Harmonisation of the requirements for electricity generators in the EU

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***Abstract*— Until 2019 there has been no harmonisation in the field of network connection requirements for power-generating modules across the European Union (EU). This has been changed by the so called RfG Regulation adopted by the EU Commission. The implementation procedure required EU member states to amend their network codes and to restructure them in order to make them compatible with the regulation. This Article therefore analyses the implementation procedure, explains the structure of the novel regulation, its main features, assess its impacts and discusses the future of the respective regulation.**

***Keywords*— electricity grid requirements, generators, network code, EÚ harmonization**

I. Introduction

One of the major objectives of the EU energy policy is to create an internal electricity market. This process has been in place already since 1999. Upon its completion it should provide all consumers with a real choice in the supply, fair business opportunities and increased cross-border trade in order to reap the benefits of greater efficiency, competitive prices, higher service standards and to contribute to security of supply and sustainability. This is however a long and difficult process requiring a restructuring of the whole system.

Backbone of an internal market should be a well-functioning interconnected electricity grid. An interconnected system however requires a common understanding of the grid connection requirements for power generators. A system with significantly different grid connection requirements in different EU member states (MSs) represents a major barrier of the internal market. Moreover, system security is partly dependant on the technical capabilities of the power generators. Within a synchronous area, frequency change in one MS would immediately impact frequency and could damage equipment in all the others. All transmission and distribution system operators should be thus eager to unify the grid connection rules. Secure system operation is only possible if there is close cooperation between power-generating facility owners and system operators. Here sufficient robustness to cope with disturbances and an ability to help to prevent a disruption or to facilitate restoration of the system after a collapse are fundamental prerequisites [1].

Commission Regulation (EU) 2016/631 establishing a network code on requirements for grid connection of generators (RfG Regulation) was an important milestone taking the sector closer to a level-playing field in terms of grid connection rules. Its importance lies in the unification of the grid connection requirements for power generators throughout the whole EU. It is stated in the recitals of the Act that harmonised rules for grid connection should be set out in order to provide a clear legal framework for grid connections, facilitate Union-wide trade in electricity, ensure system security, facilitate the integration of renewable electricity sources, increase competition and allow more efficient use of the network and resources, for the benefit of consumers [1]. Hence it is clear that the EU sees transparent and harmonised grid connection rules as an important precondition in the internal market creation. The regulation is known as a Network Code Requirements for Generators and is one of the grid codes implemented under the Third EU Energy Package. As each EU regulation, it is binding for all MSs and prevails over the national provisions, i.e., grid connection requirements for generating facilities should upon the implementation be similar in all MSs. However, if compatible with its provisions, MS can opt for a more detailed or stricter regulation.

Unlike most of the national rules, EU rules are usually subject to a long process of creation and adoption. RfG regulation was recommended to the European Commission already in 2013. In 2015 it was unanimously approved by the representatives of all the MSs. As it is a technical Act with significant implications a transition period of 3 years was adopted. TSOs and national authorities needed time for implementation of the rules into the national grid codes and both system operators and power generators needed time to adapt to the new requirements. The entire harmonised code entered into force in April 2019. The RfG regulation is not solely made up of exhaustive requirements strictly binding the MSs. It has also introduced non-exhaustive requirements that provided a framework and the details had to be shaped by the MS. Typical example being a rule defining upper or lower bounds and the MS has to choose a level within the respective range. Thus, it might be assumed that there are completely new, slightly different grid codes in all over the EU and market participants are getting used to the new conditions.

II. CATEGORIES OF POWER-GENERATING MODULES

The main novelty of the requirements is the distinction of the power-generating modules based on 2 factors. The first one being the size and effect on the overall system. Categories A, B, C and D and distinguished. The second being the generator type, i.e., whether the generator is synchronously connected to the grid or the connection is made via a power converter. This is justified by the importance of the synchronous generators as they have an inherent capability to resist or limit frequency deviations. This is in contrast with technologies connected to the grid via power converters, usually renewable sources (RES), that do not have this characteristic. Grid stability requires countermeasures to be adopted and thus the RfG regulation adopts specific rules for devices connected via a power converter. Synthetic inertia being the most relevant one. Based on that, the RfG regulation sets out general requirements applicable to all generators, specific requirements for synchronously connected devices, specific requirements for generators connected via a power converter, i.e., Power Park Modules and specific requirements applicable to AC connected offshore generators. It is important to mention that all the requirements laid down by the regulation are in principle only applicable to new sources.

