Abstract—Some new requirements were recently introduced in European grid codes, mainly due to the increasing share of renewable energy sources connecting to the European network. These requirements are sometimes differing from grid code to grid code and also from the international standards requirements (mainly IEC 60034-3 and IEEE C50.13 for turbogenerators). This paper gives an overview on some requirements from various European grid codes and presents the harmonisation efforts undertaken by the European Network of Transmission System Operators for Electricity (ENTSO-E) via the proposal of a pilot code. Furthermore a typical generator response to the low-voltage ride-through requirement proposed by the ENTSO-E is discussed and some of the power generation equipment manufacturers comments to the proposed draft pilot code are summarized. Finally, it is reminded that the generator is not the only component influencing the electrical grid transient stability.

Index Terms—Grid codes, power system transient stability, synchronous generators, voltage ride through capability.

I. INTRODUCTION

Standards are an established instrument for interaction between suppliers and customers and are usually one main source of inputs for customer specifications. For turbogenerators IEC 60034-3 [1] and IEEE C50.13 [2] are the most recognized standards and are therefore usually taken as a basis for specifications, both for the development of new standard products, as well as for customer product requirements. As these standards are internationally well accepted, compliance with them gives the manufacturer of turbogenerators the confidence of developing a product, which is acceptable for a wide range of customers. Nevertheless, such standards do not have legal value, unless they are incorporated to the legal framework of a region or a country.

The de-regulation of electricity markets has resulted in the unbundling of vertically integrated utilities into generation, transmission and distribution companies. As a consequence, grid codes have been developed by transmission system operators (TSOs) to formalize their obligations and to establish the framework of their technical relationships with generation and distribution companies. Grid codes have legal value in the region or country they apply.

Grid codes have been developed in all European countries. Some regions, like NORDEL, have adopted a single code for all countries of the region, but most of the grid codes apply for one single country. Only few of those individual grid codes share the same criteria and requirements. As example of this diversity, the formulation of the voltage ride-through capability criterion can be mentioned. A number of studies have already pointed out the wide variety of voltage ride-through requirements found in grid codes ([3], [4]) and the need of grid code harmonization ([5], [6]).

Voltage ride through capability was firstly required for wind generators to prevent massive wind generation disconnection in case of a transmission network fault. It was subsequently imposed on synchronous generators adding new requirements with respect to what IEC 60034-3 and IEEE C50.13 standards require of turbogenerators.

Since their introduction, the local grid codes are, needless to say, besides the mentioned international standards, part of the customer specifications for turbogenerators. This leads to a wider variation of requirements for turbogenerators, depending essentially on the country or region the generator is sold to, and makes the specification and development of standard products increasingly challenging.

This paper starts with an illustration of the diversity of European grid code requirements on the example of the voltage ride-through requirements and then presents the proposal made by the European Network of Transmission System Operators for Electricity (ENTSO-E) to harmonize them [7].

Furthermore the response of a typical turbogenerator [8] to one of the ENTSO-E Pilot Network Code on Grid Connection (pilot code) requirements is analyzed and some of the feedback provided to the current draft version of this pilot code is presented. Additional factors influencing synchronous generator stability are also discussed.
II. DIVERSITY OF EUROPEAN GRID CODES PRIOR TO HARMONISATION

This section shows the diversity of voltage ride through requirements found in a number of European grid codes. Grid codes of Belgium [9], England [10], France [11], Ireland [12], Italy [13], Germany [14], Scandinavia [15], Spain [16] and Switzerland [17] have been reviewed.

Voltage dips as required by the reviewed grid codes can be classified into two groups:

- rectangular voltage dips, and
- polygonal voltage dips.

Requirements of the English, Italian, Irish and French grid codes lie in the rectangular voltage dip category. The recovery voltage is sharp. English and Irish grid codes incorporate a multi-dip requirement whereas the French and the Italian ones have a single-dip one. The multi-dip requirement of the English code results from the consideration of an explicit voltage-fault duration curve. Fig. 1 compares the rectangular voltage dips examined.

