The potential of system services and power electronics components to support the stability of the German grid

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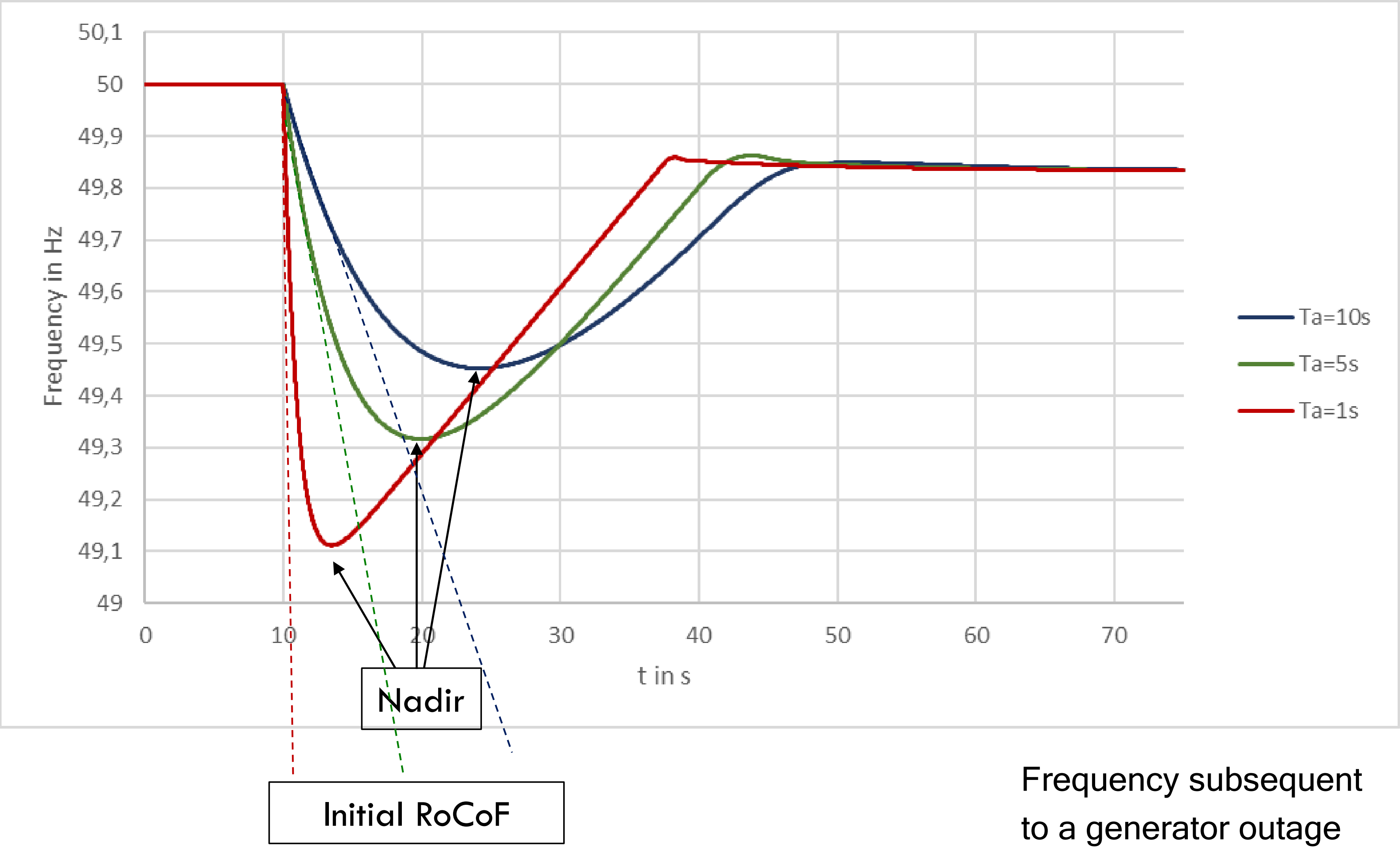
Stability of power systems (IEEE/CIGRE 2004)

Stability type	Determining factors	Extent
Frequency stability	• Active power balance • Inertia and frequency control	Global, system-wide
Rotor angle stability	• Synchronizing power and damping • Large power transfers	Local, regional, system-wide (depends on the grid structure)
Voltage stability	• Reactive power balance • Large power transfers	Local, regional (depends on the grid structure).
Resonance-stability	• Controller response • Multi-frequency network characteristics	Local

Frequency Stability - Example



Simulation of generator outages (3000MW) with different inertias

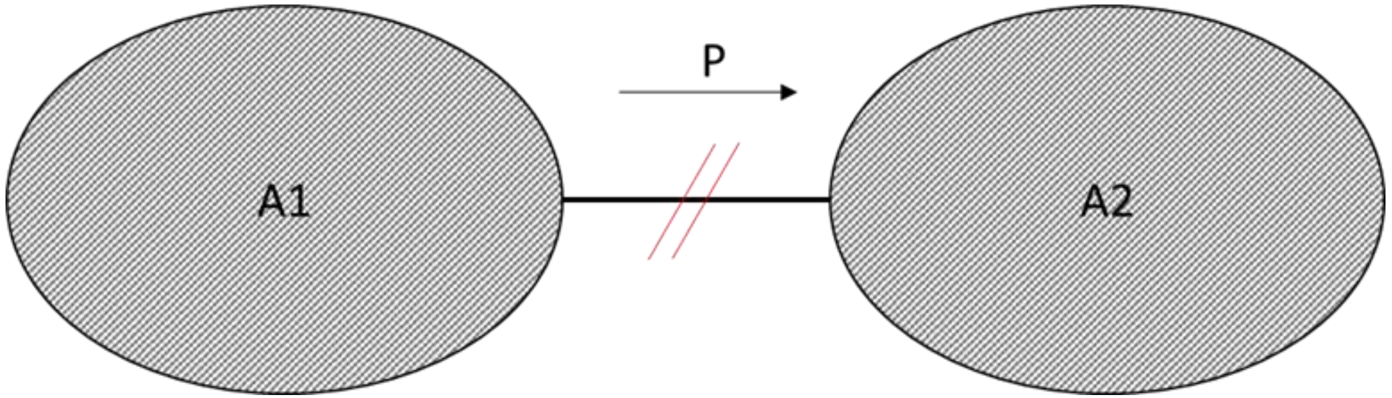
Source: M.P.E.