Type A requirements represent minimal conditions that need to be met by the generator in order to be connected to the grid. A type generator is only required to provide a limited automated response and minimal system operator control. Simply explained, the source must be able to stay in operation at small frequency deviations. The aim is to minimize the risk of simultaneous outage of small generating units even at small frequency disturbances. B type requirements provide for a wider range of automated response and higher resilience to operational events. This category has to meet all the conditions related to category A plus conditions specific for type B. The guiding principle is higher the category, stricter the rules. B category generators are required to provide a significantly higher level of system operator control and information. They are required to provide for an automated response to mitigate the impact of system events. Information exchange being the key to enable TSOs and DSOs to maintain the system stability. Operators need to have both an online overview of the state of the system and a possibility to give the power-generating modules direct operational instructions. For example, to adjust the output of the generator in order to ensure a system security. A substantial tightening of the requirements comes with category C. These generators are required to provide for a stable and highly controllable real-time dynamic response and should be able to provide ancillary services to ensure the security of supply. These sources should be able to respond to both intact and system disturbed situations, and should provide the information and control necessary to utilise generation in different situations [1]. Specificity of the category D is a higher voltage level. These generating units should meet the highest level of requirements as they are crucial in the operation of the whole interconnected system.

As it is mentioned above, categories A, B, C, D are distinguished based on the voltage level and rated power of the generating unit. The main reason why network connection requirements need to be regulated is security of supply and stability of the network as such. From the frequency stability perspective, there is only a minor difference between the outage of one 1,000 MW thermal unit and of 100,000 small 10 kW household plants [2]. As the number of distributed generators increases and this goes hand in hand with their impacts on the grid stability a threshold discussion should not focus only at large generating units. The A category threshold is therefore set to 0.8 KW. This means that once the generating unit has such an installed capacity, it needs to meet the grid connection requirements, otherwise it may not be connected. Thresholds for categories B, C and D are on the other hand defined only with the highest possible value. MSs are therefore free to lower them within the implementation procedure. Fig. 1 shows that many MSs used this option and lowered the threshold pretty significantly. Good example being Slovakia that has decided to lower the B threshold from 1 MW to 100 kW, C threshold from 50 MW to 5 MW and the D threshold from 75 MW to 20 MW [3]. An official guidance on the RfG regulation [4] explains that the thresholds shall be determined based on the national generation structure, both current and future. Shares of each module type and a share of the modules connected via a power converter should be taken into consideration. This means that Slovak implementers opted for a much stricter regulation than the baseline model set by the EU.

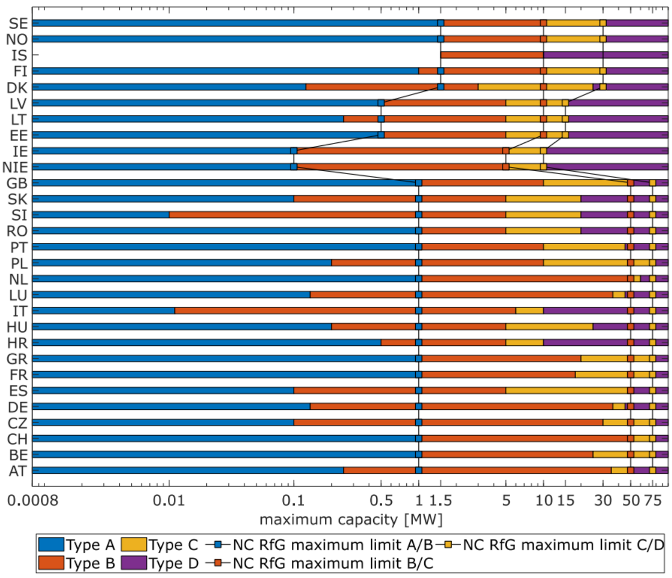

Fig. 1 Thresholds adopted in MSs for A,B,C and D categories [3]