Requirements of the German, Scandinavian, Spanish and Swiss grid codes belong to the polygonal voltage dip category. The German and the Swiss grid codes impose exactly the same requirement. The recovery voltage is smoother. Fig. 2 compares the polygonal voltage dips analyzed.

None of the grid codes surveyed, apart from the French one, details neither the generator operating condition under which the voltage ride through capability should be checked, nor the impedance connecting the generator to an infinite bus to be considered.

In this context, ENTSO-E has started the task of drafting harmonised network codes, amongst them a Pilot Network Code on Grid Connection, which will be discussed in more detail in the following (called also “pilot code” in this paper). This process, as well as, amongst others, the harmonized proposal for the above-presented low-voltage ride-through requirements, is presented in the next section.

III. HARMONIZATION OF EUROPEAN GRID CODES UNDER ENTSO-E

The European Commission Regulation 714/2009 of the European parliament and of the Council of July 13th 2009 underlines the need for an increased cooperation and coordination among transmission system operators within a European network of transmission system operators. The goal of this cooperation and coordination is to create network codes for providing and managing effective and transparent access to the transmission networks across borders, and to ensure coordinated and sufficiently forward-looking planning and sound technical evolution of the transmission system in the European community, including the creation of interconnection capacities, with due regard to the environment.

The ENTSO-E was established on December 19th 2008 and became fully operational on July 1st 2009. The ENTSO-E represents 41 TSOs from 34 European countries (Fig. 3) managing over 305,000 km of transmission lines.

One of the ENTSO-E’s tasks is to draft network codes in twelve topic areas:

- Network security and reliability
- Grid connection (pilot code)
- Third party access
- Data exchange and settlement
- Interoperability
- Operational procedures in an emergency
- Capacity allocation and congestion management
- Trading, network access and system balancing
- Transparency
- Balancing and network power reserves
- Harmonized transmission tariff structures
- Energy efficiency
These network codes have to be in line with the corresponding framework guidelines, defined by the Agency for the Cooperation of Energy Regulators (ACER) and they have to pass through a transparent public consultation and will become legally binding to all market participants after having gone through Comitology. Comitology in the European Union refers to the committee system that oversees the delegated acts implemented by the European Commission.

For manufacturers of synchronous generators, network codes related to grid connection are of particular importance as these could impact equipment design and cost (see for example [18]).

The pilot code addresses urgent issues arising as a consequence of high and rising volumes of renewable energy connecting to Europe’s networks. Non-harmonized and outdated technical connection conditions for wind, solar and other generation equipment was threatening safe system operations. The pilot process was especially valuable since it allowed early engagement of the many affected stakeholders, i.e. the owners, operators and manufacturers of generation equipment of all technologies, sizes and connection voltage levels, and thus allowed a fuller consideration of the complex issues involved in generation connection.

At the time of writing this paper, the 3rd draft Pilot Network Code on Grid Connection has been released in October 2011. The ENTSO-E will seek views from stakeholders in the last quarter of 2011 and first quarter of 2012, aiming to deliver the final draft code by June 2012.

The Pilot Network Code on Grid Connection defines a common set of requirements for power generating facilities, including synchronous generating units, power park modules and offshore generation facilities, to be connected to the network and sets up a common framework for network connection agreements between network operators and power generating facility operators.

### Table I

<table>
<thead>
<tr>
<th>Type</th>
<th>Point Voltage [kV]</th>
<th>Connection Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>&lt;110</td>
<td>D &gt;110</td>
</tr>
<tr>
<td>B</td>
<td>&lt;110</td>
<td>C &lt;110</td>
</tr>
<tr>
<td>C</td>
<td>&lt;110</td>
<td>B &lt;110</td>
</tr>
<tr>
<td>D</td>
<td>&gt;110</td>
<td>A &lt;110</td>
</tr>
</tbody>
</table>

The discussion in this paper is limited to the requirements in the grid code related to synchronous generators. As stipulated in the pilot code, the extent of the requirements depends on the voltage level of their connection point and their MW capacity according to the categories as shown in Table I.

