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Grid-forming inverters in converter-dominated power systems: control strategies, deployments, and barriers in the ENTSO-E context

Abstract: The ongoing transformation of electric power systems toward converter-dominated power systems poses major challenges for system stability, inertia provision, and voltage control. This review paper examines the role of grid-forming inverters in converter-dominated power systems, analyzing their control strategies, deployment experiences, and implementation barriers in the ENTSO-E context.

Three main control approaches – Droop-based control, Virtual Synchronous Machine (VSM), and Virtual Oscillator Control (VOC) – are analyzed in terms of operational principles, advantages and limitations. The paper synthesizes findings from recent literature, regulatory documents, and real-world implementations in the United Kingdom, Germany, and Australia. By identifying both the technical feasibility and regulatory challenges of grid-forming inverters adoption, the review contributes to the ongoing discussion on stability provision and market design for low-inertia systems.

This paper contributes to the literature by providing a systematic and policy-oriented review of grid-forming inverter control strategies and deployments, with emphasis on barriers and enablers for their adoption within the ENTSO-E framework. It integrates recent findings from both academic and industry sources (2017–2025) to bridge the gap between control theory and regulatory implementation.

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Introduction

The ongoing transformation of electric power systems is characterized by a rapid shift from conventional, synchronous generation-primarily driven by fossil fuels to inverter-based resources (IBR), such as PV installations, wind farms, and battery energy storage systems (IEA 2024). In last years, the amount of inverter-based resources connected to power systems around the world has grown exponentially, and this growth is expected to continue (ESIG 2024). While the decarbonization of energy system has accelerated IBR deployment, it also introduces challenges related to system stability, inertia, and power system operation (Borsche et al. 2014).

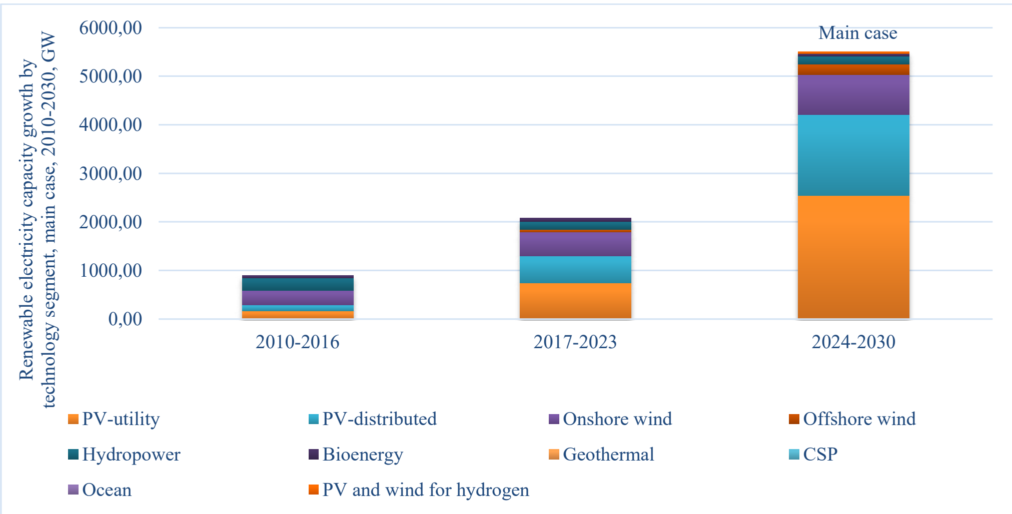

Fig. 1. Renewable electricity capacity growth by technology segment, main case, 2010–2030 (IEA 2024)

Rys. 1. Wzrost mocy zainstalowanej w sektorze energii odnawialnej w podziale na segmenty technologiczne, scenariusz bazowy, lata 2010–2030

