SMA's GFM Capabilities Perspective on ERCOT's AGS Requirements for ESR (NOGRR272 & PGRR121)

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PIONEERING RENEWABLE ENERGY SINCE 1981

Facts and Figures:

Founded by three Electrical Engineers in Germany

From a small workshop to one of the world's leaders in power conversion solutions

Global HQ in Niestetal, Germany – US HQ in Rocklin, California

Over 20 countries (sales & service)

160+ GW installed solar inverters

1,600+ patents & utility models

17,000+ SMA Central Inverters installed in North America as of Dec 2024

SMA

HISTORY OF SMA GRID FORMING TECHNOLOGY

- ~25 YEARS OF OVERALL GFM EXPERIENCE IN DIFFERENT BUSINESS SEGMENTS

  (GFM string inverters, GFM inverters for machine drives, etc)

- ~8 YEARS OF GFM EXPERIENCE IN LARGE-SCALE POWER SYSTEMS

  (Sunny Central Storage with GFM Capabilities introduced in 2017)

GFM Sunny Island 4500

X60/X61
GFM Inverters
Train Industry

GFM Sunny Island 5048

MSA125
GFM Inverter Drives

GFM Sunny Island 8.0H

Sunny Central Storage

2000 — **2005** — **2007** — **2017**

SUNNY CENTRAL STORAGE CONVERTERS

SMA Grid Forming Technology is available only for Battery Storage applications

Sunny Central Storage Models	Discharge (kVA)	Charging (kVA)	Power Electronics	Max. Efficiency	Operation Modes
NEW SCS 4600 S	4600	4600	SiC MOSFET	99.2	GFL & GFM
NEW SCS 4400 S	4400	4400	SiC MOSFET	99.2	GFL & GFM
SCS 3950 XT	4600	4129	Silicon IGBT	98.8	GFL & GFM
SCS 3800 XT	4400	3950	Silicon IGBT	98.8	GFL & GFM
SCS 3600 XT	4200	3769	Silicon IGBT	98.8	GFL & GFM
SCS 3450 XT	4000	3590	Silicon IGBT	98.8	GFL & GFM
SCS 3950	3950	3950	Silicon IGBT	98.8	GFL & GFM
SCS 3800	3800	3800	Silicon IGBT	98.8	GFL & GFM
SCS 3600	3600	3600	Silicon IGBT	98.8	GFL & GFM
SCS 3450	3450	3450	Silicon IGBT	98.8	GFL & GFM
SCS 2630 XT	3000	2750	Silicon IGBT	98.6	GFL & GFM
SCS 2530 XT	2930	2600	Silicon IGBT	98.6	GFL & GFM
SCS 2400 XT	2800	2500	Silicon IGBT	98.6	GFL & GFM
SCS 2300 XT	2660	2400	Silicon IGBT	98.6	GFL & GFM

SCS-S model: higher power, higher efficiency, increased lifetime, better temperature derating profiles, higher thermal margin

MVPS (Medium Voltage Power Station)

Inverter + MV Transformer + MV Switchgear

Inverter Module:
Sunny Central Storage Converter
Grid Forming & Grid Following

Transformer Module:
Hermetically sealed transformer
MV AC side: 12 kV to 35 kV
Biodegradable liquid (MIDEL or FR3)
Bottom side bushings (LV/MV)
Natural ventilation

Base Module:
20′ x 8′ galvanized steel platform
Oil containment option
Cable Entries

Connector Module:
Flexible AC Enclosed busbar

Shipping Module
Detachable Beams forming container frame

Medium Voltage Switchgear Module

LVac Module:
Auxiliary transformer
Circuit Breakers
Harmonics Filter
Communication Options
Protection Options

CONFIGURABLE HARDWARE OPTIONS

Examples of **INVERTER-RELATED HARDWARE** options:

- DC Grounding
- DC Connection & DC Fuse Rating
- DC Input Configuration
- DC String Monitoring
- DC Insulation Monitoring
- AC Overvoltage Protection
- Temperature Range & Altitude
- Inverter Aux Power Supply
- Enclosure
- DC coupled storage
- Communication System A & B
- Remote IO
- AC Preparation for PQ Meter
- DC pre-charging (GFM BLACKSTART)
- Customer Mounting Plate
- Q@Night (QonDemand)
- Extended Aux Buffer (PRC024-3 / IEEE2800 / NGRR245)
- Transient OV Protection (PRC024-3 / IEEE2800 / NGRR245)

DC pre-charging is the only option exclusively related to GFM applications

Examples of **SKID-RELATED HARDWARE** options:

