



FLUENCE

A Siemens and AES Company

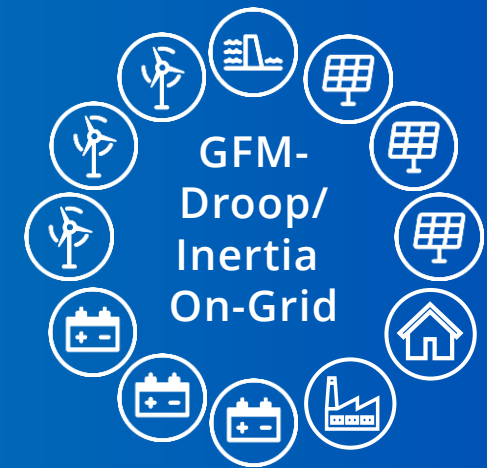
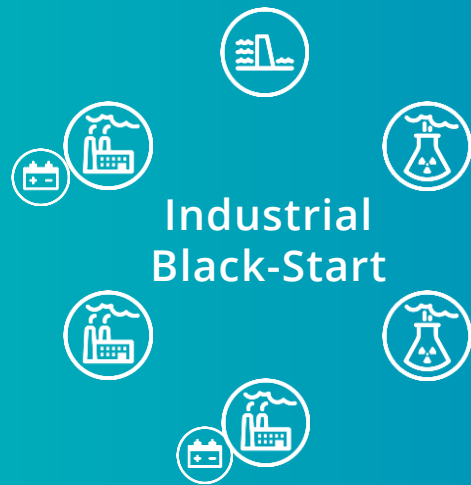
ESIG SPRING TECHNICAL WORKSHOP 25-MARCH-2024

BENJAMIN JOSEPH BRAUN

Integration of GFM Solutions for Compliance on Plant Level

How are grid-forming projects evolving?

How are BESS suppliers responding?



