Dekarbonisierung der Industrie - Stromnetze könnten zur „Achillesferse“ werden.

Thorsten Krol

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Possible future market development

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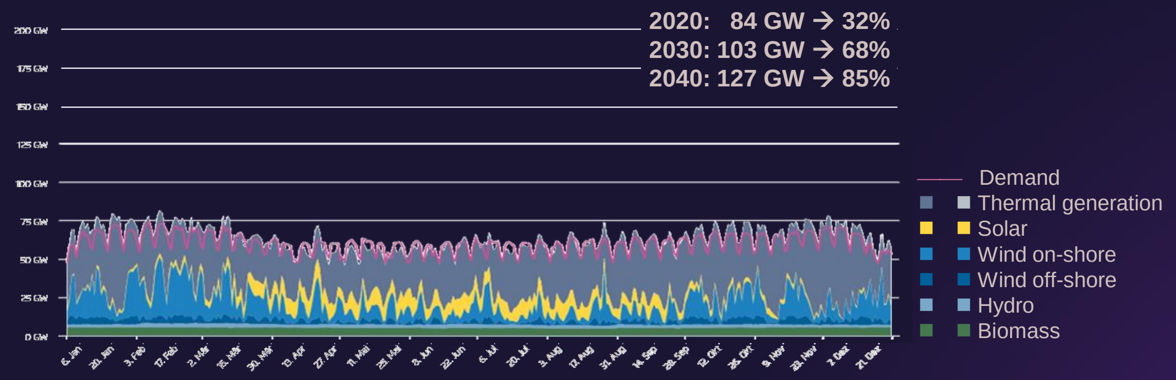
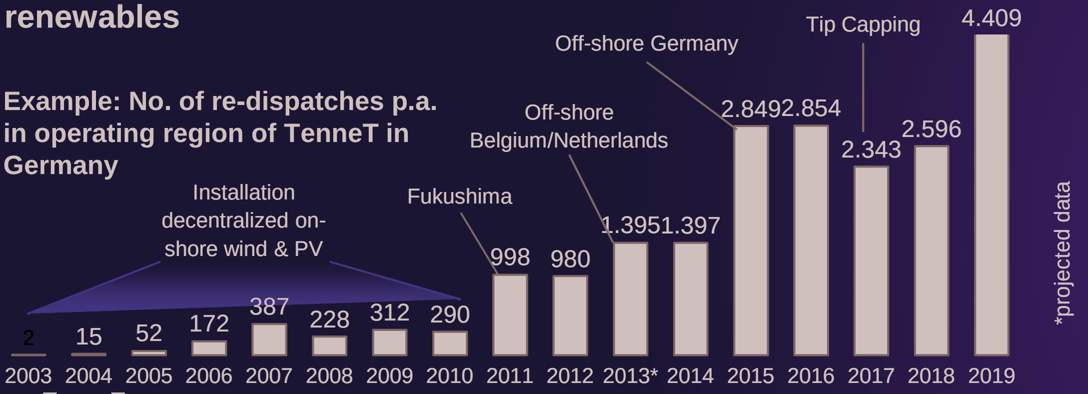
A **Expected development of demand and future generation mix**



- Demand will increase due to electrification of transportation, traffic, industries and heating
- Generation will increase mainly by renewables, but thermal generation is and will stay the reliable backbone based on green- and e-fuels
- Excess power will be used to produce e-fuels and stored to cover short term demand
- Operation of reliable power is expected to change from base- and intermediate load to peaking operation

B **Increased re-dispatch rates visible in markets with high shares of renewables**

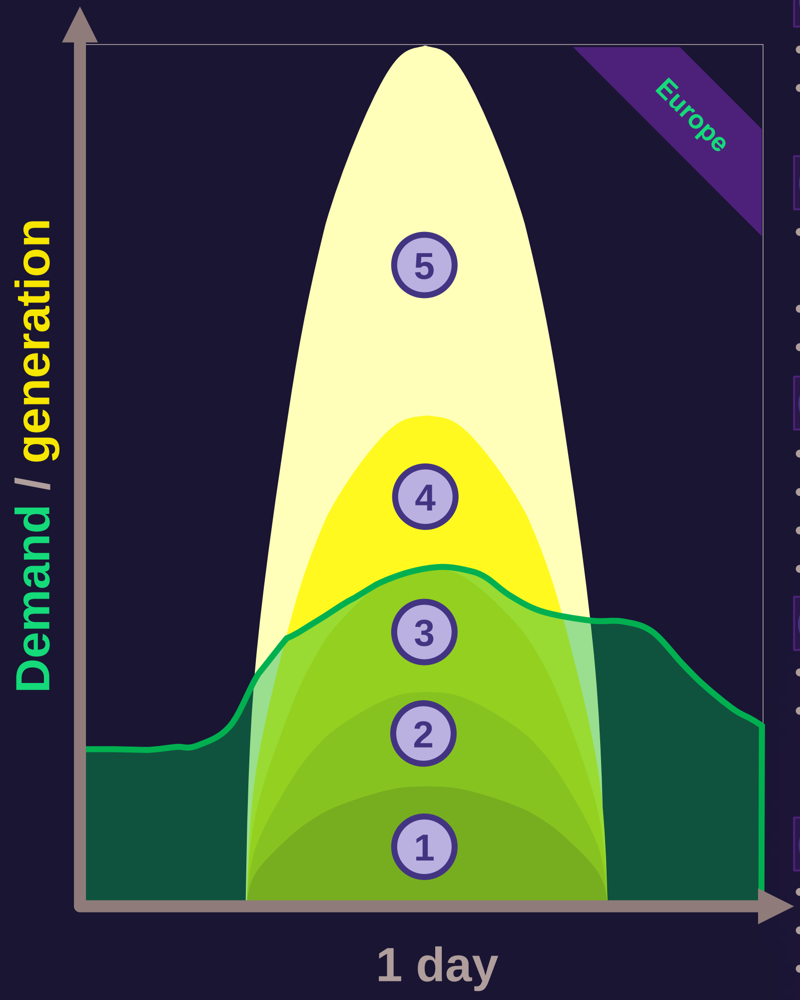
Example: No. of re-dispatches p.a. in operating region of TenneT in Germany



Source: TenneT

- Integration of wind and PV drives TSOs for additional operations stabilizing frequency and voltage
- Renewables market penetration create new business opportunities
- Players like gas engines, batteries, virtual power plants or industries enter the regulation market
- Technical requirements for fossil generation require specialized solutions based on grid generation market

