'application du RfG NC mais constituent un atout important pour les futurs réseaux électriques - ne sont traités explicitement que dans deux EM+.

Sur la base de ces constatations, les recommandations suivantes sont formulées:

1. Un schéma plus cohérent pour les définitions de type (A-D) doit être élaboré dans un future RfG NC.
2. Puisqu'il existe de nombreuses mises en œuvre nationales qui ont étendu les plages données par les exigences non exhaustives du RfG NC, un futur code de réseau (NC) devrait soit limiter clairement ces extensions par une négociation rigoureuse préalable, soit élargir son propre cadre en conséquence. Cela garantira un cadre fiable et permettra d'éviter toute extension spécifique aux membres dans les mises en œuvre au niveau national.
3. Certaines exigences supplémentaires déjà mises en œuvre dans les codes de réseau nationaux, qui, cependant, ne font pas partie du RfG NC, devraient être traitées directement par un future RfG NC. Cela s'applique en particulier aux provisions du type A. L'accent pourrait être mis sur les exigences telles que OVRT et les modes de réglage de tension ou de la puissance réactive. La norme européenne EN 50549-1 / 2 peut fournir un cadre approprié.
4. La Commission européenne devrait présenter des offres pour la réalisation d'études pertinentes sur l'impact de ces exigences supplémentaires. Ces études doivent servir comme base technique fiable pour fixer le cadre dans le RfG NC avec des exigences supplémentaires.
5. Les futurs codes de réseau établissent une distinction plus précise entre les différentes mesures de conformité à appliquer et fournissent des informations plus détaillées et d'orientation sur les procédures respectives. Les systèmes déjà existants doivent être analysés en détail, rassemblés et assemblés en une norme européenne commune. Il convient de tirer parti des programmes globaux de certification existants en Espagne et en Allemagne et des initiatives de normalisation en cours au niveau du CENELEC et / ou de l'IEC RE.
6. Compte tenu des progrès en cours et de la part croissante des systèmes de stockage dans les réseaux électriques, il est recommandé d'inclure le système de batteries dans le champ d'application du RfG NC.

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1. Definitions and categorizations within RfG NC

1.1. Definitions

This section is intended to give an overview of the terms, definitions and categorizations used within RfG NC. This will lead to a better understanding of the results presented within this report [1]:

Connection point: means the interface at which the power-generating module, demand facility, distribution system or HVDC system is connected to a transmission system, offshore network, distribution system, including closed distribution systems, or HVDC system, as identified in the connection agreement;

Fault-Ride-Through (FRT): means the capability of electrical devices to be able to remain connected to the network and operate through periods of low voltage at the connection point caused by secured faults;

MS: Member State of the European Union

MS+: means Twenty-six European member states (Malta is excluded, since it was not covered under the scope of the conducted study) and following nine other European countries:

- Bosnia and Herzegovina
- Switzerland
- Montenegro
- North Macedonia
- Serbia
- Great Britain and Northern Ireland[1], being distinguished as belonging to different synchronous areas (see below)
  Note: the UK will not be listed in this report as of 2021
- Iceland
- Norway

Power Generating Module (PGM): means either a synchronous power-generating module or a power park module;

Synchronous Power Generating Module (SPGM): means an indivisible set of installations which can generate electrical energy such that the frequency of the generated voltage, the generator speed and the frequency of network voltage are in a constant ratio and thus in synchronism;

Power Park Module (PPM): means a unit or ensemble of units generating electricity, which is either non-synchronously connected to the network or connected through power electronics, and that also has a single connection point to a transmission system, distribution system including closed distribution system or HVDC system;

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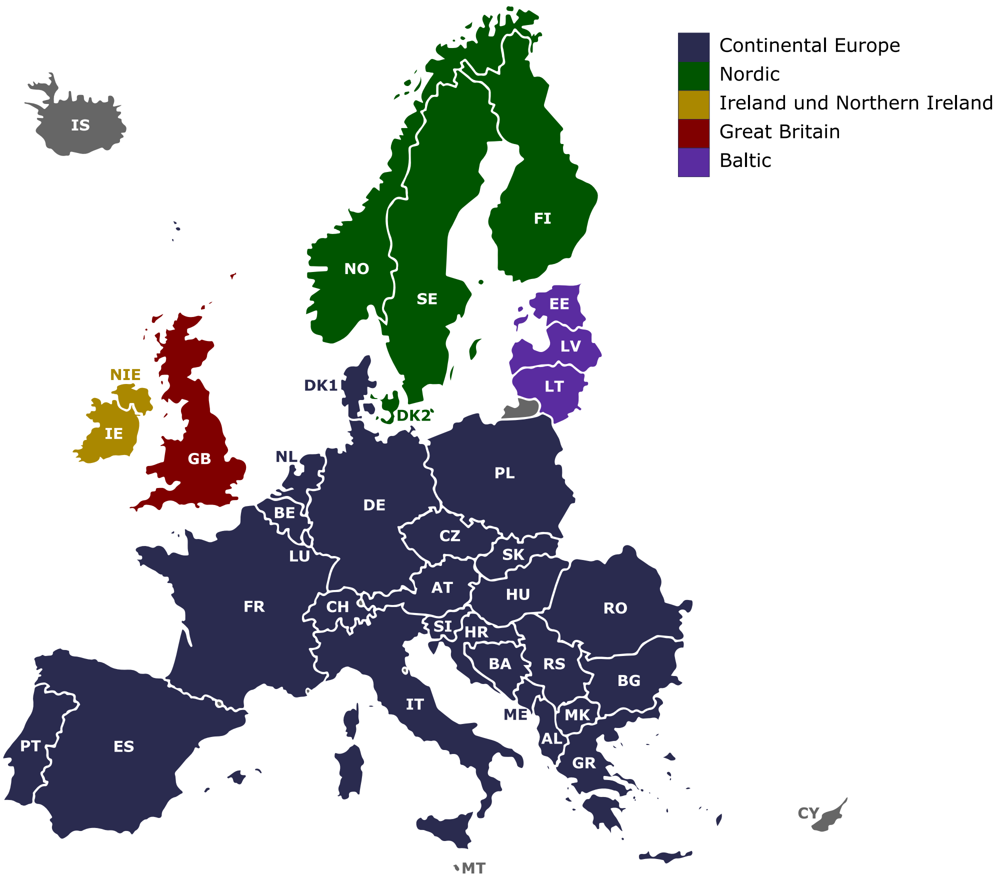
[1] Northern Ireland is not a Member State and has a separate National Regulatory Authority. It is therefore treated as a separate jurisdiction and for reasons of simplicity it is referred to as an MS+ in this report

Secured fault: means a fault which is successfully cleared according to the system operator's planning criteria;

Synchronous area: means an area covered by synchronously interconnected TSOs, such as the synchronous areas of Continental Europe, **Great Britain**, **Ireland**-**Northern Ireland** and Nordic and the power systems of **Lithuania**, **Latvia** and **Estonia**, together referred to as 'Baltic' which are part of a wider synchronous area; Figure 1 illustrates the different synchronous areas in Europe and the MS+ belonging to them. In the **United Kingdom** and **Denmark** there is more than one synchronous area.

Figure 1: Synchronous areas for European countries



1.2. Abbreviations

RfG NC: Requirement for generators network code

TSO: Transmission system operator;

DSO: Distribution System Operator;

NRA: National regulatory authority

EC: European commission

ACER: Agency for the cooperation of energy regulators

ENTSOE-E: European network of transmission system operators for electricity

PGUs: Power Generating Units

PGFs: Power Generation Facilities

1.3. Exhaustive and non-exhaustive requirements

Exhaustive requirements: Those requirements which are set in RfG NC with fixed values and are not supposed to be changed by TSO/DSOs in their own RfG NC implementation documents. An example of an exhaustive requirement in the RfG NC is Article 16 (2) (a) (i), where the operational voltage ranges are fixed for Type D power generating units.

Non-exhaustive requirements: Those requirements for which a range is set in RfG NC and the respective authorities (TSO/DSOs/NRAs) responsible for RfG NC implementation in MS+ shall select a value within the allowable range. An example of a non-exhaustive requirement in the RfG NC is Article 13 (1) (a) (ii) with respect to wider frequency ranges of operation.

1.4. Mandatory and non-mandatory requirements

Mandatory requirements: Those requirements which are compulsory for the power generating to fulfil according to RfG NC. For example, Article 14 (3) (a) sets a mandatory requirement of fault ride through capability for type B, C and D power generating seeking grid connections.

Non-mandatory requirements: Those requirements which are not made compulsory for the power generating units in RfG NC and where the respective authority (TSO/DSO/NRAs) responsible for RfG NC implementation in MS+ may choose to make it compulsory for power generating units seeking grid connection within its jurisdiction

2. Background, introduction and objective

The European Commission, Directorate General for Energy awarded a contract to FGH GmbH to perform a study related to the national implementation of the European Network Code of Requirements for Grid Connection of Generators.

Based on the Commission’s regulation 2016/631 of 14 April 2016 establishing the Network Code on Requirements for Grid Connection of Generators (hereafter referred as ‘RfG NC’) respective grid connection guidelines have to be implemented in MS+. The drafting of the network code is mainly done by European Commission, ACER and ENTSO-E. European Commission instructed ACER to develop the framework guidelines. For this purpose, ACER constituted ENTSO-E and other stakeholder groups in a transparent manner. The framework focus on the technical requirements for power generating units and power generation facility (also termed as power plants) with respect to their electrical characteristics.

The main goals of ENTSO-E in designing the rules of RfG NC are in principle the same as those of the European Third Energy Package:

- Increase sustainability in order to meet the decarbonisation goals of the EU
- Maintain security of supply despite the varying energy producing resources
- Create a single European market for electricity and thus increase market competition.

The regulation itself became mandatory in all MS+ with the date of entering into force, but nevertheless gave room for national specifications to a specific extent. The implementation of technical requirements in the individual MS+ shall be finalized considering the framework set by RfG NC. However, the implementation of requirements in individual MS+ shall also keep into account following key aspects:

- Existing grid infrastructure
- Integration of new power generating units and plants
- Share of the decentralized power generation (especially renewable energy sources)
- Previous legal framework (grid codes)

Although the aspects are similar, the effects on grid stability in individual member states are vastly varying – and so do the specifications in the national RfG NC implementation documents. Due to this fact, it is important to evaluate the convergence in the implementation of technical requirements of MS+ according to RfG NC guidelines. The focus of the study is to determine the level of convergence among the MS+ especially for type A PGUs, which will provide an indication of the efforts needed for enabling full market integration and, hence, facilitation of further expansion of renewable energy sources.

The European Commission requested to extended the scope of investigation to nine other European countries besides the MS (excluding Malta). These countries are:

- Bosnia and Herzegovina
- Switzerland
- Montenegro

- North Macedonia
- Serbia
- Great Britain
- Northern Ireland (see footnote on page 7)
- Iceland
- Norway

For simplicity reasons this report will refer to the total 35 of the investigated countries as "**MS+**". The countries themselves will be named based on the ISO 3166 Alpha2-coding. Due to the special treatment of **Northern Ireland** belonging to the synchronous area of **Ireland** and **Northern Ireland**, an additional reference "NIE" is introduced for **Northern Ireland**. For the two parts of **Denmark** belonging to the Continental (**Denmark west**) and the Nordic (**Denmark east**) synchronous area, the abbreviations DK1 and DK2 will be used respectively (cf. Figure 1).

In addition, the study will take into account the provisions of the European CENELEC (CLC) standards EN 50549-1 [4] (for the connection of generators in low-voltage distribution networks) and EN 50549-2 [5] (for the respective connection in medium-voltage distribution networks) in the course of analyses (referred to as EN 50549-1/-2).

Objectives of this study

Based on the initial requirements set out by the European Commission in its tender document, the focus of the study was laid on the following points:

- Overview of the RfG NC implementation process in MS+
- Identification of differences in implementation with respect to capacities
- Determination of convergence level for non-exhaustive requirements in MS+
- Identification of technical requirements in MS+ additional to RfG NC
- Incorporation status of European standard 50549-1/-2 in RfG NC implementations among MS+

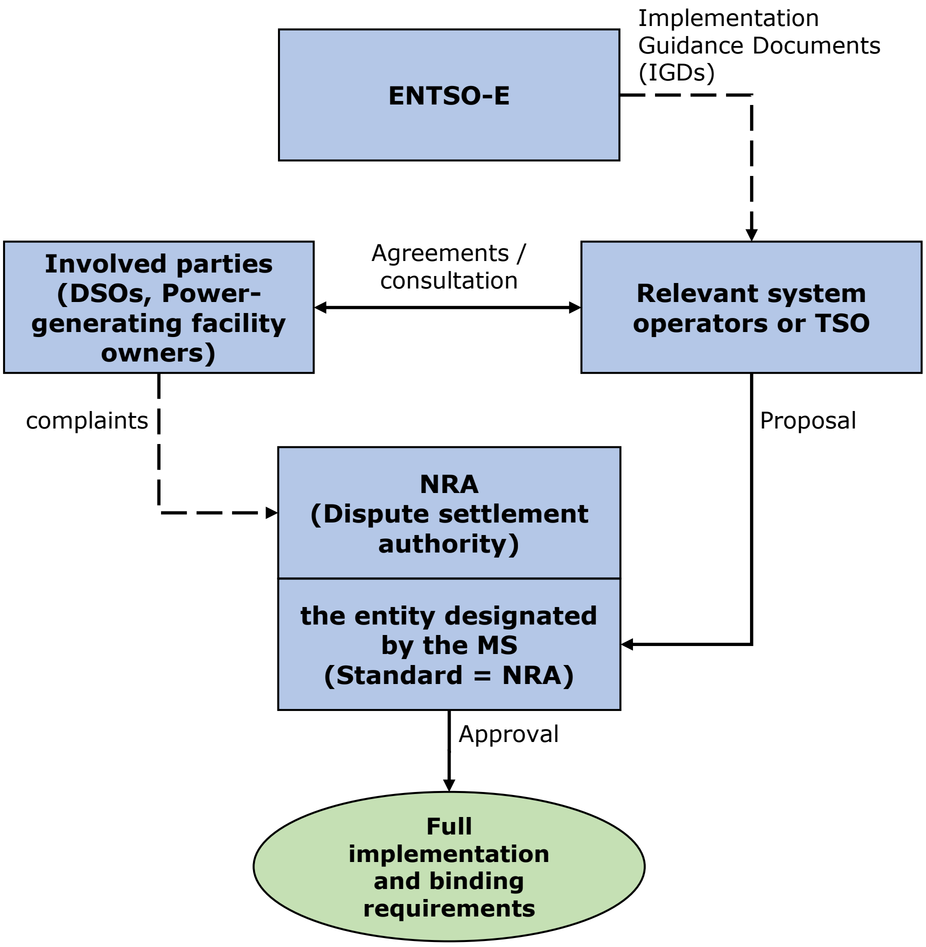
Accordingly, FGH has put its focus on the assessment of above-mentioned points, while analyzing the grid codes and technical documents among MS+. Since the aim of the study is to gauge the implementation of grid codes and technical standards after the commencement of Commission regulation 2016/631, this study in its assessment mainly focuses on those documents from MS+, where an RfG NC implementation has already taken place or at least a proposal document has been published. European MS+ where no RfG NC implementation documents have not been published until 30.05.2020, are not being considered for determination of convergence or incidence levels in this report. The convergence levels are calculated by analyzing whether each country has rightly implemented the guidelines of RfG NC. After that, the average value of the compliant MS+ is calculated. A non-existence of a requirement or a deviation of the implementation from the frameworks of RfG NC would then result in the reduction of the convergence level. The status of the ongoing RfG NC implementation in respective countries is however inquired through questionnaires.

3. RfG NC Implementations

3.1. General implementation process

In the context of the national implementation of the RfG NC, the requirements of general application are to be defined. Some or all non-mandatory requirements may be set as mandatory. The non-exhaustive requirements must also be defined specifically. According to the RfG NC, the relevant system operators or TSOs are responsible for the implementation of these technical aspects. The implementation process must be transparent and non-discriminatory. For this reason, the relevant system operators or TSO must agree with the power generating facility owners and/or DSOs each time this is required. A proposal is then submitted for approval. The MS+ shall appoint a body for the approval. The competent body may be the NRA, unless otherwise provided. The NRA should act as a dispute settlement authority in the event of an objection from any of the parties involved. Figure 2 illustrates the implementation process of the technical requirements described in RfG NC.

Figure 2: National implementation process of the requirements of general application of the RfG NC



3.2. Identification of entities involved in the RfG NC implementation at national level

According to the RfG NC, various parties at national level should be involved in the implementation process. In general, the process of drafting the technical requirements was / is led by the relevant TSOs who worked / work closely with the other DSOs. In some MS+, the elaboration of the technical requirements is partially or totally carried out under the umbrella of an association bringing together the actors involved. The identified bodies responsible for national implementation in the different MS+ are listed in Table 1, while the full list of European NRAs is presented in the "National regulatory authorities" section of the Appendix A.

Table 1: Competent Entities for the national implementation of the technical requirements of the RfG NC

MS+	Leading the elaboration process / Proposal		Approval	
	Entity	Description	Entity	Description
AT	APG / VÜN	TSOs	E-Control	NRA
BA	NOS-BiH	TSO	DERK	NRA
BE	Elia	TSO	VREG (Flanders) Cwape (Wallonia) Brugel (Brussels)	regional regulators
BG	ESO	TSO	EWRC	NRA
CH	VSE	Association	VSE	Association
CZ	CEPS	TSO	ERU	NRA
DE	FNN (VDE)	Association	FNN (VDE)	Association
DK	Energinet Dansk Energi	TSO Association	Forsyningstilsynet	NRA
EE	Elering	TSO	Konkurentsiamet	NRA
ES	REE AELEC	TSO Association	Ministerio para la Transición Ecológica	Ministry
FI	Fingrid	TSO	Energiavirasto	NRA
FR	RTE ADEeF	TSO Association	Ministère de la Transition écologique et solidaire	Ministry
GB	NationalGridESO	TSO	OFGEM	NRA
GR	IPTO	TSO	PAE	NRA
HR	HOPS	TSO	HERA	NRA
HU	MAVIR	TSO	MEKH	NRA
IE	EirGrid ESB Networks	TSO DSO	CRU	NRA
IS	Landsnet	TSO	Ministry of Industries and Innovation	Ministry
IT	Terna	TSO	ARERA	NRA
LT	Litgrid	TSO	VKEKK (VERT actually)	NRA
LU	Creos	TSO	ILR	NRA
LV	AST	TSO	SPRK	NRA
ME	CGES	TSO	REGAGEN	NRA
MK	MEPSO	TSO	PKE	NRA
NIE	SONI NIE Networks	TSO DSO	UR	NRA
NL	Netbeheer Nederland	Association	ACM	NRA
NO	Statnett	TSO	NVE	NRA
PL	PSE	TSO	URE	NRA
PT	REN EDP Distribuição	TSO DSO	Ministério Ambiente e da Ação Climática (MAAC)	Ministry
RO	Transelectrica	TSO	ANRE	NRA
RS	EMC	TSO	AERS	NRA
SE	Svenska Kraftnät	TSO	EI	NRA
SI	ELES	TSO	AGEN	NRA
SK	SEPS	TSO	URSO	NRA

3.3. RfG NC implementation status in European MS+

In the course of this study, the statuses of the RfG NC implementations with in each MS+ has been explored (cut-off date 30.05.2020). For this purpose, a categorization has been set up with respect to the implementation stages of the RfG NC.

The national implementation of the technical requirements has been completed in 29 MS+. Nevertheless, some of these MS+ are still expected to make changes to all or some existing national grid codes. In **Switzerland**, for example, a new version of the transmission grid code was recently published. However, other branch documents on the distribution network are currently in revision. Furthermore, the implementations in six other european countries are not traceable by FGH at the time of carrying out this study, namely **Bulgaria**, **Bosnia and Herzegovina**, **Cyprus**, **Montenegro**, **North Macedonia** and **Serbia**. The implementation process in **Bulgaria** however should be completed according to ENTSO-E [2][3]. With regard to the other European countries that are members of the energy community (**Bosnia and Herzegovina**, **North Macedonia**, **Montenegro** and **Serbia**), the requirements of the RfG NC are still in elaboration. In **Cyprus** the RfG NC is not applicable because Paragraph 2(a) of Article 3 excludes island systems, such as **Cyprus**. Table 2 summarizes the status and the availability of the RfG NC national implementations. Process flow diagrams about the implementation process in the individual MS+ as observed by FGH are presented in Figure 31 to Figure 65 in Appendix A.

Table 2: Status and availability of national implementations of the RfG NC requirements in the different MS+

National implementation of the technical requirements of the RfG NC				
available / found?	YES		NO	
approved / completed?	YES	NO*	YES	NO*
MS+	AT, BE, CH*, CZ*, DE, DK, EE, FI, GB, HR*, HU, IE, IS, IT, LT, LU, LV, NIE, NL*, PL, PT, RO, SE, SI*, SK*	ES, FR, GR, NO	BG*	BA, ME, MK, RS, CY**
Number of MS+	25	4	1	5
Note	*Amendments in some existing grid codes are/could be expected	*Proposals already submitted for approval	*According to ENTSO-E the implementation has been already done [2,3s]	*Proposals in elaboration **No implementation (excluded)

Note: Table 2 provide the statuses observed by FGH till the cut-off date for the carrying out the study.

3.4. Established capacity thresholds for type definitions

Based on their voltage level at the connection point and their maximum capacity at generating active power, RfG NC categorizes PGMs into 4 different types:

- connection point voltage below 110 kV and maximum capacity of 0,8 kW or more (type A);
- connection point below 110 kV and maximum capacity at or above a threshold proposed by each relevant TSO in accordance with Table 3 (type B / C / D);
- connection point at 110 kV or above (type D).

Table 3: Limits for thresholds for type B, C and D power-generating modules set in RfG NC according to synchronous areas

Synchronous area	Limit for maximum capacity threshold from which a PGM is of type		
	B [MW]	C [MW]	D [MW]
Continental Europe	1	50	75
Great Britain	1	50	75
Nordic	1.5	10	30
Ireland and Northern Ireland	0.1	5	10
Baltic	0.1	10	15

The limits of Table 3 are used in order to assess, whether the selection of thresholds at national level for each type (A, B, C or D) are within the maximum threshold set by RfG NC based on synchronous areas. In order to make the comparison diagram chosen by FGH comprehensible, Figure 3 provides an exemplary illustration of the diagram with definitions. For a given country, there would be a deviation only if the colored area representing a given type exceeds the square mark with the same color which represents the maximum limit above which the next type should be defined. The full comparison regarding the established thresholds is provided in Figure 4.

Figure 3: Exemplary threshold comparison diagram

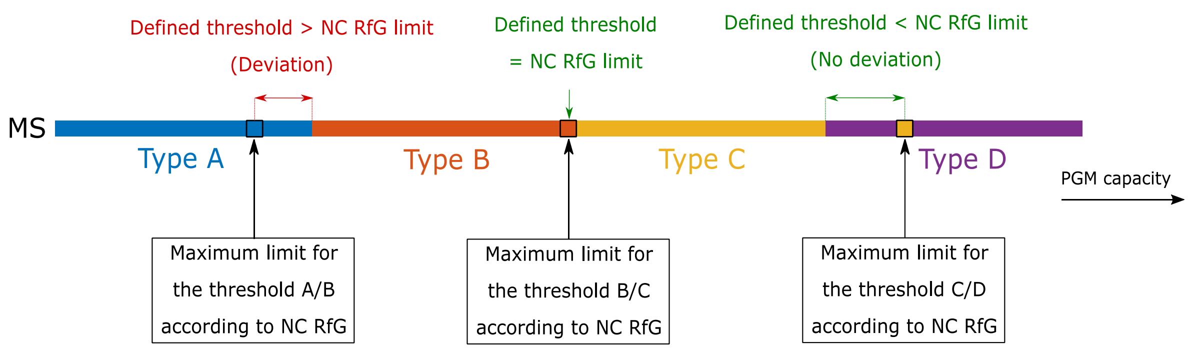
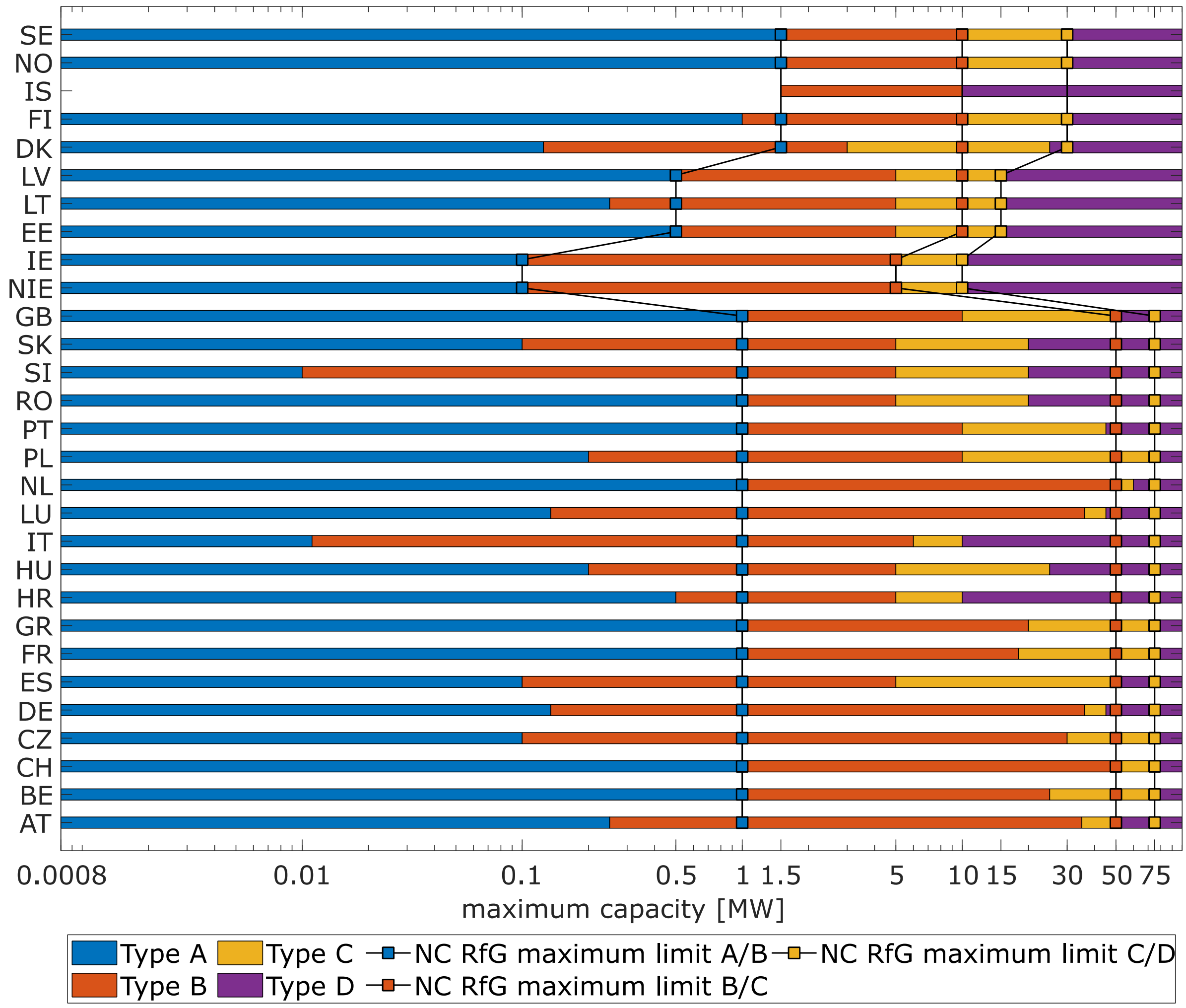


Figure 4: convergence of the capacity thresholds set in RfG NC Implementations among MS+



Note: Figure 4 utilizes a logarithmic scale for MW capacities in order to make comparison comprehensive.

A complete list of the analyzed countries with respect to their threshold values in terms of type classification is provided in Table 4.

Table 4: Maximum capacity thresholds defined for types B, C and D PGMs in MS+

Value [kW] / [MW] resp.	MS+	MS+ number	Note
Threshold A/B [kW]			
10	SI	1	
11.08	IT	1	
100	CZ*, ES, SK, NIE, IE	5	* Type B divided into B1 and B2 with threshold B1 / B2 equal to 1MW
125	DK	1	
135	DE, LU	2	
200	HU, PL	2	
250	AT, LT	2	
500	HR, EE, LV	3	
1000	BE, CH, FR, GR, NL, PT, RO, BG, FI	9	
1500	IS*, NO, SE	3	* connection point of 66 kV or less and type A not defined
n/a	BA, BG, CY, ME, MK, RS	5	
Threshold B/C [MW]			
3	DK	1	
5	ES, HR, HU, RO, SI, SK, NIE, IE, EE, LT, LV	11	
6	IT	1	
10	PL, PT, GB, FI, NO, SE	7	
18	FR	1	
20	GR	1	
25	BE	1	
30	CZ	1	
35	AT	1	
36	DE, LU	2	
50	CH, NL	2	
No type C	IS	1	
n/a	BA, BG, CY, ME, MK, RS	5	
Threshold C/D [MW]			
10	HR, IT, NIE, IE, IS*	5	* connection point of 66 kV or more and type C not defined
15	EE, LT, LV	3	
20	RO, SI, SK	3	
25	HU, DK	2	
30	AL, FI, NO, SE	4	
45	DE, LU, PT	3	
50	AT, ES, GB	3	
60	NL	1	
75	BE, CH, CZ, FR, GR, PL	6	
n/a	BA, BG, CY, ME, MK, RS	5	

Comparison of the capacity thresholds

Among all MS+ with RfG NC implementations no deviation is identified with respect to the given thresholds in RfG NC. However, some distinctiveness according to the definition of the PGM types have been identified.

Czech Republic: PGMs of type A and B are divided respectively into two subtypes A1 and A2 or B1 and B2. The threshold value A1 / A2 is 11 kW and the limit between B1 and B2 is 1 MW.

Belgium & France: In exceptional cases where a derogation is required, type D PGMs with a connection point at 110 kV or more could only meet the same requirements as a type B or type A PGM (depending on its maximal capacity) as if it had a connection point below 110 kV.

Iceland: Only type B and D are defined. A type B PGM has an installed capacity of 1,5 MW to 10 MW and a connection point of 66 kV or less. A type D PGM has a maximum capacity of at least 10 MW and has a connection point of 66 kV or more.

Observation on implemented capacity thresholds among MS+

It can be observed that the differences in defining the capacity thresholds between the MS+ introduce a challenge for PGM manufacturers who plan to sell their products outside their own country. This is because a PGM of a particular type (e.g type A) in one MS+ may be regarded as another type (e.g type B) in another MS+ and therefore the product will have to comply with more requirements. An example of this scenario can be observed by comparing **Italy** and **Finland**. The threshold A/B is 11.08 kW in the former and 1000 kW in the latter. This means that a 500 kW PGM for example is classified as type A in **Finland** and as type B in **Italy**. Therefore, the PGMs will have to comply with additional requirements within **Italy**.

Additionally, the difference in the applicability of the requirements of RfG NC at the unit (or plant) level between countries introduces inconsistency, also taking the technology of the generators into consideration (SPGM or PPM). As an example, in **Denmark**, the requirements are defined at the plant level. However, for synchronous machines, these should be set at the unit level according to RfG NC.

4. Comparison of established technical requirements

4.1. Technical requirements and methodologies of convergence assessment

4.1.1. Overview on technical requirements

The RfG NC requirements represent the leading line of this study and are provided under 4 different categories. These categories are: Frequency requirements, detailed in Table 5; Voltage requirements, detailed in Table 6; Robustness requirements, detailed in Table 7 and, finally, System Restoration requirements, detailed in Table 8.

Table 5: RfG NC's frequency general requirements

Frequency Requirements	Applicability		Not-Obligatory
	Type	Category	
Frequency limits and Minimum Service Times	A, B, C, D	SPGM, PPM, Offshore PPM	
ROCOF Requirement	A, B, C, D	SPGM, PPM, Offshore PPM	
Limited frequency sensitive mode for overfrequency setting (LFSM-O)	A, B, C, D	SPGM, PPM, Offshore PPM	
Actions in the LFSM-O when the minimum capacity for regular operation is reached	A	SPGM, PPM, Offshore PPM	x
Permissible reduction in the maximum active power output with decreasing frequency	A, B, C, D	SPGM, PPM, Offshore PPM	
Automatic connection to the network	A, B, C	SPGM, PPM	
Requirements for additional equipment for remote control of the active power output	A, B, C	SPGM, PPM	x
Adjustment of the target value of the active power output according to the instructions	B	SPGM, PPM, Offshore PPM	
Setting the limited frequency sensitive mode - underfrequency (LFSM-U)	C, D	SPGM, PPM, Offshore PPM	
Setting the frequency sensitive mode (FSM)	C, D	SPGM, PPM, Offshore PPM	
Complete activation of the frequency sensitive adjustment of the active power output (in the FSM) due to a frequency jump	C, D	SPGM, PPM, Offshore PPM	
Shorter than two seconds initial delay for PGMs without inertia	C, D	PGMs without inertia	x
Upper and lower limits for the gradient of the active power output (ramp limit values)	C, D	SPGM, PPM	
Provision of synthetic Inertia	C, D	PPM, Offshore PPM	x

Table 6: RfG NC's Voltage general requirements.

Voltage Requirements	Applicability		Not-Obligatory
	Type	Category	
Reactive power capacity for PGMs	B	SPGM, PPM	x
Provision of dynamic reactive current support in the event of faults	B, C, D	PPM, Offshore PPM	
Automatic disconnection from the grid at certain voltages at the grid connection point for PGM type C	C	SPGM, PPM	
Provision of additional reactive power at a remote connection point	C, D	SPGM, PPM, Offshore PPM	x
Reactive power capacity at maximum capacity (U-Q diagram)	C, D	SPGM, PPM, Offshore PPM	
Reactive power capacity below the maximum capacity (P-Q diagram)	C, D	PPM, Offshore PPM	
Provision of reactive power via voltage control, reactive power control, power factor control	C, D	PPM, Offshore PPM	
Prioritization of the active power contribution or the reactive power contribution in the event of faults	C, D	PPM, Offshore PPM	
Voltage ranges and minimum periods for operation (for voltage levels greater than or equal to 110kV)	D	SPGM, PPM, Offshore PPM	
Shorter minimum periods for operation with simultaneous overvoltage and underfrequency or undervoltage and overfrequency	D	SPGM, PPM	x
Automatic disconnection from the grid at certain voltages at the grid connection point for PGM type D	D	SPGM, PPM	x
Automatic Voltage Regulator	D	SPGM	

Table 7: RfG NC's Robustness general requirements.

Robustness Requirements	Applicability		Not-Obligatory
	Type	Category	
Fault Ride Through ability (FRT)	B, C, D	SPGM, PPM, Offshore PPM	
Return of the active power output after a fault	B, C, D	PPM, Offshore PPM	

Table 8: RfG NC's System Restoration general requirements.

System Restoration Requirements	Applicability		Not-Obligatory
	Type	Category	
Reconnection after an accidental disconnection due to a network failure	B, C, D	SPGM, PPM, Offshore PPM	
Black start ability	C, D	SPGM, PPM, Offshore PPM	x
Ability to participate in island operations	C, D	SPGM, PPM, Offshore PPM	x
Operation after Tripping to Houseload	C, D	SPGM, PPM, Offshore PPM	

The analysis of the individual elements of technical requirements will be broken down and thoroughly analysed in this study with respect to two main sub-sections:

- Type A requirements
- Type B, C and D requirements

Note: Main focus of the intended study awarded by EC was on type A PGMs. Hence special attention has been paid by FGH in the analysis of implementations for type A PGMs. Results of the study on type B,C and D requirements are presented in a cumulative format to provide an overall idea to the reader on the implementations in MS+. Results and observations drawn from the cumulative analysis could be different then the individual analysis of type B, C and D requirements for PGMs among MS+ implementations.

Further requirements stated in the RfG NC, as in the case of network management requirements, detailed in the Table 9, are not taken into consideration within this study as these requirements do not depend on the generator's characteristics and are mostly decided between the transmission/distribution system operator and power generation facility owner at the time of grid connection. Since grid codes mostly emphasize on the importance of agreements with respect to network management at the time of grid connection, a comparison of the requirements between the countries might not lead to any major findings.

Table 9: RfG NC's Network Management general requirements.

Network Management Requirements	Applicability		Not-Obligatory
	Type	Category	
Remote control interface (input port) to terminate the active power delivery within five seconds	A, B, C, D	SPGM, PPM	x
Systems and settings of the control devices	B, C, D	SPGM, PPM, Offshore PPM	x
Systems and settings of the protective devices	B, C, D	SPGM, PPM, Offshore PPM	x
Content of the information exchange	B, C, D	SPGM, PPM, Offshore PPM	
Criteria for determining loss of angular stability or controllability	C, D	SPGM, PPM, Offshore PPM	
Supply Quality parameters	C, D	SPGM, PPM, Offshore PPM	x
Setting of devices for fault recording	C, D	SPGM, PPM, Offshore PPM	
Setting of devices for monitoring dynamic system behavior	C, D	SPGM, PPM, Offshore PPM	
Communication protocols for data records	C, D	SPGM, PPM, Offshore PPM	x
Requirements for simulation models	C, D	SPGM, PPM, Offshore PPM	x
Additional devices for network operation or system security	C, D	SPGM, PPM, Offshore PPM	x
Grounding the star point on the network side of network transformers	C, D	SPGM, PPM, Offshore PPM	
Settings of the synchronization devices	D	SPGM, PPM, Offshore PPM	x
Technical skills to support angular stability under fault conditions	D	SPGM	x

Furthermore, the study will not take into account offshore PGMs, since the focus of the study request was put on the assessment of implementations at Type A power generating modules. Offshore PGMs are typically implemented under type D category. However, as mentioned above, additional to type A assessment, a cumulative assessment on type B, C and D for onshore technologies (both PPM and SPGM) is also included in this study.

4.1.2. Methodology of convergence analyses

In the following, the results of the analysis of national grid codes in the MS+ with respect to the implementation of the technical requirements within and outside the scope of RfG NC will be described. Next to the descriptive summary of implementation results, this report aims to analyze the convergence of the national implementations and point out respective divergences.

The convergence analysis is generally performed by first observing whether an MS+ has implemented the respective requirement of the RfG NC under consideration. If no information is found on this requirement within the grid code of a country, this would mean a divergence of that country with respect to the requirement in question. Furthermore, the implementations of MS+ are compared to the framework of RfG NC in terms of technical parameters in order to see if any boundaries or threshold values are exceeded. Again, any deviation or exceedance with respect to these values as of the RfG NC would mean a divergence. In the end, the convergence level is calculated by averaging the number of MS+ who have implemented the requirements in accordance with the RfG NC.

The following six countries have been excluded from this analysis:

- Bosnia and Herzegovina
- Bulgaria
- Cyprus
- Montenegro
- North Macedonia
- Serbia

At the time of carrying out this study, no RfG NC implementation was officially published or publicly available for the above-mentioned countries. As a result, the assessment of convergence and incidence levels in the following sections will consider a total of 29 MS+. It is worth mentioning that the response received from **Bosnia and Herzegovina** indicates that a new version of the grid code is to be expected in the first half of 2021.

In deviation to the above methodology the analyses on additional requirements, that are not (directly) included within the RfG NC, chapters 4.2.2, 4.3.2, and 4.3.3 will restrict the analysis to pointing out the incidence in which countries these additional requirements can be found in respective national grid code implementations. As specific requirements in the RfG NC are not covered, a comparison with this reference cannot be performed.

4.2. Type A requirements

4.2.1. Type A requirements within RfG NC

The following requirements apply to A modules according to the framework of RfG NC and will be analyzed with respect to national implementation in the following subsections:

Table 10: Type A requirements according to the scope of RfG NC

Type A requirements
Frequency ranges and minimum time periods for operation
Resistance to frequency gradients (Rate of Change of Frequency - ROCOF)
Permissible reduction in the maximum active power output with falling frequency
Limited Frequency Sensitive Mode - Overfrequency (LFSM-O)
Definition of Pref for PPMs
Logic interface for cease of active power
Automatic connection

Below, a detailed analysis of the above-mentioned requirements is presented.

4.2.1.1. Frequency ranges and minimum time periods for operation

According to Article 13 (1) (a) (i) of the RfG NC, PGMs of type A and above (B, C and D) must be able to maintain stable operation and respective connection to the network for a certain period of time at the specified frequency ranges. These frequency ranges and periods are shown in Table 11 and Table 12.

Table 11: Definition of the frequency ranges

Frequency range	FR0	FR1	FR2	FR3	FR4	FR5
from [Hz]	47	47.5	48.5	49	51	51.5
to [Hz]	47.5	48.5	49	51	51.5	52

Table 12: Minimum time periods for operation according to the RfG NC depending on the frequency ranges

Minimum time period [min]		Frequency range					
		FR0	FR1	FR2	FR3	FR4	FR5
	Continental Europe	n/a	≥30	$\geq t_{FR1}$	∞	30	n/a
	Great Britain	1/3	90	≥90	∞	90	15
	Ireland and Northern Ireland	n/a	90	≥90	∞	90	n/a
	Baltic	n/a	≥30	$\geq t_{FR1}$	∞	≥30	n/a
	Nordic	n/a	30	≥30	∞	30	n/a

The minimum period for operation depends on the synchronous area to which the respective country belongs. The values highlighted (beige) above are non-exhaustive parameters and shall be set by each MS+ at the national level. The other values are fixed and regarded as exhaustive parameters. For the frequency range FR2, a minimum operating time must be specified in each country. For the Baltic States and the states of the Continental European interconnection system, the specified time period shall not be shorter than that defined for the FR1 area.

Convergence of implementations

Table 13 lists the defined individual values of minimum operation periods for the frequency ranges FR0 to FR5 and the corresponding MS+. Multiple entries of one MS+ in the table means that the corresponding country has implemented the requirement based on the different aspects of that requirement (e.g. different frequency ranges or generation technologies as indicated in the comments column). However, each country is analyzed by considering all these aspects together. This is also the case for all other requirements within this report.

Table 13: Distribution of the minimum periods for operation in FR0 to FR5

Value [min]	MS+	Number of MS+	Comments
Minimum time operation in FR0			
1/3 (20 sec)	CZ, GB, IE, NIE, 50549*	4	* EN 50549-1/-2 however for these two norms this setting is not required and the default setting is 0 sec
n/a	AT, BA, BE, BG, CH, CY, DE, ES, FR*, GR, HR, HU, IT, LU, ME, MK, NL, PL, PT, RO, RS, SI, SK, EE, LT, LV, DK, FI, IS, NO, SE	31	* Project-specific
Minimum time operation in FR1			
10	CH*	1	* For 47.5 - 48 Hz
20	CH*	1	* For 48 - 48.5 Hz
30	BE, CZ, DE, ES, FR, GR, HR, HU, LU, NL, PL, RO, SI, SK, EE, LT, LV, DK, FI, NO, SE, PT, 50549*	22	* Minimum required and default setting for EN 50549-1/-2
60	AT	1	
90	GB, NIE, IE, 50549*	3	* Maximum required setting for EN 50549-1/-2
≥30 (according to product-standard)	IT*	1	* SPGMs and asynchronous PGMs with connection to the distribution network
Unlimited	IT*, IS**	2	* The other PPMs connected to the distribution network and all PGMs connected to the transmission network ** Defined for type B and D
n/a	BA, BG, ME, MK, RS, CY	6	
Minimum time operation in FR2			
30	BE, DE, FR, GR, LU, NL, PL, RO, SI, SK, EE, LT, LV, DK, FI, NO, SE, CH, 50549*	18	* Minimum required and default setting for EN 50549-1/-2
60	HR, HU	2	
90	AT*, CZ, GB, NIE, IE, 50549**	5	* Standard value and minimum 60 min ** Maximum required setting for EN 50549-1/-2
≥30 (according to product-standard)	IT*	1	* SPGMs and asynchronous PGMs with connection to the distribution network
Unlimited	ES, IT*, PT, IS**	4	* The other PPMs connected to the distribution network and all PGMs connected to the transmission network ** Defined for type B and D
n/a	BA, BG, ME, MK, RS, CY	6	
Minimum time operation in FR3			

Unlimited	AT, BE, CZ, DE, ES, FR, GR, HR, HU, IT, LU, NL, PL, PT, RO, SI, SK, GB, NIE, IE, EE, LT, LV, DK, FI, IS, NO, SE, CH, 50549*	29	* EN 50549-1/-2
n/a	BA, BG, ME, MK, RS, CY	6	
Minimum time operation in FR4			
30	AT, BE, CZ, DE, ES, FR, GR, HR, HU, LU, NL, PL, PT, RO, SI, SK, EE, LT, LV, DK, FI, NO, SE, CH, 50549*	24	* Minimum required and default setting for EN 50549-1/-2
90	GB, NIE, IE, 50549*	3	* Maximum required setting for EN 50549-1/-2
Unlimited	IT, IS*	2	* Defined for type B and D
n/a	BA, BG, ME, MK, RS, CY	6	
Minimum time operation in FR5			
15	GB, 50549*	1	* EN 50549-1/-2 however for these two norms this setting is not required and the default setting is 0 sec
30	NO	1	
60	IE, NIE	2	
n/a	AT, BA, BE, BG, CH, CZ, CY, DE, ES, FR*, GR, HR, HU, IT, LU, ME, MK, NL, PL, PT, RO, RS, SI, SK, EE, LT, LV, DK, FI, IS, SE	31	* Project-specific

Figure 5 shows that **Switzerland** has violated the RfG NC requirement regarding the non-exhaustive minimum operating periods of the frequency ranges FR1, FR2 and FR4. In **Switzerland**, for type A, B and C PGMs, there is a deviation for the frequency range FR1 in that within the range 47.5 - 48 Hz, the minimum operation time is defined as 10 min. Also, for 48 - 48.5 Hz, this value is 20 min. Both periods are shorter than the required value of at least 30 min. However, it should be noted that the grid code for **Switzerland** is still not finalized.

In **Italy**, SPGMs and asynchronous type A, B or C PGMs connected to the distribution network must maintain operation in FR1 and FR2 for at least 30 minutes according to their ability or product standard. This implementation meets the requirements of the RfG NC.

Iceland as an island system is an exception to the implementation and is therefore not affected by the requirements specified in RfG NC. Therefore, the type B and D systems (the only types defined within **Iceland**) connected to the transmission network must remain connected to the network at frequency ranges FR1 - FR4.