Traditionally, synchronous generators provided inherent mechanical inertia and reactive power support, thereby contributing to both frequency and voltage stability (Kundur 2018) (Denholm et al. 2020). In contrast, IBR, by their power electronic nature, lack intrinsic inertia and must rely on control-based emulation to replicate these stabilizing functions. Artificial inertia can only be provided when an additional energy source capable of emulating the kinetic energy stored in the rotor of a synchronous machine is available. Therefore, energy storage systems should be considered as primary sources enabling artificial inertia in inverter-based resources. As a result, the literature highlights that high penetration of IBR result in a decrease of relative inertia (Lining et al. 2020). Likewise, the level of reactive power control capability in areas with high load and high reactive power demand is reduced due to limitations of reactive power transfer over long distances (Agora Energiewende 2024).

Furthermore, traditional ancillary service markets designed around synchronous generator characteristics often fail to fully compensate IBR for providing fast frequency response and black-start capabilities. Consequently, new techno-economic mechanisms are required to ensure adequate compensation and incentivize IBR to offer grid-supporting services (Lal et al. 2021; Oureilidis et al. 2020).

Notably, these technical and market challenges are intertwined: inadequate markets for inertia and fast-frequency response limit investment in grid-forming inverter technologies, which in turn exacerbates operational limitations (Badesa et al. 2017; Paturet et al. 2020).

To summarize, the growing penetration of IBRs reshapes the stability landscape of power systems. The lack of physical inertia, the increasing complexity of voltage regulation, and the need to coordinate large numbers of distributed units challenge traditional energy systems. Grid-forming inverters (GFMs) have emerged as a key enabling technology, capable of emulating synchronous machine behavior and supporting system strength in low-inertia systems. Different control strategies such as Droop-based grid-forming, Virtual Synchronous Machines (VSM), and Virtual Oscillator Control (VOC) offer complementary advantages but also come with distinct limitations. Deployments in the United Kingdom, Germany, and Australia demonstrate that GFMs are already providing services such as synthetic inertia, black-start capability, and local grid restoration. These cases show both the technical feasibility and the systemic value of GFMs in maintaining the stability of the power system.

However, regulatory, technical, and market barriers remain significant within ENTSO-E countries. The article focuses on the following research question: what are the characteristics and limitations of the main GFM control strategies, how has this technology been implemented in practice, and what barriers need to be overcome for its wider adoption in ENTSO-E countries?

1. Methodology

This study applies a qualitative analytical approach to examine the role of grid-forming inverters in converter-dominated power systems. The research procedure consisted of three steps: (1) identification and characterization of the main grid-forming control strategies discussed in the literature, (2) analysis of selected real-world deployments in the United Kingdom, Germany, and Australia, and (3) assessment of regulatory and market barriers to wider adoption of grid-forming technologies within the ENTSO-E framework. The collected information was analyzed comparatively to identify key operational characteristics, implementation experiences, and systemic challenges associated with grid-forming inverter deployment. The review was preceded by a literature search in scientific publications (IEEE, IET, Journal of Modern Power Systems and Clean Energy), technical reports (NREL, ESIG, ENTSO-E), industry data (Modern Power Systems, PV-Magazine), and regulatory documents published between 2017 and 2025. The primary keywords included "grid-forming inverter", "virtual synchronous machine", "droop control", "virtual oscillator control", and "synthetic inertia". The Web of Science and Google Scholar databases, as well as reports from system operators and government agencies, were searched. Sources containing quantitative data on services provided by GFM or describing real projects were included. Works that did not refer to converters with their own frequency regulation (e.g., exclusively grid-following) and popular science articles without data references were excluded. Data from selected publications were synthesized thematically and assigned to the following categories: control strategies, case studies, barriers, and recommendations.