- Nominal Voltage
- Nominal Frequency
- Transformer Vector Group
- Transformer Tap changer
- Transformer Shield Winding
- Transformer Load Profile
- Transformer Losses
- Oil Containment
- MV Switchgear Feeder Type
- Safety Equipment
- Protection MVSG
- Short Circuit Rating MVSG
- Monitoring
- Accessories MVPS
- LV Transformer
- Ambient Temperature
- Environment
- Earthquake and Storm
- Transportation Package
- Accessories MVSG

CONFIGURABLE GFM FIRMWARE OPTIONS

Customizable Grid Forming Firmware Solutions

SMA GRID FORMING SUITE PERFORMANCE PACKAGES	Grid Forming for Microgrids	Essential Synchronous Grid Forming	Advanced Synchronous Grid Forming
Droop Control Mode	✔	✔	✔
Blackstart Capability[1]	✔	✔	✔
Inertia Control Modes (VSM)	-	✔	✔
Current Boost[2] for Short-Term Performance beyond Rated Power	-	-	✔

1. Blackstart capability requires UPS for auxiliary power, DC precharge circuit and suitable plant control (SMA Power Plant Manager with Hybrid Controller)
2. Current boost allows to exceed power during transient events, continuous power based on specific plant design, under consideration of e.g. ambient temperature, reactive powe range, etc.

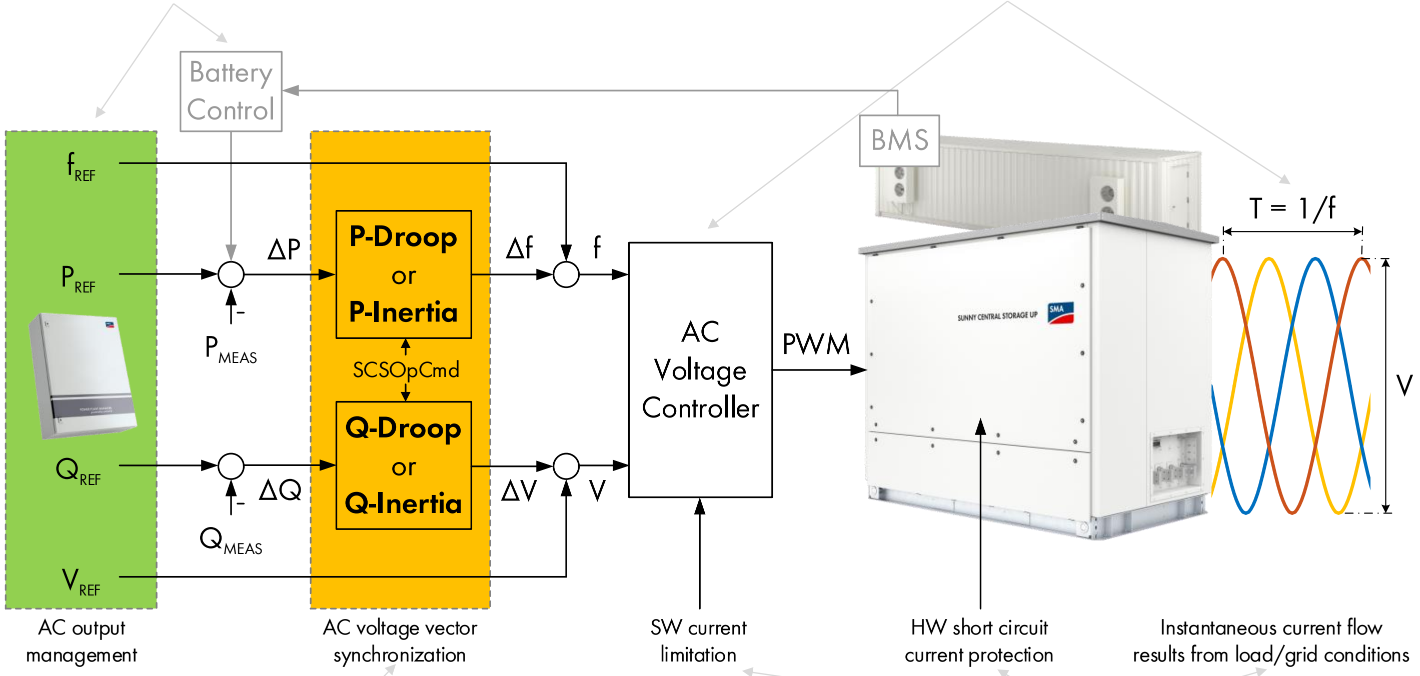
Fundamental control capabilities of the SMA Grid Forming Solution
with Sunny Central Storage

