System stability in a renewables-based power system

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System Stability in a Renewable Based Power System

Topics covered by the report:

- Power System Stability – Terms and Definitions
- Impact of VRE on power system stablity
- System services and technologies to support system stability
- Strategies to ensure system security of future power systems
- Processes and tools to operate stabiltiy constrained power systems

Stability of power systems (IEEE/CIGRE 2004)

Generation-demand balance

Frequency stability	Active power balance Inertia and frequency control	Global, system-wide

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Stable power transmission

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).

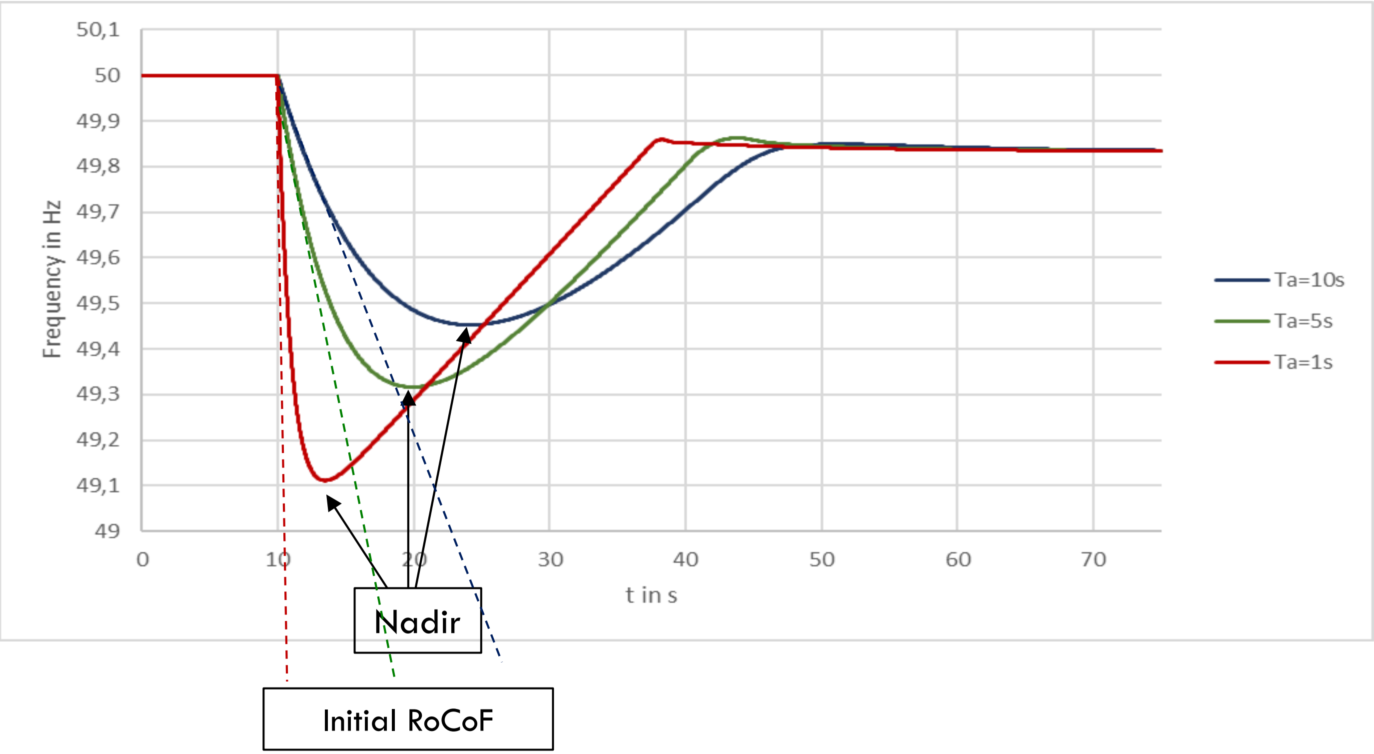
Controller and other unwanted interactions

Resonance-stability	Controller response Multi-frequency network characteristics	Local

Frequency Stability – Generator Outage Example

Main impact on frequency stability:

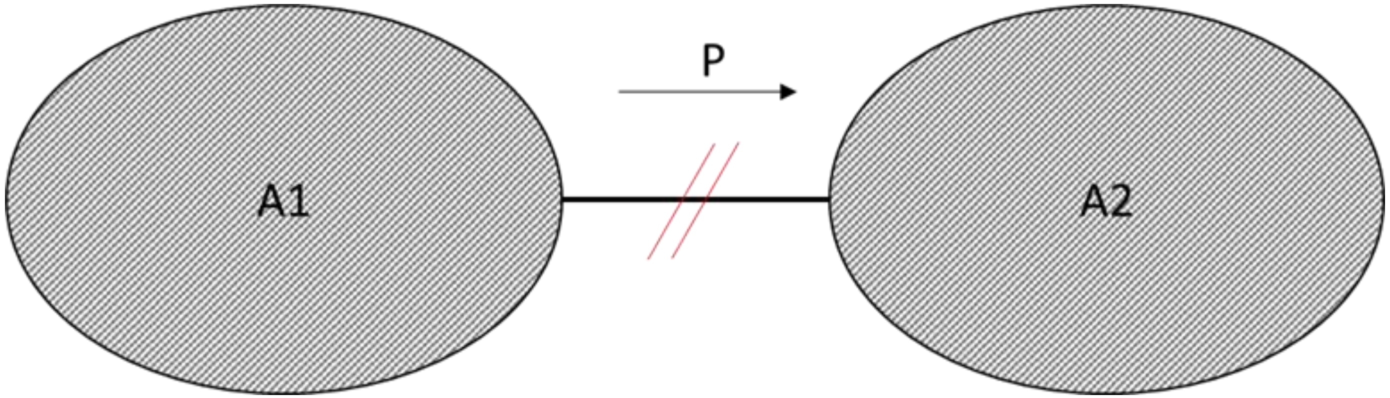
- **Active power deficit or excess:**
  The larger the active power unbalance the faster is the frequency disturbance
- **Inertia:**
  The higher the inertia, the slower are frequency disturbances



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

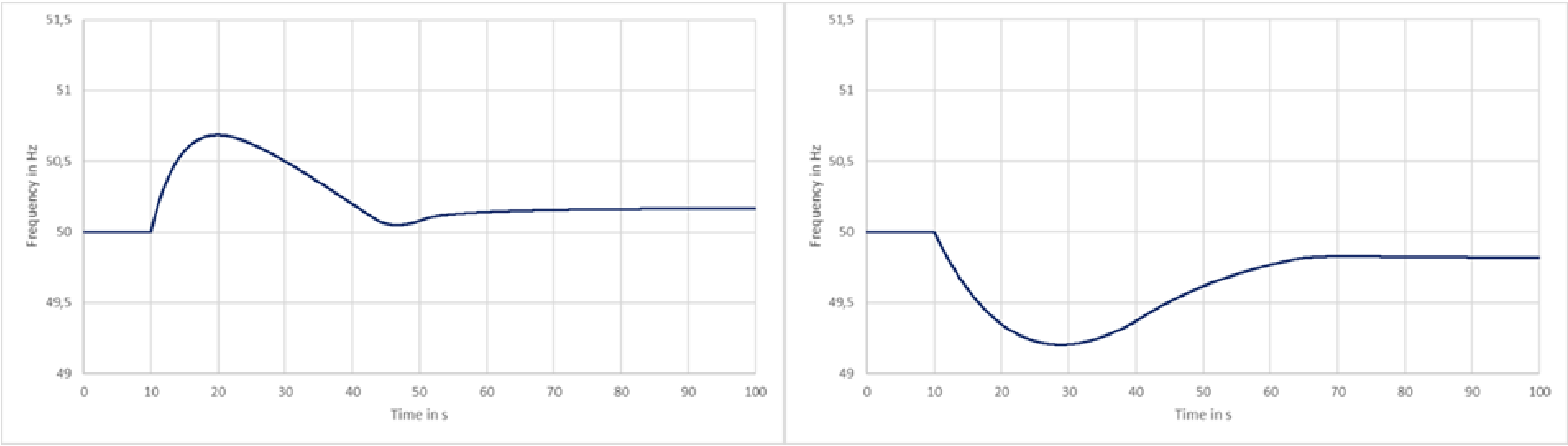
Source: M.P.E.

