New Actors on Stage - Upcoming Grid Code Requirements for Storage Systems

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Abstract — **Undoubtedly, storages are bound to play a significant role in future power systems tending towards a 100% penetration of renewable sources. Especially electric storage systems (ESS) will be substantial not only to make the renewable energy sources commercially viable but also to ensure stability of the grid with higher share of renewables. Different studies assign installations up to 200 GW and respective capacities up to 5 TWh for a renewable European scenario. It is clear that these capacities cannot be solely provided by conventional storage technologies like pump hydro due to geographical reasons. Hence, it can be assumed that most of the required installations will be coupled to the power system by power electronic interfaces and will be rather dispersed than large-scale-accumulated. This opens wide options to provide ancillary system services by such ESS in terms of reserve capabilities, frequency and voltage stability and system restoration under fault conditions – just to name today's typical requirements on power generation modules. In future, this list will be extended by more ambitious features like grid forming characteristics, that will become crucial the more conventional, thermal synchronous generators are replaced by inverter-interfaced generators. A special benefit can be derived from the typically bi-directional power-flow of ESS, i.e. their operation in charging and in power injecting mode.**

However, the European Network Code Requirements for Generators (ENC RfG), published in 2016, did explicitly exclude storage systems from its definitions on grid code requirements for connecting such installations to the grid – except for pump hydro storages. Nevertheless, some European countries have already introduced specific technical grid connection requirement on storage systems in their national grid code implementation. Whereas a quite natural requirement is to act like power generating modules when they are in an export (discharging) mode, additional provisions are also set up for the import (charging) mode while acting as a load, especially for frequency response and voltage stability features. As well, some grid codes have introduced more stringent requirements for the discharging modes, e.g. for LFSM-U due to the additional in-feeding capabilities of storages.

The paper will put focus on the enhanced grid supporting capabilities of (inverter-interfaced) storage systems and give a broad overview on technical requirements defined in the actual European national grid codes. It will also highlight challenges for the storage-based hybrid power systems in terms of grid code compliance. The overview will be based on two studies FGH has recently conducted in terms of a general capability assessment and a comprehensive grid code analysis throughout Europe, including also the standards CLC 50549-1 and -2. The picture will be enhanced by the work of the Expert Group Storage at the European Stakeholder Committee on Grid Connection.

I. Background & Introduction

Following the harmonisation inside the European Union, the European Network of Transmission System Operators for Electricity (ENTSO-E) has developed – among other Connection Codes – the *Network Code on Requirements for Grid Connection of Generators* (ENC RfG) [1]. Based on the respective Commission Regulation 2016/631, the ENC RfG is in place since May 2016 providing a binding framework for respective national regulations within the European Member States. The ENC RfG is valid for all voltage levels defining technical requirements for power generating modules (PGM) of different kind of technologies with respect to their electrical characteristics [2]. However, given the focus on power generating modules, the ENC RfG does not tackle respective provisions on storage systems except for pump hydro storages in export mode where such requirements are equal to those of PGMs.

Taking into account that the drafting of the ENC RfG started as early as in 2009 it might be understandable, that the network code didn't provide the adequate attention to storage systems which, today, just about 10 years later, are considered to play a significant role in a future decarbonized power system with, hence, renewable and intermittent energy sources. Different studies assign installations up to 200 GW and respective capacities up to 5

TWh for respective European scenarios with a 65% renewable share by 2050 [3] as storage systems shall play a significant role for balancing volatile power generation and loads [4]. Under the framework of the European Green Deal and respective renewed climate policies it is clear that the roadmaps towards such a revised energy system will even need to be accelerated. Accordingly, the European Stakeholder Committee on Grid Connection (GC ESC) [5] under the chair of the Agency for the Cooperation of Energy Regulators (ACER), which has been accompanying the implementation process of the European Connection Codes and identifying the needs for their further development, has installed the *Expert Group Storage* in order to provide appropriate definitions of respective storage devices and develop proposals for enhanced requirements on such systems in a future network code [6]. The basic results of this Expert Group will be provided in section II of this paper.

