



Grid Forming Inverters Market News, and a Future Plant Design Example

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Agenda

- 1 Grid Forming Inverter and Stability Services Fundamentals
- 2 Emerging Market Requirements
- 3 Grid Forming Control Modes
- 4 Example Future Plant Design for System Strength



SMA Solar Technology AG – Energy that Changes

Energy transition company in the power conversion business and pioneer for decarbonization & decentralization

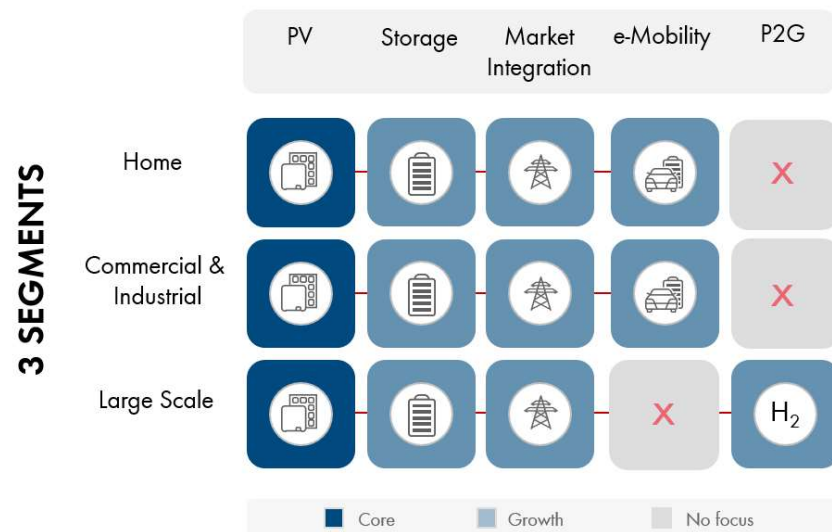


>132 GW installed solar inverters 1,700 patents & utility models

>15 GW installed battery 4,300 employees

inverters
86 MT/a CO2e avoided 20 countries (sales & service)

5 SECTORS



SMA Solar Technology

Key financials 2023

Sales: MEUR 1,904

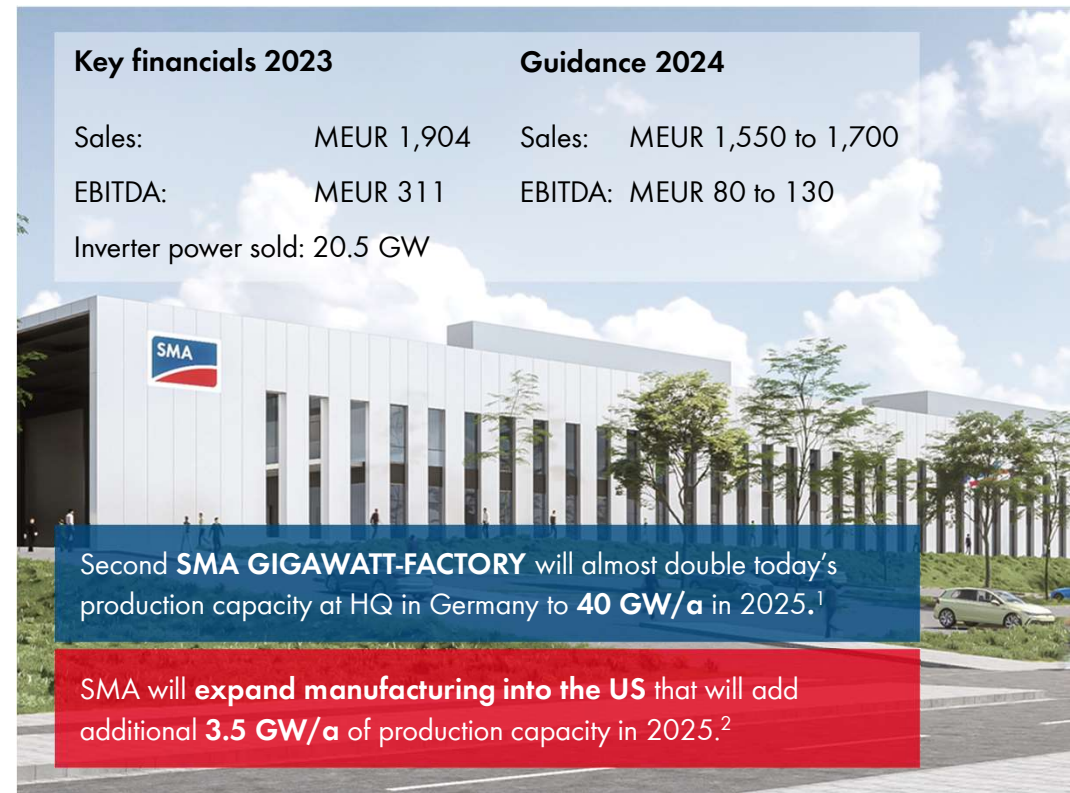
EBITDA: MEUR 311

Inverter power sold: 20.5 GW

Guidance 2024

Sales: MEUR 1,550 to 1,700

EBITDA: MEUR 80 to 130



1. From 20 to 40: ground-breaking ceremony to celebrate the start of construction of the SMA GIGAWATT FACTORY | SMA Solar
2. SMA announces plans to manufacture in the United States | SMA Solar