In general, synchronous generators in a higher category (lowest is A, highest is D) must meet all the specified requirements in the lower category in addition to the requirements in that particular category. As such, this paper refers specifically to requirements related to synchronous generating units of Type D.

The pilot code contains many requirements, some of which have no relevance to the design of the synchronous generator. As such, only a subset of requirements from the pilot code, which in the opinion of the authors may have an impact on the design of the synchronous generators, will be analyzed in the following sections, mainly with respect to differences to the most important international standards. Requirements related to frequency response, black-start, island operation, excitation system, power oscillation damping etc., that do not directly impact the design of the synchronous generator are not addressed in this paper.

### Frequency Ranges (Article 7, Paragraph 1a)

In case of deviation of the network frequency from its nominal value, due to a deviation within the frequency ranges and time periods specified, any automatic disconnection of a generating unit from the network shall be prohibited and power infeed shall be maintained within the limits specified.
as shown in Fig. 4. Frequency above 51 Hz and below 49 Hz as defined in the pilot code is inconsistent with IEC 60034-3 and IEEE C50.13 in terms of time duration.

B. Rate of Change of Frequency Withstand Capability (Article 7, Paragraph 1b).

With regard to the rate of change of frequency withstand capability, the generating unit shall not disconnect from the network due to rates of change of frequency up to 2 Hz/s. Any rate of change of frequency of 2 Hz/s or above shall be withstood by generating units for at least 1.25 seconds without disconnection from the network other than triggered by loss of mains protection. The latter statement implies that a frequency fall of greater than 2 Hz/s for 1.25 s would result in a frequency below 47.5 Hz and hence ends up outside the range defined in IEC 60034-3 and IEEE C50.13. In these standards it is furthermore ensured that over- and underfluxing conditions are limited to 5%. It can be remarked that overvoltage together with low frequency, or low voltage with over-frequency, are unlikely operating conditions. However from the pilot code it is not stated if such operating conditions may exist or not.

C. Voltage Ranges (Article 10, Paragraph 2a)

In case of a deviation of the network voltage at the connection point from its nominal value, any automatic disconnection from the network of a generating unit, with a connection point at 110 kV or above, shall be prohibited due to the deviation within the voltage ranges, expressed by the voltage at the connection point related to nominal voltage (per unit), and within the time periods specified by Table II and Table III. As per IEC 60034-3 and IEEE C50.13, turbogenerators are specified for continuous operation over voltage ranges of rated voltage ± 5%. Unless on-load tap changers for generator step-up transformers are installed it is not possible to operate the generator within these 5% voltage limits for such a wide variation in network voltages as specified by the pilot code.

D. Reactive Power Capability (Article 12, Paragraph 3e)

The reactive power capability requirement in the context of varying voltage at the connection point is defined as a U-Q/Pmax-profile that can take any shape within the inner (red) and outer (green) boundaries shown in Fig. 5.

When considering the extreme reactive power ranges in the pilot code, it is questionable, if it makes sense to require from generators to consume up to 0.5 Q/Pmax when the HV voltage is at 0.875 p.u. or to produce 0.65 Q/Pmax when the HV voltage is at 1.10 p.u.. Both IEC 60034-1 and IEEE C50.13 define reactive power capability at the terminals of the generator and machines designed to these standards may not be able to provide the reactive power as specified in the pilot code.

E. Fault Ride Through Capability (Articles 11, 3 & 13, 3)

Each TSO shall have the right to define a voltage-versus-time-profile at the connection point for fault conditions which describes the conditions in which the synchronous generating unit shall stay connected to the network and shall continue stable operation after the power system has been disturbed by secured faults on the network unless the protection scheme requires the disconnection of a generating unit from the network.

