Inverter's contribution to the stability of power systems with high contribution from renewable sources

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Agenda

1. (Short) Review on grid code requirements
2. Dynamic voltage support and frequency regulation support of DER
3. Challenges and Solutions for highly DER penetrated grids

Motivation and general grid code requirements in different sizes of PV-Systems

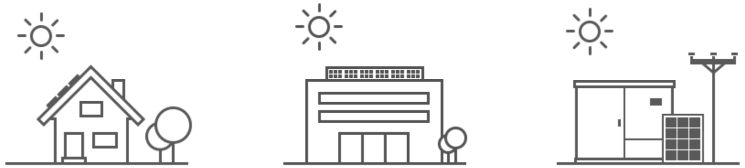
Installation of utility scale PV Systems in the recent years: approx. 40GW

Overall annual PV Installations: 50..100 GW

Rising Share of PV Systems → Higher System Impact / Responsibility → Rising Bar of Requirements

Standardized Parameter Sets	Individual Parameters / Remote Access	Project Specific Requirements

Requirement's complexity



Requirement/ Function	Generator Type		
	A – 0.8kW…1 MW	B – 1…50MW	C/D - >50MW / ≥110kV
Frequency ride through	x	x	x
Input Port to cease P output	x	x	x
Limited FSM (Overfrequency)	x	x	x
Reactive power capability		x	x
Remote active power limitation		x	x
Low voltage ride through		x	x
Fast fault current		x	x
Limited FSM (Underfrequency)			x
Frequency Sensitive Mode (FSM)			x
Black start capability			(x)
Synthetic inertia			(x)
Power system stabilizer			(x)

Exemplary requirements according to the Commission Regulation (EU) 2016/631 (also known as „Entso-e Requirements for Generators")

› **The more installed power and the larger the size of the PV-Systems, the higher the bar of requirements and complexity**

See also: Bülo et. al.: Next Generation Utility Scale PV- and Storage Systems: New Steps towards a 100% Renewable Generation, Solar and Storage Integration Workshop, Stockholm, 2019