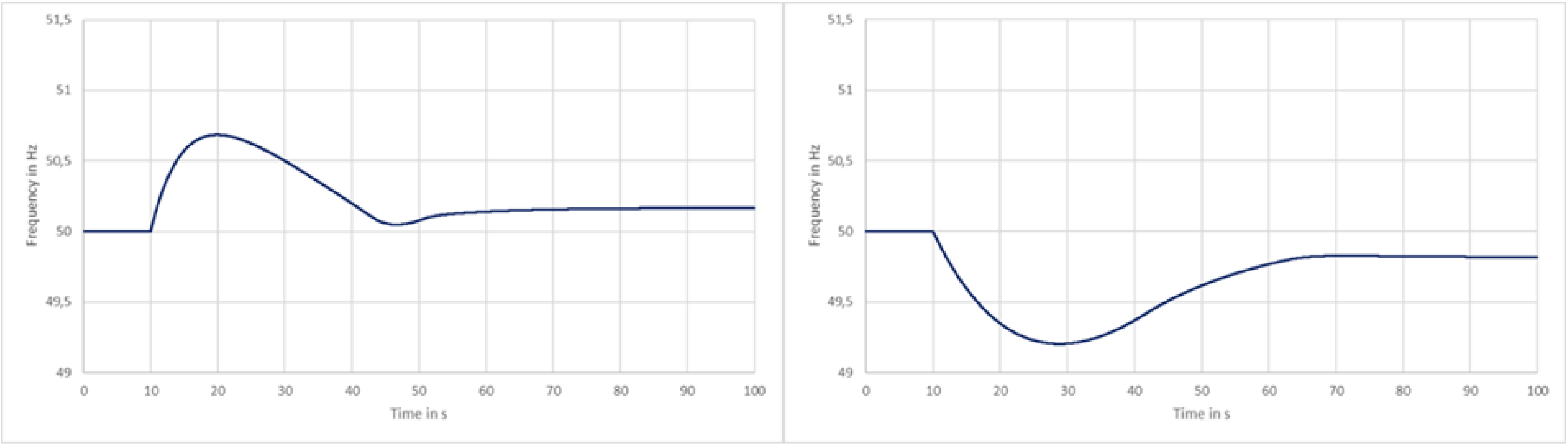
Frequency subsequent to a generator outage

Frequency Stability - System Split - Example

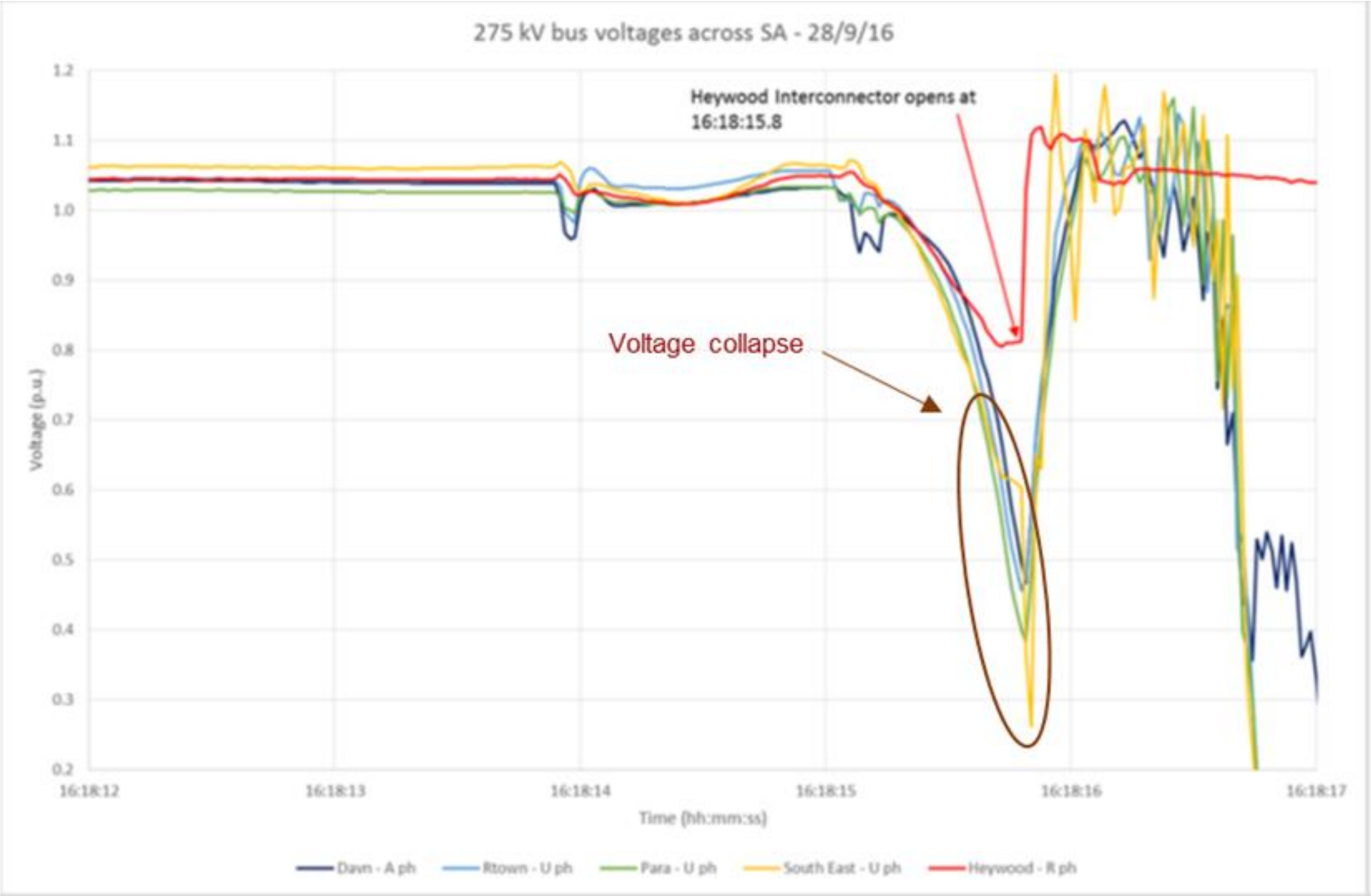
Simulation of system split between two areas