2. Review of grid-forming inverters control strategies

Grid-forming inverters are converters capable of independently setting voltage and frequency in the system regardless of external grid signals. The key difference between grid forming (GFM) and grid following (GFL) inverters arises from the applied control strategy, not the hardware design of the device. The control algorithms determine the method of synchronization with

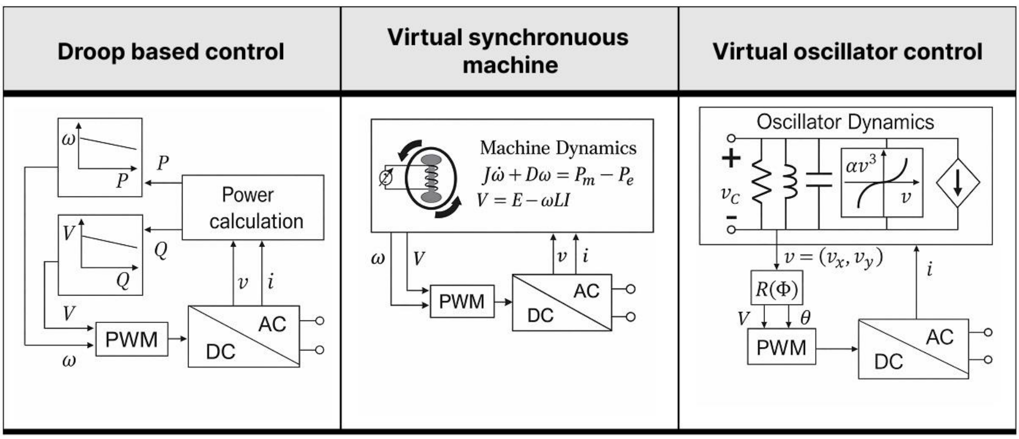

Fig. 2. Grid-forming inverter control models (Goldberg 2023)

Rys. 2. Modele sterowania falownikami tworzącymi sieć the power system as well as their dynamic characteristics. Unlike conventional grid-following (GFL) inverters, which require an external voltage reference, GFMs can act as active "shaping" elements of the system, resembling the behavior of synchronous generators. A key characteristic of GFMs is the control strategy model. This section reviews three of the most widely analyzed models: Droop-based grid-forming, Virtual Synchronous Machine (VSM), and Virtual Oscillator Control (VOC).

The droop-based control approach is based on the analogy with classical frequency and voltage regulation in synchronous generators. In this method, the inverter internal angular frequency and voltage magnitude are adjusted according to laws that link active power to frequency and reactive power to voltage. This can be expressed as (Geurrero et al. 2011):

$$\omega = \omega^{*} - k_P\left(P - P^{*}\right) \tag{1}$$

$$V = V^{*} - k_Q\left(Q - Q^{*}\right) \tag{2}$$

where:

ω^*, V^* – reference values,
k_P, k_Q – droop coefficients,
P, Q – measured active and reactive power.

The droop controller set the inverter internal voltage magnitude and frequency, ensuring synchronization and preventing circulating reactive power in multi-inverter systems (Du et al. 2021).

Droop control has been applied in decentralized power systems, particularly in microgrids. In the context of grid-forming operation, it serves as a primary control strategy that does not require communication links between units or a central reference signal. In this approach, there is a linear trade-off between the frequency and real power in addition to the voltage and reactive power. It is inspired by the steady-state operation of a synchronous machine. The droop characteristics are expressed as *P-f* and *Q-V* relationships. Therefore, each distributed generation unit will have identical frequency, and it will supply power according to its capacity, namely-droop gain. Such a decentralized method allows grid-forming inverters to balance supply and demand while sharing power among multiple units operating in parallel (Salem et al. 2023). This enables stable synchronization without the need for fast communication infrastructure. Droop control is therefore widely implemented in both microgrids and hybrid systems with grid-forming inverters. Droop control remains the most widely used GFM technology for decentralized power-sharing in microgrids and is among the most commonly adopted strategies in practical applications (Arevalo et al. 2025). Although classical droop control does not reproduce the synchronous machine swing dynamics, it remains a widely used, decentralized model. By contrast, VSM implements the swing equation with explicit inertia. Dynamic extensions of droop, such as iDroop, can improve transient performance such as noise rejection, synchronization speed, and nadir reduction without altering steady-state power sharing. However, standard droop-controlled inverters do not provide physical inertia, and thus their inertial behavior is limited compared with VSM approaches (Bahrani et al. 2024; Du et al. 2021; Jiang et al. 2021; Zhang et al. 2021).