Example: Dynamic Voltage Support and Provision of Dynamic Reactive Current

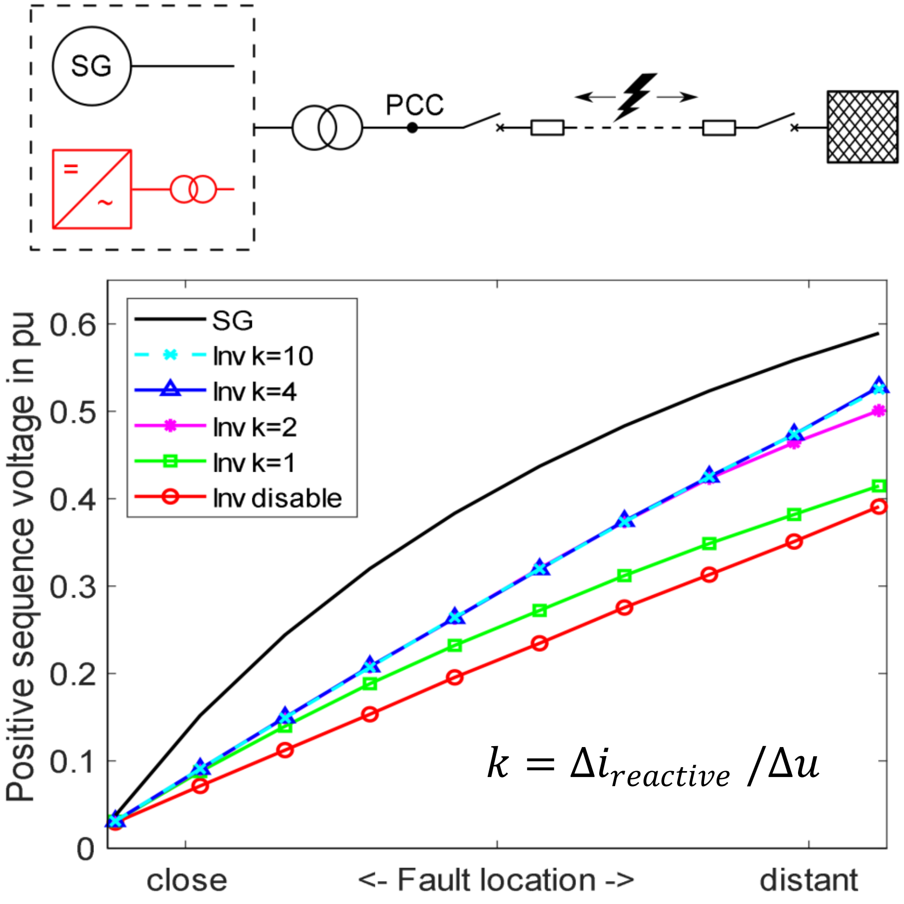
Simulation of exemplary Scenario

- Comparison of Synchr. Generator and Inverter with different values of k (relation of additional reactive current fed in and the voltage change during fault)
- Additional reactive current increases fault level at the PCC up to a k-factor of 2
- Inverter's apparent current limited to 1p.u. leads to a saturation of support
- Synchronous Generator leads to higher fault level due to overcurrent capability

Caution:

- At PCCs with low Short Circuit Ratio (SCR), high k-factors may provoke instabilities
- In such cases detailed project-wise analysis using EMT-Simulation Tools helps to ensure stable operation

> **Dynamic Voltage support of Inverter based generation is benefitial. In case of low SCR, more detailed review of parameterization is advised**



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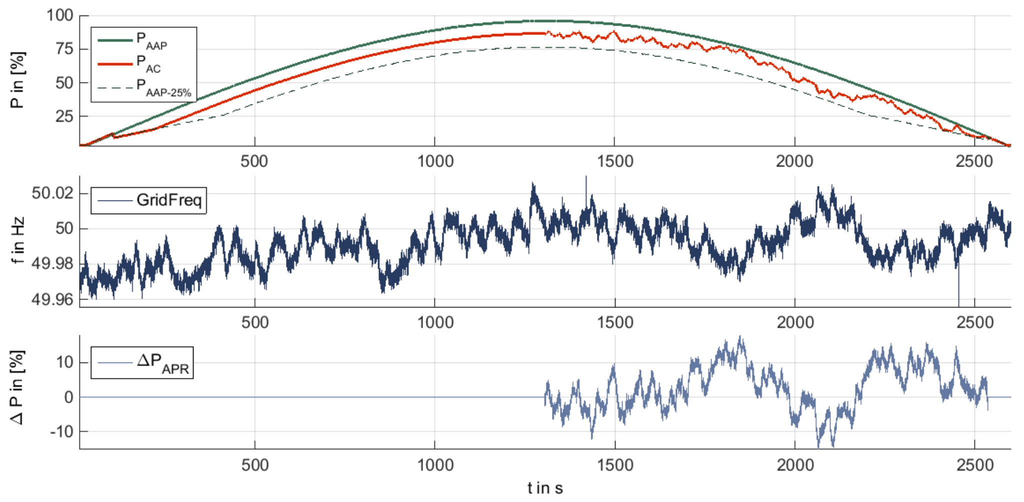
Frequency Regulation Capabilities I

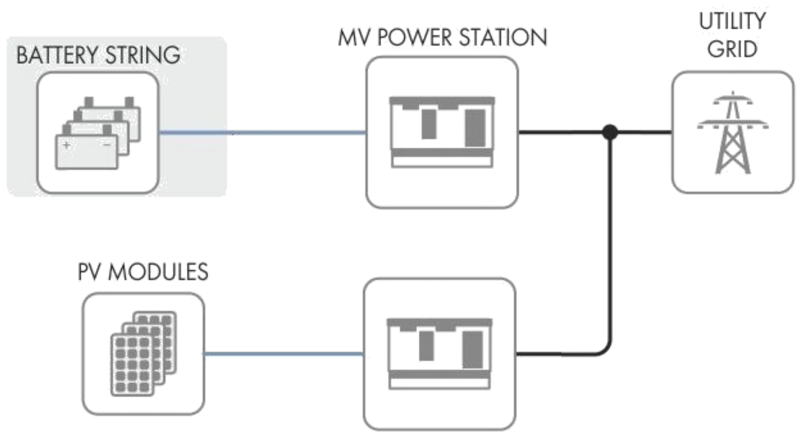
Experimental Control Scheme for PV-Systems