In some MS+, wider frequency ranges than those defined within the RfG NC framework have also been implemented. These are listed below in Table 14:

Table 14: Distribution of the MS+ with wider frequency ranges than defined in RfG NC

MS+	Frequency range [Hz]	Minimum operation time [min]	Comments
BE	51.5 - 52.5	Project specific	Only for type B, C and D PGMs
CZ	47 - 47.5	0.333	
FR	47 - 47.5	Project specific	
	51.5 - 52.5		
IT	<46.5	0.00167	Only at transmission level for type C and D
	46.5 - 47.5	0.067	
	51.5 - 52.5	0.0167	
	>52.5	0.00167	
IE	47 - 47.5	0.333	
	51.5 - 52	60	
NIE	47 - 47.5	0.333	
	51.5 - 52	60	
IS	47 - 47.5	0.333	Only defined for type B and D
	51.5 - 52	Unlimited	
	52 - 53	0.333	
NO	45 - 47.5	0.333	
	51.5 - 53	30	
	53 - 57	0.333	
	57 - 60	0.167	

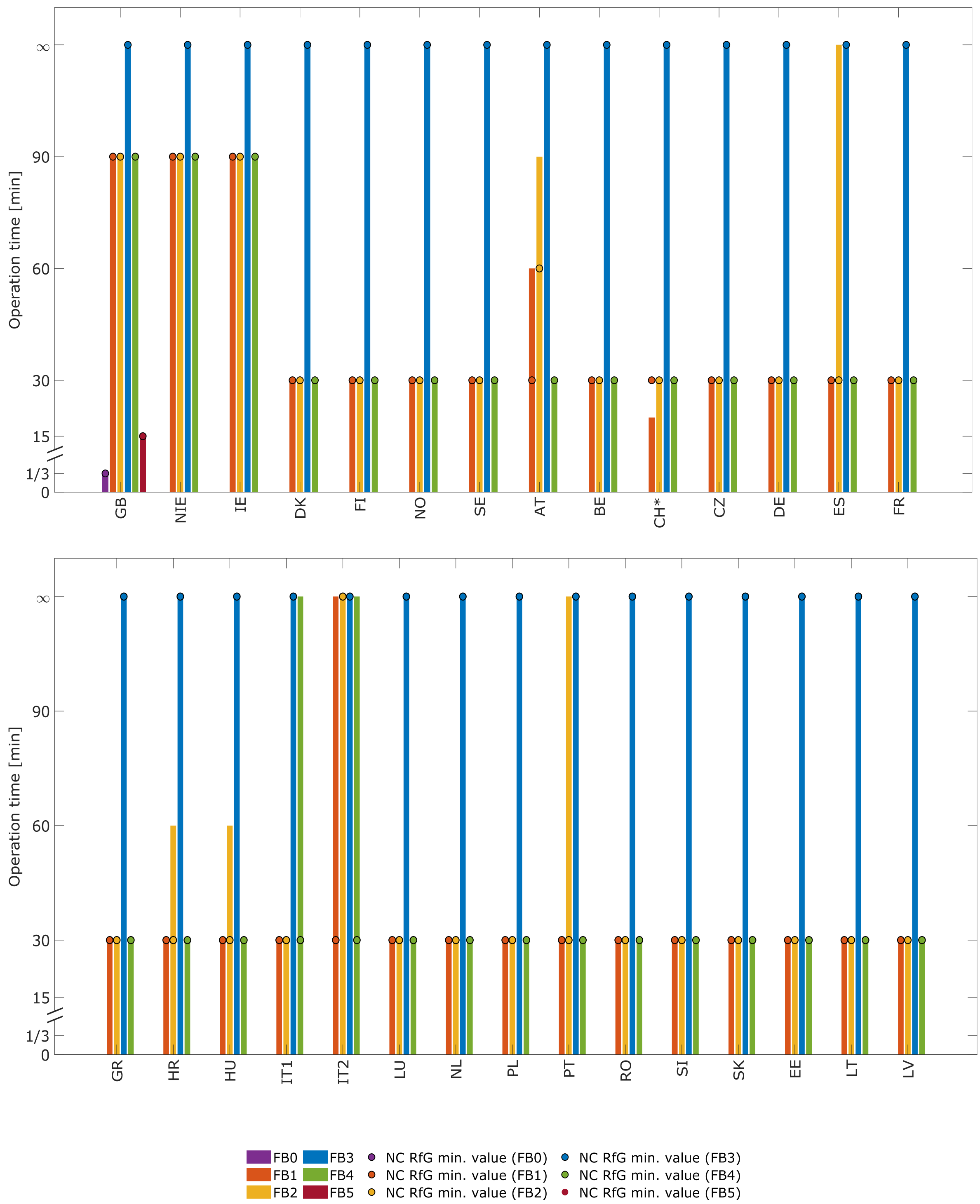
As an example, **Ireland** and **Northern Ireland** do define minimum operation times (20 sec) for the frequency range FR0 extending the operational requirement at frequencies beyond 47.5 Hz contradicting the set frequency ranges Table 2 of the RfG NC. Moreover, for frequency ranges between 51.5 Hz and 52 Hz, both countries require a minimum operation time of 60 minutes.

Note: Article 13 (1) (a) (ii) of RfG NC do allow the leverage to set wider frequency ranges after agreement between the relevant TSO and power generation facility owners. For the calculation of convergence level, FGH has taken note of this leverage and hence, counted the wider frequency ranges in the MS+ listed above as not a deviation.

The provisions of the two European standards EN 50549-1/-2 comply with those of RfG NC for the frequency ranges of FR1 - FR4. Moreover, the two European standards define operation times for FR0 and FR5 however these are not mandatory and their default time setting is 0.

Overall, based on the above analysis, the degree of convergence with respect to non-exhaustive parameters is 97% (28/29). Similarly, there are no deviations observed for the frequency ranges FR0, FR3 and FR5 (exhaustive parameters). This results in a convergence level of 100%.

Figure 5: Convergence of minimum operating periods



IT1 = Requirements for SPGMs and asynchronous PGMs connected to the distribution networks
IT2 = Requirements for other PPMs connected to the distribution networks
* For FB1 : 10 min between 47,5 Hz and 48 Hz (not illustrated) and 20 min between 48 Hz and 48,5 Hz

4.2.1.2. Resistance to frequency gradients (Rate of Change of Frequency - ROCOF)

A PGM of type A and above must be able to maintain connection to the network and operation in case of frequency gradients up to a certain value in accordance with Article 13 (1) (b) of RfG NC, unless the disconnection from the network was the consequence of the tripping of the power failure protection caused by frequency changes. Two important aspects that can be defined for the ROCOF requirement are:

- Sliding frequency measurement window
- Maximum threshold for ROCOF, above which tripping is permitted.

No particular values or ranges are defined within RfG NC with respect to ROCOF requirement and the focus was laid to introduce the ROCOF as a mandatory requirement for PGUs. The MS+ are free to set the parameters of frequency gradients and sliding windows.

Convergence of implementations

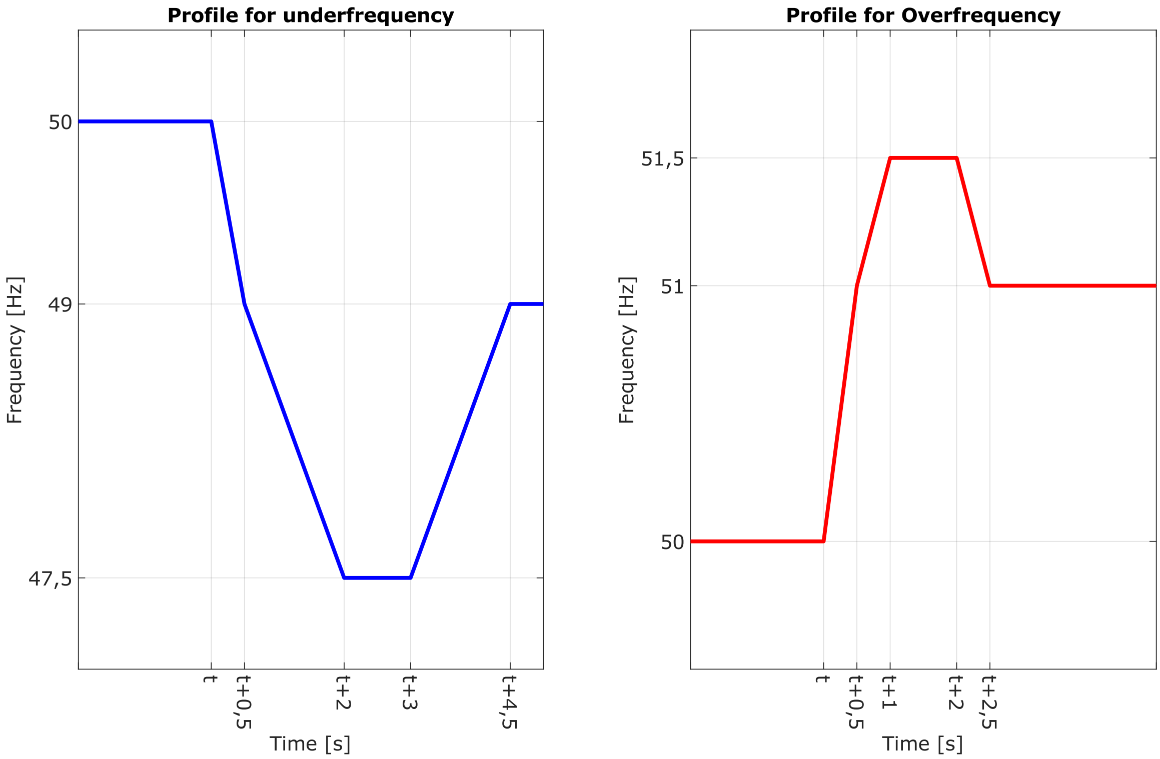
The ROCOF characteristics defined in the individual MS+ are shown in Table 15:

Table 15: Distribution of the maximum frequency gradient (+/-) with the corresponding sliding window (SW)

Value [Hz/s]	MS+	Number of MS+	Comments
0,5 (n/a for SW)	IS*	1	* Defined for type B and D
1 (for 0,5s)	GB, NIE, IE, 50549*	3	* EN 50549-1/-2, here SPGM
1,5 (for 1s)	NO	1	
2 (n/a for SW)	AT, DK	2	
2 (for 0,5s)	CZ, ES, HR, HU*, PL, SI, SK, FI, SE, PT, 50549**	10	* Defined for type B, C and D ** EN 50549-1/-2, here non-SPGM
2,5 (n/a for SW)	EE	1	
2,5 (for 0,5s)	HU*, LT, LV	3	* Defined for type A
2,5 (for 0,1s until 1s)	IT	1	
1,25 (for 2s) or 1,5 (for 1s) or 2 (for 0,5s)	DE, LU, NL, RO	4	
Over - and underfrequency profile	BE, GR	2	
n/a	CY, BA, BG, CH, FR, ME, MK, RS	8	

It is obvious that especially island-countries like **Iceland** or **Ireland** show the most stringent requirements on ROCOF capabilities due to their high needs for system stability. In **Belgium** and **Greece**, the resistance to frequency gradients is defined according to the frequency-time profiles for overfrequency and underfrequency shown in Figure 6:

Figure 6: Frequency-time profiles to define the resistance to frequency gradients in Belgium and Greece



In **France**, ROCOF is required. However, no concrete definition has been made till the cut-off date of this study. On the other hand, in **Switzerland**, there is no requirement given for ROCOF. Therefore, by considering **Switzerland** as a deviating country, a degree of convergence of 97% (28/29) is achieved with this requirement.

4.2.1.3. Permissible reduction in the maximum active power output with falling frequency

A permissible reduction in the maximum active power output with falling frequency is to be set in accordance with Article 13 (4) for PGMs of types A to D. The active power reduction is defined as a reduction gradient that shall lie within predefined limits. The lower limit corresponds to a reduction by 2% of the maximum capacity (Pmax) per frequency drop of 1 Hz below a frequency of 49 Hz. The upper limit corresponds to a reduction by 10% of the maximum capacity per frequency drop of 1 Hz below a frequency of 49.5 Hz.

The implementation status of the reduction gradient and the frequency threshold values for reducing the maximum active power output can be found in Table 16:

Table 16: Distribution of the permissible reduction in the maximum active power output with falling frequency

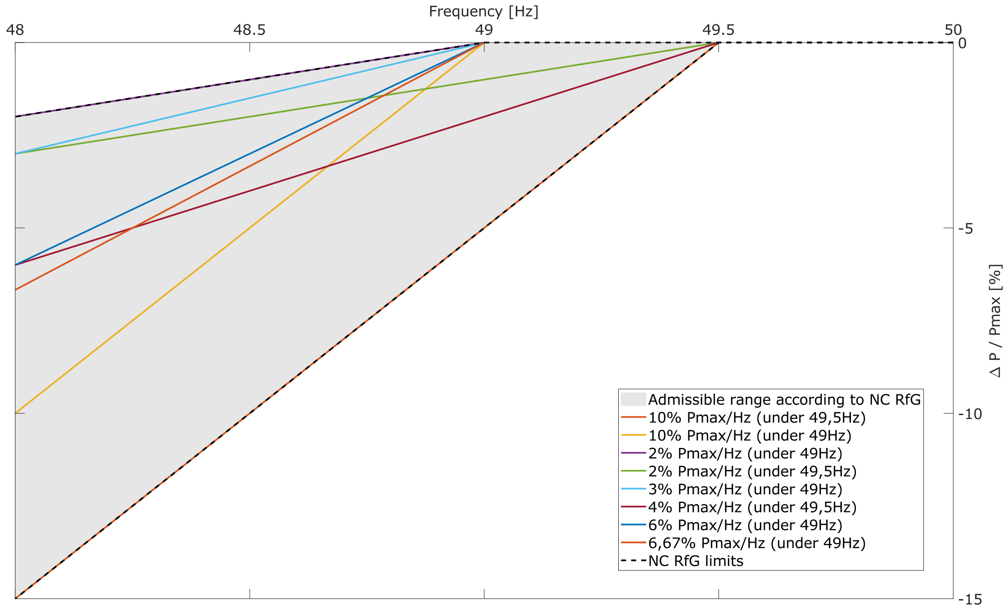
Value [%Pmax/Hz]	MS+	Number of MS+	Comments
10 (under 49.5 Hz)	AT[1], BE[2], DE, ES[3], FR[2], GR[2], LU, NL, RO, SI[2], FI, NO, CH[1] 50549[4]	13	([1]) Defined for SPGM ([2]) Defined for SPGM in the stationary range ([3]) Defined for Gas turbines ([4]) EN 50549-1/-2 default settings
10 (under 49 Hz)	PL[1]	1	(1) Defined for the other SPGMs (except gas and CCGT SPGM)
2 (under 49 Hz)	AT[1], BE[2], CZ, FR[3], GR[3], HR[1], IT[4], LU, PL[1], PT, RO[5], SI[2], SK[6], NIE[5], IE[5], EE, LT, LV, 50549[7]	18	([1]) Defined for PPM ([2]) Defined for SPGM in the transient range and PPM ([3]) Defined for SPGM in the transient range ([4]) Defined for the other SPGMs (except gas turbines and CCGT SPGM) ([5]) Defined for the transient range (SPGM and PPM) ([6]) For technologically limited PGMs ([7]) EN 50549-1/-2
2 (under 49.5 Hz)	GB, NIE[1], IE[1], IT[2]	4	([1]) Defined for the stationary range (SPGM and PPM) ([2]) Defined for gas turbines or CCGT SPGM
3 (under 49 Hz)	SE	1	
4 (under 49.5 Hz)	PL[1]	1	([1]) Defined for gas turbines or CCGT SPGM
6 (under 49 Hz)	DK	1	
6,67 (under 49 Hz)	HR[1]	1	([1]) Defined for SPGM
Between 10 (under 49.5 Hz) & 2 (under 49 Hz)	HU	1	
Not allowed	FR[1], GR[1]	2	([1]) Defined for PPM
n/a	ES[1], IT[1], CY, BA, BG, ME, MK, RS, IS	9	([1]) For PPM n/a

The technical capabilities of PGMs as well as their categories and technologies have been taken into account for the definition of the requirements. In some MS+ (e.g. **Belgium**, **France**, **Greece**, **Romania**, **Slovenia**, **Northern Ireland** and **Ireland**), maximum power reduction differs according to a so called stationary or transient mode defined for specific time ranges of the frequency drop. For example, in **Belgium**, the transient range covers the first 30 seconds starting from the detection of the frequency drop. During this time, the PGM must meet the relevant *most stringent* requirement of the applicable European standard EN 50549-1 or EN 50549-2 as indicated above. On the other hand, during steady state (i.e. after 30 seconds), the power-generating module must meet the relevant standard requirement of the applicable standard EN 50549-1 or EN 50549-2. RfG NC however does not provide technical information regarding the aspect of transient and steady state ranges.

Convergence of implementations

All national alternatives for implementing the permissible reduction in the maximum active power output with decreasing frequency are summarized and illustrated in Figure 7:

Figure 7: Convergence of the allowable reduction in the maximum active power output with falling frequency



This figure shows that all implementations are within the range specified in the RfG NC. Therefore, a degree of convergence of 100% (29/29) has been reached.

In addition, the provisions of EN 50549-1/-2 comply with the NC-RfG requirements.

4.2.1.4. Limited Frequency Sensitive Mode - Overfrequency (LFSM-O)

The requirements for the limited frequency sensitive mode - overfrequency (LFSM-O) for PGMs of types A or above must be defined in accordance with Article 13 (2) of RfG NC in terms of the frequency threshold and the droop. While the frequency threshold must be between 50.2 Hz and 50.5 Hz, the droop must be selected between 2% and 12%. Since the LFSM-O is about a frequency sensitive reduction in the active power output, a certain behavior of the PGM may be required when the minimum regulating level, i.e. the minimum power for regular operation is reached. Two actions are possible: Either the PGM must continue operating at this value or the active power must be further reduced.

Table 17 provides an overview of the values or ranges selected in the individual MS+ with regard to the parameterization of the LFSM-O:

Table 17: LFSMO) Distribution of the frequency threshold value, droop and the actions when the minimum regulating level is reached

Value [Hz], [%] resp.	MS+	Number of MS+	Implementation according to Figure 9	Comments
Frequency threshold (in Hz) at LFSM-O				
50.2 to 50.5 (Default = n/a)	IS, NO*	2	Impl.1a	* Defined for type C and D
50.2 to 50.5 (Default = 50.2)	AT, CZ, DE, FR, HU, LU, NL, PL, DK1	9	Impl.1a	
50.2 to 50.5 (Default = 50.5)	DK2	1	Impl.1a	
50.2	BE, ES, GR, HR, IT, RO, SI, SK, NIE, IE, EE, LT, LV, CH, PT, 50549*	15	Impl.2a	* Default setting for EN 50549-1/-2 however the value may be set from 50.2 Hz - 52 Hz
50.4	GB	1	Impl.3a	
50.5	FI, NO*, SE	3	Impl.4a	* Defined for type A and B
n/a	CY, BA, BG, ME, MK, RS	6	-	
Droop (in %) of LFSM-O				
2 to 10 (Default = 10)	GB	1	Impl.1b	
2 to 12 (Default = n/a)	IS, NO*	2	Impl.2b	* Defined for type C and D
2 to 12 (Default = 4)	NIE, IE, FI	3	Impl.2b	

2 to 12 (Default = 5)	AT, BE, DE, GR, HR, HU, LU, PL, RO, SI, LT, LV, CH, CZ*, 50549**	14	Impl.2b	* Distribution system ** EN 50549-1/-2
3 to 12 (Default = 5)	FR	1	Impl.3b	
4 to 5 (Default = n/a)	IT*	1	Impl.4b	* Defined for SPGM of type A and B
4 to 6 (Default = n/a)	PT	1	Impl.5b	
4 to 10 (Default = 5)	CZ*	1	Impl.6b	* Type D
4 to 12 (Default = 5)	NL	1	Impl.7b	
2,6	IT*	1	Impl.8b	* Defined for PPM
4	IT*, DK2, NO**	3	Impl.9b	* Defined for type C and D hydraulic SPGM ** Defined for types A and B
5	ES, IT*, SK, EE, DK1	5	Impl.10b	* Defined for thermal SPGM type C and D
8	SE	1	Impl.11b	
n/a	CY, BA, BG, ME, MK, RS	6	-	
Actions when the minimum regulating level is reached (LFSM-O)				
Operation to continue at this value	AT, BE, ES, GR, HR*, IT**, NL, PL, PT, SK, GB, NIE, IE, EE, LT, DK, FI, SE	18	-	* Defined for SPGM ** Defined for SPGM

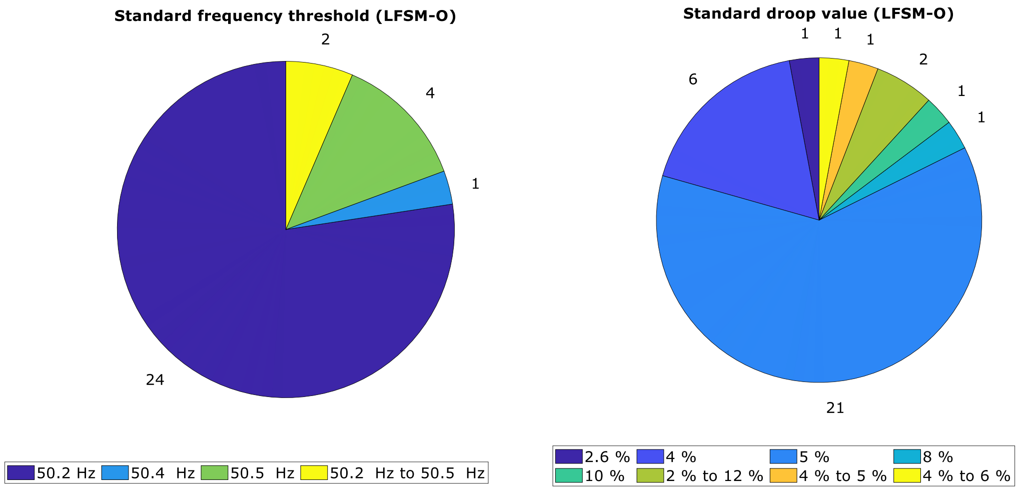
Further reduction in active power	DE, HR*, HU, IT** , LU, NO	6	-	* Defined for PPM ** Defined for PPM
n/a	CZ, FR, RO, SI, LV, IS, CY, BA, BG, CH, ME, MK, RS	13	-	

Many MS+ have defined a range for the respective parameters, in general taking the outer envelope provided by NC-RfG. Some of these have specified a default value within the specified range. In addition, other MS+ have chosen fixed values where only 6 have defined such fixed requirements for both the threshold and the droop. Again, many MS+ differentiate their requirements according to the PGM's technology (e.g. SPGM, PPM).

With respect to the requirements on the PGM's operation when the minimum regulating level is reached 18 provisions to continue operation at this level is found, whereas in six cases a further power reduction is requested. A total of 13 countries have not addressed this issue at all.

By only considering the standard and fixed values for the frequency thresholds and droops, the respective distribution of the different implementations is as given in Figure 8:

Figure 8: Distribution of the standard / fixed values for the frequency threshold and droops for the LFSM-O

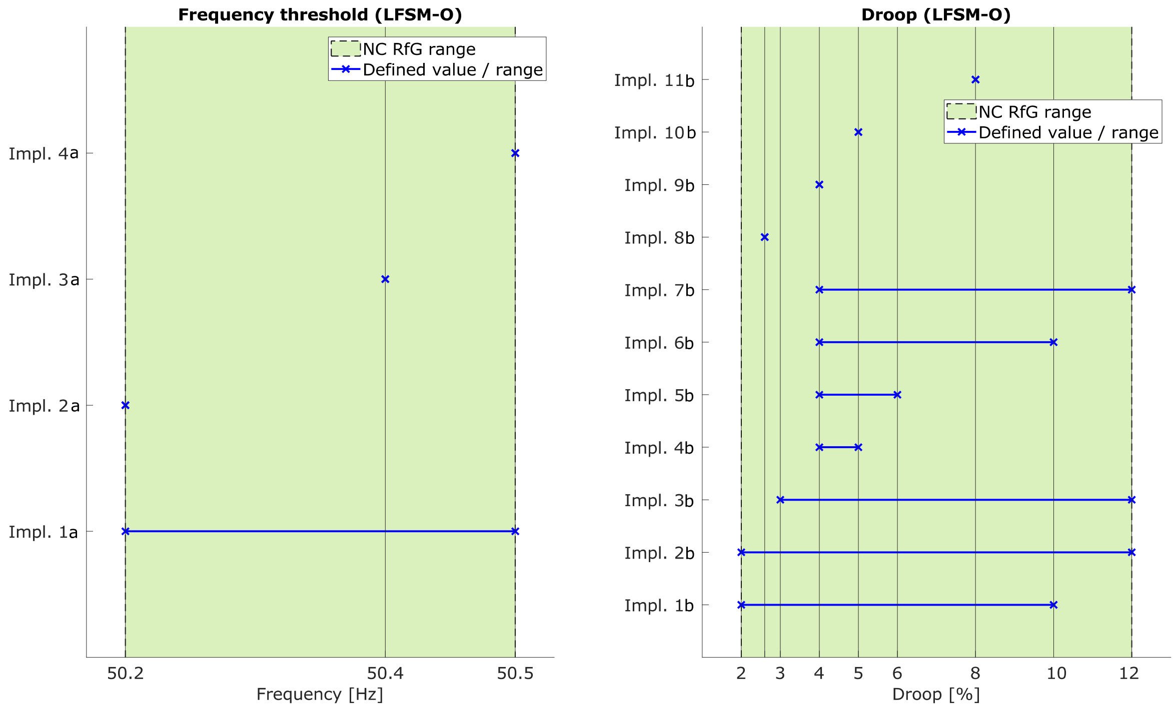


Here, the number next to the circular segments indicates the quantity of implementations of that respective value. The frequency value 50.2 Hz is most often selected as the standard / fixed threshold. In terms of droops, the most frequently selected value is 5%.

Convergence of implementations

Figure 9 assembles the different implementations that were observed in terms of the required parameters of the LFSM-O:

Figure 9: Convergence of frequency threshold and droops in LFSM-O



The labels of implementation within the above figure correspond to those within Table 17. Since all implementations are within the green areas as provided by the RfG NC, a degree of convergence of 100% (29/29) is calculated in this case.

Another convergence level may be defined with respect to the parameter "initial delay" which has to be less than 2 seconds according to RfG NC. However, even if it is more than this defined threshold, the power facility owner has to justify the reasons behind a larger delay to the relevant TSO. In that sense, it can be concluded that exemptions or derogations take place for each MS+.

4.2.1.5. Definition of Pref for PPMs

When implementing the frequency sensitive mode (FSM) or the limited frequency sensitive modes (LFSM-O and LFSM-U) for PPMs, the TSO shall specify, a reference power to which the requested droop is related to (in order to derive a nominal power reduction). This parameter can be either:

- The Maximum Capacity of the generator (Pmax) or
- The actual active power at the moment of entering into LFSM or FSM operation by passing the frequency threshold (Pmom).

For SPGMs the reference power is always Pmax.

Table 18 shows the definition of the reference active power in the various MS+.

Table 18: Distribution of the reference active power definition (Pref) for LFSM and FSM for PPMs

Definition	MS+	Number of MS+
Reference active power (Pref) for LFSM and FSM for PPMs		
Maximum Power Capacity (Pmax)	ES, GR, HR, HU, PL, PT, RO, SI, GB, NIE, IE, EE, LT, DK, FI, IS, NO, SE	18
Actual active power output at the time of reaching the threshold value (Pmom)	AT, BE, CH, DE, FR, IT, LU, NL, EN 50549-1/-2	8
Defined by the System Operator	CZ, SK, LV	3
n/a	CY, BA, BG, ME, MK, RS	6

Convergence of implementations

In some MS+ the definition of Pref is defined by the system operator as also indicated in the above table. Nevertheless, since all MS+ have defined at least one mode (LFSM or FSM), a degree of convergence of 100% applies here (29/29).

4.2.1.6. Logic interface for cease of active power

PGMs of type A and above must have the capability to case active power within 5 seconds using an interface (input port) as stated in Article 13 (6) of RfG NC.

Convergence of implementations

Table 19 demonstrates the distribution of the MS+ who have implemented the aforementioned requirement:

Table 19: Distribution of the MS+ based on the capability of PGMs to cease active power using a logic interface

Implementation	MS+	Number of MS+	Comments
Type A	AT, BE, CZ, DE, FR, GR, IT, NL, PL*, RO, SI, IE, NIE, LT*, DK, FI, NO**, GB, LU	19	* Cease within 5 sec not mentioned explicitly **In general required for units above 0.1 MW
n/a	CY, BA, BG, ME, MK, RS, CH, EE, ES, HR, HU, IS, LV, PT, SE, SK	16	

In **Lithuania** and **Poland**, a reference has been made to the corresponding article of RfG NC regarding the stoppage of active power. However, the 5 second criterion is not explicitly mentioned. Instead, an agreement must be made with the relevant network operator. A similar case exists for **Norway**, where the need to remotely disconnect units in line with article 13 (6) is in general required for units above 0.1 MW. However, again a discussion is needed with the network operator.

The above analysis results in a convergence level of 66% (19/29).

4.2.1.7. Automatic connection

This requirement refers to the automatic connection of the PGM to the network under a normal start-up operation typically with respect to some operating parameters (e.g. permissible voltage and frequency ranges before connection). This type of connection is differentiated from a reconnection after tripping of the protection system due to the occurrence of a failure in the system.

Within the context of connection, certain requirements need to be taken into account. These include the permissible frequency range, voltage range, delay time before connection and maximum active power increase gradient. The two standards EN 50549-1 and EN 50549-2 define the ranges for each of the aforementioned parameters.

Convergence of implementations

Table 20 shows the distribution of the MS+ who have implemented the above requirement:

Table 20: Distribution of the MS+ based on automatic connection requirements

Implementation	MS+	Number of MS+	Comments
Type A	AT, BE, CZ, DE, ES, FR, GR, IT*, NL, PL, PT, RO, SI, SK, IE, NIE, EE, LT, LV, DK, FI, NO, SE	23	* also required for storage units
n/a	CY, BA, BG, ME, MK, RS, CH, HR, HU, LU, IS, GB	12	

It is worth mentioning that the delay time before starting generation of electrical power is defined from 5 to 15 min in **Slovakia** which can become a deviation from the requirements of EN 50549-1/-2 considering that in these two standards a maximum delay of 10 min is possible.

According to the above table, 23 MS+ have implemented the requirement which results in a degree of convergence of 79% (23/29). As mentioned before, the six MS+ CY, BA, BG, ME, MK and RS are excluded from this report and therefore not counted.

4.2.1.8. Summarization of convergence levels

In Table 21, the results of convergence on the RfG NC technical requirements for type A PGMs are shown:

Table 21: Summary of type A related technical requirements convergence in MS+

Requirement	Convergence level [%]
Frequency ranges and minimum periods for operation	97
Resistance to frequency gradients (Rate of Change of Frequency - ROCOF)	97
Permissible reduction in the maximum active power output with falling frequency	100
Limited Frequency Sensitive Mode - Overfrequency (LFSM-O)	100
Definition of Pref for PPMs	100
Logic interface for cease of active power	66
(Automatic) connection	79
Average convergence level	91%

Results presented in Table 18 shows high degree convergence for type A requirements among MS+. It represents that almost all of the MS+ members have taken into account the RfG NC guidelines in their national implementations. Deviations in the national implementation of **Switzerland** can be attributed to the fact that the final implementations are still not published. National implementation in **Ireland** and **Northern Ireland** among other MS+ on the frequency ranges, although not taken in as a deviation in the convergence calculation, need to be specially mentioned in the context of possible deviations to the set frequency limits in RfG NC.

Table 22 demonstrates a list of all the MS+, where at least one deviation from the RfG NC framework exists with respect to type A requirements:

Table 22: MS+ with requirement deviations from RfG NC with respect to type A PGMs

No.	MS+	Requirement deviations from RfG NC	Reason for deviation
1	Switzerland	Frequency Ranges and minimum time period for operation	has violated the RfG NC requirement regarding the non-exhaustive minimum operating periods of the frequency ranges FR1, FR2 and FR4
		Resistance to frequency gradients	Requirement not defined
		Logic interface for cease of active Power	Requirement not defined
		Automatic Connection	Requirement not defined

2	Estonia	Logic interface for cease of active Power	Requirement not defined
3	Spain	Logic interface for cease of active Power	Requirement not defined
4	Croatia	Logic interface for cease of active Power	Requirement not defined
		Automatic Connection	Requirement not defined
5	Luxembourg	Automatic Connection	Requirement not defined
6	Sweden	Logic interface for cease of active Power	Requirement not defined
7	Slovakia	Logic interface for cease of active Power	Requirement not defined
8	Portugal	Logic interface for cease of active Power	Requirement not defined
9	Great Britain	Automatic Connection	Requirement not defined
10	Hungary	Logic interface for cease of active Power	Requirement not defined
		Automatic Connection	Requirement not defined
11	Latvia	Logic interface for cease of active Power	Requirement not defined
12	Iceland	Logic interface for cease of active Power	Requirement not defined
		Automatic Connection	Requirement not defined

4.2.2. Type A additional requirements

The previous section has focused on type A requirements which are within the scope of RfG NC. Hence, a convergence level was calculated in the context of the rules set out by the RfG NC framework.

In this section, additional requirements specific for type A modules outside the scope of RfG NC (for type A PGM) but required in different MS+ are analyzed. Table 23 lists an overview of these requirements. Typically, these requirements are also embedded in the EN 50549-1/-2 standards. Where a difference exists between the implementation of a requirement in a MS+ with that of the two European standards, these have been highlighted within this report.

Table 23: Type A additional requirements (outside the scope of RfG NC)

Type A additional requirements
Limited Frequency Sensitive Mode - Underfrequency (LFSM-U)
Voltage related active power reduction (P(U))
Frequency related protection
Voltage ranges and minimum periods for operation
Voltage related protection
U-Q/Pmax for SPGMs
U-Q/Pmax for PPMs
P-Q/Pmax for SPGMs
P-Q/Pmax for PPMs
Reactive power control
Power quality
LVRT for SPGM
LVRT for PPM
Over Voltage Ride Through (OVRT)
Vector shift
Zero current mode for PPM technology
Active power recovery after fault
Reconnection/synchronization requirements after disconnection
Unintentional/Intentional Islanding operation
Uninterruptible Power Supply (UPS)
Information exchange

Deviating from chapter 4.2.1 on RfG NC embedded requirements the individual specification of the above requirements in the national grid code implementation will not be depicted in the following. The analysis is restricted to the identification of MS+ having these additional requirements in their national grid code implementation and, hence, deriving a degree of incidence.

4.2.2.1. Limited Frequency Sensitive Mode - Underfrequency (LFSM-U)

This requirement for the operation with underfrequencies is defined within RfG NC for PGMs starting from type C (Article 15 (2) (c)). In **Germany**, this requirement has been implemented for type A modules (SPGMs and PPMs) as well as storage systems. Moreover, **Italy** and the **Czech Republic** have this requirement installed for energy storage systems as well.

The two standards EN 50549-1/-2 also define parameters for the LFSM-U mode for both type A and B modules. However, the information given within these standards serve as recommendations and is not mentioned as a requirement.

Incidence of implementations

For type A modules in general, the degree of incidence with respect to LFSM-U is 3% (1/29). In terms of storage systems, the degree of incidence is calculated as 10% (3/29). It is also important to note that the scope RfG NC does not include storage system.

4.2.2.2. Voltage related active power reduction (P(U))

This requirement is defined within the two standards EN 50549-1/-2. According to this requirement, PGMs are allowed to reduce their active power during an overvoltage in order to avoid tripping of the overvoltage protection.

Incidence of implementations

Among the MS+, only the **Czech Republic**, **France**, **Germany** and **Italy** have defined this requirement. This results in a degree of incidence of 14% (4/29).

4.2.2.3. Frequency related protection

According to Article 14 (5) (b) of RfG NC, the relevant network operator will specify the requirements for protection schemes which the PGM will have to comply with for all PGM of type B and above. However, RfG NC only gives generic, qualitative information without setting any boundaries for the acceptable settings of the various available protection methods. Moreover, RfG NC brings forth a list of possible protection schemes that may be implemented without making any of these mandatory. As a result, every protection related implementation is left to a coordination between the relevant network operator and the PGM.

An analysis is carried out in this report on the implementation of the two main frequency related network protection methods, namely underfrequency and overfrequency protection. Parameters that may be taken into account are the frequency threshold values for the tripping of the respective protection devices as well as the delay time needed before tripping takes place.

Incidence of implementations

Table 24 shows the distribution of the MS+ who have implemented the above-mentioned requirement for type A PGMs:

Table 24: Distribution of the MS+ based on frequency related protection schemes (Overfrequency / Underfrequency)

Implementation	MS+	Number of MS+	Comments
type A	AT, CH, CZ, DE, IT*, NL, DK, GB	8	* Also required for energy storage systems
n/a	CY, BA, BG, ME, MK, RS, HR, HU, LU, IS, BE, SI, PL, PT, RO, SK, IE, NIE, EE, LT, LV, FI, NO, SE, ES, FR, GR	27	

It must be noted that with respect to under- and overfrequency protection methods, the two standards EN 50549-1/-2 define ranges for the aforementioned parameters for modules of type B only.

The analysis results in an incidence level of 28% (8/29).

4.2.2.4. Voltage ranges and minimum periods of operation

In RfG NC, this requirement is defined for modules starting from type D (Article 16 (2)). Therefore, it is regarded as non-mandatory for type A modules. Nevertheless, the analysis has shown that some MS+ have implemented minimum operation times for various voltage ranges for the aforementioned type as well.

Incidence of implementations

The distribution of the countries with respect to the aforementioned requirement is brought within Table 25:

Table 25: Distribution of the MS+ based on the minimum time period requirement for various voltage ranges

Implementation	MS+	Number of MS+	Comments
Type A	AT, CZ, DE, IT, NL, DK, GB*, BE, FR	9	
n/a	CY, BA, BG, ME, MK, RS, CH, HR, HU, LU, IS, SI, PL, PT, RO, SK, IE, NIE, EE, LT, LV, FI, NO, SE, ES, GR	26	

*No minimum operational time is mentioned, however compliance test under grid connection procedure do mention test with below standard operational voltage limits

The two European standards EN 50549-1/-2 define ranges with respect to voltage and time periods for this requirement. For EN 50549-1, unlimited operation is required between voltage values of 0.85 - 1.1 p.u. EN 50549-2 also requires unlimited operation however, the voltage range is from 0.9 to 1.1 p.u. The detailed analysis shows that some of the nine countries having implemented the requirement do deviate from the EN standards in terms of the voltage band definition. The following observations are made by comparing these requirements with the implementation of the MS+:

1) For **Austria**, **France** and **Italy**, there exists a deviation from the European standard EN 50549-1 because these countries set a limited duration for voltage ranges between 0.85 - 0.9 p.u.

2) There is also a deviation from EN 50549-2 for **France** and **Great Britain**. Again, for **France** the same argumentation as above can be utilized, but limited for the BT (≤1kV) and HTA (≤50kV) codes. Nevertheless, for HTB1 codes (≤63kV and ≤90kV) the voltage limits required by the EN 50549-2 are met. For the case of **Great Britain**, for type A modules, operation must be unlimited. However, the defined voltage range of this country (0.94 - 1.06 p.u) is smaller than the requirement of the European Standard.

9 MS+ have implemented the requirement for type A modules. As a result, the degree of incidence is equal to 31% (9/29).

4.2.2.5. Voltage related protection

Similar to the analysis made for frequency related protection schemes, here the results are discussed for the two network protection modes, undervoltage and overvoltage. Again, according to the two standards EN 50549-1/-2, voltage related protection is only for type B modules and above. Parameters that are taken into consideration are the voltage threshold values for the tripping of the respective protection devices as well as the delay time needed before tripping takes place. In the EN standards two voltage thresholds (and respective delay times) are defined for both under- and overvoltage protection.

Incidence of implementations

Table 26 shows the distribution of the MS+ that have implemented the above-mentioned requirement:

Table 26: Distribution of the MS+ based on voltage related protection schemes (Overvoltage / Undervoltage)

Implementation	MS+	Number of MS+	Comments
type A	AT, CZ, DE, IT, NL, DK, GB	7	
n/a	CY, BA, BG, ME, MK, RS, CH, HR, HU, LU, IS, BE, SI, PL, PT, RO, SK, IE, NIE, EE, LT, LV, FI, NO, SE, ES, FR, GR	28	

From the above table, a degree of incidence of 24% (7/29) is derived.

4.2.2.6. U-Q/P_{max} for SPGMs

RfG NC defines a framework for reactive power capability at maximum capacity with varying voltage (U-Q/P_{max}) for SPGMs starting from type C (Article 18 (2). As this is a not-mandatory requirement, the threshold curves applied for type C and D generators do not apply. Within the two standards EN 50549-1/-2, this requirement is also defined for SPGMs, but actually starting from type B.

Incidence of implementations

Regardless of the above statements, some MS+ require this capability for type A modules as well. These have been listed in Table 27:

Table 27: Distribution of the MS+ based on U-Q/P_{max} for SPGMs

Implementation	MS+	Number of MS+	Comments
type A	AT, CZ*, DE, NL, DK, GB	6	* Defined for type A1 (cf. chapter 3.4)
n/a	CY, BA, BG, ME, MK, RS, CH, HR, HU, LU, IS, BE, SI, PL, PT, RO, SK, IE, NIE, EE, LT, LV, FI, NO, SE, ES, FR, GR, IT	29	

The final degree of incidence is equal to 21% (6/29).

4.2.2.7. U-Q/P_{max} for PPMs

Similar to SPGMs, RfG NC defines a framework for reactive power capability at maximum capacity with varying voltage (U-Q/P_{max}) for PPMs starting from type C (Article 21 (3) (b)). As this is a not-mandatory requirement, the threshold curves applied for type C and D generators do not apply. Within the two standards EN 50549-1/-2, this requirement is also defined for PPMs starting from type B.

Incidence of implementations

Table 28 illustrates the MS+ who have implemented the requirement for type A PPMs:

Table 28: Distribution of the MS+ based on U-Q/P_{max} for PPMs

Implementation	MS+	Number of MS+	Comments
type A	AT, DE, NL, DK, NIE	5	
n/a	CY, BA, BG, ME, MK, RS, CH, HR, HU, LU, IS, BE, SI, PL, PT, RO, SK, IE, EE, LT, LV, FI, NO, SE, ES, FR, GR, IT, CZ, GB	30	

The final degree of incidence is equal to 17% (5/29).

4.2.2.8. P-Q/Pmax for SPGMs

For SPGMs, no specific framework for the P-Q capability curve with respect to varying active power has been defined within RfG NC. In general, SPGMs must be able to operate successfully within each operating point of their alternator's predefined P-Q curve. Moreover, this applies to SPGMs starting from type C. Within the two standards EN 50549-1/-2, this requirement is also defined for SPGMs starting from type B.

Incidence of implementations

For the P-Q/P_{max} requirements, the following MS+ require this capability for type A SPGMs as well:

Table 29: Distribution of the MS+ based on P-Q/P_{max} for SPGMs

Implementation	MS+	Number of MS+	Comments
type A	AT, CZ, DE, DK, NIE	5	
n/a	CY, BA, BG, ME, MK, RS, CH, HR, HU, LU, IS, BE, SI, PL, PT, RO, SK, IE, EE, LT, LV, FI, NO, SE, ES, FR, GR, IT, NL, GB	30	

Hence, the degree of incidence is equal to 17% (5/29).

4.2.2.9. P-Q/P_{max} for PPMs

RfG NC defines a framework for reactive power capability at varying power outputs (P-Q/P_{max}) for PPMs starting from type C (Article 21 (3) (c)). Within the two standards EN 50549-1/-2, this requirement is also defined for PPMs starting from type B.

Incidence of implementations

Table 30 illustrates the MS+ who have implemented this requirement for type A PPMs:

Table 30: Distribution of the MS+ based on P-Q/P_{max} for PPMs

Implementation	MS+	Number of MS+	Comments
type A	AT, DE, NL, DK, NIE, IT	6	
n/a	CY, BA, BG, ME, MK, RS, CH, HR, HU, LU, IS, BE, SI, PL, PT, RO, SK, IE, EE, LT, LV, FI, NO, SE, ES, FR, GR, CZ, GB	29	

The analysis results in a degree of incidence of 21% (6/29).

4.2.2.10. Reactive power control

Given the requirements on reactive power supply ranges as depicted in the previous subsections, automatic reactive power control shall be provided by PPMs of type C and D according to RfG NC (Article 21 (3) (d)). The three possible modes within this framework are reactive power setpoint, voltage control (i.e. Q(U) control) or power factor setpoint. The EN standards 50549-1/-2 do address these modes as well next to an additional cos φ (P) control.

Incidence of implementations

Some MS+ require the implementation of reactive power control for type A modules (PPM and/or SPGM) as well. Furthermore, some countries define additional modes that are outside the scope of RfG NC (e.g. cos φ (P)). For technical clarity reasons Table 31 gives a detailed overview on the different mode implementations:

Table 31: Distribution of the MS+ based on reactive power control for type A modules

Implementation	MS+	Number of MS+	Comments
Constant cos φ	AT, DE	2	
cos φ (P)	AT, GB, DK, DE	4	
Q(U)	AT, NL, GB, IE, DE	5	
Constant Q	AT	1	
Q setpoint	AT, GB, IE, DK	4	
Q (cos φ)	NL, GB, IE, DK	4	
n/a	CY, BA, BG, ME, MK, RS, CH, HR, HU, LU, IS, BE, SI, PL, PT, RO, SK, EE, LT, LV, FI, NO, SE, ES, FR, GR, CZ, NIE, IT	29	

Since for type A modules this requirement is non-mandatory and also due to the fact that each of the above MS+ has their own implementations, it is checked whether each MS+ has implemented at least 1 control mode in order to calculate a degree of incidence. On this basis, the degree of incidence is 21% (6/29).

Side Note: The introduction of reactive power control requirements for low-voltage installations in Germany is mainly based on a recommendation of a study commissioned by the German standard-leading institute FNN at VDE. Here, the strong positive effects on voltage support became evident [6].

4.2.2.11. Power quality

Since the aspects revolving power quality are outside the scope of RfG NC, these have not been classified in terms of the 4 types of modules (A, B, C or D). Moreover, power quality is a concept which is analyzed at the plant level only, because it refers to the compatibility between the electric power supplied and the load connected to the system.

The following characteristics have been considered under the concept of power quality:

- Voltage increase,

- Rapid voltage change

- Harmonic current

- Flicker

- Total harmonic distortion (THD)

- Voltage asymmetry

- Short circuit power

The European standards EN 50549-1/-2 do not provide strict requirements on power quality either, but give reference to EU directives (2014/30/EU, 2014/53/EU) and external standards such as EN 61000 (with restrictions). EN 61400-21, DIN 0124-100 and EN 50160.

Incidence of implementations

Table 32 demonstrates the distribution of MS+ with respect to the aforementioned parameters related to power quality:

Table 32: Distribution of the MS+ based on power quality

Implementation	MS+	Number of MS+	Comments
Voltage increase	CZ, GB, DE	3	
Rapid voltage change	CZ, FR, HU, GB, IE, DK, DE, IT	8	
Harmonic current	CZ, FR, GB, IE, DK, IT	6	
Flicker	CZ, FR, HR, HU, GB, IE, DK, DE, IT	9	
Total Harmonic Distortion (THD)	FR, HR, HU, GB, IE, DK, DE, IT	8	
Voltage asymmetry	FR, HR, HU, IE, DK, DE, IT	7	
In accordance with standard	EE*, FI**	2	* EVS-EN 61000-4-30 ** IEC 61400-21
n/a	CY, BA, BG, ME, MK, RS, CH, LU, IS, BE, SI, PL, PT, RO, SK, LT, LV, NO, SE, ES, FR, GR, NIE, AT	24	

With respect to the implementation of power quality, the degree of incidence among the MS+ is 31% (9/29), counting each MS+ for at least one of the modes above once.

4.2.2.12. Low voltage ride through (LVRT) capabilities for SPGM

The Low Voltage Ride Through requirement is introduced by RfG NC for type B PGM and above (Article 14 (3)). Within the two standards EN 50549-1/-2 it is recommended for SPGM and PPM, only. Nevertheless, the analyses of national grid code implementation show that some MS+ have put detailed requirements into their provisions.

Incidence of implementations

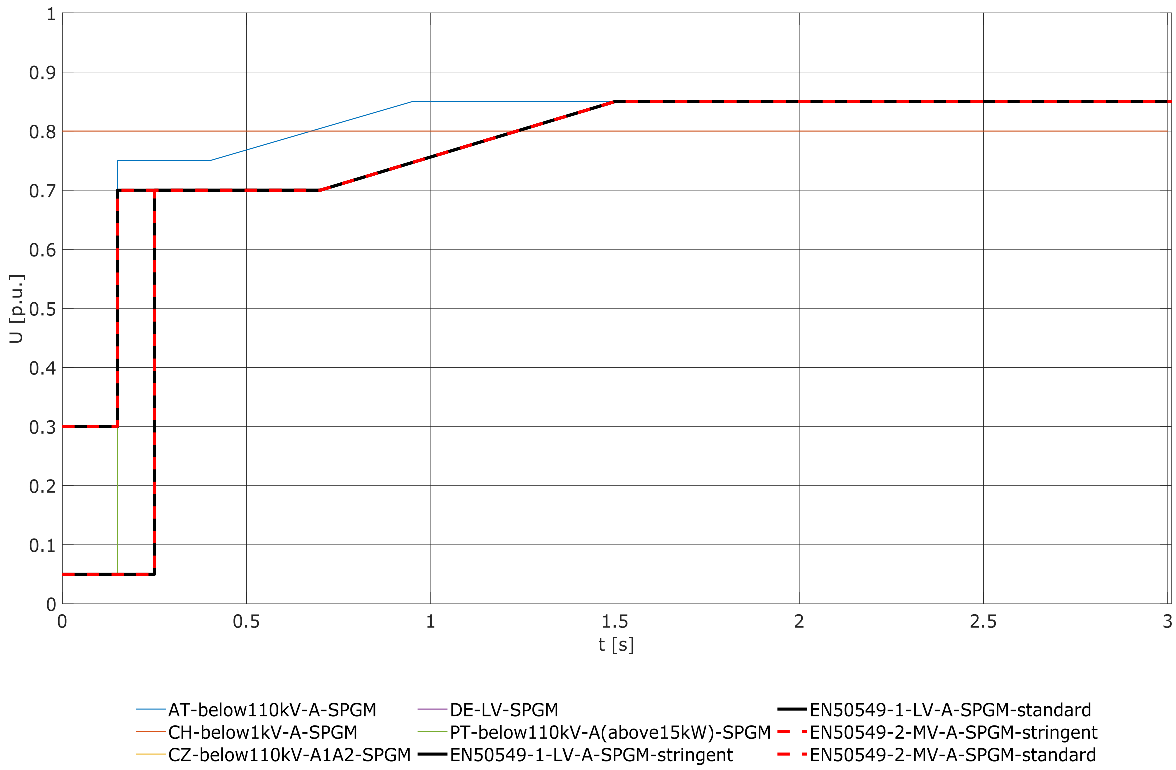
The following MS+ have implemented this requirement for type A SPGMs:

Table 33: Distribution of the MS+ based on the LVRT requirement for SPGMs

Implementation	MS+	Number of MS+	Comments
Type A	AT, CZ, DE, PT*, CH	5	* Above 15 kW
n/a	CY, BA, BE, BG, ME, MK, RS, HR, HU, LU, IS, ES, FR, GR, NL, PL, RO, SI, SK, NIE, IE, EE, LT, LV, NO, SE, IT, GB, DK, FI	31	

As LVRT capabilities may provide a significant technological challenge to type A SPGMs, especially for those of low capacity and low torque, Figure 10 gives an additional insight in the analysis results by illustrating the LVRT curves (in terms of voltage depth-time characteristics) of the above mentioned MS+ as well as the ones from the two European standards:

Figure 10: Incidence of LVRT curves for SPGMs



Austria and **Switzerland** have FRT curves outside the defined ranges of the two standards EN 50549-1/-2 (considering both the default and the stringent curves of the two European standards).