ADVANCED CAPABILITIES

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

INDEPENDENT VOLTAGE CREATION

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



COMUNICATION-FREE SYNCHRONIZATION

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

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

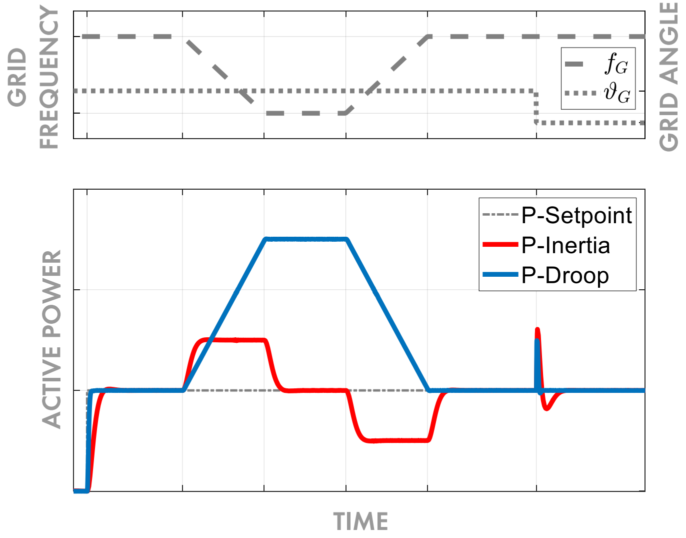
$$\frac{\Delta P}{S_n} \cong -2 \cdot H_\vartheta \cdot \frac{\Delta f_G / \Delta t}{f_n}$$

Q - DROOP

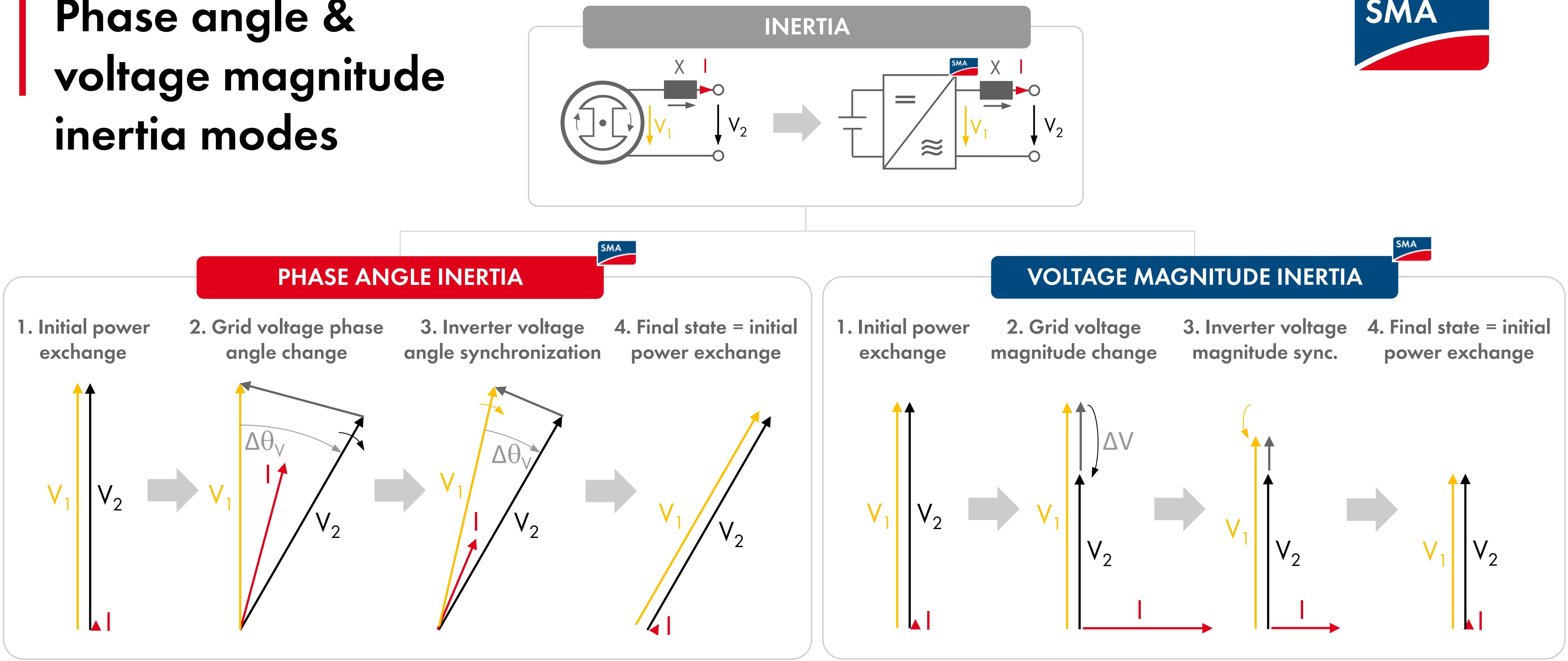
$$\frac{\Delta Q}{S_n} \cong -\frac{1}{k_V} \cdot \frac{\Delta V_G}{V_n}$$