- Curtailment relative to MPP
- Dynamic Response to over- and underfrequency
- Minimization of curtailment losses compared to fixed curtailment
- Implemented in selected prototypes



Integration of Battery Storage Systems offers new possibilities

- Response to underfrequency without curtailment losses
- Provision of ancillary services independently from the availability of primary energy source
- Grid parallel operation as a Current Control Mode Inverter (CCI) or as a Voltage Control Mode Inverter (VCI)



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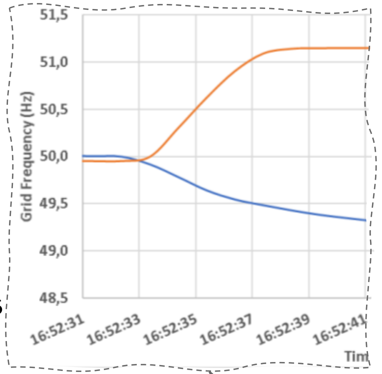
Frequency Regulation Capabilities II



Power Systems with less inertia due to reduced synchronous generation:

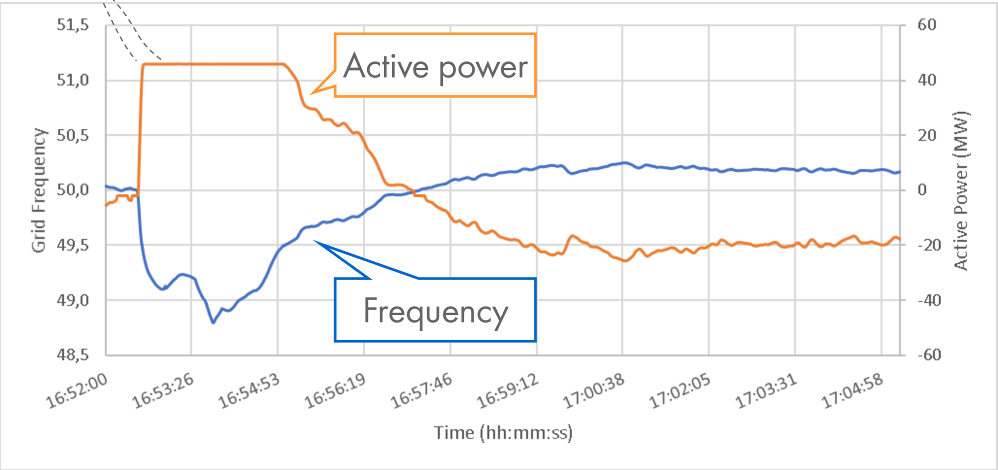
- Faster frequency regulation is needed
- UK has established new frequency response services in the recent years
- Examples: Firm Frequency Response / Enhanced Frequency Response

Storage system used e.g. for Frequency regulation (UK)

- Installed battery power: 64 MVA, commissioned 2017
- 26 units of SMA Sunny Central Storage 2475 Inverters and Plant Controller, provides FFR

Proved capability in August 9th event (2019) in the UK

- Response time approx. 1s
- Response characteristics according to stipulated behaviour



› Fast Frequency response products increase system stability, especially in grids with low inertia

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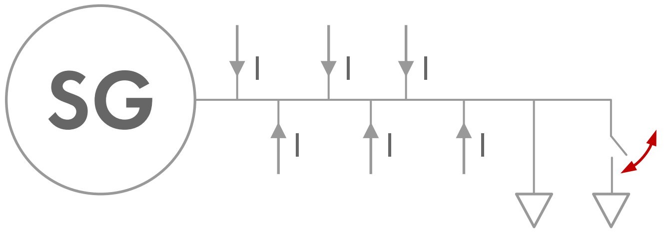
Challenges in highly penetrated Grids: Need for advanced control schemes



