Grid-Forming Capabilities: Towards System Level Integration

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About ENTSO-E

ENTSO-E, the European Network of Transmission System Operators for Electricity, is the pan-European association of 42 electricity transmission system operators (TSOs) in 35 countries. In 2009, ENTSO-E was registered in the EU legislation and has since then been given a series of legal mandates.

Introduction

In support of EU efforts to achieve carbon neutrality by 2050, ENTSO-E has recently released its vision on the system operation for 2030[1], supported by its Research, Development & Innovation (RDI) Roadmap. Both documents make the enhancement of system stability under the high penetration of non-synchronous renewables a high future priority.

As part of the energy transition, a complex cyber physical system[2] is emerging, and further innovation and development is required by ENTSO-E RDI Flagships to secure the stable operation of widespread hybrid AC-DC networks. Under such conditions, all market participants must take action to facilitate the stable transformation of the power system. As an integral part of the ENTSO-E RDI Roadmap (Flagship 5), and with the aim of meeting the system's needs for 2050, this paper highlights one of the action lines to follow to facilitate the stable operation of interconnected transmission systems with a high penetration of non-synchronous power electronic interfaced power generating modules.

1 Available at: https://vision2030.entsoe.eu/

2 See ENTSO-E, The Cyber Physical System for the Energy Transition, 2019.

Grid-forming capabilities to meet future system needs

Power system stability challenges have been identified under scenarios with the high penetration of non-synchronous renewable generation, as reported in the Migrate project [1], as well as in [13–18]. These stability issues are categorised by frequency, voltage, rotor angle, converter driven and resonance stability [2]. Recent studies [3–6] have presented "perspectives" and approaches to operating transmission systems with an extremely high penetration of non-synchronous power generation modules (converter based). Such projects have concluded that a stable and robust operation of interconnected transmission systems can be ensured under the high penetration of non-synchronous power generation modules if a certain number of capabilities are ensured during system operation. These capabilities can be provided either by synchronous or non-synchronous power generation modules [7]. In [3], seven capabilities are introduced, which are termed as grid-forming if fulfilled in their entirety.

A coordinated effort among European stakeholders to define such grid-forming capabilities for converter based facilities is initiated in [3]. It has been identified in this work that a new or extended class definition of power park modules (PPMs) and high voltage direct current (HVDC) converter stations is required to ensure stable operation with the high penetration of non-synchronous generation. More specifically, this class definition offers a set of grid-forming capabilities defined as follows:

- **Creating (forming) system voltage.**
- **Contributing to fault level (short circuit power).**
- **Contributing to total system inertia (limited by energy storage capacity and the available power rating of the PPM or HVDC converter station).**
- **Supporting system survival to enable the effective operation of low frequency demand disconnection for rare system splits.**
- **Acting as a sink to counter harmonics and inter-harmonics in system voltage.**
- **Acting as a sink to counter any unbalance in system voltage.**
- **Preventing adverse control system interactions.**

Technologies for providing the set of grid-forming capabilities in the future could potentially include new modular multi level converters (MMC)-HVDC systems, flexible alternating current transmission system (FACTS), PPMs and battery storage units. Most of these capabilities are already provided by synchronous condensers (SCs). It should be noted that all these technologies could contribute together to ensure the required grid-forming capabilities. An example of a cost–benefit analysis comparing the use of SCs versus the use of PPMs for offering grid-forming capabilities is in the context of the Migrate project [8]. The result of this cost–benefit analysis reflects the fact that the overall actualized cost over 20 years is within the same order of magnitude.

Facilitating the system-level integration of grid-forming capabilities

Grid-forming capabilities need to be defined in connection network codes (CNCs) to enable harmonised solutions

CNCs [9] are the regulatory platform at European level which define the necessary technical capabilities of power generating modules, distribution systems connected to transmission systems, demand facilities, and HVDC systems during normal and disturbed system operating conditions, including the separate operation of the main synchronous power system. CNCs accommodate a system supportive performance of grid users with the purpose of ensuring system security, especially during exceptional and out-of-range contingencies.