To summarize, droop control provides a simple and robust mechanism for decentralized power sharing, but limited dynamic capabilities motivate ongoing research.

The Virtual Synchronous Machine (VSM) model replicates the dynamics of a conventional synchronous generator by embedding its physical model into the control algorithm of the inverter. This enables the inverter to produce an output voltage with dynamic characteristics similar to those generated by the rotor of a synchronous machine. Central to this approach is the reproduction of the swing equation and the associated inertia and damping terms.

According to VSM theory, the SM's dynamic characteristics are mimicked by the VSM algorithm. Power-frequency features of transitional SGs are expressed by the swing equation:

$$J\frac{d^2\theta_m(t)}{d_t^2} = \frac{d^2\delta_m(t)}{d_t^2} = T_m(t) - T_e(t) = T_a(t) \tag{3}$$

The concept of a Virtual Synchronous Machine (VSM) is based on replicating the dynamic behavior of a conventional synchronous generator. As outlined in the literature (Abuagreb et al. 2022), the active power output can be expressed as the product of mechanical torque and angular velocity. The power output is described by multiplying the mechanical torque and the angular velocity. Due to the mathematical properties of angular speed ω, and rotor angle position θsg, the power and frequency relationship of the system with the VSM unit may be stated as shown in Equation (2):

$$\delta\theta_s(t)\cdot\frac{d}{dt} = \omega - \omega_0 = \delta\omega \tag{4}$$

$$P_{out} - P_{in} = \delta P_{VSM} = K_i\frac{d}{dt}\Delta\omega + K_p\Delta\omega \tag{5}$$

where:

ω_0 – grid's nominal frequency,

P_{out} – power output,

P_{in} – transmitted power to the converter,

K_p – damping/droop factor.

Power generation or absorption by VSM (P_{VSM}) is determined by the initial frequency change $\left(\frac{d}{dt}\Delta\omega\right)$, as shown on the right-hand side of Equation (3). K_i represents the virtual inertia characteristic (Abuagreb et al. 2022).

Research shows that full implementation of a synchronous generator's dynamic model in VSM control algorithms in highly complex; therefore, simplifications are typically applied to enable practical implementation in inverters. Virtual Synchronous Machine strategies (for example, current source of voltage source implementation) and desired complexity in simulating the precise behaviors of a synchronous machine may be chosen, allowing the device to dynamically adjusts its response to changing grid conditions. This approach enhances oscillation damping capability and ensures more stable integration of VSMs (Jafari et al. 2024).

Virtual Oscillator Control (VOC) is a decentralized grid-forming strategy in which inverters establish terminal voltage and frequency by emulating the dynamics of weakly nonlinear oscillators, rather than reproducing the synchronous machine swing equation or using steady-state droop laws. This time domain formulation allows interconnected inverters to converge to synchronized sinusoidal operation without requiring communication links between units (Sinha et al. 2016).

Compared to classical droop control, which is fundamentally defined around sinusoidal steady state and relies on filtered phasor quantities, VOC acts directly on instantaneous measurements. As a result, analyses and experiments show markedly faster and better-damped transient behavior for VOC while maintaining compatible steady-state characteristics. In particular, comparative studies report improved dynamic response and accurate power sharing under oscillator-based control, and they clarify that droop-like relations are embedded in the equilibria of the oscillator dynamics (i.e., droop can be recovered as the steady-state limit of VOC) (Awal et al. 2020; Johnson et al. 2017; Sinha et al. 2016).

