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Power System Capability Services:

STABILITY NEEDS MORE THAN CAPACITY

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Glossary of Acronyms

ACER – Agency for the Cooperation of Energy Regulators

AEMO – Australian Energy Market Operator

CAISO – California Independent System Operator

DER – Distributed Energy Resource

DS3 – Delivering a Secure, Sustainable System

(Ireland program)

ECF – European Climate Foundation

ENTSO-E – European Network of Transmission System

Operators for Electricity

FFR – Fast Frequency Response

PPA – Power Purchase Agreement

RoCoF – Rate of Change of Frequency

STATCOM – Static Synchronous Compensator

SVC – Static Var Compensator

TSO – Transmission System Operator

VRE – Variable Renewable Energy

Note on Terminology

In this paper, the term capability markets is used as a broad shorthand for structured market-based or quasi-market procurement mechanisms designed to secure specific power system operational services (such as inertia, fast frequency response, voltage support, and system strength). We recognize that in practice, most jurisdictions have not established formal, standalone markets labeled as “capability markets.” Instead, they have introduced targeted tenders, enhanced ancillary service markets, or bespoke contracts that reflect these system needs. Our use of the term aims to describe the principle of valuing and procuring these capabilities, regardless of the exact regulatory or market construct.

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EXECUTIVE SUMMARY

To secure reliability in an increasingly dynamic grid, electricity markets must evolve to procure not only energy and capacity, but also the crucial physical capabilities that keep the system stable.

Recent large-scale power system disturbances affecting millions of households across multiple countries have sparked renewed commentary about inertia and black start capabilities. Among the many important lessons from such events, one of the most significant may be under-emphasised: in simple terms, we need to rethink power system stability services and how we assign value to them.

Worldwide, electricity markets are being reshaped by the rapid expansion of renewable energy, increasing decentralization, and emerging digital technologies. These developments disrupt long-standing assumptions about power system reliability. Historically, electricity markets rewarded energy output and firm capacity, underpinned by synchronous generation that inherently provided critical stability services. That model is now out of date.

Resources such as (variable) solar, wind, and (interim) battery storage do not inherently deliver the physical services once embedded in traditional generation — frequency stability, inertia, reactive power, voltage control, system balancing, and fault ride-through (the ability of a power plant to stay connected during short disturbances). Without intentional market mechanisms to procure these capabilities, power systems face heightened operational risks. In other words, power systems are systems: merely continuing to optimise individual assets without a system approach is obviously an inadequate policy.

This white paper presents a rationale for evolving electricity market designs — in the European Union, and elsewhere in the world — to reflect these realities. It defines the concept of ‘capability markets’, reviews historical and emerging procurement mechanisms, analyzes lessons from early adopters, and identifies best practices and policy gaps. Drawing on diverse examples, technical insights, and institutional perspectives, the paper argues for a coherent shift in market design to integrate stability, flexibility, and performance as core procurement objectives.

Emerging research emphasizes that reliability and resilience require the targeted procurement of specific system capabilities rather than generic energy or capacity. Failure to price these attributes risks growing reliance on out-of-market interventions, inefficient redispatch (reordering generation to relieve congestion or maintain grid reliability), and stranded investments.

Market reforms must align incentives for diverse technologies, reduce entry barriers, and incorporate system needs into planning and operation. A modern framework must be transparent, performance-based, and responsive to evolving operational demands.

Meanwhile, actual market arrangements in many systems are lagging both the need and the opportunity to deploy capability services technologies. Instead of revenue models, potential investors are offered a limited scope of demonstration projects, grant funding, or short-term procurement.



INTRODUCTION

Power systems were historically structured around large, centralized, dispatchable generators that not only provided energy and capacity, but also a suite of operational services necessary for system stability. These included system inertia, frequency containment, reactive power, voltage control, system balancing, and fault ride-through. Because these services were co-delivered by default, market frameworks never needed to price them explicitly.

Specifically, these services are capabilities rather than capacities: inertia to slow frequency deviations, fast frequency response (FFR) to arrest frequency drops, voltage and system strength support, dispatchable flexibility from fast-ramping or peaking units, black start and restoration capabilities, and location-specific grid-forming behaviour. Relatively obscure to most energy buyers and policymakers, these crucial services can collectively be described as system attributes or essential reliability services.

Capacity markets and energy-only markets were designed for systems still dominated by firm, synchronous generation. Although these market designs provide some solutions helpful for the transition to a power system based on variable renewables, in systems with high penetration of inverter-based resources these traditional market frameworks often fail to ensure that key capabilities are available when needed.



The energy transition is exposing the limits of the existing market designs and revealing the need for new mechanisms that explicitly value system attributes — not just energy or capacity.

