Power system stability

Ensuring system stability with a rising share of renewable energy

21 November 2024

Agora
Energiewende

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Introduction and key findings

Agora Energiewende – about us

Who we are:
Agora Energiewende is a think tank, policy lab, and part of the **Agora Think Tanks**

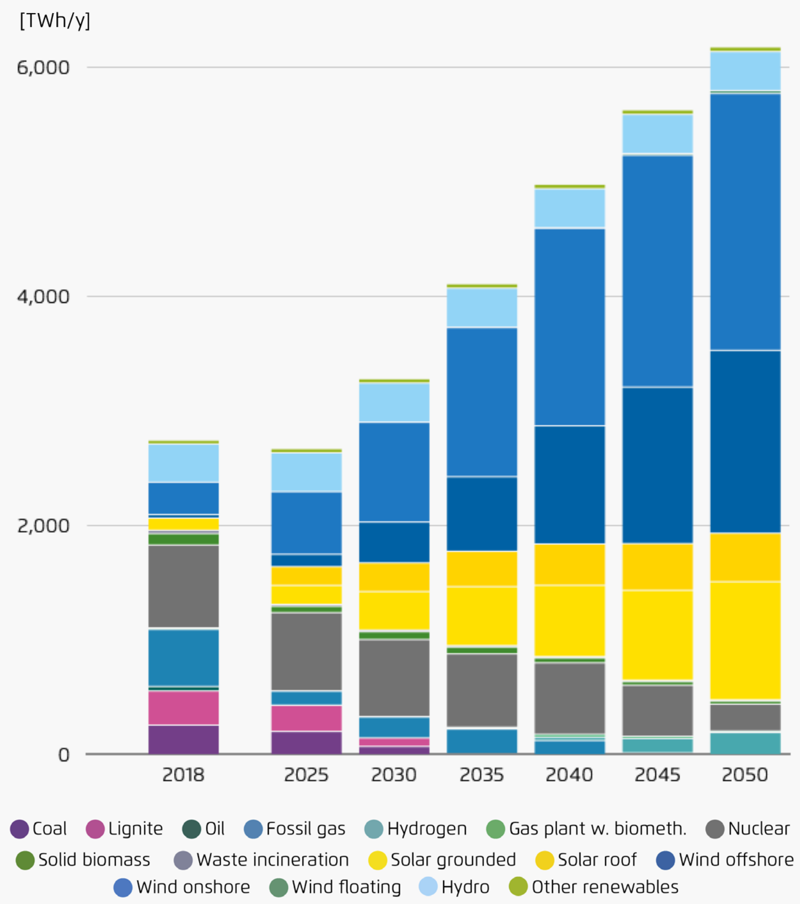
What we do:
We develop scientifically sound and politically feasible strategies for a successful pathway to **climate neutrality** in the power and buildings sectors – in Germany, Europe and around the world

How we work:
We are independent and non-partisan, with a diverse financing structure – **our only commitment is to climate action**

Where we work:
Agora Energiewende has offices in Berlin, Brussels, Beijing and Bangkok, and cooperates internationally with more than 20 partner organisations

Preface

Net electricity generation in the EU



The European Climate Law sets binding targets to achieve climate neutrality by 2050 and reduce greenhouse gas emissions by at least 55 percent by 2030. As shown in Agora's 2023 study "Breaking Free from Fossil Gas", to meet these goals, Europe's electricity sector must be largely decarbonised by 2040. This requires a shift from large, centralised power plants to distributed electricity generation based on wind and solar, and storage systems connected by inverters.

A topical question is how the integration of renewables will affect system stability and how to maintain it most efficiently. To address this, Agora Energiewende commissioned Moeller & Poeller Engineering to develop a detailed mapping of system stability needs, contributing technologies, and deployment strategies. Building on the technical analysis, we also carried out extensive exchange with system operators, authorities and industry representatives.

Our aim is to make this complex issue more accessible to a broad range of stakeholders, initiate dialogue and support informed decision-making. All these elements are vital for maintaining stable power systems while keeping consumer prices affordable – and driving the clean energy transition forward.

Émeline Spire
Director Europe, Agora Energiewende

Agora Energiewende (2023): *Breaking free from fossil gas. A new path to a climate-neutral Europe*, available here

Key findings (1/2)

1 **A successful transition to climate-neutral power generation requires a new approach to system stability.** System operation methods have traditionally been built around the physical properties of conventional power plants. Wind and solar power, and batteries are inverter-based technologies, connected by power electronics without intrinsic mechanical inertia. Aligning system stability management with renewables-based power systems should feature high on the agenda of policymakers and regulators.

2 **To make informed decisions for a renewables-powered grid, it is important to clearly quantify system stability needs using transparent methods.** As renewable energy share increases, grid operators and regulators should carefully evaluate whether there are enough stability resources. Overestimating these needs can cause extra costs and delays in integrating more renewable energy, while underestimating them could threaten grid stability.

Key findings (2/2)

3 **An optimal approach to system stability should focus on using the most cost-effective resources at the relevant location.** For example, while batteries, hydrogen and gas turbines can provide system services with few adjustments, it can be more technically complex for wind and solar, potentially leading to higher costs and delays. Such considerations should determine whether system operators install new technology or run system service auctions, or public authorities set technical provisions in tenders or enforce requirements through national and European network codes.

4 **A comprehensive dialogue among system operators, manufacturers of generation and storage and relevant authorities is critical to identify the best solutions**. A shared understanding of terminology is essential to accurately identify and quantify system stability needs. The ongoing European network code revision is an important opportunity for such alignment. Converging towards harmonised EU-wide standards would further help make supply chains for clean technologies more efficient and thus support the transition to climate-neutral power systems.

Power system stability

Reliability, security and stability in power systems

Reliability
refers to the probability of satisfactory operation over the long run. It denotes the ability to supply adequate electric service on an almost continuous basis.

Security
refers to the degree of risk in the ability of the system to survive distur-bances without interruption of customer service, taking into account probabilities and consequences of contingencies.

Stability
refers to the continuance of functional operation following a disturbance and the ability to return to a steady state. It depends on the operating conditions and the nature of the disturbance.

While reliability and security are important for overall system performance, the emphasis here is on power system stability – ensuring the grid can withstand disturbances and return to normal operation, especially in systems with high shares of renewable energy and inverter-based technologies.

When reliability, security and stability criteria are not met, system splits can occur. System splits can lead to blackouts.

Because the massive roll-out of renewables will have a considerable impact on power system stability, innovative measures are required to ensure the stability of the future power system.

Power system stability

Frequency, rotor angle, voltage and resonance stability (IEEE/CIGRE 2004)*

Frequency stability	- Active power balance - Inertia and frequency control	Global, system-wide
Rotor angle stability	- Synchronising power and damping - Large power transfers	Local, regional, system-wide (depending on grid structure)
Voltage stability	- Reactive power balance - Large power transfers	Local, regional (depending on grid structure)
Resonance stability	- Controller response - Multi-frequency network characteristics	Local

Frequency stability: Ability of a power system to balance active power (generation – load) and thus to maintain frequency.

Rotor angle stability: Ability of the synchronous machines in an interconnected power system to remain synchronised following a disturbance.

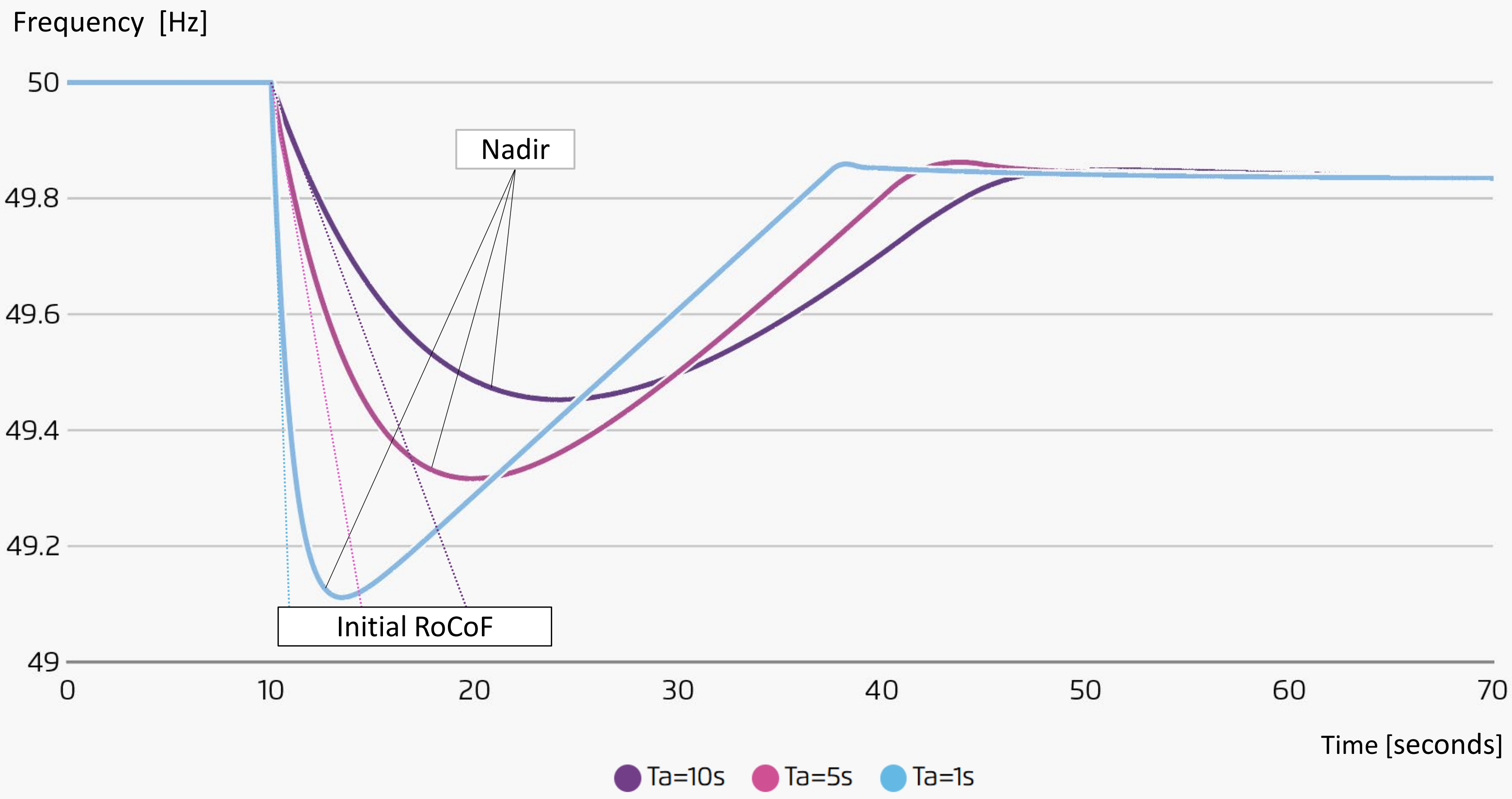
Voltage stability: Ability of a system to maintain a steady state voltage at all busbars following a disturbance.

Resonance stability: Stability resulting from the correct performance of inverters.

*Most important stability phenomena in power systems according to: IEEE/CIGRE Joint Task Force on Stability Terms and Definitions, *Definition and Classification of Power System Stability, IEEE Transactions on Power Systems*, Vol. 19, No 2, May 2004.

Frequency stability

Simulation of generator outages (3000MW) with different levels of inertia (equivalent system acceleration times)



Frequency can be impacted by generator outage, consumer outage or system splits.

The larger the active power imbalance, the faster the frequency disturbance and the higher the Rate of Change of Frequency (ROCOF). The higher the inertia, the slower the frequency disturbances.

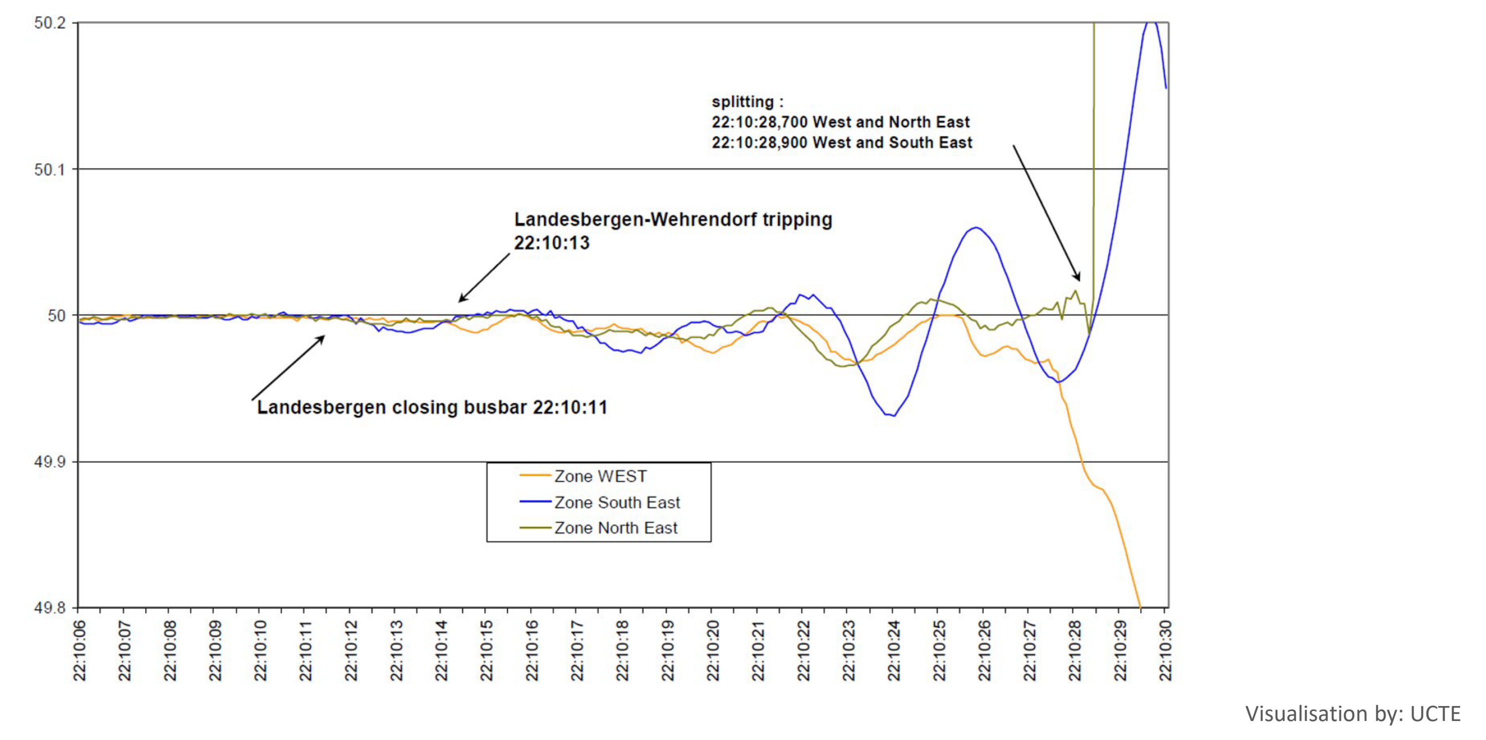
To maintain frequency stability the system requires inertia and Frequency Containment Reserves. In the longer run, automatic and manual frequency restoration reserves and frequency-sensitive demand response are used.