~99% GFL
GFM only in rare events

~100% RES
GFL only if low Wind/PV

~30%
GFM-BESS BASED

100%
Grid-Forming 24/7

50-100%
CONVERTER BASED

Qualified PCS Suppliers

Multiple

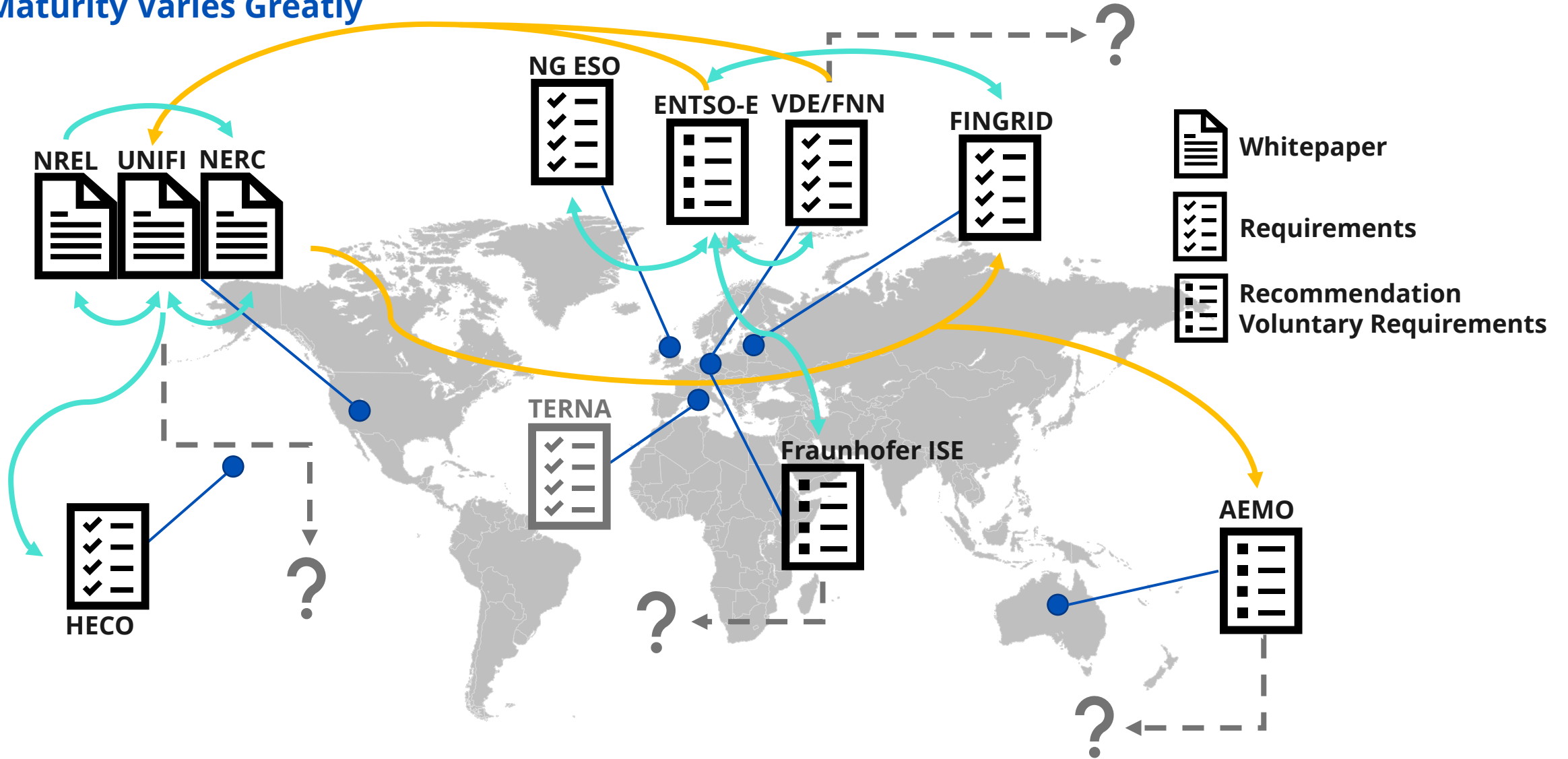
Selective

Limited



Grid-Forming Requirements/Recommendations/Whitepapers

Maturity Varies Greatly



IEC / UL / IEEE Standards still open

System Strength: Compensate vs. Compel vs. Cost-Out?

nationalgridESO STABILITY PATHFINDER 2

- Identified weak points in grid
- Focused on SC levels
- Defined technology agnostic requirements
- Public tender to incentivise grid strength
 - Fault power (MVA)
 - Upside for Inertia (MVA.s)
 - Allows Parallel Services

Technology Type	Effective SCL in MVA at 100ms for a fault at Blackhillcock 400kV (from Test 1 Step 3)	Effective SCL in MVA at 100ms for a fault at Eccles 400kV (from Test 1 Step 3)	Effective SCL in MVA at 100ms for a fault at Hunterston 400kV (from Test 1 Step 3)	Effective SCL in MVA at 100ms for a fault at Loosanget 275kV (from Test 1 Step 3)	Effective SCL in MVA at 100ms for a fault at Peterhead 275kV (from Test 1 Step 3)	Effective SCL in MVA at 100ms for a fault at Spittal 275kV (from Test 1 Step 3)	Effective SCL in MVA at 100ms for a fault at Mark Hill/Coynton 275kV (from Test 1 Step 3)	Effective SCL in MVA at 100ms for a fault at Moffat/Evanf out 400kV (from Test 1 Step 3)	Inertia x Inertia availability (MVA.s)
Grid Forming Battery Storage	8	22	74	41	7	0	125	68	0
Grid Forming Battery Storage	19	21	79	56	13	1	25	55	0
Synchronous Condenser	1918	32	70	476	574	13	18	66	549
Grid Forming Battery Storage	84	4	10	49	51	1	2	9	333
Grid Forming Battery Storage	1	44	249	95	1	1	114	211	1341
Grid Forming Battery Storage	5	936	22	41	4	1	4	57	2686



RFG2.0

- Identified weak scenarios (EU Grid Split)
- Focused on Inertia Needs
- Defined requirements more flexible for renewables (Asymmetric Inertia)
- Public Consultation to review
- Effectively compels all BESS to be GFM in ~3years
- Triggered Bundesnetzagentur to initiate a "Bonus" scheme which will compensate early adapters!