Challenges in markets integrating high shares of renewables



Operational challenges	Possible solution
1 Low share of renewables within the grid:	
• More load cycles in residual load operation • Grid connection or RES	• Flexible part load operation of existing thermal generators • Increased demand on adjustable re-active power
2 Moderate share of renewables within the grid:	
• Residual load operation requires shut down or MEL operation • Lack of static and adjustable re-active power • Load management	• Increased re-dispatch necessary • Flexible part load operation of existing thermal generators
3 Significant share of renewables within the grid:	
• Reliable generators taken off the grid • Missing inertia and short circuit power • Lack of static and adjustable re-active power • No functional market design	• Some thermal generator on MEL • Clutch between GT and Gen allows multi-use of thermal equipment • Flexible thermal units or BESS in RES-chasing operation
4 Excess renewables within the grid:	
• Excess RES power stored in BESS for load shifting • Very limited ancillary services	• Power / load management • Special equipment provides all ancillary services for active, re-active and short circuit power • Integration of FACTS and BESS for fast responding
5 Deep decarbonization:	
• Massive excess RES power available • Mainly inverter connected equipment connected to grid • No dynamic stabilization within grid • Green seasonal power required	• Long term storage for over night load shifting and seasonal storage technologies • Ancillary services and re-dispatch via special equipment • Multi use of equipment keep costs limited

MEL: minimum environmental load

Impact of increasing shares of RES on energy supply systems: Austria

	Dynamics in active power	Voltage stability	Harmonics and short circuit power	load balancing	Security of supply
2 **Moderate share**	• Reduced synchronous inertia result in increased RoCoF	• Higher demand in static compensation (increasing distance from generators and consumers)	• No / low impact	• PFR as ancillary service	• No / low impact
3 **Significant share**	• Increasing demand for SIR (real inertia) and FFR (synthetic inertia)	• Increased probability of flickers due to weaker grids and inverters connected	• Increased level of harmonics • Lower short circuit power level	• Too slow PFR result in high RoCoF and wide frequency deviation	• Residual load and black-start of Back-up power
4 **Excess renewables**	• SIR (real inertia) and FFR (synthetic inertia) required as ancillary service	• High probability of flickers due to weaker grids and inverters connected	• Missing rotating equipment • Low short circuit power level	• Long duration energy storage necessary for over night supply	• Availability of RES power requires storage
5 **Deep decarbonization**	• SIR (real inertia) and FFR (synthetic inertia) required as ancillary service	• High demand on flexible VAr compensation for industrial processes	• Missing rotating equipment • Low short circuit power level	• Intermittent excess RES power for PtX	• PtX enables power and heat supply

What is necessary for a reliable power grid?

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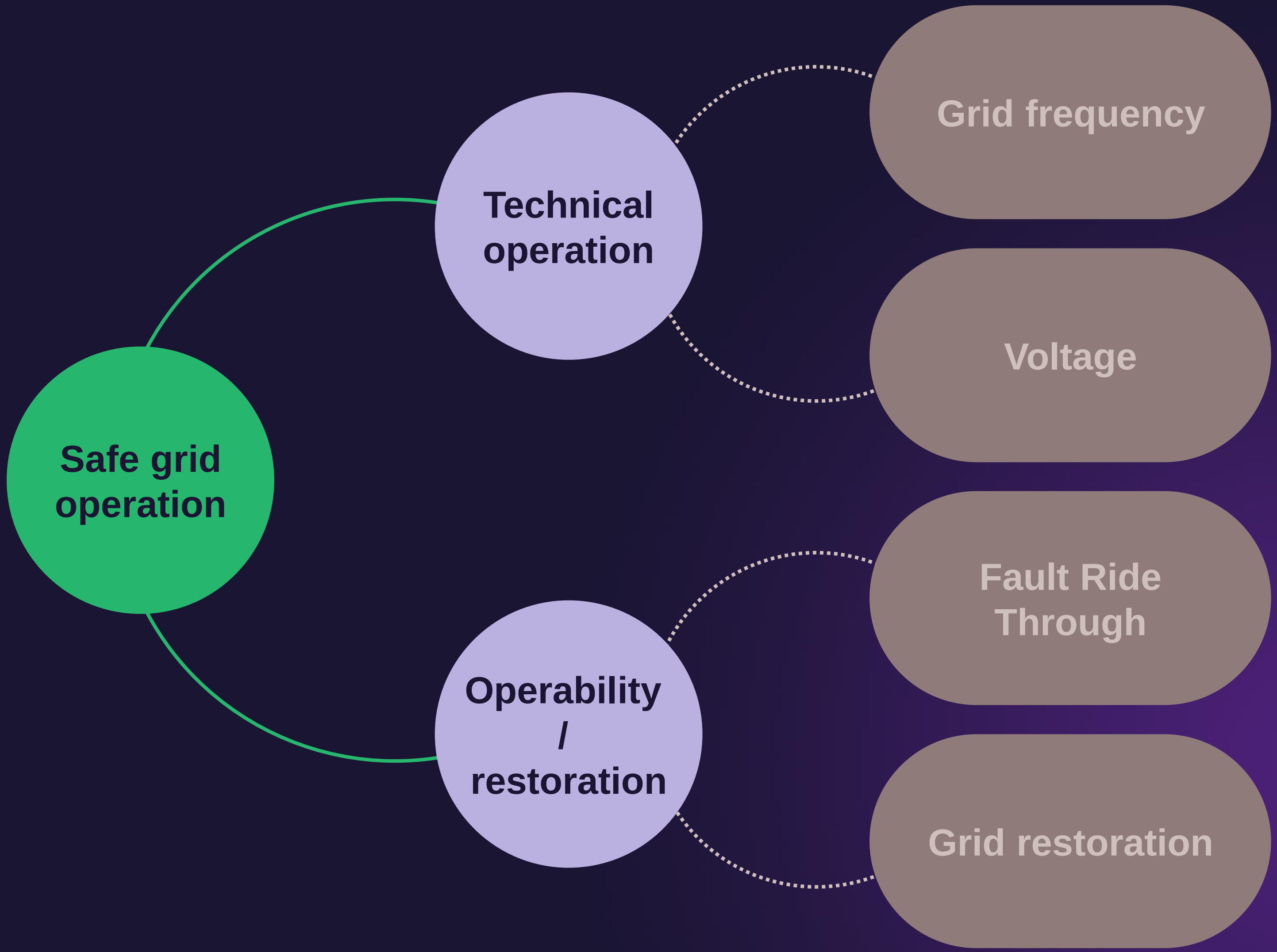