Frequency Stability – System Split - Example



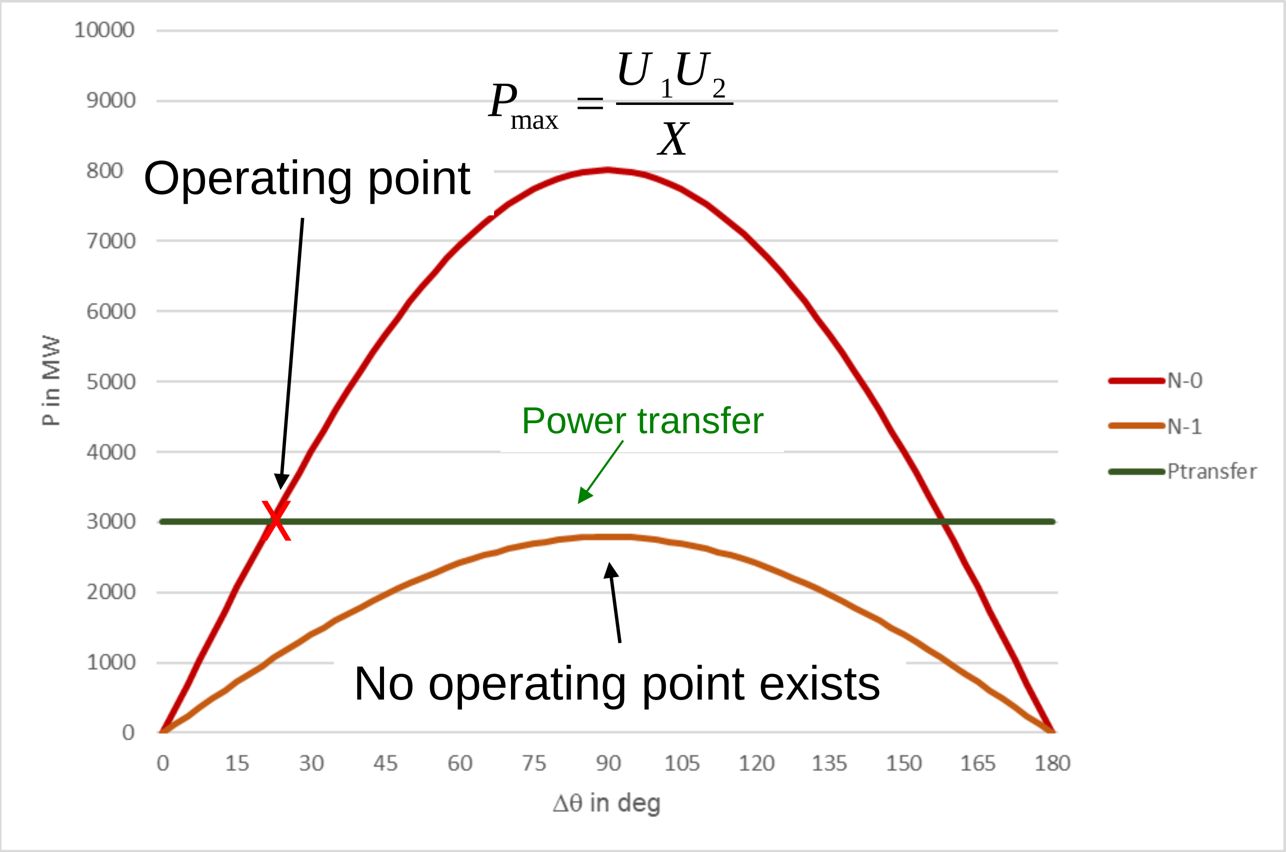
Frequency following a system split event:

- Exporting area: frequency rise
- Importing area: frequncy drop



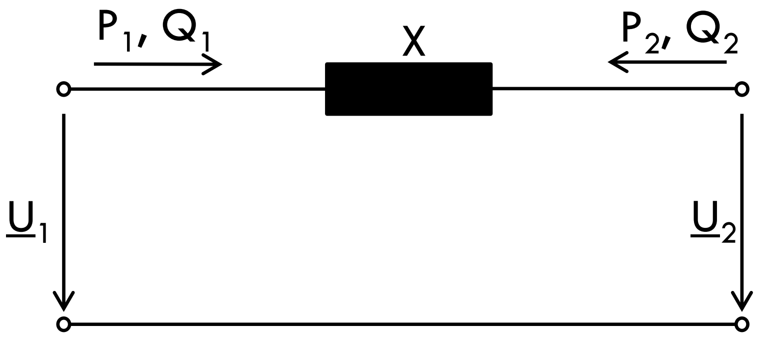
Source: M.P.E.

Stable power transmission



$$P_{\max} = \frac{U_1 U_2}{X}$$

Source: M.P.E.



Operating point exists:

System is either stable or there are rotor angle stability issues. (oscillatory, transient stability)

No operating point exists:

System is unstable. This type of instability is usually initiated by low voltages -> voltage instability

Stable power transfer - Oscillatory Stability - Example

Main impact:

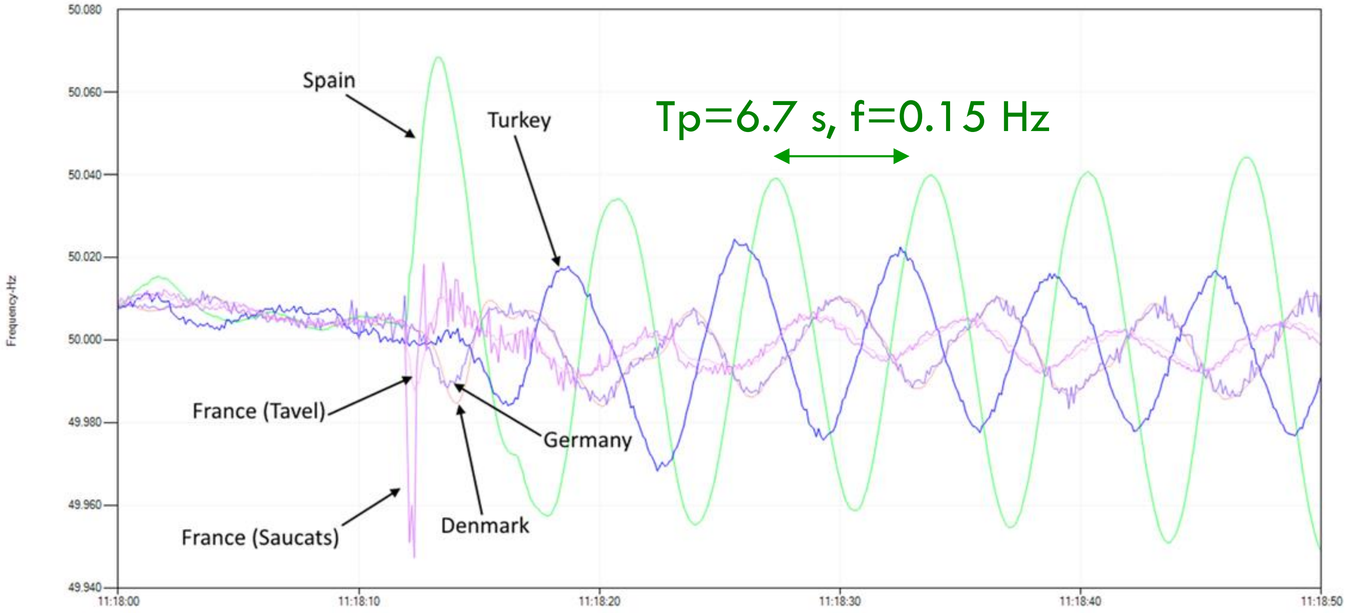
Inertia:
the larger the inertia, the lower are the characteristic frequencies.