![Fig. 5: The diagram represents a U-Q/Pmax-profile by the voltage at the high-voltage terminals of the step-up transformer to the voltage level of the connection point, expressed by the ratio of its actual value.](image-url)
This voltage-versus-time-profile shall be expressed by a lower limit of the course of one of the three phase-to-phase voltages at the connection point, which sustains the lowest retained voltage during a symmetrical or asymmetrical fault, irrespective of the voltage drop of the other two phase-to-phase voltages, as a function of time before, during and after the fault. This lower limit shall be defined by the TSO as a specific line inside or on the borders of the shaded area delimited by the red lines given in Fig. 6 (connection points below 110 kV) and in Fig. 7 (connection points at or above 110 kV).

The ability of a synchronous generator to ride through faults depends not only on the characteristics of the generator design but also on external factors such as initial operating conditions and pre- and post fault conditions of the system.

Generators designed according to IEC 60034-3 or IEEE C50.13 standards to withstand sudden short-circuits are not automatically complying with these fault ride-through requirements. These requirements may impact the generator design parameters such as inertia, short-circuit ratio, voltage ceiling factors, etc.

**F. Auto-Reclosures (Article 8, Paragraph 2a)**

With regard to auto-reclosures, the responsible network operator shall have the right to request single-phase auto-reclosures on generating unit supply lines (radial connection of one or more generating units to the public network) and single-phase or three-phase auto-reclosures on meshed network lines to be withstood by generating units without tripping.

IEEE C50.13 Section 4.4.4.4 states the following on rapid reclosure following system faults:

*While unsuccessful rapid reclosure events (reclosing into a permanently faulted line) are more severe than successful rapid reclosure events, both successful and unsuccessful rapid reclosure events are of potential concern. Because of the statistical nature of the system torques and local shaft torques and the cumulative effect of the resulting fatigue damage to shafts, generalized requirements are not possible. Where it is expected that a turbinegenerator is to be subject to power system rapid reclosures, it is recommended that the manufacturer be consulted and a possible unit-specific study be performed.*

**G. Synchronization (Article 8, Paragraph 4a)**

Synchronization of generating units shall be possible for frequencies within the ranges set out in Fig. 4. The network operator and the power generating facility owner shall agree on the settings of synchronisation devices in the conditions set forth in a non-discriminatory manner and concluded prior to operation of the generating unit. This agreement shall cover the following matters: voltage, frequency, phase angle range, phase sequence, deviation of voltage and frequency. Although the pilot code allows some flexibility in synchronizing conditions, the frequency ranges detailed in Fig. 4, especially at the lower frequency ranges may cause high stresses in the event of out-of-phase synchronization. The design of a shaft-line for such events may become challenging.

**H. Torsional Stress (Article 9, Paragraph 3b)**

With regard to torsional stress, the generating units shall be designed in a way that shaft torsional stress which may be excited by transient active power steps up to 50 % of its maximum capacity are considered a routine part of normal operation and shall be taken into account when specifying the shaft characteristics.

Switching operation at rotational speeds lower than rated rotating speed may result in higher torsional stresses. Hence, if a switching operation results in a $\Delta P$ of 50% or greater, a unit specific study should be performed to ensure torsional stresses are within the unit’s design limits.
I. Ceiling Voltage (Article 12, Paragraph 3c, 2)

The exciter shall be capable of attaining an excitation system on load positive ceiling voltage specified by the relevant network operator.

The pilot code does not define the minimum and maximum values of the ceiling voltage, which is also not done in IEC 60034-3 and IEEE C50.13. Very high ceiling voltage requirements may be limited by the generator field winding insulation and not by the excitation system capability.