Loss of frequency stability can lead to automatic disconnection of generators and consumers.

M.P.E. Note: Ta: Equivalent Acceleration Time Constant (higher the Ta, the higher the inertia, the lower the impact from an outage on frequency and the more time is available to react).

Rotor angle – oscillatory stability

Frequencies in the Continental European System prior to the system split event on 4 November 2006, showing oscillatory stability problems



Visualisation by: UCTE

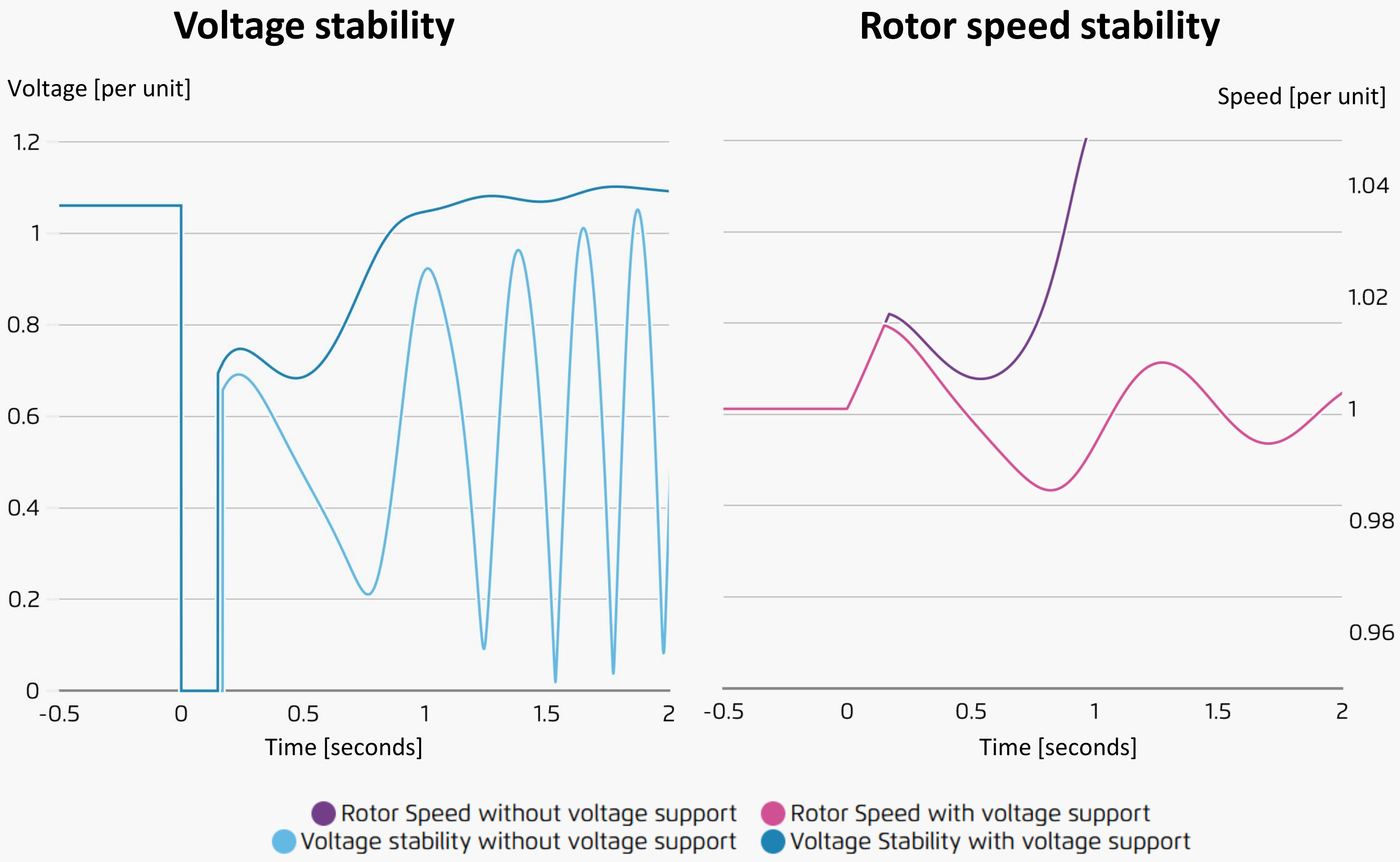
Rotor angle stability is the ability of the synchronous machines in an interconnected power system to remain in synchronism after being subjected to a disturbance.

Oscillatory stability is the stability of the rotor angle of synchronous machines (individual synchronous machines or coherent groups of synchronous machines) subsequent to small grid disturbances (e.g. switching actions, load changes).

Oscillatory instability can lead to increasing frequency disturbances, causing system-wide instability.

UCTE, Final Report: System Disturbance on 4 November 2006, 2007

Rotor angle – transient stability



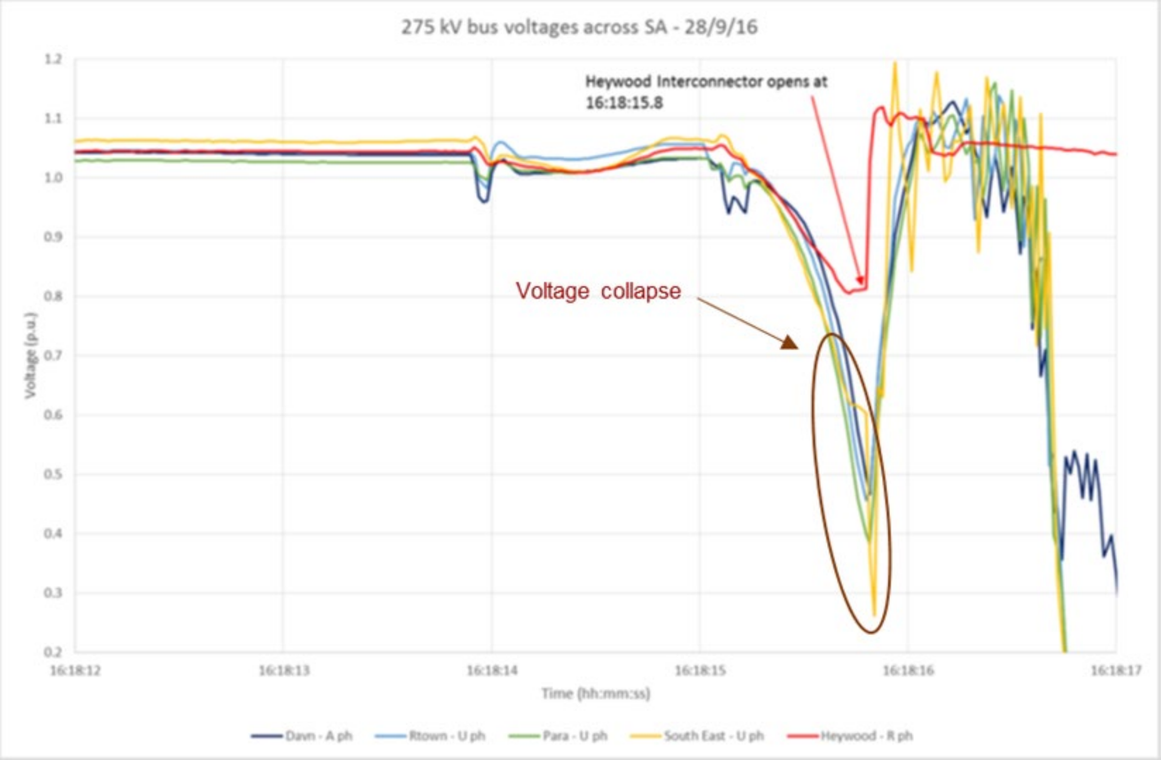
Transient stability describes the stability of rotor angles of synchronous machines at the point in time when large disturbances occur (e.g. short-circuits or major faults).

The critical fault clearing time is longer if the generated power prior to a disturbance is lower and the voltage support is better.

Transient instability may result in generators exceeding frequency limits and potentially disconnecting during large disturbances (e.g. short-circuits).

Voltage stability

Voltages around the Heywood Interconnector leading to a separation of the South Australian power system (and a subsequent black-out)



Visualisation by: AEMO

Voltage stability is the stability of the voltage magnitude at all nodes of a power system.

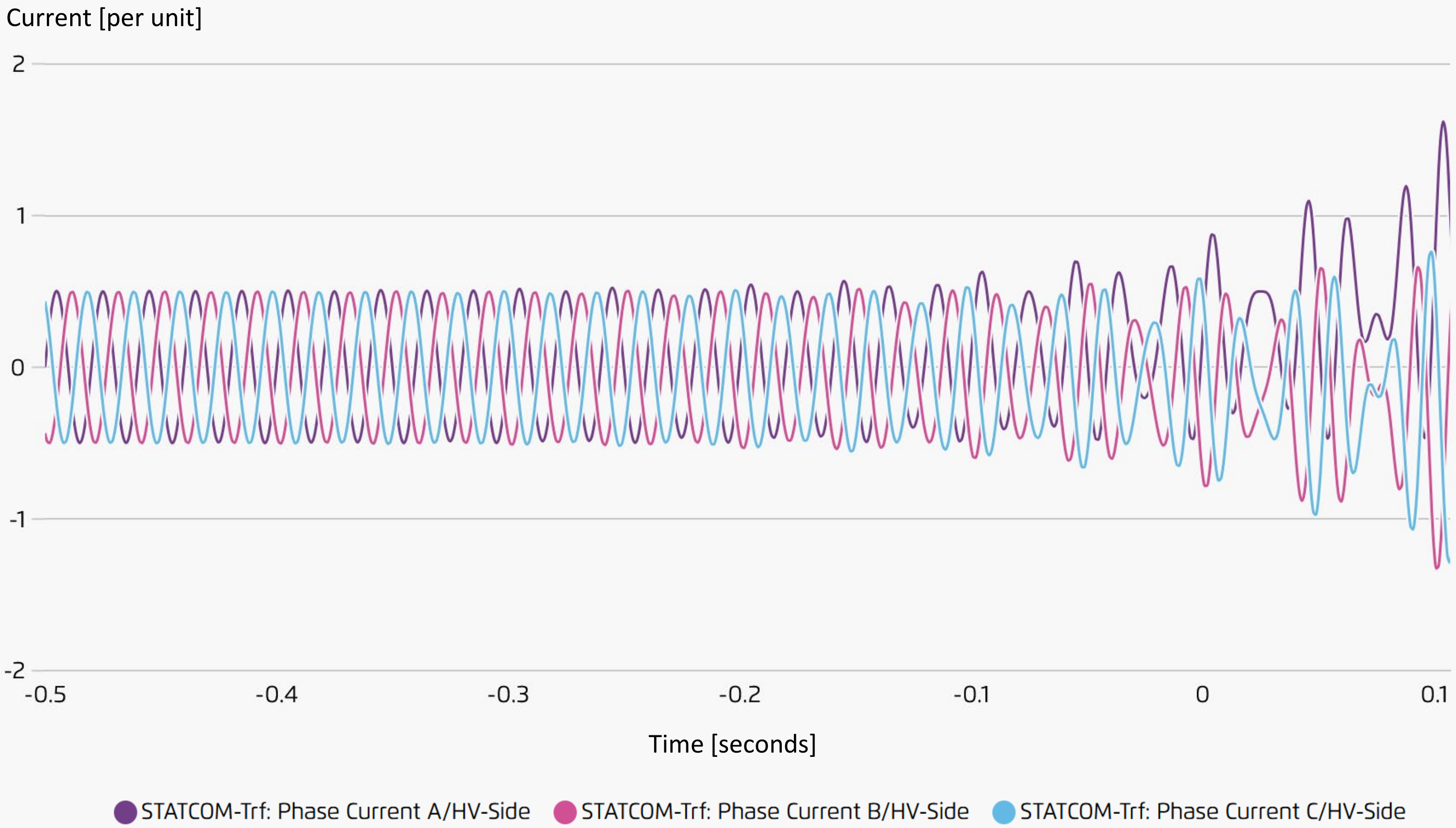
A voltage instability is related to the inability of the system to provide sufficient reactive power to cover the reactive demand e.g. of highly loaded power lines.

In most cases, a voltage instability is caused by a combination of line disconnections and generator outages in the importing zone. When the voltage starts dropping, generators may disconnect because of undervoltage, which increases the power import, reduces the reactive power control capability of the importing area and accelerates the development of a voltage collapse.

Voltage instability can trigger generator disconnections due to undervoltage, escalating power imports and reactive power deficits, eventually causing voltage collapse.

Resonance stability (controller instability)

Simulation of STATCOM with grid-following converter connected to a weak grid



Resonance stability describes the stability when high bandwidth controllers (fast controllers) interact and resonate in the high or low frequency range (super- or sub-synchronous range).

A high impedance (weak grid) increases the probability of controller instability.