The level of incidence for type A SPGMs LVRT requirements is calculated as 17% (5/29).

Side Note: The introduction of LVRT requirements for low-voltage installations in Germany is mainly based on a recommendation of a study commissioned by the German standard-leading institute FNN at VDE. Here, the positive effects on voltage support became evident also in the higher voltage levels [7].

4.2.2.13. Low voltage ride through (LVRT) capabilities for PPM

As for SPGMs, this requirement is introduced by RfG NC for type B PGMs and above (Article 14 (3)). Again, this requirement is only recommended for type A PPMs according to the two standards EN 50549-1/-2.

Incidence of implementations

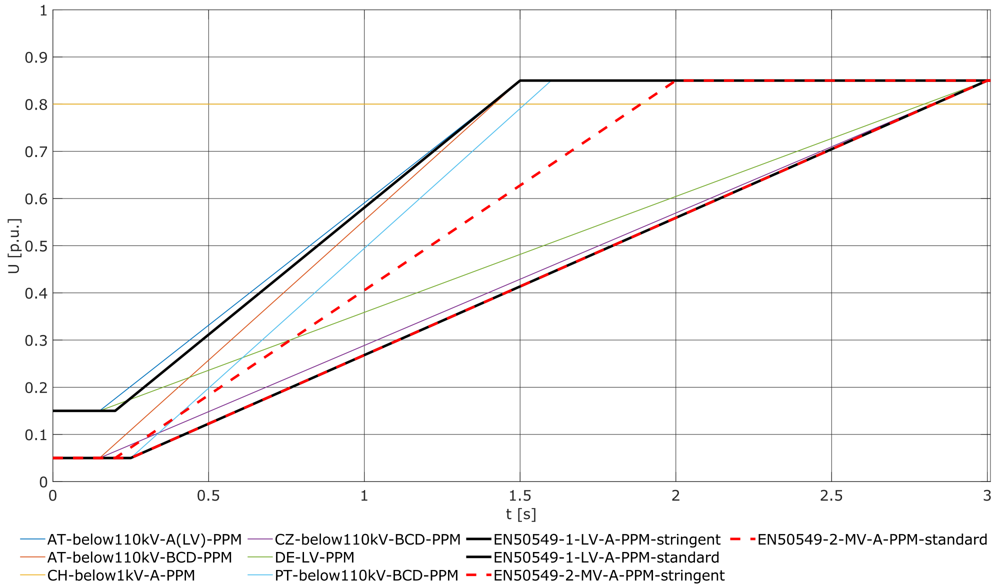
The following MS+ have implemented a requirement to ride through faults in terms of the aforementioned type and technology also for type A PPMs:

Table 34: Distribution of the MS+ based on the LVRT requirement for PPMs

Implementation	MS+	Number of MS+	Comments
Type A	AT, CZ, DE, PT*, CH	5	* Above 15 kW
n/a	CY, BA, BE, BG, ME, MK, RS, HR, HU, LU, IS, ES, FR, GR, NL, PL, RO, SI, SK, NIE, IE, EE, LT, LV, NO, SE, IT, GB, DK, FI	31	

The implementations for PPMs among the MS+ are the same as those for SPGMs. Again, Figure 11 shows the LVRT profiles (in terms of voltage depth-time characteristics) of the above-mentioned MS+ as well as those from the two European Standards:

Figure 11: Incidence of LVRT curves for PPMs



Except for **Switzerland**, all implementations are matching the most stringent requirements of the EN standards.

A degree of incidence of 17% (5/29) is obtained for PPMs of type A with respect to LVRT.

Side Note: The introduction of LVRT requirements for low-voltage installations in Germany is mainly based on a recommendation of a study commissioned by the German standard-leading institute FNN at VDE. Here, the positive effects on voltage support became evident also in the higher voltage levels [7].

4.2.2.14. Over Voltage Ride Through (OVRT)

The requirement to withstand network overvoltages (OVRT) is not addressed within the RfG NC. The two standards EN 50549-1/-2 define OVRT requirements, which PGMs must need to fulfill. For overvoltages, the PGM shall be capable of remaining connected to the grid (withstand) according to a predefined voltage-time profile.

Incidence of implementations

Many MS+ have not defined any curves (or if they have, it is relevant for PGMs from type B in most cases). The distribution is shown in Table 35:

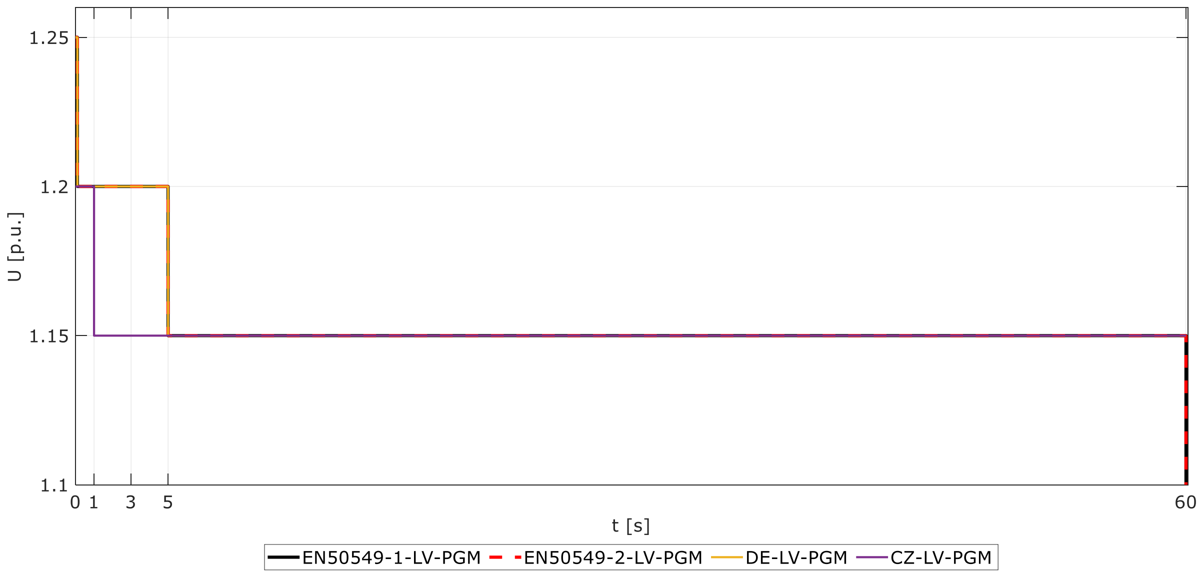
Table 35: Distribution of the MS+ based on the OVRT requirement

Implementation	MS+	Number of MS+	Comments
Type A	CZ, DE, FR	3	
n/a	AT, CY, BA, BE, BG, ME, MK, RS, CH, HR, HU, LU, IS, ES, GR, NL, PL, RO, SI, SK, NIE, IE, EE, LT, LV, NO, SE, IT, PT, GB, DK, FI	32	

Among the MS+, only the **Czech Republic**, **Germany** and **France** have defined requirements for OVRT. In the case of the **Czech Republic**, no curve is available. However, from the text written, a profile can be drawn. **France** also does not define a clear profile but rather gives reference to the standard EN 50549-1/-2. Only **Germany** has defined an individual voltage-time profile.

The curves of the above-mentioned MS+ (excluding **France**) as well as those of the two European Standards are given in Figure 12:

Figure 12: Incidence of OVRT curves



As shown in the above figure, the **Czech Republic** is not as stringent as compared to the two European standards with respect to OVRT.

For this requirement the degree of incidence is equal to 10% (3/29).

Side Note: The introduction of OVRT requirements is mainly based on experiences in some countries with LVRT-enabled PGMs. In many physical fault situations with initial voltage sags, a brief voltage increase above 115-120% nominal voltage occurred after voltage recovery, which then led to a tripping of the PGMs due to a missing OVRT capability. FGH refers to an ongoing research project (OVRTuere) [10] of the German Federal Ministry of Economics, which analyses the grid-side requirements for various generation technologies and develops corresponding specifications for OVRT capability and respective testing procedures.

4.2.2.15. Vector shift

Vector shift is a protection method used for the detection of an island situation. It is not in the scope of RfG NC for any type of PGM. In addition, no information is given regarding this topic within the two standards EN 50549-1/-2.

In many countries, no information is available on the implementation of this requirement and in some countries, it is not even allowed and the ROCOF requirement is used instead. One of the reasons behind this decision is that in some cases, the inadvertent operation of vector shift leads to the disconnection of units and, hence, to a reduction of system stability.

Nevertheless, some national grid code implementations have given incidences on this requirement as listed in the following.

Incidence of implementations

The results of the analysis on vector shift protection are displayed in Table 36:

Table 36: Distribution of the MS+ based on the vector shift requirement

Implementation	MS+	Number of MS+	Comments
Type A	CZ*, GB, DK**, FI$,	4	* Allowed, however no methodology for determining settings are available (type is also not explicitly mentioned) ** Not allowed $ Recommended
n/a	AT, CY, BA, BE, BG, ME, MK, RS, CH, HR, HU, LU, IS, ES, FR, GR, NL, PL, RO, SI, SK, NIE, IE, EE, LT, LV, NO, SE, IT, PT, DE	31	

It is important to note that in **Great Britain**, the protection shall be able to withstand (not trip) a vector shift of ±50°.

The above analysis results in a degree of incidence of 14% (4/29).

4.2.2.16. Zero current mode for PPM technology

For power park modules, the two standards EN 50549-1/-2 define a so called zero current mode. According to this requirement, PPMs shall be capable of reducing their current to or below 10% of their rated current when the voltage is outside of a predefined static range.

The standard values of the thresholds for the static voltage range are 50% in case of undervoltage and 120% for overvoltages.

This requirement is not included within RfG NC for any type of PGM.

Incidence of implementations

Germany is the only country to have implemented this requirement at LV for type A PPMs. Therefore, the degree of incidence is 3% (1/29).

4.2.2.17. Active power recovery after fault

This requirement is needed for PGMs starting from type B according to RfG NC according to Article 17 (3) & Article 20 (3) (a) and states that PGMs shall be able to provide active power after a fault according to prespecified conditions set by the relevant TSO. These include a starting threshold voltage, maximum required time for restoration of active power after the fault and the minimum required restored active power. The RfG NC itself does not provide any quantitative requirements.

Complementary to this the EN standards requires a minimum power output level no longer than 1 s after fault clearance.

Incidence of implementations

Only **Austria** and **Germany** define requirements with respect to type A modules and taking the above-mentioned parameters into account. This results in a degree of incidence of 7% (2/29).

4.2.2.18. Reconnection/synchronization requirements after disconnection

In addition to active power recovery requirements following a disturbance in the network, RfG NC defines other aspects that need to be considered before PGMs are able to reconnect. This article is defined for PGMs starting from type B (Article 14 (4) (a)). RfG NC however does not provide quantitative parameters on these conditions but rather leaves them to the responsible system operator. The aspects that typically need to be required are permissible voltage and frequency ranges, delay time before reconnection, and maximum active power increase gradient. The two standards EN 50549-1/-2 define the ranges for each of the aforementioned parameters. However, it is important to note that this requirement is defined for modules starting from type B within these two standards.

Incidence of implementations

Table 37 shows the distribution of the MS+ who have implemented the above requirement:

Table 37: Distribution of the MS+ based on reconnection requirements

Implementation	MS+	Number of MS+	Comments
Type A	CZ*, DE, IT, PT**, DK, FI,	6	* Defined for type A2 specific to CZ ** Project specific
n/a	AT, CY, BA, BE, BG, ME, MK, RS, CH, HR, HU, LU, IS, GB, ES, FR, GR, NL, PL, RO, SI, SK, NIE, IE, EE, LT, LV, NO, SE	29	

From the aforementioned table, the degree of incidence is calculated as 21% (6/29).

4.2.2.19. Unintentional/Intentional Islanding operation

According to RfG NC, islanding operation is needed for modules starting from type C (Article 15 (5)). **Ireland** and **Hungary** provide general information regarding this mode of operation without clearly specifying the type.

Romania is the only country which does not allow islanding operation for type A modules. Since Romania is the only MS+ with specific information about islanding operation, Ireland and Hungary have been excluded from the implementation. In that regard, the incidence level is equal to 3% (1/29).

4.2.2.20. Uninterruptible Power Supply (UPS)

UPS systems are mainly out of the scope of the RfG NC as well as of many of the grid code implementations among the MS+, especially for type A PGMs. The EN standards only refer in a vague and generic way to a USP that may be required for the interface protection in order to fulfill FRT requirements.

The term UPS is mentioned in **Italy** however. Here, references to other European standards are given for the compliance of UPS systems. In **Hungary** as well, some general information (and no specific technical requirements) is given for these devices. No specification regarding the type (A, B, C or D) is also found for this requirement.

In **Germany**, specific information is available regarding the duration of operation for UPS systems of PGMs.

Therefore, the incidence level is calculated as 7% (2/29), taking **Italy** and **Germany** into account.

4.2.2.21. Information exchange

This requirement is for modules starting from type B within RfG NC (Article 14 (5) (d)). Respective requirements are also found in the EN standards 50549-1/-2. Basically, references are given to external standards such as EN 60870 and EN 61850 series.

Among the MS+, 7 countries have a requirement for type A PGMs as well. These are **Austria**, the **Czech Republic**, **Switzerland**, **Lithuania**, **Denmark** and **Norway**.

Therefore, the incidence level of this requirement is equal to 21% (6/29).

4.2.2.22. Summarization of incidence levels

Table 38 provides a summary of the previous chapters on analyzing the implementation of additional requirements for type A PGMs with their respective levels of incidents:

Table 38: Summary of type A additional requirements

Requirement	Incidence level [%]
Limited Frequency Sensitive Mode - Underfrequency (LFSM-U)	7
Voltage related active power reduction (P(U))	14
Frequency related protection	24
Voltage ranges and minimum periods for operation	31
Voltage related protection	24
U-Q/Pmax for SPGMs	21
U-Q/Pmax for PPMs	17
P-Q/Pmax for SPGMs	17
P-Q/Pmax for PPMs	21
Reactive power control	21
Power quality	31
LVRT for SPGM	17
LVRT for PPM	17
Over Voltage Ride Through (OVRT)	10
Vector shift	14
Zero current mode for PPM technology	3
Active power recovery after fault	7
Reconnection/synchronization requirements after disconnection	21
Unintentional/Intentional Islanding operation	3
Uninterruptible Power Supply (UPS)	7
Information exchange	21
Average incidence level	17

4.3. Types B, C and D requirements

In addition to the requirements for type A generators already analyzed in section 4.2, this section will focus on additional requirements applicable to generators of type B or above. The requirement applicability for PGMs of types B, C and D will be explicitly specified before going into detail.

4.3.1. RfG NC mandatory requirements

An overview of the requirements for type B, C and D modules according to RfG NC is given below in Table 39:

Table 39: Type B, C and D mandatory requirements (inside the scope of RfG NC)

Type B, C and D mandatory requirements
Types C, D: Limited frequency sensitive mode - underfrequency (LFSM-U)
Types C, D: Frequency sensitive mode (FSM)
Types C, D: Full active power frequency response in FSM
Types B, C, D: Reactive power capacity of the generating plants
Types C, D: Reactive power capacity at maximum capacity for SPGMs
Types C, D: Reactive power capacity at maximum capacity for PPMs and offshore PPMs
Types C, D: Reactive power capacity below the maximum capacity for PPMs and offshore PPMs
Types D: Power System Stabilizer Implementation
Type D only: Voltage ranges and operating periods
Types B, C, D: FRT capability within symmetrical faults for the SPGMs connected below the 110 kV level
Types B, C, D: FRT capability within symmetrical faults for the PPMs connected to the network below the 110 kV level
Type D only: FRT capability in the event of symmetrical faults for SPGMs connected to the network at or above the 110 kV level
Type D only: FRT capability for symmetrical faults for PPMs connected to the network at or above the 110 kV level
Type B, C, D: FRT capability for asymmetrical faults
Types B, C, D: Information exchange
Types B, C, D: Voltage related protection
Types C,D: Loss of angular stability protection
Types B, C, D: Reconnection/synchronization after disconnection
Types C, D: Simulation requirements
Types C, D: Reactive power control modes
Types B, C, D: Active power recovery after fault
Types C, D: Active power setpoint control
Types C, D: Active power ramp rate
Types C, D: Prioritization of the active power contribution or the reactive power contribution on PPMs during faults
Types B, C, D: Frequency related protection
Types C, D: Operation after Tripping to Houseload

4.3.1.1. Types C, D: Limited frequency sensitive mode - underfrequency (LFSM-U)

This requirement is presented in Article 15 (2) (c) of the RfG NC, where PGMs of type C and D shall have the ability to adjust their active power output in LFSM-U mode at low frequency depending on the frequency. The parameters are set by specifying the droop and the frequency threshold for activating the required adaptation in active power output. According to the RfG NC, the parameter ranges are:

- LFSM-U activation threshold (between 49,8 Hz and 49,5 Hz)
- Droop (between 2% and 12%)

The parameter implementation of the MS+ in relation to the limited frequency sensitive mode at underfrequency is found in Table 40 and Table 41.

Table 40: LFSM-U activation frequency threshold

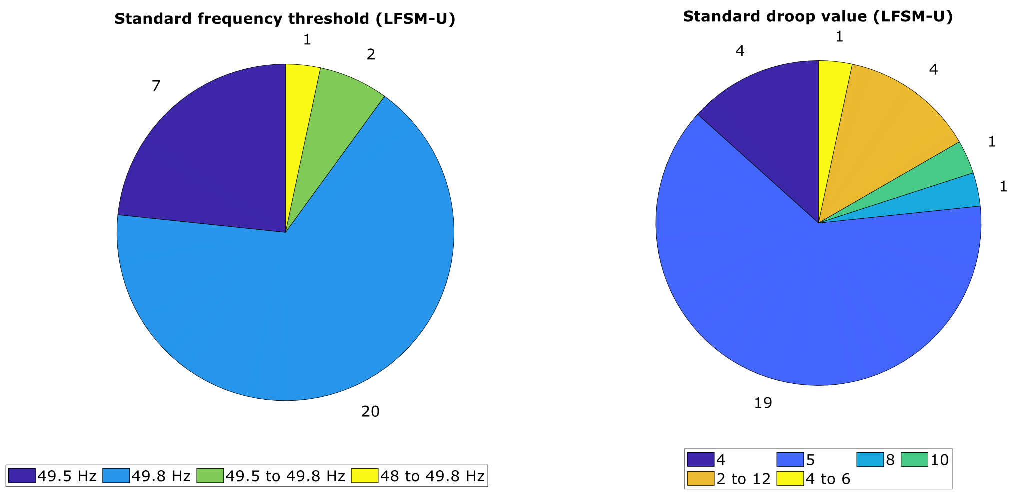
Value [Hz]	Implementation related to Figure 14	MS+	Number of MS+	Comments
48 to 49.8 (standard = not specified)	Impl.1c	IS	1	
49.5 to 49.8 (standard = not specified)	Impl.2c	HU, NO	2	
49.5 to 49.8 (default = 49.8)	Impl.2c	AT, CZ, DE, FR, LU, NL, PL	7	
49.5	Impl.3c	IT *, GB, NIE, IE, DK2, FI, SE	7	* Defined for PPM
49.8	Impl.4c	BE, ES, GR, HR, IT **, PT, RO, SI, SK, EE, LT, LV, DK1	13	** Defined for SPGM
n/a	-	CY, BA, BG, CH, ME, MK, RS	7	

Table 41: Droop parameter for LFSM-U implementation along MS+

Value [%]	Implementation related to Figure 14	MS+	Number of MS+	Comments
2 to 10 (default = 10)	Impl.1d	GB	1	
2 to 12 (default = not specified)	Impl.2d	HU, FI, IS, NO	4	
2 to 12 (default = 4)	Impl.2d	NIE, IE, DK2	3	
2 to 12 (default = 5)	Impl.2d	AT, BE, DE, GR, HR, LU, PL, RO, SI, LT, LV, DK1	12	
3 to 12 (default = 5)	Impl.3d	FR	1	
4 to 6 (standard = n/a)	Impl.4d	PT	1	
4 to 10 (default = 5)	Impl.5d	CZ	1	
4 to 12 (default = 5)	Impl.6d	NL	1	
4	Impl.7d	IT *	1	* Defined for hydraulic SPGM
5	Impl.8d	ES, IT **, SK, EE		** Defined for thermal SPGM
8	Impl.9d	SE	1	
n/a	-	IT ***, CY, BA, BG, CH, ME, MK, RS	8	*** For PPM n/a.

Taking the default values of the specified ranges into account as being the standard in the respective countries, the distribution looks like in the Figure 13. The numbers on the diagram represent the number of MS+ in which the respective standard values were selected. Different variants have been defined in some MS+. The most common default values for the frequency threshold and the droop are 49.8 Hz and 5%, respectively.

Figure 13: Distribution of the standard value for the frequency threshold and the droop for the LFSM-U



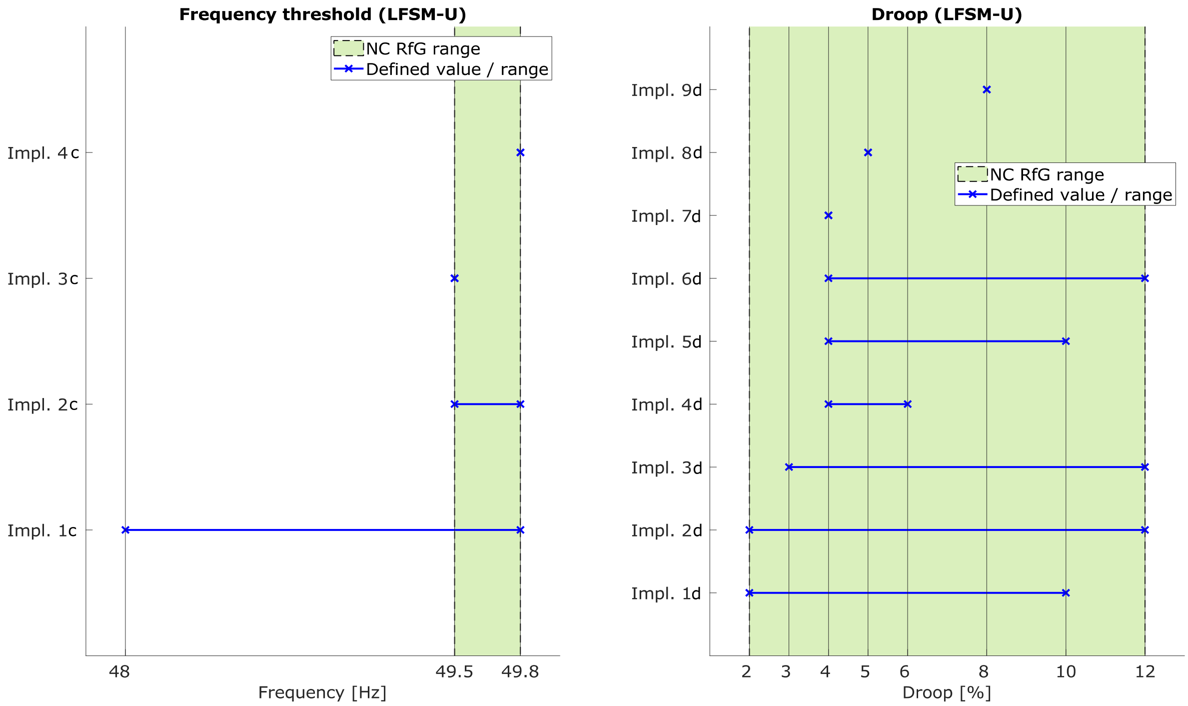
- **Convergence of parameter implementation**

Figure 14 shows the possible implementations for the respective parameters in comparison to the ranges specified in RfG NC. The selection of the droop in all relevant MS+ meets the conditions of the RfG NC. However, with respect to the frequency threshold, the implementation in **Iceland** deviates from the requirements of the RfG NC. A range between 48 Hz and 49.8 Hz is defined there. **Switzerland** does not specify LFSM-U requirements as the requirements are expected to be released in A, B and C generator types in the future. The degree of convergence is therefore reduced to a Total of 93% (27/29).

It must be noted that in **Switzerland's** case, the final network requirements for types A, B and C are yet to be approved, so the analyzed code corresponds to a version previous to the RfG NC.

Figure 14: Convergence of the frequency threshold and droop in LFSM-U

(Implementation values on the left are related to the Table 17 and Table 18)



4.3.1.2. Types C, D: Frequency sensitive mode (FSM)

In order to compensate normal operation frequency deviations, type C and D PGMs must be able to activate a frequency sensitive mode (FSM) in accordance with Article 15 (2) (d) (i). Following parameters according to RfG NC shall be fixed in the RfG NC implementation at national level:

- Dead band (between 0 mHz up to and including 500 mHz)
- Insensitivity of the frequency sensitive response (between 10 mHz and 30 mHz)
- Droop (between 2% to 12%).

The national implementation of the above-mentioned parameters can be found along the following tables, as of the dead band in Table 42, insensitivity in Table 43 and droop in the Table 44:

Table 42: Implementation of the dead band parameter for FSM along the MS+

Value [mHz]	Implementation related to Figure 15	MS+	Number of MS+	Comments
0	Impl.1e	ES, HU, PT, RO, GB	5	
0 to 10	Impl.2e	IT *	1	* Defined for gas, steam, hydraulic SPGM and for PPM
0 to 15	Impl.3e	NIE, IE	2	
0 to 20	Impl.4e	IT *	1	** For turbogas and CCGT SPGM
0 to 100	Impl.5e	SE	1	
0 to 200	Impl.6e	AT, CZ, DE, FR, LU, DK1	6	
0 to 500	Impl.7e	BE, GR, NL, PL, SI, EE, LT, LV, DK2, IS, NO	11	
20 to 200	Impl.8e	MR	1	
n/a	-	SK, FI, CY, BA, BG, CH, ME, MK, RS	9	

Table 43: Insensitivity implementation for FSM

Value [mHz]	Implementation related to Figure 15	MS+	Number of MS+	Comments
10	Impl.1f	AT, BE, CZ, DE, ES, FR, GR, HR, HU, IT, LU, NL, PL, PT, RO, SI, SK, EE, LT, LV, DK, NO, SE	23	
15	Impl.2f	GB, NIE, IE	3	
10 to 30	Impl.3f	IS	1	
n/a	-	FI, CY, BA, BG, CH, ME, MK, RS	8	

Table 44: Droop implementation for FSM

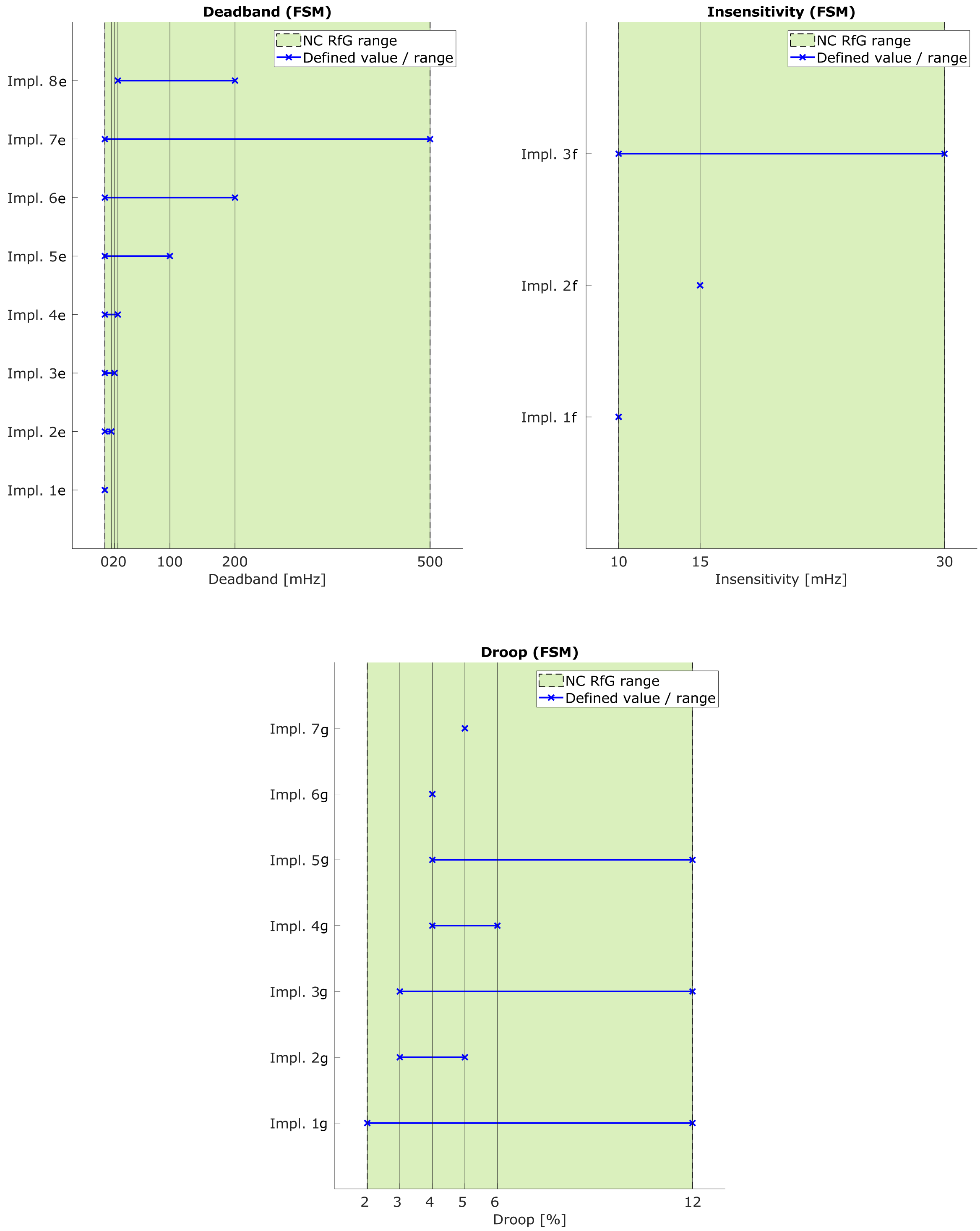
Value [%]	Implementation related to Figure 15	MS+	Number of MS+	Comments
2 to 12 (default = not specified)	Impl.1g	AT, BE, CZ, DE, GR, HR, HU, LU, PL, SI, SK, EE, LT, LV, DK, IS, NO, SE	18	
2 to 12 (default = 4)	Impl.1g	NIE, IE	2	
2 to 12 (default = 5)	Impl.1g	RO	1	
3 to 5 (default = not specified)	Impl.2g	GB	1	
3 to 12 (default = not specified)	Impl.3g	FR	1	
4 to 6 (default = not specified)	Impl.4g	PT	1	
4 to 12 (default = not specified)	Impl.5g	NL	1	
4	Impl.6g	IT *	1	* Defined for hydraulic SPGM and for PPM
5	Impl.7g	IT, IS*	2	** For gas, steam, CCGT and turbo-gas SPGM
n/a	-	FI, CY, BA, BG, CH, ME, MK, RS	8	

In some MS+ insensitivity and dead band ranges are defined as the total admissible uncertainty, hence insensitivity and dead band are not separated, but defined as a total maximum allowable uncertainty. This uncertainty in MS+ such as **Belgium**, **Germany**, **Greece**, **Luxembourg** and **Slovenia** must not exceed a value of ± 10 mHz. In **Great Britain**, **Northern Ireland** and **Ireland**, however, the maximum permissible value is set to ± 15 mHz.

Convergence of implementations

The Figure 15 shows that compliance with the areas specified in RfG NC was ensured when defining the FSM parameters in the respective MS+. A degree of convergence of 93% (27/29) can therefore be assigned as **Switzerland** and **Finland** did not specify the ranges for FSM. The active power range of the frequency sensitive adaptation is not considered when evaluating the convergence.

Figure 15: Convergence of the dead band, the insensitivity and the droop in the FSM (Implementation values on the left are related to the Table 42, Table 43 and Table 44)



4.3.1.3. Types C, D: Full active power frequency response in FSM

A further requirement when operating in FSM mode is the ability to provide a maximum active power reduction in the event of a frequency jump in accordance with Article 15 (2) (d) (iii) of the RfG NC. The respective parameters for its implementation are:

- The active power range (between 1.5% to 10%)
- The maximum permissible initial delay for units with and without inertia (t1; with a maximum of 2s)
- The maximum time until complete activation (t2; with a maximum of 30s)

Also, according to Article 15 (2) (d) (v), the system must:

- Be able to perform the complete frequency sensitive adjustment of the active power output for a defined period (between 15 and 30 minutes).

The implementation of these four different parameters are shown in the Table 45, Table 46, Table 47 (differentiating between SPGMs and PPMs due to the common implementation), Table 48 and Table 49.

Table 45: Implementation of the active power range parameter ΔP1 for the complete FSM activation

Value [% Pmax]	Implementation related to Figure 16	MS+	Number of MS+	Comments
2	Impl.1h	DE, LU	2	
3	Impl.2h	GR *	1	* Defined for SPGM
5	Impl.3h	PL, PT, IE *	3	* Defined for SPGM
8	Impl.4h	IT IS***	2	*** Defined for thermal SPGM
10	Impl.5h	GR ****, IT **, GB, NIE *, EE, LT, LV	7	**** Defined for all PGMs except thermal SPGM ** Defined for PPM * Defined for SPGM
1.5 to 10	Impl.6h	AT, CZ, HU, NL, RO, SI *, DK, IS	8	* In special cases 2 to 10
2 to 10	Impl.7h	BE, HR, SK	3	
2.5 to 10	Impl.8h	FR	1	
5 to 10	Impl.9h	NO, SE	2	
n/a	-	FI, CY, BA, BG, CH, ME, MK, RS	8	

Table 46: Implementation of the maximum allowable initial delay parameter (t1) for SPGMs for the complete FSM activation

Value [s]	Implementation related to Figure 16	MS+	Number of MS+	Comments
1	Impl.1i	LT *, IS	2	* Defined for thermal SPGM
2	Impl.2i	AT, BE, CZ, DE, ES, FR, GR, HR, HU, IT, LU, NL, PL, PT, RO, SI, SK, GB, NIE, IE, EE, LT **, LV, DK, NO, SE	26	** Defined for hydraulic SPGM
n/a	-	FI, CY, BA, BG, CH, ME, MK, RS	8	

Table 47: Implementation of the maximum allowable initial delay parameter (t1) for PPMs for the complete FSM activation

Value [s]	Implementation related to Figure 16	MS+	Number of MS+	Comments
0	Impl.1j	NIE, IE	2	
0.5	Impl.2j	AT, BE, ES, FR, HR, IT, PL, PT, RO, SI, EE, LT	12	
1	Impl.3j	CZ, DE, GR, HU, LU, GB, IS	7	
2	Impl.4j	SK, LV, DK, NO, SE	5	
n/a	-	NL, FI, CY, BA, BG, CH, ME, MK, RS	9	

Table 48: Implementation of the maximum admissible time until full activation parameter (t2) for the complete FSM

Value [s]	Implementation related to Figure 16	MS+	Number of MS+	Comments
2	Impl.1k	IT *	1	* Defined for the other wind PPM and for PV PPM
5	Impl.2k	NIE *, IE *	2	* Defined for SPGM
10	Impl.3k	IT *, RO **, GB, NO ***	4	** For type C wind PPM with connection to the distribution network *** Defined for PPM **** Defined for type C wind PPM with droop equal to 12%
15	Impl.4k	NIE ***, IE ***	2	*** Defined for PPM
30	Impl.5k	AT, BE, CZ, DE, ES, FR, GR, HR, HU, IT *, LU, NL, PL, PT, RO *, SI, SK, EE, LT, LV, DK, IS, SE	23	* Defined for SPGM
300	Impl.6k	NO *****	1	***** For type D PGM
500	Impl.7k	NO ****	1	**** Defined for type C hydraulic SPGM with a droop equal to 12%
n/a		FI, CY, BA, BG, CH, ME, MK, RS	8	

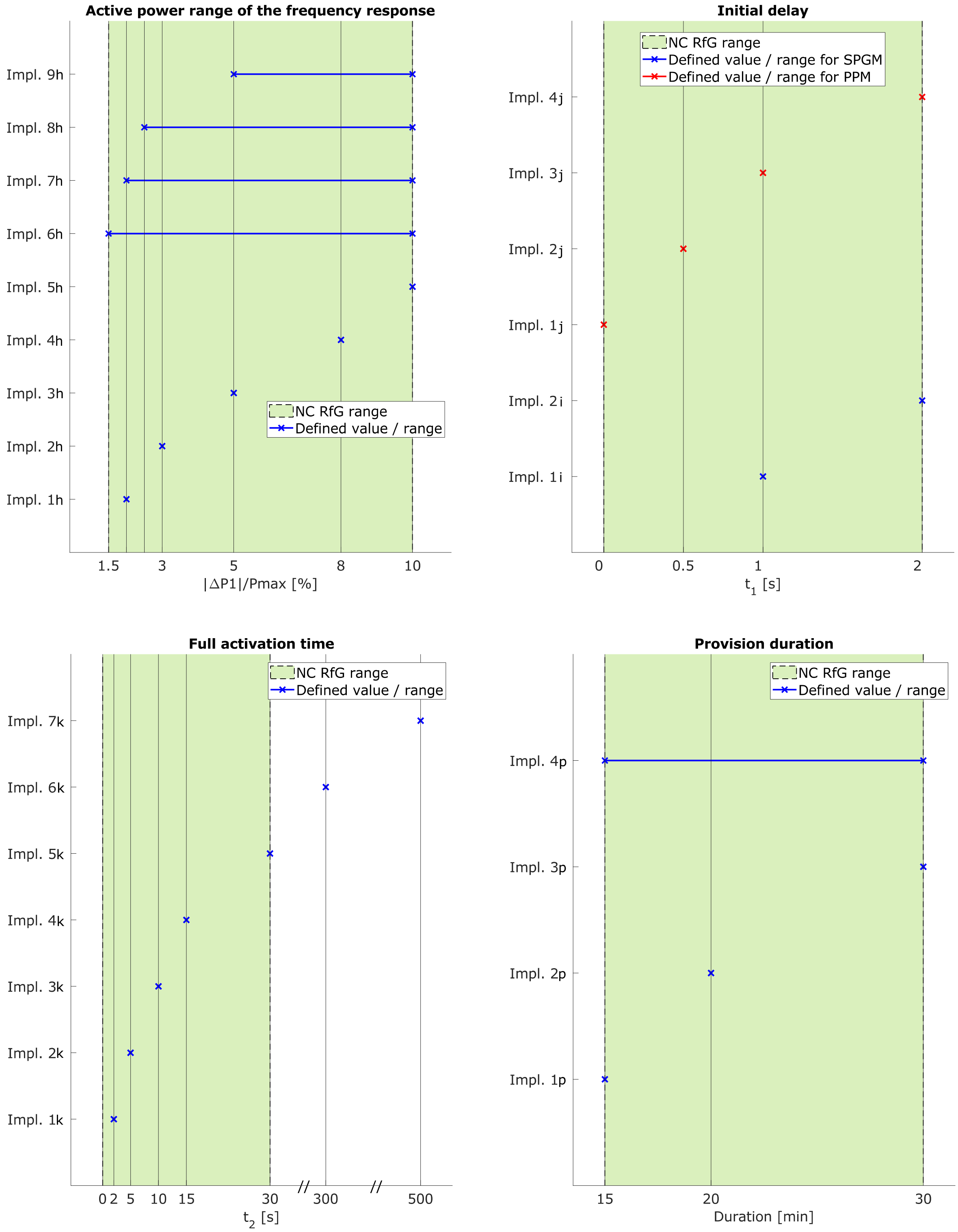
Table 49: Implementation of the activation period time parameter for the complete FSM deployment

Value [min]	Implementation related to Figure 16	MS+	Number of MS+	Comments
15	Impl.1p	BE, CZ *, DE, ES, FR, GR, HR, HU, LU, NL, PT, SI, SK, EE, DK, NO, SE	17	* Defined for steam SPGM
20	Impl.2p	NIE, IE	2	
30	Impl.3p	AT, CZ *, IT, PL, RO **, LT, LV, IS	8	** Defined for the other PGMs * Defined for SPGM
15 to 30	Impl.4p	RO ***	1	*** Defined for PPM
n/a	-	GB, FI, CY, BA, BG, CH, ME, MK, RS	9	

Convergence of implementations

Figure 16 provides a comparison between the respective implementations of the complete activation of the frequency sensitive active power adjustment and the specified RfG NC ranges for the respective parameters.

Figure 16: Convergence of the parameters for the complete FSM activation (Implementation values on the left are related to the Table 45, Table 46, Table 47, Table 48 and Table 49)



The only deviation for SPGMs was found in **Norway**. It refers to the maximum time to complete activation, which is 300 seconds for type D generators and 500 seconds for type C hydraulic SPGMs with a droop of 12%. This deviation does not affect the degree of convergence, since the setting of a value longer than 30 seconds is permitted for reasons of system stability.

For the case of PPMs, no fixed values or ranges have been defined in **Ireland** and **Northern Ireland** regarding the determination of the range of active power change. Instead, it is required that at least 60% of the expected adjustment (based on the droop setting) is achieved within 5 seconds and 100% within 15 seconds, hence the full active power response is considered as implicitly required. **Switzerland** and **Finland** have not explicitly mentioned any requirement. For the case of **Norway**, where the final grid code implementation is still under discussion, requirements outside the RfG NC defined ranges are established. **Great Britain** does not specify any requirement in matter of provision time.

Since Ireland and Northern Ireland do define the full active power response time parameters (albeit implicitly in the case of t1), they are not counted as deviating from RfG NC. Therefore, 3 MS+ (Great Britain, Switzerland and Finland) present a deviation from the RfG NC, giving a convergence of 90% (26/29).

4.3.1.4. Types B, C, D: Reactive power capacity of the generating plants

The voltage stability requirements include the definition of the reactive power supply capabilities (and its control) by the PGM as this will directly affect the voltage level of the power system at least in the local region of the PGM's point of connection. Hence, the generators connected to the grid should, then, contribute to the efficient and stable operation by providing reactive power – both, inductive and capacitive.

According to Articles 17 (2) (a) and 20 (2) (a) of the RfG NC the relevant system operator shall have the right to specify reactive power capacity for SPGMs and PPMs of type B, respectively. These are non-mandatory requirements for type B generators and there are no further restrictions.

In contrast, the reactive power capacity of the PGMs of type C and D is defined in the form of a U-Q diagram or P-Q diagram. The U-Q diagram describes the ability to deliver reactive power at the grid connection point at different voltages and must be determined in accordance with Articles 18 (2) (b), 21 (3) (b), and 25 (5) for SPGMs, PPMs and offshore PPMs at maximum capacity (P = Pmax). For this purpose, a fixed external frame was specified in the RfG NC, which any U-Q diagram implementation on a national level must not go beyond. In addition, a maximum range for the reactive power as well as for the voltage was specified for the dimensioning of the diagram, whose respective values must not be exceeded. The details of the RfG NC specifications regarding the definition of the U-Q diagram for SPGMs, PPMs, and offshore PPMs of type C and D are summarized in the Table 50:

Table 50: Requirements of the RfG NC for reactive power capacity at maximum capacity (U-Q diagram) for SPGMs, PPMs, and offshore PPMs of type C and D

<table>
<tr><th rowspan="2">Synchronous - area</th><th rowspan="2">Category</th><th colspan="4">Fixed outer frame</th><th colspan="2">Inner frame</th></tr>
<tr><th>Min. U [pu]</th><th>Max. U [pu]</th><th>Min. Q/ Pmax</th><th>Max. Q / Pmax</th><th>Max. range of U [pu]</th><th>Max. range of Q / Pmax</th></tr>
<tr><td rowspan="2">Continental Europe</td><td>SPGM</td><td rowspan="12">0.875</td><td rowspan="12">1.1</td><td rowspan="12">-0.5</td><td rowspan="12">0.65</td><td rowspan="2">0.225</td><td>0.95</td></tr>
<tr><td>PPM / offshore PPM</td><td>0.75</td></tr>
<tr><td rowspan="4">Great Britain</td><td>SPGM</td><td rowspan="4">0.225</td><td>0.95</td></tr>
<tr><td>PPM</td><td>0.66</td></tr>
<tr><td>offshore PPM config. 1</td><td>0</td></tr>
<tr><td>offshore PPM config. 2</td><td>0.33</td></tr>
<tr><td rowspan="2">Ireland and Northern Ireland</td><td>SPGM</td><td rowspan="2">0.218</td><td>1.08</td></tr>
<tr><td>PPM / offshore PPM</td><td>0.66</td></tr>
<tr><td rowspan="2">Baltic States</td><td>SPGM</td><td rowspan="2">0.22</td><td>1</td></tr>
<tr><td>PPM / offshore PPM</td><td>0.8</td></tr>
<tr><td rowspan="2">Northern Europe</td><td>SPGM</td><td rowspan="2">0.15</td><td rowspan="2">0.95</td></tr>
<tr><td>PPM / offshore PPM</td></tr>
</table>

The definition of a P-Q diagram in a national grid code implementation is only required for PPMs generators of type C and D in accordance with Article 21 (3) (c) of RfG NC. This diagram shall describe the reactive power capacity of the PPM at the grid connection point with different active power outputs below the maximum capacity (P <Pmax). As an outcome of the analysis, the information regarding the fixed outer frame and the maximum range of reactive power, which must be considered when determining the P-Q diagram, can be found in Table 51:

Table 51: Types C, D: Requirements of the RfG NC for the reactive power capacity below the maximum capacity (P-Q diagram) for PPMs of type C and D

<table>
<tr><th rowspan="2">Synchronous area</th><th colspan="4">Fixed outer frame</th><th>Inner frame</th></tr>
<tr><th>Min. P / Pmax</th><th>Max. P / Pmax</th><th>Min. Q / Pmax</th><th>Max. Q / Pmax</th><th>Maximum range of Q / Pmax</th></tr>
<tr><td>Continental Europe</td><td rowspan="5">0</td><td rowspan="5">1</td><td rowspan="5">-0.5</td><td rowspan="5">0.65</td><td>0.95</td></tr>
<tr><td>Great Britain</td><td>0.95</td></tr>
<tr><td>Ireland and Northern Ireland</td><td>1.08</td></tr>
<tr><td>Baltic States</td><td>1</td></tr>
<tr><td>Northern Europe</td><td>0.95</td></tr>
</table>

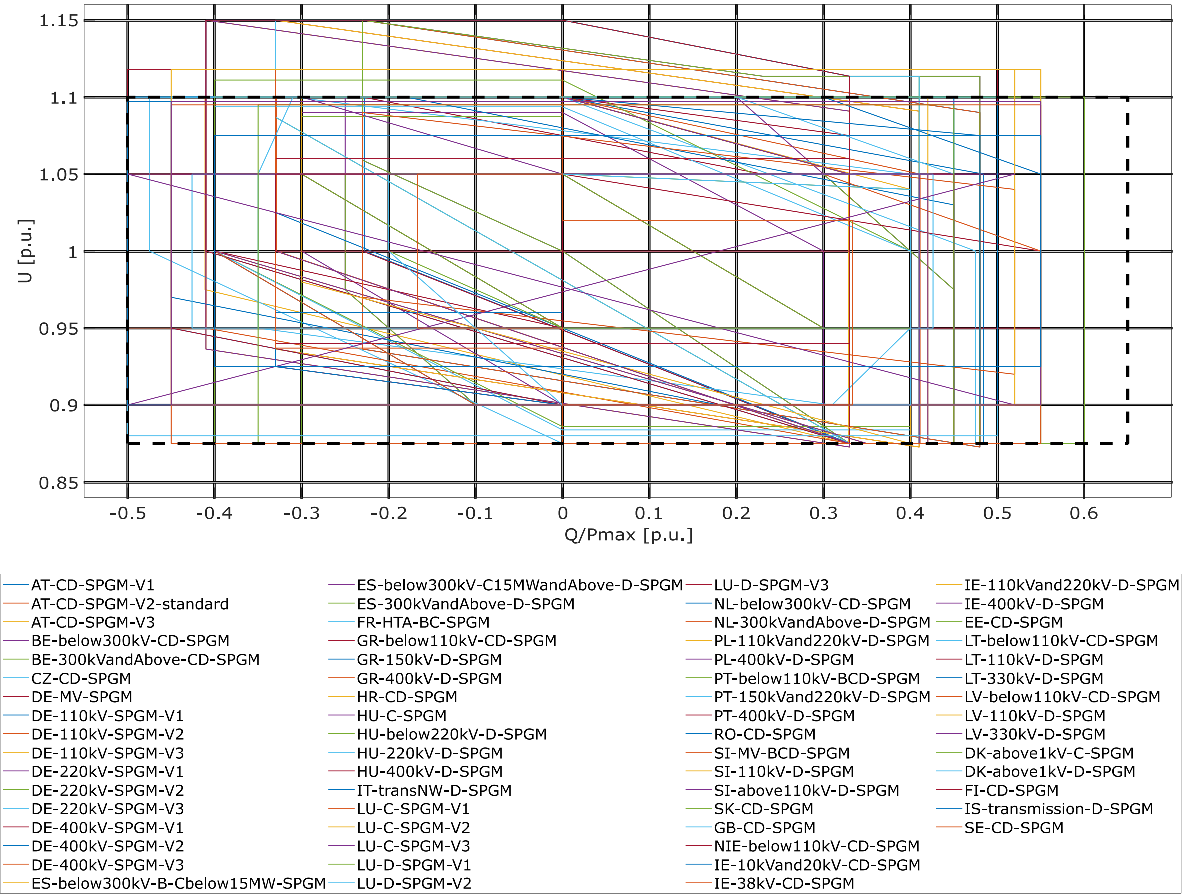
In accordance with Article 18 (2) (c), SPGMs must be able to work at any possible operating point within the P-Q diagram of their generator and at least up to the minimum power for stable operation at an active power output in the grid connection point, where the delivered power is below the maximum capacity (P <Pmax). Here, the own consumption and, if applicable, the transformer losses have to be considered. There are no further restrictions regarding the P-Q diagram for SPGMs in the RfG NC.