Grid frequency

- Grid frequency of 50/60 Hz
- Frequency is always within safe tolerance band
- Sinus wave / Harmonics
- Balancing of generation and demand
- Availability at each location within power grid

Voltage

- Voltage is always within tolerance band around defined voltage level
- Sinus wave, absence of flickers and harmonics
- Balancing of static and fluctuating provision and demand

Fault Ride Through

- Providing sufficient Short Circuit Power
- Safe grid management

Grid restoration

- Provide black start capabilities across the whole grid environment
- Capability to execute grid restoration measures after black- or brown-out

Possible impact of grid instabilities on industrial processes

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Changes in ENTSO-E Grid Codes under evaluation

- Frequency: 47 – 52,5 Hz
- RoCoF: from 2 Hz/s to 5 Hz/s for 250 ms (max. values)
- Short Circuit Level in grid cut by half (protect inverters)
- …

Impact on industrial production processes

Electrical Machines synchronous motors and generators

→ Increase in losses
→ Premature wear of rotors
→ Inconsistency of motor speeds
→ changes in torque and power (i.e. protection settings of devices)
→ Hunting

Light sources

→ Variations in light flux might impact automated optical processes

Induction motors

→ voltage fluctuations may lead to changes in torque and slip
→ Inconsistency of motor speed
→ Excessive vibrations may reduce mech. strength and shortening the motor service life

Electro Heat Equipment

→ Lower efficiency
→ Longer melting time – lower productivity

Phase controlled static rectifiers

→ Decrease in power factor
→ generation of non-characteristic harmonics and inter-harmonics.

Electrolyzers

→ Reduction of efficiency
→ Forced wear and tear and cyclic life
→ Degradation of high current lines

Impact of grid structure and stability

- Voltage: longer distance to RES generators
- More frequent fluctuations in voltage and frequency (e.g. flickers etc.)
- Additions of instabilities by electrification of industrial processes (e.g. EAF)

Integration of all potential local revenue and regulation aspects can be crucial for the final business case of the solution

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Goals of Approach

- To create detailed outline of business cases for a combined solution

Outcomes

- Multiple scenarios of business case developed and aligned to ensure the optimal setup considering grid connections cost, operational saving, regulatory aspects etc.

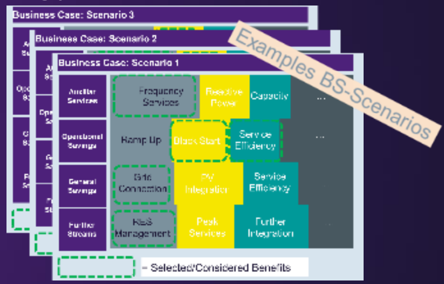
Tasks to achieve the outcomes

1 Select Use Cases and Data for external Factors

- Select the applicable revenue streams given the nature of the solutions setup (auxiliary services, frequency services, arbitrage)
- Collect data from location and asset owner on regulation, future demand, local initiatives, RES goals etc.
- Align on any further relevant requirements and constraints for initiative design (e.g. time, availability of resources, political initiatives etc.)

2 Design Final Business Case with Options

- Design a detailed Business Case and include different scenarios based on local conditions:
  - Auxiliary Services, RES Streams etc.
  - Cost Reductions with BESS
  - Benefits from existing connections, demand forecasts, energy utilizations…



Which services are necessary to stabilize highly renewable penetrated power grids?

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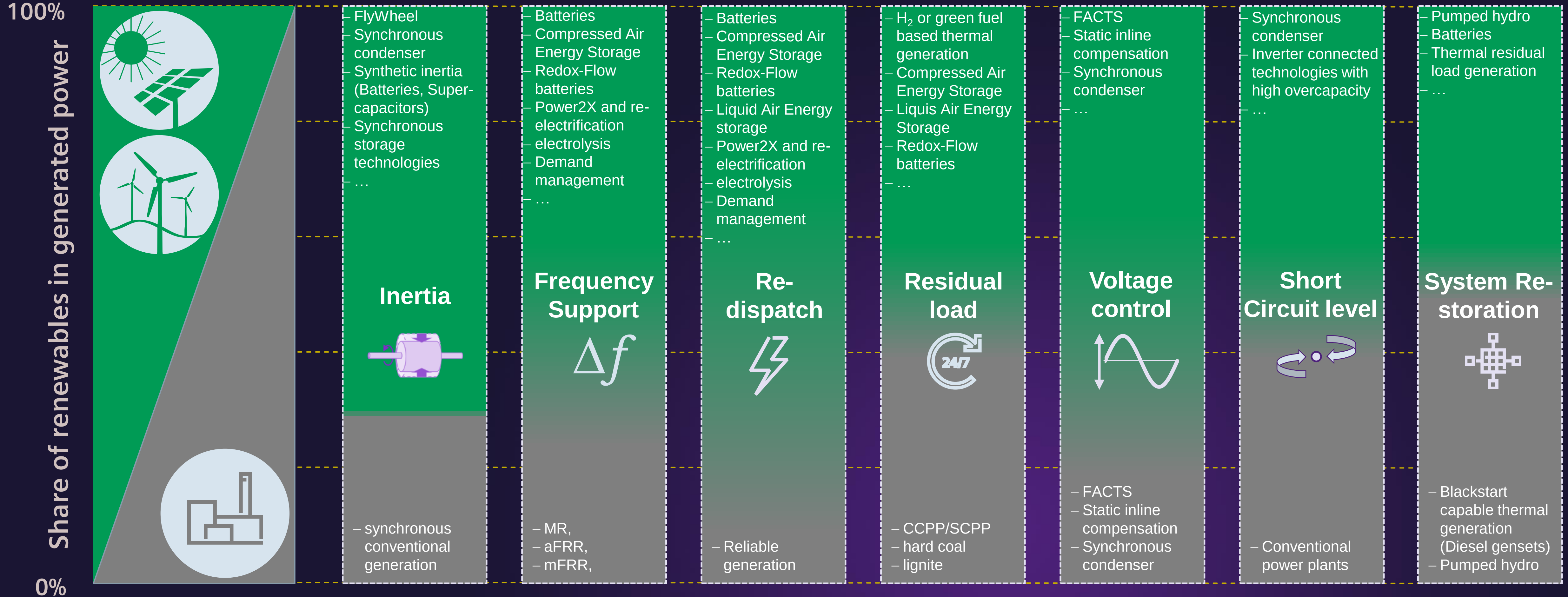
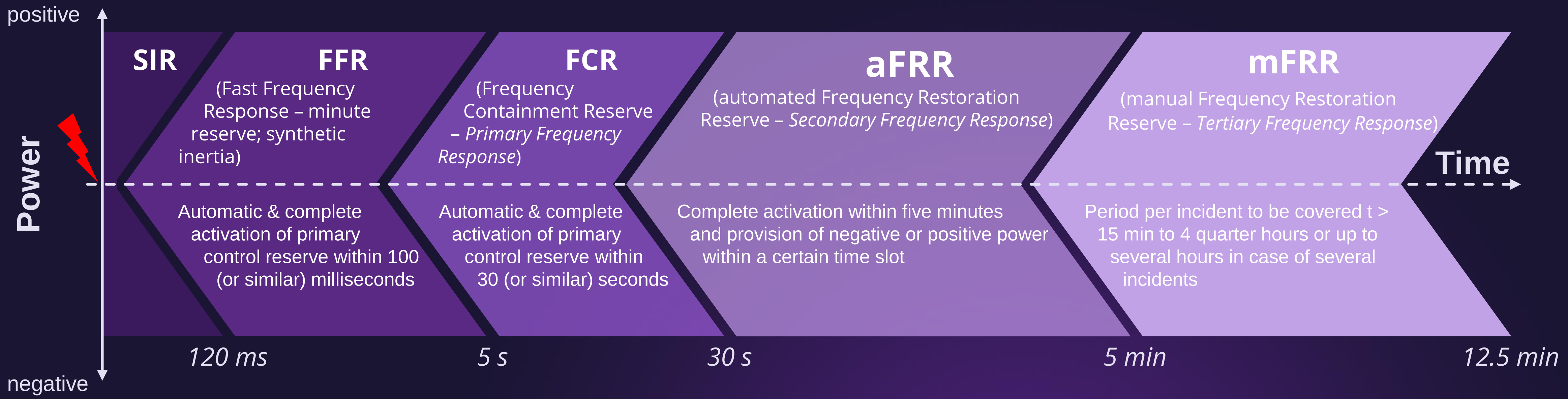