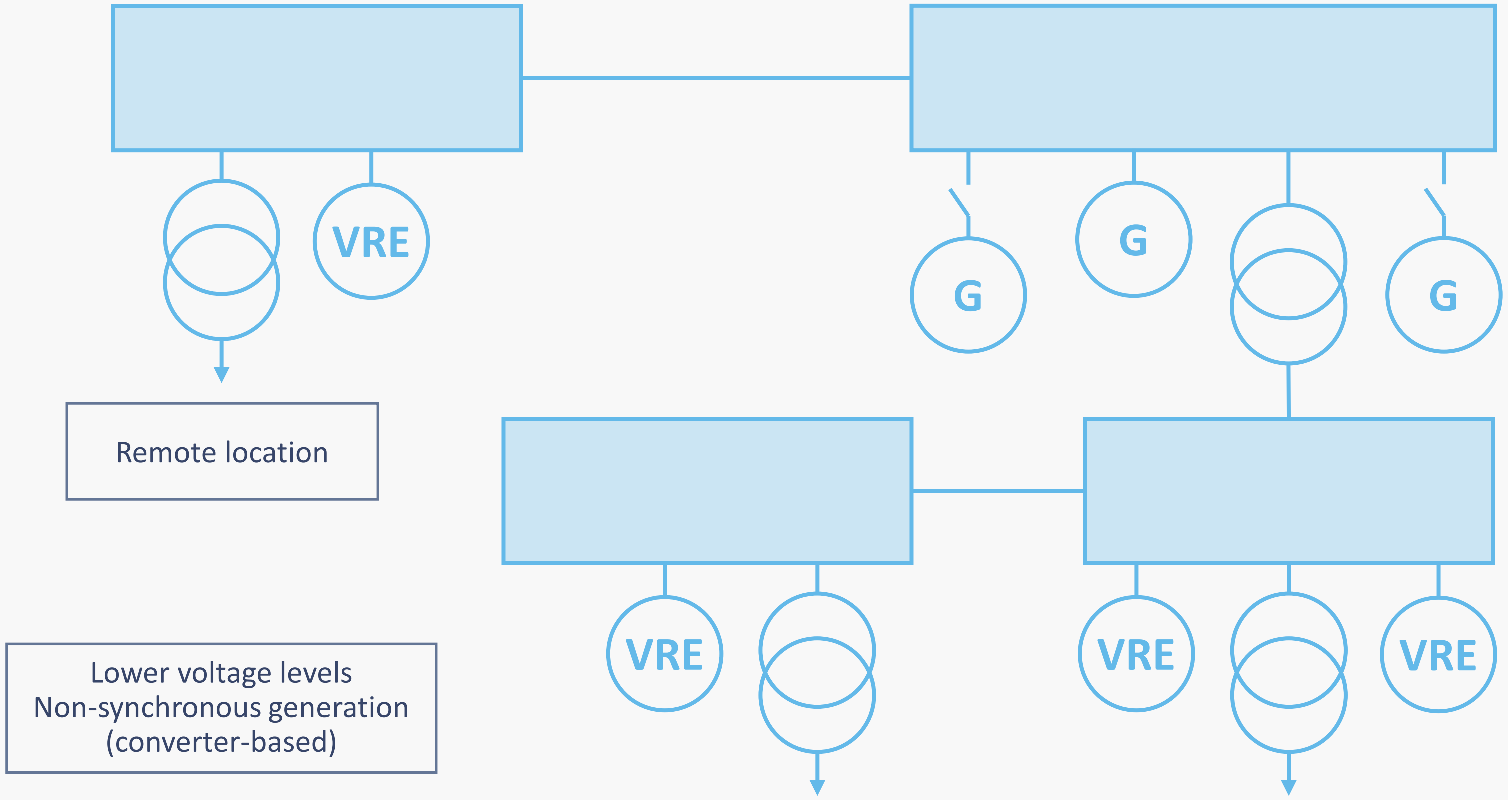
Resonance stability is highly dependent on the controller‘s characteristics.

Resonance instability can cause oscillations in the power system, leading to equipment damage, reduced power quality and potential disconnection of generators or loads.

Impact of renewable energy on power system stability

Power system with large share of renewables

Power system with increasing shares of inverter-based generation



Remote location

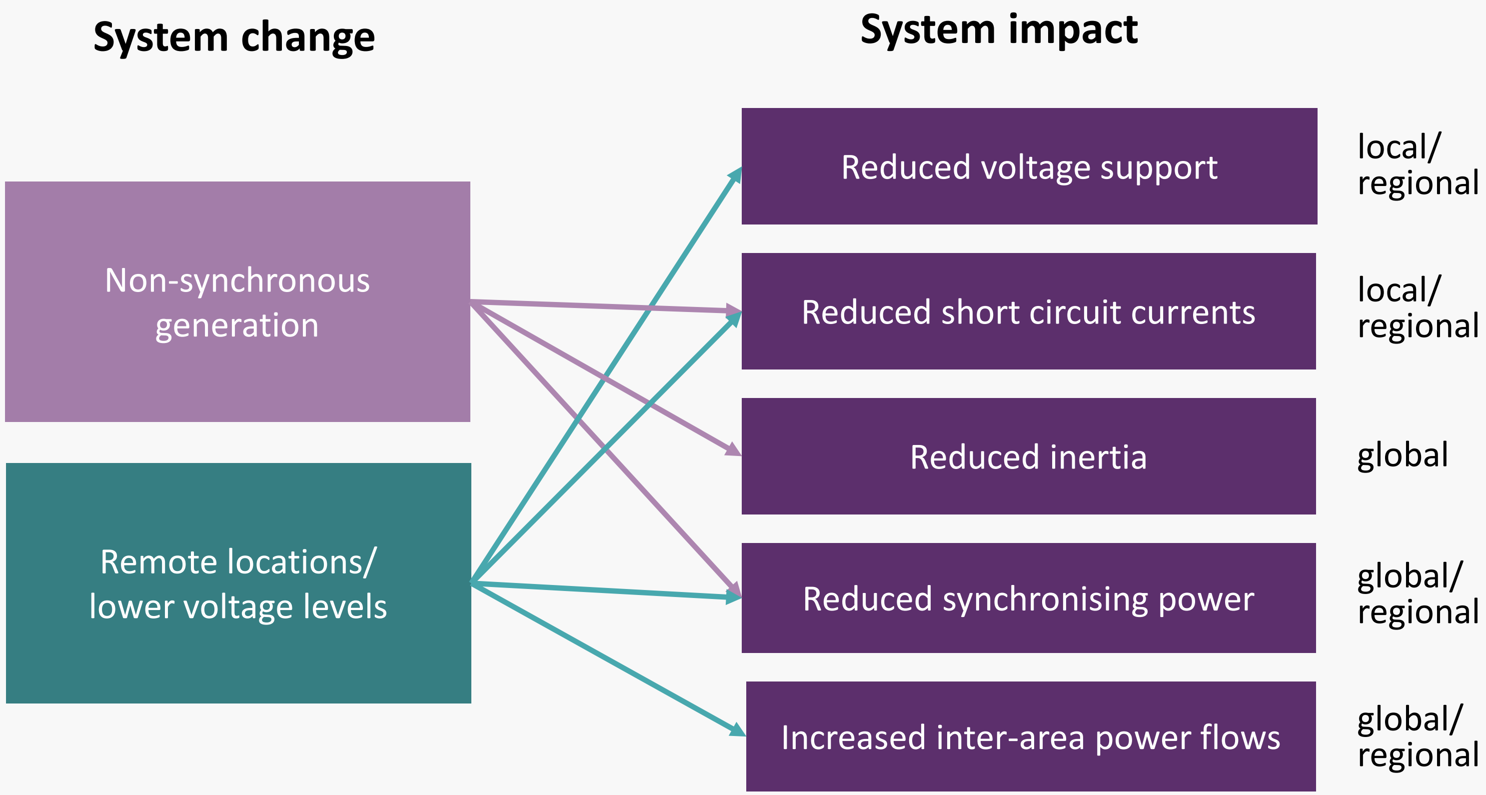
Lower voltage levels
Non-synchronous generation
(converter-based)

With increasing amounts of renewable energy, conventional generators are producing less energy and are more frequently disconnected.

Renewable energy is often connected at lower voltage grid levels and transported over longer distances, which increases demand for system services.

Impact of large share of renewables on system stability

System impact of large share of renewables



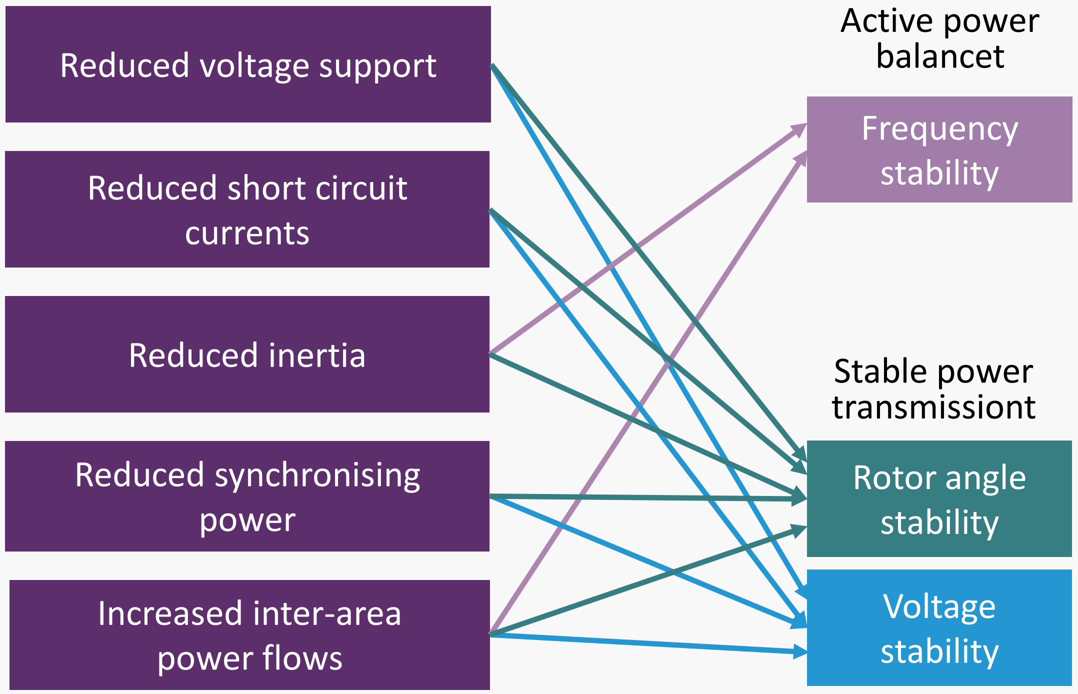
Renewables are non-synchronously connected to the grid: This leads to reduced short circuit currents*, reduced inertia and reduced synchronising torque**.

Remote locations: Renewables are often connected in locations further away from consumption centres and at lower voltage levels, increasing the technical distance to the transmission grid. This leads to reduced voltage support, reduced short circuit current, reduced synchronising torque and increased inter-area power flows.

*Short circuit current: The electric current that flows when there is a fault in the system, such as a direct connection between two points of different potential (e.g. a short circuit). It is typically much higher than normal operating current and can damage equipment if not controlled. **Synchronising torque: The force that helps keep a generator's rotor aligned with the rotating magnetic field of the power system, ensuring it remains synchronised with the grid. Without sufficient synchronising torque, the generator may lose synchronism and disconnect from the system.

Impact of large share of renewables on system stability

Stability impact of VRE



Reduced voltage support

Reduced short circuit currents

Reduced inertia

Reduced synchronising power

Increased inter-area power flows

Active power balancet

Frequency stability

Stable power transmissiont

Rotor angle stability

Voltage stability

Frequency stability: decreasing inertia leads to increasing rate of change of frequency in event of power imbalance.

Rotor angle stability (oscillatory and transient stability): with less synchronous generation and electricity transmitted over longer distances, the system gets closer to rotor angle stability limits and dynamic voltage support may decrease; however, damping of rotor angle oscillations improves.

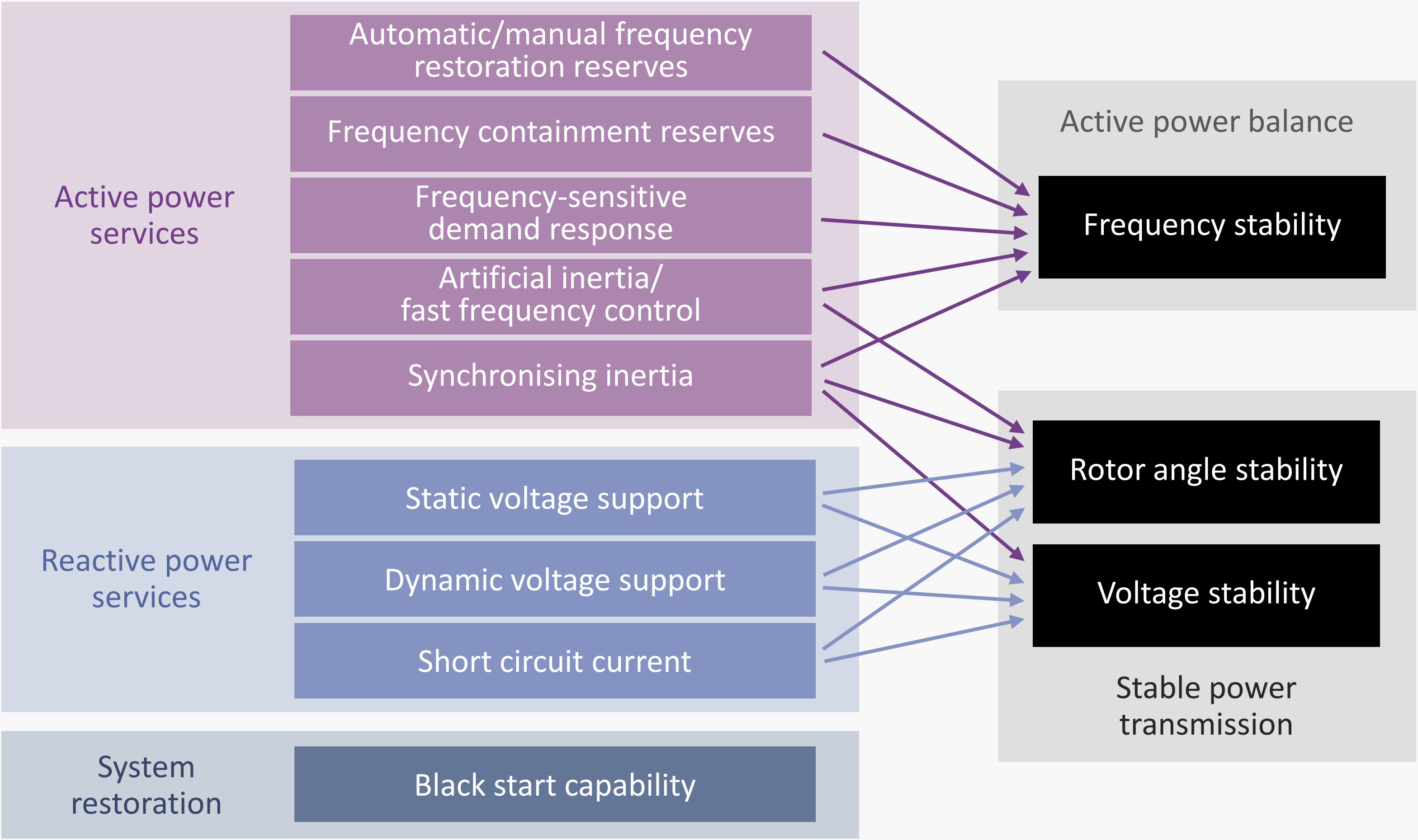
Long-term voltage stability: lower reactive power control capability as renewable energy is often connected at remote locations and lower voltage levels. Higher utilisation of lines increases the reactive power demand.