From an implementation perspective, oscillator-based control avoids reliance on filtered phasor signals. Instead, it directly regulates terminal voltages in the time domain. In practice, this enables rapid synchronization and coordinated power sharing among parallel units (Awal et al. 2020).

VOC is now recognized alongside droop based and VSM approaches as one of the principal families of grid-forming controls reviewed in the recent literature, with multiple studies documenting its synchronization properties and suitability for converter-dominated microgrids (Teng et al. 2022).

The following table summarizes an overview of grid-forming inverter control models, highlighting their main principles of operation, advantages, and limitations mentioned before.

Table 1. Overview of grid-forming inverter control models

Tabela 1. Przegląd modeli sterowania falownikami tworzącymi sieć

	Principle of operation	Advantages	Limitations
Droop-based grid forming	adjusts frequency (P-f) and voltage (Q-V) proportionally to power deviations;	simple, robust, and decentralized; enables power sharing without communication;	lacks physical inertia; limited dynamic performance compared to VSM; requires extensions (e.g., iDroop);
Virtual Synchronous Machine (VSM)	replicates synchronous generator dynamics via swing equation; includes virtual inertia and damping;	provides synthetic inertia mimics physical generator behavior; improves stability under high converter penetration;	highly complex for full implementation; simplifications often needed;
Virtual Oscillator Control (VOC)	emulates nonlinear oscillator dynamics; synchronization emerges in the time domain;	fast transient response; accurate power sharing; inherently decentralized avoids phasor-based filtering;	still under research; less mature for commercial deployment; implementation complexity in oscillator design.

Source: own elaboration.

3. Analysis of selected grid-forming inverter deployments

The application of grid-forming inverters (GFMs) is moving beyond laboratory testing and pilot demonstrations and entering real-world deployment in power systems, especially in areas with a high share of renewable energy. The main role of GFMs is to substitute services traditionally provided by synchronous machines such as inertia, oscillation damping, black-start capability, and reactive power support. This chapter reviews selected deployments in the United Kingdom, Germany, and Australia, representing three approaches: market-based integration, research pilots, and commercial-scale implementation.

The GB transmission system operator – NESO – created the Stability Pathfinder program to secure stability as transmission-connected synchronous generation declines, targeting cost-effective, lower-carbon solutions (NESO 2026). Phase 1 in this project delivered 12 synchronous compensators providing contracted inertia, marking the initial build-out of non-energy stability assets. In Phase 2 (which was limited to Scotland), NESO moved to procure both synchronous condensers and grid-forming batteries, with targets for short-circuit level (SCL) and inertia. In March 2025, NESO confirmed five grid-forming batteries and five synchronous condensers contracted under Phase 2, and announced Great Britain's first grid-forming battery connection