J. Short-Circuit-Ratio (Article 34, Paragraph 3b)

The pilot code requires compliance tests to validate the Short-Circuit-Ratio (SCR) of the synchronous generator. The test is deemed passed if SCR is not less than 0.5 or a lower value specified by the relevant TSO. This SCR of not less than 0.5 is inconsistent with IEC 60034-3 or IEEE C50.13 standards that specify a SCR of not less than 0.35.

IV. Generator Response to the ENTSO-E Voltage Ride-Through Proposal

As could be seen in the discussion of selected requirements of the pilot code in the preceding chapter, sections A. to J., some of these requirements differ from the international standards and some of them might not be defined precisely enough. For illustration, the response of a typical turbogenerator [8] to the voltage dip specified in the ENTSO-E pilot code proposal is studied in more detail and commented in this section. Precisely, the upper boundary of the voltage dip, which is the less demanding one, will be considered.

The generator is connected to the network through its step-up transformer. A bus fed static excitation system supplies the generator excitation. The excitation system incorporates a speed deviation power system stabilizer. The excitation system and stabilizer models are displayed respectively in Fig. 8 and Fig. 9. Although speed deviation stabilizers are not commonly used, the simulation model has considered the stabilizer proposed in [8]. The simulation model has neglected the synchronous machine stator and the network transients and has assumed that the turbine supplies constant mechanical power throughout the transient. The generating unit data are provided in the Appendix.

The voltage profile specified by the ENTSO-E can be interpreted either as an exact voltage-time profile to be applied at the connection point or as data pairs (dip depth and dip length) representing possible faults. The response of the generator to both interpretations is studied in the following subsections.

A. Interpretation as Voltage-Time Profile

The most favourable generator operating condition at rated active power, extreme lagging power factor and no connecting impedance to the infinite bus are assumed. Fig. 10 shows the test case simulated.

![Connection Point](image)

**Fig. 10:** Voltage dip at the connection point.

Fig. 11 shows the time variation of the voltage at the connection point and the generator terminal voltage. The generator looses synchronism. Synchronism is lost, not because of the fault duration, but due to the voltage profile during the recovery period.

![Generator Response](image)

**Fig. 11:** Generator response in case of the ENTSO-E voltage dip required at the connection point.

B. Interpretation as Data Pairs

In this case the first available data pair is considered: the voltage drops to zero for 150 ms at the connection point. Moreover, an external reactance connecting the step-up transformer high voltage terminals to the infinite bus according to Fig. 12 is assumed. In contrast to the test case of Fig. 10, the very demanding operating condition at rated active power and extreme leading power factor has been assumed.
Fig. 13: Comparison of generator terminal voltage with E.ON and WECC

Fig. 12: Fault at the connection point.

V. COMMENTS TO THE ENTSO-E PILOT CODE PROPOSAL

The ENTSO-E requirements to synchronous generators have been compared to international standards requirements and a typical turbogenerator response to one of these requirements has been analysed in detail in the previous two sections. It could be observed that there are some differences to standards requirements and also that some of these requirements might not yet be formulated precisely enough. As these requirements have an impact on the design of the synchronous generators, manufacturers have actively been involved in providing feedback to the ENTSO-E with regards to these requirements in the pilot code.