Agenda

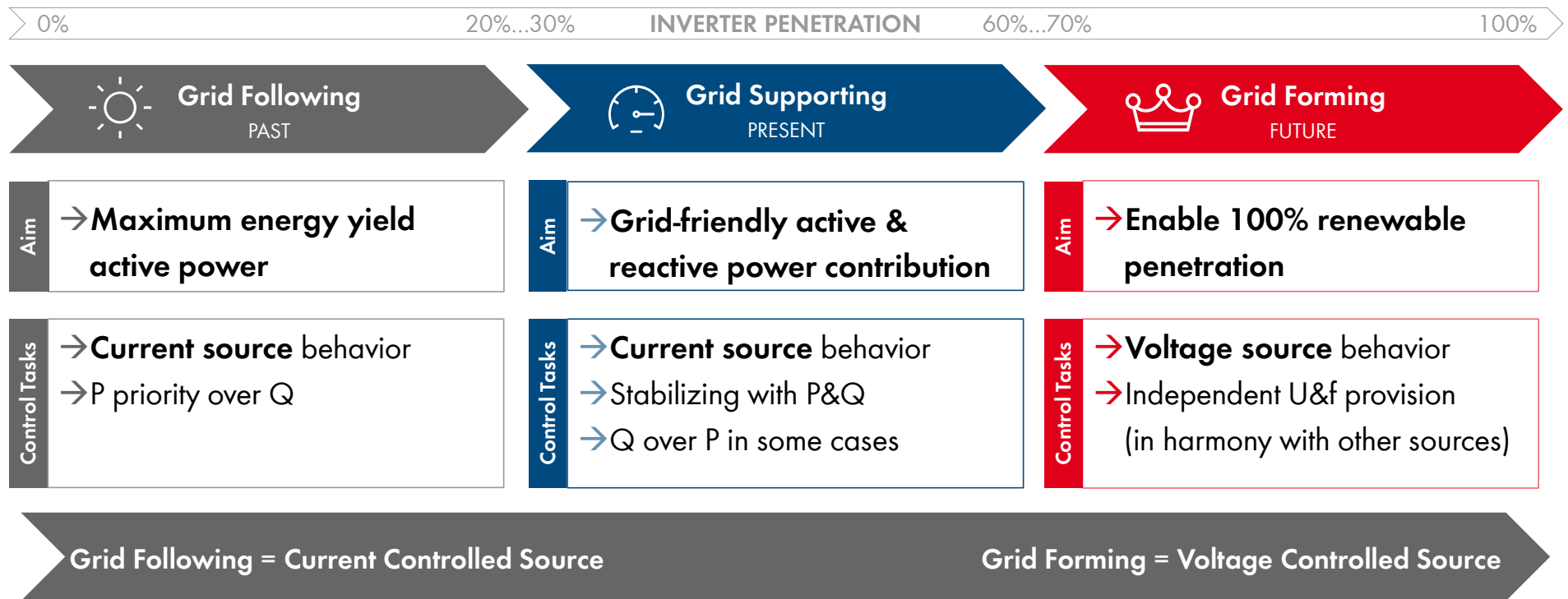
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SMA Large Scale Energy Solutions – SOLAR, STORAGE, P2G

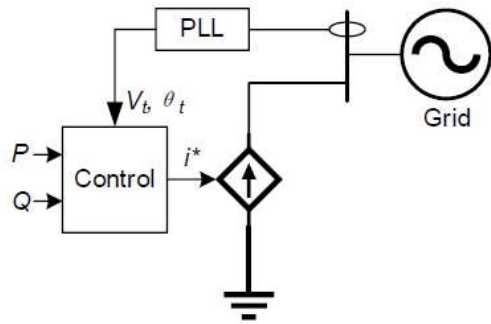


Grid Following vs. Grid Forming



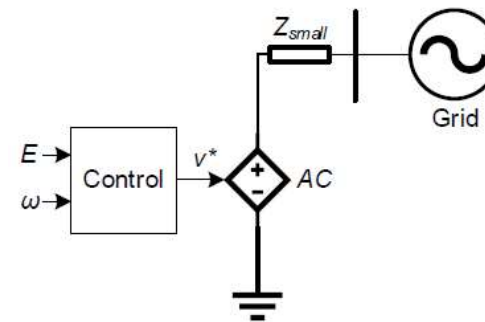
GFL vs. GFM comparison

Grid Following (GFL)



- PLL control is used to generate the output signal of the inverter
- Control the active and reactive power

Grid Forming (GFM)



- PLL is only used for measurements in the grid, but not for control
- Control the voltage magnitude and phase/frequency