Proposals submission (2 years) – Article 7(4)
 RSO or TSO shall submit a proposal for requirements of general application, or the methodology used to calculate or establish them within two years of entry into force of this Regulation

Approval (6 months) – Article 7(6)
 Competent entities shall take decisions on proposals for requirements or methodologies within six months



Grace period (3 years) – Article 72
 The requirements shall apply from three years after publication of this Regulation



SYSTEM STRENGTH CHARGE

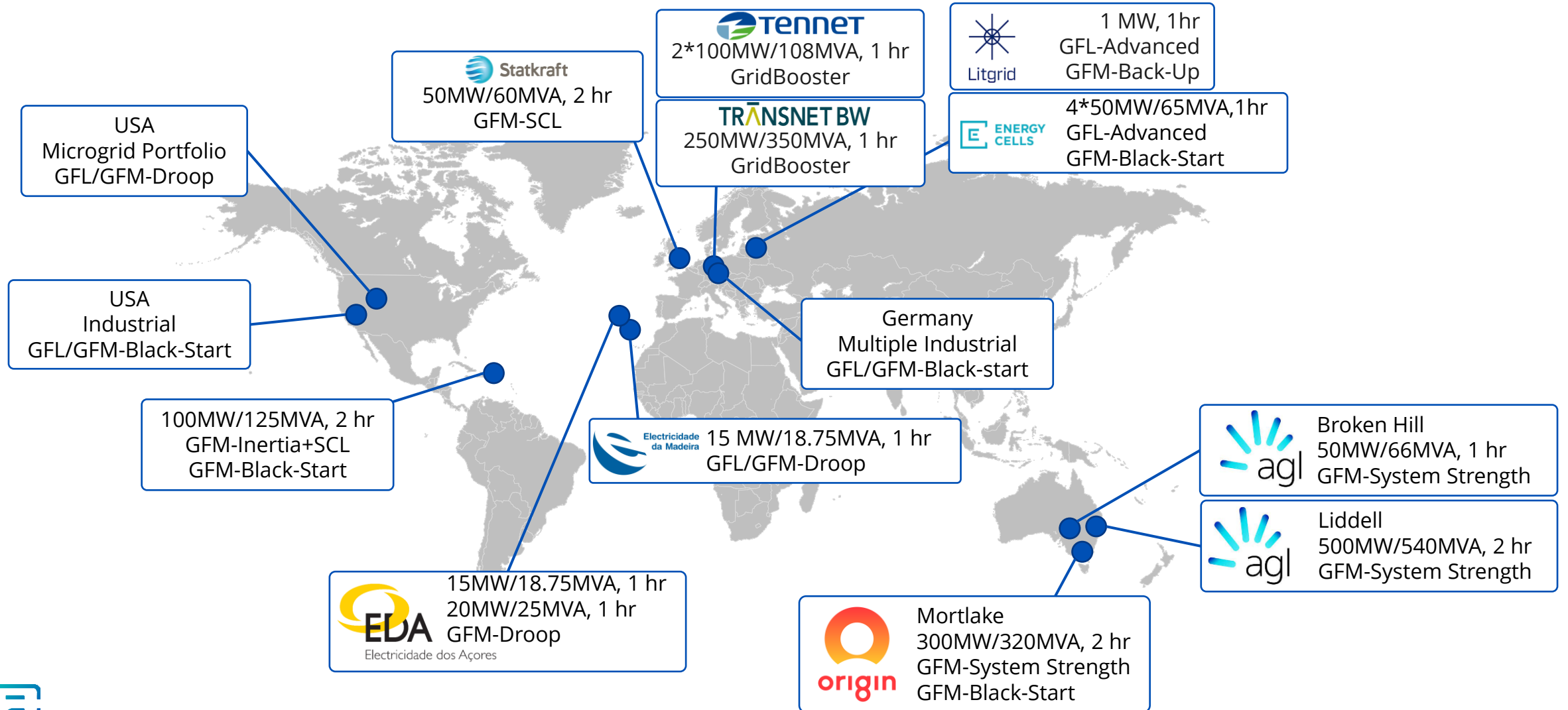
- Identified weak points in grid
- Focused on SC ratios
- Defined technology agnostic evaluation tests
- Charging mechanism to promote
 - Siting to strength
 - Improved GFL controls (lower SCR)
 - GFM controls
 - Synchronous Condenser/Generator