As renewable penetration increases and synchronous generators retire, increasingly, power systems are encountering situations where sufficient energy is available, but essential operational capabilities are lacking. Energy-only markets do not incentivize attributes such as fast-ramping capability or inertial support, while traditional capacity mechanisms often treat all megawatts as equivalent regardless of their contribution to stability.

Organizations across the power sector are increasingly recognizing the need to move beyond existing market constructs. While some jurisdictions have begun experimenting with new approaches, progress remains uneven, and integration with long-term planning and system needs is often insufficient.



CAPABILITY MARKETS: CONCEPT AND PURPOSE

Capability-oriented procurement frameworks are emerging as targeted solutions to this evolving system challenge. Rather than compensating resources solely for their energy production or static capacity, these markets aim to procure the specific physical attributes and operational characteristics that modern grids require.

The core objective of capability markets is to ensure that crucial system operational services are available when and where they are needed.

This requires shifting from a model that rewards availability in megawatts to one that also values responsiveness, locational performance, and system impact.

When they are designed for power systems dominated by variable renewables, capability markets help create investable revenue streams for emerging and existing technologies and enable a broader set of resources to participate in maintaining grid stability. Those emerging technologies include grid forming configurations of large batteries combined with advanced inverter controls – for example in upgrades to wind turbine controls – new power electronics devices, and decarbonised rotating assets.

So, what would a capability market mean? To enable a broader set of resources to participate in maintaining grid stability, an effective capability market design needs to include clear product definitions, forward procurement signals, verification mechanisms, and technology-neutral frameworks. Attributes like response speed, ride-through performance, and locational value must be explicitly reflected in pricing and qualification criteria.

This approach would not only reduce system costs through greater efficiency and innovation, but also enhance resilience in increasingly weather-dependent and decentralized grids.



INTERNATIONAL EXPERIENCE AND CASE STUDIES

Several jurisdictions have taken steps toward capability-based procurement, motivated by reliability risks and structural changes in their generation mix.

In 2011, Ireland launched the Delivering a Secure, Sustainable Electricity System (DS3) program to address the operational challenges of operating with high shares of non-synchronous generation. Through a suite of competitive service products — including inertia, FFR, ramping, and voltage support — DS3 has enabled the system operator to reliably manage up to 75% instantaneous renewable penetration. The framework introduced 14 distinct ancillary services with differentiated remuneration structures. Products were paid based on response time, duration, and controllability, with higher payments offered to faster and more reliable resources. This pricing model successfully incentivized early investment in grid-scale batteries and upgrades to wind turbine controls. By 2022, over 650 MW of battery storage capacity had been contracted under DS3.

Australia has evolved the Australian Energy Market Operator's (AEMO) Engineering Framework, beginning with mandatory primary frequency response and moving toward market-based procurement of FFR and system strength. Under the FFR Market Ancillary Services trial, launched in 2021, ultra-fast responding resources such as batteries were compensated in the ancillary services market. Although price volatility remains high, the expectation of enduring need has supported a growing pipeline of battery projects.

The United Kingdom has implemented structured capability products through National Grid ESO's Stability Pathfinder and new dynamic frequency response services: Dynamic Containment, Dynamic Regulation, and Dynamic Moderation are services procured through daily auctions, with prices reflecting response speed and control accuracy. The Stability Pathfinder targets inertia and fault-level performance.

These mechanisms have directly triggered investments in grid-forming batteries and synchronous machines. Europe's largest battery storage installation, the 300 MW / 600 MWh Blackhillock battery in Scotland, exemplifies this trend. The first 200 MW / 400 MWh phase is operational, with the remaining 100 MW / 200 MWh scheduled for 2026. Located strategically between Inverness and Aberdeen, Blackhillock reduces grid congestion from major offshore wind farms and provides critical stability services. It delivers synthetic inertia and frequency stabilisation through grid-forming inverters — a capability that has proven vital for grids with high shares of inverter-based resources during recent major grid events.

In 2016, California introduced the Flexible Ramping Product (FRP) to compensate resources for real-time ramping flexibility. While modest in value, FRP has supported behavioral changes and investment in batteries, now exceeding 6 GW in the California Independent System Operator (CAISO) footprint.

Europe, through the European Network of Transmission system Operators for Electricity (ENTSO-E) and national Transmission system Operators (TSOs), is exploring capability procurement via coordinated pilots for voltage control, restoration, and inertia. These efforts remain primarily national in implementation, but ENTSO-E has taken steps to promote convergence of service definitions, procurement timelines, and performance standards. The "Vision for Market Design 2030" and ENTSO-E's coordination with the Agency for the Cooperation of Energy Regulators (ACER) signal a direction of travel toward harmonized cross-border procurement. However, significant regulatory fragmentation persists, and practical integration across European borders remains limited.