The set of grid-forming capabilities must be described in the CNCs (limited to the current and power ratings of the power park modules and HVDC converter stations) to facilitate the aligned requirements' availability throughout European member states, preferably as mandatory non-exhaustive requirements in the CNCs to start and accelerate the process of grid-forming implementation. Further specifications in national implementations of the CNC requirements may depend on the location and urgency in each member state [10].

Developing sufficient conditions for grid-forming capabilities via national level ancillary services

The Clean Energy Package [11] defines the so-called non-frequency ancillary services within its articles 2, 31 and 40. Although the definition by law includes functionalities such as steady state voltage control, fast reactive current injection, inertia for local grid stability, short-circuit current, black start capability and island operation capability, the provision of grid-forming capabilities would contribute to all of them [3]. Moreover, the regulatory authority of each member state has to decide whether a market-based procurement is considered economical beneficial or not, with the right to suspend such a market on the national level.

With the aim to harmonise requirements for grid-forming capabilities and not leave them to the national prequalification procedures (depending on national definition) under the different viewpoints of national regulatory authorities, well defined grid-forming capabilities in the CNCs may be still the better approach to enable manufacturers to devise harmonised implementations that serve the needs and demands across Europe.

At the same time, however, the decision whether a market is implemented or not, as well as market organisation, is still left to the national regulatory authority. A good example of such a procedure is the requirements for primary control (also called Frequency Sensitive Mode in CNCs). Although the procurement of primary reserve (known as frequency containment reserve [FCR]) is achieved through reserve markets, and the prequalification is even handed over to individual transmission system operators (TSOs), the basic requirements for generators can be found in the relevant CNCs, which are harmonised throughout Europe. The latter also guarantees the availability of the functionalities associated to primary control in the system, even if market mechanisms may malfunction in critical situations, providing a higher level of system security, especially during large disturbances. The same approach can be followed for functionalities associated with the grid-forming capabilities which ensure the containment of large system disturbances (system split) and the provision of novel system services (voltage and frequency control) from synchronous and/or non-synchronous generation units.

HVDC, FACTs and SCs are the immediate candidates to explore the development of the grid-forming capabilities

Following the CNC developments and harmonised requirements, TSOs could initiate the development of grid-forming capabilities by specifying their new assets, such as HVDC systems, FACTs and SCs. There is, naturally, a cost and regulatory dimension to this aspect which will trigger further interactions with the regulators at a national level. In France, for example, such initial discussions are underway and the regulator understands and acknowledges this need. Cost – benefit analysis is key here (depending on the capability requested, costs could be higher or lower).

Storage and sector coupling facilities should be further explored in order to unlock their full potential of providing grid-forming capabilities

Storage facilities could play an important role in delivering grid-forming capabilities in the future. The maturity of the technology is high, and battery storage facilities could already today offer grid-forming capabilities [12]. To support the TSOs in their responsibility to ensure system-wide frequency stability, the utilisation of distribution system operator (DSO) connected storage facilities could be a promising option to explore. Unlocking the full potential could be achieved via well-defined TSO–DSO interfaces, roles and responsibilities. In some countries, grid-forming capabilities have already been demonstrated through projects supported by the regulator. Sector coupling could also provide such grid-forming capabilities, depending on the total installed capacity per country. Finally, hybrid power plants is a future option worth exploring.

Abbreviations

Acronym	Meaning
AC	Alternating Current
CNCs	Connection Network Codes
DC	Direct Current
DSO	Distribution System Operator
ENTSO-E	European Network of Transmission System Operators for Electricity
FACTs	Flexible Alternating Current Transmission System
FCR	Frequency Containment Reserves
HVDC	High-Voltage Direct Current
MMCs	Modular Multi Level Converters
PPMs	Power Park Modules
RDI	Research & Development & Innovation
SCs	Synchronous Condensers
TSO	Transmission System Operator

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