III. SLOVAK IMPLEMENTATION

Regulation's implementation procedure in Slovakia is explained in Fig. 2. As in all the other MSs, procedure was in hands of the TSO and the national regulatory authority. The process resulted in a major amendment of network codes covering the technical operation of the transmission and regional distribution grids. However, even the EU harmonisation has not managed to change the fact that the grid connection of significant sources in Slovakia was basically prohibited due to technical constraints connected with the impact of renewable power generation on the system security. Slovak TSO has explained that new connections will only be allowed after an increase in interconnection capacity on the border with Hungary. This condition has been fulfilled only recently. Two 400 kV power lines connecting Veľký Ďur, Gabčíkovo and Gönyű and one 400 kV power line connecting Rimavská Sobota and Sajóivánka came into an operation on April 6, 2021. This has unlocked further grid connection capacity and gave an end to the so-called stop-state for new generating modules connection that has been in place since 2012.

First amendments of the distribution network codes were already visible in 2017. This were although only negligible and covered the new EU-wide distinction of power-generating modules into 4 categories based on their size and voltage level. More detailed implementation took place only in 2019. Although it is important to highlight the fact that only the recent capacity opening gave a real practical power to the novel regulation.

An important observation that has been made by a comparison of novel distribution network codes is that individual codes implemented the regulation almost identically. However, some non-exhaustive requirements allowing for a choice in details were set differently. Examples are differences in the setting of protections, slightly different voltage time courses during a short circuit operation and reactive power requirements for synchronous units of type C, D.

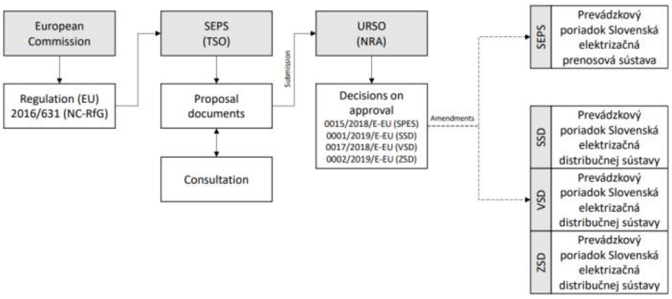

Fig. 2 Implementation procedure in Slovakia [3]

IV. CONTENT OF THE AMENDMENTS

The central change is the introduction of 4 categories of power-generating modules based on which the complexity of requirements is defined. As already mentioned, thresholds distinguishing the categories were set uniformly for whole Slovakia. Sources connected to the distribution grid below 110 kV level may be covered by any of the A, B, C categories depending on the size of their installed capacity. And units connected to the 110 kV distribution grid or the transmission system fall exclusively into category D. Each individual category is linked with a list of requirements that need to be meet in order for the generator to be connected to the system.

The requirements are mainly focused on the security of the system and the impacts a power-generating module may have on the grid. They may be distinguished into several categories.

- Frequency and voltage parameters;
- Requirements for reactive power;
- Load-frequency control related issues;
- Short-circuit current;
- Requirements for protection devices and settings;
- Fault-ride-through capability; and
- Provision of ancillary services.

The first set of requirements is connected to frequency. Primary requirement being generating unit's capability to remain in operation for a defined period of time in case of a frequency deviation within a range of 47.5 to 51.5 Hz. Specific rates of change of frequency and specific timeframes are set for individual A, B, C and D categories. C and D type generating units also need to fulfil various conditions related to primary and secondary frequency regulation. These may be described as their active power frequency response capabilities enabling them to react to overfrequency and underfrequency. Their control systems must be able to adjust the set value of active power in accordance with the instructions of the relevant DSO. Related requirements focus on the frequency limit of the active power activation, droop setting, initial reaction of the generator to the frequency variation, unit's capability to provide a full reserve of active power at a specified time, real-time communication with the control centre and other similar matters. A new feature of the Slovak regulation is the fact that the obligation to meet these capabilities has been extended to power-generating modules connected via a power converter and thus covering renewable sources such as photovoltaics.