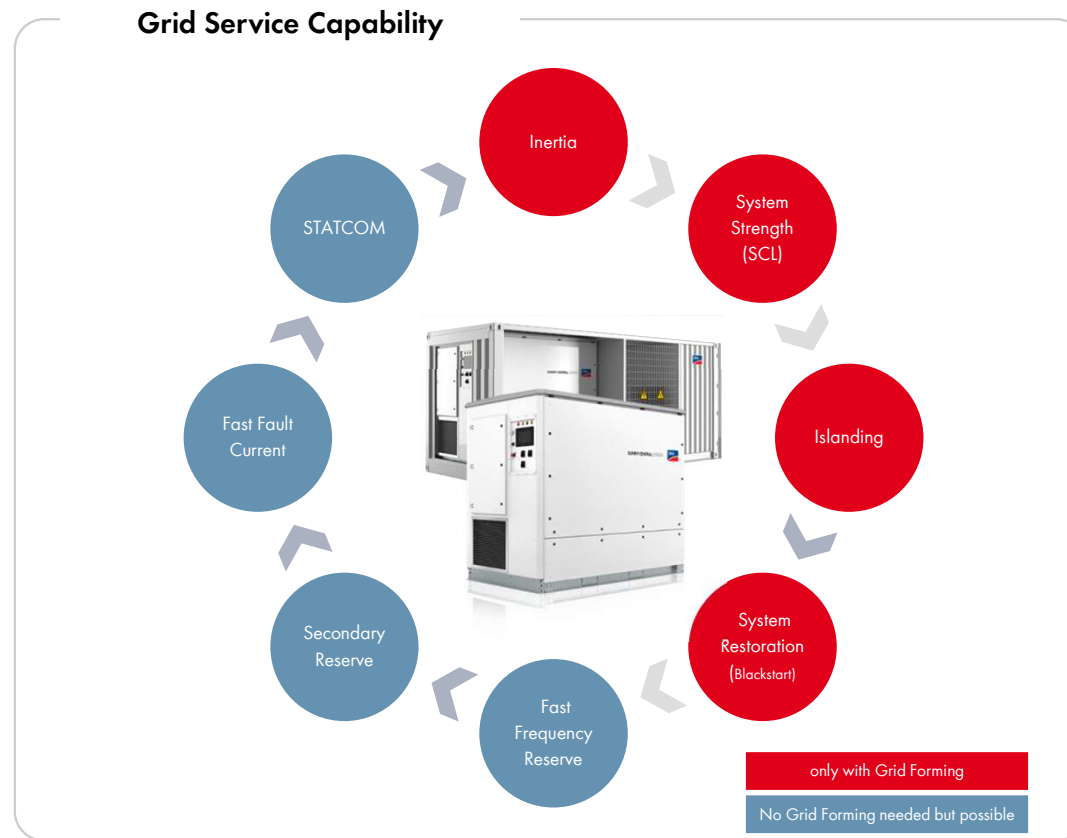


What is Synchronous Grid Forming

- Inverters operating in Voltage Source Control Mode - **Grid Forming**
- In **synchronism** with a large interconnected network
- Stabilizing weak grid regions and the overall power system
- Compatible with existing systems, and enabling 100% inverter-based generation.

Synchronous Grid Forming is the key enabler for 100% renewable generation.

Overview: What Stability Services Does Grid Forming Unlock?



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Power system operators and regulators globally are working on solutions to guarantee grid stability as IBR penetration increases



ISO Functional Requirements are Emerging



Test	NERC	MISO	ERCOT	AEMO
Loss of Synchronous Machine - discharging	Green	Grey	Green	Light Blue
Loss of Synchronous Machine - charging	Green	Green	Green	Light Blue
Loss of Synchronous Machine - limits	Green	Green	Green	Light Blue
Loss of Synchronous Machine - power imbalance	Grey	Green	Green	Light Blue
Stability under changing frequency i.e. ROCOF	Grey	Green	Green	Light Blue
SCR step down with fault	Grey	Green	Green	Light Blue
Phase jump	Grey	Green	Green	Light Blue
Series compensation step test	Grey	Grey	Green	Grey
Voltage magnitude step test	Grey	Grey	Green	Grey
Energy response test	Grey	Grey	Green	Grey
Frequency scan	Grey	Grey	Green	Light Blue
Power oscillation damping	Grey	Grey	Grey	Light Blue

Similarities exist in adoption approaches, but differ in test requirements and even test specifics within an individual test