Based on the recent fast developments in battery storage systems and given the emerging penetration of electric vehicles as well as domestic storage systems – most likely in combination with rooftop PV – it is foreseeable, that future storage systems will be significantly shaped by inverter-interfaced, small- to midscale and distributed (mobile) ESS which provide the option of a bi-directional power flow, i.e. power consumption (in charging or import mode) as well as power injection (in generation or export mode). Naturally, such systems, comparable to the power park modules of the ENC RfG, provide a full range of ancillary system services in order to support the power network operation as well in stable as under fault conditions. Section III will sum up an overview on typical features. Following the lessons learnt from the growing installations of wind and PV power in the first decade [7] it is highly recommended by the authors to early define respective grid code requirements for connecting these installations to the power grid in order to ensure a level playing field for all stakeholders involved – manufacturers, project developers and network operators.

In 2020 FGH has conducted a study [8] for the European Commission on the status quo of grid code implementation according to the provisions of the ENC RfG. The study has investigated the national status quo on the specifications with respect to PGM type thresholds and non-exhaustive requirement definitions. FGH has intended to enlarge the study to give also note to the status quo of European wide definitions of storage system connection requirements. Section IV will provide an overview on these results. They are compared with another study of FGH which summed up some recommendations for connection of storage systems into hybrid systems based on a study survey in 2019 [9].

Finally, grid code provisions on ESS need to be become effective to the power system by appropriate and conforming implementation. Hence, a respective compliance monitoring system as already required for power generating modules within the ENC RfG is also recommended for ESS. Section V will give an overview on the status quo on respective compliance schemes.

II. Definitions and Recommendations on Storage Systems for Further Grid Code Development

In 2018, the GC ESC established the Expert Group Storage. The Terms of Reference lists the identification of different storage devices and their appropriate definitions, the identification of distinguished kinds of operation and finally the analyses of possible grid supporting features and recommendation of respective grid code requirements. Where possible, explicit proposals for enhancing the existing European Network Codes on grid connection (ENC RfG, but also Demand Connection Code (ENC DCC) and HVDC Code) should be elaborated and open questions and issues targeted for further consideration. The Expert Group Storage has by definition excluded pump hydro storage systems but gave a special consideration to electric vehicles. The work has been structured in two phases. Both final reports are available at [6].

The Expert Group Storage has given the following definition to Electricity Storage (to be referred within this paper as Electric Storage System, ESS):

"Electricity storage" means the conversion of electrical energy into a form of energy which can be stored, the storing of that energy, and the subsequent reconversion of that energy back into electrical energy.

Subsequently, such ESS has to be distinguished from a general *energy storage*, e.g. as defined within the EU Clean Energy for all European Package [10], which allows the "reconversion of such" (stored) "energy into electrical energy or use as another energy carrier". Here, a discharging mode, injecting power into the power system, is not mandatory by definition.

As a major distinction within ESS the Expert Group has introduced two categories of ESS technologies alongside the PGM definitions of the ENC RfG (see Figure II.1):

- **Synchronous Electricity Storage Module:** Here, the energy conversion (i.e. charging or discharging) of the electrical energy would be through one or more synchronous machines connected to the electrical network with a single connection point to the system.
- **Non-Synchronous Electricity Storage Module:** Here, the energy conversion (i.e. charging or discharging) of that electrical energy would be through an asynchronous machine or through a power electronic converter connected to the electrical network with a single connection point to the system.

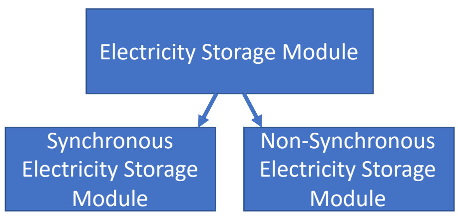

Figure II.1: Distinction of ESS technologies; Source: Illustration by FGH based on [6]

Accordingly, inverter-connected ESS are non-synchronous electricity storage modules.