Reduced SG / Voltage Source

Load steps are initially covered by fewer sources

Technical limit for share of current sources

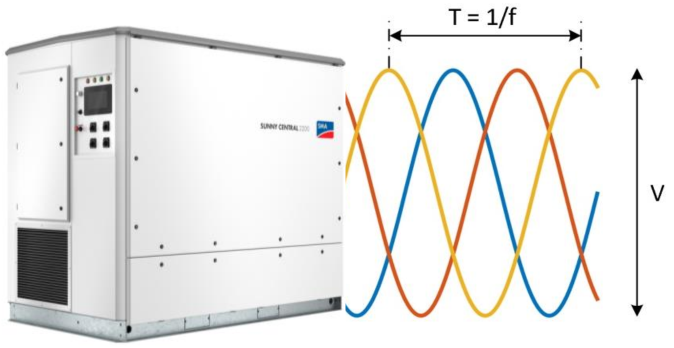
More Current Sources in the Grid, transport over wide disntances large impedances

Need for clean, firm reference voltages not always satisfied

Current controlled Infeed reaches stability limits

Introduction of Inverter-based voltage sources

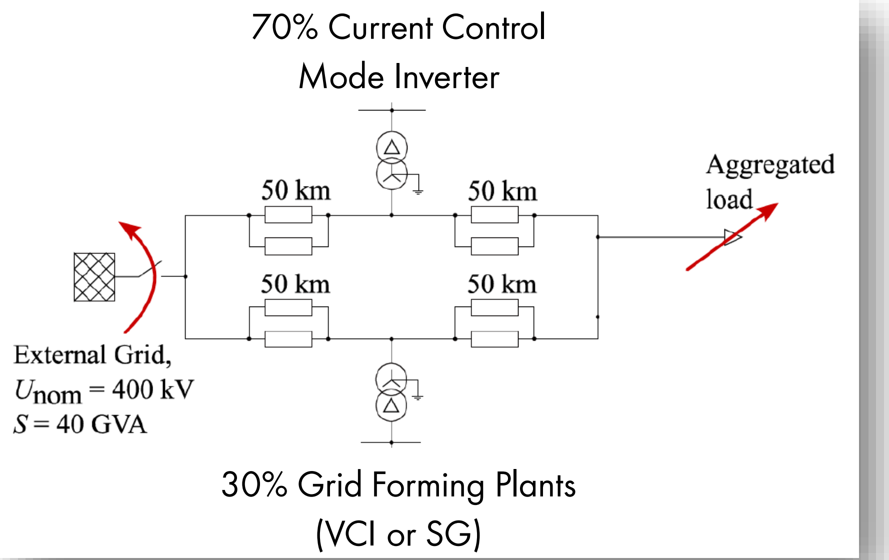
Input:
Normalized P/Q exchange with grid