In India, capability procurement is currently approached mainly through centralized tenders, particularly for battery energy storage and hybrid renewables. These tenders increasingly articulate requirements to support a high renewable penetrated grid like ramping requirements. While this specification-driven method is a necessary and pragmatic first step, it lacks the ongoing price signals and system-wide incentives that dynamic markets provide. Local experts are starting to discuss how, without broader frameworks that define, measure, and reward these capabilities beyond one-off procurements, India may face challenges in aligning resource behaviour with evolving system needs. Over time, tender-based approaches should be complemented by more structured, performance-based mechanisms — such as capability markets or incentive frameworks — to ensure long-term reliability in a high-renewable grid.

Today, the strongest investment response has occurred where capability products are clearly defined, remunerated transparently, and integrated with procurement frameworks. Ireland, the UK and Australia provide the clearest examples, with measurable impacts on battery uptake, synchronous machine deployment, and advanced inverter configuration. In contrast, jurisdictions relying solely on mandates or grid codes — without compensation — have seen slower uptake of advanced technologies.

While high shares of variable renewables create the technical need, it is the combination of system characteristics, regulatory culture, and proactive institutional responses that has made these jurisdictions the true innovators.

TECHNICAL SOLUTIONS AND MARKET INTERFACES

Capability markets are reshaping economic signals to unlock the potential of an expanding suite of technical solutions that can deliver the system-critical services once embedded in conventional generation. To scale, however, these solutions now require clear policy commitments, investment signals, and durable revenue frameworks.

Synchronous condensers are a proven technology for delivering inertia, short-circuit strength, and reactive power. They are especially effective in areas where thermal units have retired and grid strength is weak. While technically mature, their capital-intensive nature demands long-term contracting or regulated returns or cost recovery to become viable.

Gas turbines, when configured for flexible operation, can contribute to fast frequency response, spinning reserve, and voltage support, offering dispatchable system services that complement variable renewables. If fitted with a clutch, they can also operate as synchronous condensers when not generating power, providing inertia and reactive support without burning fuel.

Battery storage systems are among the most flexible contributors to system services. When configured with advanced inverter controls, they can deliver fast frequency response, synthetic inertia, ramping flexibility, voltage support, and black start. In some jurisdictions, they also provide voltage regulation and system strength or short-circuit support. However, investment in battery capabilities hinges on multi-year revenue certainty. Battery pilots and short-term tenders rarely align with these financing structures.

Inverter-based renewable generation, such as solar and wind, can also contribute to stability through grid-forming inverters. These allow plants to operate independently of synchronous machines, managing frequency and voltage actively. Yet these services are often uncompensated or undervalued, slowing deployment.

Power electronics technologies, such as STATCOMs, grid-forming inverters, and advanced control systems, enable high efficiency in the conversion and control of power to meet specific needs, including regulating voltage or current, or converting AC to DC or vice versa, while minimising energy loss.

Demand-side resources and power electronics devices such as STATCOMs are also emerging as contributors to grid services. Flexible industrial loads, aggregators, and distributed energy resources can provide balancing, congestion relief, and even synthetic inertia.

Participation, however, is frequently constrained by unclear qualification criteria and lack of access to revenue streams. For example, in Europe, definitions for inertia vary across jurisdictions. In many systems, compensation for system capabilities remains fragmented: reliant on demonstration projects, grant funding, or short-term procurement.

Without clear, performance-based remuneration integrated into planning and procurement cycles, new entrants and technologies face significant investment risk. Forward-looking auctions, standard product definitions, and co-optimization with energy and capacity markets are critical steps toward aligning technical capabilities with commercial viability.



The following table summarizes key technology options for grid stability, showing which capabilities they provide and their main advantages and disadvantages:

Technology	Inertia	FFR	Voltage Support	Black Start	System strength	Advantages/ Disadvantages
Synchronous condensers	✓		✓		✓	✓ Proven technology; long life ✗ High capex, long delivery time
Gas turbines (with/without clutch)	✓ (only when generating; clutch enables when offline)	✓	✓		✓ (when generating or w/ clutch)	✓ Dual use (power + stability); flexible siting ✗ Emissions unless decarbonized
Battery storage (grid-forming)	✓ (synthetic)	✓	✓	✓	✓ (if grid-forming)	✓ Fast response; modular; multi-service ✗ Costly for grid-forming; needs revenue certainty
Inverter-based renewables (grid-forming)	✓ (synthetic)	✓	✓		✓ (if grid-forming)	✓ Uses existing assets; no extra land needed ✗ Slow uptake; rarely compensated today
STATCOM / SVC			✓		✓ ▲ Supports voltage/ reactive power but does not provide fault current	✓ Compact; quick to deploy ✗ No inertia; single-function
Demand-side / DERs	✓ (▲ Limited, indirect synthetic inertia possible)	✓			✓ ▲ Can contribute to balancing, congestion relief — not direct fault current	✓ Low cost; leverages existing assets ✗ Aggregation and participation barriers