Short-term voltage stability: converter-driven generators control the electrical active power in a very short time frame (0.01–0.1s). If the injected active power is above the stability limit of the grid under low voltage conditions, the system becomes unstable.

Resonance stability: a large number of grid-forming converters can negatively impact resonance stability if they are not coordinated well.

System services to support system stability

System services and their impact on different stability phenomena



FCR: Frequency Containment Reserves deliver additional active power within 30s in the event of frequency deviations.

aFRR/mFRR: TSOs are using automatic and manual Frequency Restoration Reserves to replace FCR and rebalance the system frequency at 50Hz.

Frequency sensitive demand response: It supplements FCR in supporting system frequency. It disconnects load at higher frequency thresholds than the regular underfrequency load shedding scheme.

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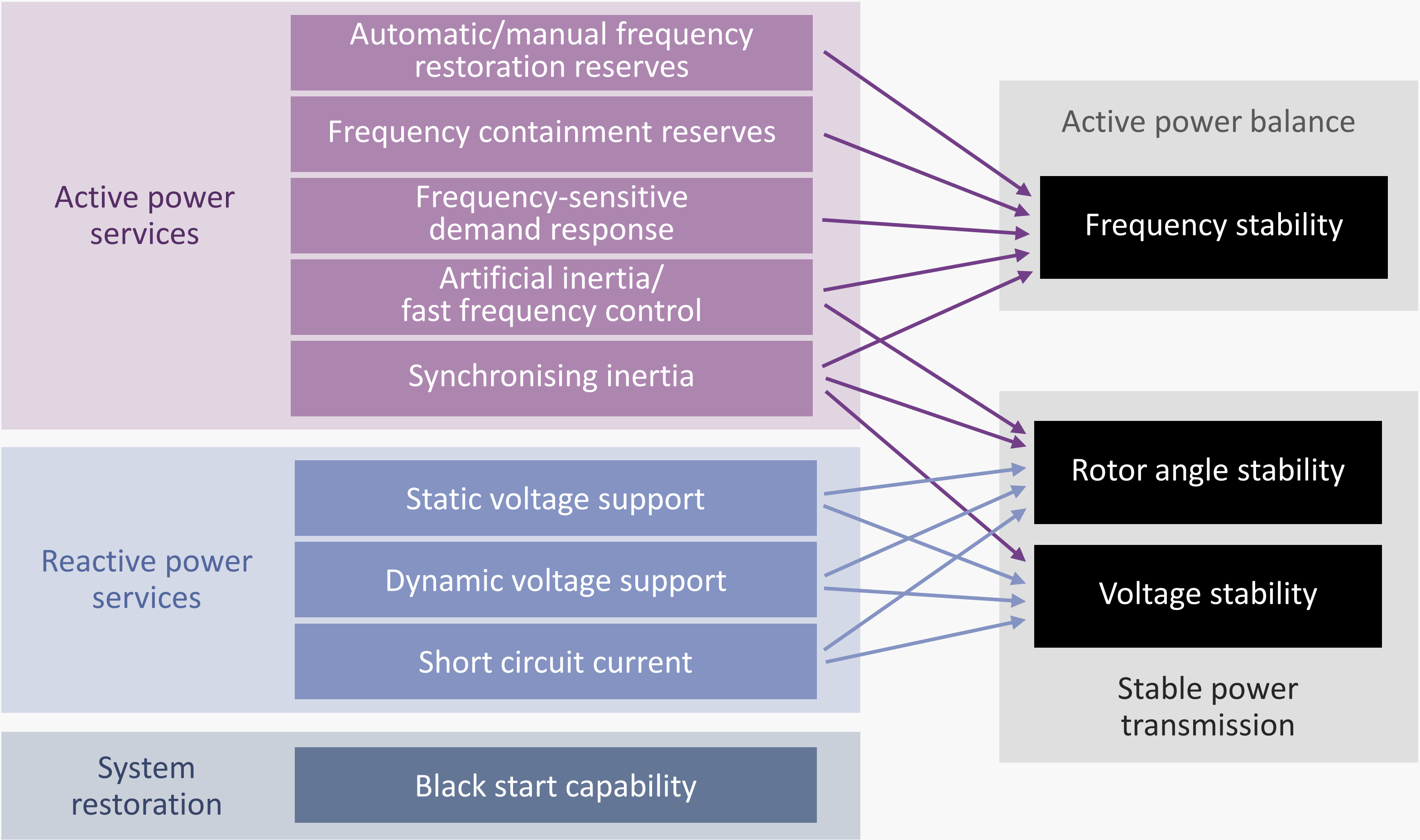
System services and their impact on different stability phenomena



Active power services

- Automatic/manual frequency restoration reserves
- Frequency containment reserves
- Frequency-sensitive demand response
- Artificial inertia/ fast frequency control
- Synchronising inertia

Reactive power services

- Static voltage support
- Dynamic voltage support
- Short circuit current

System restoration

- Black start capability

Active power balance

- Frequency stability

Stable power transmission

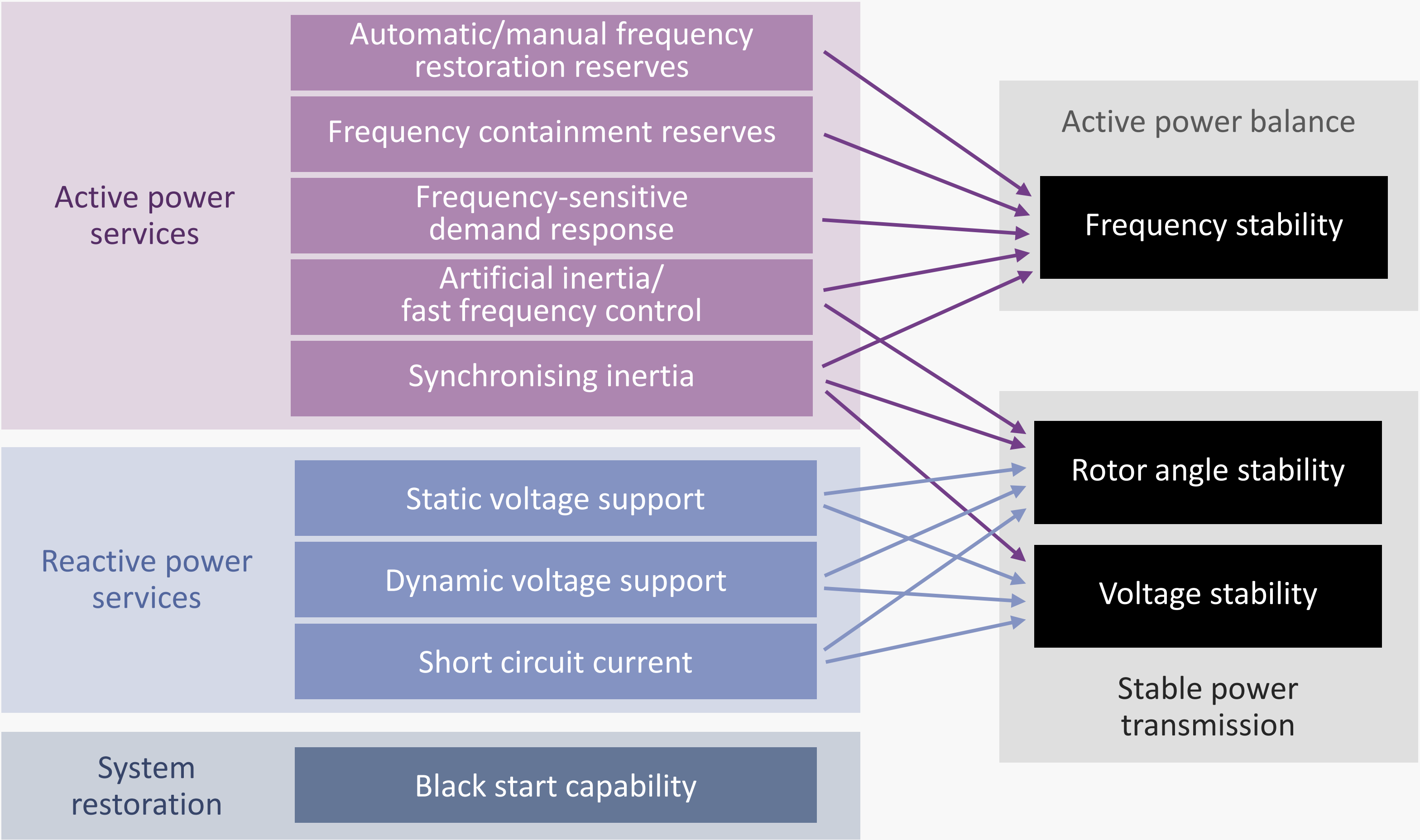
- Rotor angle stability
- Voltage stability

Artificial inertia/Fast frequency control: Injection of additional active power in proportion to the frequency gradient (ROCOF).

Synchronising inertia (also named “True Inertia” or “grid-forming inertia): Provides synchronising power and inertia. It is activated without any delay as it responds to changes of the voltage angle and not to frequency measurements.

Static voltage support: Long-term voltage stability (time frame of minutes and hours) ensures that voltage can be maintained within the permitted limits.

System services and their impact on different stability phenomena



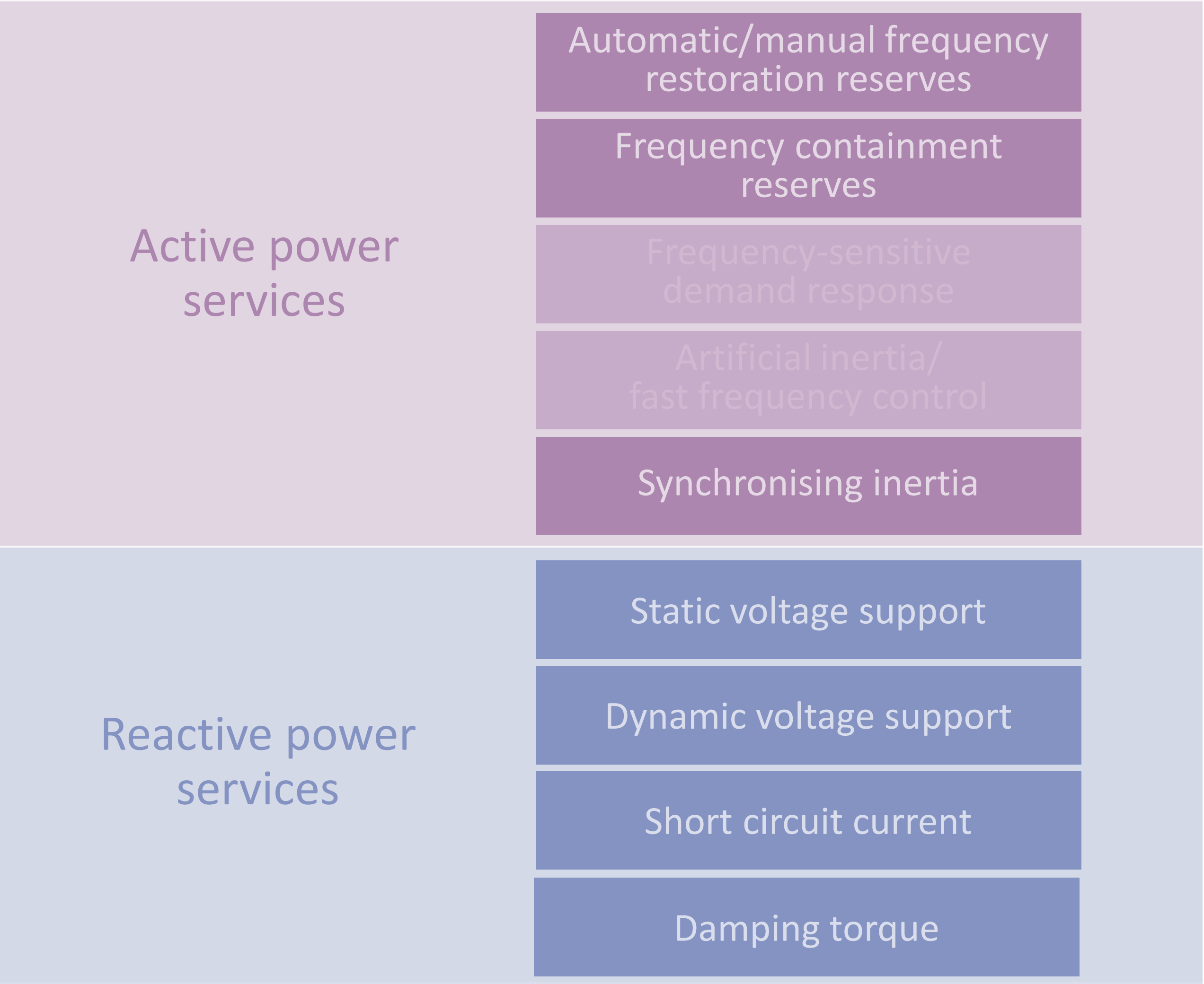
Dynamic voltage support: Dynamic voltage support (or fast voltage regulation) means a voltage regulation with an activation time of 10-100ms.

Short circuit current: It injects reactive current into the grid in the event of a voltage dip.

Black start capability: Capability of a generator to start itself without any grid and to operate an island without support from any other generator.