The analysis of the PGMs with respect to reactive power capability is displayed in the following three sections depending on whether the PGM is operating at or below maximum capacity and also on the generator technology.

4.3.1.5. Types C, D: Reactive power capacity at maximum capacity for SPGMs

Figure 17 shows the different implementations with regard to the reactive power capability requirements of SPGMs of type C and D operating at maximum (nominal) active power output. The location, size and shape of the U-Q diagram differ significantly from one MS+ to another. This is due to the fact that the RfG NC enables free or partially free design, and even more than one U-Q diagrams may be defined in a MS+. This depends, however, on the type of system (C or D) or on the voltage level of the grid connection point. In addition, in several MS+ such as **Austria**, **Germany** and **Luxembourg**, several possible variants for the same voltage level or the same system type were specified to be chosen by the TSO on project level.

Figure 17: Convergence of reactive power capacity with maximum capacity (U-Q diagram) for SPGMs



In **France**, the U-Q diagrams for the voltage levels HTB1 (63 kV and 90 kV), HTB2 (225kV), and HTB3 (400kV) are widely different because it depends on the dimensioning voltage (Udim). The value maintained for Udim is determined in the connection agreement within the normal voltage range. The U-Q diagram at maximum capacity results graphically as the intersection of the trapezoid "A, B, C, D" with the upper and lower limits of the normal voltage range at the grid connection point. It is then assumed that this implementation meets the RfG NC requirements.

The Figure 17 shows that in some implementations the requirements of the RfG NC are not met. The violations identified with regard to the U-Q diagrams shown in this figure are summarized in Table 52. The cases of non-compliance with the RfG NC ranges were identified in six MS+, namely **Germany**, **Luxembourg**, **Hungary**, **Ireland**, **Lithuania** and **Latvia**. It should be noted that the definition of the U-Q diagram in **Luxembourg** is based on the **German** VDE standards. Hence, the implementation here is the same as in **Germany**.

Regarding **Hungary**, according to the response from the questionnaire, an explanation has been provided on the upper voltage limit (1.111 p.u.) as follows: "The reason of the given parameter is that the 220 kV nominal voltage equipment is 245 kV. The chosen base voltage of p.u. for 220 kV voltage level is 223 kV. According to parameter 223 kV * 1,1111 = 248,886 kV, close to permanent admissible limit."

A similar response has been provided by AST (TSO) from **Latvia**: "The main reason for it was that while the nominal voltage (from which p.u. is derived) is 110 kV, due to historical reasons our 110 kV network is normally operated on slightly higher voltage which is in the range of 1.0-1.118 p.u. and most equipment is actually rated for 115 kV rather than 110 kV. Therefore, the range was extended to 1.118 p.u. without violating the maximum range of voltage which is 0.220 p.u.". AST has also pointed out that they will address the situation to see if any changes will be required since their connection to the Continental Europe system is planned for 2025.

Overall, a degree of convergence of 79% (23/29) is to be assigned when defining reactive power capacity at maximum capacity for SPGMs of type C and D. Again, the MS+ CY, BA, BG, ME, MK and RS are not considered because no information was found or available from them.

Table 52: Cases of non-compliance with the RfG NC limit values when defining the reactive power capacity at maximum capacity for SPGMs (type C and D)

Cases of non-compliance		Value [pu]	MS+	Comments
Fixed outer frame	Falling below the minimum U	0.873	DE *, LU **	* 110 kV ** Type C
	Exceeding the maximum U	1.111	HU *	* Type D (<220 kV)
		1.118	IE *, LT **, LV **	* Type C and D (<400 kV) ** 110 kV (Type D)
		1.15	DE *, LU **	* 110 kV and 220 kV ** Type C and D
	Falling below the minimum Q	-	-	No
	Exceeding the maximum Q	-	-	No
Inner frame	Exceeding the maximum range of U	0.275	DE *, LU **	* 220 kV ** Type D
		0.277	DE *, LU **	* 110 kV ** Type C
	Q exceeded the maximum range	-	-	No

4.3.1.6. Types C, D: Reactive power capacity at maximum capacity for PPMs and offshore PPMs

Similar to the previous section, the respective U-Q diagrams on reactive power capacity requirements at nominal power output level for PPMs of type C and D are designed very differently from one MS+ to another. This design can vary in a particular MS+ according to type or voltage level. In addition, several variants may be defined for a single voltage level or for a single system type per MS+. This is the case e.g. in **Austria, Germany and Luxembourg**.

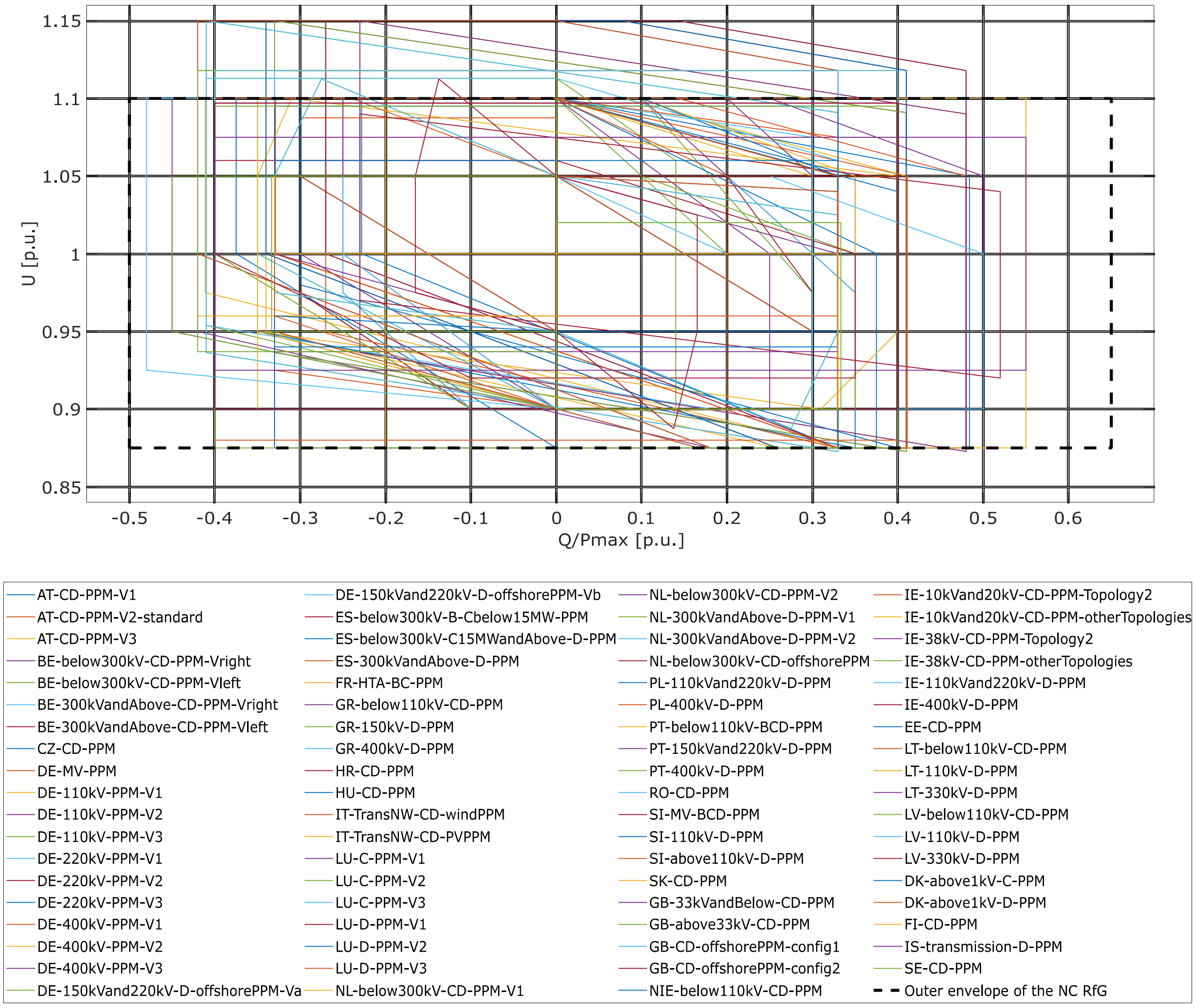
Figure 18 shows the U-Q diagrams of the various MS+.

The variants for **Belgium** lie on the far right and far left, which can be found in Figure 18.

For the case of **France**, the U-Q diagram for the voltage levels HTB1, HTB2, and HTB3 are designed in the same way as for SPGMs (see previous section).

In **Italy**, type C wind turbines connected to the distribution grid must provide a reactive power capacity in the range of -0.35 Pmax to 0.3 Pmax. In addition, the reactive power range for type C PV systems with connection to the distribution network in **Italy** should be between -0.35 Pmax and 0.2 Pmax No U-Q diagram in the sense of the RfG NC is specified for the two PPM categories when connected to the distribution network.

Figure 18: Convergence of reactive power capacity with maximum capacity (U-Q diagram) for PPMs and offshore PPMs



The deviations from the RfG NC with regard to the RfG NC requirements for the reactive power capacity at maximum capacity for PPMs of type C and D are shown in Table 53. Cases of non-compliance have been identified in six MS+, namely **Germany, Luxembourg, Great Britain, Ireland, Lithuania and Latvia**. However, in the case of **Great Britain**, an answer has been provided by National Grid ESO which states that the profile does not actually come into conflict with the regulations of RfG NC. According to their explanation, at 400 kV, the voltage limit is set at 1.05 - 1.1 p.u for 15 minutes meaning that they do not require a steady state operation above the limits of RfG NC. Moreover, they provide the following text from paragraph ECC.A.7.2.2.7 of their TSO grid code:

"For Onshore Grid Entry Point voltages (or User System Entry Point voltages if Embedded or Interface Point voltages) above 105%, the leading Reactive Power capability of the OTSDUW Plant and Apparatus or Onshore Power Park Module or Onshore HVDC System Converter should be that which results from the supply of maximum leading reactive current whilst ensuring the current remains within design operating limits".

The above explanation means they do not mandate the plant to operate outside the RfG NC framework.

Overall, a degree of convergence of 83% (24/29) can be assigned when defining the reactive power capacity at maximum capacity for PPMs and offshore PPMs of type C and

D. The MS+ CY, BA, BG, ME, MK and RS are also not considered because no information was found or available for them.

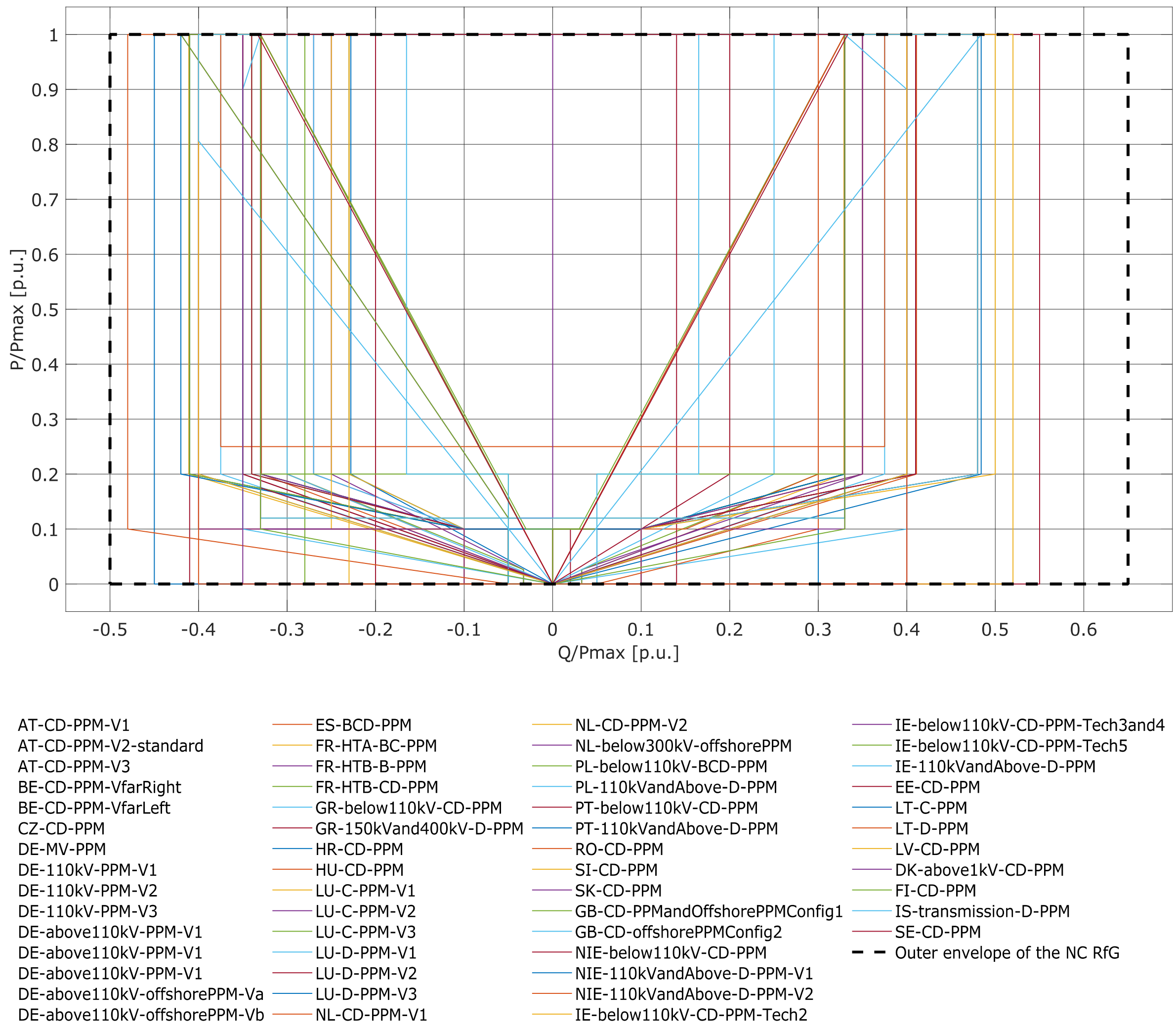
Table 53: Cases of non-compliance with the RfG NC limit values when defining reactive power capacity at maximum capacity for PPMs and offshore PPMs (type C and D)

Cases of non-compliance		Value [pu]	MS+	Comments
Fixed outer frame	Falling below the minimum U	0.873	DE *, LU **	* 110 kV ** Type C
	Exceeding the maximum U	1.113	DE *, GB **	* Offshore PPM (150kV and 220 kV) * Type C and D PPM (> 33 kV) and offshore PPM
		1.118	IE *, LT **, LV **	* Type C and D (<400 kV) ** 110 kV (Type D)
		1.15	DE *, LU **	* 110 kV and 220 kV ** Type C and D
	Falling below the minimum Q	-	-	No
	Exceeding the maximum Q	-	-	No
Inner frame	Exceeding the maximum range of U	0.275	DE *, LU **	* 220 kV ** Type D
		0.277	DE *, LU **	* 110 kV ** Type C
	Q exceeded the maximum range	0.66	GB *	* Offshore PPM (configuration 1)

4.3.1.7. Types C, D: Reactive power capacity below the maximum capacity for PPMs and offshore PPMs

When comparing the different definitions of reactive power capacity below the maximum capacity, i.e. nominal active power output, for PPMs of type C and D, there are many differences between the individual MS+. Figure 19 provides an overview of the different respective P-Q diagrams. As with Q-U diagrams, the MS+ may provide several diagrams that depend on the voltage level or the system type. In addition, in several MS+ such as **Austria, Germany** and **Luxembourg**, several possible variants for the same voltage level or the same system type are specified. In **Belgium**, analogous to the Q-U diagram, the reactive power range can be shifted between -0.3 Pmax and 0.35 Pmax. However, a minimum range of 0.6 Pmax is required. In **Italy**, type C wind turbines connected to the distribution grid have a reactive power capacity in the range of -0.35 Pmax to 0.3 Pmax. In addition, the reactive power range for type C PV systems with connection to the distribution network should be between -0.35 Pmax and 0.2 Pmax. In contrast to wind and PV systems connected to the distribution network, where no P-Q diagram is defined, a P-Q diagram is defined for each of the two categories when connected to the transmission network.

Figure 19: Convergence of reactive power capacity below the maximum capacity (P-Q diagram) for PPMs



When determining the reactive power capacity below the maximum capacity for PPMs and offshore PPMs (type C and D), there are no deviations in terms of the outer or inner frame from the RfG NC. As a result, a degree of convergence of 100% (29/29) is achieved.

No information found or available for the MS+ CY, BA, BG, ME, MK and RS. Therefore, they are excluded from the convergence assessment.

4.3.1.8. Type D: Power System Stabilizer Implementation

The PSS is a control system which is there to reduce, regulate and stabilize electrical oscillations within the power system through an AVR (Automatic Voltage Regulator) with this capability. The presence of a PSS function is mandatory in the Article 19 (2) (b) (v) for SPGMs but not enforced for PPMs as stated in the Article 21 (3) (f). The system operator should define the power value in MW from which the PSS should be implemented in the PGM.

The various parameters implementation between the European MS+ can be found along the Table 54:

Table 54: Implementation of PSS requirements for typeD generators in terms of the power value from which the PSS should be implemented [MW]

Value [MW]	MS+	MS+ number	Comments
All new excitation sets of production modules	CZ	1	
5	SK	1	
10	IT, SI, NIE, IE	4	
15	EE, LT, LV	3	
20	PL	1	
25	BE, DK	2	
30	NO	1	
40	HR*	1	* Type D whose short circuit power at the connection point is >4Pmax
45	DE, LU, PT	3	
50	ES, GR, GB	3	
60	NL**	1	** Type D connected at Voltage level≥220kV
75	CH, FR, SE	3	
100	HU	1	
150	RO	1	
200	AT	1	
n/a	FI, IS, BA, BG, CY, ME, MK, RS	9	

Convergence of Implementations

As the definition of a PSS is mandatory for the case of SPGM but not for PPS in the **Czech Republic**, each newly installed excitation set of a production module connected to a transmission system must be equipped with a system stabilizer (PSS). Moreover, for asynchronous modules, the requirement starts from B2 modules. The convergence level is 93% (27/29).

No information referring to PSS was found for the case of **Finland** and **Iceland**. However, some particularities can be discussed as the case of **Croatia**, which specifies the need of a PSS for the case of type D generators whose short circuit power at the terminal node is greater than four times the maximum capacity of the generator, so, the minimum case would be 40MW as the type D generator is defined from 10MW. Another case is the **Netherlands**, which specifies it for type D generators whose voltage connection level is equal or above 220kV, so, for the case of Transmission Networks.

4.3.1.9. Type D: Voltage ranges and operating periods

According to Articles 16 (2) (a) and 25 (1), PGMs of type D must be able to maintain connection to the network and operation in defined voltage ranges for a minimum period of time. This requirement concerns the voltage levels or base voltages of 110 kV or more. The RfG NC requirements regarding the minimum periods of operation for the respective voltage ranges are listed in Table 55. Some operating periods have not been defined and should be determined at national level. These correspond to the fields marked in red in the table.

Table 55: RfG NC definitions with regard to the minimum periods for operation in different voltage ranges

<table>
<tr><th colspan="2">Voltage range [pu]</th><th>0.85 - 0.88</th><th>0.88-0.9</th><th>0.9 - 1.05</th><th>1.05 - 1.097</th><th>1.097 - 1.1</th><th>1.1 - 1.118</th><th>1.118 -1.15</th></tr>
<tr><td rowspan="6">Operating periods [min] (≥ 110 kV and < 300 kV)</td><td>Continental - Europe</td><td colspan="2">60</td><td colspan="4">∞</td><td>20 to 60</td></tr>
<tr><td>Great Britain</td><td colspan="2">n/a</td><td colspan="3">∞</td><td colspan="2">n/a</td></tr>
<tr><td>Ireland and Northern Ireland (SPGM and PPM)</td><td colspan="2">n/a</td><td colspan="4">∞</td><td>n/a</td></tr>
<tr><td>Ireland and Northern Ireland (offshore PPM)</td><td colspan="2">n/a</td><td colspan="3">∞</td><td colspan="2">n/a</td></tr>
<tr><td>Baltic States</td><td colspan="2">30</td><td colspan="4">∞</td><td>20</td></tr>
<tr><td>Northern Europe</td><td colspan="2">n/a</td><td>∞</td><td colspan="2">60</td><td colspan="2">n/a</td></tr>
<tr><td rowspan="6">Operating periods [min] (≥ 300 kV)</td><td>Continental - Europe</td><td colspan="2">60</td><td>∞</td><td colspan="2">20 to 60</td><td colspan="2">n/a</td></tr>
<tr><td>Great Britain</td><td colspan="2">n/a</td><td>∞</td><td colspan="2">15</td><td colspan="2">n/a</td></tr>
<tr><td>Ireland and Northern Ireland (SPGM and PPM)</td><td colspan="2">n/a</td><td>∞</td><td colspan="4">n/a</td></tr>
<tr><td>Ireland and Northern Ireland (offshore PPMs)</td><td colspan="2">n/a</td><td colspan="3">∞</td><td colspan="2">n/a</td></tr>
<tr><td>Baltic States</td><td>n/a</td><td>20</td><td colspan="2">∞</td><td colspan="3">20</td></tr>
<tr><td>Northern Europe</td><td colspan="2">n/a</td><td>∞</td><td colspan="2">up to 60</td><td colspan="2">n/a</td></tr>
</table>

Table 56 summarizes the parameter value of the non-conclusively defined minimum operating periods in the relevant MS+. Only those MS+ that belong to the northern or continental European network system come into question. According to the table, the areas of the RfG NC are complied with by all implementations but **Switzerland** as it requires an unlimited minimum operation time for a voltage range 1.05-1.1 p.u. for a nominal voltage of ≥ 300 kV, when the RfG NC states that the time limit should not be more than 60min. Therefore, the degree of convergence is of 95% (21/22).

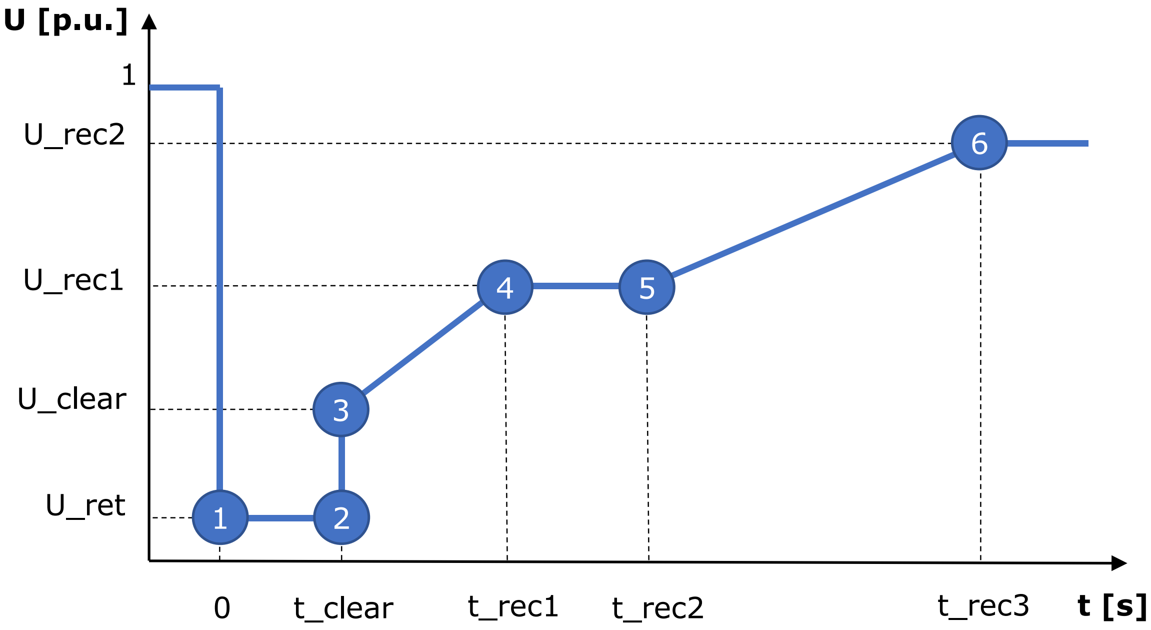
Table 56: Implementation of the non-exhaustive defined minimum periods for operation in different voltage ranges

Value [min]	MS+	MS+ number	Comments
Operating period between 1.118 pu and 1.15 pu (≥ 110 kV & < 300 kV for continental Europe)			
20	BE, FR, NL *, PT, RO	5	* Defined for SPGM and PPMs
30	AT, CH, DE, LU	4	
60	CZ, ES, GR, HR, HU, IT, NL *, PL, SI, SK, DK1	11	* Defined for offshore PPM
n/a	CY, BA, BG, ME, MK, RS	6	
Operating period between 1.05 pu and 1.1 pu (≥ 300 kV for continental and northern Europe)			
20	BE, FR, NL, PT, RO	5	
30	AT, DE	2	
60	CZ, ES, GR, HR, HU, IT, PL, SI, SK, DK, FI, IS, NO, SE	14	
Unlimited	CH	1	*Applies the same range as per >110kV & <300kV
n/a	LU *, CY, BA, BG, ME, MK, RS	7	* No 400 kV level

Requirements regarding robustness

The requirements of the RfG NC for robustness basically include the ability of PGMs of type B, C and D to drive through the faults (Fault-Ride-Through, abbr. FRT). According to Articles 14 (3) (a) and 16 (3) (a), a PGM must maintain connection to the grid and operate at temporarily low voltages at the grid connection point, typically induced by network sided faults. The FRT capability is defined through a voltage against time profile using a lower limit of the actual course of the phase-to-phase voltages on the network voltage level at the connection point during a symmetrical fault, as a function of time before, during and after the fault. This lower limit is shown in Figure 20.

Figure 20: Description of the general course of the FRT profile and definition of its parameters



The coordinates of the marked points represent the parameters of the FRT profile. U_ret is the residual, minimum voltage at the grid connection point, to which the PGM has to stay connected. t_clear is the point in time at which system faults are typically resolved. Urec1, Urec2, trec1, trec2 and trec3 are specific supporting points acknowledging typical physical voltage recovering characteristics and, hence, defining the further technical (minimum) capability of the PGM to stay connected. The RfG NC provides areas in which the FRT parameters are to be defined. Table 57 provides an overview of the parameter areas of the RfG NC. These differ according to the system category (SPGM or PPM) and the voltage level (above or below the 110 kV level).

Table 57: Definition of the RfG NC on the FRT parameters for symmetrical faults

Voltage level		<110 kV		≥ 110 kV	
Type		B, C, D		D	
category		SPGM	PPM	SPGM	PPM
U_ret [pu]	from	0.05	0.05	0	0
	to	0.3	0.15		
U_clear [pu]	from	0.7	U_ret	0.25	U_ret
	to	0.9	0.15		
U_rec1 [pu]	from	U_clear	U_clear	0.5	U_clear
	to			0.7	
U_rec2 [pu]	from	0.85 *	0.85	0.85	0.85
	to	0.9 *		0.9	
t_clear [s]	from	0.14	0.14	0.14	0.14
	to	0.25 **	0.25 **	0.25 **	0.25 **
t_rec1 [s]	from	t_clear	t_clear	t_clear	t_clear
	to			0.45	
t_rec2 [s]	from	t_rec1	t_rec1	t_rec1	t_rec1
	to	0.7		0.7	
t_rec3 [s]	from	t_rec2	1.5	t_rec2	1.5
	to	1.5	3rd	1.5	3rd

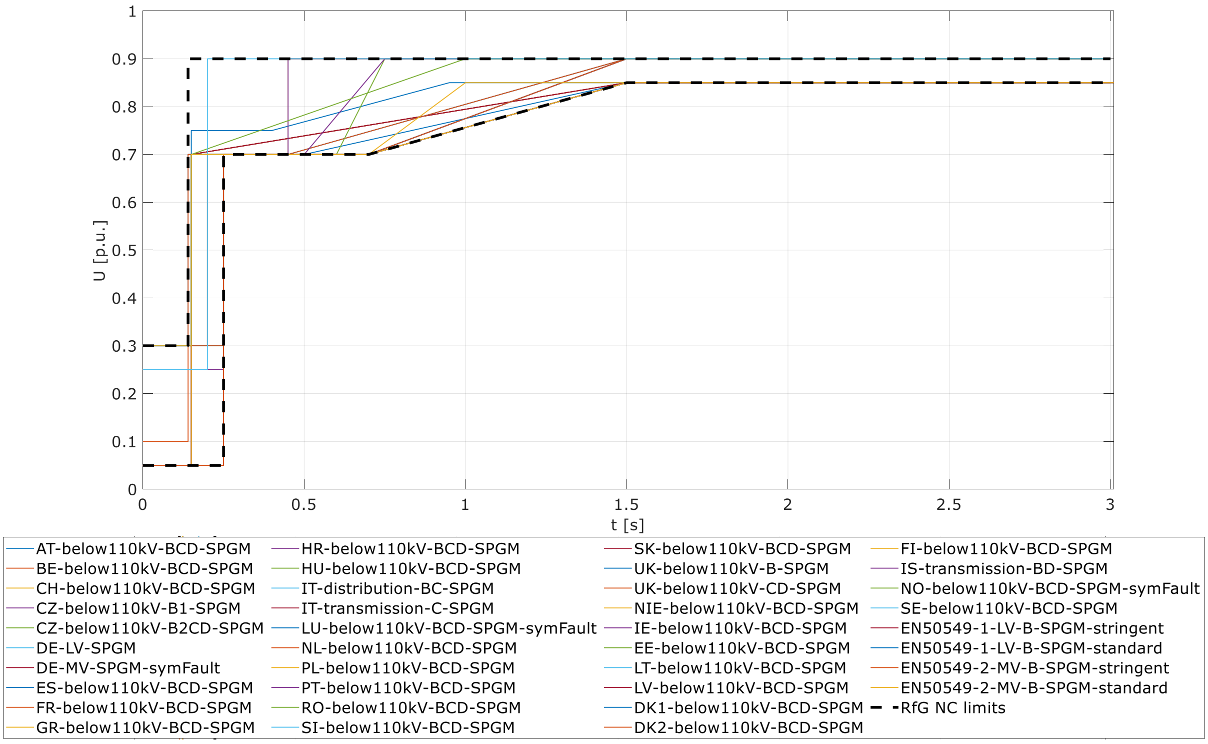
* Urec2 ≥ U_clear; ** if necessary for network protection and safe operation (otherwise 0.15)

In the case of asymmetrical faults, the FRT capability of the PGMs shall be determined in accordance with Articles 14 (3) (b) and 16 (3) (c) of the RfG NC. However, no parameter ranges are provided for this.

4.3.1.10. Types B, C, D: FRT capability within symmetrical faults for the SPGMs connected below the 110 kV level

Figure 21 shows the FRT profiles for symmetrical faults for SPGMs of type B, C and D that are connected to the network below the 110 kV level. These profiles are between the upper and lower limits of the RfG NC. In some MS+, several variants were defined depending on the network, voltage level or system type. This is the case in the **Czech Republic**, **Germany**, **Italy** and **Great Britain**.

Figure 21: Implementation of the FRT requirements with symmetrical faults for the SPGMs of type B, C and D connected to the network below the 110kV level



To draw a conclusion about convergence, the definition of the FRT parameters with respect to the voltage and time settings must also be considered in detail. Table 58 and Table 59 show how the parameterization of the FRT profiles was carried out in the different MS+. The table points out that the parameters were selected in the respective RfG NC areas. As a result, a degree of convergence of 100% (29/29) can be assigned to this implementation.

From the perspective of the EN 50549-1/-2, only **Switzerland**, the **Czech Republic**, **Germany**, **Hungary**, **Luxembourg**, **Poland**, **Portugal**, **Romania**, **Slovenia**, **Lithuania** and **Latvia** comply with the standard's requirements, corresponding to a convergence level of 38% (11/29).

Table 58: Implementation of FRT voltage parameters for symmetrical faults in SPGMs of type B, C and D (<110kV)

Value [pu]	MS+	MS+ number	Comments
U_ret			
0.05	CZ *, ES, FR, HR, IT **, NL, PL, PT, SI, SK, NIE, IE, LT, LV, FI	15	* Defined for types B2, C and D ** Defined for types B and C with connection to the distribution network and for type C with connection to the transmission network
0.1	GB *	1	* Defined for type C and D.
0.25	EE, IS *, SE	3	* Defined for type B and D with connection to the transmission network
0.3	AT, BE, CH, CZ *, DE **, GR, HU, LU, RO, GB ***, DK, NO	12	* Defined for type B1 ** Defined for connection to low or medium voltage network *** Defined for type B.
n/a	CY, BA, BG, ME, MK, RS	6	
U_clear = U_rec1			
0.7	BE, CH, CZ, DE *, ES, FR, GR, HR, HU, IT **, LU, NL, PL, PT, RO, SI, SK, GB, NIE, IE, EE, LT, LV, DK, FI , IS ***, NO	27	* For connection to the low or medium voltage network ** Defined for type B and C with connection to the distribution network and for type C with connection to the transmission network ** * Defined for type B and D with connection to the transmission network
0.75	AT	1	
0.9	SE	1	
n/a	CY, BA, BG, ME, MK, RS	6	
U_rec2			
0.85	AT, CH, CZ, DE, ES, GR, HU, IT *, LU, NL, PL, PT, RO, SI, SK, LT, LV, FI	18	* Defined for type B and C with connection to the distribution network and for type C with connection to the transmission network
0.9	BE, FR, HR, GB, NIE, IE, EE, DK, IS *, NO, SE	11	* Defined for type B and D with connection to the transmission network
n/a	CY, BA, BG, ME, MK, RS	6	

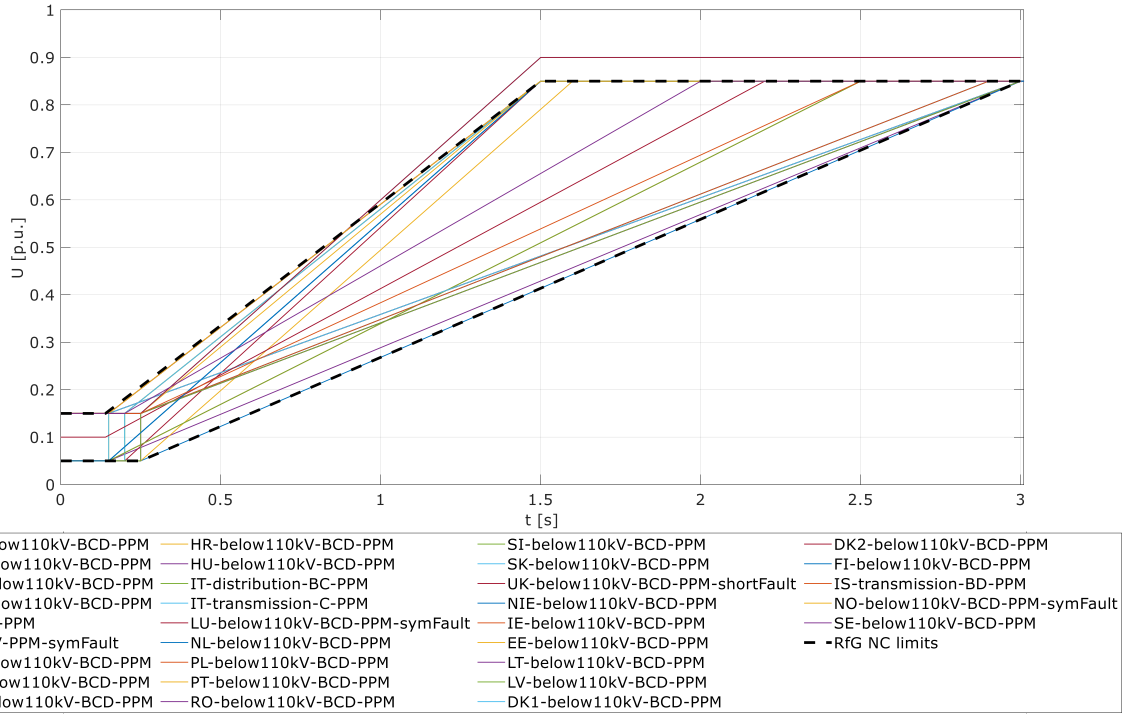
Table 59: Implementation of FRT timing parameters for symmetrical faults for SPGMs of type B, C and D (<110kV)

Value [s]	MS+	MS+ number	Comments
t_clear = t_rec1			
0.14	GB	1	
0.15	AT, CH, CZ, DE, ES, FR, GR, HR, IT *, LU, NL, PL, PT, SI, SK, NIE, IE, FI, NO	19	* Defined for type B and C with connection to the distribution network and for type C with connection to the transmission network
0.2	BE, SE	2	
0.25	HU, RO, EE, LT, LV, DK, IS *	7	* Defined for type B and D with connection to the transmission network
n/a	CY, BA, BG, ME, MK, RS	6	
t_rec2			
0.15	GR, IT *, NL, SK, NO	5	* Defined for type B and C with connection to the distribution network and for type C with connection to the transmission network
0.4	AT	1	
0.45	GB, NIE, IE	3	
0.5	ES, IS *, SE	3	* Defined for type B and D with connection to the transmission network
0.6	EE	1	
0.7	BE, CH, CZ, DE, FR, HR, HU, LU, PL, PT, RO, SI, LT, LV, DK, FI	16	
n/a	CY, BA, BG, ME, MK, RS	6	
t_rec3			
0.45	NIE, IE	2	
0.5	SE	1	
0.75	EE, IS *	2	* Defined for type B and D with connection to the transmission network
0.95	AT	1	
1	FI, NO	2	
1.5	BE, CH, CZ, DE, ES, FR, GR, HR, HU, IT, LU, NL, PL, PT, RO, SI, SK, GB, LT, LV, DK	21	
n/a	CY, BA, BG, CH, ME, MK, RS	6	

4.3.1.11. Types B, C, D: FRT capability within symmetrical faults for the PPMs connected to the network below the 110 kV level

Figure 22 shows the FRT profiles for the type B, C and D PPMs connected to the network below the 110 kV level. In **Austria**, **Germany** and **Italy** more than one profile is defined, typically for different voltage levels.

Figure 22: Implementation of FRT requirements within symmetrical faults for the PPMs of type B, C and D connected to the network below the 110 kV level



In **Hungary**, there was mistake in the grid code for the values entered for the FRT profiles of type B, C and D PPMs. This led to a false conclusion that they were not complying with the required FRT curve with respect to PPMs. This mistake was found out after discussions with MEKH. They have stated that they have corrected the parameters and will publish the new document after a public consultation. The new values according to MEKH are as follows:

Table 60: Modified voltage and time parameters in Hungary for B, C, D PPMs in case of symmetrical faults

Voltage parameters [pu]		Time parameters [sec]	
U_ret	0.15	t_clear	0.15
U_clear	0.15	t_rec1	0.15
U_rec1	0.15	t_rec2	0.15
U_rec2	0.85	t_rec3	1.5

For BCD PPMs asymmetrical faults)

Table 61: Modified voltage and time parameters in Hungary for B, C, D PPMs in case of asymmetrical faults

Voltage parameters [pu]		Time parameters [sec]	
U_ret	0	t_clear	0.15
U_clear	0	t_rec1	0.15
U_rec1	0	t_rec2	0.15
U_rec2	0.9	t_rec3	1.5

Taking the above-listed symmetrical values into account, **Hungary** complies with the requirements set out in RfG NC.

In **Denmark**, the parameter U_rec2 is set to 0.9 p.u., which means that the RfG NC requirement on this setting is not met. More details on the parameterization of the FRT profiles in the MS+ can be found in Table 62. The fields marked in red represent the cases of non-compliance. Overall, a degree of convergence of 97% (28/29) is derived. If only the EN 50549-2 requirements are considered (for MV), **Germany**, **Italy** and **Austria** would fail to comply with the standard as these MS+ define the starting voltage of the LVRT for MV networks above the standard's requirement, reducing the convergence level to 86 % (25/29) for MV.

Table 62: Distribution of FRT voltage parameters for symmetrical faults for PPMs of type B, C and D (<110kV)

Value [pu]	MS+	MS+ number	Comments
U_ret			
0.05	AT, CZ, ES, FR, HR, IT *, NL, PL, PT, SI, SK, LT, LV, FI	14	* Defined for type B and C with connection to the distribution network and for type C with connection to the transmission network
0.1	GB	1	
0.15	BE, CH, DE *, GR, LU, RO, NIE, IE, EE, DK, IS **, NO, SE, HU	14	* Defined for connection to the low or medium voltage network * * Defined for type B and D with connection to the transmission network
n/a	CY, BA, BG, ME, MK, RS	6	
U_clear = U_rec1			
0.05	AT, CZ, ES, FR, NL, PL, PT, SI, FI	9	
0.1	GB	1	
0.15	BE, CH, DE *, GR, HR, IT **, LU, RO, SK, NIE, IE, EE, LT, LV, DK, IS ***, NO, SE, HU	19	* Defined for connection to low or medium voltage network ** Defined for type B and C with connection to distribution network and for type C with connection to transmission network ** * Defined for type B and D with connection to transmission network
n/a	CY, BA, BG, ME, MK, RS	6	
U_rec2			
0.85	AT, BE, CH, CZ, DE *, ES, FR, GR, HR, HU, IT **, LU, NL, PL, PT, RO, SI, SK, GB, NIE, IE, EE, LT, LV, FI , IS ***, NO, SE	28	* Defined for connection to low or medium voltage network ** Defined for type B and C with connection to distribution network and for type C with connection to transmission network ** * Defined for type B and D with connection to transmission network
0.9	DK	1	
n/a	CY, BA, BG, ME, MK, RS	6	

Table 63: Distribution of FRT timing parameters for symmetrical faults for PPMs of type B, C and D (<110kV)

Value [s]	MS+	MS+ number	Comments
t_clear = t_rec1 = t_rec2			
0.14	GB	1	
0.15	AT, CH, CZ, DE *, FR, GR, HR, LU, PL, SI, SK, FI, NO, HU	14	* Defined for connection to the low or medium voltage network
0.2	BE, ES, IT *, SE	4	* Defined for type B and C with connection to the distribution network and for type C with connection to the transmission network
0.25	HU *, NL, PT, RO, NIE, IE, EE, LT, LV, DK, IS **	11	* Defined for t_clear and t_rec 1 * * Defined for type B and D with connection to the transmission network
n/a	CY, BA, BG, ME, MK, RS	6	
t_rec3			
1.5	AT, BE, CH, ES, FR, GR, HR, HU, IT *, EE, DK, FI, NO	13	* Defined for type B and C with connection to the distribution network and for type C with connection to the transmission network
1.6	PT	1	
2nd	SE	1	
2.2	GB	1	
2.5	PL, SI, IS *	3	* Defined for type B and D with connection to the transmission network
2.9	NIE, IE	2	
3rd	CZ, DE *, LU, NL, RO, SK, LT, LV	8	* Defined for connection to the low or medium voltage network
n/a	CY, BA, BG, ME, MK, RS	6	

4.3.1.12. Type D only: FRT capability in the event of symmetrical faults for SPGMs connected to the network at or above the 110 kV level

The FRT capabilities for symmetrical faults that have been specified for SPGMs of type D with a mains connection at or above the 110 kV level of the power system differ significantly from one MS+ to another. An overview of the defined FRT profiles is shown in Figure 23. In **Finland**, one FRT profile is defined for the 400 kV network and another for smaller voltage levels. In **Denmark**, the required skills differ according to the respective synchronous area.

Figure 23: Implementation of the FRT requirements in the case of symmetrical faults for the SPGMs of type D connected to the network at or above the 110 kV level

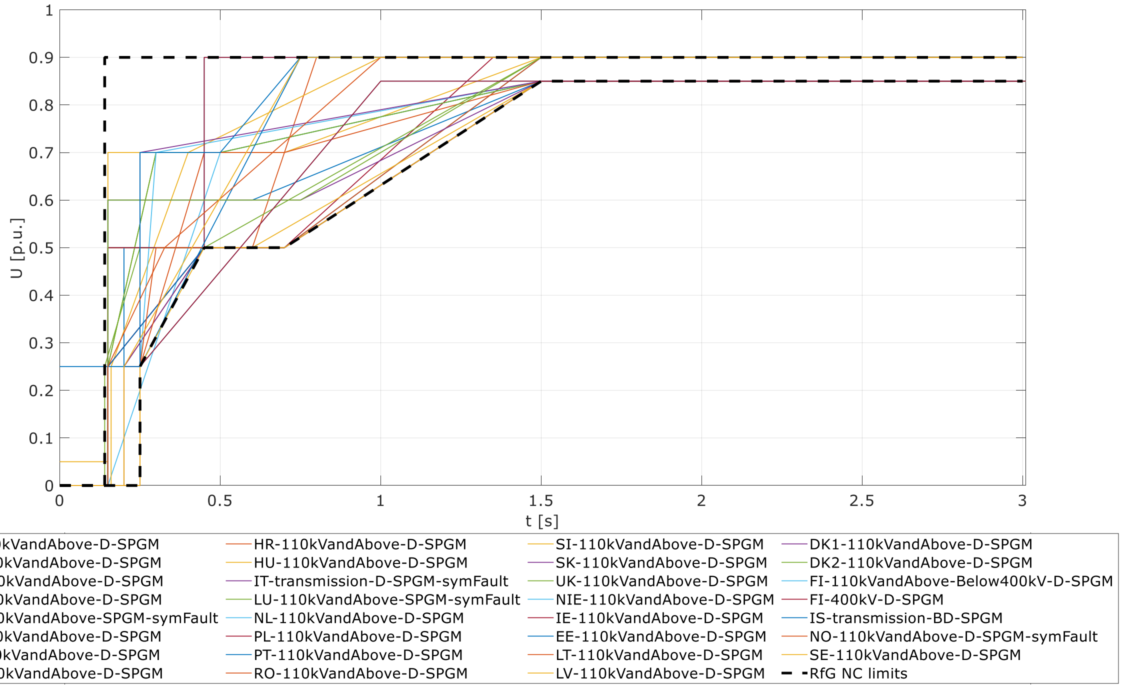


Figure 23 shows that some profiles exceed or fall below the RfG NC limits. This is the case for **Iceland**, **Spain** and **Finland**. This is due to the different selection of some parameters. In fact, the same FRT profile is defined in **Iceland** as for type B SPGMs.