In addition, the Expert Group gave a formal distinction to the connection topology of storage systems:

- **Standalone storage system:** A facility comprising solely of storage units which are controlled as one or more Electricity Storage Modules for their own.
- **A co-located storage system:** Here, the storage system and additional generation or demand/load is installed at a joint facility with a single point of connection to the power system.

For the co-located sites, the group has further distinguished two kinds of operation:

- **Independently Controlled/Operated Components:** Here, the operation of the storage device is independent from the operation of other parts of the facility (generation/demand). In that case, it is possible to have the storage device running when the other component(s) of the facility is (are) switched off.
- **Supplementary Components:** Here, the operation of the storage device is linked to the operation of the generating unit/demand unit. Hence, the storage system cannot be independently controlled.

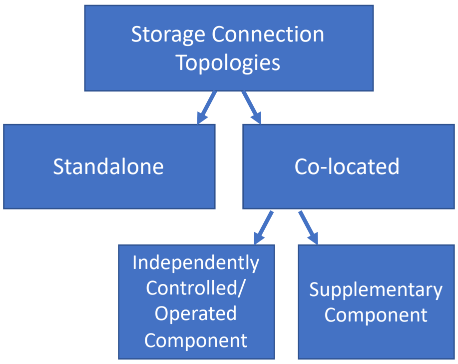

Figure II.2: Distinction of ESS connection topologies and modes of operation/control; Source: Illustration by FGH based on[6]

Figure II.2 summarizes these extended definitions. It is obvious, that the electrical characteristics to be requested by grid code provisions will depend both on the kind of storage system technologies and the kind of topology, i.e. operation. Especially for co-located systems requirements to the facility as a whole may be distributed to their best availability to generators and storages (and loads) and specific technological restrictions may have to be taken into account just like for mixed customer installations [11].

The GC ESC expert group's recommendations on respective grid code provisions will be taken up in the following section. Respective proposals on ESS requirements for the future revisions of the European Network Codes, mainly the ENC RfG and the ENC DCC, have been published with the final report of phase II [6].

III. Ancillary Services of Electric Storage Systems

Similar to PGMs, EES connected to the power grid also provide a full range of ancillary system services in order to support the power network e.g. in terms of frequency stability, voltage stability and FRT capabilities. In addition to power generating modules, further benefits result from the following characteristics of ESS:

- In most installations ESS provide a bi-directional power flow. Hence, active power control is not only restricted to the generation mode but can also be expanded to the consumption mode.
- Unlike renewable PGM, ESS are not depending on volatile primary energy sources, which enables the utilization of ancillary services by these technologies independently of the availability of such primary technologies – both in terms of local / geographical and temporal availability.
- Moreover, there is no underlying mechanical primary energy conversion like in wind energy converters or synchronous generators and, in general, also the electro-chemical conversion in most battery systems is more immediate than the MPP tracking in PV systems. Hence, the dynamics of an ESS can be quicker for the benefit of fast response services on power supply.

Based on these benefits, respective grid code provisions on ESS may be enhanced compared to those on PGMs aligned to the general requirements as shown in figure III.1.

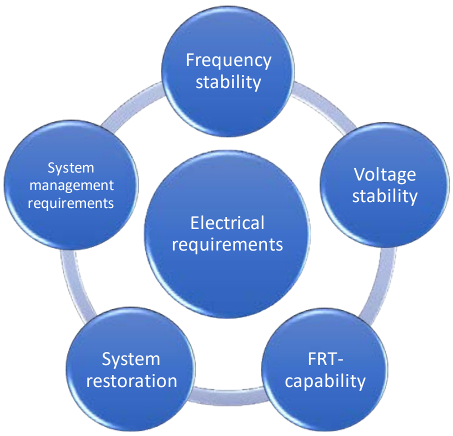

Figure III.1: Structure of grid code requirements; Source: FGH

It is obvious and had been pointed out by GC ESC expert group, that the assignment of these requirements to specific ESS installations will depend on the respective voltage level of grid connection as well as on the total installed capacity and may, hence, be clustered similarly to the type A-D definition within the ENC RfG. It was proposed by the expert group to set up a common revised framework for the type definition in a future ENC as the existing one is already subject to some concerns (see e.g. [2]).