Technologies to provide system services

Synchronous machine power plants



Active power services

Automatic/manual frequency restoration reserves

Frequency containment reserves

Frequency-sensitive demand response

Artificial inertia/ fast frequency control

Synchronising inertia

Reactive power services

Static voltage support

Dynamic voltage support

Short circuit current

Damping torque

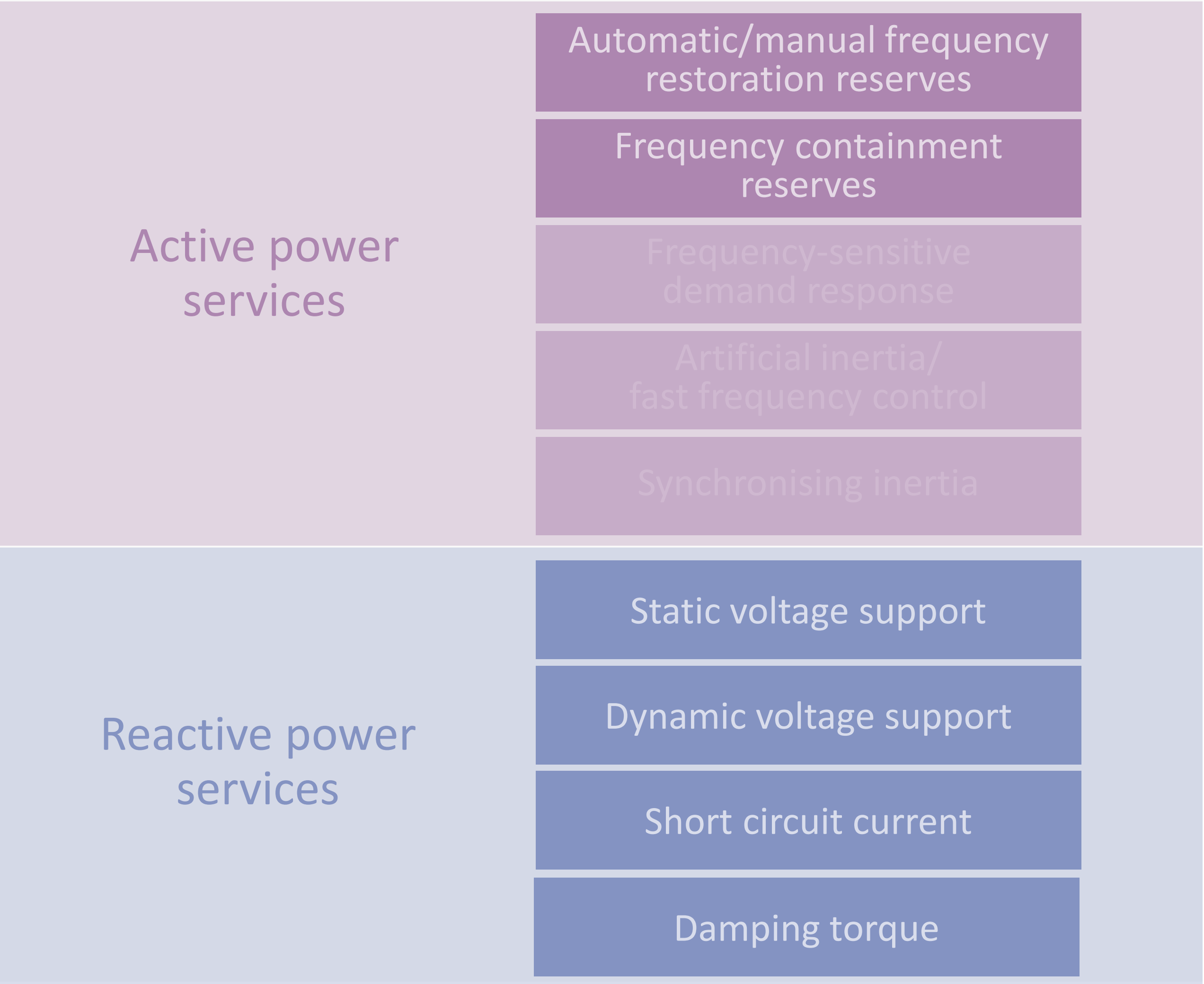
→ Synchronous machine power plants can provide most system services when operating.

→ If equipped with a clutch in the drive train for disconnecting the generator from the turbine shaft, synchronous machine power plants can also provide all reactive power services and synchronizing inertia when not being dispatched. Thus, they can act as synchronous condensers.

Active power services: ● can be provided ● cannot be provided

Reactive power services: ● can be provided ● cannot be provided

Wind and PV generators



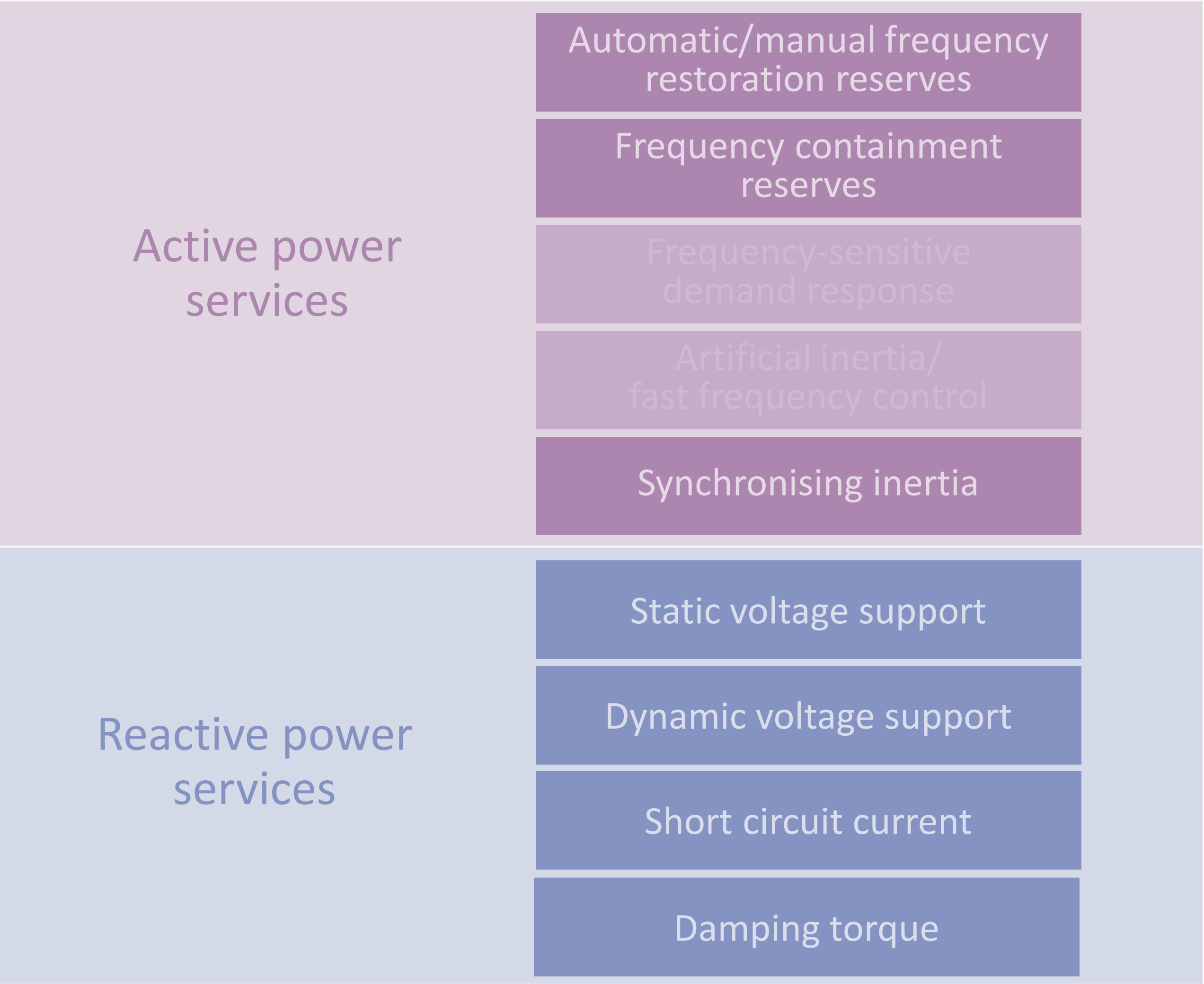
→ Wind and PV generators can provide

- voltage support,
- downward active power services when producing,
- active power reserve in both directions when being curtailed or when equipped with additional storage capacities.

→ Wind and PV generators are normally connected with grid-following inverters.

Active power services: ● can be provided ● cannot be provided Reactive power services: ● can be provided ● cannot be provided

Wind and PV generators with grid-forming converter



Active power services

Automatic/manual frequency restoration reserves

Frequency containment reserves

Frequency-sensitive demand response

Artificial inertia/ fast frequency control

Synchronising inertia

Reactive power services

Static voltage support

Dynamic voltage support

Short circuit current

Damping torque

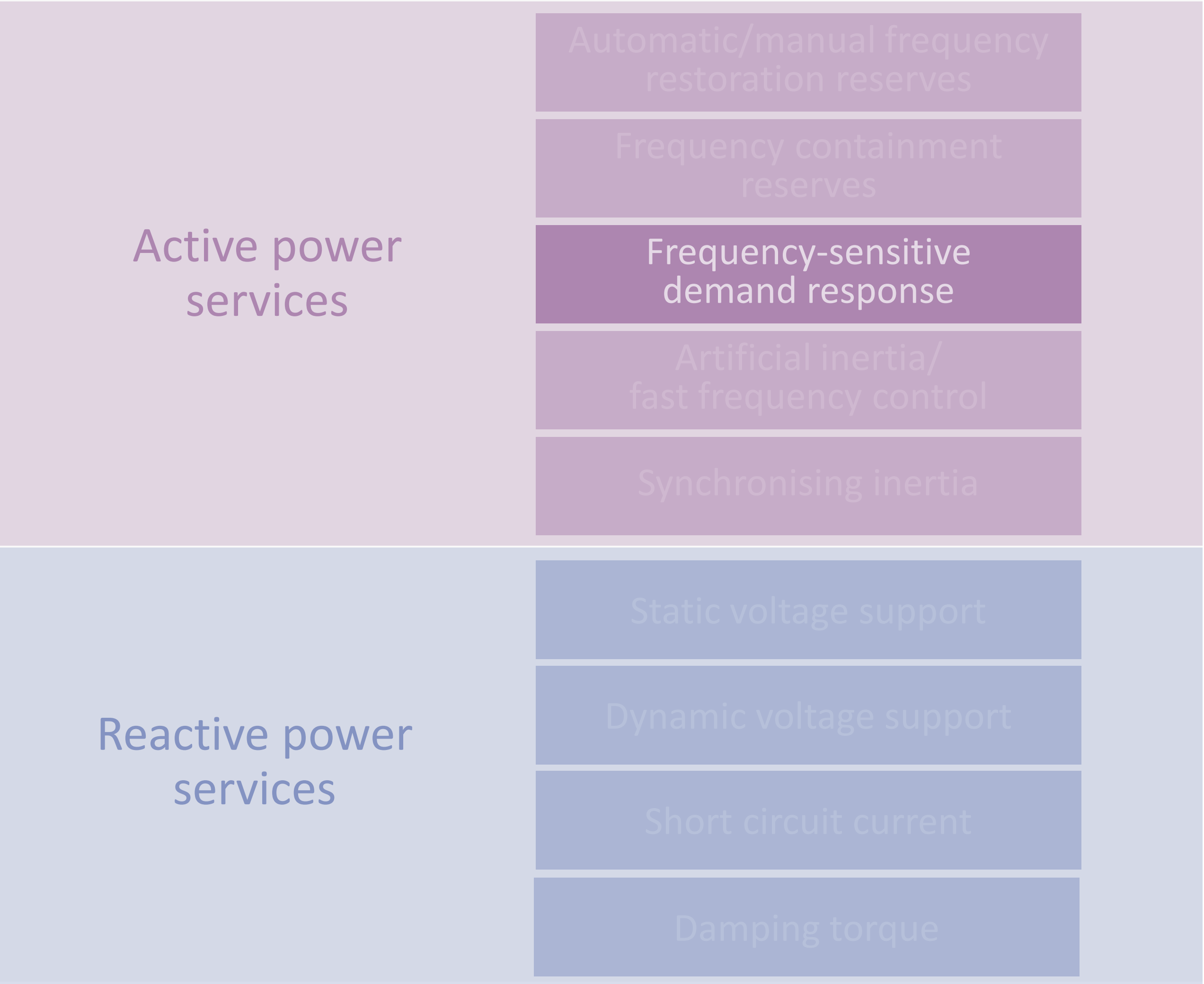
→ Wind and PV generators can be equipped with grid-forming converters to provide synchronising inertia when producing active power.

→ Equipping all wind and PV plants with grid-forming converters may be costly and delay the energy transition, especially if grid-forming requirements vary across Member States.

→ Additionally, if all new renewable generators were to provide active power system services, the interactions between these units could lead to risks for oscillatory and transient stability.