DESIGN CONSIDERATIONS AND CHALLENGES

Designing effective capability markets requires careful attention to technical definitions, investment signals, and regulatory coordination. Product requirements must be detailed enough to reflect physical system needs but also sufficiently streamlined to enable widespread participation.

A key issue is the misalignment between short-term operational procurement and long-term planning. System services are often procured with one- to two-year contracts or through real-time dispatch, offering limited investment certainty. This deters capital deployment in technologies with long development timelines or higher upfront costs. Experience has shown that long-term, bankable contracts for capability delivery can reduce cost of capital and accelerate deployment. Examples include multi-year inertia and system strength contracts under the UK Stability Pathfinder and AEMO's system strength remediation framework, which act as de facto PPAs for system capabilities. However, standardized, tradable long-term capability contracts do not yet exist at scale.

Crucially, verification and measurement frameworks must be standardized and automated wherever possible. While energy and capacity markets were designed to reward dispatchability and adequacy, capability markets must incentivise more operational system contributions. This is particularly important for enabling participation from distributed resources, aggregated loads, and advanced inverter-based technologies. Without credible performance monitoring, market entry remains limited to established actors.

There is also a need to balance operational flexibility with regulatory stability. Overly complex or frequently shifting market rules can erode investor confidence. Conversely, inflexible market structures can fail to keep pace with evolving system requirements and technology capabilities.

One challenge that differentiates capability markets from traditional energy and capacity markets is liquidity — both in terms of the number of participants and the depth of tradable products. Several early tenders for system capabilities such as inertia, FFR, and system strength have been conducted through bespoke or bilateral procurement processes, often with limited competition and no secondary trading. This creates multiple risks: price volatility due to limited competition, financing challenges due to lack of forward market visibility,

and operational inefficiencies due to insufficient flexibility for system operators.

While these risks are real, they do not outweigh the need to value and procure system-critical capabilities. Well-integrated capability markets — those with standardized product definitions, co-optimization with existing energy and capacity markets, and clear regulatory frameworks — can reduce overall system costs and enable renewable technology deployment. In contrast, failure to price these attributes risks growing reliance on out-of-market interventions, inefficient redispatch, and stranded investments. The key is not to layer markets arbitrarily, but to design them coherently, with transparency, long-term signals, and harmonized integration across jurisdictions.

Cross-border coordination remains a major challenge, particularly in Europe. Different countries operate under divergent regulatory frameworks and procurement timelines. Definitions for inertia, synthetic response, and voltage support vary across jurisdictions, complicating regional integration. The lack of harmonized standards and verification protocols creates inefficiencies and inhibits the development of regional capability markets.

Finally, the role of digital infrastructure and data transparency must be elevated. Advanced telemetry, automated verification tools, and open-access performance data are essential to enable participation, reduce transaction costs, and enhance regulatory oversight. These tools also support price discovery and help system operators assess the contribution of diverse technologies in real time.

The key is not to layer markets arbitrarily, but to design them coherently, with transparency, long-term signals, and harmonized integration across jurisdictions.

EMERGING SYSTEM SERVICES AND MARKET DIRECTIONS

In response to the evolving needs of modern power systems, several new ancillary service products are being developed or refined beyond traditional primary and secondary reserves. These services aim to address specific operational challenges posed by reduced inertia, decentralized generation, and dynamic load patterns.

FFR services are being implemented in systems with declining inertia to contain frequency drops within 1-2 seconds. The UK's Dynamic Containment product, launched in 2020, initially cleared at high prices of around €20-23/MW/h due to limited competition. As battery participation scaled up, prices fell to around €6-12/MW/h by late 2022, stabilizing as market liquidity improved. Ireland's DS3 Fast Frequency Response initially offered premium pricing to attract investment, but procurement costs have moderated as capabilities have matured and project volumes increased. In Australia, AEMO's FFR trials are expected to reduce reliance on slower contingency reserves, though pricing remains under development as the service transitions into formal markets.