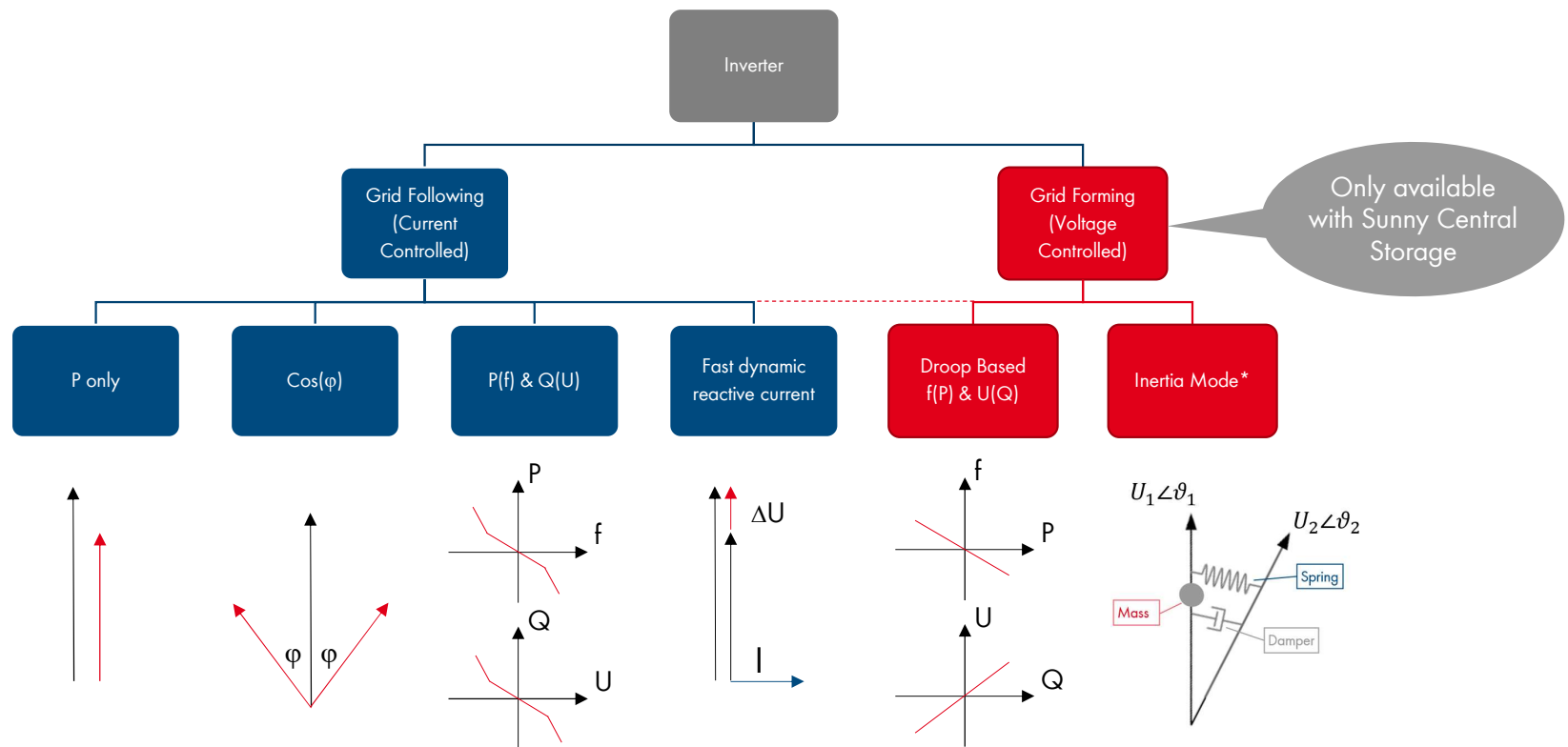
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HIGH LEVEL CONTROL MODES