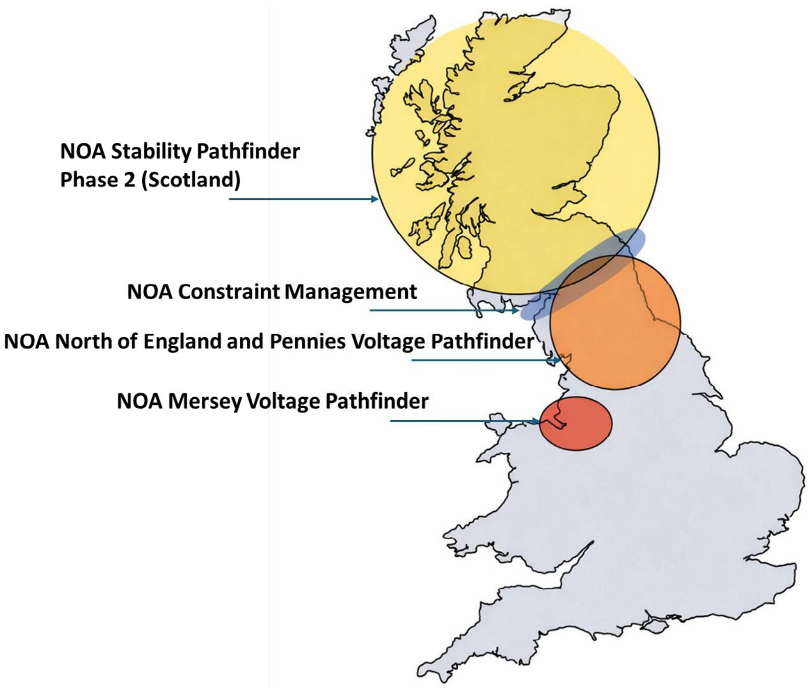

Fig. 3. NESO is running three Pathfinders projects, each designed to solve specific problems in the system (Maisch 2023)

Rys. 3. NESO realizuje trzy projekty w ramach programu Pathfinders, z których każdy ma na celu rozwiązanie konkretnych problemów występujących w systemie

(NESO 2025). These steps show a transition from machine-only stability (Phase 1) to a mixed portfolio where grid-forming BESS are explicitly contracted to contribute to short-circuit-level and inertia alongside rotating stabilizers as an operational pathway rather than a lab pilot.

In Germany, GFM activity is presently on field demonstrations rather than market procurement. The C/sells program (2017–2020) explored decentralized renewables and storage operating with grid-forming control in regional/microgrid contexts, including islanding and local restoration functions (Zeiselmair et al. 2020). More recently, Fraunhofer ISE's SUREVIVE project has begun real-grid tests of grid-forming inverters at distribution level, including a ~20 MW/55 MWh battery connected at a transformer station, with staged lab and field validation to assess interaction, stability, and interoperability and to produce best-practice guidance for DSO (Fraunhofer 2025). Germany's pathway emphasizes standards, interoperability, and operational know-how in distribution grids, positioning GFM as a future building block while avoiding premature large-scale procurement.

Australia has moved early to operational GFM at utility scale. The Hornsdale Power Reserve (HPR) expansion implemented Tesla's Virtual Machine Mode (VMM), enabling grid-forming behavior for services that include synthetic inertia and a virtual synchronous response.

The ARENA technical summary released by Neoen indicates that VMM has been validated for full-scale implementation following modeling and pilot trials. The approach enables HPR to emulate the dynamic response of synchronous machines, effectively reproducing grid inertia behavior. (Hicks and Green 2022). According to Neoen's final project report, after the expansion, HPR could provide up to 3,000 MWs of inertia, an amount equivalent to maintaining grid stability during significant disturbances in South Australia (Tulip and Hicks 2024). Independent analysis from Electrek highlighted that Tesla's VMM implementation at HPR acted as a world-first delivery of grid-scale inertia through battery storage. Hornsdale Power Reserve's VMM enabled it to deliver a substantial portion of the state's inertia requirements, previously met by coal and gas generators (Peacock 2022). This Australian deployment illustrate how grid-forming inverters are used in full-scale operation in interconnected power systems, providing services traditionally supplied by synchronous machines while advancing frameworks for inverter integration.

The presented cases reveal differences in the motivation and scale of implementations. The United Kingdom and Australia have introduced stability market products and contracts that provide predictable revenues for inertia, which has accelerated the adoption of GFM. Germany, on the other hand, focuses on research and interoperability testing without yet creating a market. A common conclusion is that GFM technology is technically viable however, regulatory and economic frameworks are needed to enable scaling.

4. Barriers to grid-forming inverter deployment in ENTSO-E countries

As mentioned above, GFMs are increasingly recognized as a critical technology for stabilizing converter-dominated power systems. However, their broader deployment in ENTSO-E countries faces a combination of market, regulatory, and technical barriers. While few pilot projects demonstrate their technical potential, some challenges remain that limit their integration into mainstream system operation.