Less reliable, thermal generation in the power mix require additional effort within a highly decarbonized grid!

Inverter connected Wind and PV in power mix

Conventional generation in power mix

Dynamic stabilization of the Frequency
Visual



SIR: Synchronous Inertial Response – Minute Reserve (inertia provided by synchronous rotating equipment)

Grid stability - solutions for emerging grids

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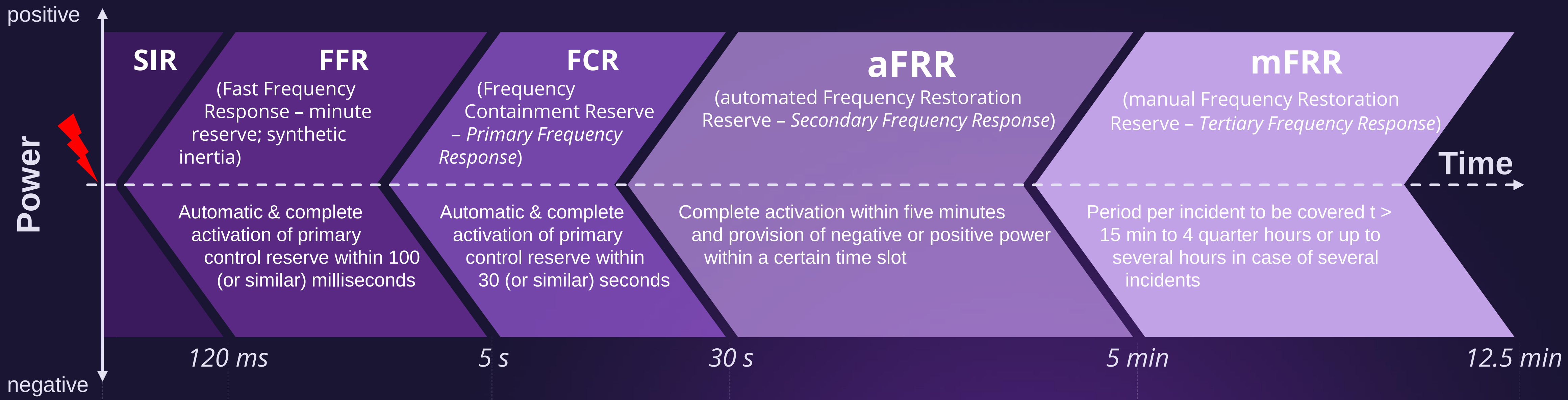
Technology / System needs	Inertia	Voltage control / Reactive Power	Short Circuit Level	System Restoration
Existing Technologies				
Synchronous Condenser	✓ (green)	✓ (green)	✓ (green)	✓ (yellow)
Flywheel	✓ (green)	✓ (green)	✓ (yellow)	✗ (red)
Static Compensators	✗ (red)	✓ (green)	✓ (yellow)	✗ (red)
Pumped Hydro	✓ (green)	✓ (green)	✓ (green)	✓ (green)
Emerging Technologies				
Grid Forming Technologies /VSM	✓ (yellow)	✓ (yellow)	✓ (yellow)	✓ (yellow)
Power Electronics with Energy Storage	✓ (yellow)	✓ (yellow)	✓ (yellow)	✓ (yellow)
Hydrogen Powered Gas Turbines	✓ (green)	✓ (green)	✓ (green)	✓ (green)
Bioenergy with Carbon Capture and Storage	✓ (green)	✓ (green)	✓ (green)	✓ (green)
Gas Plants with Carbon Capture and Storage	✓ (green)	✓ (green)	✓ (green)	✓ (green)
Innovation in Power Electronics	✗ (red)	✓ (yellow)	✓ (yellow)	✓ (yellow)

- ✓ (green) Mature technology
- ✓ (yellow) At early stages of deployment / technology that can supply some of the service
- ✗ (red) Technology that's unlikely to supply the service