$$\Delta AFL_{IBR1} = (-SCR_{withstand} + \alpha) \times P_{rated}$$



Grid-Forming Projects Increase in Size and Number

Fluence Contracted Projects Exceed 2000 MVA

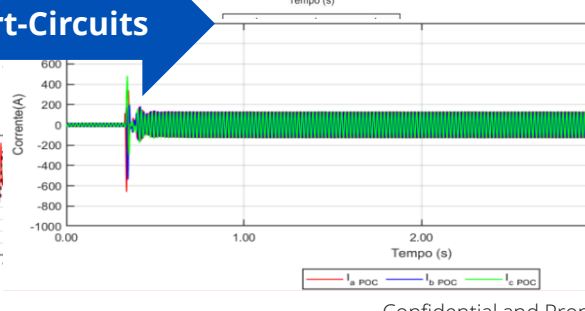
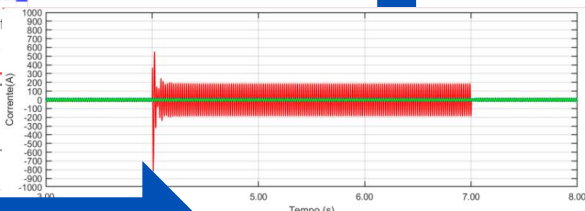
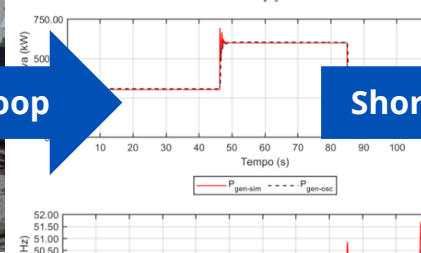
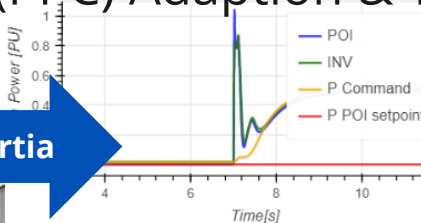
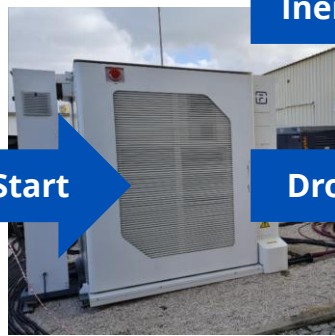
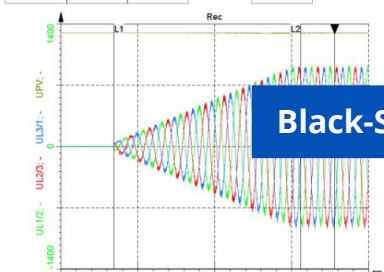


Fluence PCS: Qualification & Integration

Picking Apart the PCS

- Documentation Diligence
- EMT Simulations (PSCAD, PF, PSSE, HiL)
- Factory Witnessed Test
 - Direct Controls/Sequences, Accuracy, Speed, CMV, Black-Start, Short-time >>I
- Core Lab(s): Simulation & Validation
 - Fluence PPC/Cube, 1..2xPCS, MV Trafo, Grid and/or Grid Emulators, Load banks
- Power Plant Controls (PPC) Adaption & Tuning in EMT
- Project Execution