A. Frequency stability

Active power control: In general, the controllable lower setting range of ESS is not limited by any technical minimal point of operation as for some PGM, but zero. Hence, ESS shall be fully controllable by the system operator in terms of their active power injection and consumption between zero and maximum power at least in terms of discrete steps both for charging and generation mode. In case of a participation of the storage system at the electricity balancing market rules of priority have to be established between the ability of participation on the one and respecting the active power reduction due to high network load on the other hand.

Frequency control: the general scheme of the limited frequency sensitive modes for over- and underfrequencies (LFSM-O and LFSM-U) as for PGMs can be extended for the charging mode of ESS. Here, power consumption needs to be reduced in case of underfrequencies and increased in case of overfrequencies. Moreover, the requirements on rise- and settling times for the power transition may be more stringent due to the fast response capabilities of ESS.

The GC ESC expert group gave a special recommendation to meet a requirement of the European Emergency and Restoration (E&R) Code, that ESS should be capable to switch from importing (charging) mode to exporting (generation) mode in case of falling frequencies with cycle times and setpoints to be defined by the TSO, or trip if not capable. Taking into account different storage technologies, the expert group elaborated a proposal for a droop characteristic in order to prevent sudden shocks on the power system by large scale shifting operations and/or tripping. Figure III.2 displays the respective characteristic, where the frequencies at points A, B and C as well as respective transition times need to be defined by the TSO with the ranges set out by the European E&R Code.

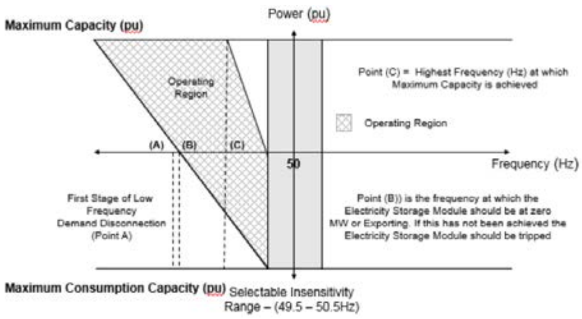

Figure III.2: Applicable power control for underfrequencies; Source: Final report, phase II [6]

As a further recommendation for charging-only electric vehicles (so-called V1G, though they are not ESS in the above definition) the expert group proposed to apply the lower part of the characteristics for $P < 0$ p.u. (meaning for active power consumption)

B. Voltage stability

Reactive power control: In addition to the general requirements on reactive power ranges, set-point control and Q- or cos φ-characteristics for PGMs when exporting active power into the power grid, respective requirements may be enhanced for ESS while charging in the import mode. This requirement appears to be particularly important when connecting electric vehicles in the low-voltage grid with partly high-power flows with regard to voltage stability.

C. FRT capability

UVRT and OVRT: In addition to the general requirements on PGMs' Fault-Ride-Through- (FRT-) capabilities to maintain in operation during power systems faults with gridside under- and overvoltages, ESS may be capable of this feature also in consumption mode. Moreover, inverter-interfaced storages shall actively contribute with a well-defined fast-fault-current and active power gradient to support the network voltage recovery.

D. System restoration

Reconnection after faults: Like PGMs, ESS shall take on the same provisions on reconnection in terms of voltage and frequency thresholds and active power gradients. In addition, the resumption of the charging mode may be suppressed by the system operator.