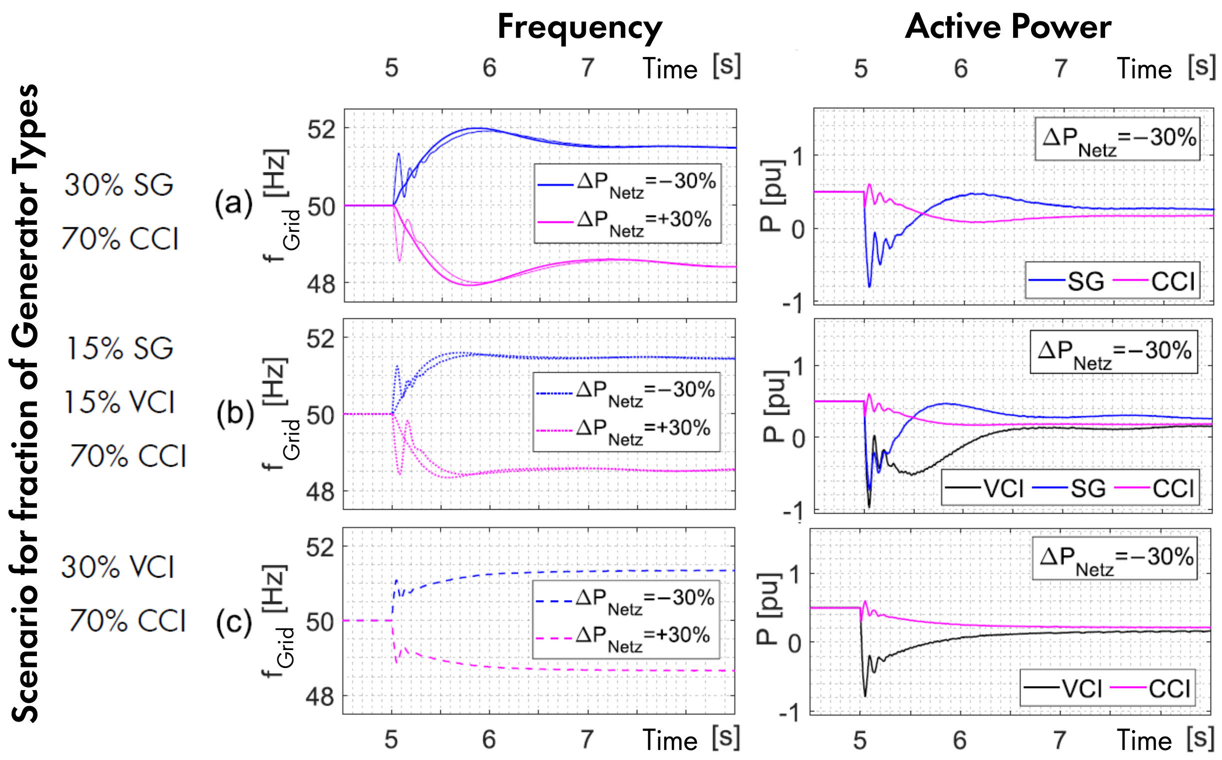


Output:
Voltage Sine Wave with dedicated Amplitude and Frequency

Can Gridforming Battery Systems substitute Synchronous Generators? System-behaviour during System-Split[1]

- System Split at a power transit of 30% of the grid part's power
- Variation of fraction of generator technologies
  - SG: Synchronous Generator[2]
  - CCI: Current Control mode Inverter[3]
  - VCI: Voltage Control mode Inverter[4] („Gridforming")





- VCI takes over significant share of initial load
- System stays stable, CCI follows change in frequency

> Equivalent parameterized Grid Forming Inverter can substitute the functionality of the Synchronous Generator

> 30% Gridforming is sufficient in this scenario

[2]SG with FSM (Frequency Sensitive Mode), Ta=10s
[3]CCI with LFSM (Limited Frequency Sensitive Mode)
[4]VCI with FSM; equivalent Ta=10s

[1] EMT-Simulations done by SMA, scenarios based on: Vennemann et. Al.: „Systemic Issues of Converter-based Generation and Transmission Equipment in Power Systems"

Inertia and immediate load sharing:
Real world generator shut down test in an island system