Inertia and synthetic inertia products are also emerging. These services aim to slow the rate of change of frequency (RoCoF) and are being procured through tenders in systems with declining synchronous generation. In the UK's Stability Pathfinder rounds, early contracts with synchronous condensers and advanced batteries have delivered inertia at equivalent costs of €11-23/kW/year, depending on location and configuration. Costs have declined in subsequent rounds, as project delivery risk has fallen and more technologies qualified, particularly grid-forming batteries. However, pricing remains variable due to the localized and bespoke nature of service needs. It remains an open question whether this localized pricing and bespoke nature will persist as a structural feature, or whether greater standardization, liquidity, and regional integration will emerge as these markets mature.

System strength and short-circuit current support have become critical in weak-grid areas. Australia's move to market-based system strength procurement - replacing mandatory connection standards - has revealed significant locational price differences. Contracts for system strength services have been awarded at levels between €15-27/kVA/year, depending on network topology and the availability of synchronous support or grid-forming resources. These services are generally long-term (5-10 years), helping to improve project bankability.

Voltage support and reactive power are shifting from regulated provision to competitive procurement. In many countries, these services are still remunerated under cost-based mechanisms. However, pilot tenders in the UK, Italy, and France have produced price signals in the range of €5-15/kVAR/year, especially in constrained or congested zones. Where local grid needs are acute, the marginal value of reactive support rises significantly, indicating that competitive, locational tenders could drive efficiency.





Black start and restoration capabilities are also evolving. Traditionally provided by diesel and hydro units under regulated contracts, newer providers, including batteries and hybrid plants, are entering the scene. In the UK and parts of the US, battery-based black start solutions have demonstrated cost savings of 30-50% compared to conventional black start providers, while also enabling additional grid services to be provided from the same asset. These cost reductions come alongside faster restart times and more modular deployment options.

Congestion management and locational flexibility products are increasingly being used to resolve real-time and forecasted grid constraints. In the UK, Local Flexibility Services and Dynamic Moderation auctions have procured location-specific demand reduction and flexible generation at prices ranging from €230-690/MWh, with premiums in densely loaded urban areas. Germany's Redispatch 2.0 framework, although not yet fully market-based, has exposed the cost of uncoordinated curtailment and compensation mechanisms - reinforcing the argument for locational capability procurement.

Across all these services, a similar pattern emerges: early market formation typically requires higher prices to attract investment, mitigate risk, and signal policy commitment. Over time, as qualification processes mature, competition increases, and confidence grows, procurement costs decline, sometimes significantly. This trend mirrors the trajectory seen in earlier ancillary service markets such as primary and secondary reserves, where initial scarcity and complexity gave way to more efficient pricing with broader participation.

These developments indicate a broader shift toward unbundled, performance-based markets that value the full spectrum of grid services. They also underscore the need for harmonized standards, automated verification, and coordinated planning across regulatory and operational levels. If designed well, capability-oriented procurement can reduce overall system costs while improving reliability and enabling faster integration of clean technologies.

CONCLUSION AND PATH FORWARD

Electricity markets must evolve to reflect the physical needs of modern power systems. As renewables replace synchronous generators, operational capabilities such as inertia, fast frequency response, and voltage control must be explicitly defined and procured.

System services are not investable just on the basis of capacity markets. Capability markets offer a solution. They align economic signals with engineering needs and accelerate investment in clean, stable, and flexible technologies. Lessons from leading jurisdictions show that well-designed capability markets can deliver measurable system benefits and crowd in private investment.

Going forward, markets must integrate capability procurement into system planning, provide long-term, performance-based contracts, simplify access and ensure technology neutrality, harmonize regional procurement where feasible, and leverage digital tools for verification and transparency. But markets alone are not enough. The technology solutions capable of delivering these services are ready and proven. From synchronous condensers and flexible gas turbines to grid-forming batteries, inverter-based renewables, and demand-side resources, a broad suite of options is available to secure system stability.

System adequacy is the sum of market design, technical power system solutions, and regulatory frameworks. An imbalance in any of these forces the other two to compensate or overperform to maintain stability. As market design evolves, integrated system planning must become the guiding principle for delivering long-term adequacy. This ensures capability market procurement aligns with the optimal generation mix, informs infrastructure investment decisions, and prepares systems to meet the demands of new load centres.

We can't just keep optimising individual assets — markets must adopt a system approach.

This doesn't mean a single one-size-fits-all model, but it does mean clear priorities.

Capability markets should already be a core focus in systems with high shares of variable renewables. As they say, the best moment to act was at the start — but the second best moment is now. Markets with lower variable renewable energy (VRE) shares should also look ahead, learning from pioneers. At the same time, system operators and investors should build confidence in, and deploy, the technical solutions that can meet these needs today.



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