Source: M.P.E.





Voltage Stability - Example

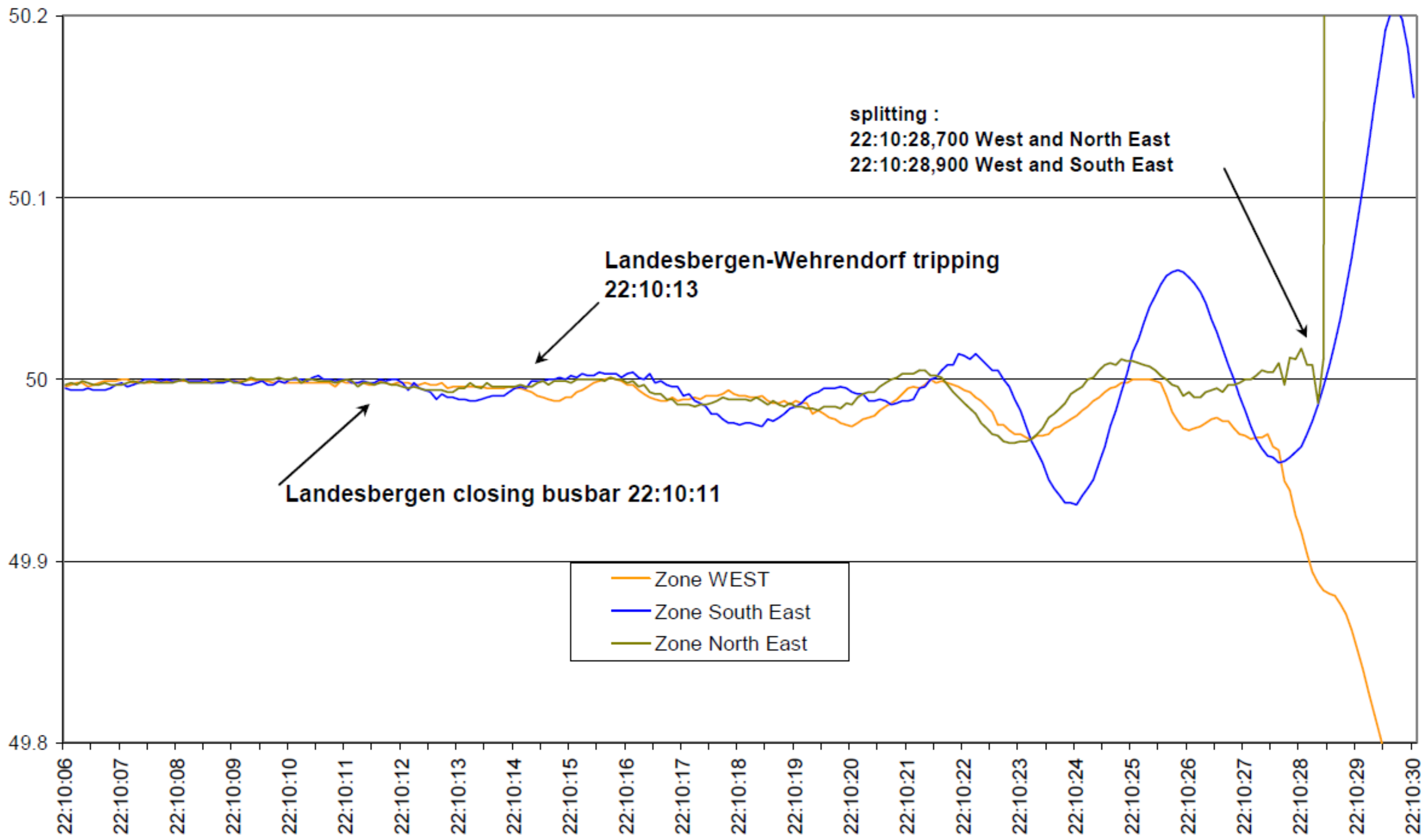


Voltages around the Heywood Interconnector leading to a separation of the South Australian power system (and a subsequent black-out of it).