### TABLE IV

<table>
<thead>
<tr>
<th>Subject</th>
<th>Comments/Proposed Modifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Ranges</td>
<td>The 90 minutes requirement is a long duration. Generators will heat up in case of frequency deviations of such extent. In order to support the grid for long duration, in case of frequency drop, a reduction in active power shall be permitted in order to protect the machine.</td>
</tr>
<tr>
<td>Rate of Change of Frequency</td>
<td>There is no limitation to the rate of change of frequency for 1.25 sec and this is not acceptable. The rate of change of frequency value of 2Hz/s is acceptable but: - limited to the boundary frequency range in Table 2 (out of this range means instantaneous disconnection from the grid); - rate of change of frequency higher than 2 Hz/s can be permitted for a very short period (much shorter than 1.25 sec) and limited by the technical capability of the machine.</td>
</tr>
<tr>
<td>Auto-Redlosures</td>
<td>Auto-redlosures need supervision by a synchro-check relay and maybe even synchronizing is necessary. With out-of-phase reclosure, the phase angle should typically be not greater than 30°. Machine integrity shall be considered a first priority for grid reliability / availability.</td>
</tr>
<tr>
<td>Torsional Stress</td>
<td>This requirement needs a thorough investigation to provide a proper response. This is a new requirement and current technologies have not considered up to now such needs. For design of turbogenerator shaft-lines, the frequency and amplitude of such torsional disturbances needs to be known (steps amplitude, how many times, how frequently happens, etc). State-of-the-art design criteria should not be changed.</td>
</tr>
<tr>
<td>Voltage Ranges</td>
<td>The concern is that according to the tables the plant will be sometime oversized. The maximum voltage level as minimum requirement shall be harmonized with EN 62271. Combined voltage/frequency variations shall be limited. Suggestion: V/f in accordance with IEC standards.</td>
</tr>
<tr>
<td>Fault Ride Through for Network Voltages &lt; 110kV</td>
<td>Conditions shall be agreed based on a realistic fault condition. The voltage profile is not a realistic profile. Interpretation of curve is not clear: course over time of one specific fault or plot of data pairs, each representing a possible fault? We recommend the latter interpretation similar to UK code. Normal fault clearing time for primary protection for close up faults should be less than 150 ms. Clearing time longer than this can be critical. Conditions at PCC have a significant influence on the stability of the system. In case of weak grids at the PCC it will be difficult to satisfy such requirements. The TSO should have a responsibility to define reasonable and normal pre conditions at the PCC, extreme and abnormal conditions should not be considered.</td>
</tr>
<tr>
<td>Reactive Power Capability</td>
<td>The reactive power capability requirements are possible only where on-load tap changers are installed on step-up transformers. The reactive power capability requirements should only be applicable for unlimited frequency ranges. Table 6 voltage level ranges do not correspond to table 5.1 and 5.2 in chapter 1 paragraph 2. This table can be intended as the ranges for type C and D units. The table shall be corrected and clear indication submitted. Recommendation in any case is that voltage limits as per IEC standards apply for all generating units.</td>
</tr>
<tr>
<td>Fault Ride Through for Network Voltages &gt; 110kV</td>
<td>Conditions shall be agreed based on a realistic fault condition. The voltage profile is not a realistic profile. Interpretation of curve is not clear: course over time of one specific fault or plot of data pairs, each representing a possible fault? We recommend the latter interpretation similar to UK code. Normal fault clearing time for primary protection for close up faults should be less than 150 - 250 ms. Clearing time longer than this can be critical. Conditions at PCC have a significant influence on the stability of the system. In case of weak grids at the PCC it will be difficult to satisfy such requirements. The TSO should have a responsibility to define reasonable and normal pre conditions at the PCC, extreme and abnormal conditions should not be considered.</td>
</tr>
<tr>
<td>Synchronization</td>
<td>Although the pilot code allows some flexibility in synchronizing conditions, the frequency ranges detailed in Table 2, especially at the lower frequency ranges may cause high stresses in the event of out-of-phase synchronization.</td>
</tr>
<tr>
<td>Ceiling Voltage</td>
<td>The pilot code does not define the maximum value of the ceiling voltage. Generator manufacturers cannot design units with very high ceiling factors even though the excitation system can achieve them.</td>
</tr>
<tr>
<td>Short-Circuit Ratio (SCR)</td>
<td>This requirement on SCR of not less than 0.5 is inconsistent with IEC 60034-3 or IEEE C50.13 standards that specify a SCR of not less than 0.35.</td>
</tr>
</tbody>
</table>
Especially in the case of turbogenerators, all major manufacturers try to develop standard generators, which are then sold with only minor project-specific adaptations. This approach allows keeping costs at a reasonable level, while benefiting from a large fleet experience, leading to increased reliability. This practice is also driven by the nature of the driving engines (steam and gas turbines), whose design is also highly standardized. The established practice is to design these standard generators primarily according to international standards. In recent times some specific requirements from grid codes have additionally been considered in the design, depending on the target markets. As could be seen in the previous chapters, some of these additional requirements have an influence on generator lifetime (e.g. due to material fatigue, see for example torsional stress and auto-reclosure). For the requirements in the main international standards a lot of design experience exists, which is not the case for the wide variety of new requirements.