Voltage requirements are built on unit's fault-ride-through and automatic connection after faults or planned disconnections capabilities. New regulation therefore defines exact voltage and frequency ranges for individual categories of generating units, under which they can be reconnected back into the system by means of a phasing element. The phasing element can be switched on after receiving a signal for unlocking the main disconnection point from the control centre or automatically at a specified delay. The switch-on delay is in principle determined by the time during which the voltage and frequency must be within the specified range. Proper behaviour during short circuits is crucial for maintaining the system safety in terms of their participation in short circuit detection, maintaining voltage during a short circuit and its post-short circuit restoration and ensuring frequency stability by quick post-short circuit active power recovery, is particularly important in small systems [2]. These functionalities can only be ensured if the generating unit has an ability to stay operable during a short-circuit. Fault-ride-through requirements are again distinguished based on the category of the generator and defined by a time course of the voltage under fault conditions at the connection point, in which the generating unit needs to remain connected and to continue in stable operation after the fault clearing. Different time courses are defined for synchronous and asynchronous sources. Best example of an asynchronous module being a photovoltaic power plant. Asynchronous modules of type C and D with a fault-ride-through capability are for example required to be able to supply active power no later than 150 ms from the fault inception and to be capable of contributing to damping power oscillations.

Fig. 3 compares the fault-ride-through time course of the voltage for type B and type C synchronous and asynchronous generating modules with type D synchronous and asynchronous modules.