E. System management and protection requirements

System (voltage) perturbation / power quality: The requirements for the limitation of system disturbances including at least harmonic emissions, flicker and voltage fluctuation, switching frequency emissions and unbalanced currents shall be implemented for both, the charging as well as the discharging mode.

It has to be noted that power quality issues are not subject to the ENC RfG as they do not provide a cross border impact. However, the GC ESC expert group agreed that voltage quality is becoming more important especially when connecting a growing number of high power-low energy ESS like electric vehicles to the low voltage network.

Electrical protection schemes and setting: The provisions on the protection devices and their setting should at least meet the requirements as it is postulated for PGMs. This includes grid as well as machine protection.

Asymmetrical power: Asymmetrical variants (1- or 2-phase) of storage systems shall only be permitted to connect to the grid until a certain limit.

Maximum active power: When operating an ESS in parallel to a PGM (cf. also section III) the sum of total power injection must not exceed the maximum active power as agreed with respect to the grid connection. For this purpose, an energy flow management system with a control and detection of the energy flow direction (sensors) is recommended (e.g. current direction relay).

IV. STATUS QUO ON ONGOING GRID CODE DEFINITION FOR STORAGE SYSTEMS

A major outcome of the study survey [8] conducted by FGH for the European Commission was, that for time of the evaluation on national grid code implementations only a few countries had already embedded specific requirements on storage systems while some other had at least started the work on respective codes.

- **Belgium:** The formal, legislative framework for the definition of technical requirements for storage systems has been implemented in the federal technical grid code and published in 2019 [11]. In a second step the DSOs' network codes C10 and C11 will be revised.
- **Germany:** Grid code requirements for storage systems (ESS as well as electric vehicles V1G in charge-only mode) have been incorporated throughout the latest VDE Technical Connection Rules in 2018 [13], i.e. VDE-AR-N 4100 and VDE-AR-N 4105 for low voltage connection, VDE-AR-N 4110 for medium voltage connection and VDE-AR-N 4120/4130 for high/extra high voltage connection.
- **Great Britain:** the integration of grid code requirements on storage systems into the G99 grid code had been adopted by the NRA OFGEM and published in 2020 [14].
- **Italy:** Storage systems are subject to the existing grid codes CEI 0-21 for low voltage connection, CEI 0-16 for medium voltage connection and the TERNA grid code for transmission system connection [15], but only with respect to a unit-type-definition for inverter-coupled electrochemical devices on their DC-side. A further extension to a more general class of ESS according to the latest GC ESC expert group's recommendation is planned.

In fact, the status quo of grid code development on ESS has also been listed in the reports of the GC ESC Expert Group Storage [6]. Ongoing standardisation work has been reported from France, the Netherlands and Switzerland. Compared to the FGH survey of 2019 a slight progress can be reported [9].

While the research on the status quo of the implementations in the European member states was not very fruitful (yet), it must be emphasised here that the European Cenelec standards EN 50549-1 (for low voltage connection) [16] and EN 50549-2 (for medium voltage connection) [17] already provide extensive specifications for the grid connection of storage systems.

In general, the European standards do expand all requirements for power generating units also on ESS in both generation and charging mode. Only for the frequency sensitivity modes LFSM-O and LFSM-U further provisions are stipulated.

In case of LFSM-O for overfrequencies above a specific threshold, ESS in charging mode shall not decrease and should (if possible) increase their charging power according to the defined droop curve until frequency returns below a specific threshold. If maximum charging capacity is reached or to prevent risk of injury or equipment damage, a reduction of charging power is permitted.

Figure IV.1 depicts the respective requirement for LFSM-U which is equal for EN 50549-1 and EN 50549-2 with a programmable threshold frequency f_1 between 46 Hz and 49,8 Hz and a programmable droop s between 2% and 12%. It has to be noted that the European standards do not provide a more stringent, i.e. faster transition requirement for ESS on LFSM-U/O active power control whereas e.g. the German Technical Connection Rules for medium voltage connection and higher shortens the response time from 10s to 1s and the settling time from 30s to 10s. As well, here the active power gradient is enlarged from 40% P_{ref}/Hz to 100% P_{ref}/Hz.