UL10 - [M]	UL20 - [M]	UL31 - [M]	PowerOP: [M]	PowerOQ_H1	PowerOPF: [M]
630	629	629	21	21	055971
IL1 - [A] RM	IL2 - [A] RM	IL3 - [A] RM	PowerOfFrequ		
5	4	5	50000		



Inertia

Droop

Short-Circuits

Black-Start



Energy Cells - Lithuania



GridBooster - Germany



Madeira - Portugal

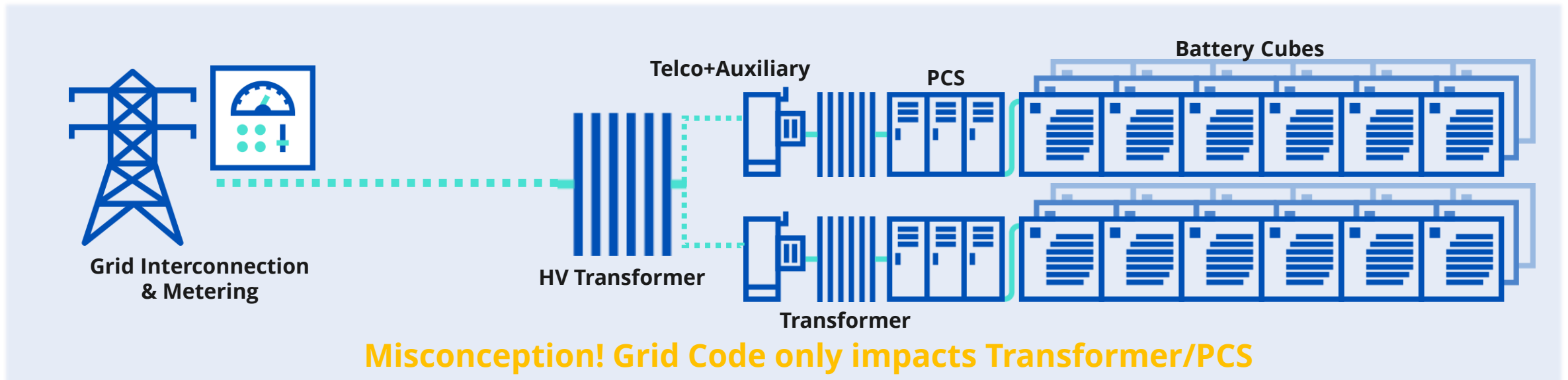


Terceira - Portugal



ALL Requirements Apply to the Design of ALL Components

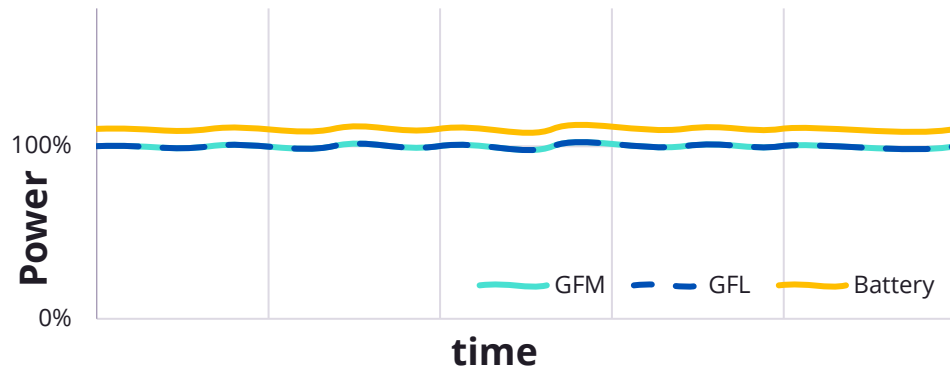
- PCS performance is tied to proper PPC controls and correct implementation of BESS and BOP
 - Protection
 - Stability
 - Plant Response time
 - Application Stacking
 - Service Sequencing
- Grid Code implications do not stop at the PCS
 - Plant Controls and Metering
 - Operation Modes (Subnetwork, Black-Start)
 - Aux system (e.g. LVRT/HVRT)
 - UPS
 - DCDC Converters (if applicable)
 - Battery Overload