Synchronizing power :
Depends on the equivalent impedance, voltage and power transfer. The higher the synchronizing power, the higher are the characteristic frequencies.

Damping torque:
Damping torque is provided by synchronous machines and PODs. The lower the characteristic frequencies, the lower is the damping of the synchronous machines.

Power transfer:

The larger the power transfer, the lower is the synchronizing power and the damping.



Frequencies in different locations of CE,

Source: ENTSOE, „Analysis of the CE inter-area oscillations of 1st December 2016“, 13.07.2017

Stable power transfer - Transient Stability - Example

Main impact:

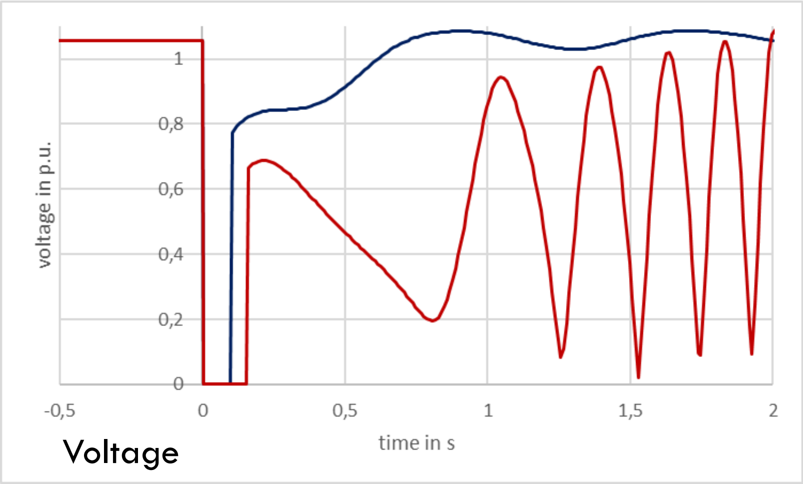
Duration of a fault:
The longer the fault clearing time, the more likely it is that the generator(s) lose synchronism.

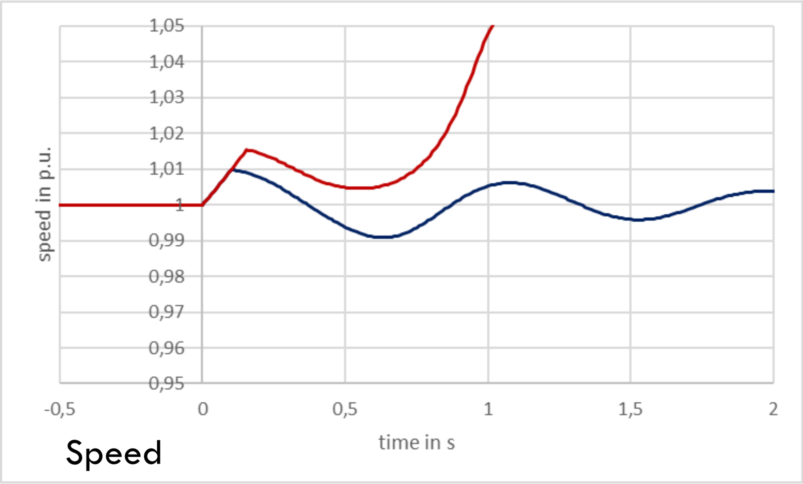
Generated power/power transfer:
The higher the generated power prior to a disturbance, the shorter is the Critical Fault Clearing Time

Synchronizing power (short circuit power):
The larger the short circuit power, the larger are Critical Fault Clearing Times

Voltage/reactive power support:
The better the voltage support, the larger are Critial Fault Clearing Times.

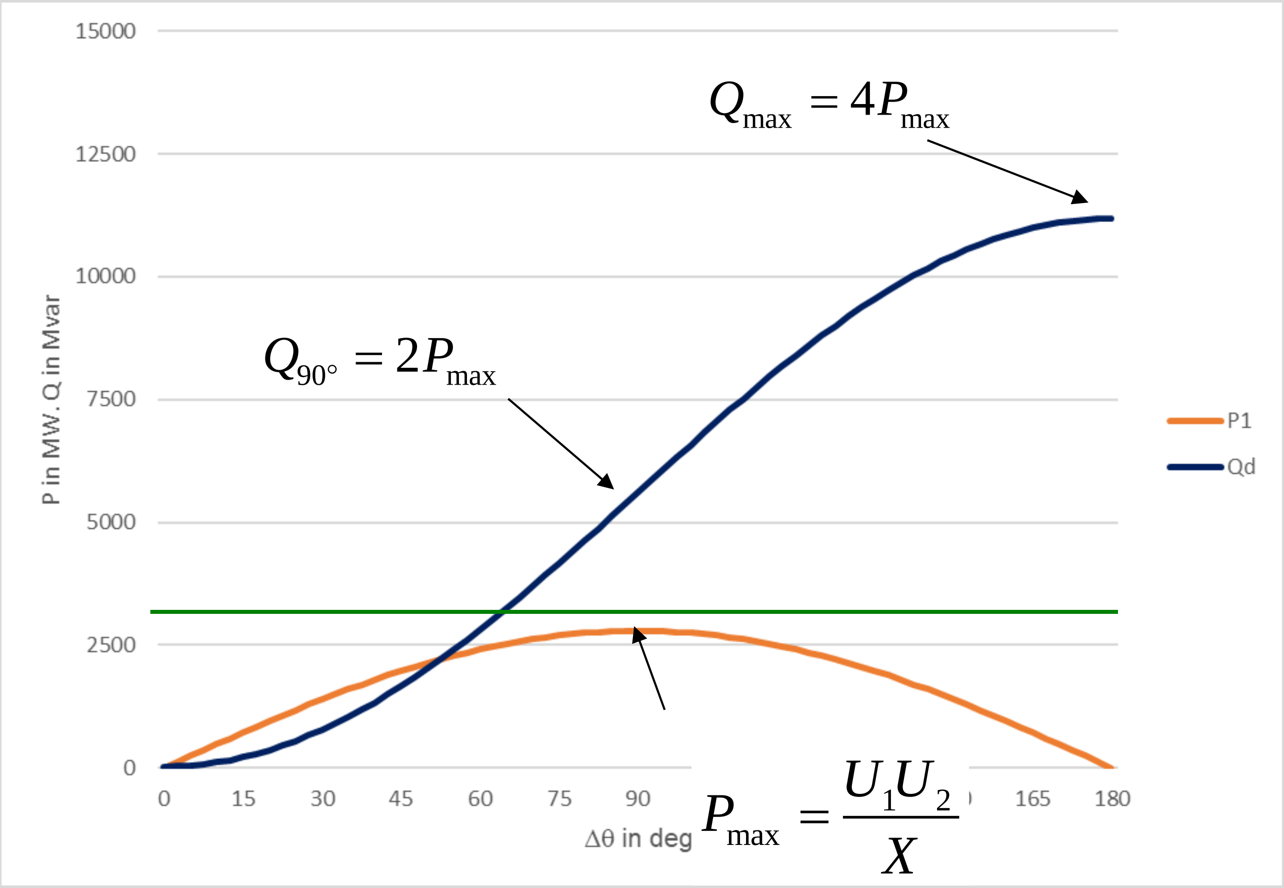
Inertia:
The higher the acceleration time constant of a generator, the higher is the critical fault clearing time.