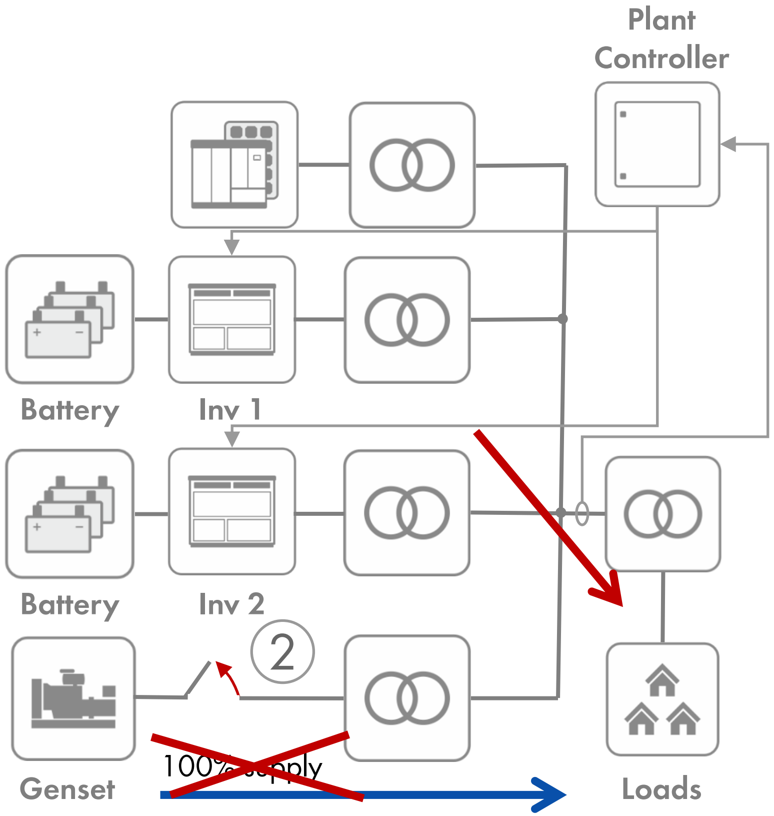
1 - Load is supplied by diesel genset with battery inverters in parallel standby

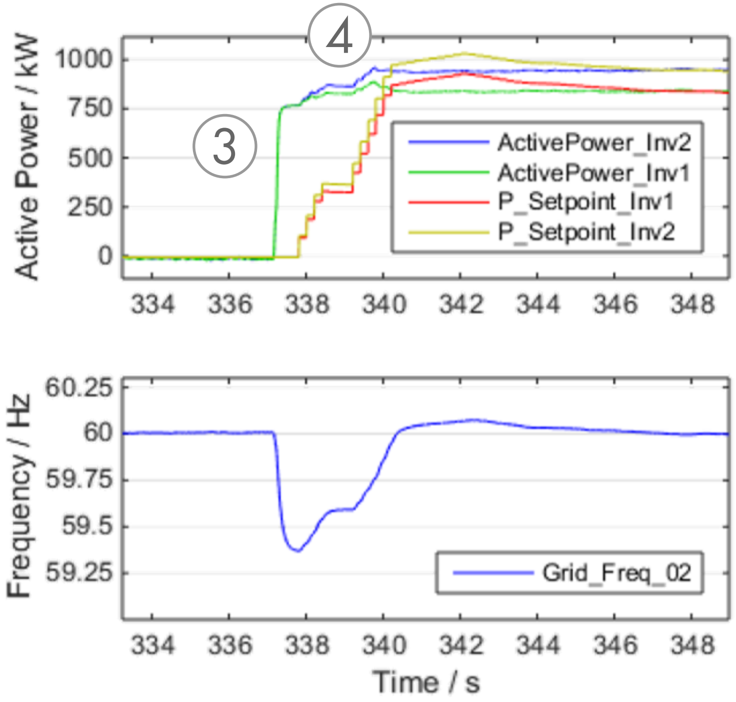
2 - Diesel genset is shut down

No measurement of frequency is needed!

3 - Battery inverters take over the load immediately, sharing load equally

4 - Setpoint for the reference point of f(P)-droop is adjusted (ext. control)





> **Capability proven in Island projects can be applied in grid connected applications**