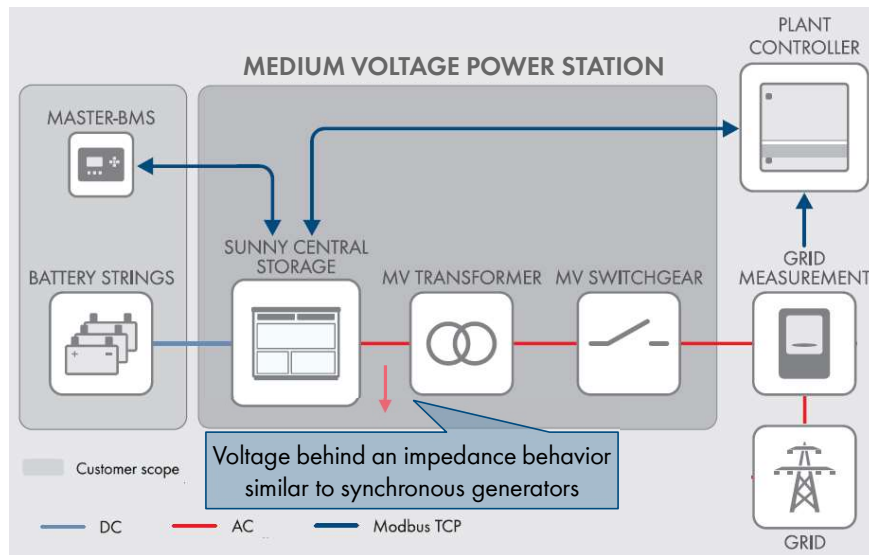
Grid Following and Grid Forming



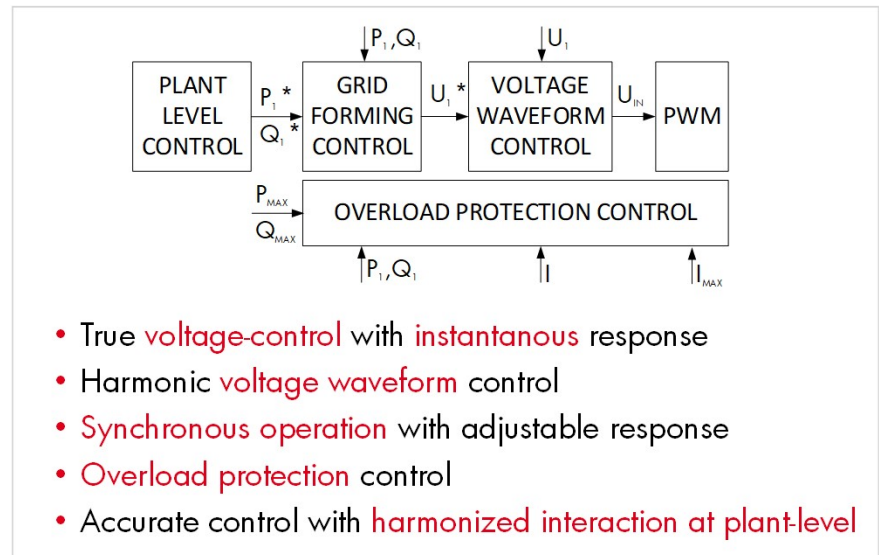
SMA Grid Forming energy storage system concept for multiple utility-scale applications



Perfectly matching system components



Enhanced grid forming controls



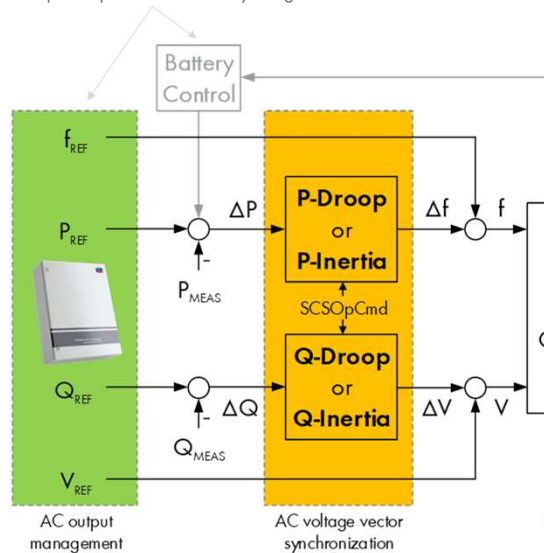
SMA Grid Forming storage system can enhance renewable plants with grid forming capabilities. The scalable system solution leaves a high degree of flexibility for customization and expandability.

Fundamental control capabilities of the SMA Grid Forming Solution with Sunny Central Storage Grid Forming inverters



ADVANCED CAPABILITIES

for V & f control, load adjustment, battery management, grid services and plant operation services by using additional and overlaid controls.

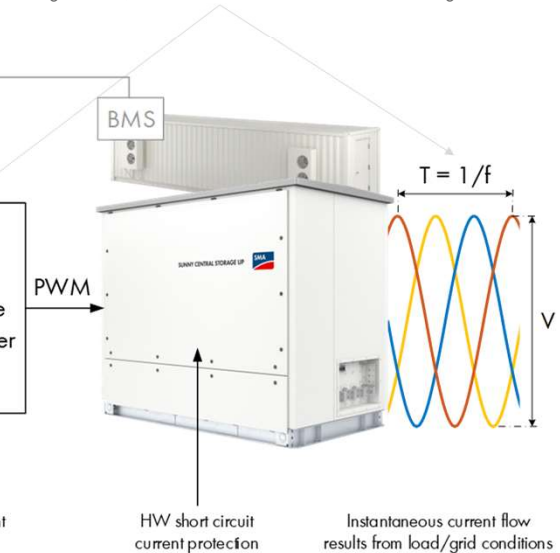


COMMUNICATION-FREE SYNCHRONIZATION

with other voltage sources by configurable V & f adjustment based on active and reactive load only (no PLL usage!).

INDEPENDENT VOLTAGE CREATION

using voltage amplitude and frequency setpoints and a true AC voltage control, harmonic waveform control and balancing.