Source: M.P.E.

Stable power transmission



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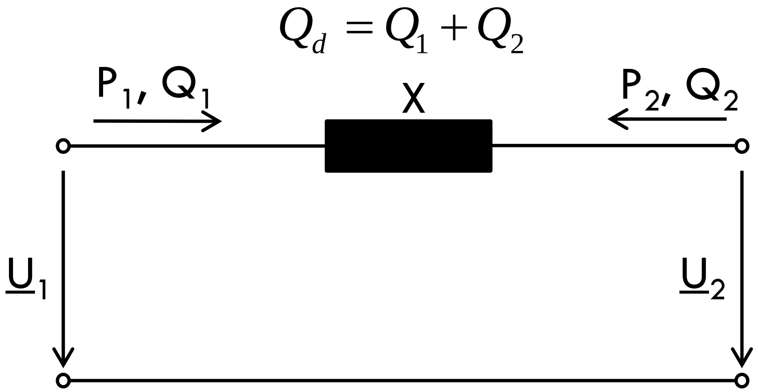


Reactive demand Q_d:

Low voltage angles:
reactive demand Qd is very low.

However, with increasing angles, Qd rises very steeply.

If reactive demand cannot be covered, the system experiences a voltage instability (voltage collapse, synchronism is lost).

Stable power transfer - Voltage Stability - Example

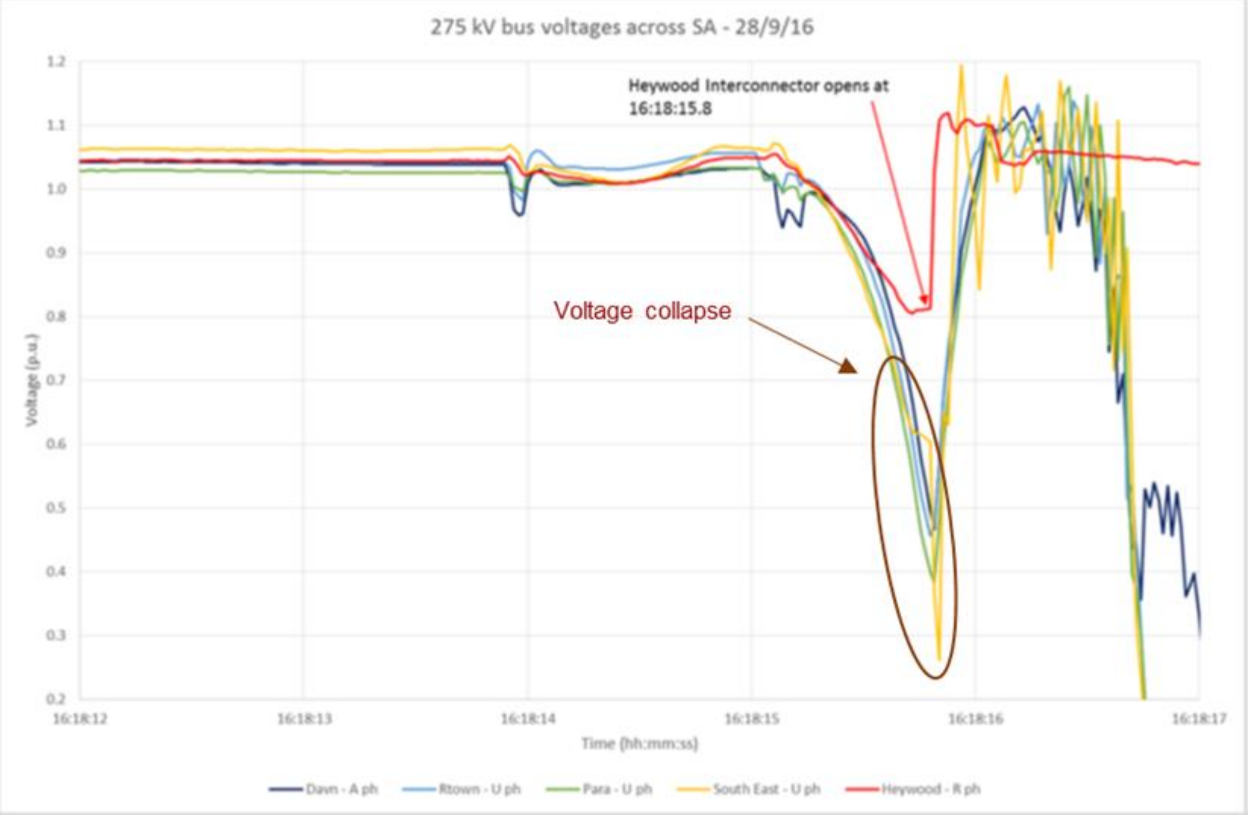
Main impact on voltage stability:

Reactive power support:

The higher reactive power support, the larger are voltage stability constrained transfer limits.

Equivalent impedance

The lower the equivalent impedance (the higher the short-circuit level), the higher is the voltage stability constrained transfer limit.



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

Resonance Instability - Example

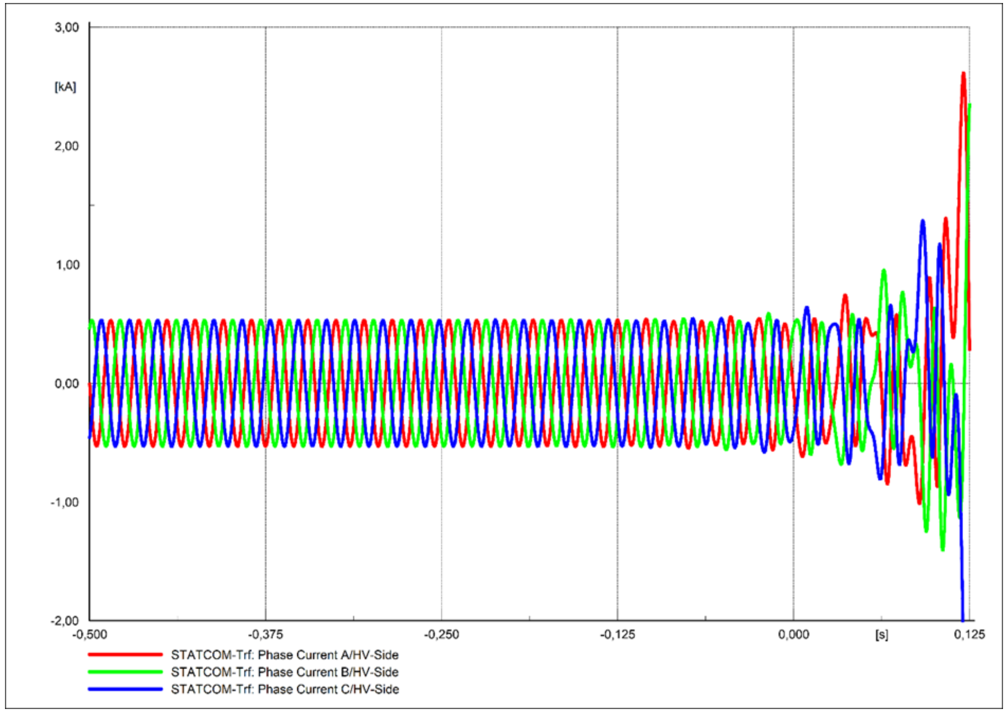
High bandwidth controllers (fast controllers) can cause instability in a wide frequency range.