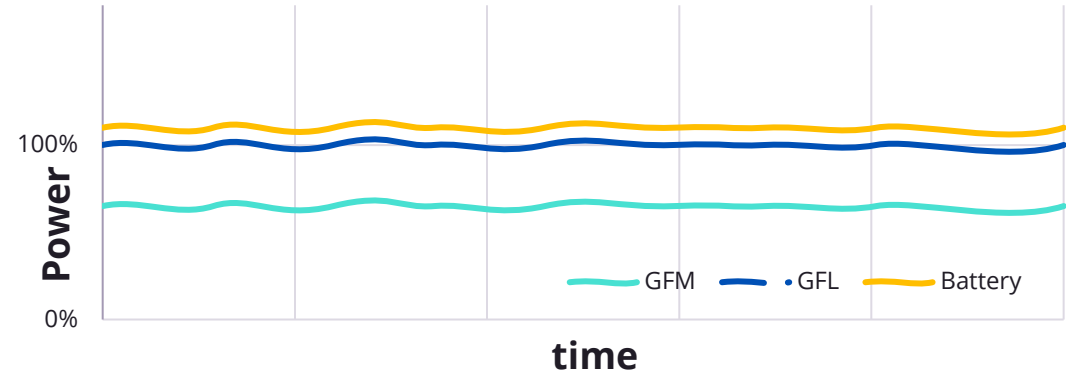
Knowing your Limits

Short-term overload requires careful consideration, and constant dynamic re-assessment