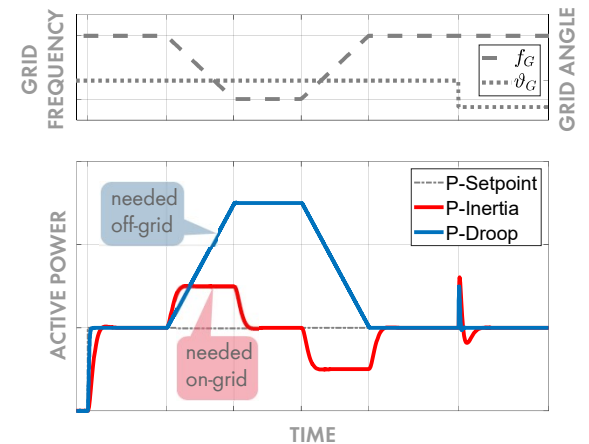


ROBUST RIDE-THROUGH + OPTIONAL CURRENT BOOST

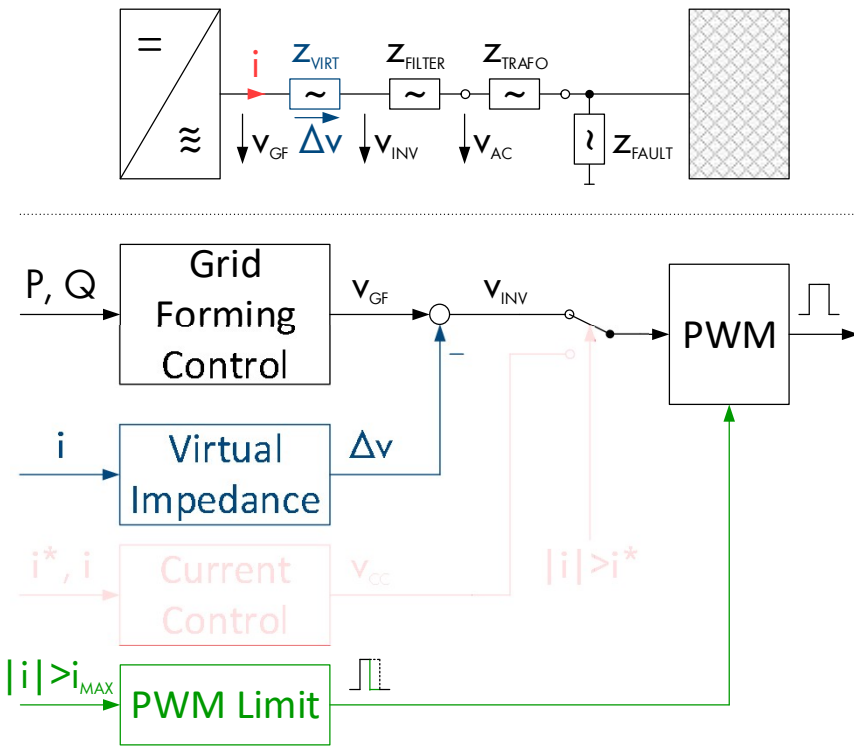
at high load conditions by inner voltage phasor adjustment while keeping voltage source behavior.

CONFIGURABLE RESPONSE TO GRID EVENTS

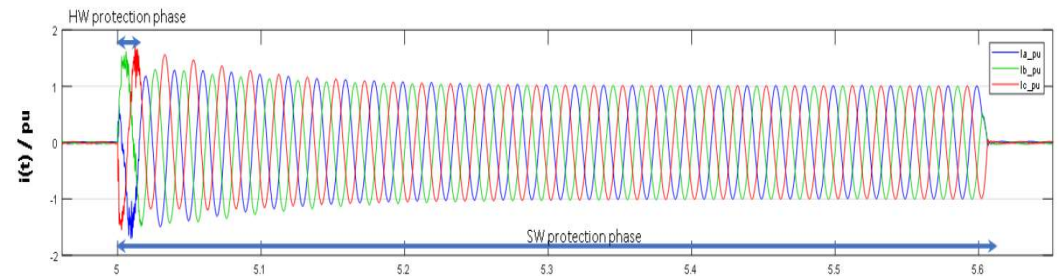
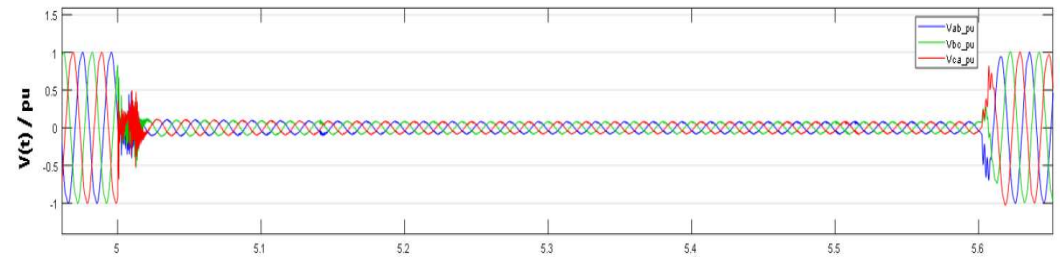
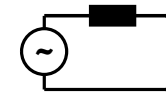
P - DROOP $\frac{\Delta P}{S_n} \cong -\frac{1}{k_f} \cdot \frac{\Delta f_G}{f_n}$	P - INERTIA $\frac{\Delta P}{S_n} \cong -2 \cdot H_p \cdot \frac{\Delta f_G / \Delta t}{f_n}$
Q - DROOP $\frac{\Delta Q}{S_n} \cong -\frac{1}{k_v} \cdot \frac{\Delta V_G}{V_n}$	Q - INERTIA $\frac{\Delta Q}{S_n} \cong -2 \cdot H_v \cdot \frac{\Delta V_G / \Delta t}{V_n}$



Method of fault current provision¹



Virtual impedance:



"Basic" vs "Advanced" Grid Forming Asset Designs

- A Closer Look at Stability Services



Generator Behavior Benefits of Grid Forming IBRs



Instantaneous response to grid events due to physics of voltage phasor control





Ride-through of extreme grid events overcoming physical limits of electric machines