Table 64 shows how the parameters were set in the MS+. The fields marked in red represent the selected values that do not comply with the parameter areas of the RfG NC.

Table 64: Implementation of FRT's voltage parameters for symmetrical faults for SPGMs of type D (≥110kV)

Value [pu]	MS+	MS+ number	Comments
	U_ret		
0	AT, BE, CZ, DE, ES, FR, GR, HR, HU, IT *, LU, NL, PL, PT, RO, SI, SK, GB, NIE, IE, EE, LT, LV, DK, FI, NO, SE	27	* Defined for type D with connection to the transmission network
0.05	CH	1	
0.25	IS *	1	* Defined for type B and D with connection to the transmission network
n/a	CY, BA, BG, ME, MK, RS	7	
	U_clear		
0	ES	1	
0.25	BE, CH, CZ, DE, HR, HU, IT *, LU, NL, PL, PT, RO, SI, SK, GB, NIE, IE, EE, LT, LV, FI, NO, SE	23	* Defined for type D with connection to the transmission network
0.5	FR, GR	2	
0.6	AT, DK	2	
0.7	IS *	1	* Defined for type B and D with connection to the transmission network
n/a	CY, BA, BG, ME, MK, RS	6	
	U_rec1		
0.25	FI	1	
0.5	BE, CZ, FR, GR, HR, IT *, PL, PT, SI, GB, NIE, IE, LT, LV, NO	15	* Defined for type D with connection to the transmission network
0.51	EE	1	
0.545	SE	1	
0,6	AT, DK	2	
0.7	CH, DE, ES, HU, LU, NL, RO, SK, IS *	9	* Defined for type B and D with connection to the transmission network
n/a	CY, BA, BG, ME, MK, RS	6	
	U_rec2		
0.85	AT, CZ, DE, ES, IT *, LU, NL, PL, PT, RO, SI, SK, LT, LV, DK1, FI	16	* Defined for type D with connection to the transmission network
0.9	BE, CH, FR, GR, HR, HU, GB, NIE, IE, EE, DK2, IS *, NO, SE	14	* Defined for type B and D with connection to the transmission network
n/a	CY, BA, BG, ME, MK, RS	6	

Table 65: Implementation of FRT timing parameters for symmetrical faults for SPGMs of type D (≥110kV)

Value [s]	MS+	MS+ number	Comments
t_clear			
0.14	GB	1	
0.15	AT, CH, CZ, DE, ES, FR, HR, LU, PL, PT, SI, NIE, IE, DK, FI *, NO	16	* Defined for voltage levels less than 400kV (≥ 110 kV & <400kV)
0.16	HU	1	
0.2	BE, GR, IT *, FI **, SE	5	* Defined for type D with connection to the transmission network ** Defined for the voltage level equal to 400kV
0.25	NL, RO, SK, EE, LT, LV, IS *	7	* Defined for type B and D with connection to the transmission network
n/a	CY, BA, BG, ME, MK, RS	6	
t_rec1			
0.15	AT, CH, FR, HR, SI, NIE, IE, DK, FI *	9	* Defined for voltage levels less than 400kV (≥ 110 kV & <400kV)
0.2	GR, FI *	2	* Defined for voltage level equal to 400kV
0.25	SK, GB, IS *	3	* Defined for type B and D with connection to the transmission network
0.3	DE, LU, NL, LT	4	
0.3267	NO	1	
0.4	HU	1	
0.45	BE, CZ, IT *, PL, PT, RO, EE, LV, SE	9	* Defined for type D with connection to the transmission network
0.5	IT	1	
n/a	CY, BA, BG, ME, MK, RS	6	
t_rec2			
0.25	SK, FI	2	
0.3	NL	1	
0.3267	NO	1	
0.4	HU	1	
0.45	GB, NIE, IE, EE, SE	5	
0.5	DE, ES, LU, IS *	4	* Defined for type B and D with connection to the transmission network
0.6	AT, BE, SI	3	
0.7	CH, CZ, FR, GR, HR, IT *, PL, PT, RO, LT, LV	11	* Defined for type D with connection to the transmission network
0.75	DK	1	
n/a	CY, BA, BG, ME, MK, RS	6	
t_rec3			
0.45	NIE, IE	2	
0.75	EE, IS *, SE	3	* Defined for type B and D with connection to the transmission network

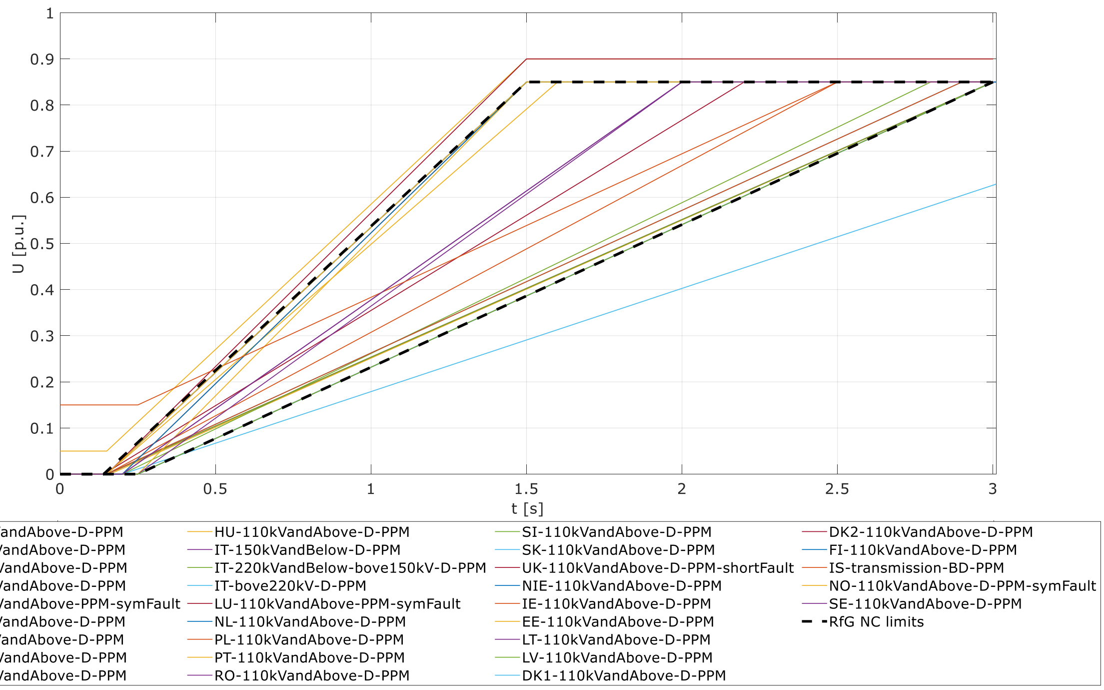
0.8	BE	1	
1	HU, FI, NO	3	
1.35	FR	1	
1.5	AT, CH, CZ, DE, ES, GR, HR, IT *, LU, NL, PL, PT, RO, SI, SK, GB, LT, LV, DK	19	* Defined for type D with connection to the transmission network
n/a	CY, BA, BG, ME, MK, RS	6	

Other cases of non-compliance can be found in Table 64 and Table 65. Although the FRT profiles are not outside the maximum and minimum possible limits of the RfG NC, the selection of some parameters in MS+ such as **Switzerland**, **France**, **Greece**, **Italy**, **Austria**, **Denmark**, **Finland, Spain** and **Iceland** show deviations from the specified areas. Overall, a degree of convergence of 69% (20/29) can be achieved.

4.3.1.13. Type D only: FRT capability for symmetrical faults for PPMs connected to the network at or above the 110 kV level

In the case of a network connection at or above the 110 kV level, PPMs of type D should have the FRT capabilities shown in Figure 24. The defined FRT profiles for **West** and **East Denmark** are different. In **Italy**, three profiles were defined depending on the voltage level. Deviations can be seen in Figure 24:

Figure 24: Implementation of the FRT requirements in the case of symmetrical faults for the PPMs of type D connected to the network at or above the 110 kV level



In **Iceland**, type D PPMs have to provide the same FRT capability as type B. However, this does not meet the requirements of the RfG NC with regard to some parameters. In **Italy**, a time t_rec3 of 4 seconds is required for PPMs with connection to the transmission network and voltage level greater than 220 kV. In **East Denmark** and **Switzerland**, the parameter

U_rec2 is set to 0.9 p.u. set. In the cases mentioned in **Italy** and **Denmark**, it is also a question of non-compliance with the areas or values provided in the RfG NC.

All information regarding the national definition of the various parameters of the FRT capability can be found in Table 66. All deviations are marked in red. Overall, a degree of convergence of 86% (25/29) can be assigned to this implementation, where **Switzerland**, **Denmark**, **Iceland** and **Italy** deviate from the RfG NC requirements.

Table 66: Distribution of FRT Voltage parameters for symmetrical faults for PPMs of type D (≥110kV)

Value [pu] / [s]	MS+	MS+ number	Comments
U_ret = U_clear = U_rec1			
0	AT, BE, CZ, DE, ES, FR, GR, HR, HU, IT *, LU, NL, PL, PT, RO, SI, SK, GB, NIE, IE, EE, LT, LV, DK, FI, NO, SE	27	* Defined for type D with connection to the transmission network
0.05	CH	1	
0.15	IS *	1	* Defined for type B and D with connection to the transmission network
n/a	CY, BA, BG, ME, MK, RS	6	
U_rec2			
0.85	AT, BE, CZ, DE, ES, FR, GR, HR, HU, IT *, LU, NL, PL, PT, RO, SI, SK, GB, NIE, IE, EE, LT, LV, DK1, FI, IS **, NO, SE	28	* Defined for type D with connection to the transmission network * * Defined for type B and D with connection to the transmission network
0.9	CH, DK2	2	
n/a	CY, BA, BG, ME, MK, RS	6	

Table 67: Distribution of FRT Timing parameters for symmetrical faults for PPMs of type D (≥110kV)

Value [pu] / [s]	MS+	MS+ number	Comments
t_clear = t_rec1 = t_rec2			
0.14	GB	1	
0.15	AT, CH, CZ, DE, ES, FR, GR, HR, LU, PL, PT, SI, NIE, IE, DK, NO	16	
0.16	HU	1	
0.2	BE, IT *, FI, SE	4	* Defined for type D with connection to the transmission network
0.25	NL, RO, SK, EE, LT, LV, IS *	7	* Defined for type B and D with connection to the transmission network
n/a	CY, BA, BG, ME, MK, RS	6	
t_rec3			
1.5	AT, BE, CH, ES, FR, GR, HR, EE, DK, FI, NO	11	
1.6	PT	1	
2	IT *, LT, SE	3	* Defined for connection to the transmission network with a voltage level less than or equal to 150kV
2.2	GB	1	
2.5	PL, IS *	2	* Defined for type B and D with connection to the transmission network
2.8	IT *	1	* Defined for connection to the transmission network with a voltage level greater than 150kV and less than or equal to 220kV
2.9	NIE, IE	2	
3	CZ, DE, HU, LU, NL, RO, SI, SK, LV	9	
4	IT *	1	* Defined for connection to the transmission network with a voltage level greater than 220kV
n/a	CY, BA, BG, ME, MK, RS	6	

4.3.1.14. Type B, C, D: FRT capability for asymmetrical faults

According to Article 14 (3) (b) and Article 16 (3) (c) of RfG NC, FRT requirements in case of asymmetrical faults shall be defined by the TSO. In most MS+, the identical FRT capability is required during an asymmetrical fault as with a symmetrical fault. Different FRT profiles for asymmetrical faults are defined for SPGMs in **Germany**, **Luxembourg** and **Italy**. With regard to the PPMs, there are differences in the FRT capability between symmetrical and asymmetrical faults in **Germany**, **Hungary** and **Luxembourg**. The asymmetrical faults profile which differs from the symmetrical ones are shown in Figure 25 and Figure 26 for SPGMs and in Figure 27 and Figure 28 for PPMs. Since all MS+ have defined the FRT profiles for asymmetrical faults – specific ones or with reference to symmetrical fault requirements –, a degree of convergence of 100% (29/29) can be achieved here.

Figure 25: FRT requirements for asymmetrical faults for SPGMs that is defined differently than for symmetrical faults on types B, C and D generators (<110kV)

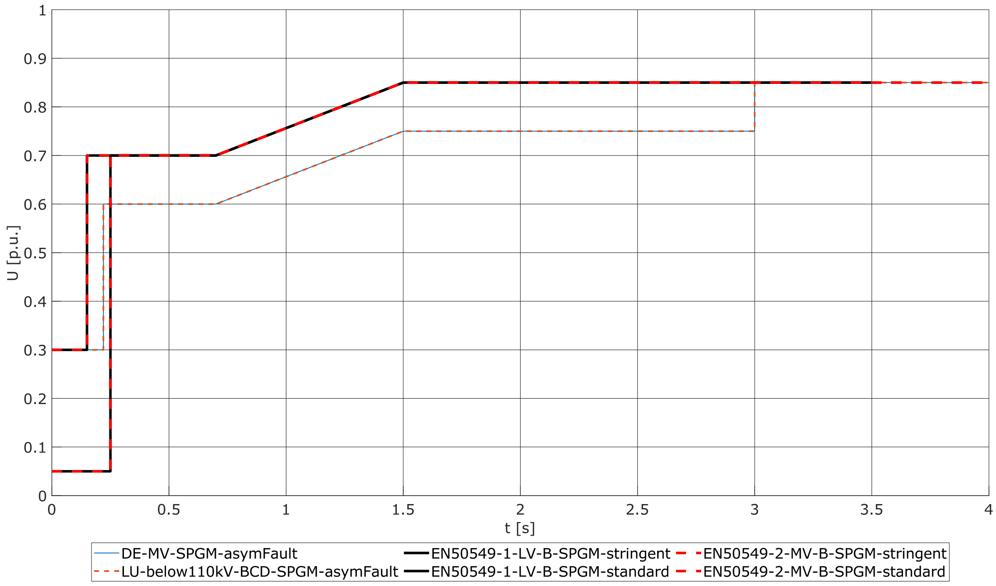


Figure 26: FRT requirements for asymmetrical faults for SPGMs that is defined differently than for symmetrical faults on type D generators (≥110kV)

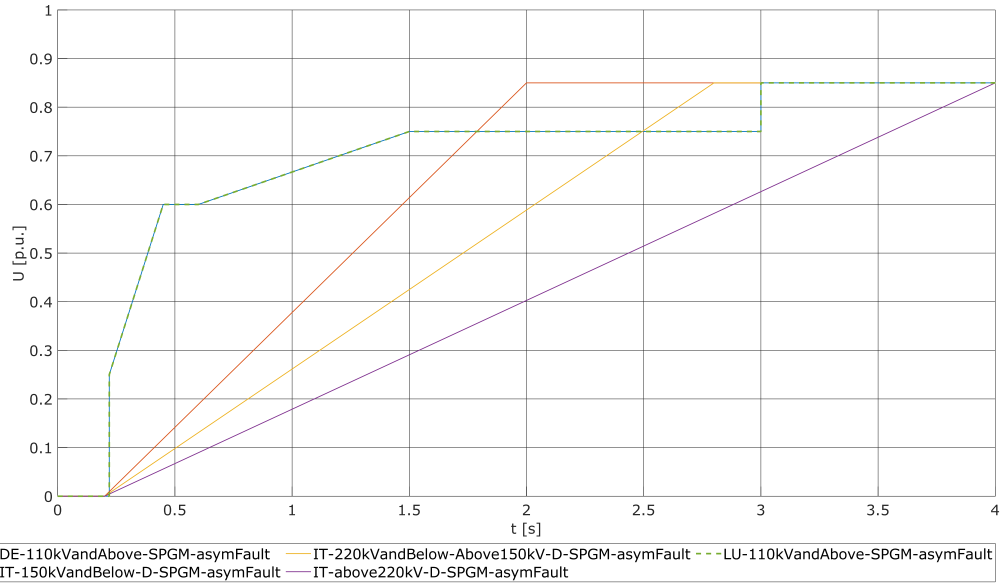


Figure 27: FRT requirements for asymmetrical faults for PPMs that is defined differently than for symmetrical faults on types B, C and D generators (<110kV)

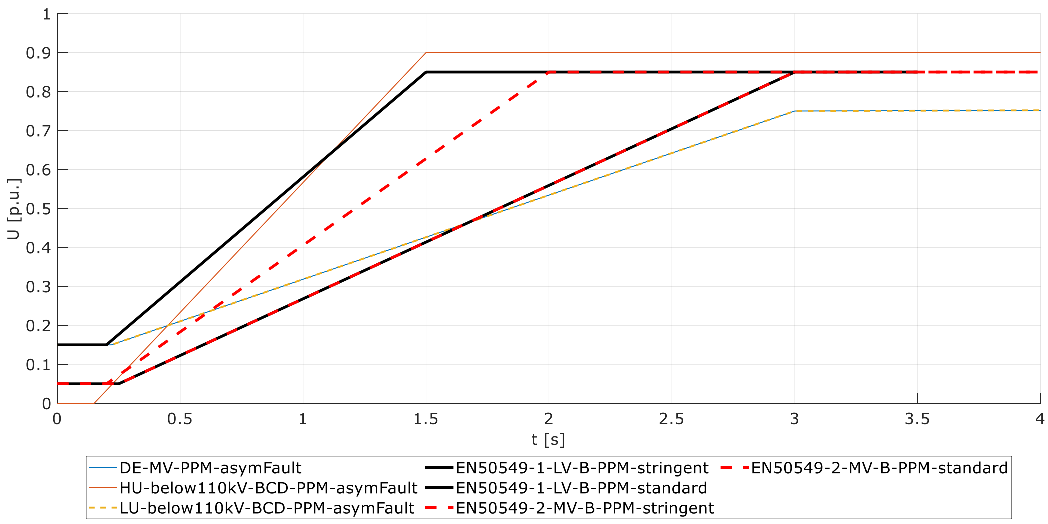
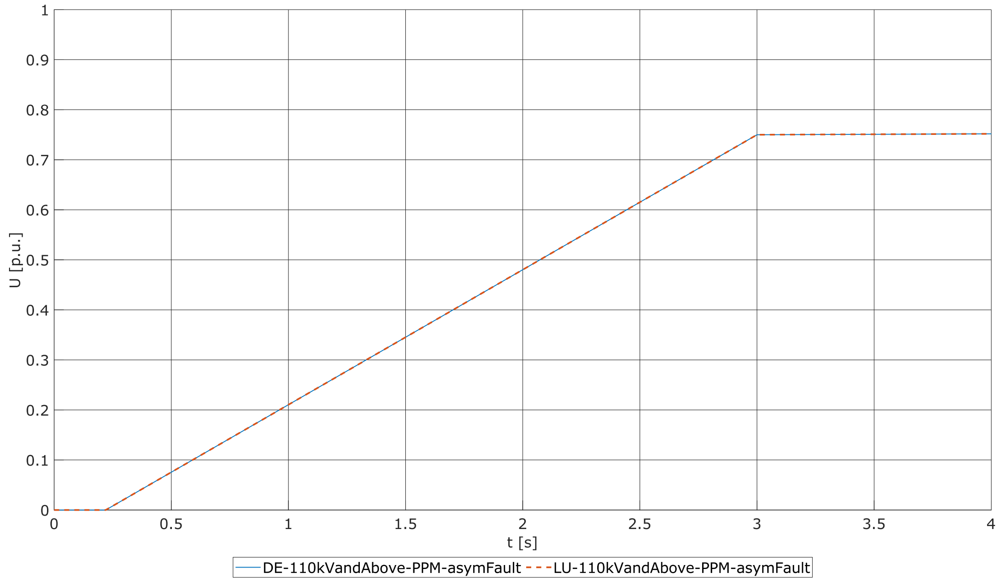


Figure 28: FRT requirements for asymmetrical faults for SPGMs that is defined differently than for symmetrical faults on type D generators (≥110kV).



4.3.1.15. Types B, C, D: Information exchange

The communication system of a power system is generally defined by the secondary equipment, like protection or multi-functional relays. It plays a significant role for the PGM's remote operation, maintenance and measurement. The definition of a communication protocol has a similar equivalence as the language for a country, where, the degree of adoption of some major protocols increases also the operation harmony of the interconnected network from a macro perspective, while, adopting different protocols can also require the incorporation of protocol conversion equipment to ensure interoperability. In the RfG NC, the information exchange is presented in the Article 14 (5) (d) in terms of functionality. It represents a mandatory requirement for types B, C and D, which states that generation facilities shall be capable of exchanging information, whose protocols and variables may be defined by the relevant System Operator if not explicitly stated in the Grid Code, where the type A communication exchange requirement is non-mandatory as expressed in the Article 13 (6). For types B, C and D, the analysis is carried out such that if no protocol is stated but the requirement is within a particular MS+, that MS+ is considered as compliant. The two most commonly used protocols are IEC 61850 and IEC 60870. The list of MS+ having implemented these two communication protocols is given below.

Convergence of implementations

In Table 68 the different protocols adoption and the conformity with Article 14 (5) (d) are found:

Table 68: Distribution of the major power system's communication protocols adoption and information exchange requirements

Value	MS+	MS+ number	Comments
IEC 61850	IT, GB, NIE, LT, FI	5	
IEC 60870	AT, BE, FR, GR, HU, IT, NIE, EE, LT, FI, NO	11	
Other Protocols or to be defined by the Relevant System Operator	CH, CZ, DE, ES, HR, PL, RO, SI, SK, IE, NIE*, DK, IS	13	*DNP3 protocol can also be adopted
n/a	BA, BG, CY, LU, ME, MK, NL, PT, RS, LV, SE	11	
Total*		40	*Some MS+ have adopted more than one protocol

Again, BA, BC, CY, ME, MK and RS, have been excluded from the convergence calculation due to the absence of national grid code implementation, hence, the degree of convergence is 83% (24/29). From these, the reference to the standard IEC 61850 gives a convergence level of 17% (5/29) whereas the respective level for the standard IEC 60870 was found to be 38% (11/29). 80% of the countries (4/5) which adopted the 61850 have decided to adopt the 60870 at the same time (with the only exception being **Great Britain**).

A particular situation was **Northern Ireland**, where the possibility of applying the DNP3 protocol is given as well as the other two mentioned protocols.

4.3.1.16. Types B, C, D: Voltage related protection

Similar to the analysis carried out in section 4.2.2.5, this part of the report is related to the implementation of the voltage related protection for type B, C and D PGMs.

Convergence of implementations

Table 69 and Table 70 show the distribution of the MS+ who have implemented the above-mentioned requirement:

Table 69: Implementation on voltage related protection schemes (overvoltage / undervoltage) on type B generators.

Implementation	MS+	Number of MS+	Comments
Type B	AT, BE, CH, CZ, DE, ES, IT, SI, GB, IE, DK, LT	12	
n/a	CY, BA, BG, ME, MK, RS, FR, GR, HR, HU, LU, NL, PL, PT, RO, SK, NIE, EE, LV, FI, NO, SE, IS,	23	

Table 70: Implementation on voltage related protection schemes (overvoltage / undervoltage) on types C and D generators.

Implementation	MS+	Number of MS+	Comments
Types C and D	AT, BE, CH, CZ, DE, ES, FR, GR, HR, HU, IT, LU, PL, RO, SI, SK, GB, NIE, IE, EE, LT, LV, DK	23	
n/a	CY, BA, BG, ME, MK, RS, NL, PT, FI, IS, NO, SE	12	

The EN 50549-1/-2 standards require the definition of voltage protection parameters for type B generators in LV and MV systems. From all the countries which have defined these parameters, all of them comply with the standard. Therefore, a convergence level of 41% (12/29) is achieved between the countries.

From Table 69, the degree of convergence for type B generators in reference to the Article 14 (5) (b) of the RfG NC is 41% (12/29).

For the case of Types C and D generators, as shown in Table 70 and with respect to Article 15 (3) of the RfG NC, the convergence degree amounts to 79% (23/29) in between MS+.

4.3.1.17. Types C, D: Loss of angular stability protection

The ability to detect a loss of angular stability and trip the protection in order to avoid damaging the PGM is defined in RfG NC for modules starting from type C (Article 15 (6) (a)).

Convergence of implementations

The MS+ which have adopted this requirement are listed in Table 71:

Table 71: Implementation of loss of angular stability protection

Implementation	MS+	Number of MS+	Comments
Type C	CZ, ES*, FR, PL, LT, FI, DE	7	Only defined for type D
Project specific	AT, HR, HU, PT, SI, IE, EE	7	
n/a	CY, BA, BE, CH, IT, BG, ME, MK, RS, GR, LU, NL, GB, RO, SK, NIE, LV, NO, SE, IS, DK	21	

From the above table, it is concluded that 13 MS+ have introduced the loss of angular stability protection requirement within their grid codes. However, **Spain** only considers the requirement for type D modules which is not the same as in RfG NC (from type C). Therefore, the convergence level is calculated as 45% (13/29).

4.3.1.18. Types B, C, D: Reconnection/synchronization after disconnection

As described in the section 4.2.2.18, this requirement applies for PGMs starting from type B in the Article 14 (4) (b). This requirement is also manifested in the EN 50549-1/-2.

Convergence of implementations

Table 72 lists the MS+ who have implemented the above requirement:

Table 72: Implementation on reconnection requirements

Implementation	MS+	Number of MS+	Comments
Types B, C and D	AT, BE, CZ, DE, ES, GR, HR, HU, IT, LU, NL, PL, PT, RO, SI, SK, GB, NIE, IE, EE, LT, LV, DK, FI, IS, NO	26	
n/a	CY, BA, BG, ME, MK, RS, CH, FR, SE	9	

From the aforementioned table, the convergence level is calculated as 90% (26/29).

In between these countries having defined the respective requirements, **Portugal**, **Great Britain**, **Iceland**, **Norway**, **Ireland**, **Northern Ireland**, **Romania** and **Poland** do not comply with the EN 50549-2 standard, giving a convergence level of 62% (18/29).

4.3.1.19. Types C, D: Simulation requirements

According to Article 15 (6) of RfG NC, type C and D PGMs are required to submit steady state and dynamic simulation models at the request of the network operator.

Convergence of implementations

Table 73 shows the distribution of MS+ corresponding to the aforementioned requirement:

Table 73: Implementation on simulation requirements

Implementation	MS+	Number of MS+	Comments
Types C and D	AT, BE, CZ[1], DE[2], ES, FR[3], GR, HR, HU, IT, LU[2], NL, PL, RO, SI, GB[2], NIE, IE, LV, DK, FI, IS[4], NO	23	1) type B2 as well 2) type B as well 3) type A as well 4) only type D
n/a	CY, BA, BG, ME, MK, RS, CH, SE, PT, SK, EE, LT	12	

From the above table, the convergence level is calculated as 79% (23/29).

4.3.1.20. Types C, D: Reactive power control modes

Article 21 (3) (d) of RfG NC requires the implementation of at least one of the different reactive power control modes (voltage control, reactive power setpoint control or power factor control) on PPMs of the types C and D. This, hence, represents also an additional requirement on type B PGMs according to the RfG NC.

convergence of implementations

Table 74 summarizes the power control modes adopted by the different MS+ in Europe.

Table 74: Distribution of the MS+ based on reactive power control for types C and D generation modules

Implementation	MS+	Number of MS+	Comments
cos φ	AT, BE, CH, DE, ES, FR, GR, LU, NL, PL, RO, SK, GB, NIE, IE, LT, LV, DK, FI, IS, NO, SE, HU	23	
Q(U)	AT, CH, CZ, BE, DE, ES, FR, GR, HR, IT, LU, NL, PL, PT, RO, SI, SK, GB, NIE, IE, EE, LT, LV, DK, FI, IS, NO, SE, HU	29	
Q setpoint	AT, BE, CH, ES, FR, GR, HR, NL, PL, PT, RO, GB, NIE, IE, DK, FI, IS, NO, SE, HU	20	
n/a	CY, BA, BG, ME, MK, RS	6	

For type C and D generators all MS+ have explicitly defined the reactive control modes, giving a convergence degree of 100% (29/29) in terms of control modes definition for reactive power.

4.3.1.21. Types B, C, D: Active power recovery after fault

As described in the section 4.2.2.17, this requirement is needed for PGMs starting from type B as stated in the Article 17 (3) and the Article 20 (3). The magnitude and time for active power recovery shall be defined by the TSO.

Convergence of implementations

The application distribution of the Active Power Recovery is found in Table 75:

Table 75: Implementation on the Active Power Recovery requirements on types B, C and D PGMs

Implementation	MS+	Number of MS+	Comments
Types B, C and D	AT, BE, CZ, DE, ES, FR, GR, HR, HU, IT, LU, NL, PL, PT, RO, SI, SK, GB, NIE, IE, EE, LT, LV, DK, FI, IS, NO, SE	28	
n/a	CY, BA, BG, ME, MK, RS, CH	7	

The present requirement is present in 97% (28/29) of the MS+.

4.3.1.22. Types C, D: Active power setpoint control

According to Article 15 (2) (a) of RFG NC, the TSO shall specify requirements regarding a tolerance band for a given setpoint as well as time period within which the PGM shall adjust its active power value to the new setpoint value. This requirement starts for PGMs of type C and above.

Convergence of implementations

The table below illustrates the MS+ which have introduced this requirement:

Table 76: Implementation on the Active Power setpoint requirements on types C and D PGMs

Implementation	MS+	Number of MS+	Comments
Types C and D	AT, BE, CZ, DE, ES, FR, GR, HR, HU, IT, LU, NL, PL, RO, SI, SK, GB, NIE, IE, EE, LT, DK, FI, IS*, NO, SE	26	* Defined only for type D
n/a	CY, BA, BG, ME, MK, RS, CH, PT, LV	9	

Even though the above requirement is for PGMs starting from type C, a comparison is worthwhile with respect to the tolerance band values between the MS+ and the European standards EN 50549-1/-2.

The aforementioned European standards define a tolerance band of 5% of rated active power. However, in **Croatia**, **Hungary**, **Italy**, the **Netherlands**, **Poland**, **Slovenia**, **Slovakia**, **Ireland**, **Northern Ireland**, **Lithuania**, **Denmark**, **Iceland**, **Norway** and **Sweden**, even more stringent tolerance bands are applied. The above analysis results in a convergence level of 90% (26/29).

4.3.1.23. Types C, D: Active power ramp rate

Article 15 (6) (e) of RFG NC introduces a requirement on the maximum and minimum ramp rates which must bet set on controlling the increase/decrease of active power of PGMs of type C and above.

Convergence of implementations

The distribution of the MS+ which have implemented the above mentioned requirement is shown in Table 77:

Table 77: Implementation on the Active Power ramp rate requirements on types C and D PGMs

Implementation	MS+	Number of MS+	Comments
Types C and D	AT, BE, CZ, DE, ES, FR[b], GR[c], HR, HU[c], IT, LU, NL, PL, RO, SI, SK, GB[b], NIE, IE, EE, LT[c], DK, FI, IS[a], NO[c], SE, PT[b], LV	28	a) Defined only for type D b) only maximum rate defined c) only minimum rate defined
n/a	CY, BA, BG, ME, MK, RS, CH,	7	

28 of the MS+ have implemented ramp rates on active power although it should be noted that in some of them, only one limit (upper or lower) is applied. The level of convergence is calculated as 97% (28/29).

4.3.1.24. Types C, D: Prioritization of the active power contribution or the reactive power contribution on PPMs during faults

If a fault occurs that requires FRT capability, the priority of the active or reactive power contribution for PPMs and offshore PPMs should be controlled in accordance with Article 21 (3) (e). It must be defined which of the two contributions has priority.

Convergence of implementations

Table 78 summarizes the definitions regarding the prioritization of the active power contribution or the reactive power contribution in the different MS+.

Table 78: Implementation of the prioritization of the active power contribution or the reactive power contribution

Value	MS+	MS+ number	Comments
P	SK *, NIE, IE	3	* Within 150 ms
Q	AT, CZ, ES, FR, PL, PT, SI, GB, EE, LT, LV, DK, FI	13	
n/a	BE, DE, GR, HR, HU, IT, LU, NL, RO, IS, NO, SE, CY, BA, BG, CH, ME, MK, RS	19	

The requirement is applied in 55% (16/29) of the MS+.

4.3.1.25. Types B, C, D: Frequency related protection

Similar to the analysis carried out in section 4.2.2.3, this part of the report is related to the implementation of the frequency related protection for types B, C and D PGMs.

Convergence of implementations

Table 79 shows the distribution of the MS+ who have implemented the above-mentioned requirement:

Table 79: Implementation on frequency related protection schemes (overfrequency / underfrequency) on types B, C and D

Implementation	MS+	Number of MS+	Comments
Types B, C and D	AT, CH, CZ, DE, HU*, IT, SI, DK, GB, LT	10	* Defined only for type B
n/a	CY, BA, BG, ME, MK, RS, HR, LU, IS, BE, NL, PL, PT, RO, SK, IE, NIE, EE, LV, FI, NO, SE, ES, FR, GR	25	

The standards EN 50549-1/-2 define boundaries for the frequency protections in LV and MV levels, applicable for types B generators, where, in between the countries which have defined respective frequency protection parameter values, all of them comply with the EN 50549-1/-2, resulting in a convergence value of 34% (10/29) for all the analyzed countries.

The analysis results in a convergence level of 34% (10/29).

4.3.1.26. Types C, D: Operation after tripping to houseload

If a PGM type C or D whose minimum resynchronization time is greater than 15min is disconnected from the network, the generator must have the ability to trip to houseload, in accordance with Article 15 (5) (c) (ii). In this case, the PGM must continue to work in houseload operation in order to supply its own load. The minimum operation time shall be determined by the relevant system operator in coordination with the TSO, as stated in the Article 15 (5) (c) (iii).

Table 80 shows the stipulated minimum operating period for houseload operation:

Table 80: Implementation of the minimum operation time after tripping to Houseload

Value [h]	MS+	MS+ number	Comments
0	DK	1	
1	RO *, FI **	2	* Defined for SPGM ** For the other PGMs (except gas, hydraulic and nuclear PGMs)
2	AT, CZ, DE, GR *, HR, HU, LU, PL, SK, NO	10	* Defined for steam PGM
3	SI	1	
4	ES, FR *, GR **, NIE, IE	5	* Defined for thermal PGMs ** Defined for gas and hydraulic PGMs
6	EE, LT, LV	3	
8	FI *	1	* Defined for gas and hydraulic PGMs
12	IT *, SE	2	* Defined for Type D thermal PGM
To be defined by the System Operator or Project specific	PT, IS, BE	3	
n/a	GB, CY, BA, BG, CH, ME, MK, RS, NL	9	

Convergence of implementations

RfG NC does not specify any discrete minimum time for the operation. The minimum operating period can be selected without restrictions. However, it has not yet been specifically defined in **Great Britain,** the **Netherlands** as well as in **Switzerland**.

The only MS+ who must implement this requirement are **Germany** and **Luxembourg** since in these countries the reconnection time could be higher than 15 minutes. The degree of convergence is therefore 100%.

4.3.2. Types B, C and D: Non mandatory requirements inside the RfG NC

Below, the non-mandatory requirements for type B, C and D modules are listed:

Table 81: Type B, C and D non mandatory requirements (inside the scope of RfG NC)

Type B, C and D non mandatory requirements
Types B, C, D: Synthetic inertia provision by PPMs
Types B, C, D: Fast fault current injection by PPMs
Types C, D: Black Start capability
Types C, D: Island Operation

4.3.2.1. Types B, C, D: Synthetic inertia provision by PPMs

The synthetic inertia capability may be provided for type B PPMs according to Article 14 (5) (c) (ii) while, according to the Article 21 (2) (a), the TSO shall have the right to require this capability of type C and D PPMs.

Incidence of implementations

Regardless of the above statements, some MS+ require this capability for types B, C and D in a general way. These are listed in Table 82:

Table 82: Implementation of the synthetic inertia requirement for type B, C and D PPMs

Implementation	MS+	Number of MS+	Comments
types B, C and D	AT, ES, FR, GR, HR, IT, LU, NL, PT, RO, GB, NIE, IE, EE, LT, LV, IS	17	
Not required	BE, HU, PL	3	
n/a	CY, BA, BG, ME, MK, RS, CH, CZ, DE, SI, SK, DK, FI, NO, SE	15	

The definition of Synthetic inertia is a requirement left to the system operator, hence, even when not mentioned in the grid code, it can be required by the TSO. However, given the explicit implementation in MS+'s grid codes an incidence level of 59% (17/29) is derived. **Belgium**, **Hungary** and **Poland** explicitly express that there are no requirements regarding to this point.

4.3.2.2. Types B, C, D: Fast fault current injection by PPMs

As defined in the Article 20 (2) (b) the fast fault current injection capability in PPMs may be requested by the TSO in the case of symmetrical fault events. This requirement applies for types B, C and D PGMs. The requirement is also mentioned in the EN 50549-2.

Incidence of implementations

The implementation for the aforementioned requirement has been listed in Table 83:

Table 83: Distribution of the fast fault current requirement for types B, C and D PPMs

Implementation	MS+	Number of MS+	Comments
type B, C and D	AT, BE, CH, CZ, DE, ES, FR, GR, HU, IT, LU, NL, PL, PT, RO, SI, GB, IE, NIE, EE, DK, FI, IS, NO	24	
n/a	CY, BA, BG, ME, MK, RS, HR, SK, LT, LV, SE,	11	

This requirement may be defined by the TSO and does not require a direct definition. Nevertheless, it is defined in 83% (24/29) of the MS+. The same value (83%) applies for the convergence level for the EN 50549-2 standard.

4.3.2.3. Types C, D: Black start capability

According to the RfG NC, the black start capability is defined as the capability of starting from shutdown without any external electrical energy supply within a given time frame and within defined limits of voltage and frequency for re-synchronization to the power system. This is a requisite only applicable to SPGMs of types C or above. The respective time frame may be defined by the system operator as well as being explicitly specified in the grid code. It is defined in the Article 15 (5) (a) and the requisite is considered as not mandatory for any the MS+.

Table 84 shows the stipulated maximum time period for the Black Start capability as defined in the MS+.

Table 84: Distribution of the maximum start-up time to ensure the black start capability in SPGM.

Value [min]	MS+	MS+ number	Comments
Maximum Start-up Time			
15	BE, ES, SK	3	
30	CZ*	1	* Specified also for type B2
45	SI	1	
To be specified by the System Operator	AT, CH**, DE, GR, HR, LU, NL, RO, GB, NIE, FI, IS, NO	13	** Specified for type D only
n/a	BA, BG, CY, FR, HU, IT, ME, MK, PL, PT, RS, IE, EE, LT, LV, DK, SE	17	

Convergence of Implementations

The Article 15 (5) (a) does not specify values for a maximum period for starting up, so it can be considered without restrictions. Nevertheless, only **Belgium**, **Spain**, **Slovakia**, the **Czech Republic** and **Slovenia** have explicitly specified a time limit for the maximum start-up time of the PGM. For other MS+, the requirement is mentioned but left on the hand of the system operator for its definition. Even when the requirement is not mandatory, it is implemented in 62% (18/29) of the MS+.

4.3.2.4. Types C, D: Island Operation

Island Operation represents an operation state without connection to the overlying power system. The island, thus defined, typically includes the neighbouring customers. This kind of operation state may occur in case of large system disturbances. This operation is not mandatory to any of the MS+, however, once implemented, some frequency and voltage limits are defined within the Article 15 (5) (b). The article defines also some power requirements, especially referring to FSM, as well as methods to detect the conditions for changing from interconnected to island state. A compliance with the regulation requires that the implementation complies with the mentioned requirements, so, in case the generator has to be resynchronized with the European Grid, this will not affect or disturb the current operation state, especially during a grid restoration process.

In Table 85 can be found the implementation of the capability of Island Operation.

Table 85: Distribution of application of the capability for island operation along MS+

Implementation according to RfG NC	MS+	MS+ number	Comments
Yes	AT, BE, CH*, DE, ES, FR, GR, IT, LU, NL, PL, RO, SI, SK, GB, NIE, LT, FI, IS	19	* Only specified for Type D
No	DK, NO	2	* Specified also for type B2
n/a	BA, BG, CY, CZ, HR, HU, ME, MK, PT, RS, IE, EE, LV, SE	14	

Convergence of Implementations

An island operation capability is not a mandatory requirement of the RfG NC, hence the inclusion within the MS+ grid codes is not required. Nevertheless, respective definitions have been identified in 19 MS+, thus the incidence level is 66% (19/29). **Switzerland** represents a very particular case as it only specifies the capability for type D generators system as the new grid code for the distribution network is still under redaction process, while the current one discourages the island operation capability for generators different than type D unless they do present a galvanic isolation with the network.

4.3.3. Additional requirements for types B, C and D PGMs

This section comprises requirements which:

- Are mentioned in the RfG NC but are obligatory for some of the 4 types of PGMs and the types above. As a result, the existence of information for a lower type would mean an additional requirement for that particular type.
- Are totally outside the RfG NC but can be considered as relevant for the convergence analysis of the EN 50549-1/-2

Table 86 presents an overview of the additional requirements for type B, C and D modules:

Table 86: Type B, C and D additional requirements (outside the scope of RfG NC)

Type B, C and D additional requirements
Additional: Voltage ranges and minimum periods for operation on types B and C
Additional: U-Q/Pmax for SPGMs on Type B generators
Additional: U-Q/Pmax for PPMs on Type B generators
Additional: P-Q/Pmax for SPGMs on type B generators
Additional: P-Q/Pmax for PPMs on Type B generators
Additional: Over Voltage Ride Through (OVRT) on types B, C and D PGMs
Additional: Reactive power control modes on types B, C and D PGMs

4.3.3.1. Additional: Voltage ranges and minimum periods for operation on types B and C

As previously described in the section 4.2.2.4, this parameter applies only for type D generators, so its application for types B and C is not enforced.

Incidence of implementations

The distribution of the MS+ with respect to the aforementioned requirement is brought within Table 87 and Table 88:

Table 87: Implementation on the minimum time period requirement for various voltage ranges on type B generators

Implementation	MS+	Number of MS+	Comments
Type B	AT, BE, CZ, DE, FR, IT, LU, NL, PT, RO, GB, NIE, DK	13	
n/a	CY, BA, BG, ME, MK, RS, CH, ES, GR, HR, HU, PL, SI, SK, IE, EE, LT, LV, FI, IS, NO, SE	22	

Table 88: Implementation on the minimum time period requirement for various voltage ranges on type C generators

Implementation	MS+	Number of MS+	Comments
Type C	AT, BE, CZ, DE, FR, IT, LU, NL, PT, RO, GB, NIE, DK, FI, NO,	15	
n/a	CY, BA, BG, ME, MK, RS, CH, ES, GR, HR, HU, PL, SI, SK, IE, EE, LT, LV, IS, SE	20	

The two standards EN 50549-1/-2 define ranges with respect to voltage and time for this requirement. For EN 50549-1, unlimited operation is required between voltage values of 0.85 - 1.1 p.u.. EN 50549-2 requires unlimited operation however, the voltage range is from 0.9 to 1.1 p.u. The following observations can be made by comparing these requirements with the implementation of the MS+:

1) For **Austria**, **Belgium**, **France**, **Italy**, **Germany**, **Luxembourg**, the **Netherlands**, **Portugal**, **Great Britain** and **Northern Ireland**, there exists a deviation from the European standard EN 50549-1 because these MS+ set a limited duration for voltage ranges between 0.85 - 0.9 p.u. bringing the convergence level to just 10% (3/29) with respect to EN 50549-1.

2) For the case of **Great Britain**, for type B modules, operation must be unlimited, beside the defined voltage range here (0.94 - 1.06 p.u) is smaller than the requirement of the European standard. In this case, a convergence of 41% (12/29) to the EN 50549-2 is reached, leaving only **Great Britain** out of the MS+ which implement type B protection but does not comply with the 50549-2.

In summary, 13 MS+ have implemented the requirement for type B modules and 15 have done it for type C. As a result, the degree of incidence is equal to 45% (13/29) for type B requirements, while it is 52% (15/29) for type C.

4.3.3.2. Additional: U-Q/P_{max} for SPGMs on Type B generators

As previously described in the section 4.2.2.6, this requirement applies for type C generators, hence, from the RfG NC point of view it represents an additional requirement when it comes to type B generators. Nevertheless, the EN 50549-1/-2 establish the requirement for type B generators as mandatory.

Incidence of implementations

The implementation for the aforementioned requirement has been displayed in Table 89:

Table 89: Implementation on U-Q/P_{max} for SPGMs on Type B generators

Implementation	MS+	Number of MS+	Comments
type B	AT, BE, CZ, DE, ES, FR, IT, PL, PT, RO, SI, GB, NIE, IE, EE, LT, DK	17	
n/a	CY, BA, BG, ME, MK, RS, CH, GR, HR, HU, LU, NL, SK, LV, FI, IS, NO, SE	18	

All MS+ are compliant with the EN 50549-2, whereas EN 50549-1 addresses LV requirements and not all of the MS+ have established requirements in LV for PGMs. The compliant MS+ with respect to EN 50549-1 are: **Austria**, **Belgium**, the **Czech Republic**, **Germany**, **France**, **Portugal** and **Denmark**. Hence, a incidence level of 24% (7/29) is established.

In general, it can be said that 59% (17/29) of the MS+ apply additional requirements in reference to the RfG NC.

4.3.3.3. Additional: U-Q/P_{max} for PPMs on Type B generators

As previously described in the section 4.2.2.7, this requirement applies for type C generators, hence, from the RfG NC point of view it represents an additional requirement when it comes to type B generators. Nevertheless, the EN 50549-1/-2 establish the requirement for type B generators as mandatory.

Incidence of implementations

Table 90 illustrates the MS+ who have implemented the requirement for type B PPMs:

Table 90: Implementation on U-Q/P_{max} for PPMs on Type B generators

Implementation	MS+	Number of MS+	Comments
type B	AT, BE, CZ, DE, ES, FR, HU, IT, NL, PL, PT, RO, SI, GB, NIE, IE, EE, LT, DK	19	
n/a	CY, BA, BG, ME, MK, RS, CH, GR, HR, LU, SK, LV, FI, IS, NO, SE	16	

The MS+ compliant with the EN 50549-2 are: **Austria**, **Belgium**, the **Czech Republic**, **Germany**, **France**, **Portugal** and **Denmark**. Hence, a convergence of 24% (7/29) is reported, same as for type B SPGMs.

The analysis results in terms of application of the present additional requirement in an incidence level of 66% (19/29), where **the Netherlands** and **Hungary** are MS+ which apply the requirement for PPM and not for SPGMs.

4.3.3.4. Additional: P-Q/P_{max} for SPGMs on type B generators

This section represents an additional requirement for type B SPGMs. For types C and D it is stated in the Article 18 (2) (c), that the generator should be able to operate within its own P-Q diagram as long as it is within the stable operation conditions. Nevertheless, even when the requirement is not present in the RfG NC, it’s a mandatory requirement for the standards EN 50549-1/-2.

Incidence of implementations

In addition to the already analyzed types, the following MS+ require this capability for type B modules as described in the Table 91:

Table 91: Implementation on P-Q/P_{max} for SPGMs on type B PGMs

Implementation	MS+	Number of MS+	Comments
type B	AT, BE, CZ, DE, FR, IT, LU, NIE, IE, DK	10	
n/a	CY, BA, BG, ES, HU, PL, RO, GB, EE, LT, ME, MK, RS, CH, GR, HR, NL, PT, SI, SK, LV, FI, IS, NO, SE	25	

The MS+ which comply with the EN 50549-1/-2 in terms of the present requirement are as follows: **Austria**, **Belgium**, **Germany**, **France** and **Denmark** giving a convergence level of 17% (5/29).

As an additional requirement to the RfG NC, the application degree is equal to 35% (10/29).

4.3.3.5. Additional: P-Q/P_{max} for PPMs on Type B generators

This section represents a mandatory requirement for the EN 50549-1/-2 but is additional from the RfG NC perspective.