Q - INERTIA

$$\frac{\Delta Q}{S_n} \cong -2 \cdot H_V \cdot \frac{\Delta V_G / \Delta t}{V_n}$$



Phase angle & voltage magnitude inertia modes



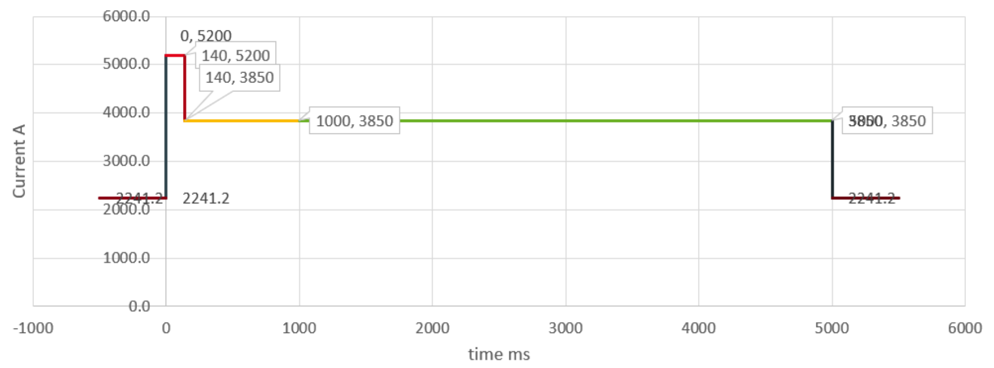
Inertia = synchronization delay to phase angle or magnitude changes of the grid voltage vector, that results in a delay-free and decaying active or reactive power response respectively

CURRENT BOOST CAPABILITIES FOR TYPICAL APPLICATIONS

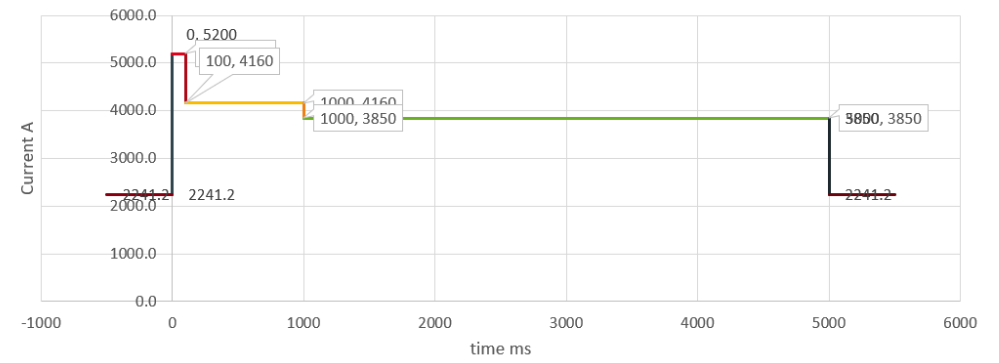
Short-Term Performance beyond Rated Power

Additional short circuit current capability

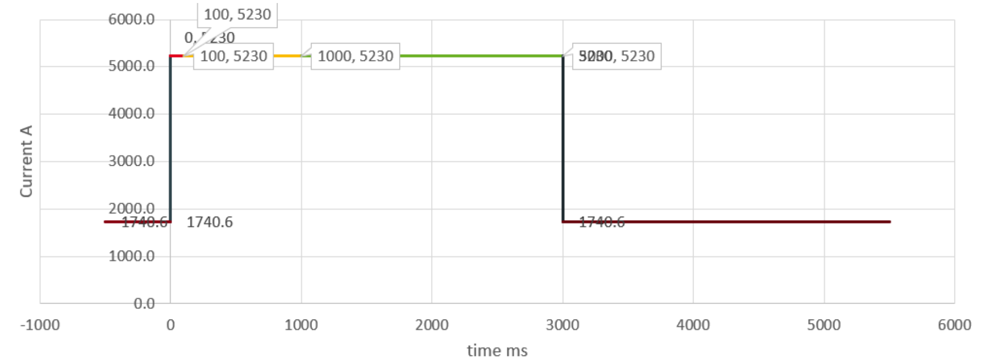
- Allows to **exceed rated power during transients** (SCS-S)
- Additional current **up to 5 seconds**
- **Different current boost profiles available**