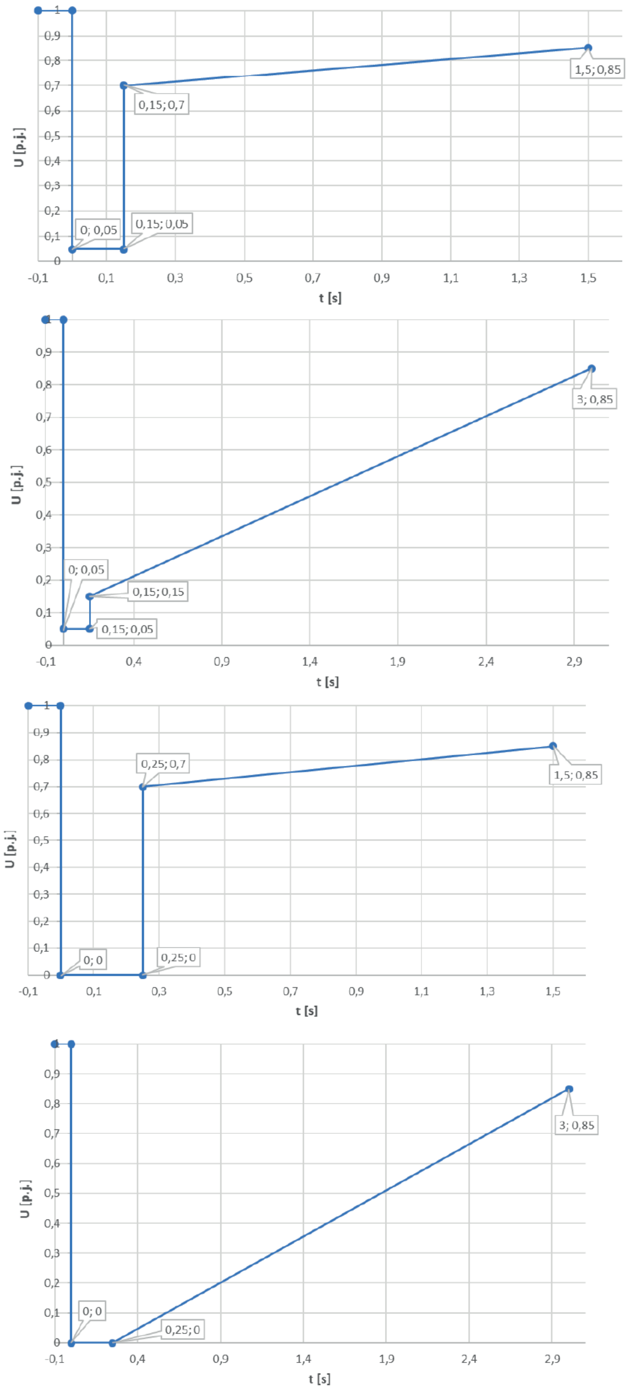

Fig. 3 Comparison of fault-ride-through time courses of the voltage for various types of modules [5]

Third set of requirements is connected to the reactive power. Slovak network codes only apply reactive power related conditions to C and D sources despite the fact that the DSO could define relevant reactive power conditions also for category B. Although the conditions are set separately for synchronous and asynchronous modules, overall rules are very similar for both types. The main requirement is that in case of a maximum active power output, a synchronous power-generating module must be able to operate within the inner envelope of the diagram shown in fig. 4. In case of a lower output, it is required to operate within its PQ diagram. Similar applies to asynchronous modules. They should be able to operate within the inner envelope of the fig. 5 in case of a maximum active power output and in case of a lower output, it is required to operate within the limits of the fig. 6. Individual DSOs adopted slightly different limits of the inner envelope, but in principle still very similar regulations. An interesting finding based on a comprehensive comparison of Slovak network codes and the original EU regulation may be may be seen upon an analysis of the fig. 5 and fig. 6. The profile in question forms a binding part of the network code adopted by the western distribution system operator. However, other distribution network codes adopted similar diagrams. The figure says that axis y represents voltage. However, the original profile enacted in the EU regulation specifies that the y axis in question represents active power expressed by the ratio of its actual value and the maximum capacity. We might suppose that this is an implementation error. Interesting fact is that it has been adopted by all three DSOs.

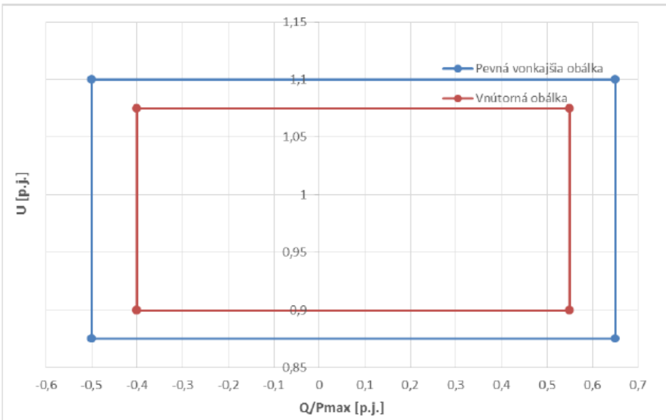

Fig. 4 U-Q/Pmax-profile of a synchronous power-generating module [6]

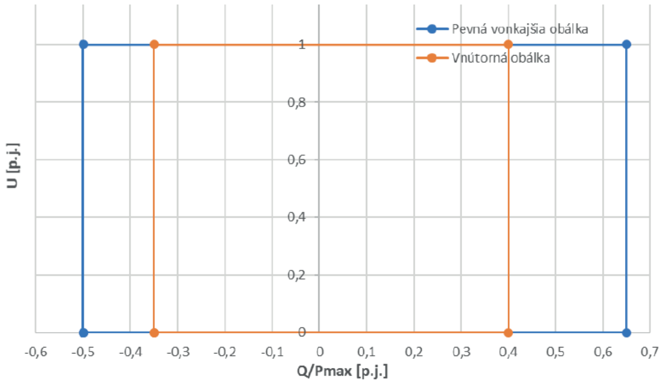

Fig. 5 U-Q/Pmax-profile of an asynchronous power-generating module [5]