Dynamic stabilization of the Frequency
Visual



Possible of frequency instabilities using Li-Ion Battery Energy Storage Systems

SIR: X
- No synchronous equipment

FFR: (✓)
- Fast response time required
- Special BESS necessary

FCR: ✓
- Response time sufficient
- Mandatory capacity must be reserved

aFRR: ✓
- Response time sufficient
- Mandatory capacity must be reserved

mFRR: ✓
- Response time sufficient
- Mandatory capacity must be reserved

SIR: Synchronous Inertial Response – Minute Reserve (inertia provided by synchronous rotating equipment)

Requirements for Black Start and aFRR (POS & NEG)

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100 %

0 %

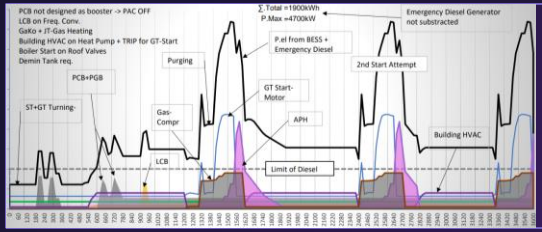
Use capacity in urgent cases or when well paid

Keep operation between SOC 20 % and 80 % for extended cyclic life

Use capacity in urgent cases or when well paid

Deep discharge not usable to avoid damage of BESS

Requirements for Black-Start:



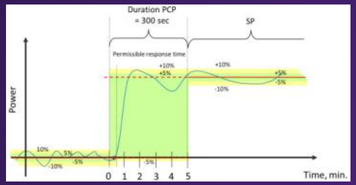
Demand with SGT-800 3x1:

- GTs and ST on turning gear
- Cooling system intermittent
- Control system remains powered
- HVAC reduced to min.

		min.	+ failure invest.	+ cool down
Capacity depending on factor of safety:	3 failed starts:	2.5	1.0	0.4 MWh
	4 failed starts:	3.3	1.5	0.4 MWh

Requirements for SFR / aFRR:

> 5 MW, capacity reserved > 60 min (compared to marketable power for aFRR POS and aFRR NEG)
Activation sequence requirements:



Response time < 30 s
Power Change period: < 5 min.
Stationary Period: ≥ 10 min (> 60 min mandatory reserved)

- no fuel may be drained or burned unused for aFRR POS or aFRR NEG
- Recharge management must be established and qualified according to spec.
- guaranteed availability 100%

Reference: PQ-Anforderungen (regelleistung.net)

SVC PLUS®

Applications: Typically, where the increase of transfer capabilities of power network is needed

Function: Provides fast-acting voltage support with power compensation

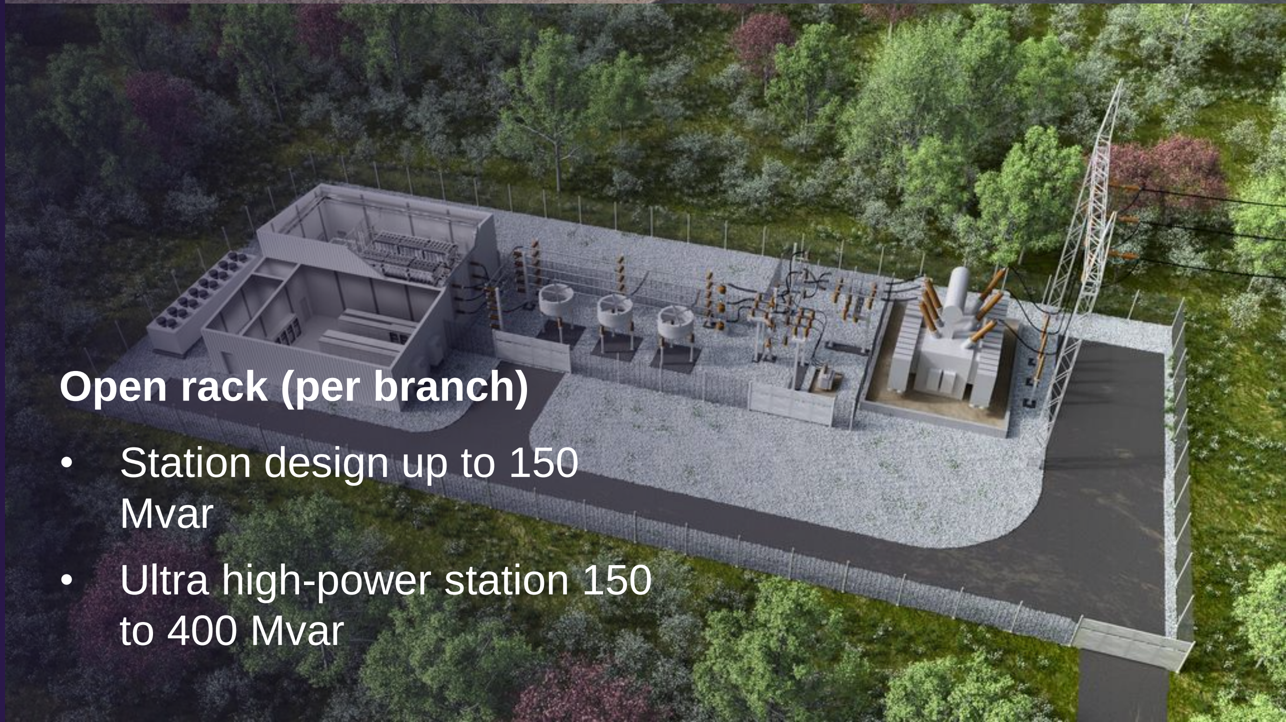
Ratings: up to 400 Mvar per branch

Main advantages:

- Robust and flexible solution in a fast-changing environment
- **Handling changes in grid topology, power quality, and system requirements**
- Superior over- and undervoltage behavior
- Active Filter functionality
- **Transient voltage support after network events**
- Cost-efficient, space-saving, flexible solution to increase dynamic stability and power quality of the grid
- **Grid forming control capacity**

Containerized Solution

- Compact container up to 50 Mvar (per branch)
- High power container solution 50 to 150 Mvar



Open rack (per branch)