Current-Boost Profile 2



Current-Boost Profile 1



Current-Boost Profile 3

ADVANCED GRID SUPPORT – ENERGY STORAGE RESOURCES

Site-Specific Model Quality Tests (MQT) Proposed by ERCOT

SMA

- **Summary of EMT simulation test results using PSCAD GFM models following ERCOT's AGS requirements**:

TEST #	TEST NAME	TEST BENCH	SMA GFM INVERTER + SMA PLANT CONTROLLER		
			INVERTER – DROOP (P-droop, Q-droop); PPC – DROOP (P-droop, Q-droop)	INVERTER – INERTIA (P-inertia, Q-droop); PPC – DROOP (P-droop, Q-droop)	INVERTER – INERTIA + P(f) (P-inertia+P(f), Q-droop); PPC – DROOP (P-droop, Q-droop)
1	FLAT START	TB1	✔	✔	✔
2	PHASE ANGLE JUMP	TB1	✔	✔	✔
3	SMALL VOLTAGE DISTURBANCE	TB1	✔	✔	✔
4	FREQ CHANGE & INERTIA RESPONSE	TB1	✔	✔	✔
5	SYSTEM STRENGTH	TB1	✔	✔	✔
6	LARGE VOLTAGE DISTURBANCE	TB1	✔	✔	✔
7	LOSS OF SYNCHRONOUS MACHINE	TB2	✔	✔	✔

- SMA GFM capabilities meet AGS requirements with additional margins (e.g. phase jump, ROCOF, etc)
- Passing all tests is not an indicative of addressing real stability issues (testbenchs above versus challenges from real grid) – okay as 1st screening, though!
- Depending on the stability issues identified during SIS → Need to review GFM control modes selected → Fine-tuning and parameters Optimization

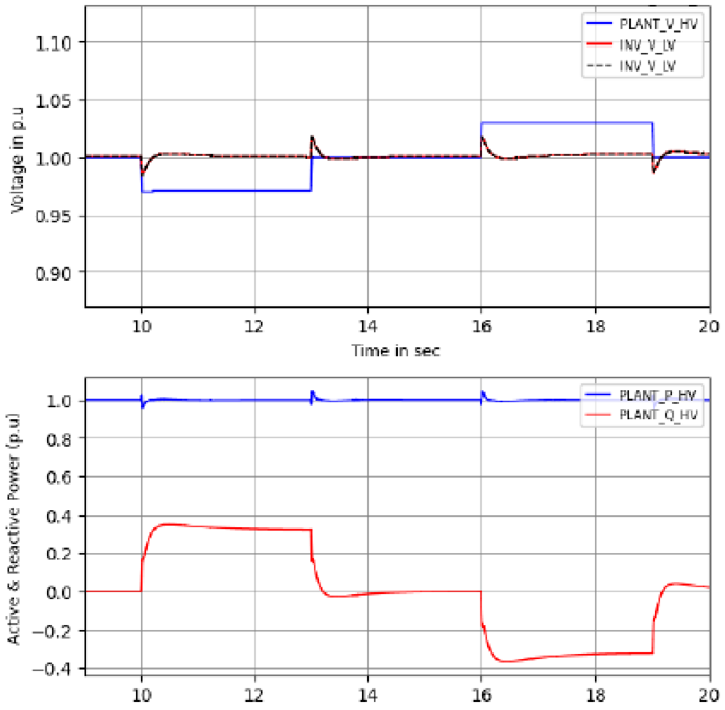
ADVANCED GRID SUPPORT – ENERGY STORAGE RESOURCES