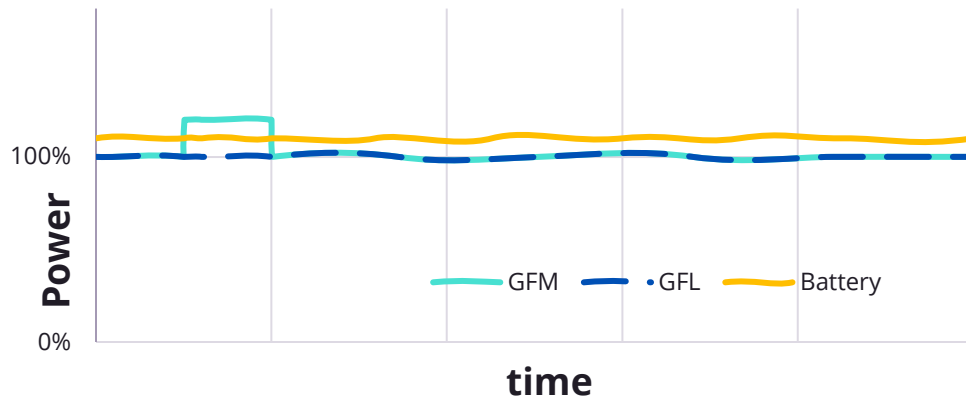
Initial Expectations



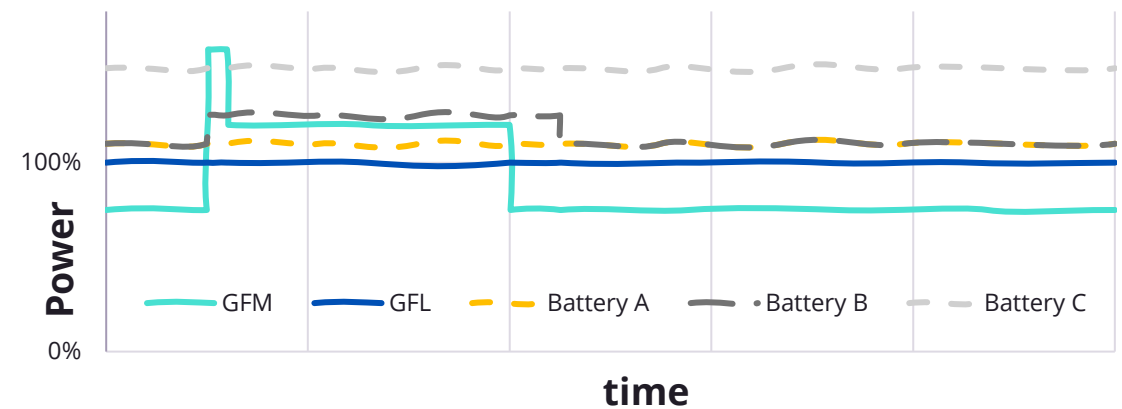
Conservative



Status Quo

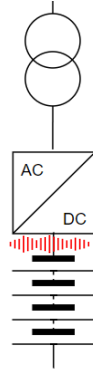


Trade-Off

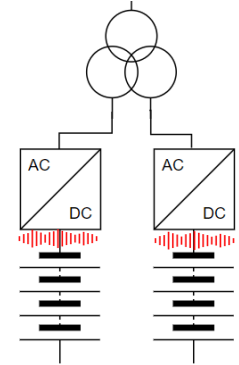


Hardware Configurations

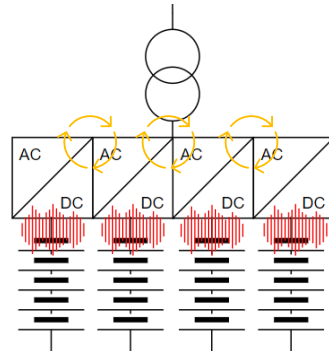
Single Winding
 Single GFM Controller
 Multi-Synched-Stack
 Single-DC-Bus



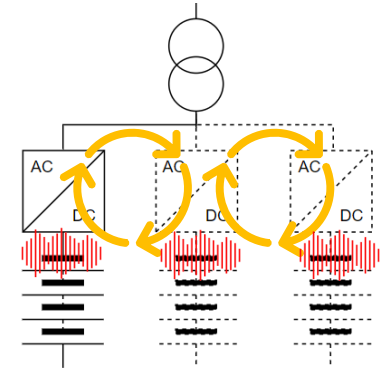
Multi Winding
 Multi GFM Controller
 Multi-Synched-Stack
 Single-DC-Bus



Single Winding
 Single GFM Controller
 Multi-Synched-Stack
Multi-DC-Bus



Shared Winding
Multi GFM Controller
 Multi-PCS-Pseudo-Synch
Multi-DC-Bus



 Common Mode Voltage (CMV)  Circulating Current (CC)