Main impact:

Network impedance (short circuit level):
A high impedance (weak grid) increases the probability of controller instability

Equivalent converter impedance:

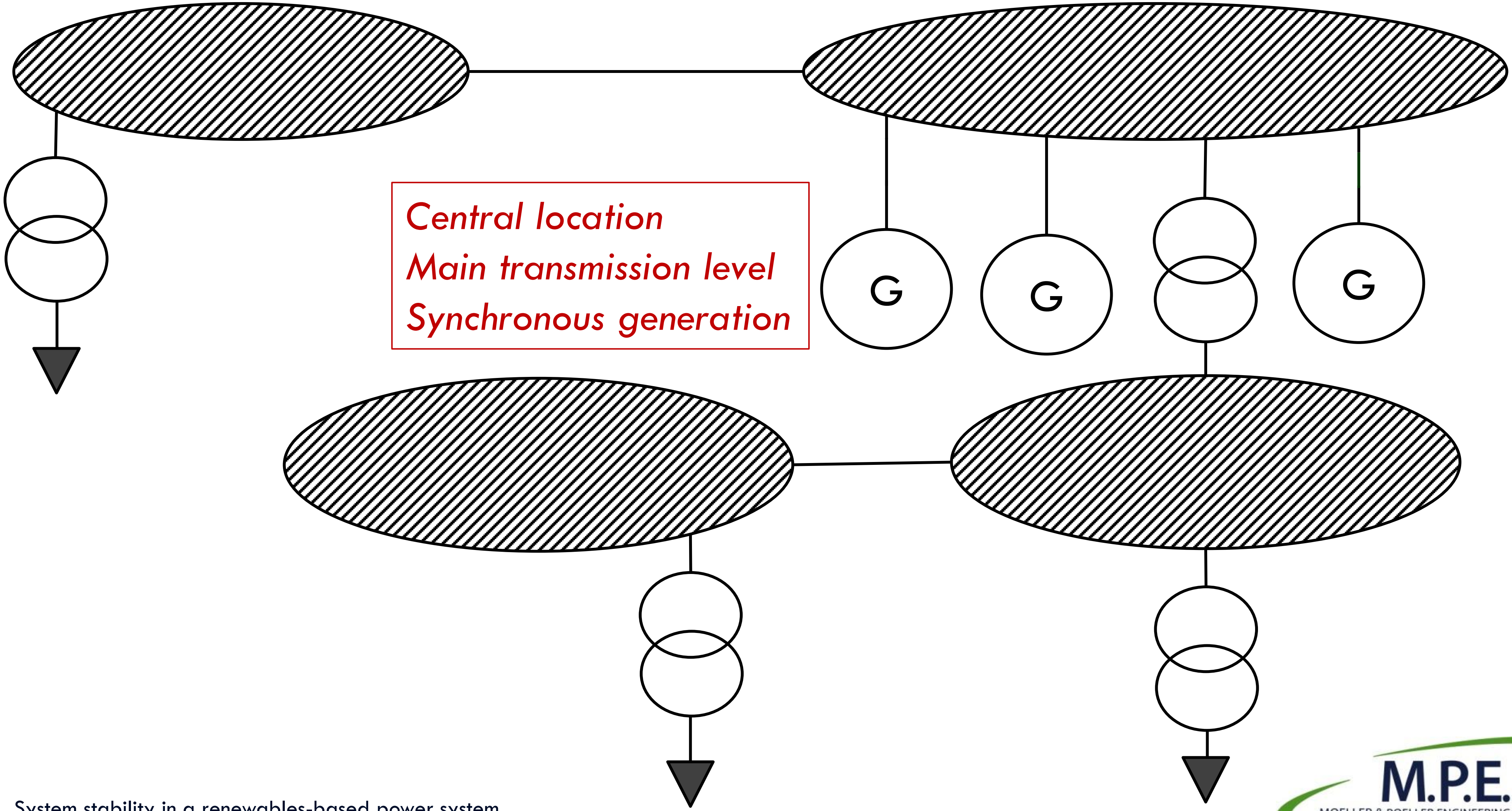
Frequency ranges with negative resistance are prone to controller instability



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

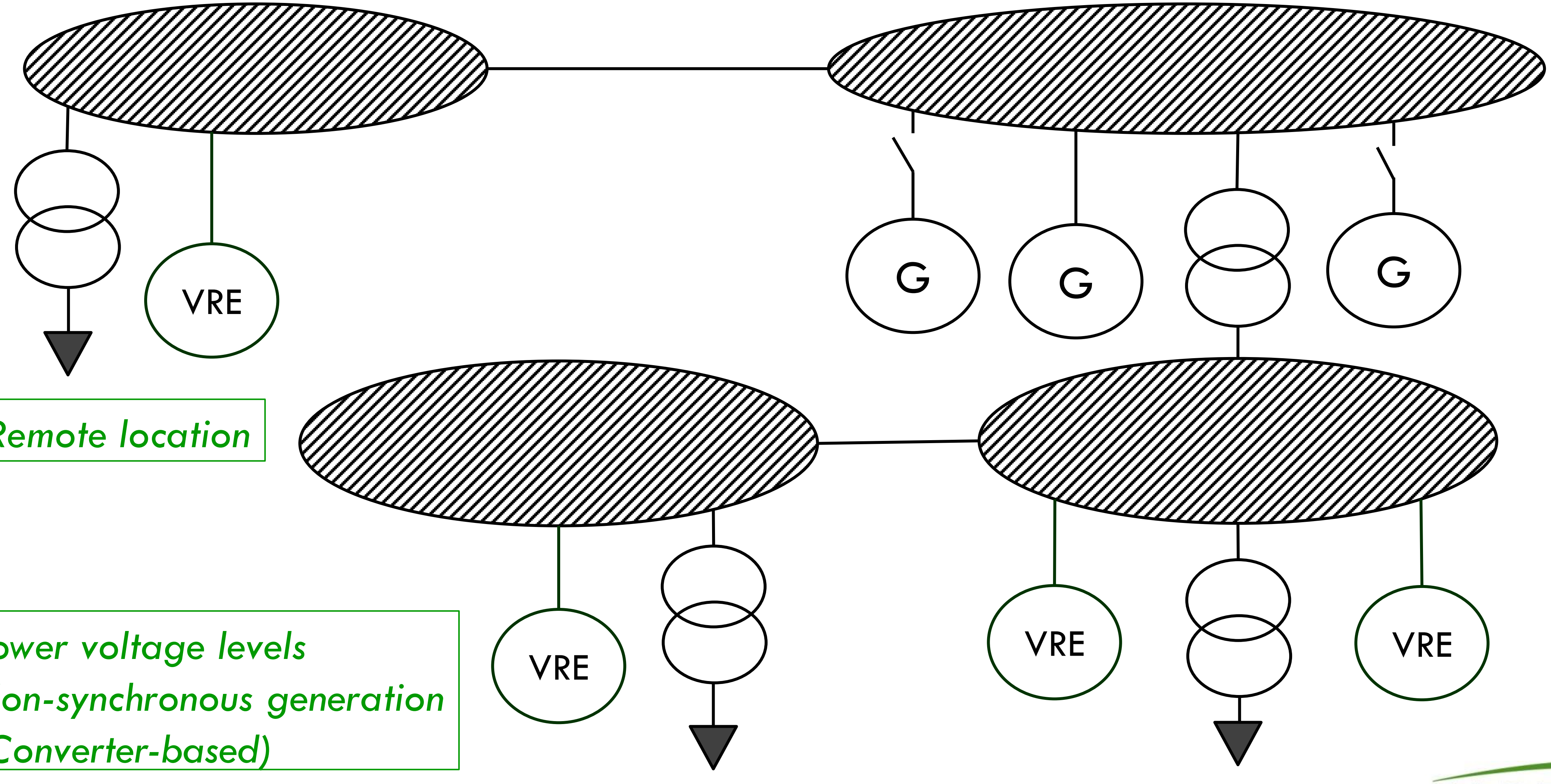
Source: M.P.E.