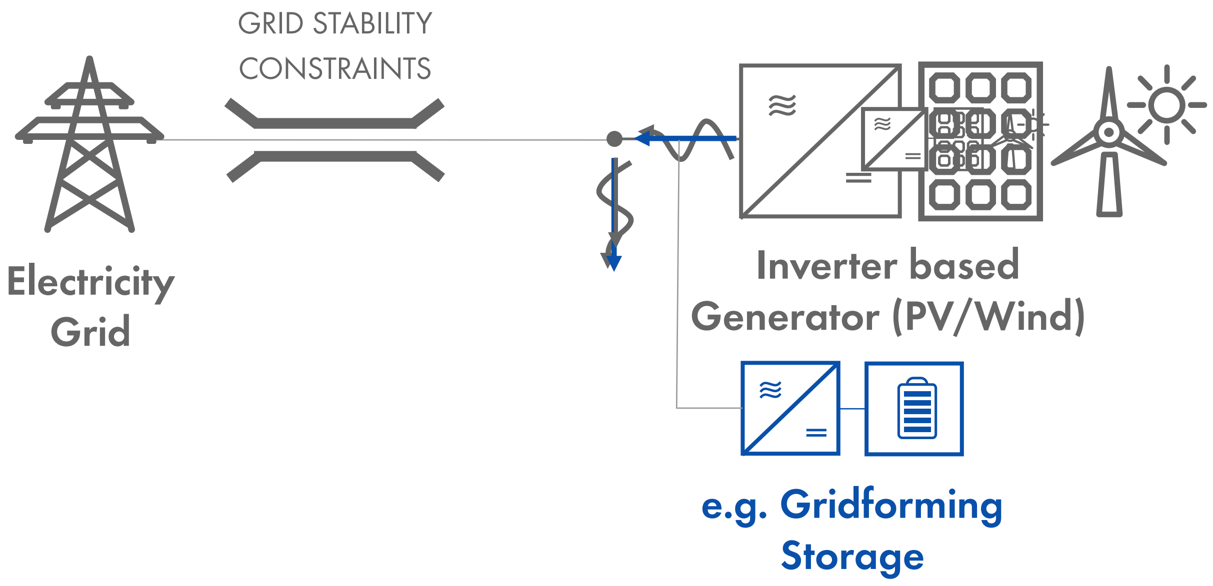
1

See also: Schömann et. al.: Experiences with large Gridforming Inverters on the Island St. Eustatius, portability to public power grids, Solar Integration Workshop, 8th international Workshop on the Integration of Solar Power into Power Systems, Stockholm, 2018

Need for System Strength needs to be satisfied by Inverter Based Resources

Large PV-/Wind Power Plants in „weak“ grids

- Long distance transport of high generation capacity
- Grid's Short Circuit Power is relatively small related to plant's generating capacity („Low SCR“ (approx. 2))
- Control stability is hard to achieve for current controlled power plants, since they have a feedback on their own voltage reference
- Gridforming / VCI Inverters can stabilize the behaviour in steady state operation and in case of faults (as an alternative to synchronous condensers)



Requirements: Characterization of „class 1" inverters

CREATES SYSTEM VOLTAGE (does not rely on being provided with firm clean voltage)

Contributes to FAULT LEVEL (PPS & NPS within first cycle)

Contributes to Total System INERTIA (limited by energy storage capacity)

Supports fast dynamics (FIRST CYCLE) SURVIVAL for system splits and from brown & black outs

Controls act to PREVENT adverse CONTROL SYSTEM INTERACTIONS

Act as a SINK TO counter HARMONICS & INTER-HARMONICS and UNBALANCE in system voltage

- CLASS 1 POWER PARK MODULES shall be capable of supporting the operation of the AC power system under normal, disturbed and emergency states WITHOUT having to rely on SERVICES FROM SYNCHRONOUS GENERATORS

Options for Establishing new Technologies for Stabilizing Grids with High Share of Renewable Sources

Grid Codes / Connection Rules

Use Gridcodes to force new capabilities

- Technical risks in Wind and PV result in longer implementation / Time to market

New Grid Operator's Assets

Grid operator uses and owns new dedicated assets to provide Stability / Inertia / Dynamic Reactive Power

- May be used to gain experiences with new technologies to provide new services as a role model for other approaches (market based / Grid Codes)
- Separation of Grid Stabilization and Energy provision

Market based approaches

Define new system services and provide incentives / tenders

- May provide a positive dynamics / competition and constructive attitude of developers
- Example: UK Stability Pathfinder Program