Incidence of implementations

Table 92 illustrates the MS+ who have implemented the requirement for type B PPMs:

Table 92: Implementation on P-Q/P_{max} for PPMs

Implementation	MS+	Number of MS+	Comments
type B	AT, BE, CZ, DE, ES, FR, HU, IT, LU, NL, PL, RO, GB, NIE, IE, EE, LT, DK	18	
n/a	CY, BA, BG, ME, MK, RS, CH, GR, HR, PT, SI, SK, LV FI, IS, NO, SE	17	

The following MS+ comply with the EN 50549-1/-2 in terms of the present requirement: **Austria**, **Belgium**, the **Czech Republic**, **Germany**, **France**, **Lithuania** and **Denmark**, resulting in a convergence level of 24% (7/29).

As an additional requirement to the RfG NC, the incidence degree is equal to 62% (18/29), where the Netherlands establishes the requirement for PPMs but not for SPGMs.

4.3.3.6. Additional: Over Voltage Ride Through (OVRT) on types B, C and D PGMs

As previously described in the section 4.2.2.14, OVRT requirement is not part of the RfG NC, but it is required for types A and B PGMs in the EN 50549-1/-2 standard.

Incidence of implementations

Few MS+ have defined OVRT requirements as this is not mentioned in the RfG NC. Table 93 lists the MS+ which defined OVRT requirements within their national grid code for type B, C and D PGMs:

Table 93: Implementation on the OVRT requirement for types B, C and D PGMs

Implementation	MS+	Number of MS+	Comments
Types B, C, D	CZ, DE, ES, FR, IT, DK	6	
n/a	AT, CY, BA, BE, BG, ME, MK, RS, CH, HR, HU, LU, IS, GR, NL, PL, RO, SI, SK, NIE, IE, EE, LT, LV, NO, SE, PT, GB, FI	29	

An incidence degree of 21% (6/29) has been reached for this requirement. In between these 6 countries, only **France** and **Germany** comply with the EN 50549-1/-2 standard as the rest (the **Czech Republic**, **Spain**, **Italy** and **Denmark**) apply lower limits than the required by the standard.

Side Note: The introduction of OVRT requirements is mainly based on experiences in some countries with LVRT-enabled PGMs. In many physical fault situations with initial voltage sags, a brief voltage increase above 115-120% nominal voltage occurred after voltage recovery, which then led to a tripping of the PGMs due to a missing OVRT capability. FGH refers to an ongoing research project (OVRTuere) [10] of the German Federal Ministry of Economics, which analyses the grid-side requirements for various generation technologies and develops corresponding specifications for OVRT capability and respective testing procedures.

4.3.3.7. Additional: Reactive power control modes on types B, C and D PGMs

Some MS+ require the implementation of reactive power control for type B modules (PPM and/or SPGM). Furthermore, some countries define modes that are outside the scope of RfG NC (e.g. $\cos\varphi$ (P)).

Incidence of implementations

The implementation of the above mentioned requirement on type B, C and D PGMs is listed in Table 94:

Table 94: Implementation on reactive power control for type B, C and D generation modules

Implementation	MS+	Number of MS+	Comments
Constant cos φ	AT, BE, CZ, DE, NIE, LT,	6	
cos φ (P)	AT, BE, CZ, DE, PT, NIE, LT, DK	8	
cos φ (U)	CZ, LT	2	
Q(U)	AT, BE*, DE, CZ, DE, PT, GB, NIE, IE, LT, DK	11	* For units above 1 MW, this mode must be replaced with constant alternator terminal voltage mode
Constant Q	AT, CZ, NIE, LT,	4	
Q setpoint	AT, BE, GB, IE, DK	5	
Q (cos φ)	GB, IE, DK	3	
Q(P)	BE, CZ, GB, LT	4	
n/a	CY, BA, BG, ME, MK, RS, CH, ES, FR, GR, HR, HU, IT, LU, NL, PL, RO, SI, SK, EE, LV, FI, IS, NO, SE	25	

Only 38% (11/29) of the countries have defined this requirement, with Q(U) being the most spread control mode. The incidence level (38%) is the same with regard to the requirements given in the EN 50549-1/-2 standard.

4.3.4. Convergence level for types B, C and D generators

The parameter value of the various RfG NC requirements show different degrees of convergence. For most of the evaluated aspects, a degree of convergence is close to 100%. However, deviations in the implementation can be identified in some MS+. This leads to lowering the degree of convergence in other technical aspects. Table 95 summarizes the different aspects assessed in relation to the RfG NC requirements with the respective degrees of convergence achieved. Overall, an average degree of convergence of 90% can be achieved for the requirements with RfG NC restrictions for the implementation of the technical provisions of the RfG NC at European level. Nevertheless, it can be seen in the Table 96 that, for the non-mandatory requirements, the convergence level reported is 77%. Finally, in between requirements outside the RfG NC, summarized in the Table 97, an average incidence level of 53% is reached. It is important to remark that the difference of type definition thresholds between the countries will result in requirements beyond the ones established by RfG NC and this in turn presents difficulties for PGM manufacturing companies to gain access to the markets because it implies additional characteristics and compliance procedures.

Table 95: Average convergence of mandatory requirements for types B, C and D PGMs among MS+

Evaluated aspect (RfG NC requirement)	Convergence degree [%]
Capacity threshold values for type B, C and D systems (<110 kV)	100
Resistance to frequency gradients (Rate of Change of Frequency – ROCOF; also considered for type A)	97
Frequency ranges and minimum periods of operation	97
Permissible reduction in the maximum active power output with decreasing frequency	100
Limited frequency sensitive mode - overfrequency (LFSM-O) (Also considered for Type A)	72
Limited frequency sensitive mode - underfrequency (LFSM-U)	93
Frequency sensitive mode (FSM)	86
Full active power frequency response in FSM	90
Reactive power capacity at maximum capacity for SPGMs (type C and D)	79
Reactive power capacity at maximum capacity for PPMs (type C and D)	83
Reactive power capacity below the maximum capacity for PPMs (type C and D)	100
Power System Stabilizer (type D)	93
Voltage ranges and operating periods	95
FRT capability with symmetrical faults for the SPGMs of type B, C and D connected to the network below the 110 kV level	100
FRT capability for symmetrical faults for the SPGMs of type D connected to the network at or above the 110 kV level	69
FRT capability for symmetrical faults for the PPMs of type B, C and D connected to the network below the 110 kV level	97
FRT capability for symmetrical faults for the type D PPMs connected to the network at or above the 110 kV level	86
Information Exchange	83
Voltage related protection	41
Loss of angular stability protection	45
Reconnection/synchronization after disconnection	90
Types C, D: Simulation requirements	79
Types C, D: Reactive Power Control Modes	100
Active Power Recovery after fault	97
Types C, D: Active power setpoint control	90
Types C, D: Active power ramp rate	97
Prioritization of the active power contribution or the reactive power contribution during fault events	55
Frequency Related Protection	34
Operation after Tripping to Houseload	100
Total number of requirements: 29	Average convergence level: 84

Table 96: Incidence level for the non-mandatory requirements of types B, C and D among MS+

Evaluated aspect (RfG NC requirement)	Incidence degree [%]
Synthetic Inertia provision by PPMs	59
Fast Fault Current Injection by PPMs	83
Black Start	62
Islanded Operation	66
Total number of requirements: 4	Average incidence level: 68

Table 97: Incidence level of requirements outside the RfG NC for types B, C and D among MS+

Evaluated aspect (RfG NC requirement)	Incidence degree [%]
Voltages ranges and minimum operation periods (types B, C)	52
U-Q/Pmax for SPGMs on type B generators	59
U-Q/Pmax for PPMs on type B generators	66
P-Q/Pmax for SPGMs on type B generators	35
P-Q/Pmax for PPMs on type B generators	62
OVRT on types B, C, D	21
Additional reactive power control modes for type B, C, D PGMs	38
Total number of requirements: 7	Average incidence level: 48

In addition to the above assembling summary of the convergence of requirements for PGMs of type B, C and D, and following the analyses given in section 4.3.1 and 4.3.2 on existing deviations from RfG NC provisions, Table 98 provides a country-wise overview on those MS+, where national grid code provisions violate the respective RfG NC requirements.

Table 98: MS+ with requirement deviations from RfG NC with respect to type B, C and D PGMs

No.	MS+	Requirement deviations from RfG NC	Reason for deviation
1	Switzerland	Types C, D: Limited frequency sensitive mode - underfrequency (LFSM-U)	Mode not specified
		Types C, D: Frequency sensitive mode (FSM)	Mode not specified
		Types C, D: Full active power frequency response in FSM	Requirement not defined
		Type D only: Voltage ranges and operating periods	Operation time more than what is defined by RfG NC
		Type D only: FRT capability for symmetrical faults for PPMs connected to the network at or above the 110-kV level	FRT parameters outside RfG NC limits
		Type D only: FRT capability in the event of symmetrical faults for SPGMs connected to the network at or above the 110 kV level	FRT parameters outside RfG NC limits
		Types B, C, D: Active power recovery after fault	Requirement not defined
		Types C, D: Operation after tripping to houseload	Requirement not defined
		Types C, D: Active power ramp rate	Requirement not defined
		Types C, D: Simulation requirements	Requirement not defined
		Types C, D: Active power setpoint control	Requirement not defined
		Types C, D: Loss of angular stability protection	Requirement not defined
		Types B, C, D: Reconnection/synchronization after disconnection	Requirement not defined
		Types C, D: Prioritization of the active power contribution or the reactive power contribution on PPMs during faults	Requirement not defined
2	Iceland	Type D: Limited frequency sensitive mode - underfrequency (LFSM-U)	Frequency threshold deviation
		Type D: Power System Stabilizer Implementation	Requirement not defined

		Type D only: FRT capability for symmetrical faults for PPMs connected to the network at or above the 110 kV level	FRT parameters outside RfG NC limits
		Type D only: FRT capability in the event of symmetrical faults for SPGMs connected to the network at or above the 110 kV level	FRT parameters outside RfG NC limits
		Types B, C, D: Voltage related protection (B & C, D)	Requirement not defined
		Types C, D: Loss of angular stability protection	Requirement not defined
		Types B, C, D: Frequency related protection	Requirement not defined
3	Finland	Types C, D: Frequency sensitive mode (FSM)	Mode not specified
		Types C, D: Full active power frequency response in FSM	Requirement not defined
		Type D: Power System Stabilizer Implementation	Requirement not defined
		Type D only: FRT capability in the event of symmetrical faults for SPGMs connected to the network at or above the 110 kV level	FRT parameters outside RfG NC limits
		Types B, C, D: Frequency related protection	Requirement not defined
		Types B, C, D: Voltage related protection (B & C, D)	Requirement not defined
4	Ireland	Types C, D: Reactive power capacity at maximum capacity for SPGMs	Curve outside RfG limits
		Types C, D: Reactive power capacity at maximum capacity for PPMs and offshore PPMs	Curve outside RfG limits
		Types B, C, D: Frequency related protection	Requirement not defined
5	Great Britain	Types C, D: Reactive power capacity at maximum capacity for PPMs and offshore PPMs	Curve outside RfG limits
		Types C, D: Full active power frequency response in FSM	Duration of activation period not defined
		Types B, C, D: Active power recovery after fault	Requirement not defined
		Types C, D: Operation after tripping to houseload	Requirement not defined
		Types C, D: Loss of angular stability protection	Requirement not defined

6	Germany	Types C, D: Reactive power capacity at maximum capacity for SPGMs	Curve outside RfG limits
		Types C, D: Reactive power capacity at maximum capacity for PPMs and offshore PPMs	Curve outside RfG limits
		Types C, D: Prioritization of the active power contribution or the reactive power contribution on PPMs during faults	Requirement not defined
7	Italy	Type D only: FRT capability for symmetrical faults for PPMs connected to the network at or above the 110 kV level	FRT parameters outside RfG NC limits
		Types C, D: Loss of angular stability protection	Requirement not defined
		Types C, D: Prioritization of the active power contribution or the reactive power contribution on PPMs during faults	Requirement not defined
8	Luxembourg	Types C, D: Reactive power capacity at maximum capacity for SPGMs	Curve outside RfG limits
		Types C, D: Reactive power capacity at maximum capacity for PPMs and offshore PPMs	Curve outside RfG limits
		Types B, C, D: Information exchange	Requirement not defined
		Types C, D: Loss of angular stability protection	Requirement not defined
		Types B, C, D: Frequency related protection	Requirement not defined
		Types C, D: Prioritization of the active power contribution or the reactive power contribution on PPMs during faults	Requirement not defined
		Types B, C, D: Voltage related protection (only B)	Requirement not defined
9	Spain	Type D only: FRT capability in the event of symmetrical faults for SPGMs connected to the network at or above the 110 kV level	FRT curve outside RfG NC limits
		Types B, C, D: Frequency related protection	Requirement not defined

10	Hungary	Types C, D: Reactive power capacity at maximum capacity for SPGMs	Curve outside RfG limits
		Types C, D: Prioritization of the active power contribution or the reactive power contribution on PPMs during faults	Requirement not defined
		Types B, C, D: Voltage related protection (only B)	Requirement not defined
11	Lithuania	Types C, D: Reactive power capacity at maximum capacity for SPGMs	Curve outside RfG limits
		Types C, D: Reactive power capacity at maximum capacity for PPMs and offshore PPMs	Curve outside RfG limits
		Types C, D: Simulation requirements	Requirement not defined
12	Latvia	Types C, D: Reactive power capacity at maximum capacity for SPGMs	Curve outside RfG limits
		Types C, D: Reactive power capacity at maximum capacity for PPMs and offshore PPMs	Curve outside RfG limits
		Types B, C, D: Information exchange	Requirement not defined
		Types C, D: Loss of angular stability protection	Requirement not defined
		Types C, D: Active power setpoint control	Requirement not defined
		Types B, C, D: Frequency related protection	Requirement not defined
		Types B, C, D: Voltage related protection (only B)	Requirement not defined
13	Denmark	Types B, C, D: FRT capability within symmetrical faults for the PPMs connected to the network below the 110 kV level	FRT parameters outside RfG NC limits
		Type D only: FRT capability for symmetrical faults for PPMs connected to the network at or above the 110 kV level	FRT parameters outside RfG NC limits
		Type D only: FRT capability in the event of symmetrical faults for SPGMs connected to the network at or above the 110 kV level	FRT parameters outside RfG NC limits

		Types C, D: Loss of angular stability protection	Requirement not defined
14	France	Type D only: FRT capability in the event of symmetrical faults for SPGMs connected to the network at or above the 110 kV level	FRT parameters outside RfG NC limits
		Types B, C, D: Reconnection/ synchronization after disconnection	Requirement not defined
		Types B, C, D: Frequency related protection	Requirement not defined
		Types B, C, D: Voltage related protection (only B)	Requirement not defined
15	Austria	Type D only: FRT capability in the event of symmetrical faults for SPGMs connected to the network at or above the 110 kV level	FRT parameters outside RfG NC limits
16	Greece	Type D only: FRT capability in the event of symmetrical faults for SPGMs connected to the network at or above the 110 kV level	FRT parameters outside RfG NC limits
		Types C, D: Loss of angular stability protection	Requirement not defined
		Types B, C, D: Frequency related protection	Requirement not defined
		Types C, D: Prioritization of the active power contribution or the reactive power contribution on PPMs during faults	Requirement not defined
		Types B, C, D: Voltage related protection (only B)	Requirement not defined
17	Belgium	Types C, D: Loss of angular stability protection	Requirement not defined
		Types C, D: Prioritization of the active power contribution or the reactive power contribution on PPMs during faults	Requirement not defined
		Types B, C, D: Frequency related protection	Requirement not defined

18	Poland	Types B, C, D: Frequency related protection	Requirement not defined
		Types B, C, D: Voltage related protection (only B)	Requirement not defined
19	Norway	Types B, C, D: Voltage related protection (B & C, D)	Requirement not defined
		Types C, D: Loss of angular stability protection	Requirement not defined
		Types B, C, D: Frequency related protection	Requirement not defined
		Types C, D: Prioritization of the active power contribution or the reactive power contribution on PPMs during faults	Requirement not defined
20	Estonia	Types C, D: Simulation requirements	Requirement not defined
		Types B, C, D: Frequency related protection	Requirement not defined
		Types B, C, D: Voltage related protection (only B)	Requirement not defined
21	Netherlands	Types C, D: Operation after tripping to houseload	Requirement not defined
		Types B, C, D: Frequency related protection	Requirement not defined
		Types C, D: Prioritization of the active power contribution or the reactive power contribution on PPMs during faults	Requirement not defined
		Types B, C, D: Information exchange	Requirement not defined
		Types C, D: Loss of angular stability protection	Requirement not defined
		Types B, C, D: Voltage related protection (B & C, D)	Requirement not defined
22	Sweden	Types B, C, D: Information exchange	Requirement not defined
		Types C, D: Loss of angular stability protection	Requirement not defined
		Types C, D: Simulation requirements	Requirement not defined

		Types B, C, D: Reconnection/synchronization after disconnection	Requirement not defined
		Types B, C, D: Frequency related protection	Requirement not defined
		Types C, D: Prioritization of the active power contribution or the reactive power contribution on PPMs during faults	Requirement not defined
		Types B, C, D: Voltage related protection (B & C, D)	Requirement not defined
23	Portugal	Types B, C, D: Information exchange	Requirement not defined
		Types C, D: Active power setpoint control	Requirement not defined
		Types C, D: Simulation requirements	Requirement not defined
		Types B, C, D: Frequency related protection	Requirement not defined
		Types B, C, D: Voltage related protection (B & C, D)	Requirement not defined
24	Romania	Types C, D: Loss of angular stability protection	Requirement not defined
		Types B, C, D: Frequency related protection	Requirement not defined
		Types C, D: Prioritization of the active power contribution or the reactive power contribution on PPMs during faults	Requirement not defined
		Types B, C, D: Voltage related protection (only B)	Requirement not defined
25	Slovakia	Types C, D: Loss of angular stability protection	Requirement not defined
		Types C, D: Simulation requirements	Requirement not defined
		Types B, C, D: Frequency related protection	Requirement not defined
		Types B, C, D: Voltage related protection (only B)	Requirement not defined
26	Croatia	Types B, C, D: Frequency related protection	Requirement not defined

		Types C, D: Prioritization of the active power contribution or the reactive power contribution on PPMs during faults	Requirement not defined
		Types B, C, D: Voltage related protection (only B)	Requirement not defined
27	Northern Ireland	Types B, C, D: Voltage related protection (only B)	Requirement not defined
		Types C, D: Loss of angular stability protection	Requirement not defined
		Types B, C, D: Frequency related protection	Requirement not defined

5. Compliance assessment of the technical requirements

Compliance assessment plays a crucial role in order to get grid code requirements becoming effective and, hence, providing an impact on grid stability in real life. In Title III and IV, the RfG NC has given a binding framework on compliance schemes both for the commissioning phase of PGMs, i.e. the operational notification procedure, and the compliance monitoring during the PGM's lifetime. In general, compliance have to be proven in terms of testing and simulation. So called equipment certificates may be utilized to substitute some of the measurements on PGM level by appropriate measures on the equipment level. Despite the scope of the tender document for this study, FGH has broadened the survey on the investigation of existing compliance schemes.

Whereas articles 40 - 56 provide a framework on which requirements are to be assessed by testing and/or simulations, the RfG NC does not give nor refer to a detailed testing or validation/simulation procedure how to perform and report such verifications. It does not provide a precise information, to what extent equipment certificates could substitute on-site measurements on PGM level, and how respective type testing should be performed. Moreover, the code does not refer to any certification programme which, however, is necessary for issuing any kind of certificate.

In opposite to the fixed timeframe for implementing the technical requirements on national level, the RfG NC has not facilitated a respective schedule for the implementation of compliance schemes.

Given these uncertainties the survey provides a mixed picture among the MS+. Table 99 demonstrates the technical requirements for which at least one reference to any form of compliance methodology was found for the respective technical requirement in a MS+ RfG NC implementation. I.e., for calculating the incidence level for each requirement, the following assumption has been made: Any given form of compliance methodology for a MS+ with respect to a requirement means the existence of compliance for that requirement in the respective country. Therefore, the convergence/incidence level for each requirement is defined as the percentage of MS+ that require compliance in at least one way for the corresponding requirement.

Table 99: Incidence level for the compliance of modules among MS+

Technical requirement	Compliance enforcement incidence level [%]	Comments
LFSM-O	62	
LFSM-U	59	
FSM	62	
Synthetic inertia	28	
Frequency restoration	45	
Reactive power capability	66	
P-setpoint	52	
ROCOF	14	Outside RfG NC
Q(U)	45	
Q($\cos\varphi$)	35	
PSS	45	
Q setpoint	31	Outside RfG NC
Constant U	14	Outside RfG NC
Constant $\cos\varphi$	21	Outside RfG NC
Q(P)	17	Outside RfG NC
LVRT	69	
Fast fault current injection	48	
OVRT	10	Outside RfG NC
Active power reduction during faults	14	Outside RfG NC
Active power recovery	48	
Islanding operation	62	
Black start	45	
Tripping to houseload	48	
Tests on interface protection system	24	Outside RfG NC
Tests on power quality	31	Outside RfG NC
Connection and reconnection and P-gradient	28	Outside RfG NC
Automatic reconnection	17	Outside RfG NC
Quasi stationary operation of voltage and frequency	24	Outside RfG NC
Active power reduction with falling frequency	14	Outside RfG NC
Verification of the direct component of the output current	3	Outside RfG NC
Generator parameters	10	Outside RfG NC
Inertia constant	10	Outside RfG NC
AVR response testing	21	Outside RfG NC
Over/under excitation limiters	10	Outside RfG NC
Turbine speed limiter / speed controller response	10	Outside RfG NC
Information exchange with SCADA	17	Outside RfG NC

Dynamic behavior of voltage regulation and stability in small movements	3	Outside RfG NC
load stability	3	Outside RfG NC
voltage withstand during frequency variation	10	Outside RfG NC
protection system compatibility	3	Outside RfG NC

The average convergence level is calculated with respect to the requirements for which a compliance procedure is available within RfG NC and is equal to 51%. On the other hand, the average incidence level corresponds to additional compliance requirements outside the scope of RfG NC and amounts to 15%, only.

In general references to compliance measures in the grid code often remain vague. Some MS+ have published detailed testing procedures in accompanying documents. Spain and Germany refer to a detailed certification programme both on a generation unit and PGM level (as well as for components). However, it has to be noted, that these two countries have a long-term tradition in grid compliance certification for more than ten years.

It has to be stressed that today's heterogeneous requirements on compliance throughout Europe poses major challenges for manufacturers in particular. Next to very much varying technical requirements as pictured in the previous sections of this survey, manufacturers even may have to provide different kind of compliance documents for their products to their customers, i.e. PGM developers, and / or system operators. Cost intensive measurement campaigns on type testing may be multiplied due to slight differences in national testing procedures requiring different parameter settings.

ENTSO-E has started a process in late summer 2020 to revise its Implementation Guideline Documentation (IGD) on compliance testing and compliance monitoring in order to provide a clearer framework for national RSOs to define their requirements on compliance measures.

A most feasible way for resolving these issues is the development of international standards on testing, model validation and simulation and certification. Respective approaches have started on the CENELEC (CLC TS 50549-10) and IECRE level.

6. Incorporation of European Standards 50549-1/-2 in RfG NC Implementations of MS+

As already depicted throughout this survey the European CENELEC standards EN 50549-1/-2 have been developed to provide a general framework on grid code requirements for generators with connection to the low and medium voltage power grid respectively (to some extend an even direct reference to PGMs of type A and Type B is given for some of the technical features). For this purpose, available information on national requirements have been assembled in a common frame, differentiating between "regular" and "more stringent" requirements. As a result, the requirements do extend the provisions of the RfG NC, as especially MS+ with a high degree of decentralised power generation in the distribution networks have already established advanced requirements, e.g. on voltage stability, controllability and/or fault behaviour, even in the low voltage network, hence, typically applied to type A generators (cf. section 4.2.2).

It has to be noted, that the standards have been published in the beginning of 2019, hence, taking into account the drafting and voting procedure, still not all national grid code requirements in the course of RfG NC implementation could have been taken into account.

Whereas the previous sections have sorted in the EN standards into respective requirements (where applicable), this section will give an overview on the direct reference to the standard in national codes as well as on the convergence level of national implementation with the EN standards.

Analysis results

For the analysis of the implementation along MS+, the grid code of 29 countries have been analyzed. Two main elements were taken into consideration during the grid code analysis of the different MS+:

- A direct mention to the EN 50549-1/-2 in general in their grid codes
- A possible partial implementation of the EN 50549-1/-2 in the grid codes by comparing the requirements of MS+ with those of the EN, also taking into account extra requirements which are not mentioned in RfG NC (e.g. OVRT)

In Table 100 and Table 101 the detailed information about the implementation degree along MS+ in Europe can be found:

Table 100: Direct reference of the EN 50549-1/-2 in Europe

Implementation	MS+	Number of MS+	Comments
Direct reference to the EN 50549-1/-2	AT, BE, CZ, HR, FR, DK, FI	7	
n/a	CY, BA, BG, ME, MK, RS, CH, DE, ES, HU, IT, LU, IS, GR, NL, PL, RO, SI*, SK, NIE, IE, EE, LT, LV, NO, SE, PT, GB	28	* According to the response from the questionnaire, Standards EN 50549-1/-2 have been considered in the proposal of the System Operating Instructions for the Electricity Distribution System (National Grid Code for Distribution System). The proposal is currently in the process of approval by the AGEN (NRA).

Table 101: EN 50549-1/-2 Convergence Levels along MS+

EN 50549-1/-2 Convergence Levels	
Requirement	**Convergence [%]**
Frequency Related Protection	34
Voltage Related Protection	41
Voltage Ranges and Minimum Periods	10
Reactive Power Control	38
Fast Fault Current Injection	83
U-Q/Pmax for SPGMs	24
U-Q/Pmax for PPMs	24
P-Q/Pmax for SPGMs	17
P-Q/Pmax for PPMs	24
LVRT for SPGMs	38
LVRT for PPMs	86
OVRT	21
Frequency ranges and minimum time periods for operation	97
Resistance to frequency gradients (Rate of Change of Frequency - ROCOF)	97
Permissible reduction in the maximum active power output with falling frequency	100
Limited Frequency Sensitive Mode - Overfrequency (LFSM-O)	100
Definition of Pref for PPMs	100
Voltage related active power reduction (P(U))	14
Zero current mode for PPM technology	3
Reconnection/synchronization after disconnection	62
(Automatic) connection	79
Total requirements: 21	52%

- **Degree of convergence**

The degree of convergence study can be divided in between a direct reference in the national grid code and a partial implementation. According to Table 100, only 7 countries (corresponding to a convergence level of 24% (7/29)) have directly declared the implementation of the EN 50549-1/-2 in their grid codes, where in the Table 101, a partial implementation (of around 52%) can be found. In some cases, with high convergence levels, such as **Spain** and **Germany**, the implementation is reported as not intentional as officially stated by the National Regulatory Authority of the MS+ after establishing communication, hence, many of these requirements can be categorized just as higher requirements levels for generators according to the national standards.

7. Conclusion & Recommendations

7.1. Conclusion

The rules laid out under RfG NC within the ACER Framework Guidelines on Electricity Grid Connection were aimed to meet the principles of the Third Energy Package namely to increase sustainability, security of supply and to elaborate the concept of a single European market for electricity. Hence, the provisions within RfG NC defined requirements on power generating facilities in order to ensure grid stability and security of supply with a special focus on cross-border issues.

The definition of grid connection requirements took within RfG NC into account respective technical needs of the different synchronous areas in Europe. For a majority of the requirements additional leeway for implementation has been given to the national TSOs in terms of so-called non-exhaustive requirements providing ranges for national implementation in order to select grid-specific setpoints and parameters.

Indeed, one objective brought in by various stakeholders in the course of the network code development was to obtain a strong coherence in grid connection requirements throughout Europe, hence, lowering or even eliminating market barriers in terms of country-specific product specifications and respective PGM designs. Thus, the network codes were supposed to contribute to the idea of a single European market.

The survey given in this study provides a different picture, though. On the one hand, an overall convergence level of **91%** for **type A specific requirements** among 29 MS+ can be stated (cf. Table 21), where the RfG NC implementation have already been taken place. The result indicates that the wide majority of the MS+ have taken care of the boundaries set in the non-exhaustive requirements the RfG NC associated with type A PGU's.

Figure 29 maps the convergence level country-wise for type A PGMs. Most of the MS+ which are not fully compliant with the framework of RfG NC deviate only in one or two requirements. Hence, it could be stated that a high degree of uniformity among the implementations for type A power generating units has been achieved.

However, another result of this survey is, that the above-mentioned convergence level is significantly adversely affected by a variety of additional requirements for type A PGMs set individually at national level, which are not being addressed by RfG NC – these are, e.g., measures for voltage stability, fault-ride-through-capabilities or re-connection requirements; in general requirements, that have been introduced for generators of type B, C and/or D within the RfG NC, but not initially for type A. Here, a low overall incidence level of **17%** with respect to these additional requirements is obtained (cf. Table 38). For some of the requirements, the incidence level is even below **10%**, baring very specific barriers for manufacturers and PGM developers for the market entry in these respective countries. However, it must be noted that most of these additional provisions are also addressed by the European Standard CLC 50549-1/2.

As the tender document for this survey has put a special focus on type A PGMs it must be emphasised that an additional divergence has been put on the European landscape due to the concession of individual national definitions of thresholds for distinguishing between the PGM types (A-D) taking into account the installed capacity. Especially for the type A/B-threshold the survey has revealed differences in the national implementation by a factor of 150 - from 10 kW as in the case of **Slovenia** up to 1,5 MW in **Norway** and **Sweden** (cd. Figure 4 and Table 4). This diversity imposes that small power generating units, e.g. PV or CHP, may be subject to type A requirements in country A only, while in the neighbouring country B the full scale of type B requirements will apply. This imposes major challenges especially for manufacturers with products in this lower capacity range. In particular small CHP power generating units with low torque do face problems with stringent FRT requirements.

Figure 29: Overall deviation chart for type A PGMs

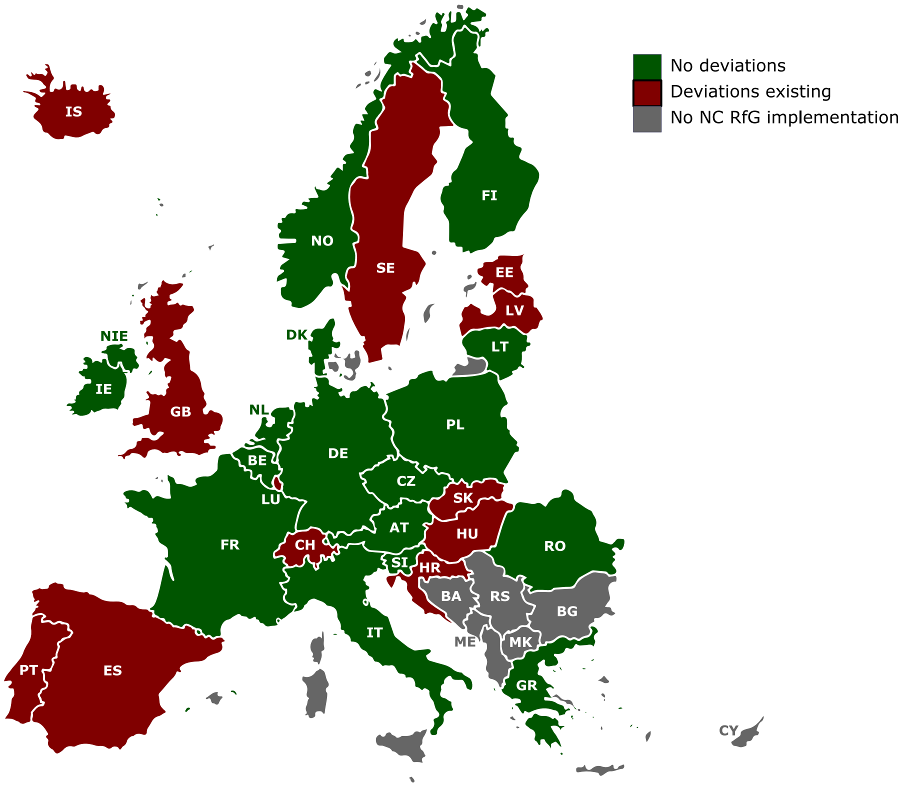
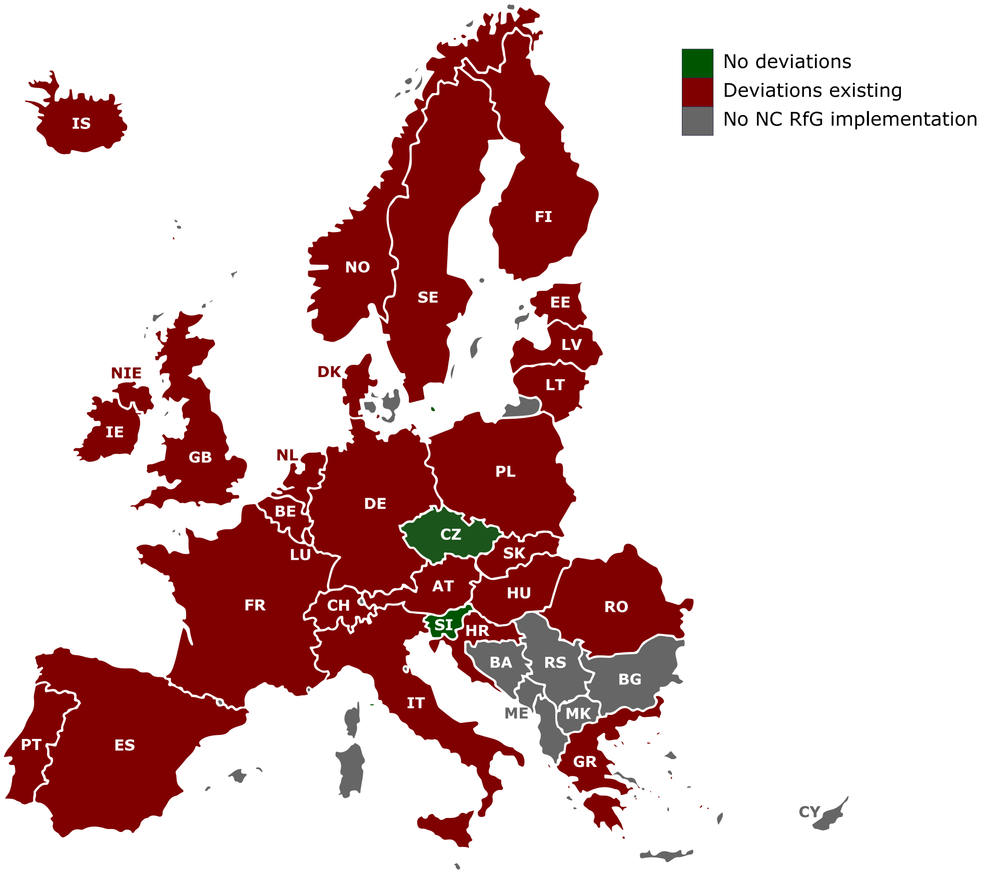


Figure 30: Overall deviation chart for types B, C and D PGMs



With respect to the mandatory requirements of the RfG NC for PGMs **of type B, C and D** the overall coherence level yields a value of **84%**. Although that value looks quite positive, it has to be noted, that, however in contrast to type A requirements, a total of 27 countries have at least one deviation in their RfG NC implementation against the set European framework (cf. Table 98). Figure 30 illustrates the cumulative mapping of the convergence level country-wise with respect to the RfG NC requirements for PGMs of type B, C and D. Deviations are mostly due to different FRT requirements and/or reactive capability provisions.

With respect to the implementation of non-mandatory requirements for PGMs of type B, C and D the convergence level drops down to **68%** as expected as MS+ were free to implement these.

Again, as already analysed for type A generators, some additional requirements for PGMs of type B, C and D can be found in a number of national grid codes that have not been addressed to these types by the RfG NC. In some MS+, requirements on voltage bands for continuous PGM operation as a regular requirement for type D PGMs only have been shifted also to type B and C PGMs, and enhanced reactive power supply capabilities – actually required for type C and D PGMs only – have been shifted to type B generators as well. However, with the additional requirement on overvoltage-ride-through (OVRT) a new feature has been introduced in a total of six countries that has not been tackled by the RfG NC at all. Naturally, the incidence level drops down to **48%** for these additional requirements for type B, C and D PGMs.

The survey has also reflected the consideration of the **European CENELEC standards EN 50549-1/-2**.These provide a well elaborated further framework for grid connection requirements especially for those not being addressed by the RfG NC.

The analysis also took a look on existing provisions on requirement for the grid connection of **storage systems**. As the RfG NC explicitly excludes storage systems from its provisions the survey did figure out only a few respective provisions, namely in **Italy** and **Germany**, that would address specifically both the feed-in and the consumption mode of a storage system, hence treating it as generator and a load and utilizing respective capabilities for power system support. In general, in most countries the national grid connection codes have to be applied to storage systems when operating in the feed-in mode. It has to be noted that the *Expert Group Storage Systems* under the *European Stakeholder Committee on Grid Connection* has concluded its report in summer 2020 with a full range of recommendations for future NC extension to address storage systems in their full operational modes.

Finally, the survey has tackled the national implementation of **compliance schemes**. However, due to a vague framework on respective testing, simulation and/or certification procedures within the RfG NC and a missing binding timeline for implementation, the national regimes are still in a quite early and undefined stage. A number of MS+ give references to the application of equipment certificates within the operational notification process and / or the compliance monitoring. However, only **Spain** and **Germany** provide respective, overall certification programmes that are subject to respective accreditation of authorized certification bodies. As a result, coherence between the compliance schemes is very low today, thus imposing additional challenges to manufacturers and project developers next to the differing technical requirements in terms of varying compliance documentation. In a worse case, manufacturer may have to provide different, cost-intensive measurements due to differing national testing procedures. Therefore, a future driving factor for coherent compliance schemes will be provided by international standards on testing, simulation and model validation and certification.

Closing remark: Though the analysis of the geneses of national grid code implementations in the MS+ was not subject to this study, the authors acknowledge based on their long-term participation in RfG consultations by ENTSO-E and respective standardisation bodies as well as on their deep involvement in various grid code developments in **Germany** that the introduction of new grid code requirements will always bare significant challenges to both, manufacturers and PGM project developers. On the one hand, the progressive integration of volatile and decentralised PGMs requires a far-sighted identification of the technical requirements of the power grids, as these facilities will determine the generation structure and corresponding system services for several decades. On the other hand, these requirements necessitate new technical developments and generally higher costs. Scientific studies can provide a valid basis for deciding which requirements are sensible and when, and, thus, support the negotiations within stakeholder processes. Examples of this are given in the study.

7.2. Recommendations

Based on the results obtained through the study, the following recommendations are made to increase the benefits of future RfG NC revisions.

1. A fundamental barrier for the coherence of pan-European requirements for PGMs of the same kind (technology, capacity) is due to the high divergence of type definition thresholds on national level for type A-D PGMs according to the RfG NC. Especially for the distinction of type A and B PGMs the threshold varies between some 10 kW and 1,5 MW, hence, a factor of 150. This imposes significant challenges to manufacturers of small power generating units in particular in terms of technical specification of their products, as requirements differ a lot between type A and B installations, and may provide respective market entrance barriers. Therefore, it is highly recommended to elaborate a more coherent scheme for type definitions in a future NC. The inconsistency surrounding the applicability of the requirements at the unit/plant level among the various MS+ (taking the technology of the PGM into account) must also be addressed.

2. A central result of the survey points out that many national grid code implementations have extended the ranges given by the non-exhaustive requirements of RfG NC. In order to provide a reliable framework for technical design and PGM specification that will not be violated on national level a future NC should either catch-in these national specialities by a stringent negotiation beforehand or enlarge the ranges of non-exhaustive requirements within the NC.

3. Since the number of non-exhaustive requirements under RfG NC for type A PGMs is less compared to those for type B-D PGMs, a significant number of additional requirements in national implementations has been found. The convergence level among these additional requirements is significantly lower compared to the implementation of the non-exhaustive RfG NC requirements (type A). Hence it is recommended to address these additional requirements directly in a future RfG NC. Focus could be laid on additional requirements such as OVRT, voltage or Q-control modes, directly supporting grid stability on a local scale – but addressing cross-border-issues due to scale effects in the course of growing decentralisation at the same time. The same issue applies to additional requirements for type B and C PGMs. As many of these additional requirements are following the respective provision of the European Standard CLC 50549-1/2, this standard may provide a suitable framework for RfG NC extension.

   Note: the *European Stakeholder Committee on Grid Connection* has started the new Expert Group *Baseline for type A power-generating modules* (EG BtfA) in order to elaborate a guidance for such extended type A requirements [8].

4. The European commission should provide tenders for performing relevant studies on the impact of these additional requirements. These studies shall serve as a reliable technical basis to set the framework in the RfG NC with additional requirements.

5. Although RfG NC has set a general framework on compliance, a significant number of countries have not provided concrete guidelines for compliance so far. However, compliance documentation becomes crucial in the course of operational notification procedures and the required compliance monitoring during the PGMs lifetime. Moreover, compliance requirements are naturally an issue for the market entrance of suppliers. It is recommended that future NCs shall distinguish more precisely between the different compliance measures to be applied and provide more detailed and guiding information on respective procedures. The analysed national grid code implementation reveals a full range of respective testing, modelling and evaluation guidelines. These should be analysed in details, gathered and assembled to a

standard. Benefit should be taken from the existing overall certification programmes in **Spain** and **Germany**.

6. Storage systems are not covered under the scope of RfG NC (except for hydro pump storages). It is obvious, that battery systems can provide a significant contribution to the power system stability in terms of positive and negative primary reserve as well as for other dynamic ancillary services. **Germany** and **Italy** have gone on to set the requirements for battery storage systems. Considering the ongoing progress and increasing share of battery storage systems in power grids, it is recommended to include to the battery system within the scope of RfG NC.

   Note: the *European Stakeholder Committee on Grid Connection* has guided the Expert Group *Identification of Storage Devices* (EG Storages) which has made several recommendations for extended grid code provisions on storage systems [9].

Appendix A

National regulatory authorities

MS+	NRA	
	Name	**Abbreviation**
AT	Energie-Control Austria	E-Control
BA	Državna regulatorna komisija za električnu energiju / State Electricity Regulatory Commission	DERK
BE	Commission pour la Régulation de l'Electricité et du Gaz	CREG
BG	Energy & Water Regulatory Commission	EWRC
CH	Swiss Federal Electricity Commission	ElCom
CY	Cyprus Energy Regulatory Authority	CERA
CZ	Energetický Regulační Úřad / Energy Regulatory Office	ERU
DE	Bundesnetzagentur / Federal Network Agency for Electricity, Gas, Telecommunications, Posts and Railway	BNetzA
DK	Forsyningstilsynet / Danish Utility Regulator	Forsyningstilsy net
EE	Konkurentsiamet / Estonian Competition Authority	Konkurentsiam et
ES	Comisión Nacional de los Mercados y la Competencia / National Commission for Markets and Competition	CNMC
FI	Energiavirasto / The Energy Authority	Energiavirasto
FR	Commission de Régulation de l'Energie	CRE
GB	Office of Gas and Electricity Markets	OFGEM
GR	Ρυθμιστική Αρχή Ενέργειας / Regulatory Authority for Energy	PAE
HR	Hrvatska energetska regulatorna agencija / Croatian energy regulatory agency	HERA
HU	Magyar Energetikai és Közmű-szabályozási Hivatal / Hungarian Energy and Public Utility Regulatory Authority	MEKH
IE	Commission for Regulation of Utilities	CRU
IS	Orkustofnun / National Energy Authority	Orkustofnun
IT	Autorità di Regolazione per Energia Reti e Ambiente	ARERA
LT	Valstybinė energetikos reguliavimo taryba / National Energy Regulatory Council	VERT
LU	Institut Luxembourgeois de Régulation	ILR
LV	Sabiedrisko pakalpojumu regulçðanas komisija / Public Utilities Commission	SPRK
ME	Regulatorna Agencija za energetiku / Energy Regulatory Agency of Montenegro	REGAGEN
MK	Регулаторна комисија за енергетика и водни услуги / Energy and water services regulatory commision	PKE
NIE	Utility Regulator	UR
NL	Authority for Consumers and Markets	ACM
NO	Norges vassdrags- og energidirektorat / Norwegian Water Resources and Energy Directorate	NVE
PL	Urząd Regulacji Energetyki / The Energy Regulatory Office of Poland	URE
PT	Entidade Reguladora dos Serviços Energéticos / Energy Services Regulatory Authority	ERSE
RO	Antoritatea Nationala de Reglementare in domeniul Energiei / Romanian Energy Regulatory Authority	ANRE
RS	Energy Agency of the Republic of Serbia	AERS
SE	Energimarknadsinpektionen / Energy Markets Inspectorate	EI
SI	Agencija za energijo / Energy Agency	AGEN

SK	Úrad pre reguláciu sieťových odvetví / Regulatory Office for Network Industries	URSO

Implementation process and status

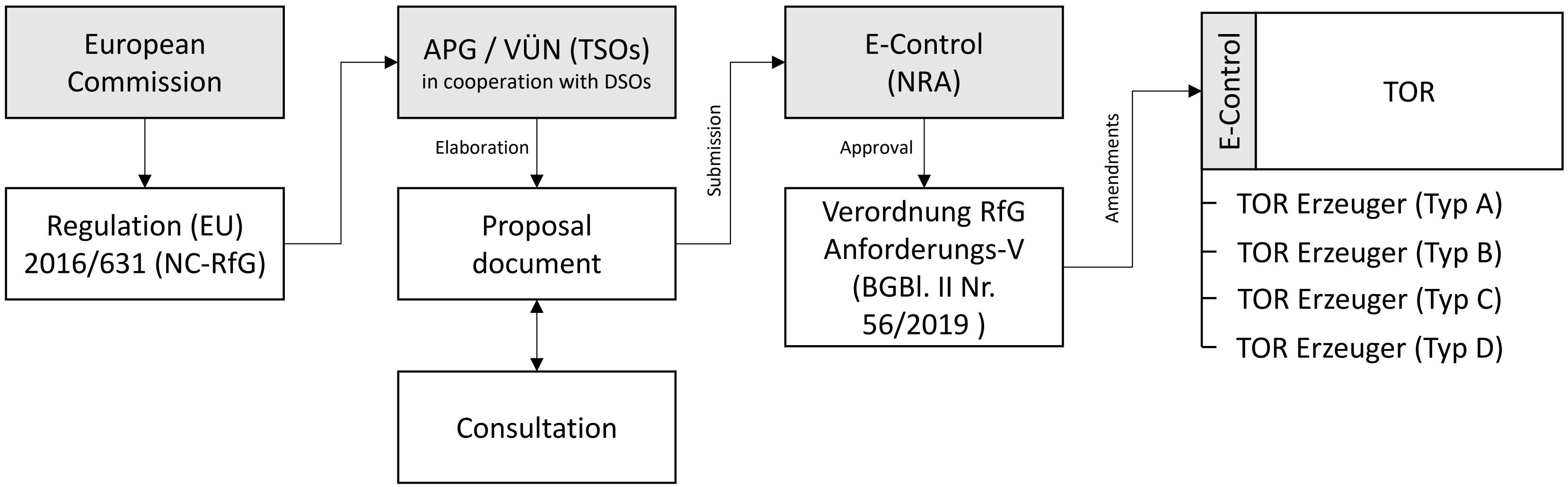
Notes:

1- The dashed lines in the following figures means that the respective step is / can be expected. However, it has not yet been carried out or there is no information about its accomplishment.

2- For some MS+, mentioning only the TSO as the leader of the technical requirements elaboration process does not mean that other system operators did not participate.