Stability of systems with large share of VRE – what's different?



Central location
Main transmission level
Synchronous generation

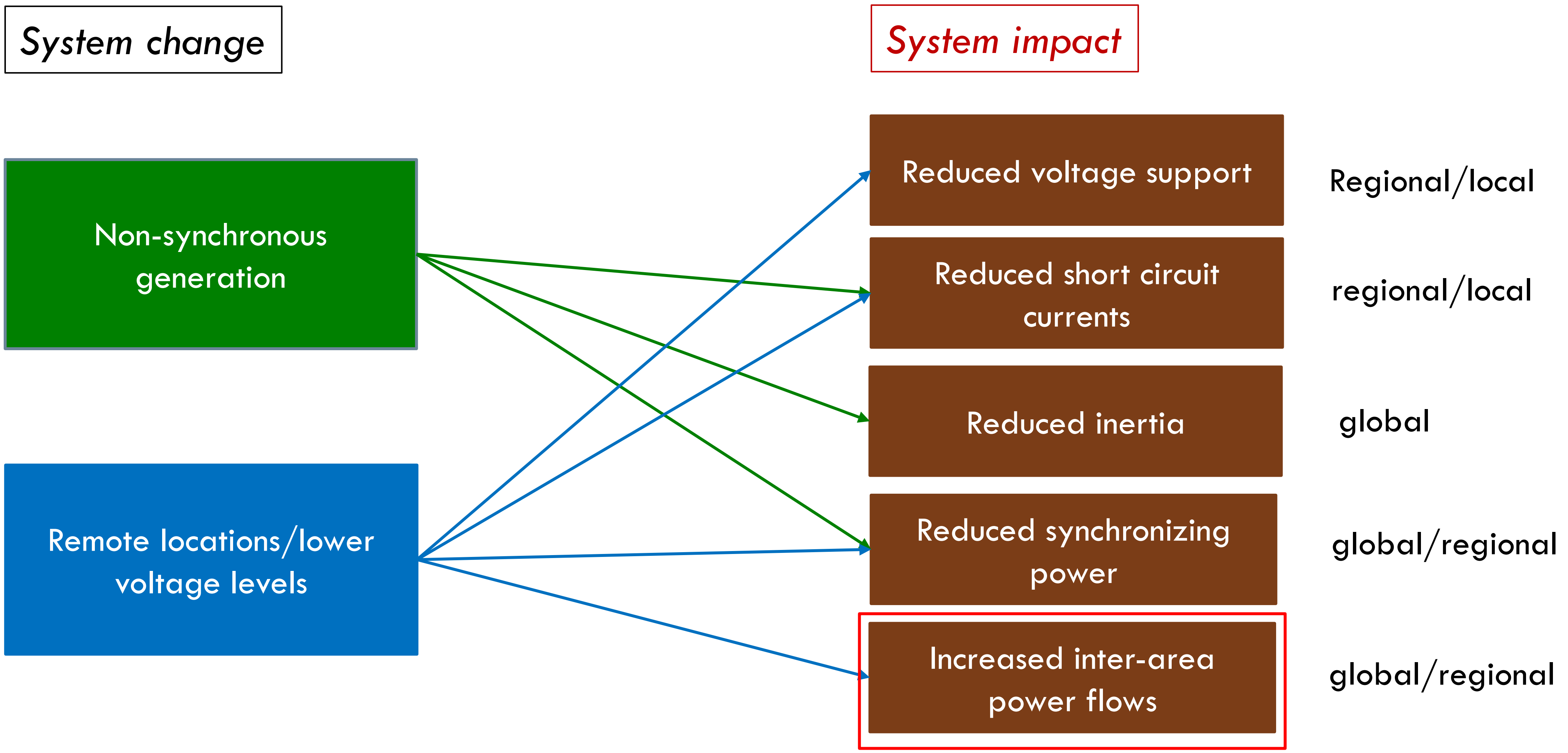
Stability of systems with large share of VRE – what's different?



Remote location

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

Potential stability issues in systems with high VRE



System change

System impact

Non-synchronous generation

Remote locations/lower voltage levels

Reduced voltage support — Regional/local

Reduced short circuit currents — regional/local

Reduced inertia — global

Reduced synchronizing power — global/regional

Increased inter-area power flows — global/regional

Impact of VRE on System Stability

The negative impact of (grid following) VRE on System Stability is mainly a result of being passive. VRE do not support the stability of other components (e.g. synchronous machines). They behave neutral in many regards (no rotor angle oscillations but also no fast voltage control[1]*).*

In addition to this, they are usually placed farer away from load centres than conventional power plants and therefore, larger power transfers occur having a negative stability impact.

The positive impact of (grid following) VRE on some stability aspects is also a result of their passivity. They do not need much to remain stable (much less interactions with other generators than synchronous machines).

The large-scale integration of VRE changes the nature of stability problems:
away from the classical rotor angle stability problems towards voltage stability issues

-> Stability in a renewable based power system is different from a synchronous-machine-based system

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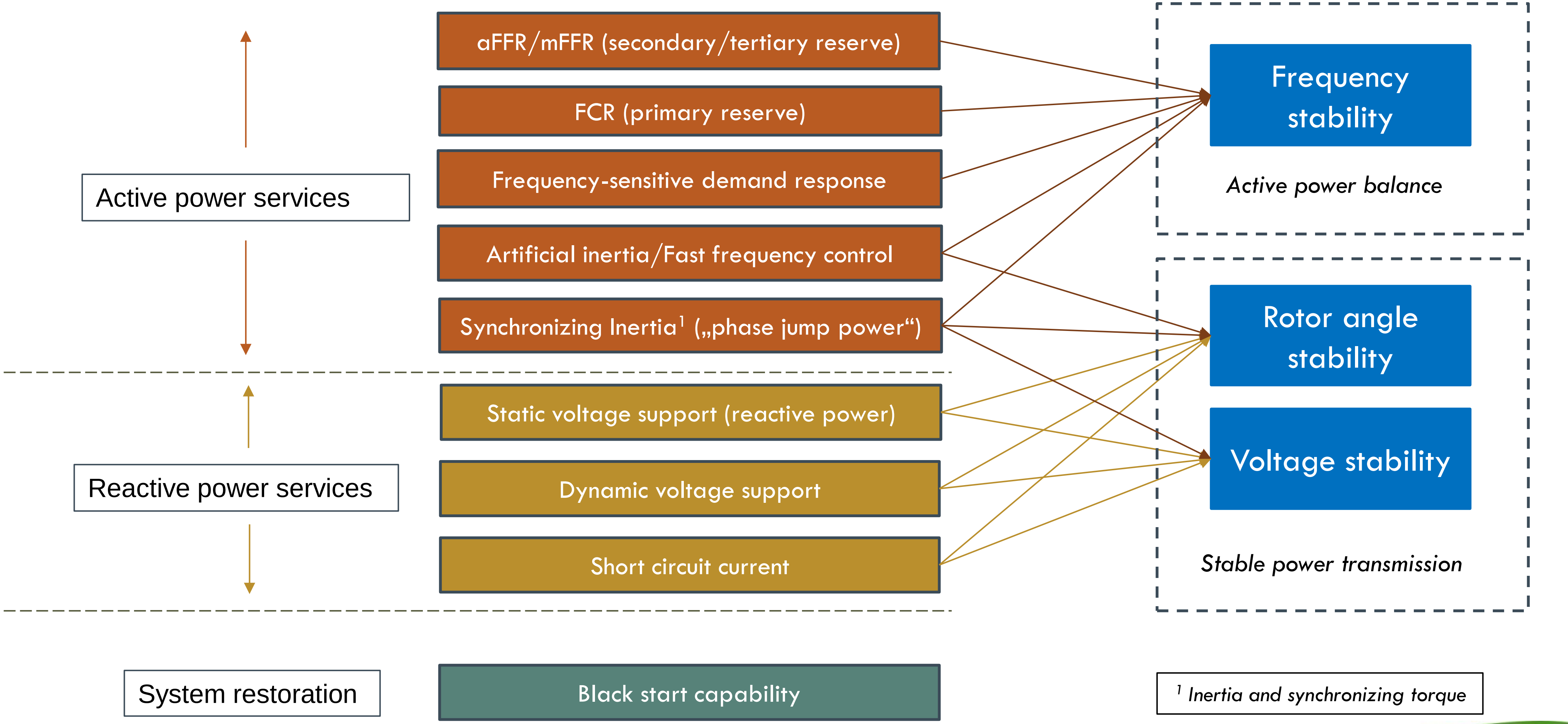
[1] Technically, grid following converters can provide fast voltage control, but because it is not required by most grid codes, the large majority of grid following VRE does not provide it.