> **Market based approaches or the definition of new grid operator's assets may pave the way for the application of gridforming technologies**

Summary and Outlook

Status Quo

Inverter based generators provide can provide a lot of robustness and variety of system services already

Challenges

With increasing shares of inverter based generators and decreasing share of Synchr. Generators, there is a need for new voltage sources to a certain extent

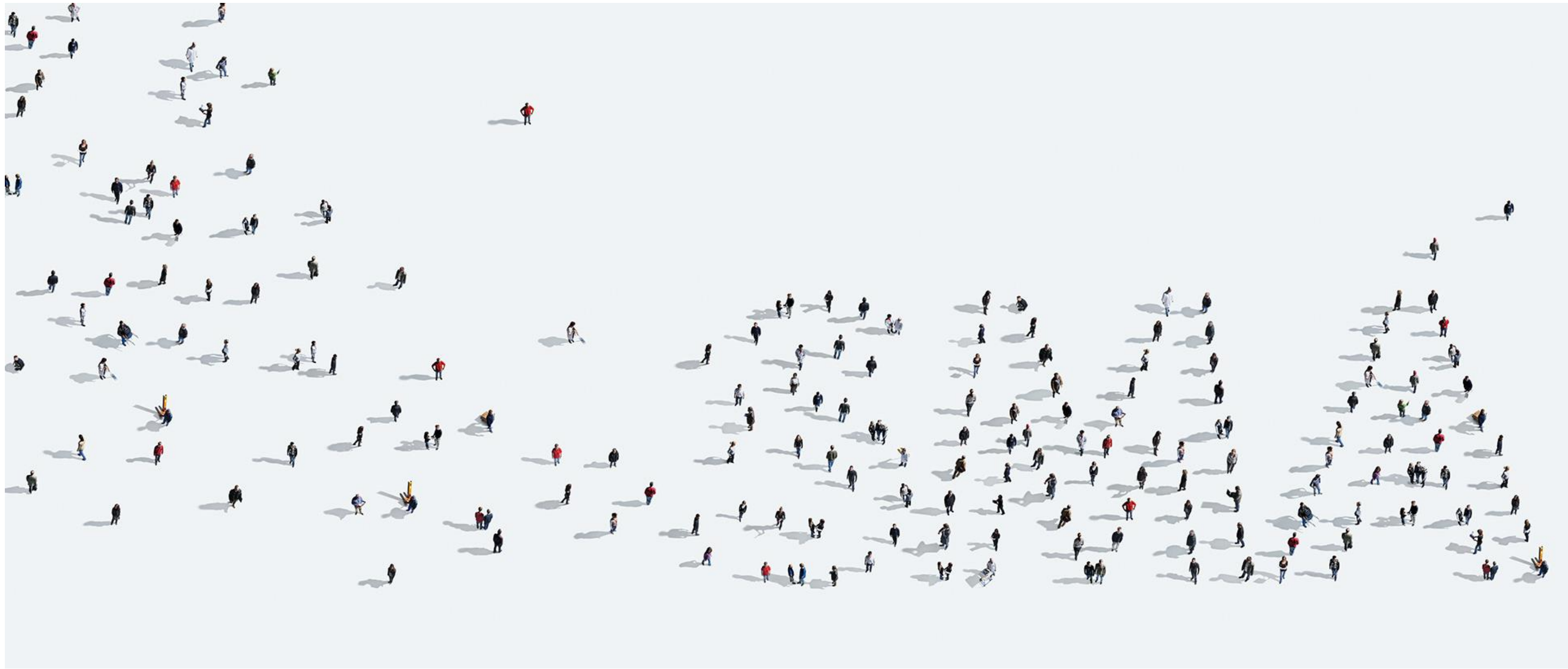
Solution

New "Gridforming" control schemes in combination with transient power provision capabilities by short or long term storage

Open questions

For each power grid, the demand and solution approach has to be determined and an appropriate regulation has to be applied

Thank you!



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