Active power services: ● can be provided ● cannot be provided Reactive power services: ● can be provided ● cannot be provided

Consumers

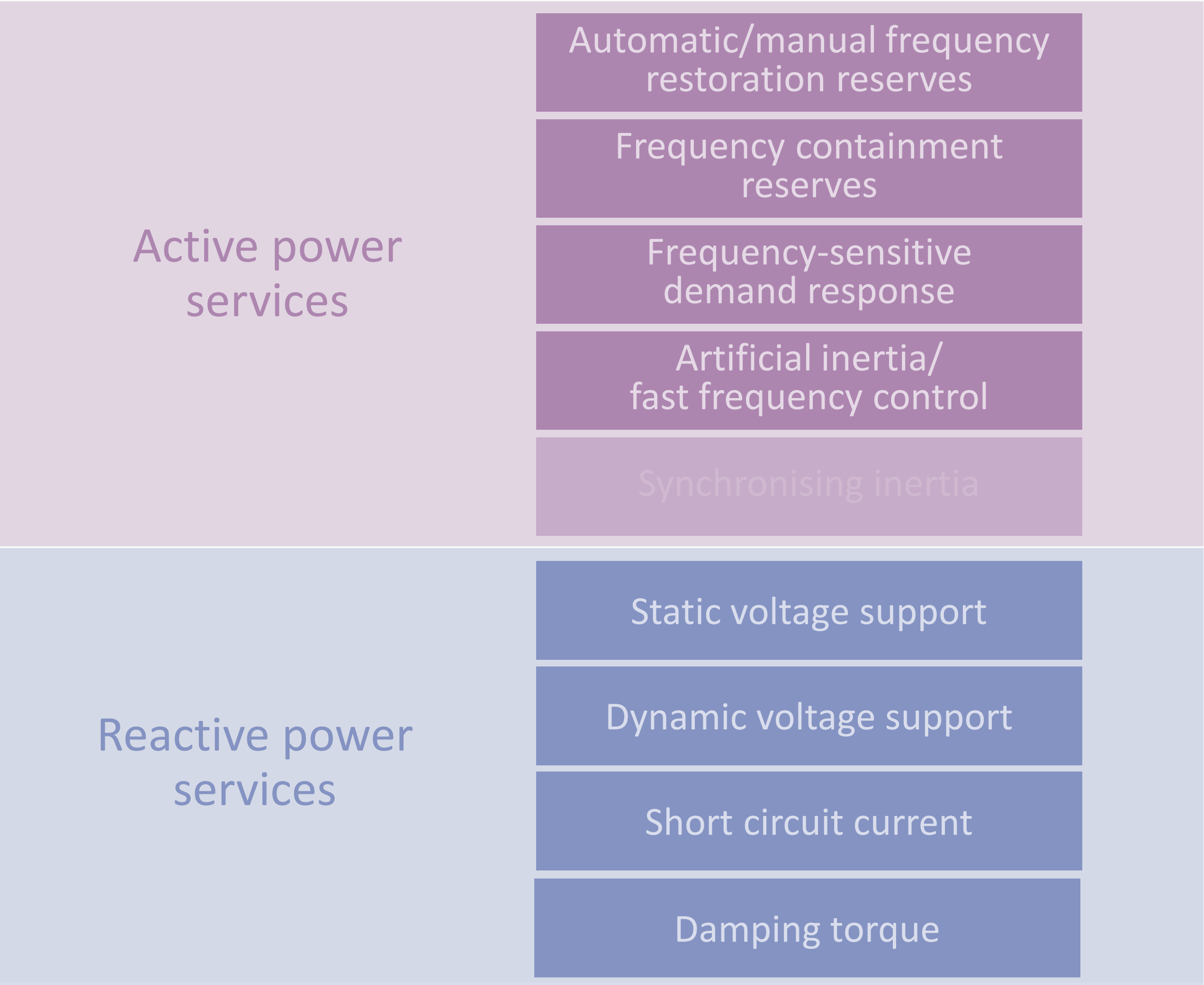


- → In the event of severe grid incidents, consumers can contribute to frequency support during underfrequency situations by quickly shedding loads.
- → Demand response from large industrial consumers like steel and aluminum plants or the chemical sector would mainly contribute to frequency sensitive demand response.

Active power services: ● can be provided ● cannot be provided

Reactive power services: ● can be provided ● cannot be provided

Controllable consumers



Active power services

- Automatic/manual frequency restoration reserves
- Frequency containment reserves
- Frequency-sensitive demand response
- Artificial inertia/ fast frequency control
- Synchronising inertia

Reactive power services

- Static voltage support
- Dynamic voltage support
- Short circuit current
- Damping torque

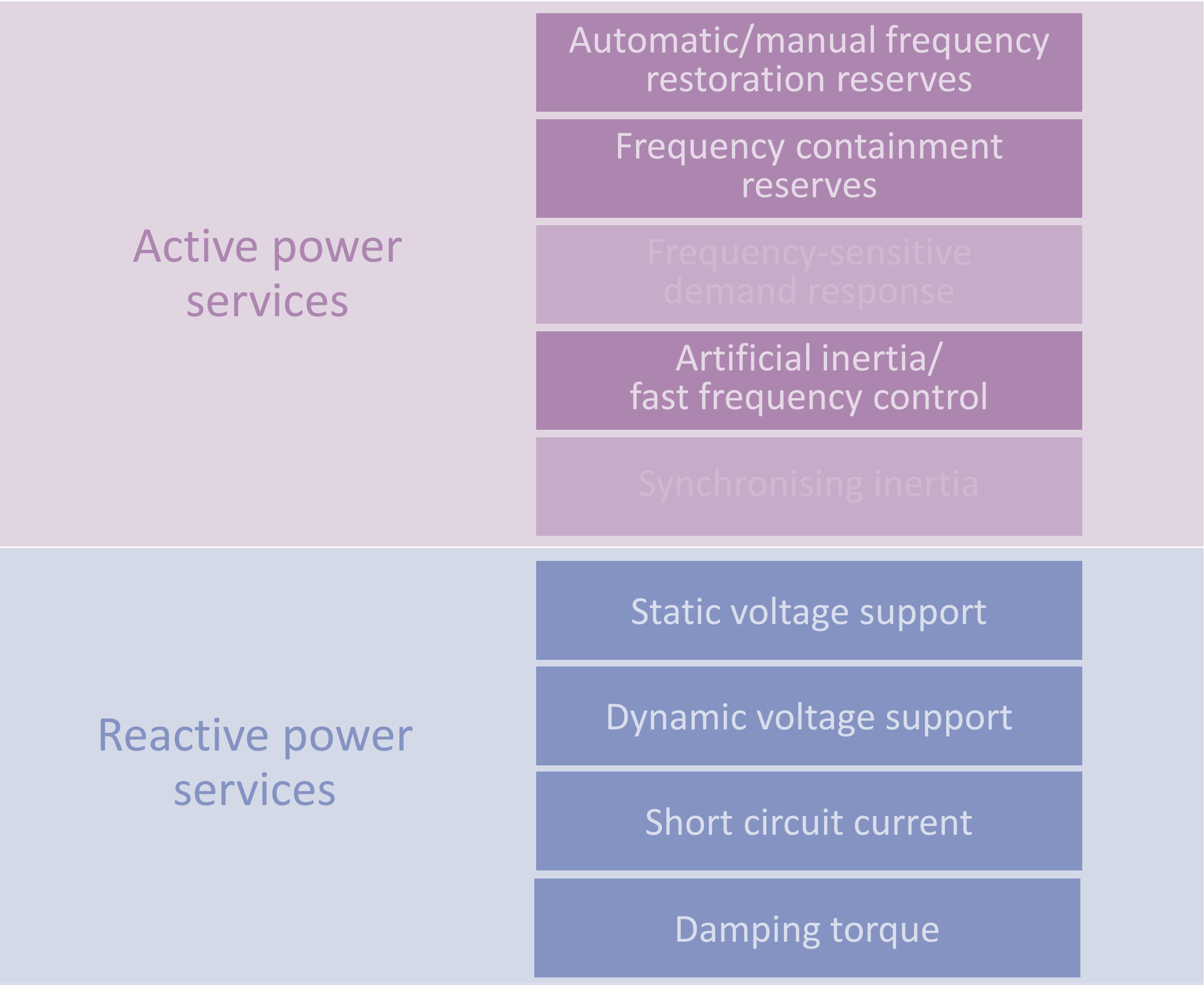
→ Demand response from e.g. electrolysers and heat pumps can be continuously controlled.

→ When connected with grid-forming inverters they can contribute to active power and voltage support services.

Active power services: ● can be provided ● cannot be provided

Reactive power services: ● can be provided ● cannot be provided

Utility-scale battery energy storage systems (BESS)

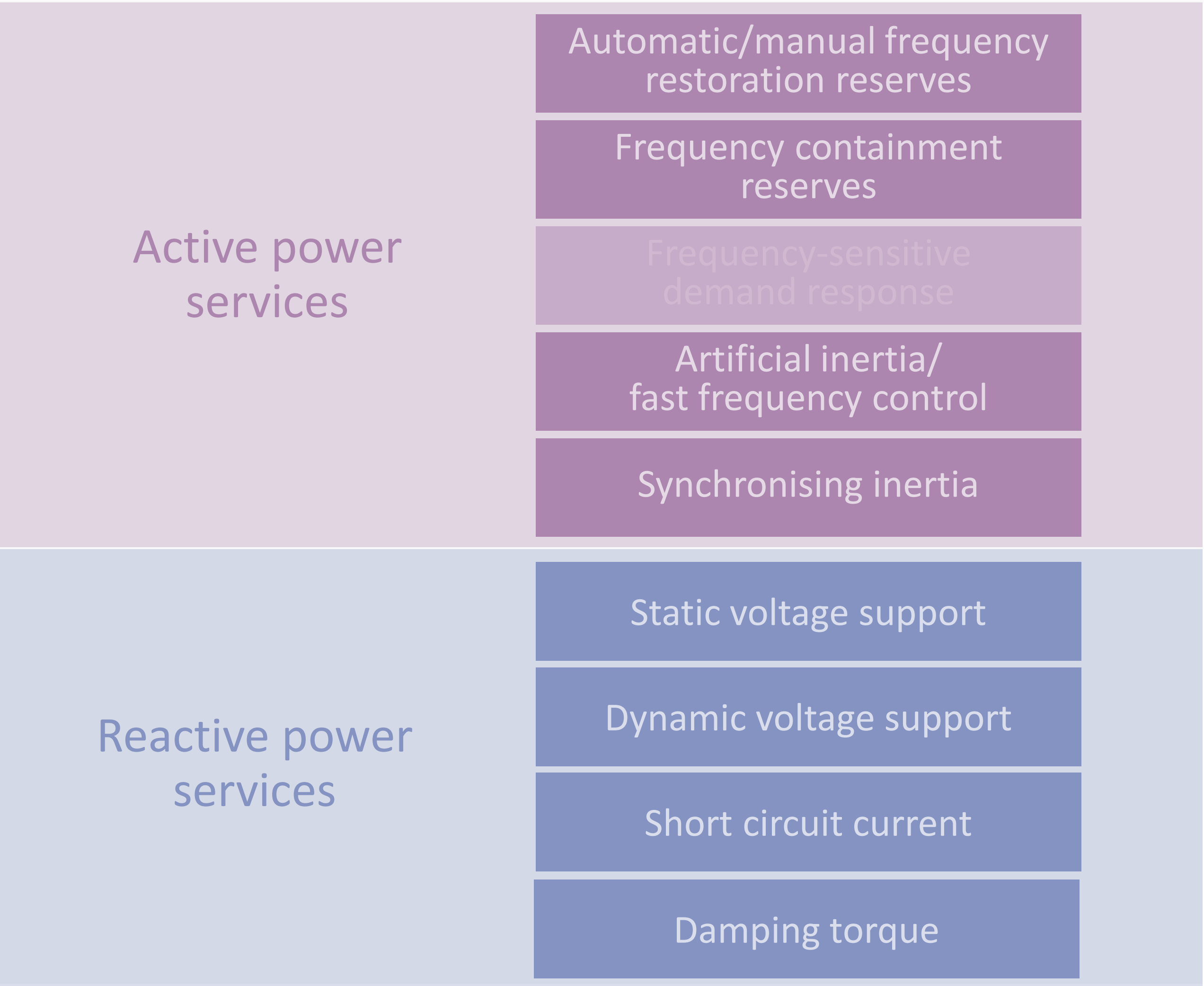


- → Batteries can provide most system services apart from synchronizing inertia in grid-following mode at moderate additional cost.
- → Batteries can provide reactive power services independent of state of charge while active power services depend on the state of charge.

Active power services: ● can be provided ● cannot be provided

Reactive power services: ● can be provided ● cannot be provided

Utility-scale BESS with grid-forming converter (GF-BESS)

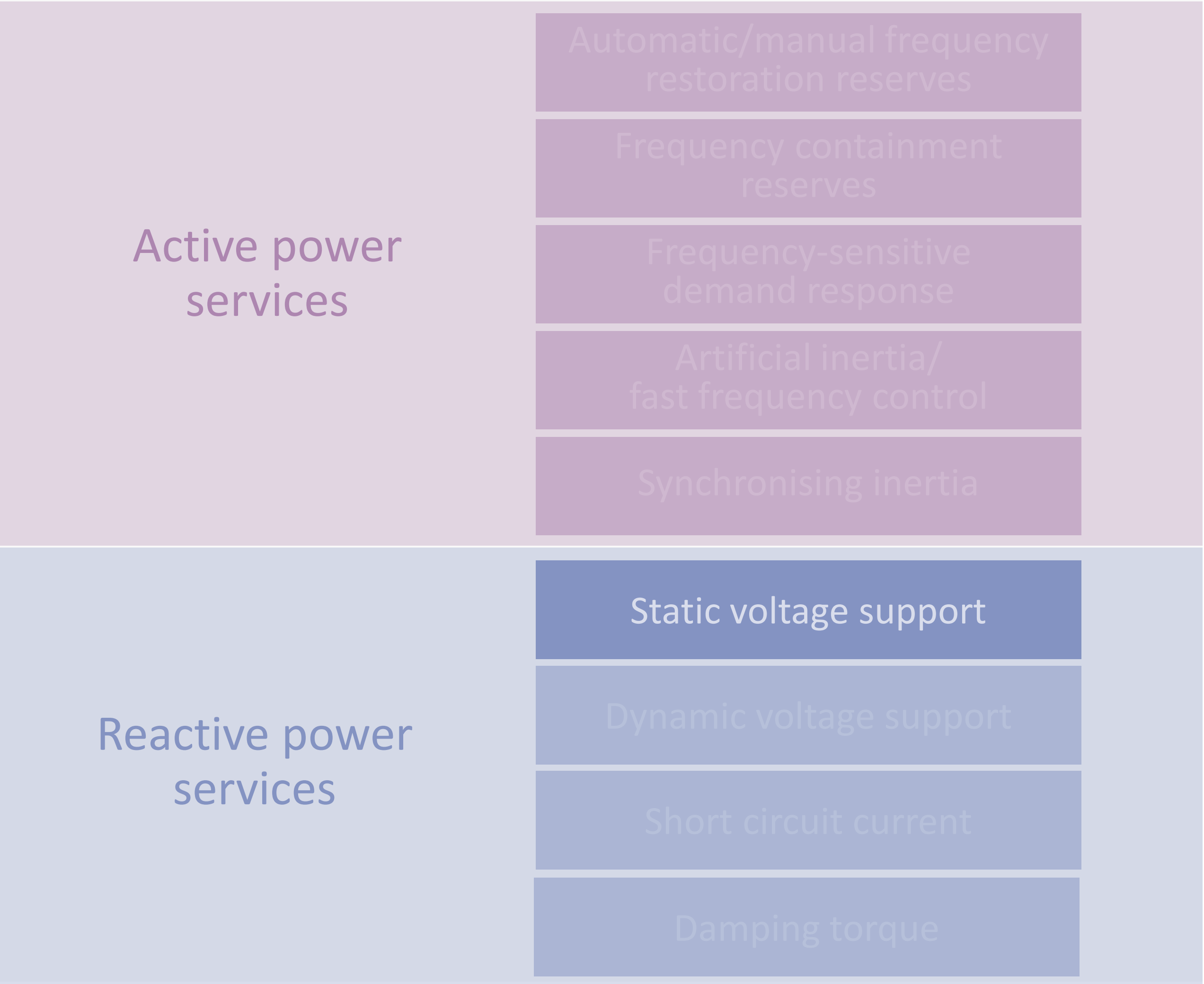


→ Batteries equipped with a grid-forming converter can provide all system services at moderate additional cost.