Stability and system services



Active power services

- aFFR/mFFR (secondary/tertiary reserve)
- FCR (primary reserve)
- Frequency-sensitive demand response
- Artificial inertia/Fast frequency control
- Synchronizing Inertia[1] („phase jump power“)

Reactive power services

- Static voltage support (reactive power)
- Dynamic voltage support
- Short circuit current

System restoration

- Black start capability

Frequency stability

Active power balance

Rotor angle stability

Voltage stability

Stable power transmission

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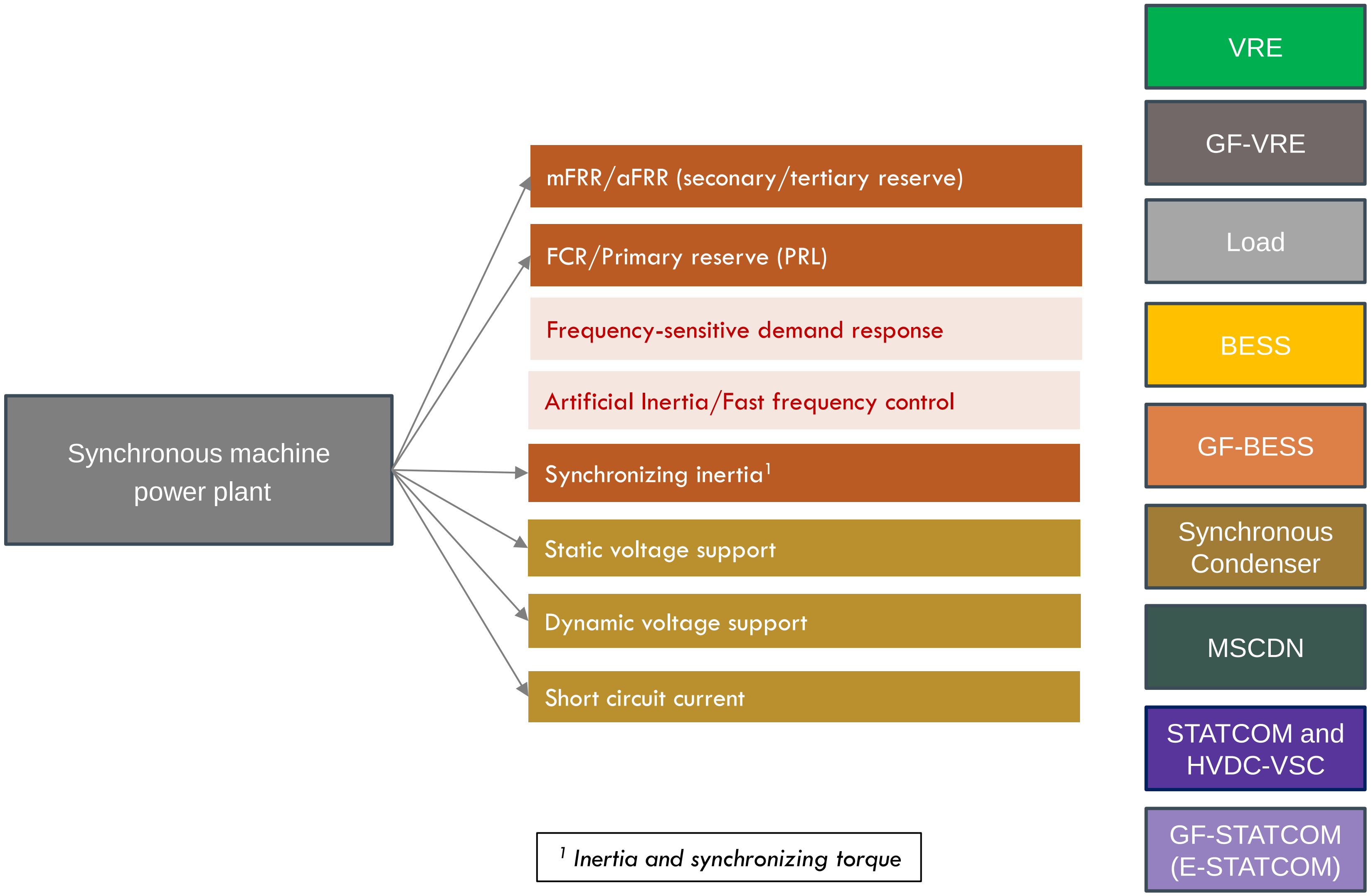
[1] *Inertia and synchronizing torque*

System services and technologies to provide them



Synchronous machine power plant

mFRR/aFRR (seconary/tertiary reserve)

FCR/Primary reserve (PRL)

Frequency-sensitive demand response

Artificial Inertia/Fast frequency control

Synchronizing inertia[1]