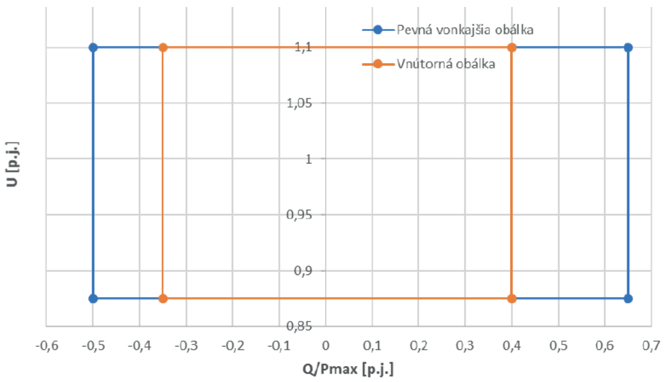

Fig. 6 U-Q/Pmax-profile of an asynchronous power-generating module [5]

It is important to explain that requirements for A and B modules are not that extensive. A significant increase in prerequisites comes with the C category, i.e., in Slovak conditions in case the capacity of the generating module exceeds 5 MW. Type C and D generators must for example meet various requirements concerning the black start capability, island operation, houseload operation, the loss of angular stability and the instrumentation of the generating facility. The instrumentation needs to cover requirements related to facility to provide fault recording and monitoring of both the operation and of the dynamic system behaviour. Voltage, active power, reactive power and frequency parameters have to be recorded in defined time periods. C and D sources shall also provide monitoring the behaviour of the system by measuring frequency oscillations and with regard to loss of angular stability or loss of control, these power-generating modules shall be capable of disconnecting automatically from the network in order to help preserve system security or to prevent damage. As mentioned above, C and D units are required to be capable of island operation and to be galvanically isolated at the main disconnection point. Another important requirement is related to the obligation to provide the system operator with simulating modules reflecting the behaviour of the unit in both steady-state and dynamic simulations or in electromagnetic transient simulations.

Authors need to express their opinion that the individual requirements in all new Slovak network codes are not organized in a transparent manner. If we compare the structure of the original regulation and the structure of the network code, we have to conclude that the structure of the network code is very chaotic. Slovak codes miss the systematic order of the requirements based on the category of the generating unit. Thus, it will be very difficult for a laic investor to understand the code and to find out which are the requirements that must be met. Guidelines provided by the TSOs and DSOs would be very relevant.

V. Conclusion

RfG regulation needs to be considered as a significant step towards a continental grid unification, a big step towards a level-playing field, transparency and an EU wide internal electricity market. Up until its adoption, network connection requirements have only been regulated at the level of the continental Europe's synchronous system by provisions of an Operational Handbook, Policy 1 and Policy 5. As opposed to national network codes, these standards haven't been binding. TSOs' adherence to it was voluntary and they only became binding pursuant to provisions of a multilateral interconnection agreement [2]. Moreover, Handbook has never laid down concrete requirements for generating modules. It has rather focused on requirements that had to be met by the regulatory area as such. In practice it was still in the hands of the national authorities do adopt their own rules reflecting the needs to follow the Handbook. These were however often significantly different.

RfG regulation may be seen as a platform for further legislative processes and closer harmonisation. This has also been acknowledged by the EU commission. Its comprehensive comparison of implementation results in the individual MSs has shown that non-exhaustive rules gave the MSs a significant room, that in case of many requirements ended up in substantial differences across the whole EU [3]. A good example may be fig. 1 showing the thresholds for individual categories of power-generating modules. Differences may have various negative impact and are a barrier in the internal market. One of the negative impacts being the fact that different thresholds introduce a challenge for generator manufacturers who plan to sell their products outside their own country. This is because a module of a particular type in one MS may be regarded as another type in another MS and therefore the product will have to comply with more requirements [3].

In spite of the fact that the implementation results were different across the EU, the harmonisation has shown that unified requirements for the whole EU are possible and that a transparent unified EU-wide grid code may be a reality in a near future.

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