Active power services: ● can be provided ● cannot be provided

Reactive power services: ● can be provided ● cannot be provided

Mechanically switched capacitors with damping network (MSCDN)

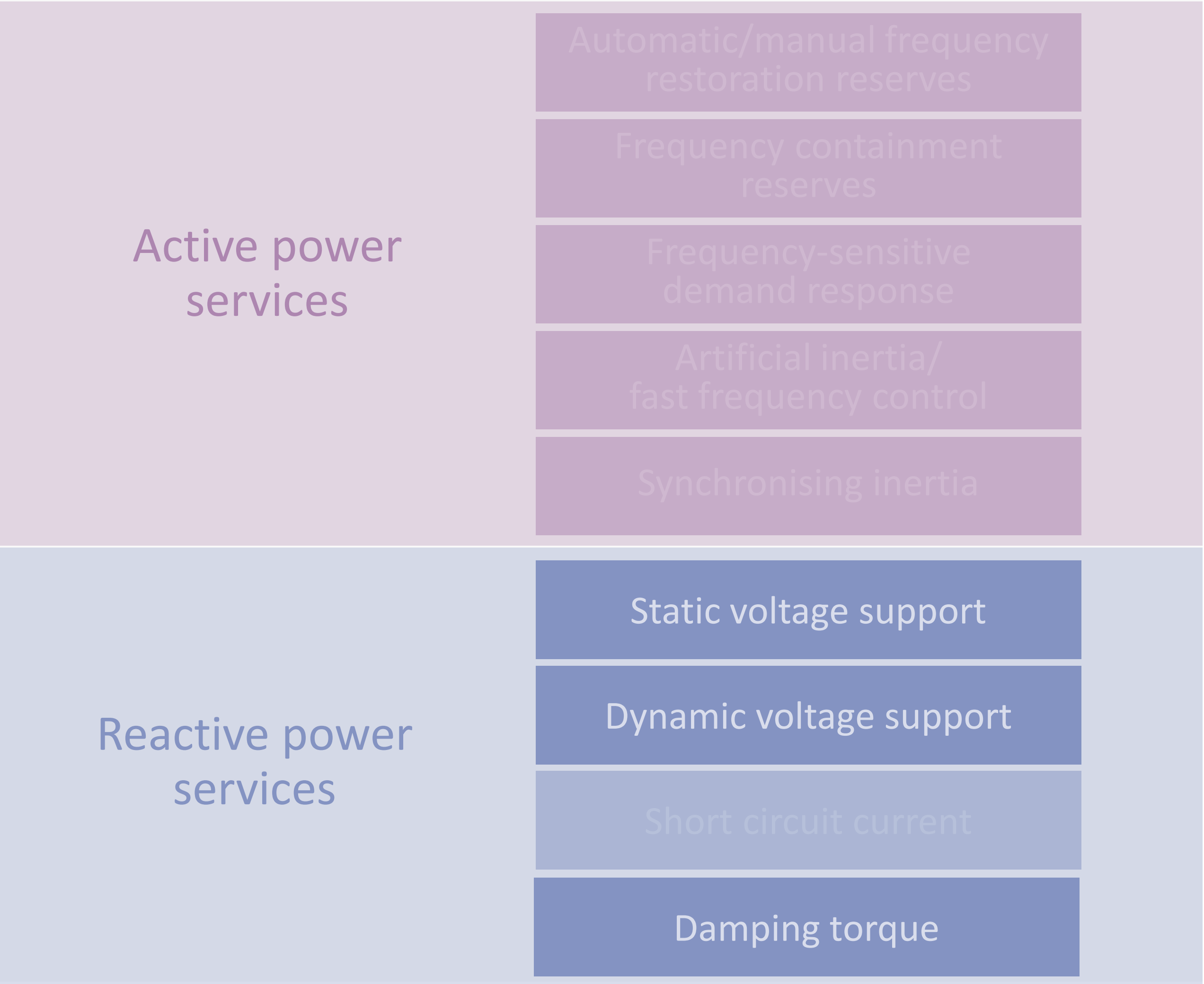


- → MSCDNs, usually regarded as grid assets, are devices to support voltage stability. They use capacitors to provide reactive power to reduce sudden voltage changes. They are switched on or off mechanically according to grid requirements.
- → MSCDN can provide static voltage support but not dynamic voltage support as they are mechanically switched, which takes time.
- → MSCDN can help balance reactive power requirements in the long term especially for periods with high demand.
- → MSCDN are highly effective at providing bulk reactive power compensation at low cost.

Active power services: ● can be provided ● cannot be provided

Reactive power services: ● can be provided ● cannot be provided

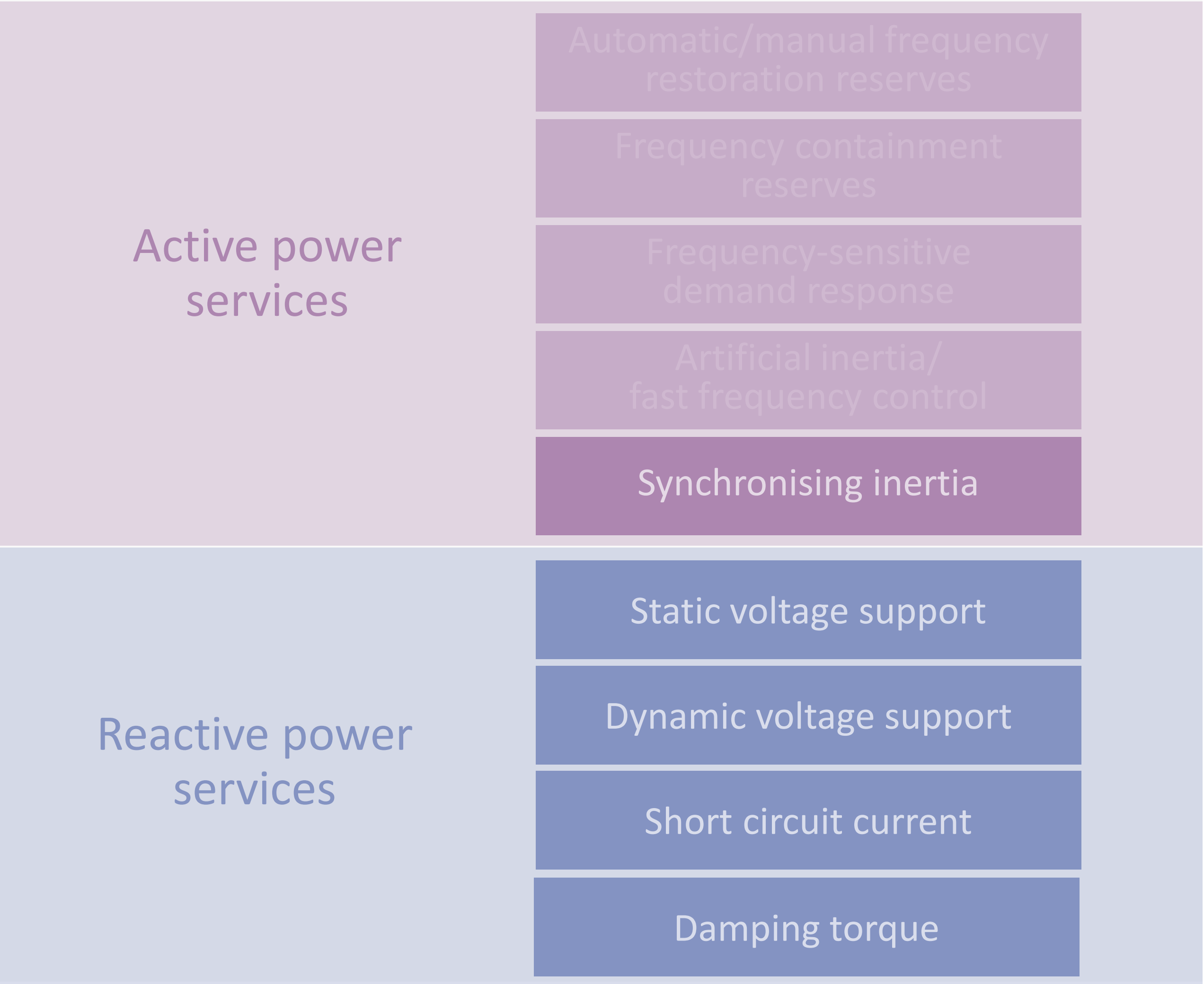
STATCOM (static synchronous compensators) and HVDC-VSC (voltage sourced converters)



- → STATCOMs (Static Synchronous Compensators) are dynamic reactive compensation devices based on power electronic converters (voltage-sourced converters/VSC). They are usually installed and operated by the TSOs.
- → STATCOMs can respond to voltage fluctuations within milliseconds and offer a broad reactive power range. They are particularly useful in grids with high levels of renewable energy. HVDC-VSC systems can independently regulate both active and reactive power, providing superior control over grid stability, voltage, and power flow.
- → STATCOMs provide reactive power and voltage support, but they do not contribute to active power balancing or frequency regulation.

Active power services: ● can be provided ● cannot be provided   Reactive power services: ● can be provided ● cannot be provided

STATCOM with grid-forming converter and energy storage (E-STATCOM)

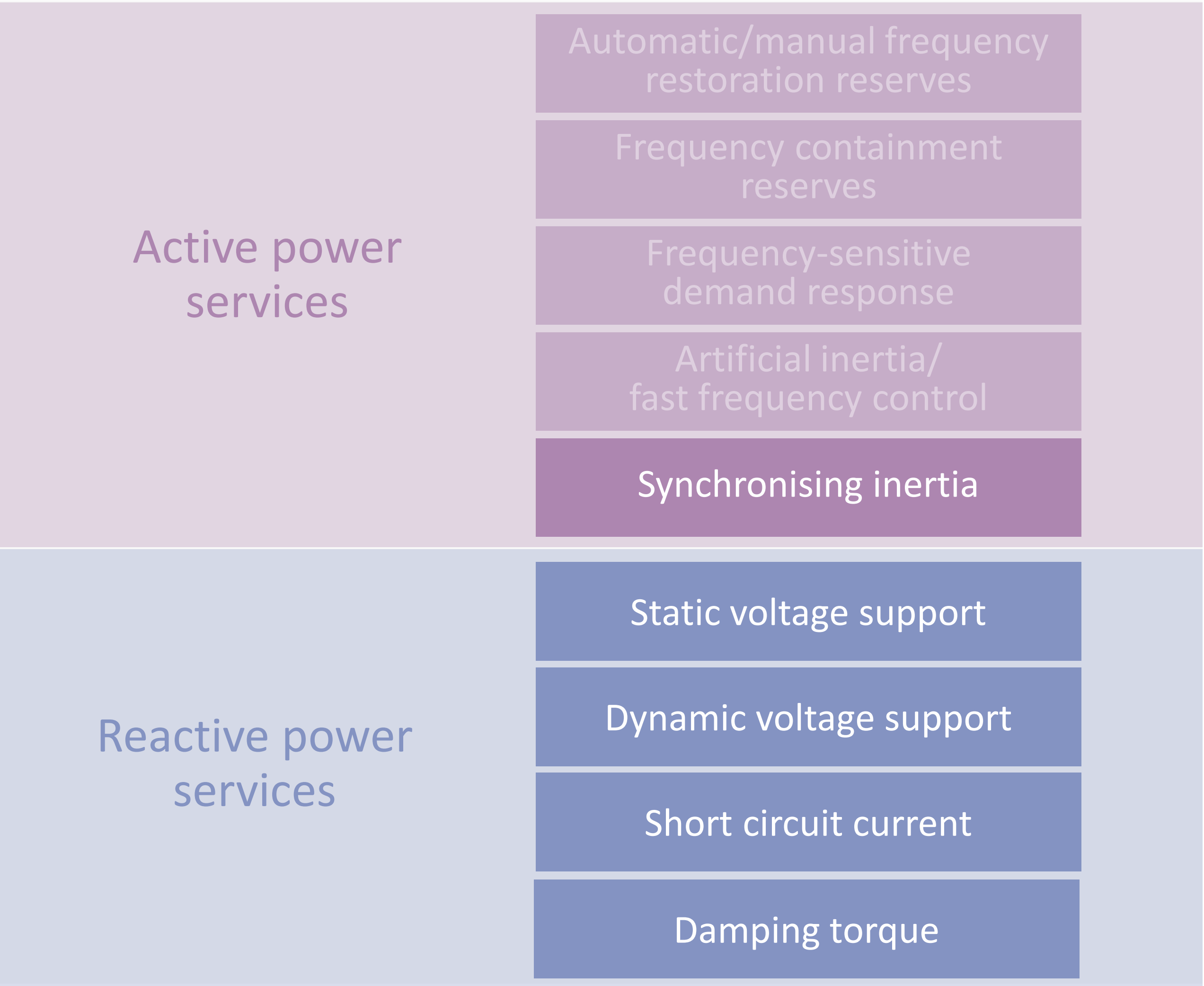


- → Combining a STATCOM with a grid-forming converter and a static energy storage device (e.g. super-capacitors) makes it possible to provide short-term active power services like artificial inertia or fast frequency control. With a grid-forming converter, an E-STATCOM ("Energy-STATCOM") can provide synchronising inertia. It is therefore fully comparable to a synchronous condenser. Such combinations are usually installed and operated by the TSOs.
- → The integration of energy storage significantly increases the cost of an E-STATCOM compared to traditional STATCOMs or synchronous condensers.