Static voltage support

Dynamic voltage support

Short circuit current

VRE

GF-VRE

Load

BESS

GF-BESS

Synchronous Condenser

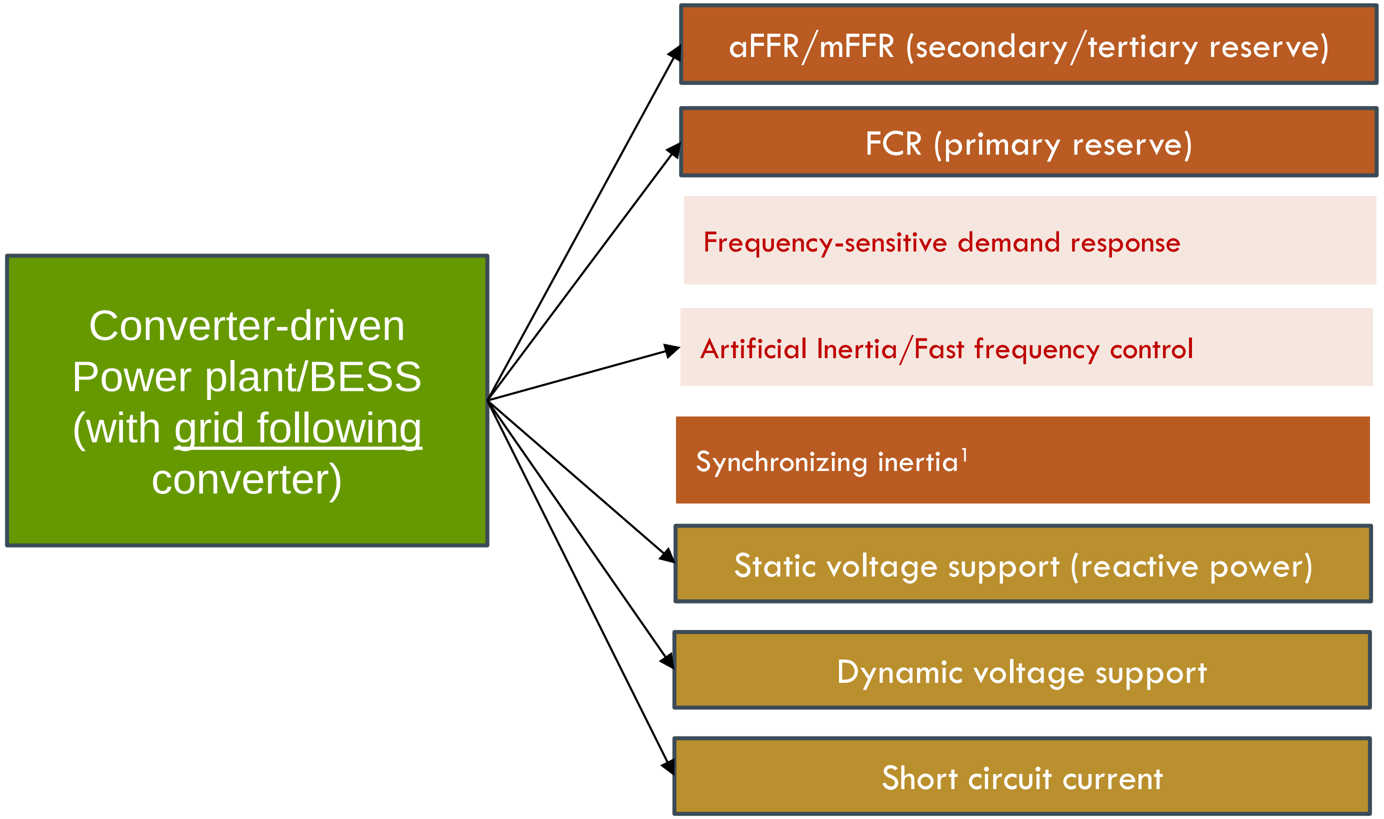
MSCDN

STATCOM and HVDC-VSC

GF-STATCOM (E-STATCOM)

[1] Inertia and synchronizing torque

Stability and system services – grid following converter plant



Converter-driven Power plant/BESS (with grid following converter)

aFFR/mFFR (secondary/tertiary reserve)

FCR (primary reserve)

Frequency-sensitive demand response

Artificial Inertia/Fast frequency control

Synchronizing inertia[1]

Static voltage support (reactive power)

Dynamic voltage support

Short circuit current

- (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)

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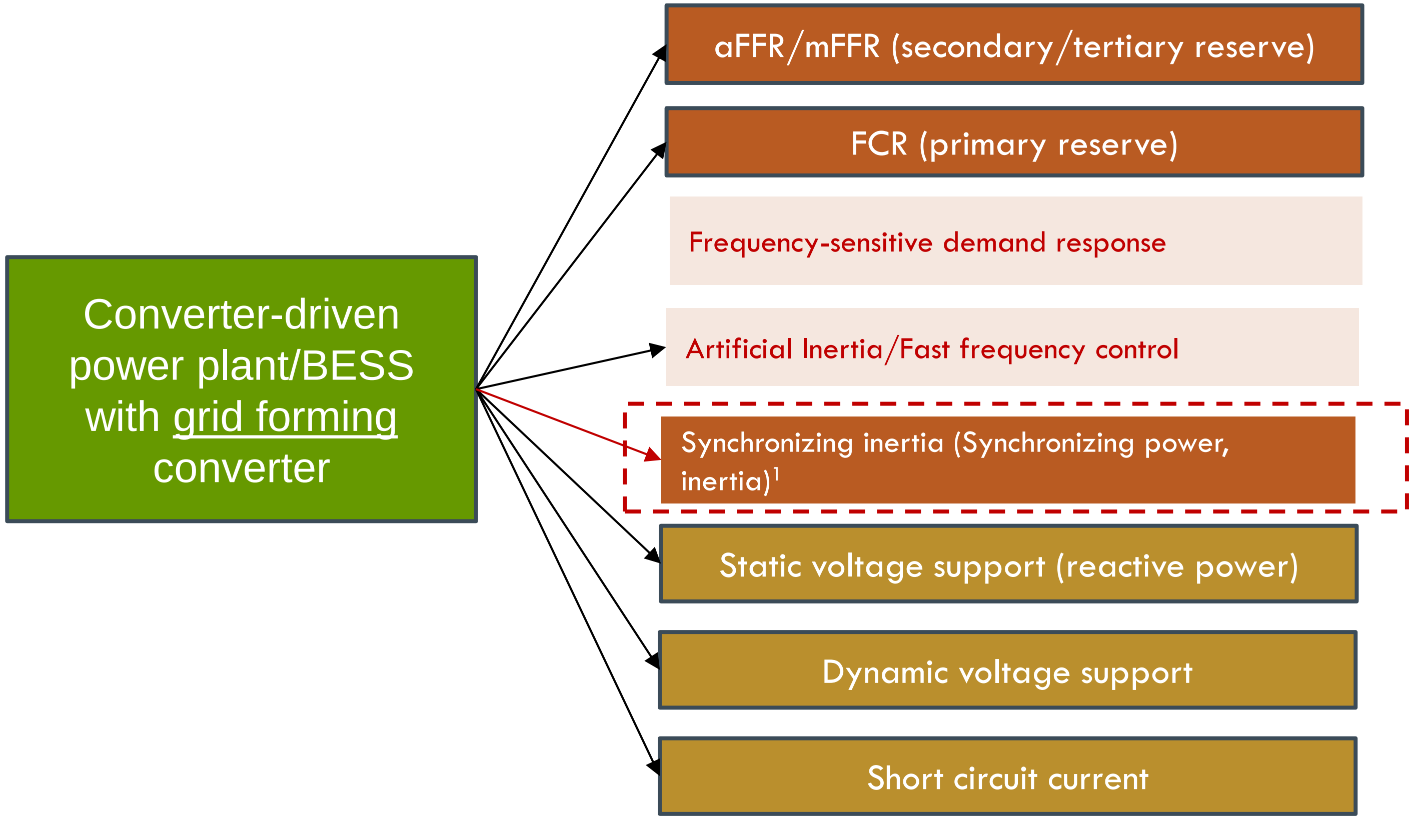
[1] *Inertia and synchronizing torque*

Stability and system services – grid forming converter plant



- 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 (“phase jump 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)

[1] *Inertia and synchronizing torque*

What to do to ensure system stability in future?

- Ensure that the required system services are provided, either by VRE directly or by additional components (e.g. STATCOMs, BESS or network components like PSTs or series compensation).
- Ensure that voltage supporting components are installed at the right locations in the network.
- Keep in mind that some of the system services also represent a burden to the grid (e.g. inertia). Therefore, it is very important to study the full range of system stability phenomena and not only selected aspects of it.
- If the system service needs are identified, the most economic strategies to procure the required services must be defined. In particular, this applies to the introduction of grid forming converter technologies.
- Adapt the operational procedures to future system needs (e.g. management of stability constrained transfer limits, introduction of advanced tools like DSA and WAMS, more automation etc.)

Thank you!

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