System black event, South Australia, September 2016.

Source: AEMO

Oscillatory Stability - Example



Frequencies in the Continental European System prior to the system split event on November 4th, 2006

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

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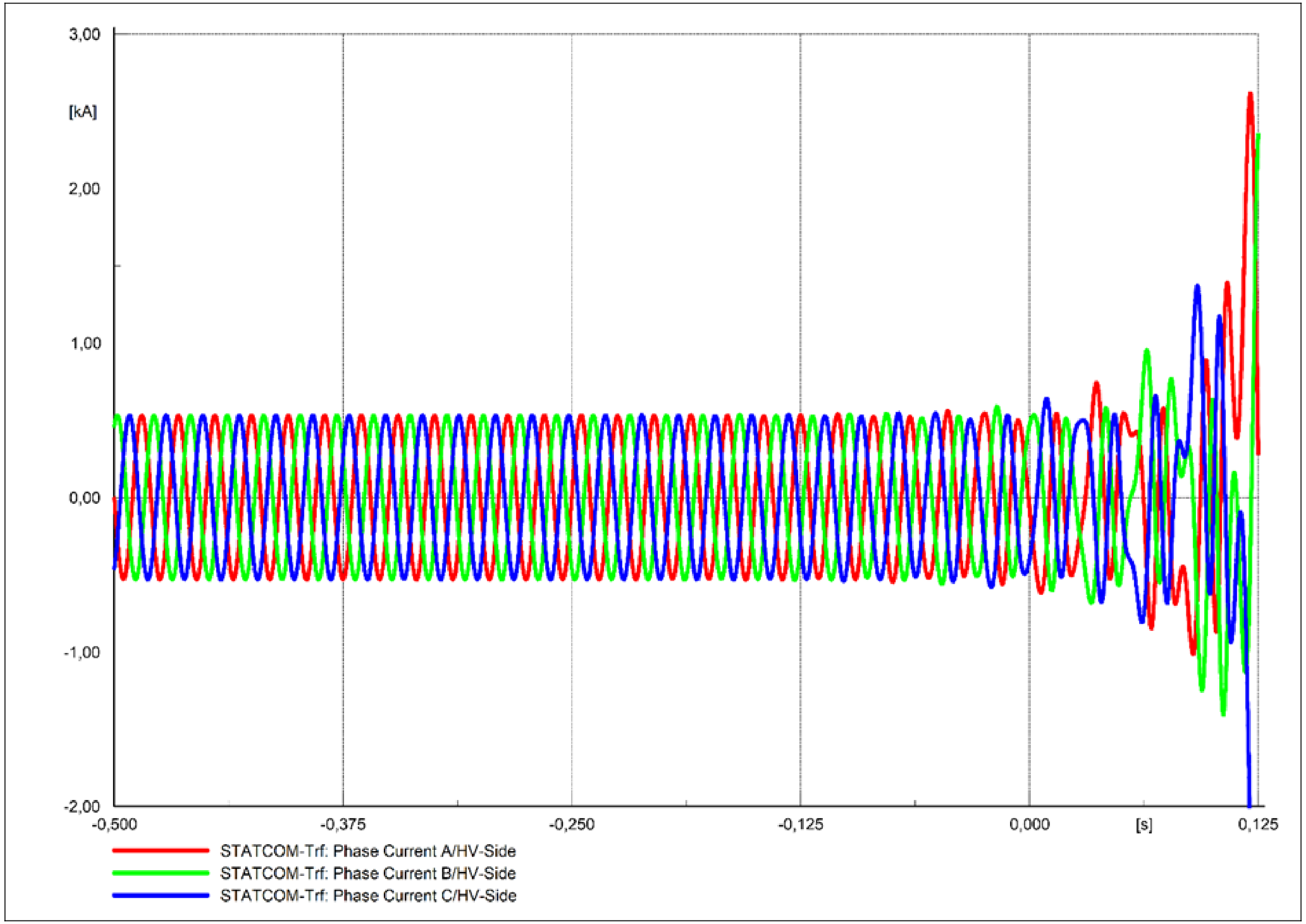
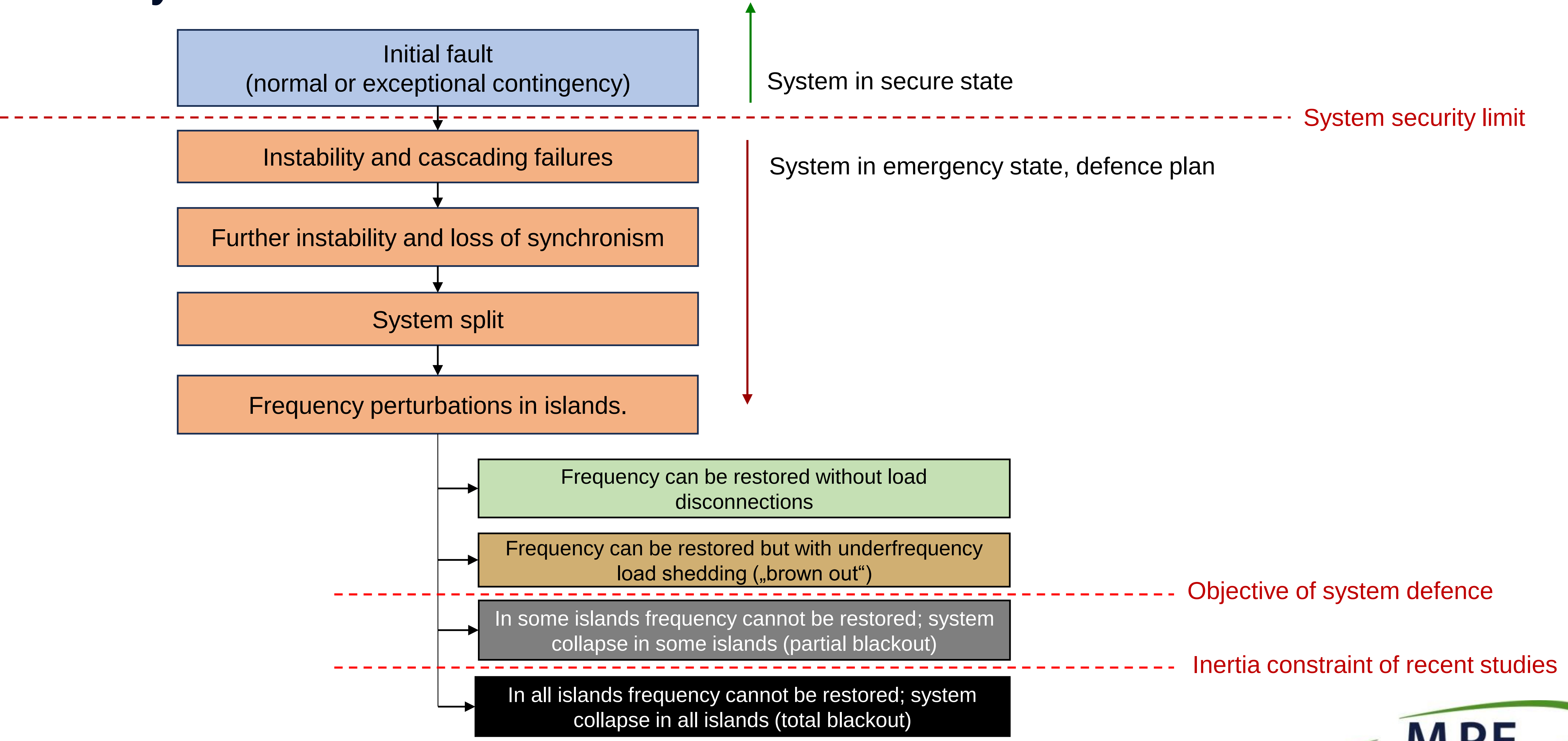
Controller Instability - Example