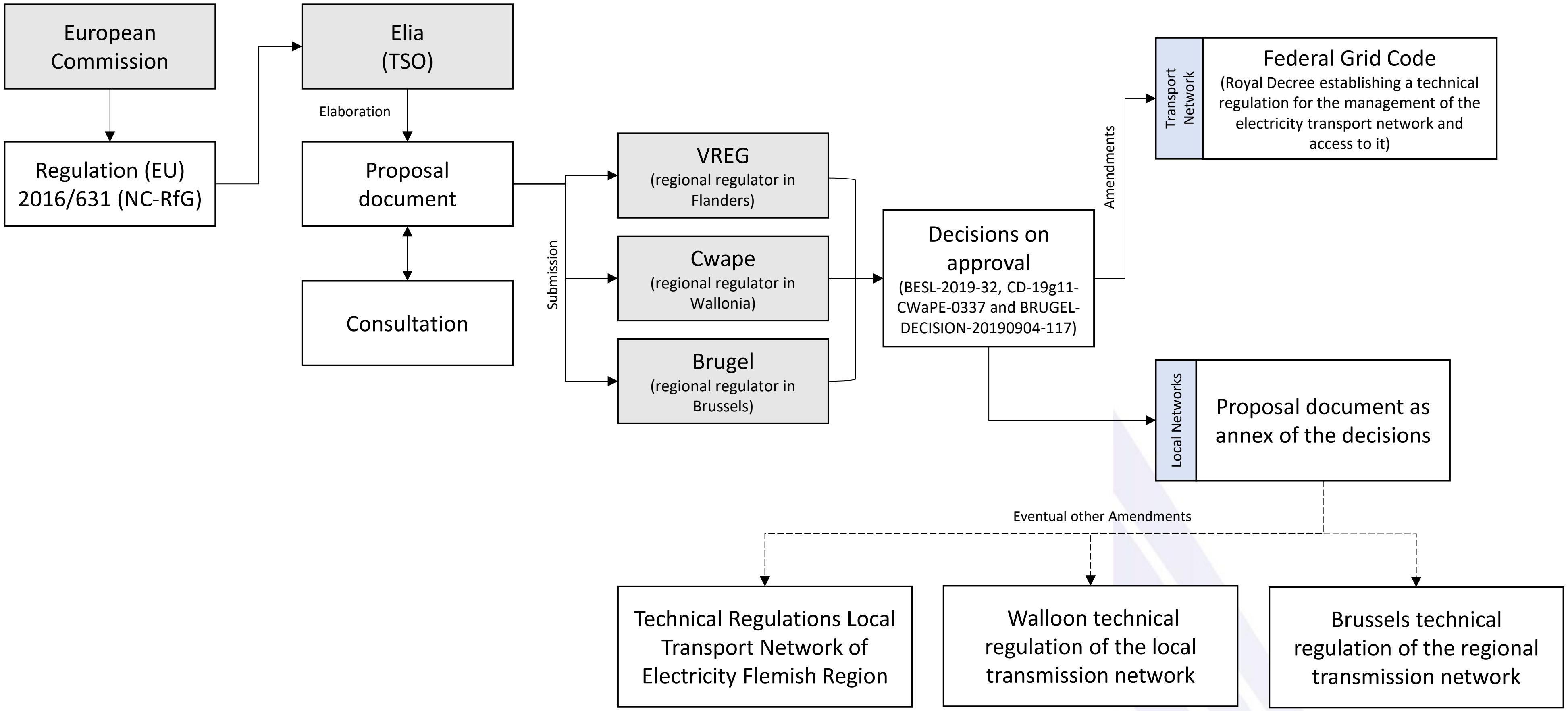
▪ **Austria**

Figure 31: Implementation process in Austria



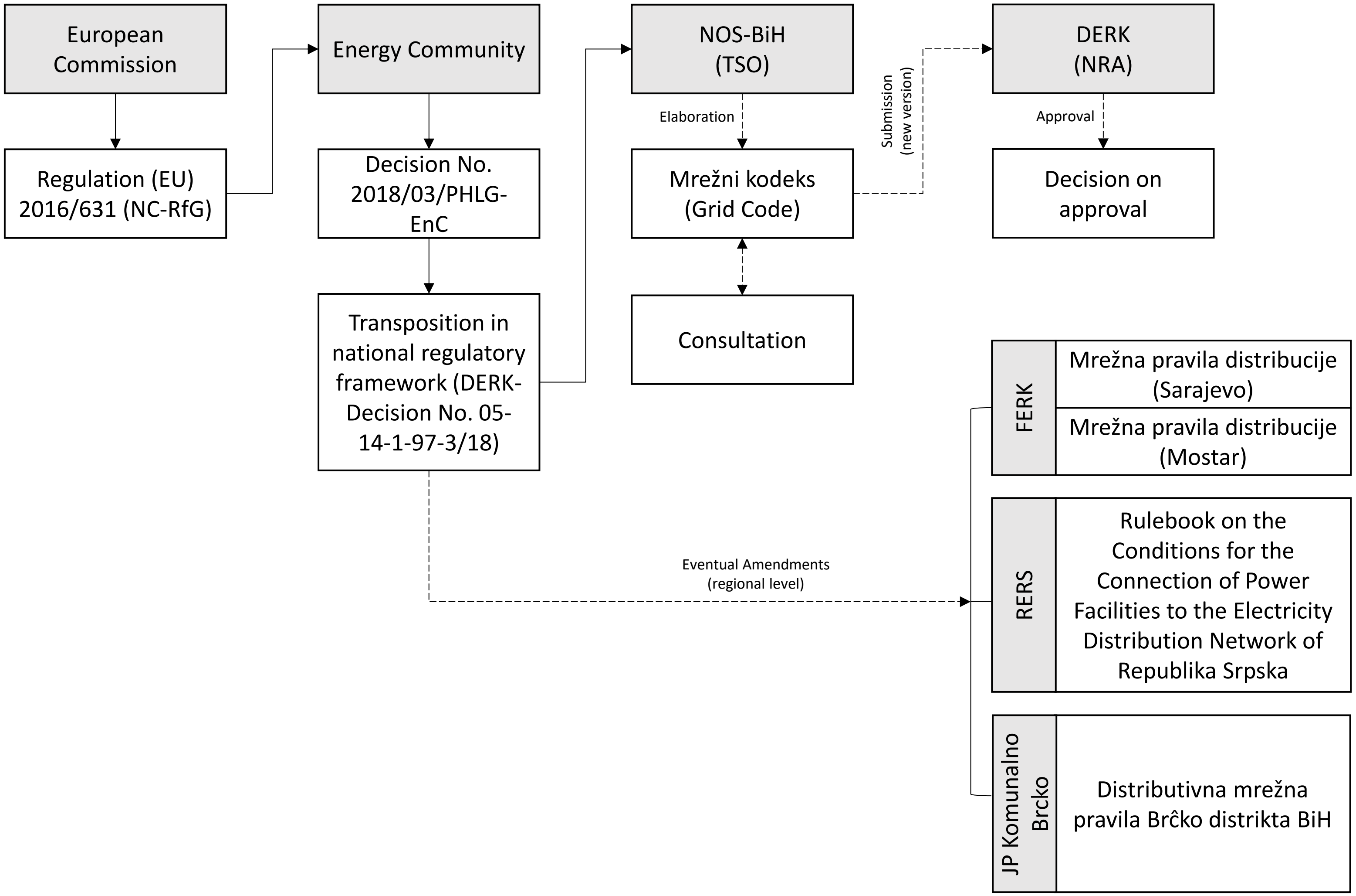
- **Belgium**

Figure 32: Implementation process in Belgium



- **Bosnia and Herzegovina**

Figure 33: Implementation process in Bosnia and Herzegovina

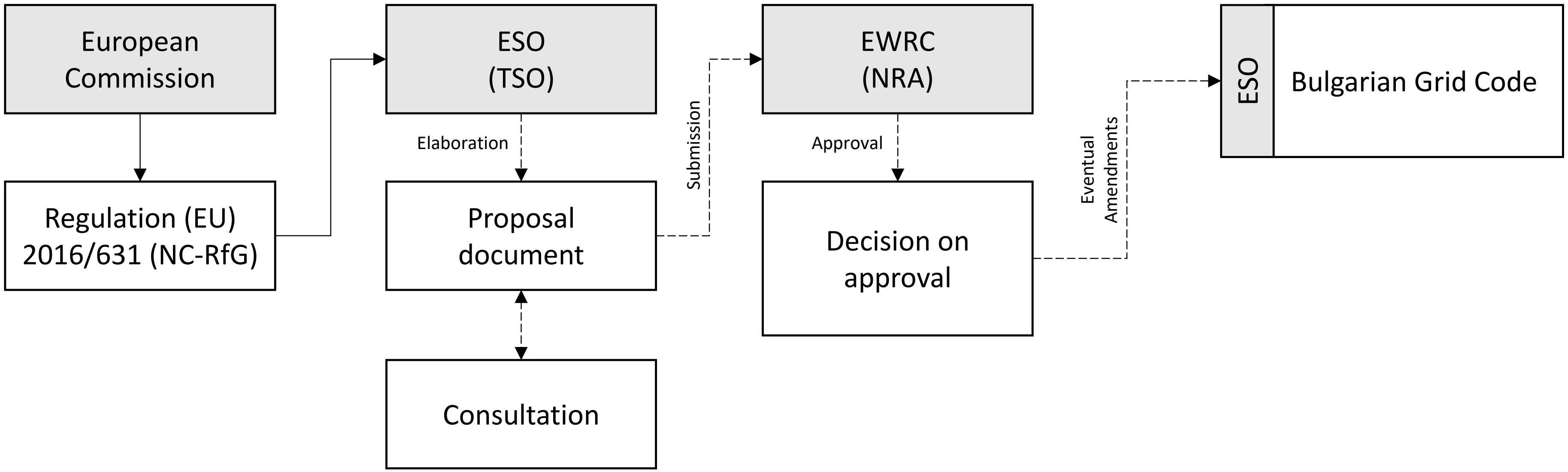


Update (response from questionnaire): SERC confirmed the diagram and provided the following remark)

SERC adopted Rulebook on Network Operation Related to Connection and Decision Specifying Criteria for Granting Derogations From Requirements for Connection of Generating Modules in line with the deadlines prescribed by 2018/03/PHLG-EnC.

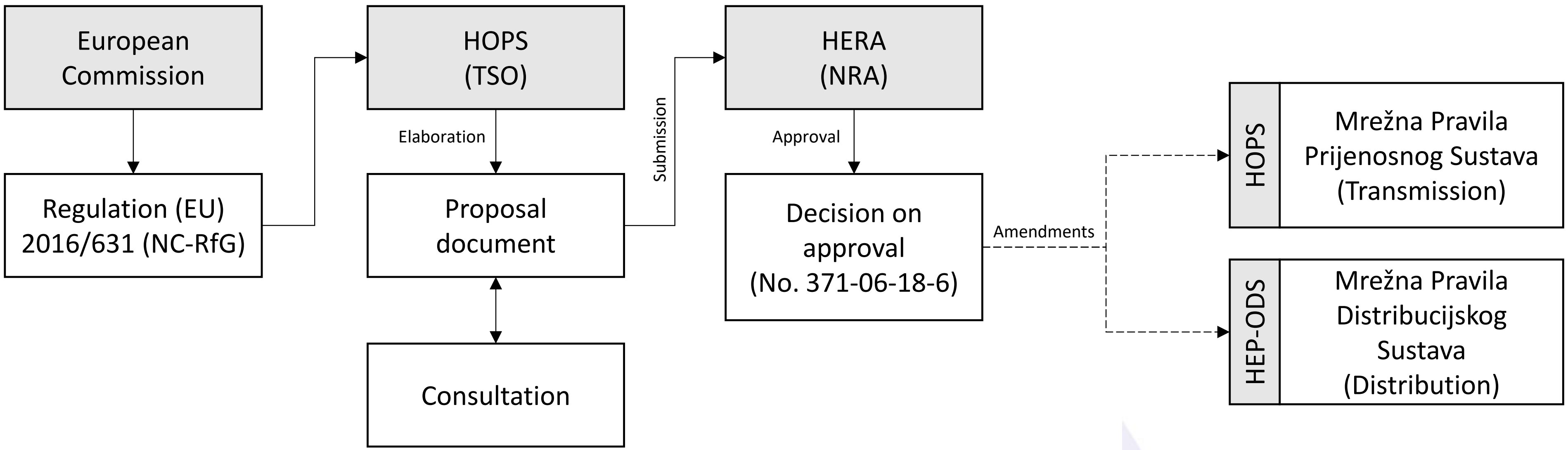
- **Bulgaria**

Figure 34: Implementation process in Bulgaria



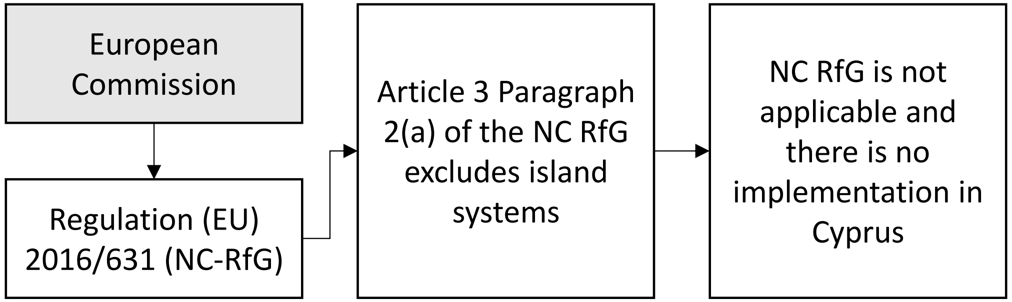
- **Croatia**

Figure 35: Implementation process in Croatia



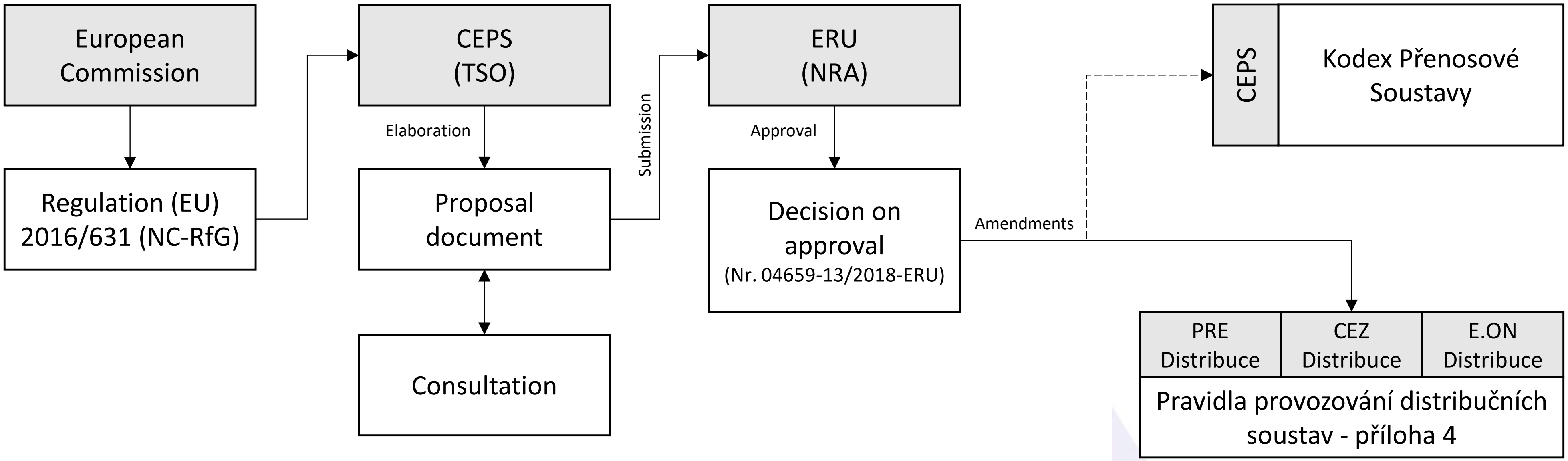
- **Cyprus**

Figure 36: Implementation process in Cyprus

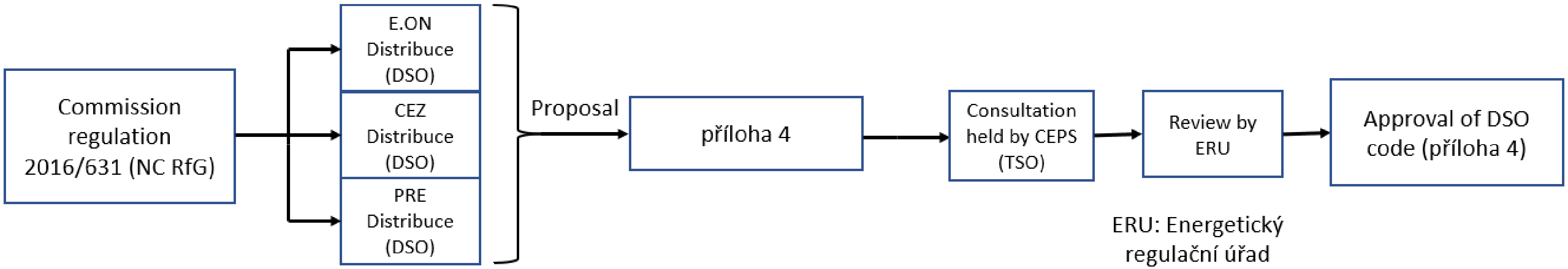


- **Czech Republic**

Figure 37: Implementation process in Czech Republic



Update (response from questionnaire): The figure shown above is an updated version for the **Czech Republic** and was made after an internal re-examination. The original version of the diagram representing the process that was forwarded within the questionnaire is as shown below:

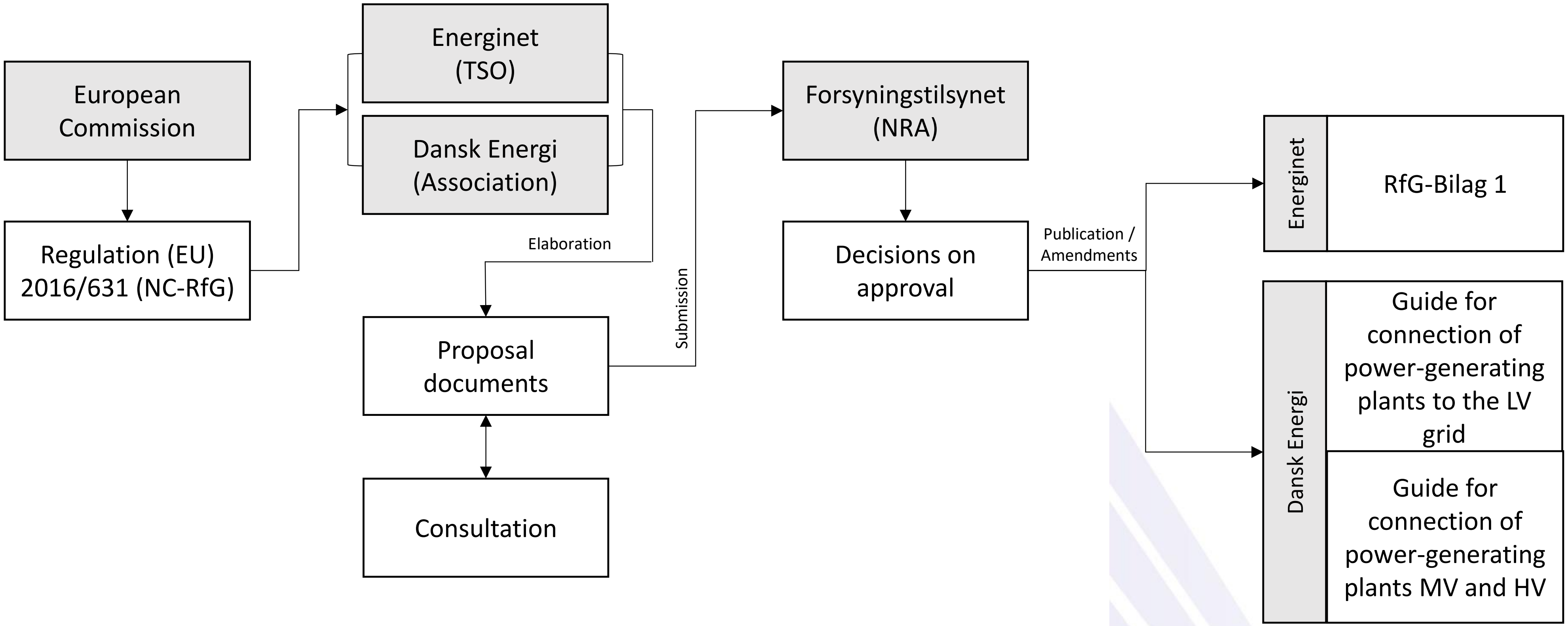


Regardless, below is the answer provided to FGH GmbH by ČEPS, a.s.:

The figure below doesn't describe implementation process completely. The implementation of RfG NC was prepared in the common expert team of system operators (including DSOs, TSOs experts and NRA representative). Once the implementation of RfG NC was finished then the public consultation was organized (by DSOs in cooperation with CEPS) before official deadline of the RfG NC implementation. The public consultation took place as a physical meeting with the stakeholders (association of producers, power generating owners/operators, regulator authority, member state representative …). All the comments raised during the physical meeting was settled and the final RfG NC implementation was updated accordingly. After that the implementation was submitted to NRA for approval.

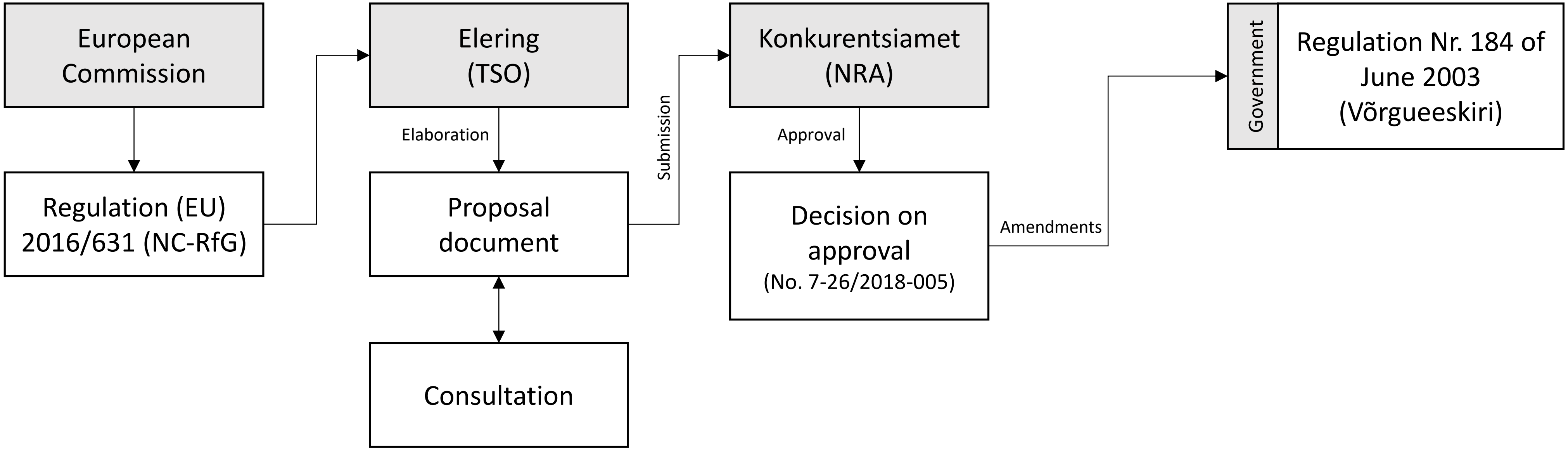
▪ **Denmark**

Figure 38: Implementation process in Denmark



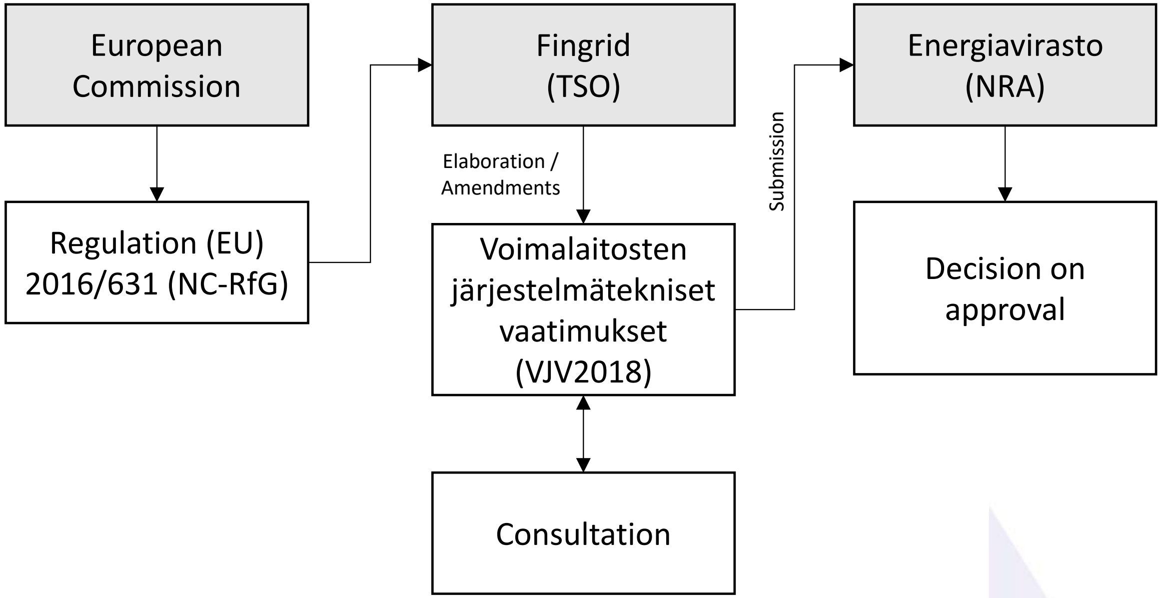
- **Estonia**

Figure 39: Implementation process in Estonia



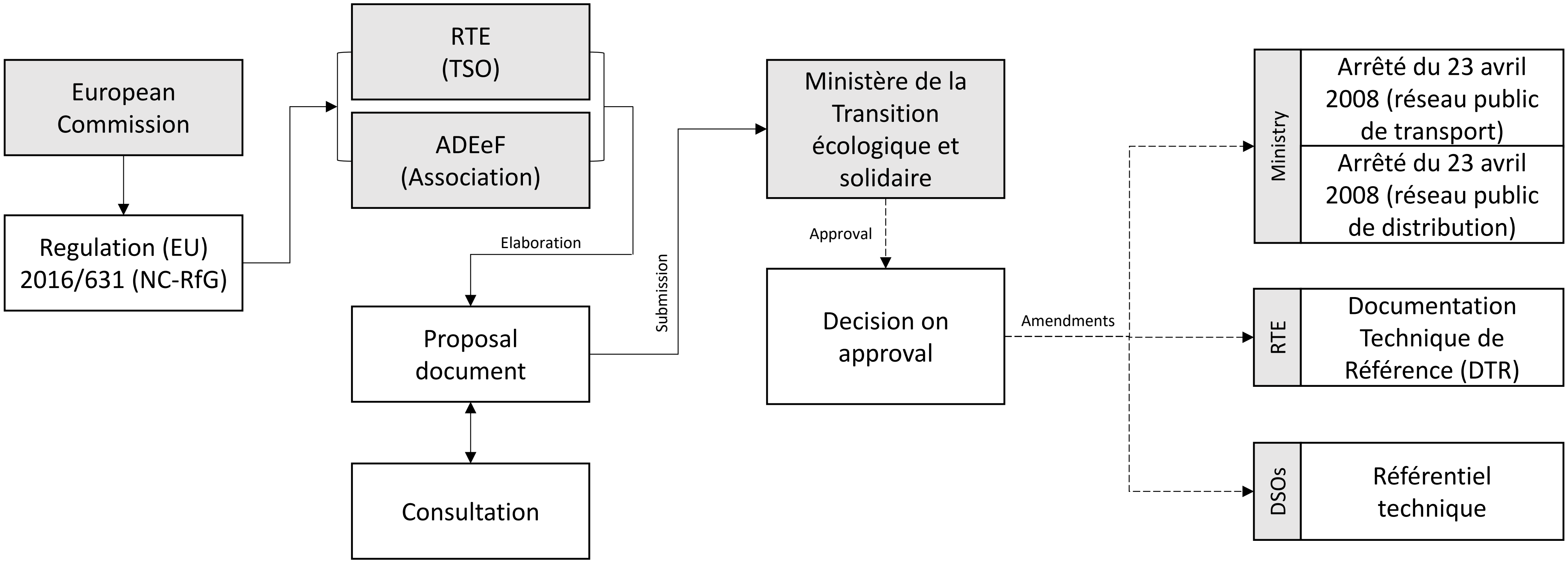
- **Finland**

Figure 40: Implementation process in Finland



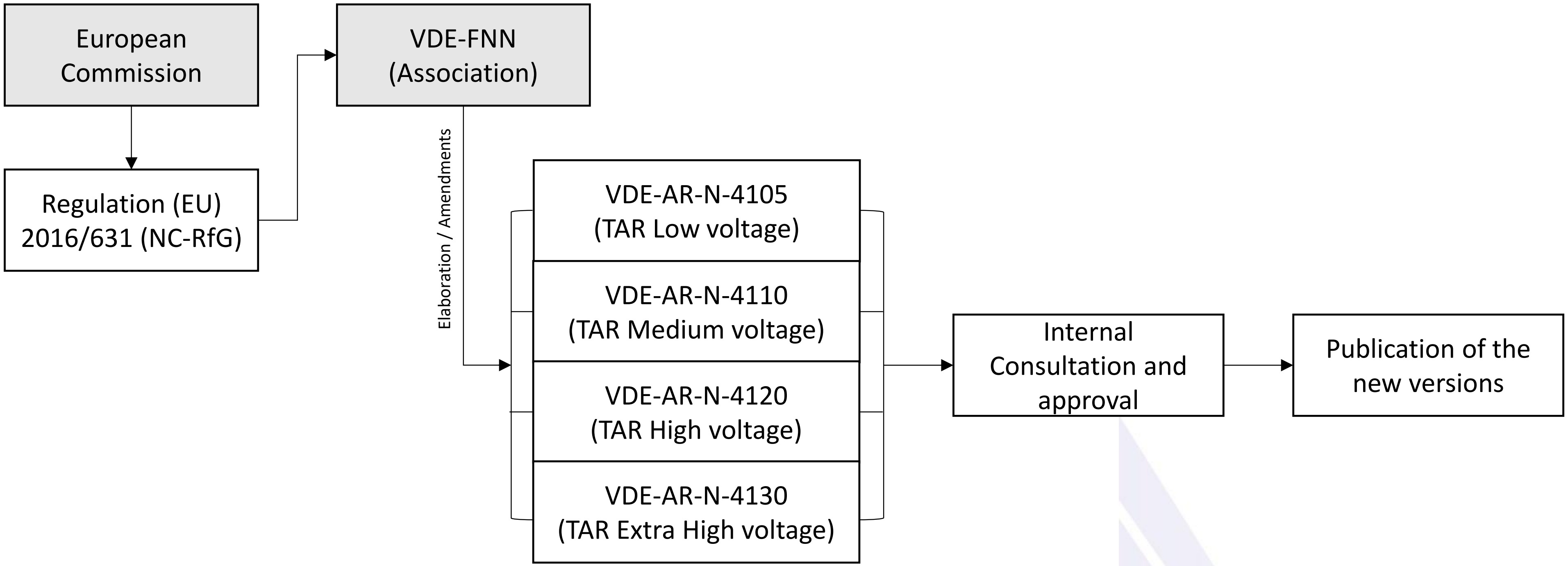
- **France**

Figure 41: Implementation process in France



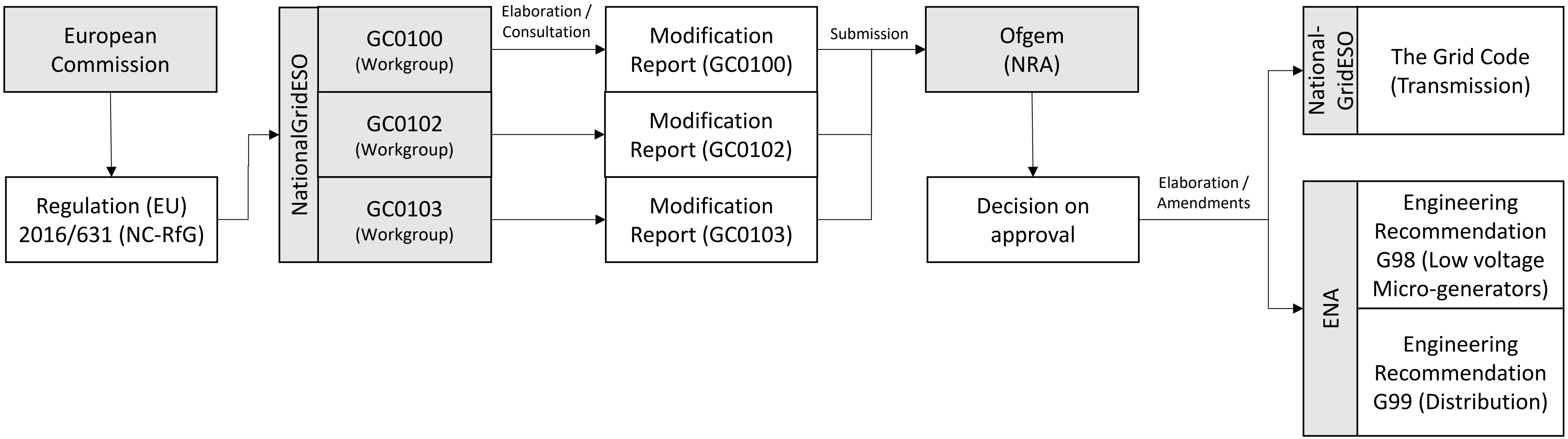
- **Germany**

Figure 42: Implementation process in Germany



- **Great Britain**

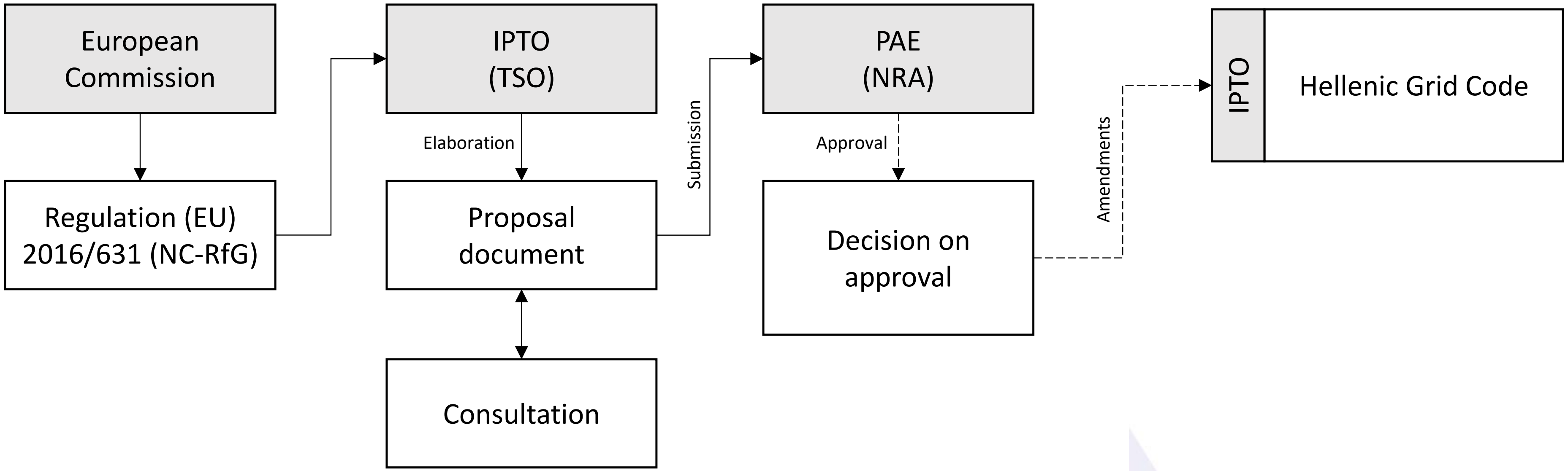
Figure 43: Implementation process in Great Britain



Update (response from questionnaire): Broadly though GC0103 should be changed to GC0101. The Distribution code and G98/G99 was also subject to its own separate consultation Process. Also – G98 limit is defined by 16A per phase, not LV.