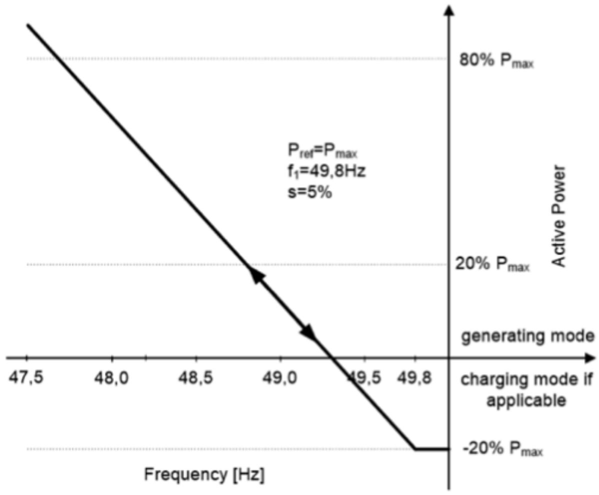

Figure IV.1: LSFM-U requirement for ESS; Source: EN 50549-1/-2 [16, 17]

Furthermore, it is noteworthy that the European standards introduce various additional requirements that are outside the scope of RfG NC for type A and (in parts) type B power generators. Some of these additional requirements are shifted down from Type C and D requirements to low and medium installations in general – like reactive power control and UVRT capabilities. Others, like OVRT, are introduced completely anew. For a detailed overview, see [8].

Hence, given the total of grid code requirements on ESS from the European standards, the first implementations in European national grid codes and the recommendation of the GC ESC expert group it can be concluded, that all of the features as listed in section III are tackled. As grid code development will further evolve, new features are already in sight, e.g. the utilization of grid forming converters, that will have also an impact on respective requirements on storage systems [18].

V. COMPLIANCE SCHEMES

Alongside the rather hesitant implementation of grid code requirements for storage systems in Europe, the definition of respective compliance schemes for these requirements is mostly missing. At least for the power injecting generation mode most countries request the same manners of conformity statements (e.g. measurements, simulations, certificates) as for PGMs. Here, coherent, high-level compliance schemes are missing anyways throughout Europe [2]. However, it is notable, that even in countries with a quite advanced formal certification scheme and more or less well-defined grid code requirements on the charging mode of storage systems like in Germany, respective compliance provision remain quite vague or less stringent (e.g. approval of manufacturer's declarations) or are equipped with generous transition periods.

As for the European standards EN 50549-1 and EN 50549-2 a respective testing guideline (CLC TS 50549-10, [19]) is in its final stage of preparation and shall be published in 2022. It will address the respective measurement routines for the grid codes requirements on ESS and therefor provide a useful measure for compliance.

Given the experiences with PGMs in the last 20 years, the authors highly recommend to introduce appropriate and conforming compliance measures as early and stringent as possible in order to turn grid code provisions on ESS effective to the power system support. Especially for the mass-market products of inverter-coupled ESS, that are most likely produced in a module base manner, a unit type certification based on type testing and comprising a validated model will provide a most cost-efficient conformity statement for further application on facility level [20].

VI. CONCLUSION

Electric storage systems (ESS), that are capable to be charged from the power network and to discharge electric energy back to the power network, will play a significant role in future power systems. Naturally, they can contribute a full range of ancillary system services to support the power network operation as well in stable operation as under fault conditions, which may even extend the capabilities of solely power generating modules. The paper demonstrates that ongoing grid code developments throughout Europe is taking on this challenge to define such grid code requirements for ESS. However, while European standards have already implemented a good view on ESS, national grid code implementations still need further progress. For the European Network Codes, to be revised in the near future, well elaborated proposals on the integration of ESS have been provided. In a second step, these requirements must be supplemented by respective compliant schemes.

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