Adjustable power response for adaption to changing market conditions



Reduced risk for asynchronous tripping with advanced synchronization controls

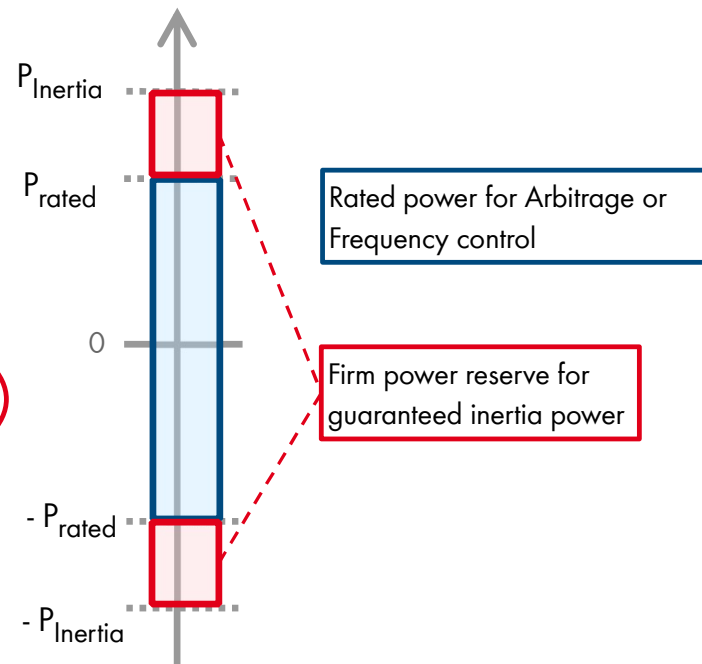
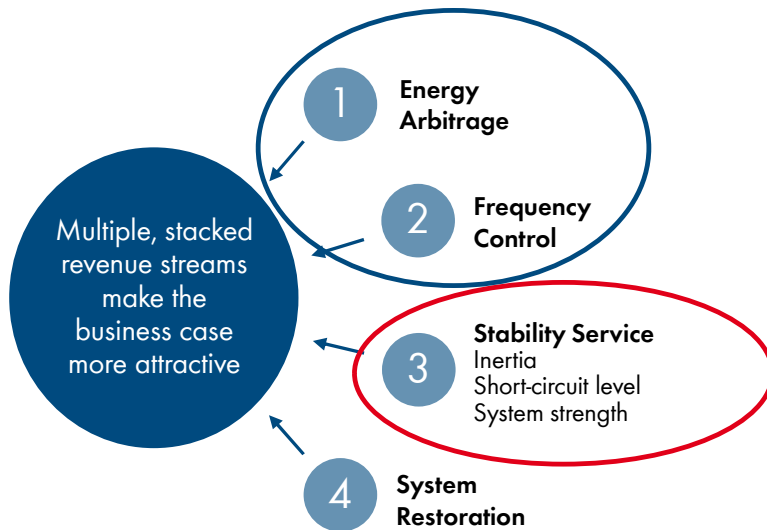
	"Basic" Plant Design w/out Headroom	"Advanced" Plant Designed for Stability Services
System Strength (SCR) Improvement	Improved voltage stability due to fundamental phasor control methodology	
RoCoF / Inertia	Amount of inertia is limited by the state of the plant operation in the moment of need	 Tunable inertia > 1pu available at all times
Short Circuit Current	Inherent, instantaneous fault current response, but limited to nameplate current	 Current boost for <u>firm</u> response > 1 pu even when plant is operating at nominal power

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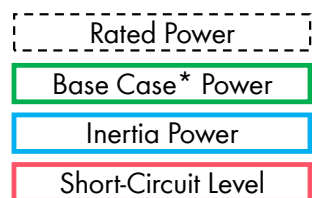
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2023+ Multi-Use of Battery Energy Storage Solution