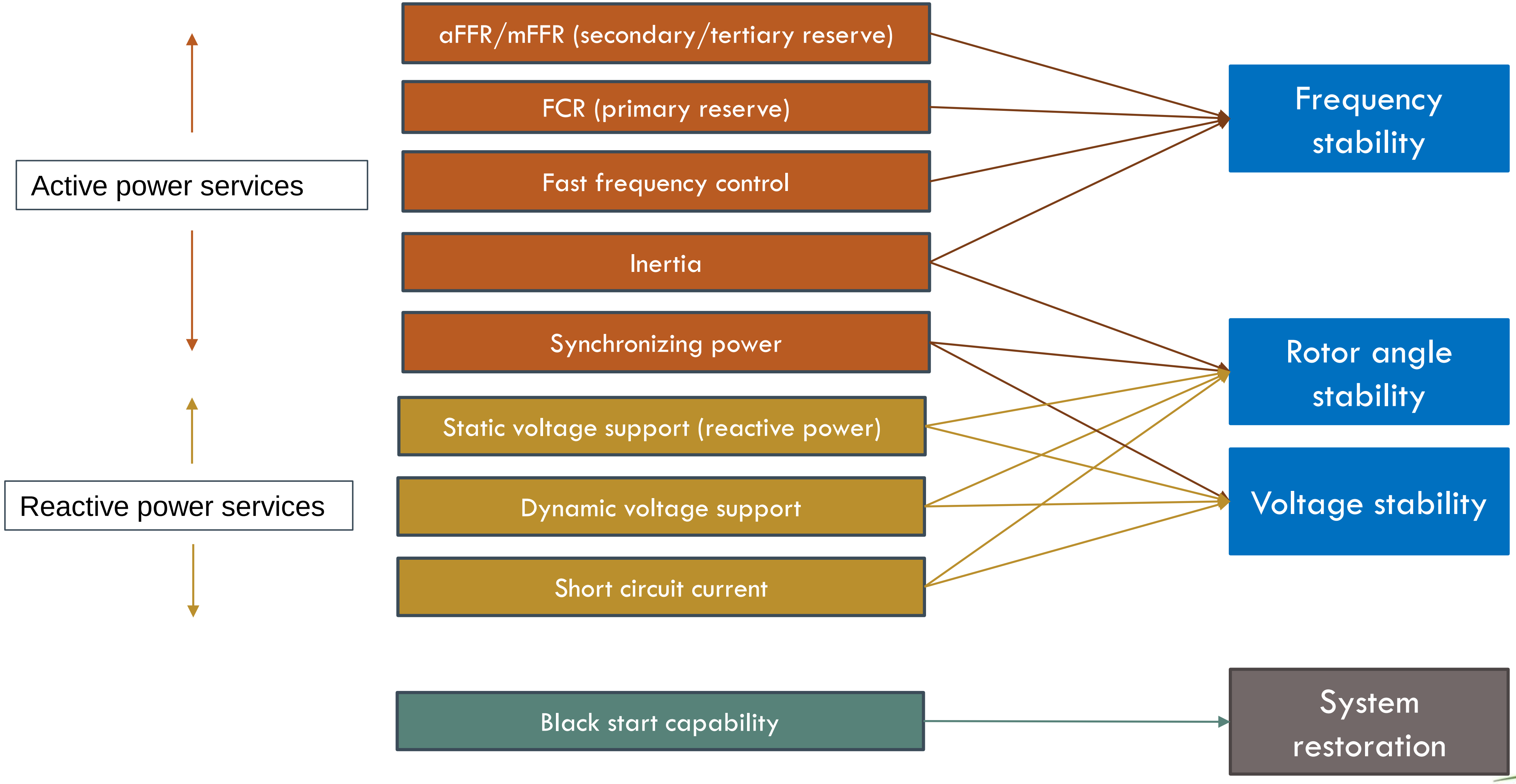
Simulation of STATCOM with grid-forming converter connected to a weak grid

Source: M.P.E.