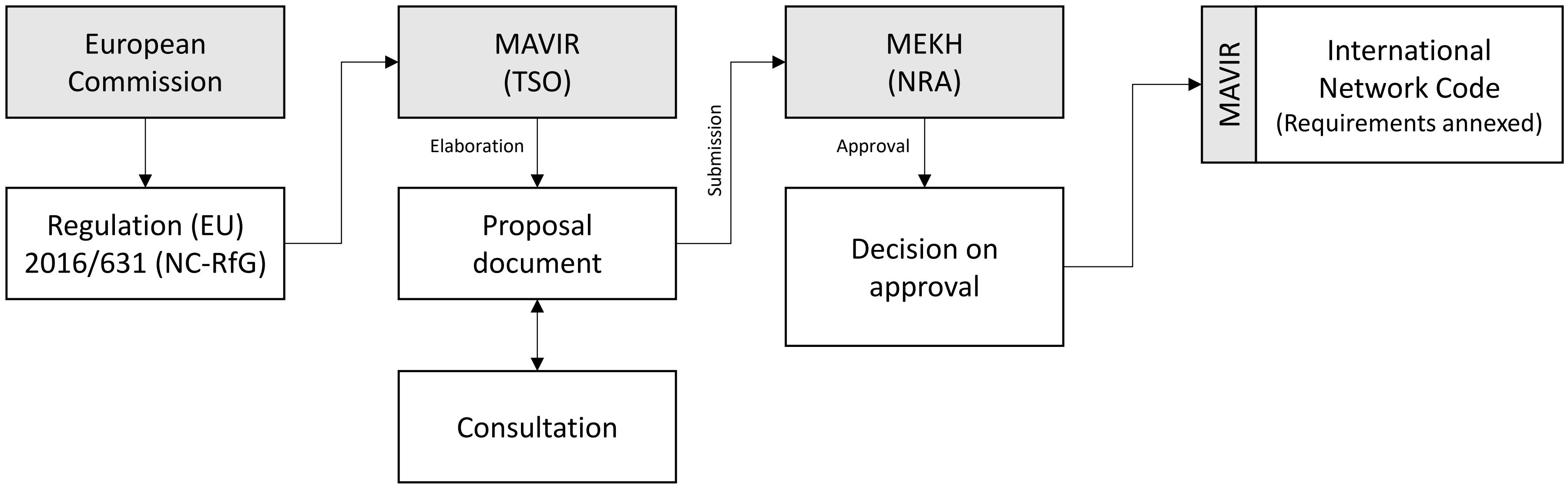
- **Greece**

Figure 44: Implementation process in Greece



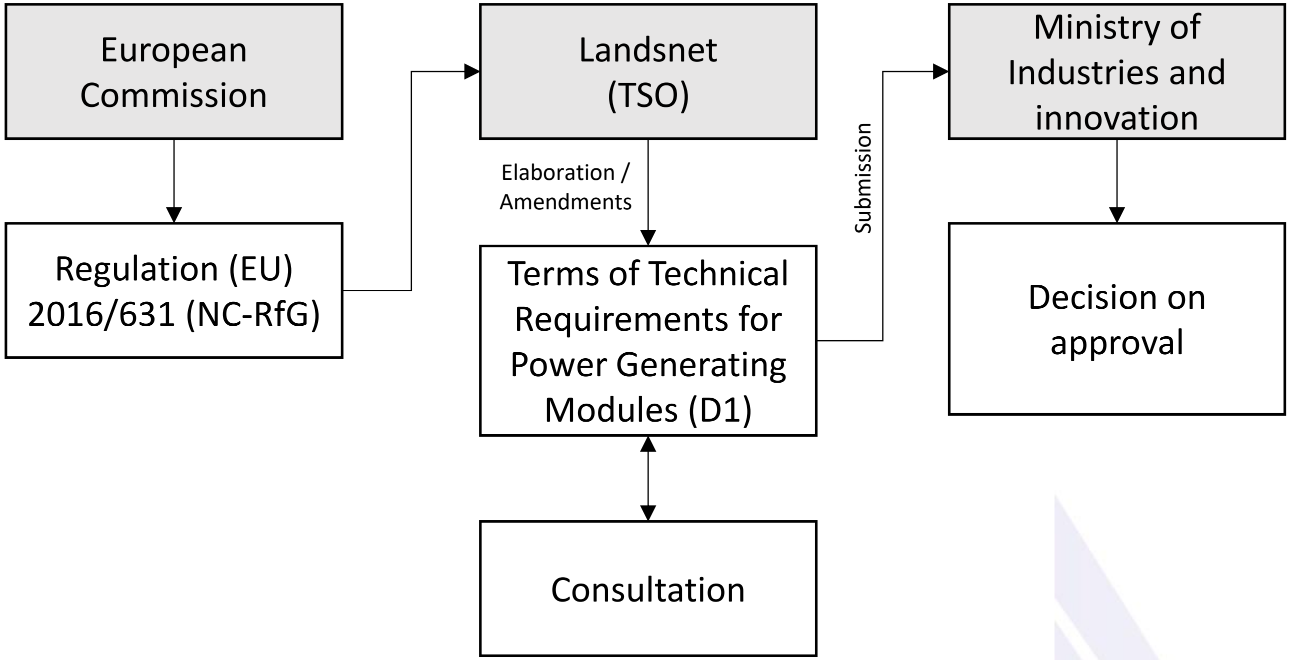
▪ **Hungary**

Figure 45: Implementation process in Hungary



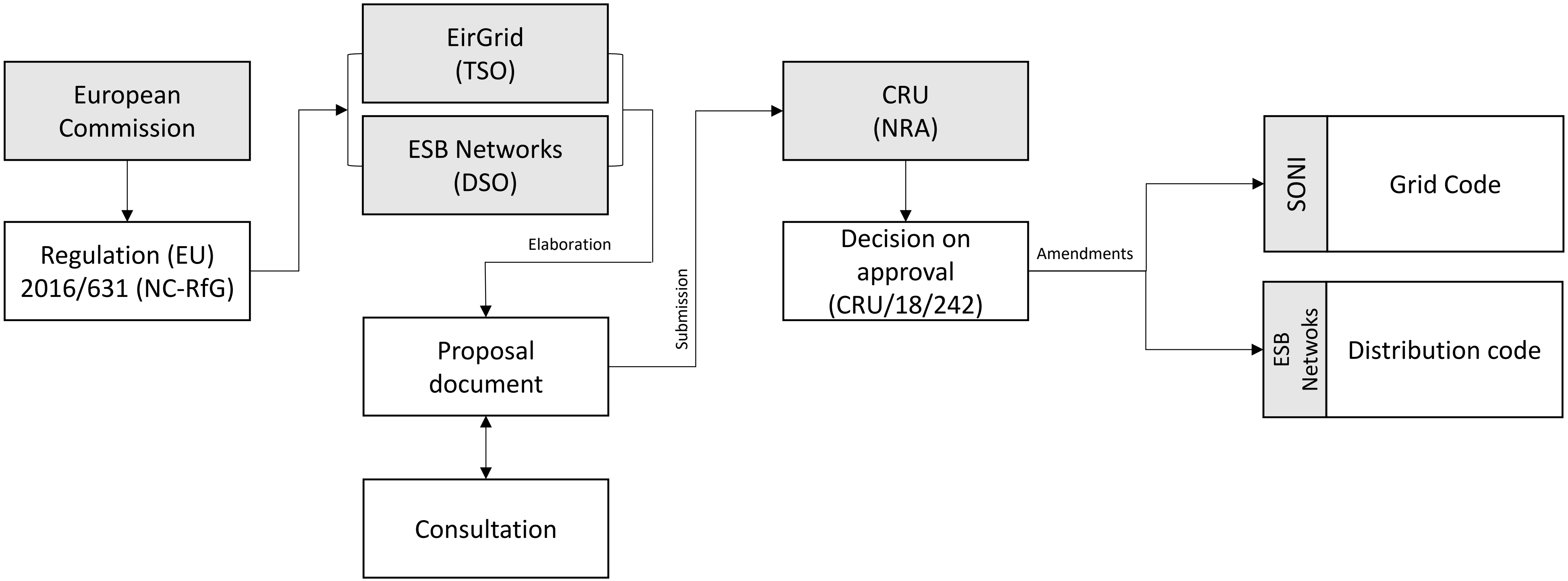
- **Iceland**

Figure 46: Implementation process in Iceland



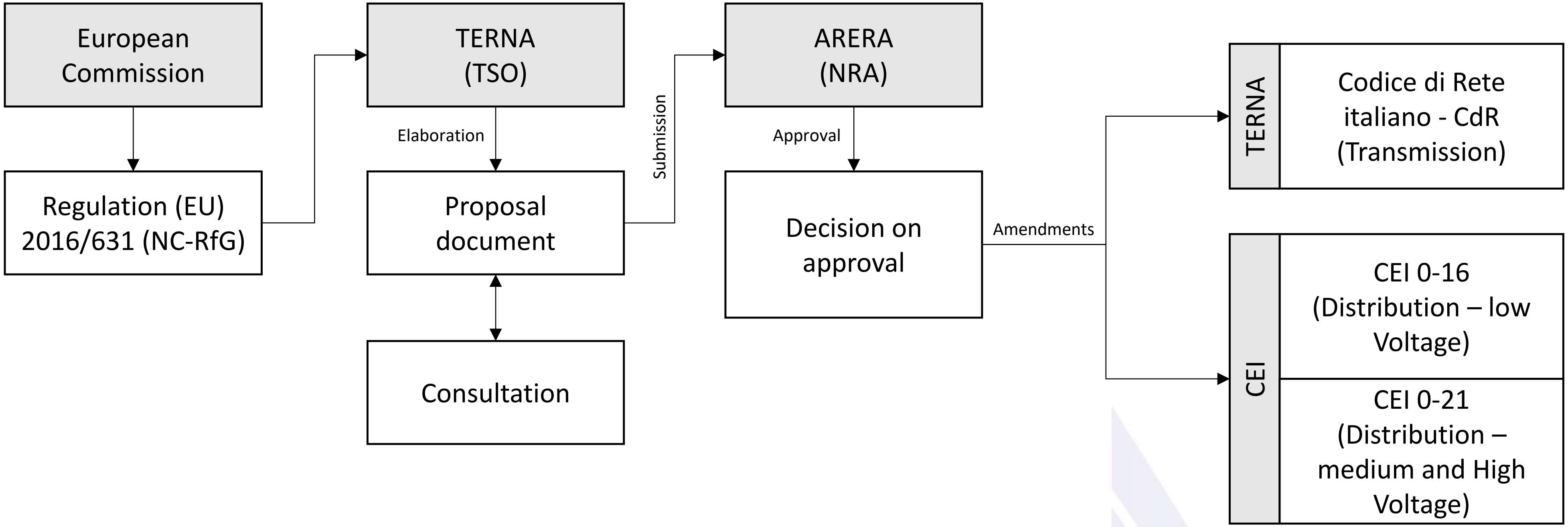
- **Ireland**

Figure 47: Implementation process in Ireland



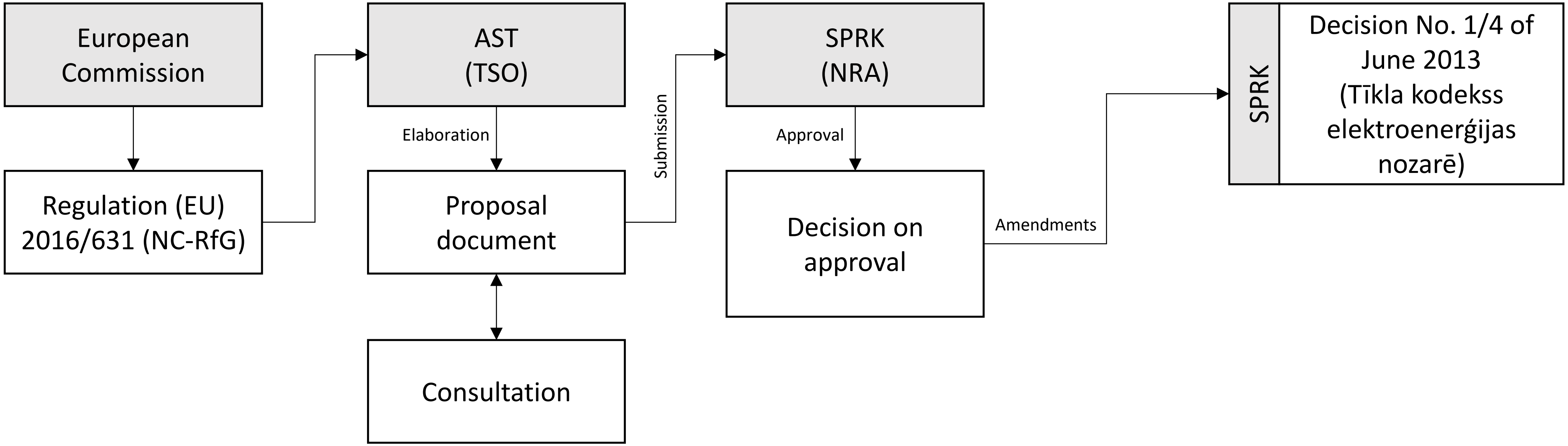
- **Italy**

Figure 48: Implementation process in Italy



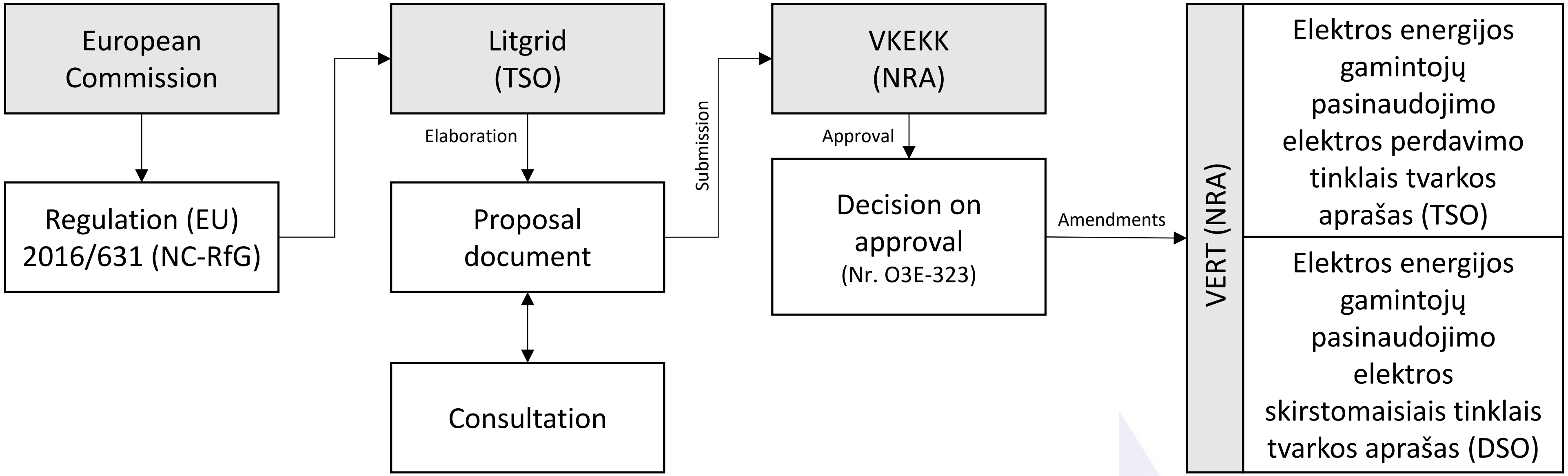
- **Latvia**

Figure 49: Implementation process in Latvia



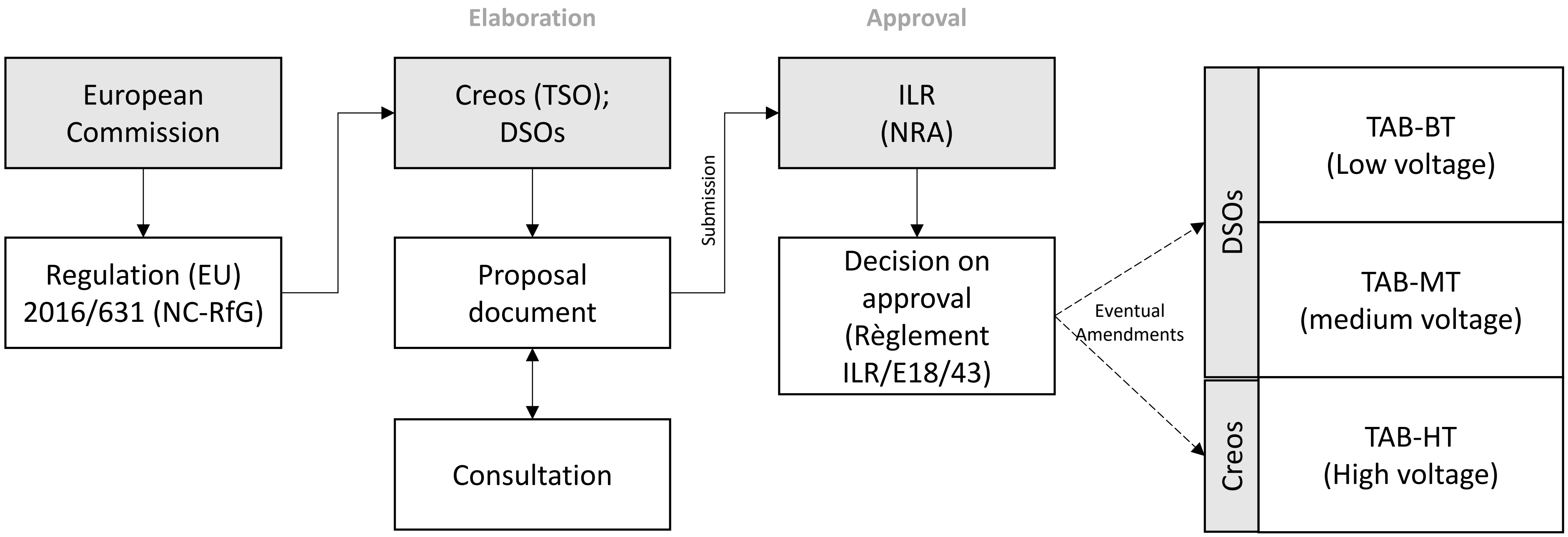
- **Lithuania**

Figure 50: Implementation process in Lithuania



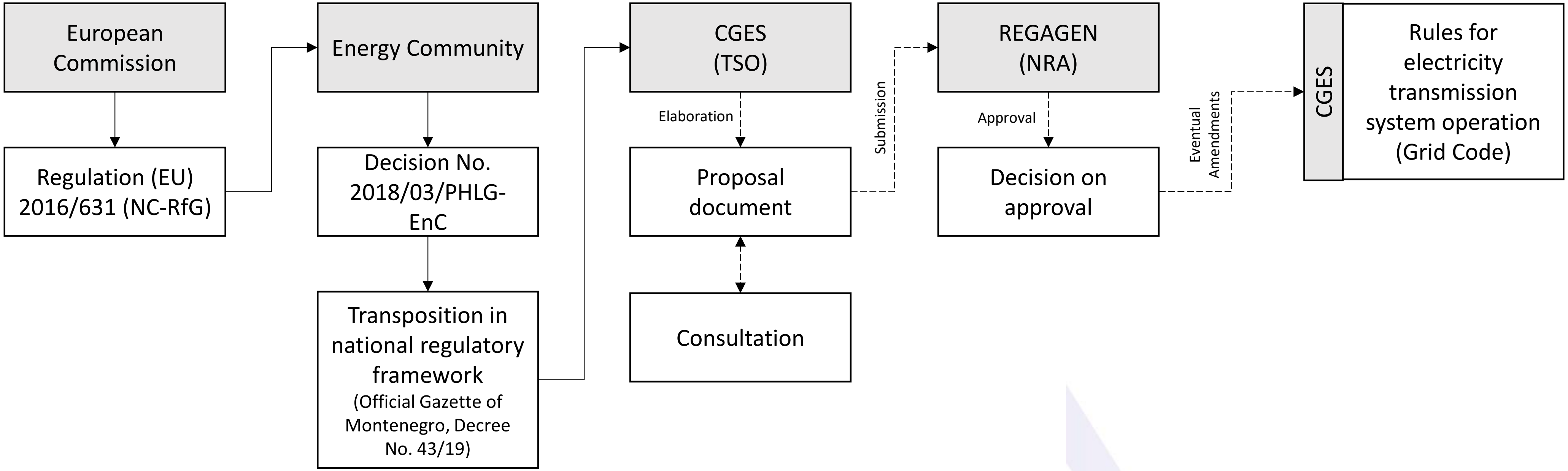
▪ **Luxembourg**

Figure 51: Implementation process in Luxembourg



- **Montenegro**

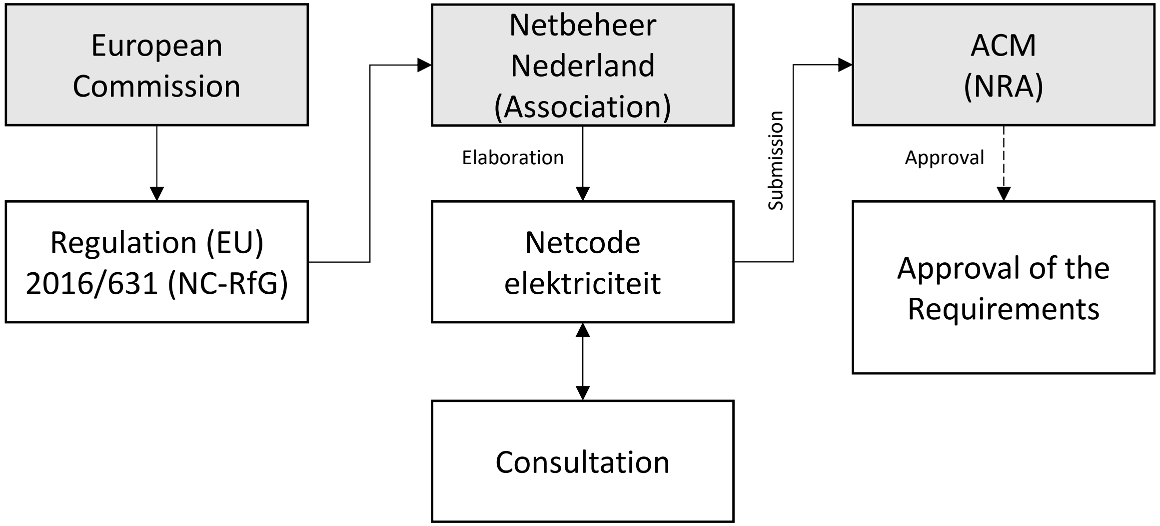
Figure 52: Implementation process in Montenegro



Update (response from questionnaire): RfG is transposed in national regulatory framework via Regulation on conditions for connection of electricity producers to the transmission and distribution network (Official Gazette of **Montenegro**, No. 43/19). Regulation is proposed by CGES and issued by Government.

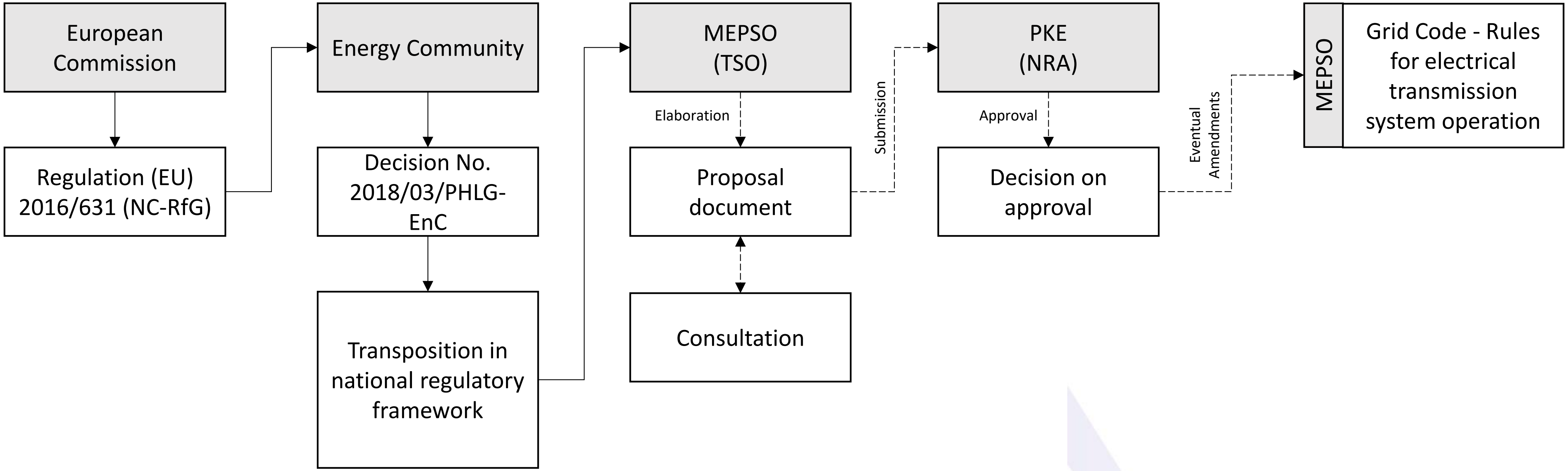
- **Netherlands**

Figure 53: Implementation process in Netherlands



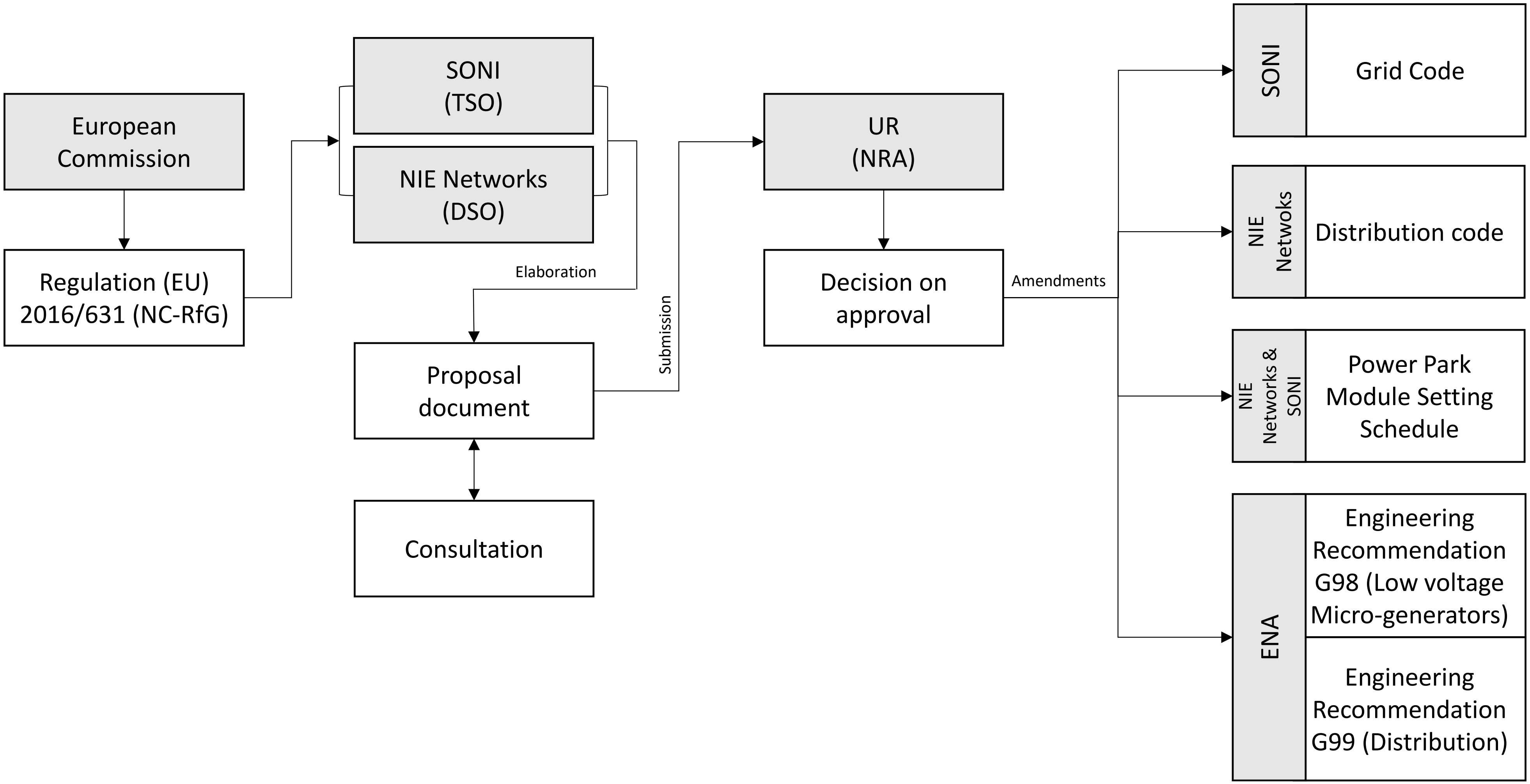
- **North Macedonia**

Figure 54: Implementation process in North Macedonia



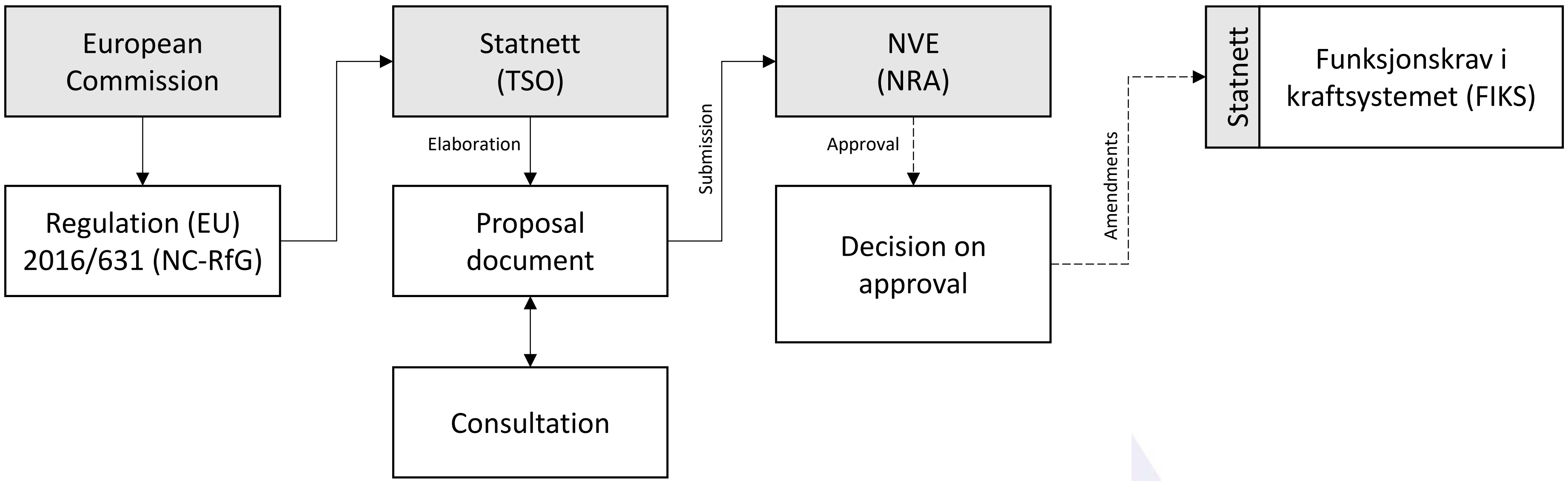
▪ **Northern Ireland**

Figure 55: Implementation process in Northern Ireland



- **Norway**

Figure 56: Implementation process in Norway

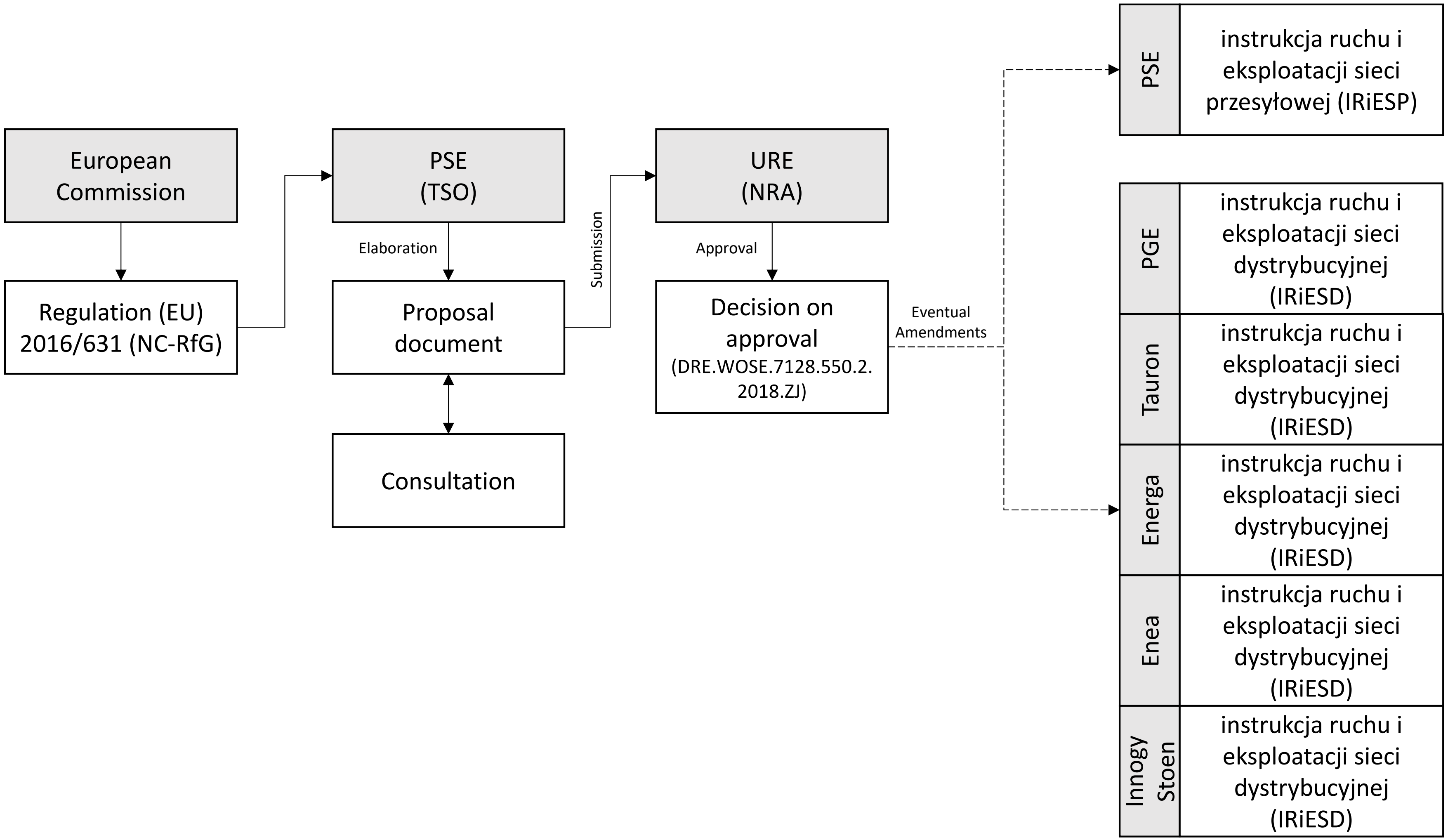


Update (response from questionnaire): The main structures of the connection codes are implemented under the current national regulation for the technical requirements for grid connection. (Fos § 14, and national guidelines for system operation).

The process describing the RfG Implementation in **Norway** will be finalized in the formal RfG Implementation Document.

- **Poland**

Figure 57: Implementation process in Poland

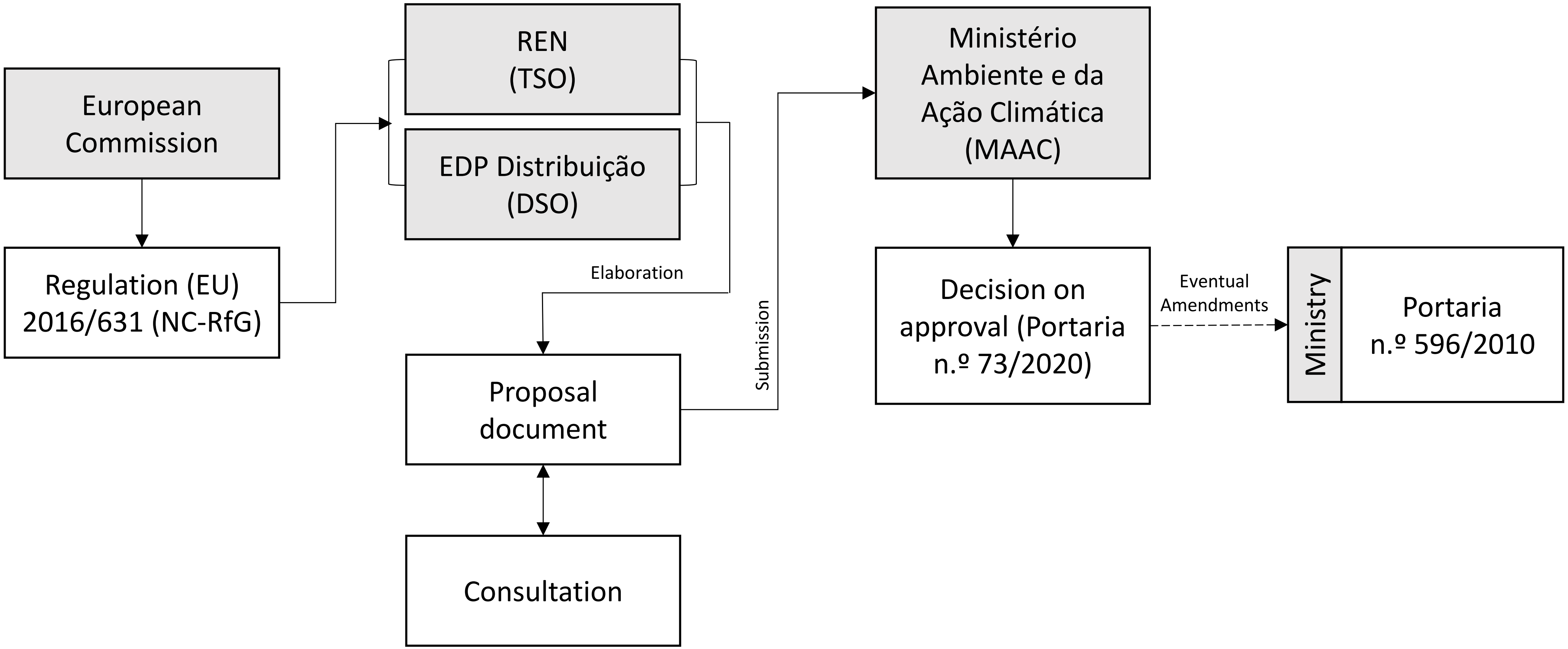


Update (response from questionnaire): Generally, the scheme is proper but please, take into account the document „Wymogi ogólnego stosowania wynikające z Rozporządzenia Komisji (UE) 2016/631 z dnia 14 kwietnia 2016 r. ustanawiającego kodeks sieci dotyczący wymogów w zakresie przyłączenia jednostek wytwórczych do sieci (RfG NC)" is not a part of IRiESP and/or IRiESD. It is independent document approved by URE as described above.

In addition: There are more DSOs in **Poland**, than the ones presented in the diagram above – the same applies to them. List of all SOs is available on **Poland** NRA website: https://rejestry.ure.gov.pl/o/15

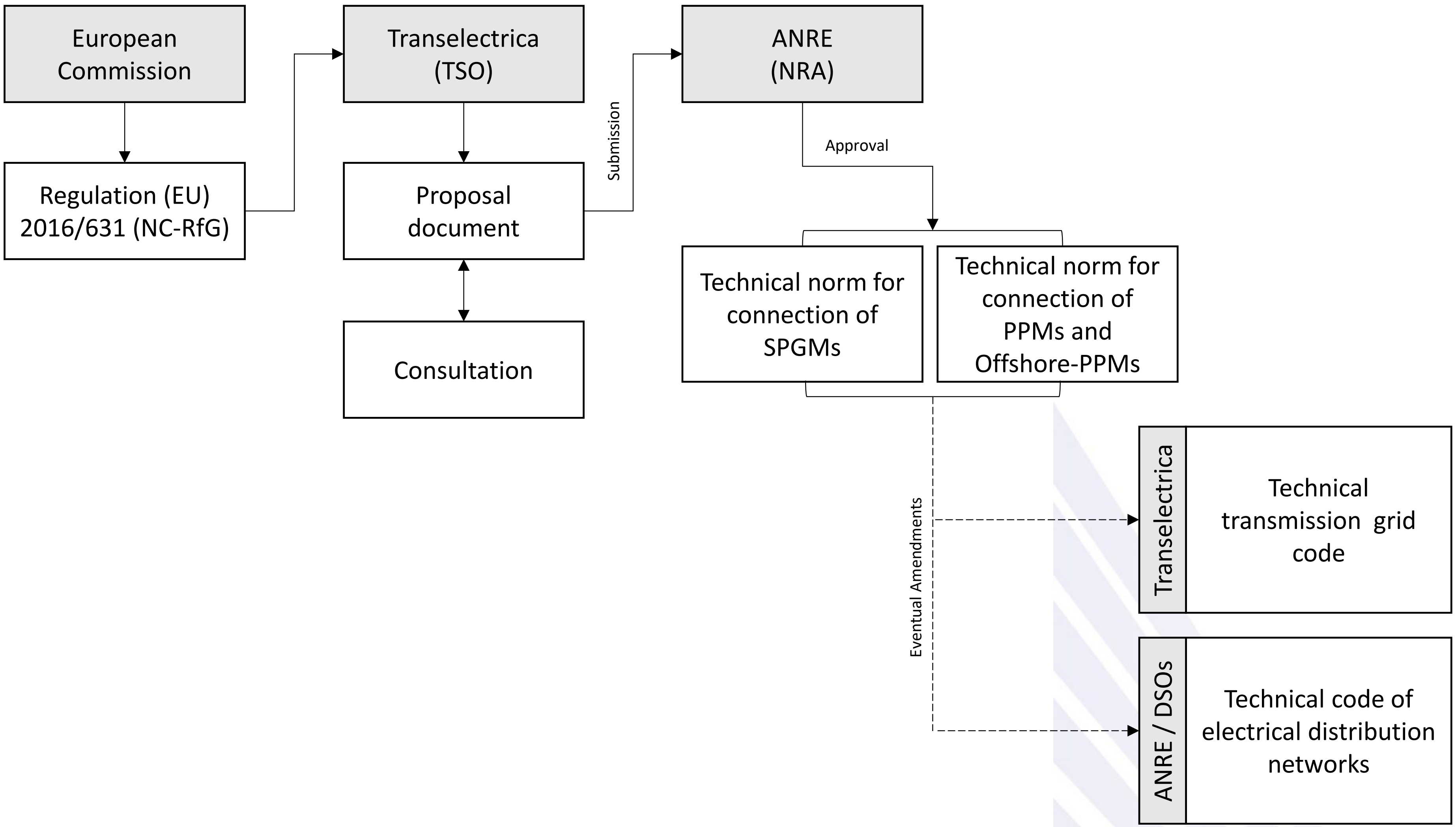
▪ **Portugal**

Figure 58: Implementation process in Portugal



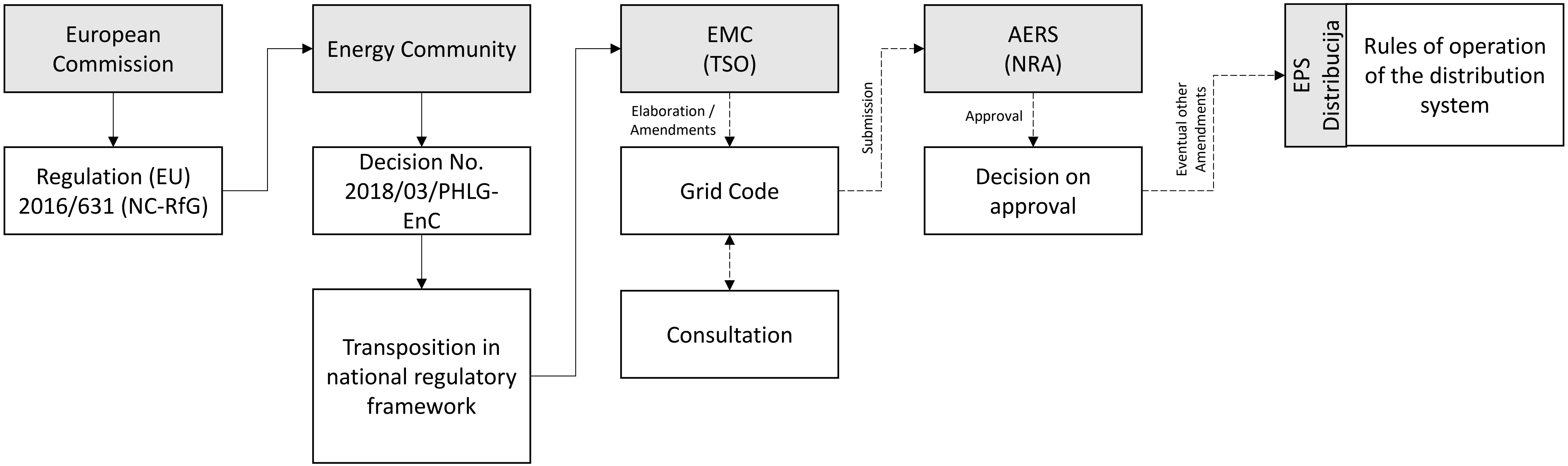
- **Romania**

Figure 59: Implementation process in Romania



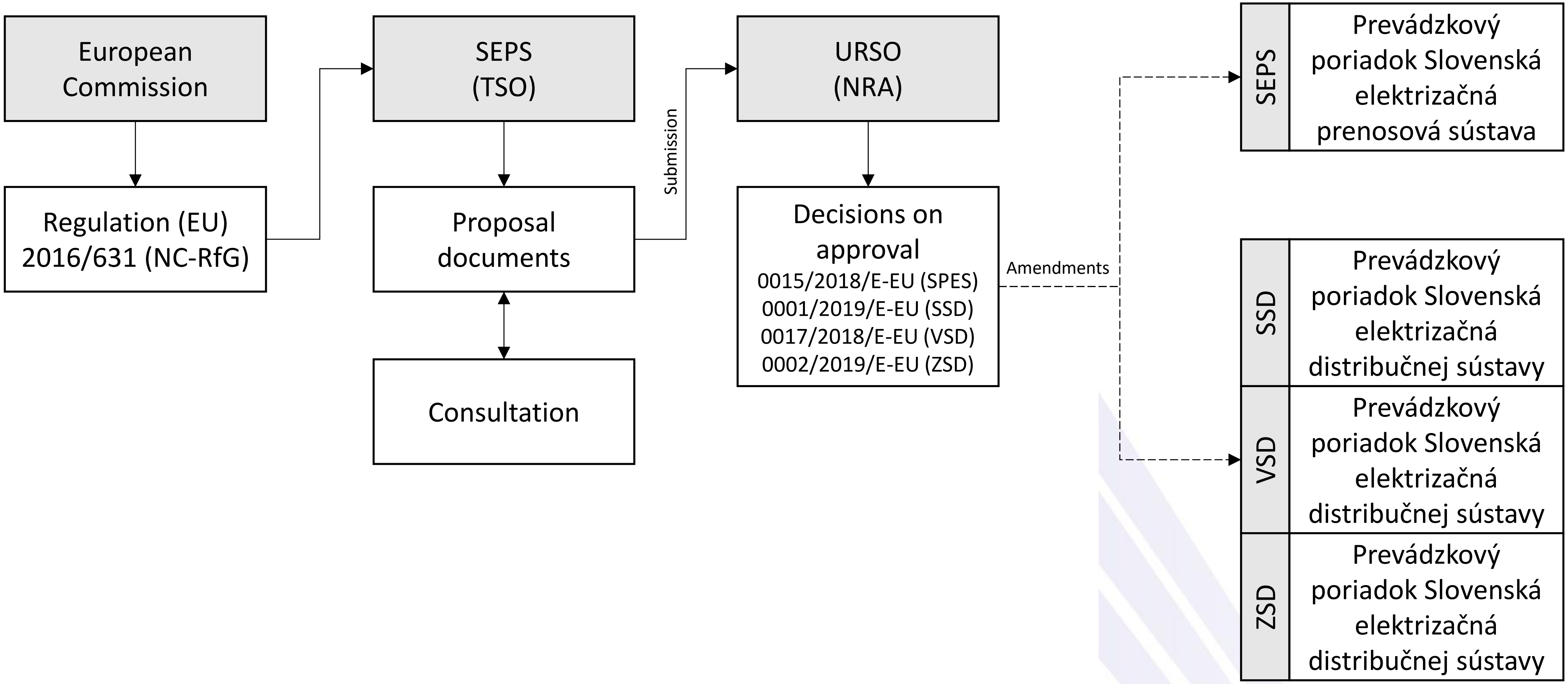
- **Serbia**

Figure 60: Implementation process in Serbia

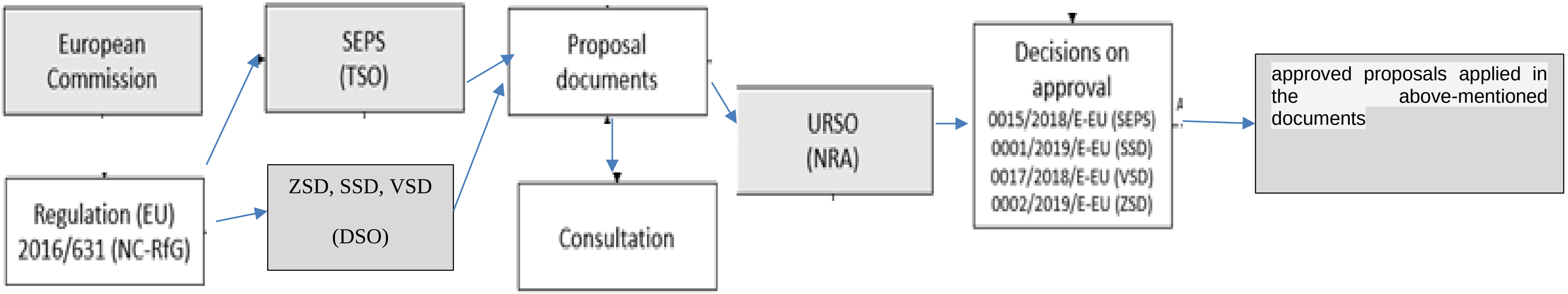


- **Slovakia**

Figure 61: Implementation process in Slovakia

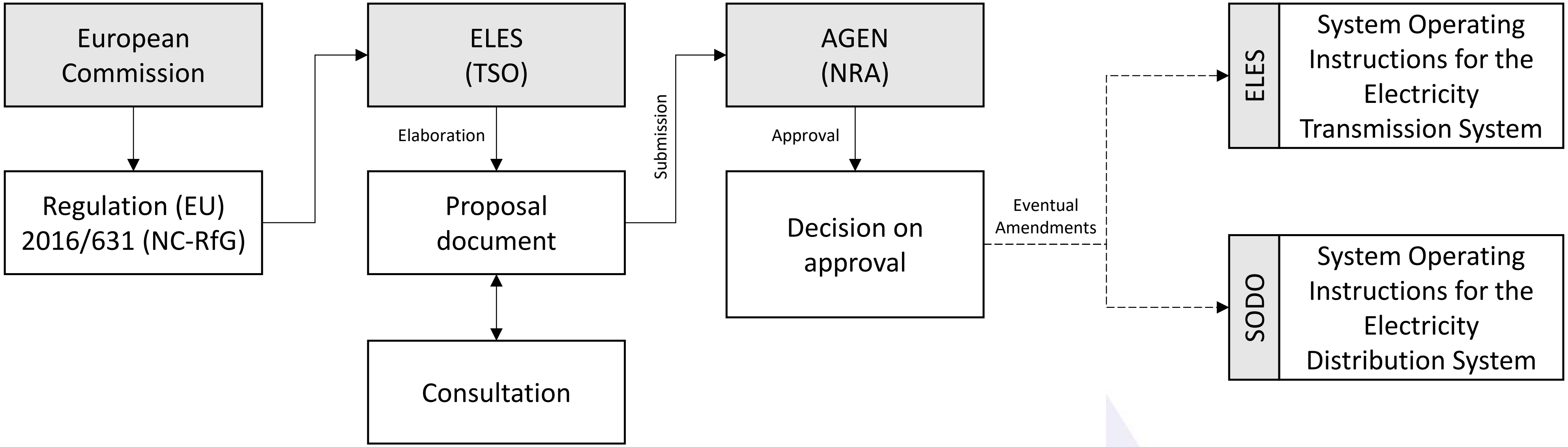


Update (response from questionnaire): According to the response provided by URSO, the correct process is depicted below:



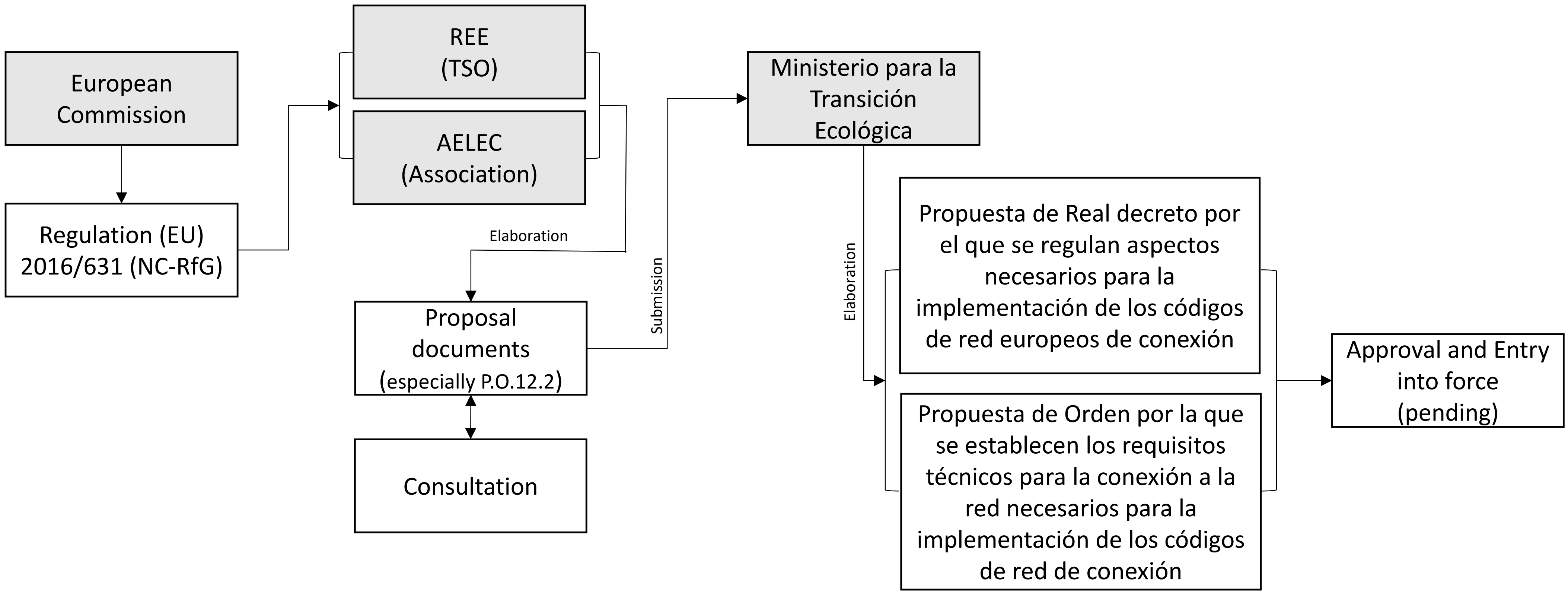
- **Slovenia**

Figure 62: Implementation process in Slovenia



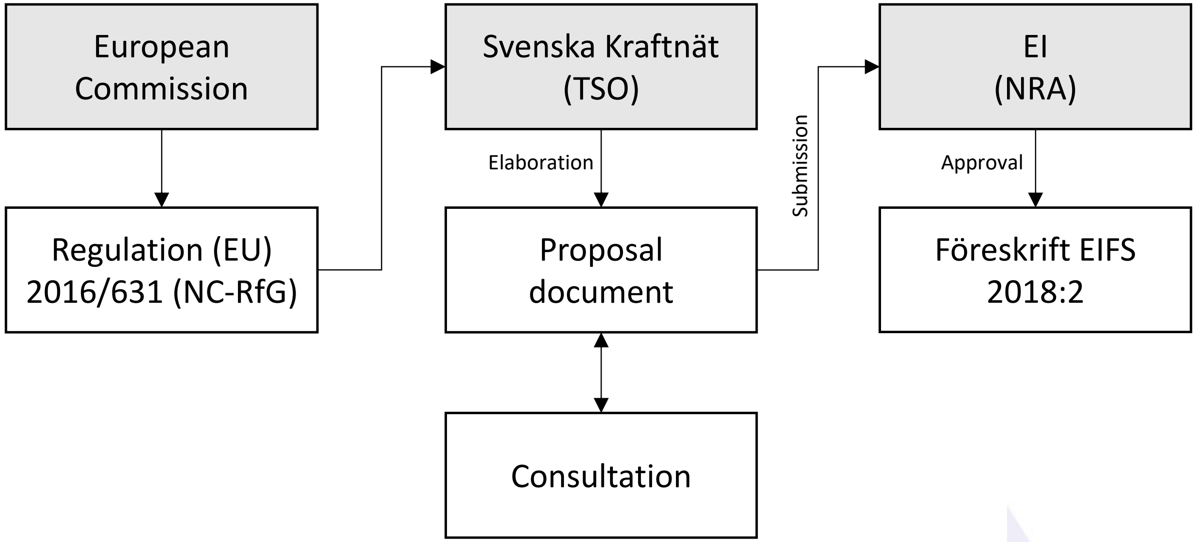
- **Spain**

Figure 63: Implementation process in Spain



- **Sweden**

Figure 64: Implementation process in Sweden



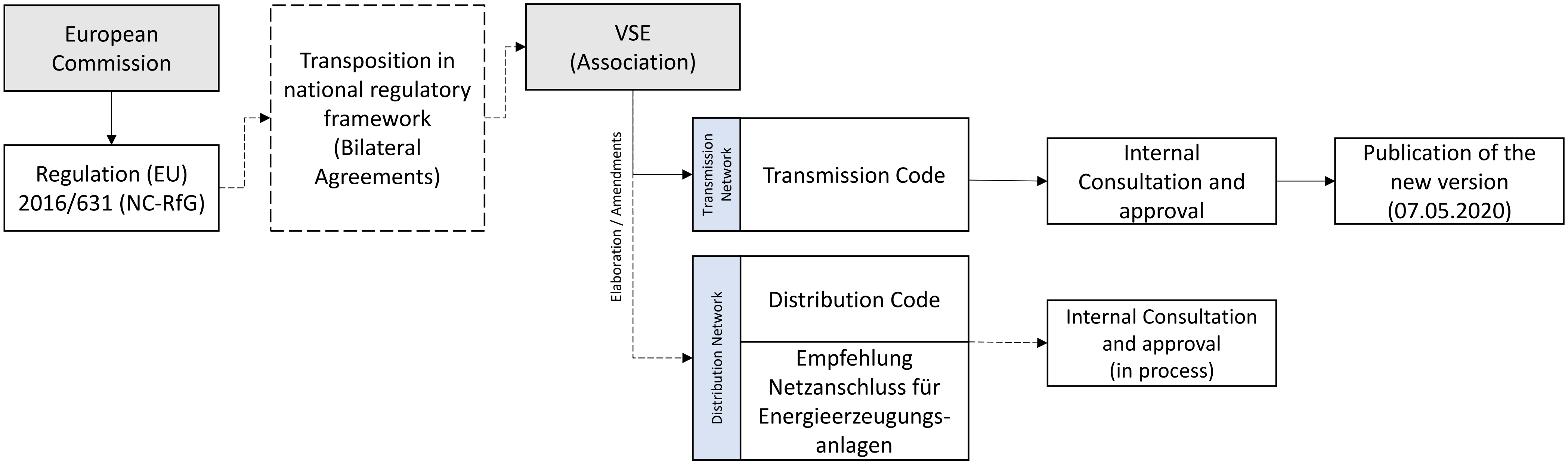
Update (response from questionnaire): Below is the answer provided by Ei:

The flowchart depicts almost correct the implementation process in Sweden. Svenska kraftnät had a consultation regarding the thresholds, in accordance with Article 10 and 5 (3) in RfG NC: https://www.svk.se/press-och-nyheter/nyheter/natkoder/2018/offentligt-samrad-om-troskelvarden-for-kraftproduktionsmoduler/

And Ei had a consultation before our decision in EIFS 2018:2 (as this is a requirement in Swedish regulation): https://www.ei.se/sv/for-energiforetag/el/Natforeskrifter-och-kommissionsriktlinjer-for-el/natkod-requirements-for-generators-rfg/pagaende-arenden-rfg/Artikel-71-och-53-Generellt-tillampliga-krav-pa-kraftproduktionsmoduler-och-Maximala-troskelvarden-for-kraftproduktionsmoduler-av-typ-B-C-och-D/

- **Switzerland**

Figure 65: Implementation process in Switzerland



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MJ-09-21-258-EN-N

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