- Station design up to 150 Mvar
- Ultra high-power station 150 to 400 Mvar

SVC PLUS® Mobile

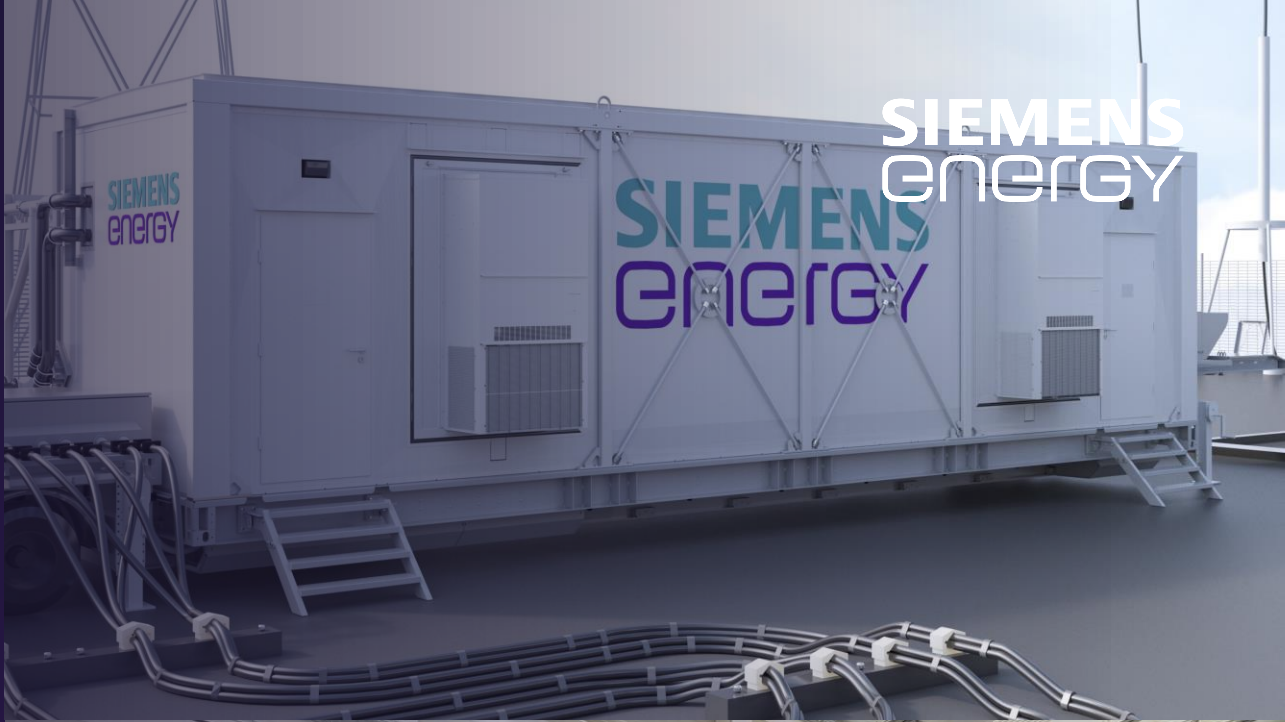
Applications: Typically, where a plug and play multi-tool for transmission grids is needed

Function: Enables temporary grid support and grid resilience against emergencies

Ratings: ± 50Mvar

Main advantages:

- Relocatable
- **Quick assembly and disassembly**: plug-connection of modules
- Fast grid stabilization and restoration
- A **mobile and low footprint**
- All modules are available on trailers
- Proven technology of SVC PLUS® with the best performance
- No civil work is needed in many cases (depending on soil conditions)
- “Greenfield” operation is possible



SVC PLUS Frequency Stabilizer®

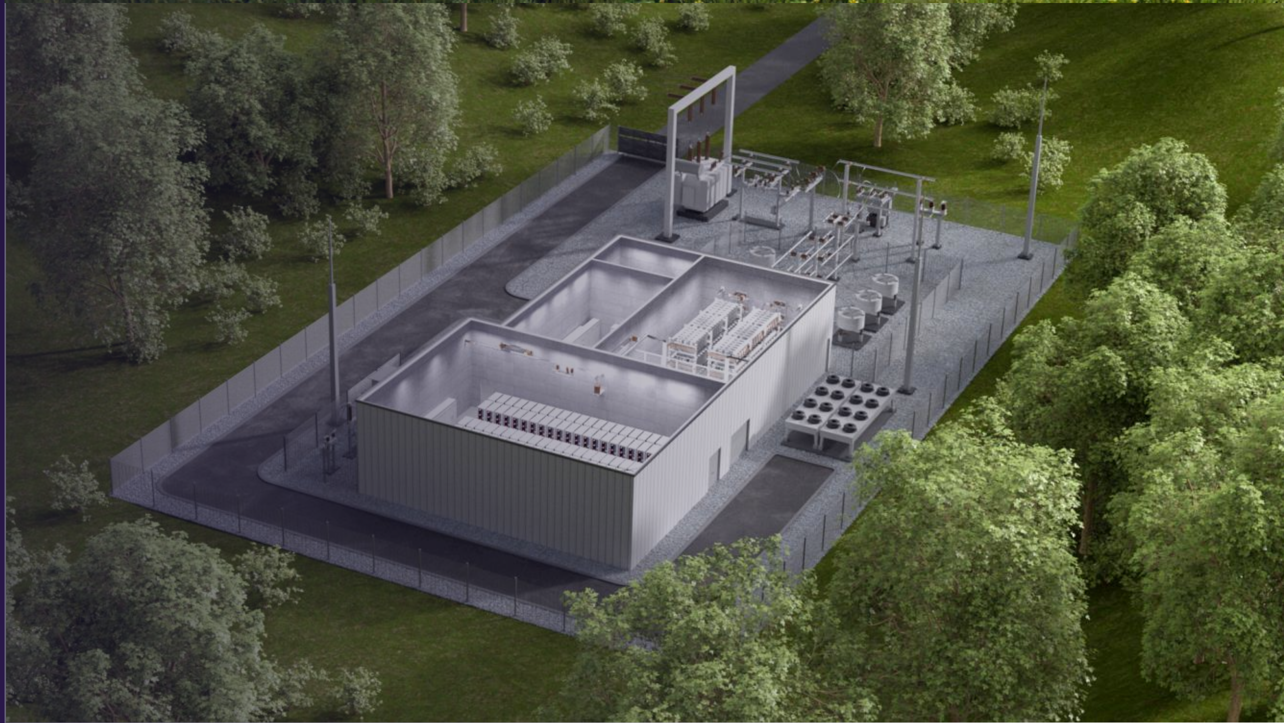
Applications: Typically, to stabilize voltage and frequency in the grid

Function: Emulates system inertia by boosting high active power when needed

Ratings: available energy 450 MJ
scalable up to 500MWs

Main advantages:

- SVC PLUS FS® can address any voltage level
- **Blackout prevention due to dynamic voltage and frequency support** combined in one unit
- Cost-efficient solution
- **Short respond time with high active power output** over several seconds
- **Highly adaptable solution with a small footprint**
- Independent of power generation
- Proven technology of SVC PLUS® with the best performance



Synchronous Condenser

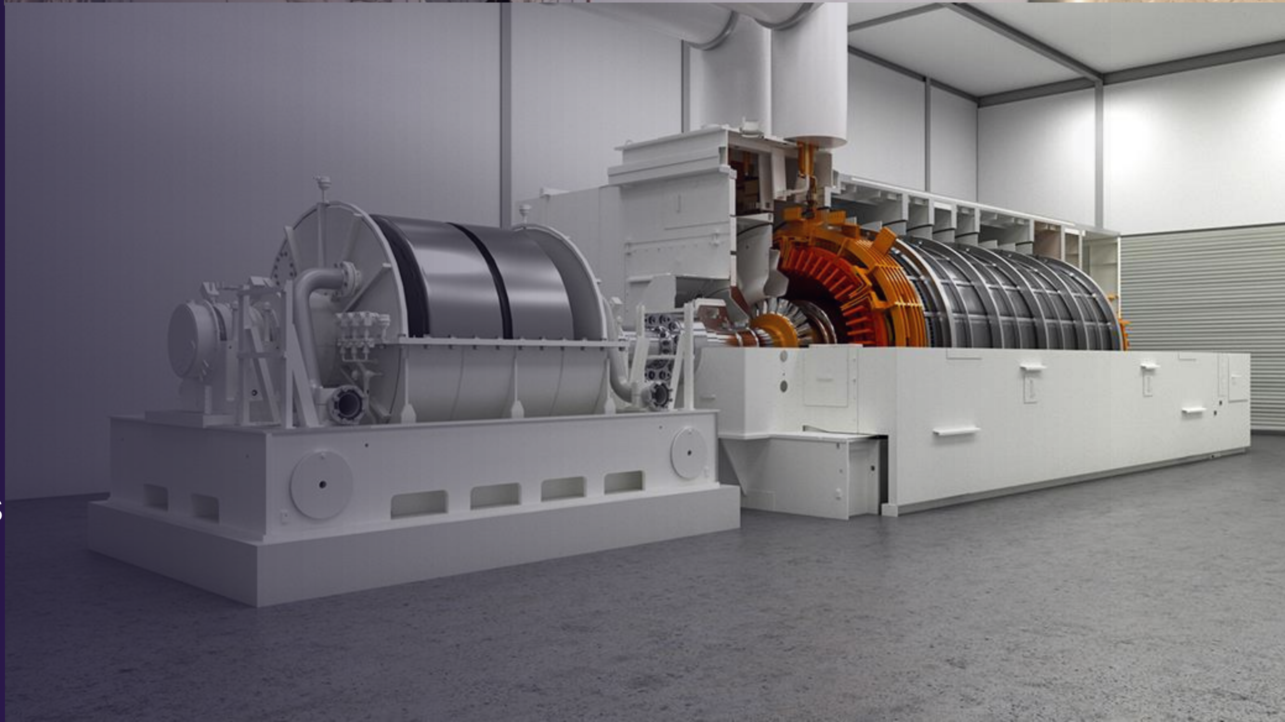
Applications: Typically, to stabilize High Voltage grid during faults

Function: Provides short-circuit power and inertia for system strength and reactive power for voltage stability in the grid

Ratings: up to 4000 MWs inertia (including flywheel)
at generator terminals:
> 2000 MVA short circuit power
> -250/ +450 Mvar reactive power

Main advantages:

- **Inherent synchronous inertia response** for system strength
- High short-term overload capability
- Voltage support and contribution of **short-circuit power**
- **Various flywheel sizes** in vacuum to reduce friction losses
- Long term service agreement



Hybrid Generation and Grid Stabilizing Package

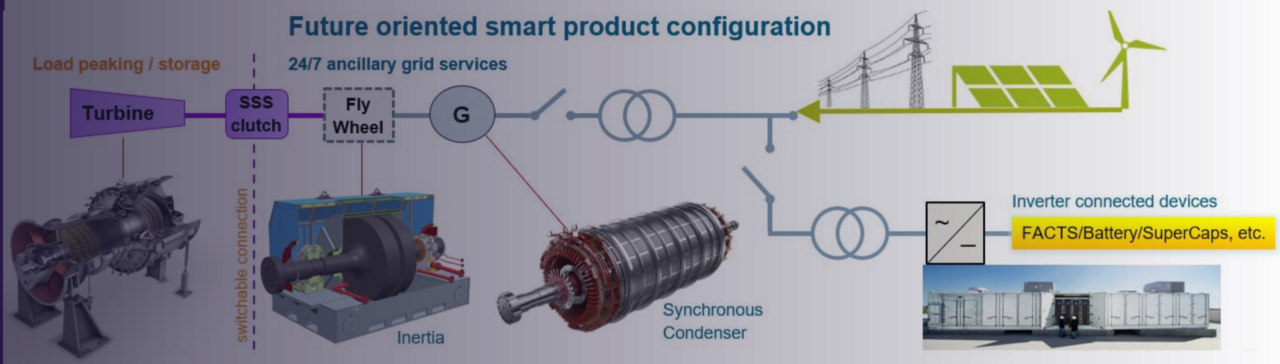
Applications: Flexible power and heat generation and/or balancing services when required

Function: Provides all grid balancing services continuously and active power and heat on demand

Ratings: active power 5-500MW, more than 4000 MWs inertia (including flywheel + synthetic inertia from the BESS)
at generator terminals:
> 2000 MVA short circuit power
> -250/ +450 Mvar reactive power

Main advantages:

- All use Cases along the power value chain can be monetized
- **Dynamic mitigation of power quality issues** caused by undesired impact **of difficult industrial loads** to the feeding grid
- Allows **controlled shut down of critical industrial processes** in critical cases



iSVC PLUS for Industry / Load Compensation

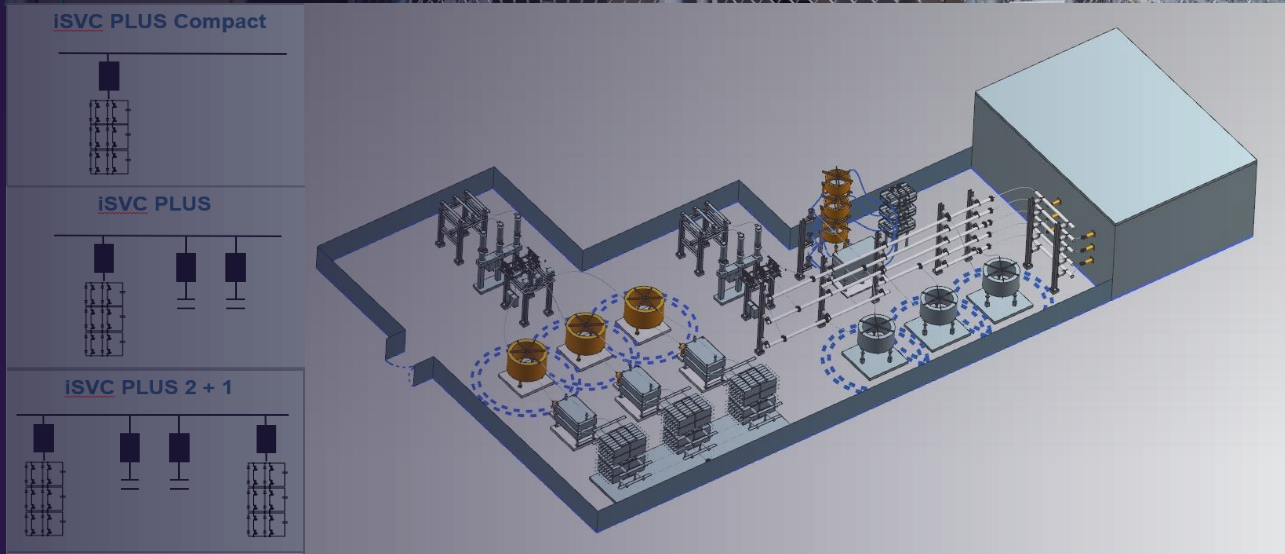
Applications: Typically, where large dynamic loads have undesired impact to the feeding grid (Electric Arc Furnaces, Mill Drives) – directly on MV load busbar

Function: Provides extra-fast reactive power support independently in 3 phases for flicker & harmonics reduction, voltage stabilization, load balancing and power factor improvement

Ratings: for loads in the range of approx. 30-250 MVA

Main advantages:

- Robust and flexible solution in a highly demanding industrial environment
- **Mitigating power quality issues** caused by undesired impact **of difficult industrial loads** to the feeding grid
- **Active harmonic filtering** of the converter, supported by filter circuits where required



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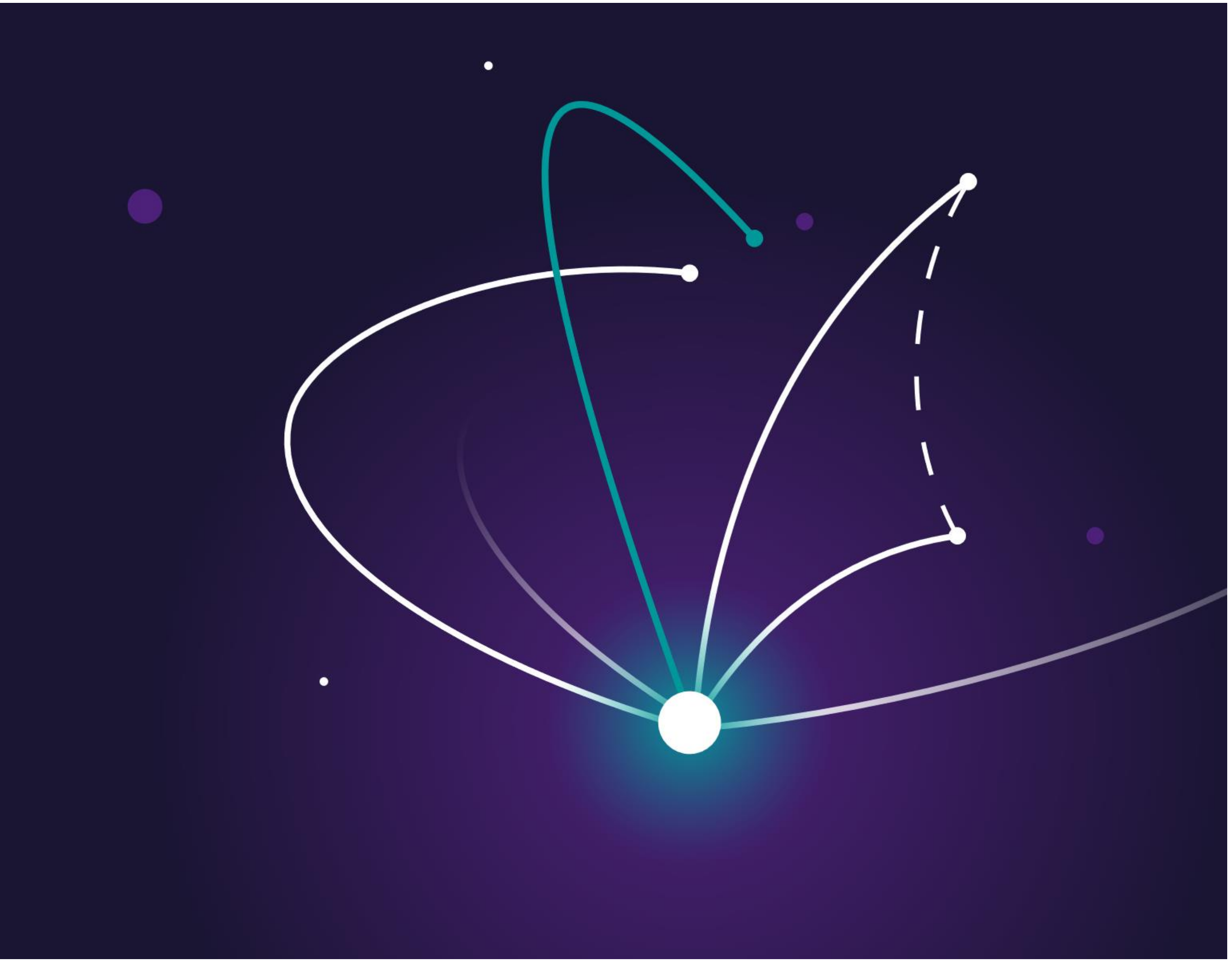

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