System defense

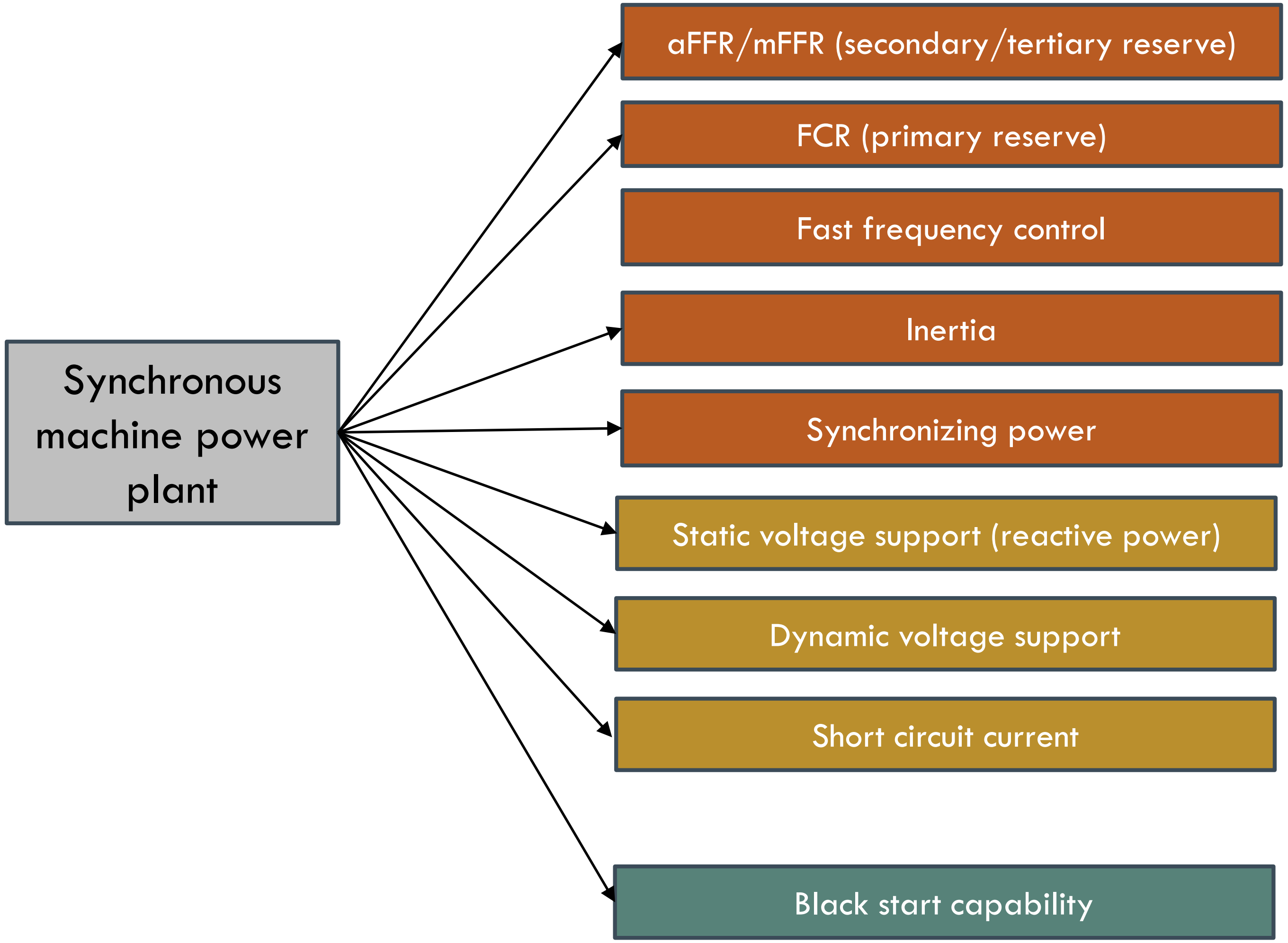


Stability and system services



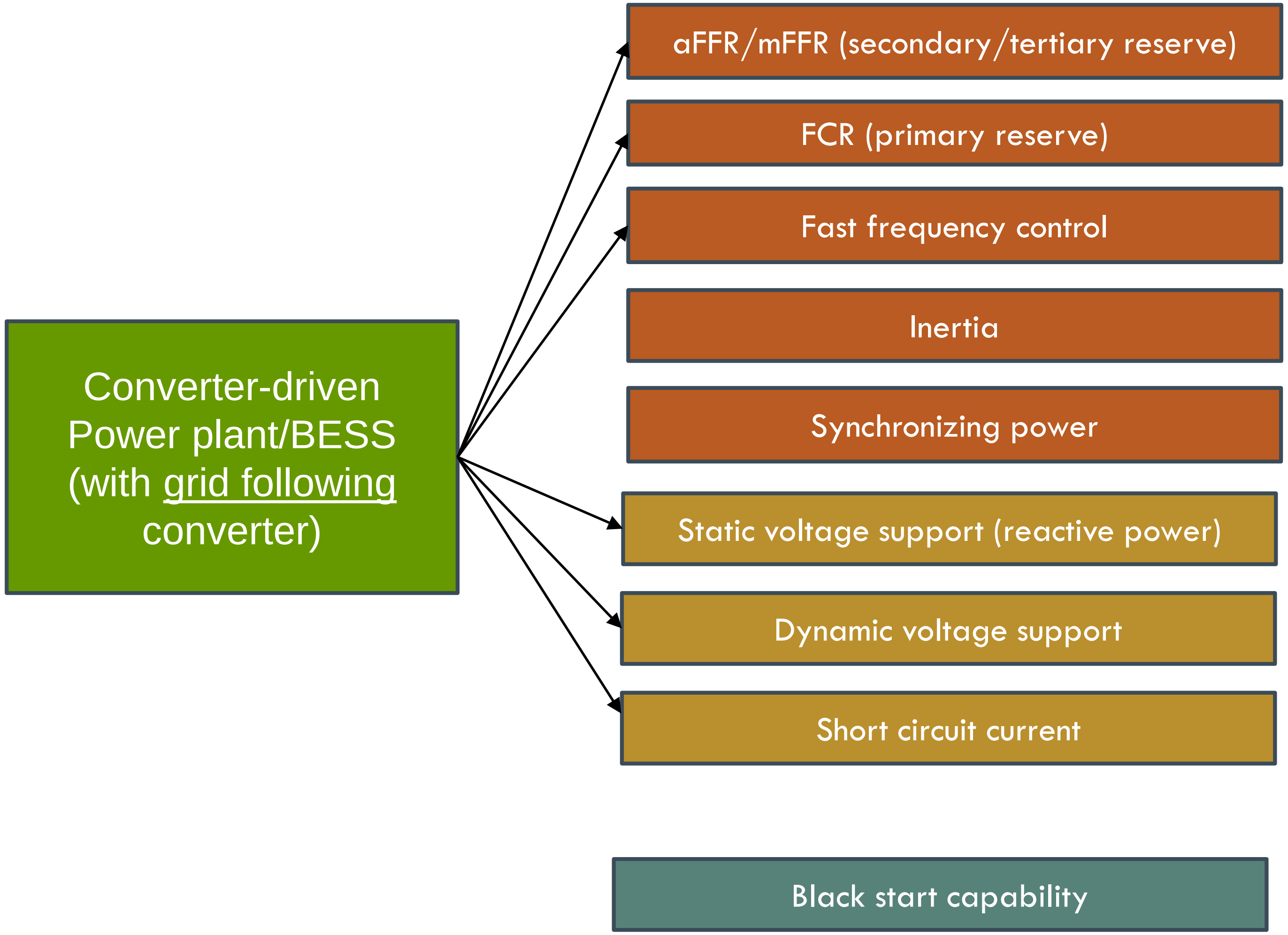
System services to support the stability of the German Grid

Stability and system services



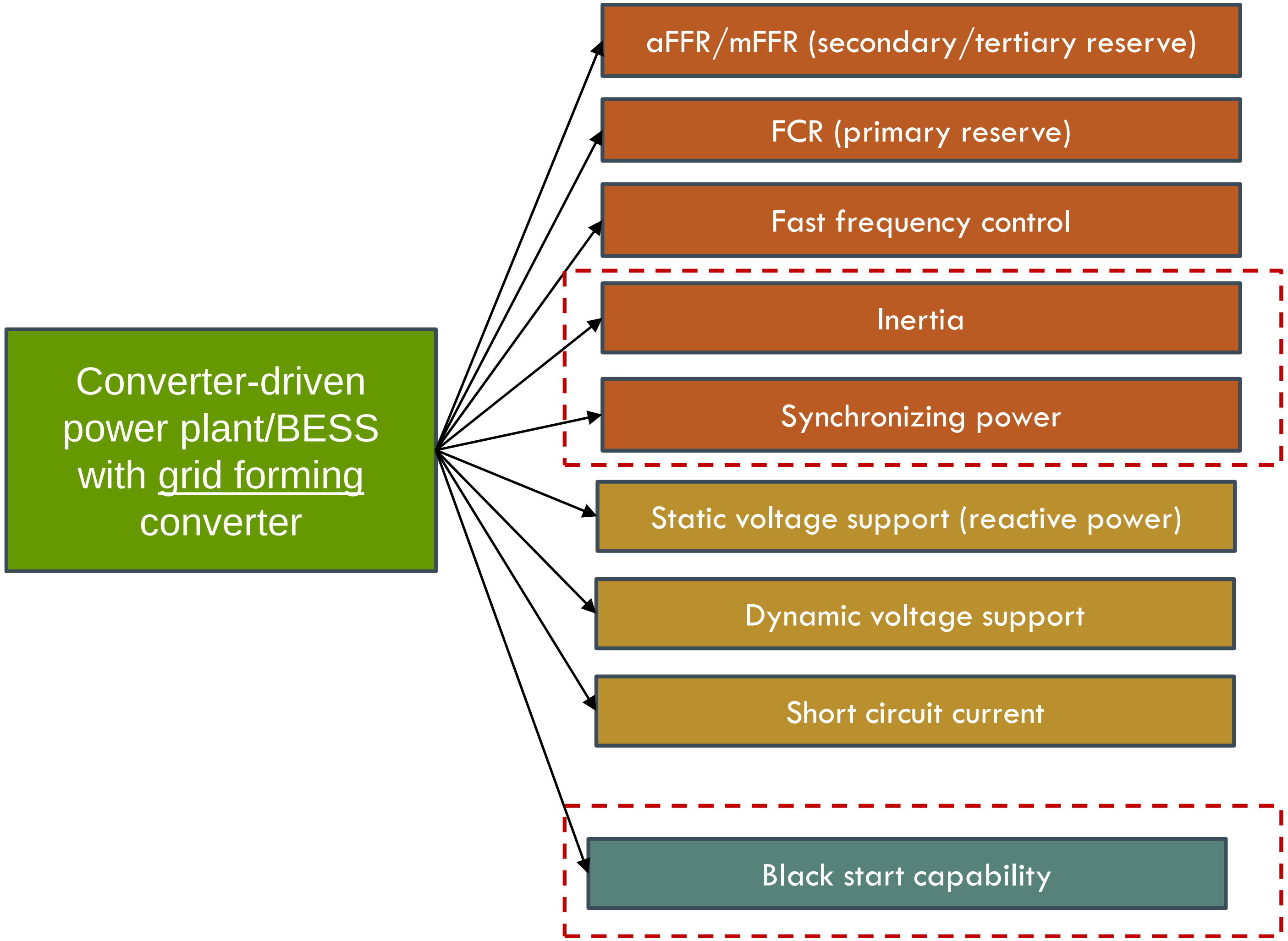
- Synchronous machine power plants can provide all required system services.
- Synchronous machine power plants can also black-start the system (if equipped with necessary systems to black-start the process).
- Synchronous condensers are synchronous machines without turbine and can provide reactive power services and inertia.
- Synchronous machines provide synchronizing power but also need synchronizing power to remain in synchronism.