Site-Specific Model Quality Test

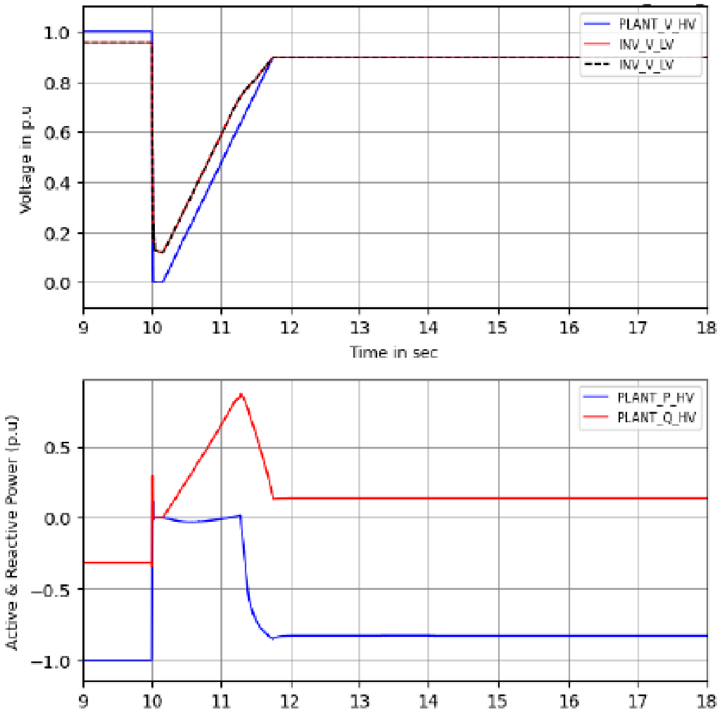
- Examples of test results: **SMA GFM INVERTER → P-Inertia + P(f) Function + Q-Droop**

  SMA PLANT CONTROLLER → P-Droop + Q-Droop

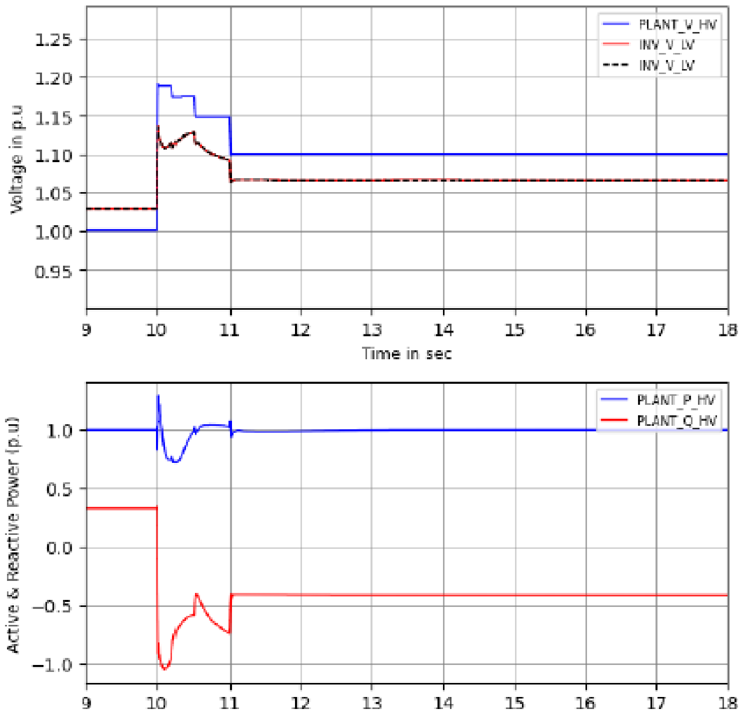
SMALL VOLTAGE DISTURBANCE DISCHARGING



LVRT LEAD CHARGING TEST (LEGACY)



HVRT LAG DISCHARGING (LEGACY)



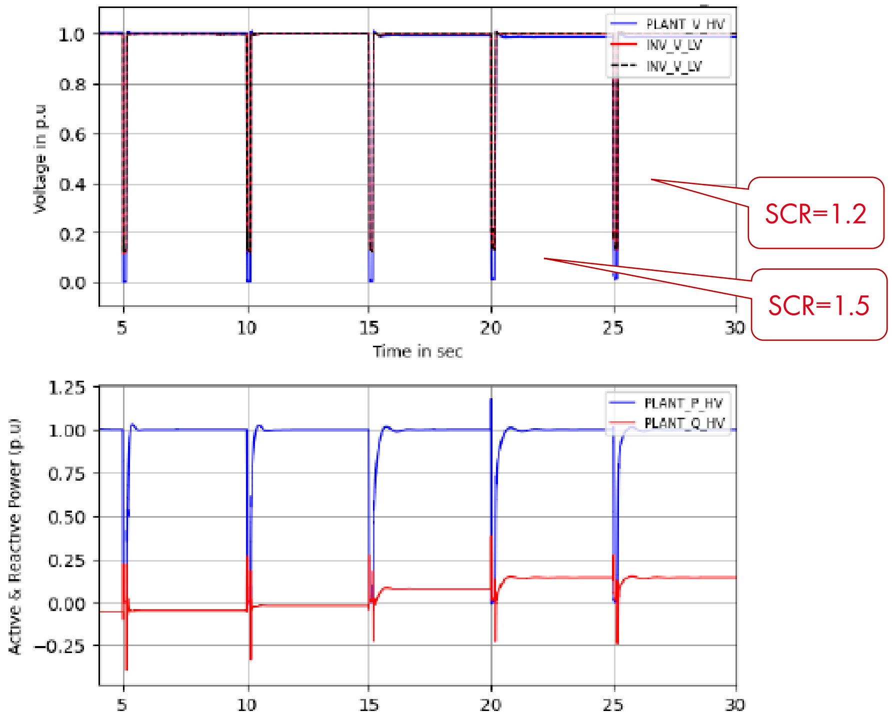
ADVANCED GRID SUPPORT – ENERGY STORAGE RESOURCES