Active power services: ● can be provided ○ cannot be provided

Reactive power services: ● can be provided ○ cannot be provided

Synchronous condenser



- → A synchronous condenser is a synchronous machine without a turbine. It can provide reactive power services and inertia (like an E-STATCOM). Synchronous condensers can be optimised for the delivery of system services.
- → Synchronous condensers provide physical inertia through their rotating mass, helping to stabilise grid frequency during disturbances by slowing the rate of frequency change (RoCoF). They also offer dynamic and continuous reactive power services, helping voltage regulation across the grid.
- → When decommissioning a power plant, the synchronous condenser can remain connected to the system to provide system services.

Active power services: ● can be provided ● cannot be provided

Reactive power services: ● can be provided ● cannot be provided

Power stability in grid-forming and grid-following capabilities

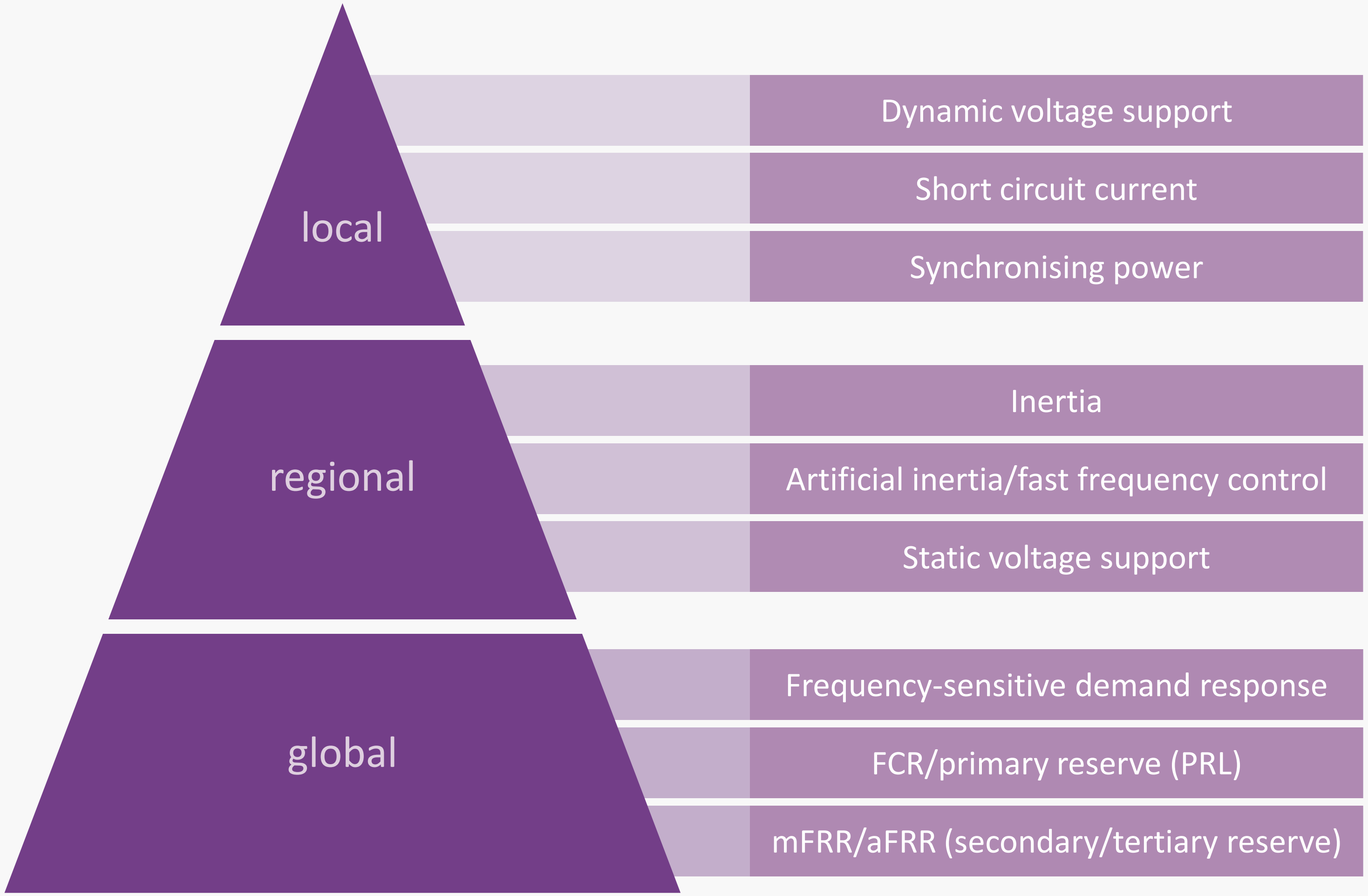
	Primary Functions	Role in Frequency and Voltage Control	Inertia and Stability Contribution	Synchronisation and Dependency on Grid Conditions	Issues and risks
Grid-forming	Establishes and maintains grid frequency and voltage, acting as a reference point for other generators.	Directly controls both frequency and voltage, providing essential grid services like frequency regulation and voltage support.	Provides inertia through synchronous machines or virtual inertia (in the case of inverter-based systems), which is crucial for stabilising the grid during disturbances.	Able to create the grid and capable of operating in isolated or islanded modes.	Grid-forming capability is not yet sufficiently defined. Additional requirements add costs. Uncertainty about grid impact if all new generators are equipped with grid-forming capability.
Grid-following	Synchronises to the existing grid frequency and voltage using phase-locked loops, and follows the grid parameters.	Depends on an external reference from the grid; lacks autonomous voltage & frequency-setting capability.	Minimal inertia support, as they synchronise to existing grid inertia but do not contribute directly.	Fully reliant on the grid for synchronisation; cannot operate independently.	The grid may become unstable if too many devices are connected only providing grid-following capability.

Summary of technologies supporting system stability

Technologies	Automatic/ manual Frequency Restoration Reserves	Frequency Containment Reserves	Frequency-sensitive demand response	Artificial inertia / Fast frequency control	Synchronising inertia	Static voltage support	Dynamic voltage support	Short circuit current	Damping torque
Synchronous machine power plants	x	x			x	x	x	x	x
Wind and PV generators	x	x				x	x	x	x
Wind and PV generators with grid-forming converter	x	x			x	x	x	x	x
Consumers			x						
Controllable consumers	x	x		x	x	x	x	x	x
Utility-Scale Battery Energy Storage Systems (BESS)	x	x		x		x	x	x	x
BESS with Grid-Forming Converter (GF-BESS)	x	x		x	x	x	x	x	x
Mechanically Switched Capacitors (MSC/MSCDN)						x			
STATCOM (Static Synchronous Condensators) and HVDC-VSC						x	x		x
STATCOM with Grid-Forming Converter and Energy Storage (E-STATCOM)					x	x	x	x	x
Synchronous Condenser					x	x	x	x	x

Strategies to ensure the stable operation of future power systems

Global, regional and local provision of system services



local

- Dynamic voltage support
- Short circuit current
- Synchronising power

regional

- Inertia
- Artificial inertia/fast frequency control
- Static voltage support

global

- Frequency-sensitive demand response
- FCR/primary reserve (PRL)
- mFRR/aFRR (secondary/tertiary reserve)

Frequency related system services can be provided anywhere in a synchronous area and are organised in EU-wide markets.

Inertia and static voltage support can be provided on national/regional level.

Voltage related system services need to be provided at specific locations (busbar level).

Strategies to ensure sufficient capacities for providing system services are available

System service markets

Markets to procure system services either through existing or new-built assets. The markets could be shorter term if existing capacities are available or longer term if they need to trigger investments. Costs are recovered through the market, which is financed by grid tariffs.

Compulsory services

Requirement for new renewables, batteries and/or (hydrogen-ready) gas power plants to provide system services, either included in individual tender specifications or generally in European or national grid codes. Costs are recovered through higher prices for the investments, leading potentially to higher wholesale electricity prices.

System operators invest in technical components

System operators invest in assets (E-Statcoms, MSCDNs, synchronous condensers) that can provide system services or agree bilateral contracts to provide system services. System operators recover their costs through the grid tariffs.

Examples for system service markets: frequency containment reserves and UK Pathfinder Programme

Frequency containment reserves

- → The Austrian, Belgian, Czech, Danish, Dutch, French, German, Slovenian and Swiss TSOs together form the FCR cooperation currently procuring their FCR in a common market.
- → The FCR Cooperation organises currently daily auctions with four-hour symmetric products. The auction applies to the next delivery day.

UK stability pathfinder programme

National Grid ESO's Stability Pathfinder Programme included tenders and long-term contracts for inertia, reactive power, voltage control and fast frequency response:

- → Phase 1 focused on synchronous condensers and novel stabilising services.
- → Phase 2 addressed the system services required due to the higher concentration of renewables in Scotland.
- → Phase 3 aimed to enhance inertia and short-circuit capacity in England and Wales.

Example for compulsory services: network code on requirements for generators, 2016

Grid connection requirements for different types of generators

	Type A	Type B	Type C	Type D
General Require-ments	Basic operational and performance standards	Enhanced reactive power support	Comprehensive, including dynamic grid responses	Most stringent, fulfilling all applicable articles
Voltage Stability	No specific requirements	Basic reactive power support	Detailed reactive power profiles, including specific U-Q/Pmax and P-Q/Pmax profiles for reactive power provision at varying capacities.	Similar to Type C, may have fewer profiles
Grid-Forming Capability	Not applicable	Limited operational stability	Enhanced requirements for synthetic inertia and connection stability under dynamic conditions.	Requirements for contributing to frequency stability and synthetic inertia are robust, aligning with high-performance standards.
Damping Control	Not Applicable	Some requirements for power oscillation damping, but less stringent than Type C and D.	Strong requirements for power oscillation damping, with capabilities specified for inter-area oscillations.	Explicit focus on power oscillation damping, including following requests from TSOs.

Generators are categorised based on their size, capabilities, and impact on the grid:

- → **Type A:** Small-scale generators, with limited automated responses, like small solar installations or rooftop photovoltaics.
- → **Type B:** Larger generators, with enhanced capabilities for dynamic grid responses. Examples include medium-sized wind farms or combined heat and power (CHP) units.
- → **Type C:** Highly controllable generators that ensure grid stability by providing real-time dynamic responses, such as large wind farms or utility-scale solar plants.
- → **Type D:** High-voltage plants with significant grid impact, responsible for system-wide stability, like large coal or gas power plants or offshore wind farms.

Note: Pursuant to Article 5 (Determination of Significance) of Requirements for Generators (RfG), the Proposals for the maximum capacity thresholds for Types B, C, and D power-generators must be approved by the relevant regulatory authority or, if applicable, the Member State.

Example for system operators investing in technical components: German grid development plan

Authorised investments for system stability according to German grid development plan 2023

	Transnet BW	**50Hertz**	**TenneT**	**Amprion**
Static inductive reactive power (Gvar)	0.75	7.10	3.72	3.20
Static capacitative reactive power (Gvar)	3.25	5.10	5.40	5.70
Dynamic reactive power (Gvar)	1.70	3.90	6.30	2.40
Inertia (GJ)	14.00	25.38	107.88	30.75

The German regulator, Bundesnetzagentur, confirmed investments by the four German TSOs in technical assets to maintain system stability within the network development plan 2023 in the timeframe from 2023–2037/2045.

Summary

Summary (1/3)

- → Under the clean energy transition, wind and solar power plants and batteries gradually replace fossil-based power plants.
- → Conventional generation methods (gas, coal, lignite, nuclear, hydro), with their synchronously connected rotating masses, automatically contribute to voltage and frequency related system services when dispatched.
- → Renewables-based generation, which is connected asynchronously via inverters*, can provide voltage related system services, but it is more complex for them to provide frequency related services.
- → Renewable electricity will be transmitted over longer distances, as renewables are connected at more remote locations, and the infrastructure will be more heavily utilised; therefore the characteristics of the power system and the associated type and volume of system services required will change.
- → Furthermore, the nature of other stability phenomena, like rotor angle stability or resonance stability, will change due to the massive integration of renewables. The impacts of these changes can be both positive and negative, and it is therefore very important to properly assess the stability of the future power system.

*Inverters are a specific type of converter that focuses on DC to AC conversion. Inverters can be grid following or grid forming. Converters are devices broadly defined as systems used to transform electrical power from one form to another.

Summary (2/3)

- → The electricity system needs to be reliable, secure and stable, meaning that the system needs to be able to operate in the long term and to have the capacity to recover from disturbances and remain stable in the event of incidents. To ensure system stability, frequency and voltage need to be maintained within their operational limits and transient and oscillatory stability aspects need to be taken into consideration.
- → Frequency stability requires frequency containment and frequency restoration services, as well as inertia and synchronising inertia. Voltage stability, transient and oscillatory stability all require a combination of static and dynamic voltage support as well as short-circuit current and synchronising inertia.
- → System services can be provided by thermal and renewable power plants, utility-scale batteries and technologies such as static synchronous compensators (with battery storage), static VAR compensators and synchronous condensers.
- → Thermal and hydro power plants and utility-scale batteries can provide frequency and voltage related system services with limited modifications. Thermal and hydro power plants can be equipped with a clutch so they can operate in synchronous condenser mode when not producing active power. Batteries may need to be connected via a grid-forming inverter to provide system services.

Summary (3/3)

→ Renewable power plants can provide voltage related system services in all situations. To provide frequency related system services, they can be regulated downward, their production can be curtailed so they can be steered in both directions, or they can be supplemented with batteries. In order to provide synchronising inertia, renewables need to be connected via so-called grid-forming inverters*. For wind turbines, the provision of frequency/active power system services may increase wear, which might require adjusting the design of the turbines, thereby increasing costs for designing, producing, marketing and maintaining them. Additionally, if all new renewable generators were to provide active power system services, the interactions between these units could lead to risks for oscillatory and transient stability.

→ To ensure sufficient system services are available, system operators have several options. They can connect static VAR compensators, synchronous condensers and static synchronous compensators to their grid; they can add requirements in public tenders for utility-scale batteries to be equipped with grid-forming inverters and for new thermal power plants to be equipped with a clutch; they can auction specific system services at specific locations to identify the most cost-efficient sources for system services; and they can introduce general connection requirements (selectively or universally) for new generator types via grid and network codes.

*Grid forming inverter – Grid-forming inverters are advanced inverters that can create and maintain a stable voltage and frequency on the grid, even without help from traditional power plants. They act like virtual generators, providing the stability and control needed for a reliable power system, especially with high levels of renewable energy.

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