Stability and system services



- (Self-commutated) power electronics converters can provide all reactive power services.
- If the primary energy source allows for it, they can also provide active power services.
- Without active primary energy source (wind turbine, PV-module, etc.) converters can provide reactive power services only (STATCOM).
- Power electronic converters (with grid following converters) cannot provide synchronizing power.
- On the other hand, they require only very low synchronizing power to be synchronized (behave “passive” with respect to voltage angle variations)

Stability and system services



- Power electronics converters with grid-forming control can provide all system services.
- The ability to provide active power services depends on the primary energy source.
- To provide synchronizing power, an energy source is required that allows delivering active power for some seconds.
- On the other hand, grid-forming converters (with energy source/storage) require synchronizing power to be synchronized with the rest of the system (behave "active" with respect to voltage angle variations)

Cost of active power reserves from wind/PV

- Wind and PV plants can either provide active power reserve from the primary energy source or from storage.
- Providing active power reserve from the primary energy source is expensive (reserve is equal to “energy not delivered” -> opportunity cost).
- Cost of additional storage depends on the time frame of the active power service to be delivered. To deliver inertia and synchronizing power, only storage in the time frame of a few seconds is required. Usually, super-capacitors or small batteries can be used for it.
  - For PV, super-caps could either be integrated at the DC-side of the converter or additional battery energy storage would have to be installed.
  - For wind, integration of super-caps in the converter is not an option because the converters are in the nacelle. Therefore, additional storage (super-caps or small battery with converter and transformer) are required.

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Cost of active power reserves from Energy STATCOMs and BESS

- Energy-STATCOMs and BESS can provide active power reserve from the stored energy.
- STATCOM:
  - CAPEX for the addition of short-term storage (e.g. super-caps).
  - No opportunity cost associated with the provision of active power reserve.
  - Only for very short-term active power reserve (synchronizing power, inertia)
- BESS:
  - No additional CAPEX.
  - During times of charging or operation at zero power: no opportunity costs.
  - Provision of longer-term reserve (e.g. FCR, aFRR/mFRR) is possible.

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Summary

Technical:

- Converter-driven power plants and storage systems with state-of-the art converter controls (grid following) can provide all system services except from synchronizing power, (true) inertia and black start capability.
- To provide (true) inertia and synchronizing power efficiently, converter-driven power plants require grid-forming converters and short-term storage. Therefore, the provision of these services form wind and PV increases their cost (CAPEX).
- The provision of “negative” inertia and “negative” synchronizing power does not need additional storage in theory. However: “Single-sided” grid-forming capability is not recommended because of adverse impact on small disturbance stability.

Cost:

- The provision of synchronizing power and inertia from wind and PV is possible but expensive (more expensive than from synchronous machine power plants)
- The provision of synchronizing power and inertia from BESS and Energy-STATCOMs is more effective and less expensive.

Conclusions

- The actual need for inertia and grid-forming capability should be studied in more detail to avoid over-conservative estimates of the required amount of inertia (which can be very costly).
- The inertia of synchronous machine power plants should be used as much as possible (including clutches required for synchronous condenser mode).
- Storage components (BESS, pumped storage) should be used as much as possible to provide the required inertia.
- Inertia alone is insufficient to prevent a system collapse in exporting areas. Fast frequency response is required too (fast reduction of active power). This is possible with grid following controls.
- Use predominantly transmission connected plant (e.g. Energy-STATCOMs, large BESS, synchronous machine power plants, very large wind/PV farms) to provide the required synchronizing power and inertia (grid forming capability) because it is most effective (in terms of synchronizing power and voltage support).
- The behaviour of grid-forming converters, especially in distribution networks, must be studied in very much detail before requiring grid-forming capability of every converter-driven plant (risk of new stability issues).

Thank you!

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