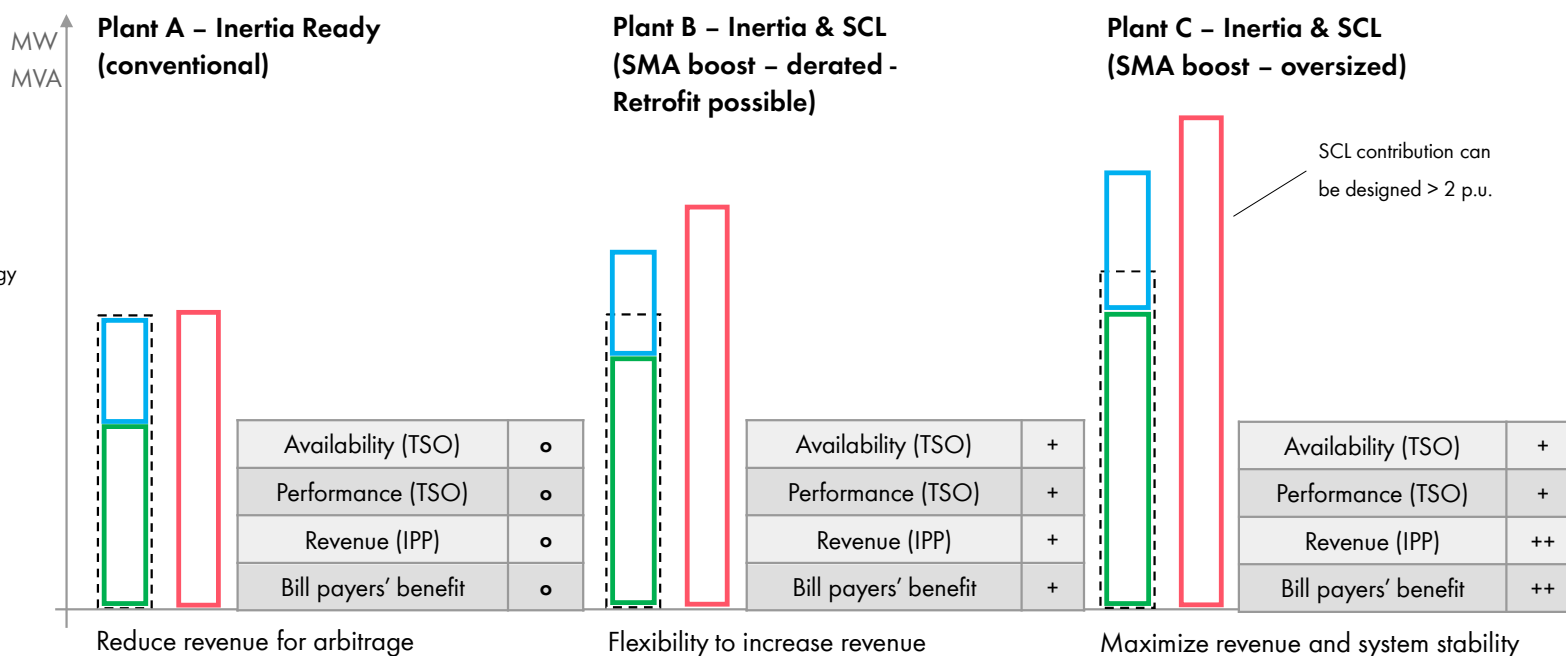
DESIGN EXAMPLE FOR BESS WITH STABILITY SERVICES



* Is the power normally used for energy arbitrage and ancillary service market

Minimum set of design relevant parameters:

- Continuous power [MW]
- Inertia [MWs] @ RoCoF
- SCL [MVA]
- Reactive [MVar] or $\cos \phi$
- w/ or w/o Blackstart



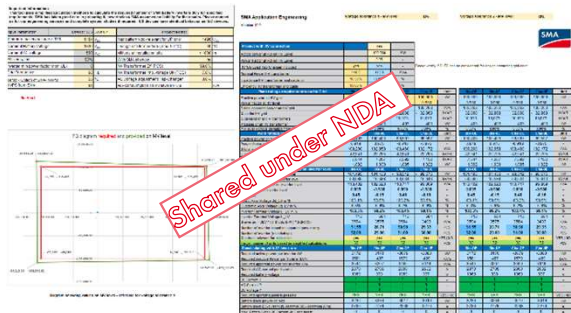


Example Plant Design Exercise

Example Plant Design Exercise – 12.5% more PCS for >2 pu overcurrent on POI



SMA POI PQ sizing tool



Example base case: 100MW /0.95 PF, 40C, HV POI

Sizing Result: 32 x SCS 3950-UP-US

Adding only 4 PCS (+12.5%/36 PCS) to achieve 2.13 pu overcurrent on the POI

Inverter level current boost profile



Selection of additional inverter (added to J46:T46) **4**

ISC for 100 ms per inverter	5200 A				
ISC for additional 900 ms per inverter	4160 A				
ISC for additional 4000 ms per inverter	3850 A				
ISC for 100 ms per site	187200 A				
ISC for additional 900 ms per site	149760 A				
ISC for additional 4000 ms per site	138600 A				
Please enter nominal voltage @POI	110 kV				
ISC for 100 ms @POI	1174.3 A	2.13	ISC/N @POS	159	Transformer Ratio LV/HV
ISC for additional 900 ms @POI	939.4 A	1.70	ISC/N @POS	552.5	A Nominal Current @POS @UnHV @PFn
ISC for additional 4000 ms @POI	869.4 A	1.57	ISC/N @POS	2447	A Nominal Current @inverter

Profile 1

Different profiles available

Boost Capability Summary	
Continuous apparent power @ POI as requested	105.3 MVA
5 sec peak apparent power	165.6 MVA
5 sec additional peak apparent power (on top of cont.)	60.4 MVA
100 ms peak short-circuit power @POI	223.7 MVA

Preliminary values, peak capability for symmetric loading, to be confirmed by grid study. Actual dynamic values may be lower (e.g. due to asymmetry, overshoot, evaluation criteria).

Theoretical available for additional inertia power reserve (tbc in grid study, values in dynamic conditions may be lower)
Maximum available SCL (tbc in grid study)



THANK YOU

SMA America, LLC