Site-Specific Model Quality Test

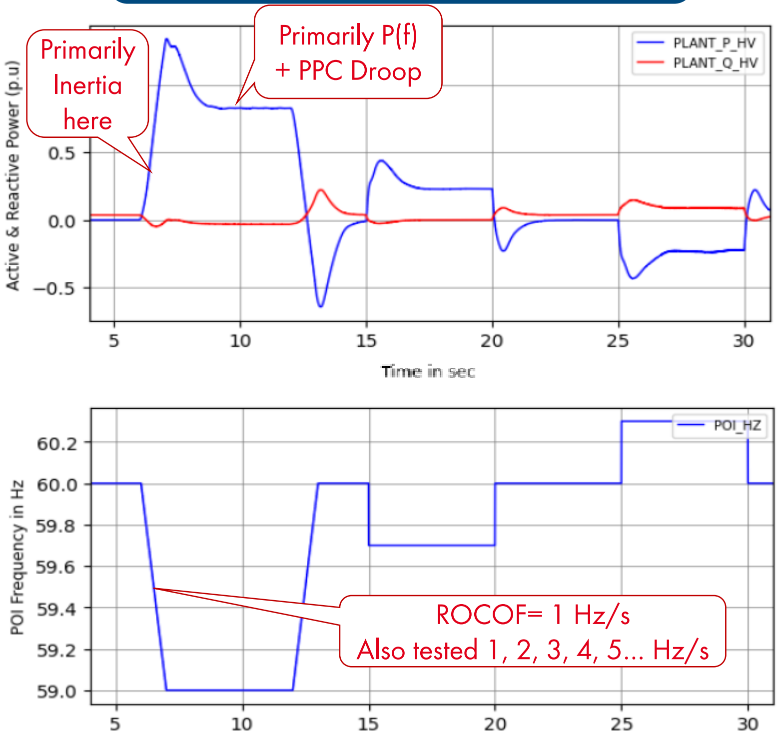
- Examples of test results: **SMA GFM INVERTER → P-Inertia + P(f) Function + Q-Droop**

  SMA PLANT CONTROLLER → P-Droop + Q-Droop

SCR DISCHARGING



FREQUENCY CHANGE TEST AND INERTIA RESPONSE



ADVANCED GRID SUPPORT – ENERGY STORAGE RESOURCES

GFM Unit Model Validation Tests (lots of efforts if using real equipment)