One of the barriers is the absence of a harmonized market framework for inertia-like services. While frequency containment and restoration reserves are procured across Europe, no harmonized scheme exists that compensates synthetic inertia from inverter-based resources. At present, synthetic inertia is not remunerated as a standalone ancillary service in most ENTSO-E jurisdictions. Industry stakeholders emphasize that grid operators have not yet defined transparent mechanisms to quantify and contract GFM capabilities. As noted in (SolarPower 2023), implementation details are often left to national processes or non-public guidance documents, creating uncertainty for investors. This lack of explicit remuneration reduces the economic attractiveness of GFM investments. According to (Boyle 2025) "there is not yet a market for this in Europe," for synthetic inertia, meaning there is little incentive for asset owners to deploy more expensive GFM-enabled devices compared to standard inverters. A similar concern is highlighted in (Shah 2025), which stresses that although synthetic inertia benefits the system as a whole, its lack of a revenue stream discourages private sector investment. This stands in contrast to Australia, where system operators have explicitly contracted synthetic inertia services (e.g., Hornsdale Power Reserve). In Europe, however, the lack of a dedicated product discourages investment in GFM technology, since revenue streams remain uncertain.

A second barrier concerns fragmented and incomplete regulatory frameworks. The current Network Code on Requirements for Generators (NC RfG) specifies functional capabilities such as fault-ride-through, black-start, and reactive power regulation for type B, C, and D units. However, it does not explicitly define grid-forming control modes or establish a certification profile for GFMs. The issue has been flagged in multiple recent reviews. The ENTSO-E interim technical report on grid-forming capabilities notes that requirements for synthetic inertia contributions are left to Transmission System Operators (TSOs) to specify, rather than being standardized at the European level (ENTSO-E 2024). This creates fragmentation, as national operators interpret and apply requirements differently.

A third barrier is the absence of standardized testing and certification protocols, which is a critical limitation. Without consensus on how to validate GFM performance, especially in real-world or lab-to-field scenarios, equipment cannot be uniformly certified or trusted for critical stability functions. The 2024 NREL study on grid-forming inverters states: “There is a lack of standard testing protocol for GFM inverters” (Wang and Ganguly 2024). This shows that testing frameworks remain undeveloped, making it difficult to assess performance across suppliers. Moreover, earlier NREL work presents a testing framework designed to evaluate GFM resources’ voltage-source behavior and guide specification development, a step toward formal alignment (Shah et al. 2023). In initiatives such as the Energy System Integration Group provides provisional recommendations for laboratory and simulation testing, these remain advisory only and aren’t part of an official standard (High Share of Inverter-Based Generation Task Force 2022).

Forth barrier is the lack of clear responsibility for defining system needs and certifying GFM services. Regulators and TSOs are often slow to set explicit requirements for inertia thresholds, transparent procurement rules, or sandbox mechanisms for pilot deployments. This institutional uncertainty compounds technical and economic barriers, slowing the pace of GFMs’ adoption across ENTSO-E countries.

5. Recommendations

Based on the identified barriers, several recommendations have been proposed below, whose implementation could accelerate the wider deployment of grid-forming inverters (GFMs) in ENTSO-E countries. They focus on market design, regulatory harmonization, and technical standards:

1. A dedicated ancillary service for inertia should be introduced, allowing both synchronous compensators and GFMs resources to compete on equal terms. Inspired by the UK's Stability Pathfinder and Australia's AEMO procurement schemes, Europe could design multi-year contracts for inertia and short-circuit strength services, ensuring stable revenue streams for investors.

2. The NC RfG should be extended to explicitly include grid-forming capabilities. A European-level certification profile would define requirements for services such as inertia emulation and oscillation damping, validated through EMT/RMS models and dynamic performance tests. This would remove current ambiguities and provide manufacturers with a clear compliance pathway.

3. Standardized procedures for laboratory and field testing are essential. Work by NREL and ESIG offers a basis for developing harmonized test protocols that cover multi-inverter scenarios and high-IBR conditions. Adopting these as binding standards would ensure comparability of GFM performance across vendors and accelerate certification.