If specific grid code requirements cannot be met due to technical deficiency of the generators, then solutions have to be found either in the form of adapting the grid code requirements, improving the technical capability of the generator or a combination of both. Therefore, as part of the ENTSO-E consultation process with stakeholders, manufacturers have proposed modifications to the pilot code with regard to grid connection requirements. At the time of writing this paper, Alstom has provided feedback for proposed modifications of the draft pilot code dated March 2011. A subset of the modifications concerning primarily the synchronous generator rather than the turbines is summarized in Table IV. This should illustrate the way in which observations, such as the ones presented in chapters III. and IV. , were fed back to the ENTSO-E.

VI. FACTORS INFLUENCING SYNCHRONOUS GENERATOR STABILITY

Many factors affect the large-disturbance stability of a synchronous generator. Amongst them, the machine operating conditions and the external reactance must be highlighted.

The latest draft of the pilot code [7] does recognize the influence of these factors and has added a subparagraph addressing issues such as pre- and post fault minimum short-circuit capacity as well as pre-fault operating conditions.

Fig. 14 shows the impact of the value of the connecting external reactance and the generator power factor on the critical clearing time. The critical clearing time is the maximum clearing time for which the generator remains stable. As can be observed, the critical clearing time varies from 120 to 240 milliseconds in the extreme leading power factor specified by the ENTSO-E, whereas it varies from 160 to 355 milliseconds in the extreme lagging power factor.

Furthermore it needs to be discussed, if some requirements really reflect the complex reality with sufficient precision. For example the case of the low-voltage ride-through requirement illustrated in section IV. illustrates that caution must be exercised with respect to the attempts to address the complex large-disturbance stability problem by setting a voltage ride-through requirement expressed in simple terms. The discussion contained in [19] may help to proceed further in the direction of realistic and effective requirements to achieve large-disturbance stability.

VII. CONCLUSIONS

In this paper the diversity of European grid code requirements for synchronous generators has been presented. This diversity has led to the currently on-going attempt of the ENTSO-E to harmonise these codes.

Some examples illustrate the fact that there are sometimes significant differences to the requirements of international standards for turbogenerators. Furthermore, some of these requirements seem to be trivialising the complex problem of large-disturbance stability of synchronous generators connected to an electrical grid. At the same time, some important additional factors are often not considered, as for example the characteristics of the grid at the connection point or the generator operating point.

For this reason generation equipment manufacturers have provided extensive feedback to the ENTSO-E draft pilot code. Nevertheless, such additional requirements and their diversity make the design of standard generators more difficult, as they might have an important impact on the layout of the generator.

VIII. REFERENCES

Excitation system model parameters: \( KA = 200pu \), \( TR = 0.01s \), \( EFD_{\text{max}} = 6.4pu \), \( EFD_{\text{min}} = -6.4pu \), \( KC = 0.1pu \)

Stabilizer model parameters: \( KS = 20pu \), \( TS1 = 0.05s \), \( TS2 = 0.02s \), \( TS3 = 3s \), \( TS4 = 5.4s \), \( TS5 = 10s \), \( V_{\text{max}} = 0.05pu \), \( V_{\text{min}} = -0.05pu \)

Transformer electrical data: \( X_t = 0.15pu \)

X. BIOGRAPHIES

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