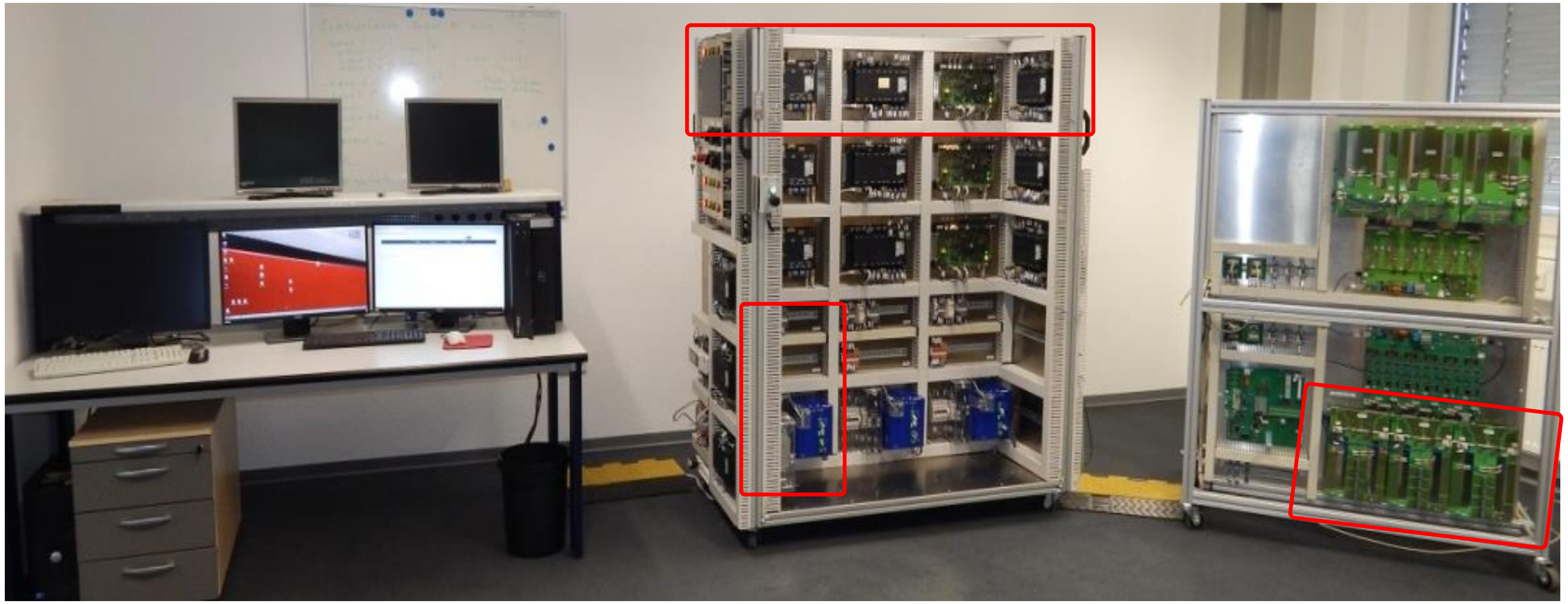


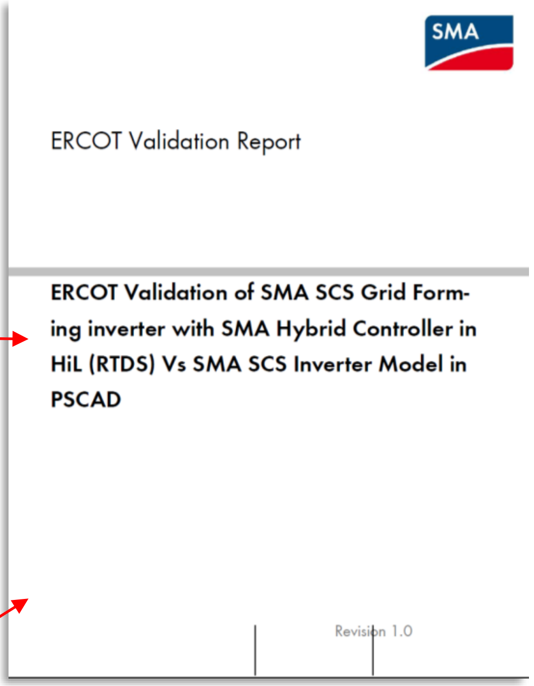
ADVANCED GRID SUPPORT – ENERGY STORAGE RESOURCES

GFM Unit Model Validation Tests (easier with HIL)

SMA in-house Hardware-in-the-Loop (HIL) simulation platform

- Exact **same control system like the complete inverter**
- **Inverter control boards in the loop** (FPGAs, DSPs, controls, communication processors, etc) **running real firmware**
- Possibility to test scenarios and cases that only a handful of lab worldwide could test




ERCOT Validation Report

ERCOT Validation of SMA SCS Grid Forming inverter with SMA Hybrid Controller in HiL (RTDS) Vs SMA SCS Inverter Model in PSCAD

Revision 1.0

- Other real-time digital simulation systems used by SMA: RTDS/GTSOC, OPAL-RT, TYPHOON
- **Validation reports of PSCAD GFM inverter and PPC models versus HIL are available to customers via NDA**

KEY POINTS

- SMA GFM technology is commercially available and in operation in BESS projects globally
- SMA GFM capabilities meet AGS requirements with additional margins (e.g. phase angle jump, ROCOF, etc)
- Passing ERCOT's GFM MQT is not an indicative of addressing real stability issues (e.g. gap between testbench system procedures versus challenges from real grid) – okay as a 1st screening, though!
- Depending on the stability issues identified during SIS → Need to review GFM control modes → Fine-tuning and parameters optimization
- SMA experience from other markets globally (e.g. UK, Germany) show us that a compensation mechanism for stability services help to address specific stability risks and accelerate the deployment of GFM solutions for increased grid reliability

Business Segment Large Scale

Thank you

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