4. TSOs and national regulators should take a proactive role in defining minimum system inertia requirements, designing transparent procurement rules, and creating regulatory sandboxes for GFM pilots. Experiences from AEMO in Australia demonstrate that such institutional involvement can create investment certainty and accelerate learning processes. For example, Australia provides a useful example: the Australian Energy Market Operator (AEMO) published a detailed methodology for inertia requirements and stability services procurement, explicitly including GFM batteries as eligible providers. A similar model could be adopted in Europe, with ENTSO-E coordinating common frameworks and national regulators enabling pilot-based learning processes.

Together, implementing these recommendations can foster the transition from pilot projects to systematic deployment of GFM technology. Implementing them requires coordinated action between TSOs, regulators, and market stakeholders. This cooperation is necessary to establish economic signals, harmonized technical requirements, and certification pathways.

Summary

Grid-forming inverters are emerging as an important technology for stabilizing future power systems dominated by inverter-based resources. They enable the provision of synthetic inertia and voltage regulation functions traditionally delivered by synchronous machines. A review of control strategies, deployment cases, and regulatory barriers highlights both the technical feasibility and systemic value of GFMs. At the same time, it reveals persistent challenges, such as the lack of market mechanisms for inertia, the absence of harmonized certification frameworks, and the shortage of standardized testing protocols. Addressing these gaps through technology-neutral markets, unified regulation, and common test standards will be key to unlocking GFMs' full potential in Europe's energy transition.

The Author has no conflicts of interest to declare.

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Krzysztof Szetela

Falowniki tworzące sieć w systemach elektroenergetycznych zdominowanych przez konwertery: strategie sterowania, wdrożenia i bariery w kontekście ENTSO-E

Streszczenie

Trwająca transformacja systemów elektroenergetycznych w kierunku systemów zdominowanych przez przetworniki stanowi poważne wyzwanie dla stabilności systemu, zapewnienia bezwładności oraz regulacji napięcia.

W niniejszym artykule przeglądowym zbadano rolę falowników kształtujących sieć w systemach elektroenergetycznych zdominowanych przez przetworniki, analizując strategie ich sterowania, doświadczenia związane z wdrażaniem oraz bariery wdrożeniowe w kontekście ENTSO-E.

Przeanalizowano trzy główne podejścia do sterowania – sterowanie oparte na charakterystyce opadania napięcia (Droop), wirtualną maszynę synchroniczną (VSM) oraz sterowanie wirtualnym oscylatorem (VOC) – pod kątem zasad działania, zalet i ograniczeń. W artykule zsyntetyzowano wyniki badań z najnowszej literatury, dokumentów regulacyjnych oraz rzeczywistych wdrożeń w Wielkiej Brytanii, Niemczech i Australii. Poprzez zidentyfikowanie zarówno technicznej wykonalności, jak i wyzwań regulacyjnych związanych z wdrożeniem falowników kształtujących sieć, niniejszy przegląd wnosi wkład do toczącej się dyskusji na temat zapewniania stabilności oraz projektowania rynku dla systemów o niskiej bezwładności.

Niniejszy artykuł wnosi wkład do literatury przedmiotu, przedstawiając systematyczny i zorientowany na politykę przegląd strategii sterowania falownikami kształtującymi sieć oraz ich wdrożeń, z naciskiem na bariery i czynniki sprzyjające ich wdrożeniu w ramach ENTSO-E. Artykuł integruje najnowsze wyniki badań pochodzące zarówno ze źródeł akademickich, jak i branżowych (2017–2025), aby wypełnić lukę między teorią sterowania a wdrożeniami regulacyjnymi.

Słowa kluczowe: falownik tworzący sieć, regulacja spadku napięcia, wirtualna maszyna synchroniczna, sterowanie wirtualnym oscylatorem, ENTSO-E