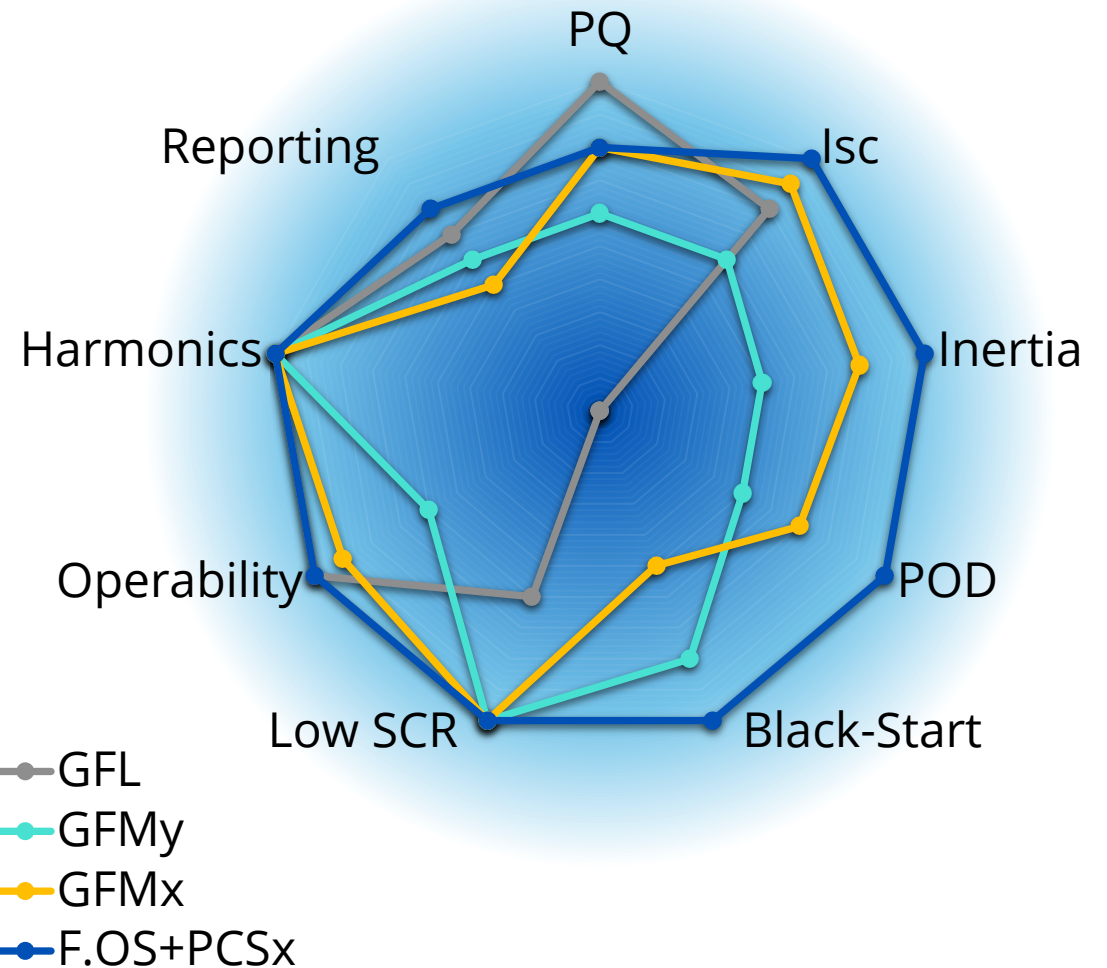


PPC's Coordinating Roles

Turning GFM Controls of PCS into Standardized Plant Products

How do we meet the needs of the many, while respecting the limits of all?

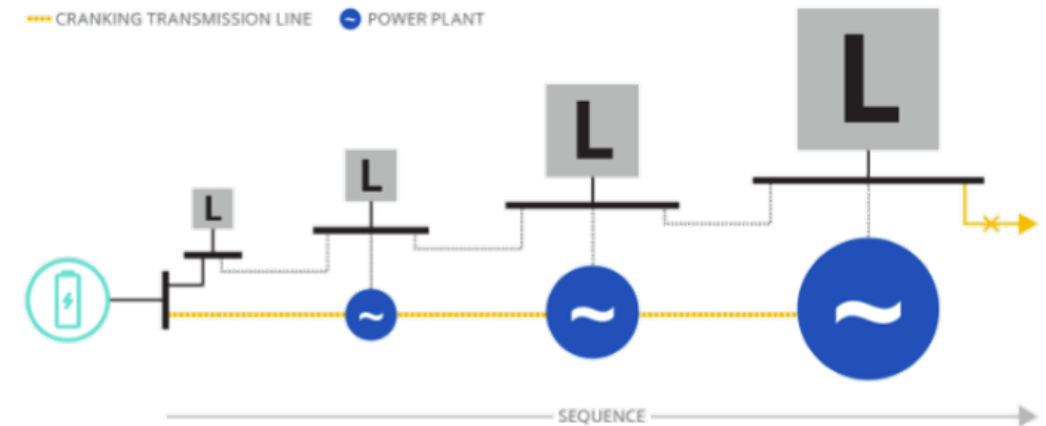
- Coordinate Plant Performance
 - Accurate P/Q, Energy
 - GFM-Droop/Inertia
- Increase plant stability
 - Balance Asymmetry
 - Outages
 - Oscillation damping
- Process and Report Total Plant Metrics
 - P, Q, MWh, Isc, MWs, Droop
 - "Re-Dispatch" GFM-Parameters
- Coordinate Sequences/Switches
 - MV/HVSG
 - Auxiliary
 - Self-Supply/Black-Start/Grid-Restoration



„Black-Start“ is more than just Black-Start

Various Scenarios and Sequences for PPC:

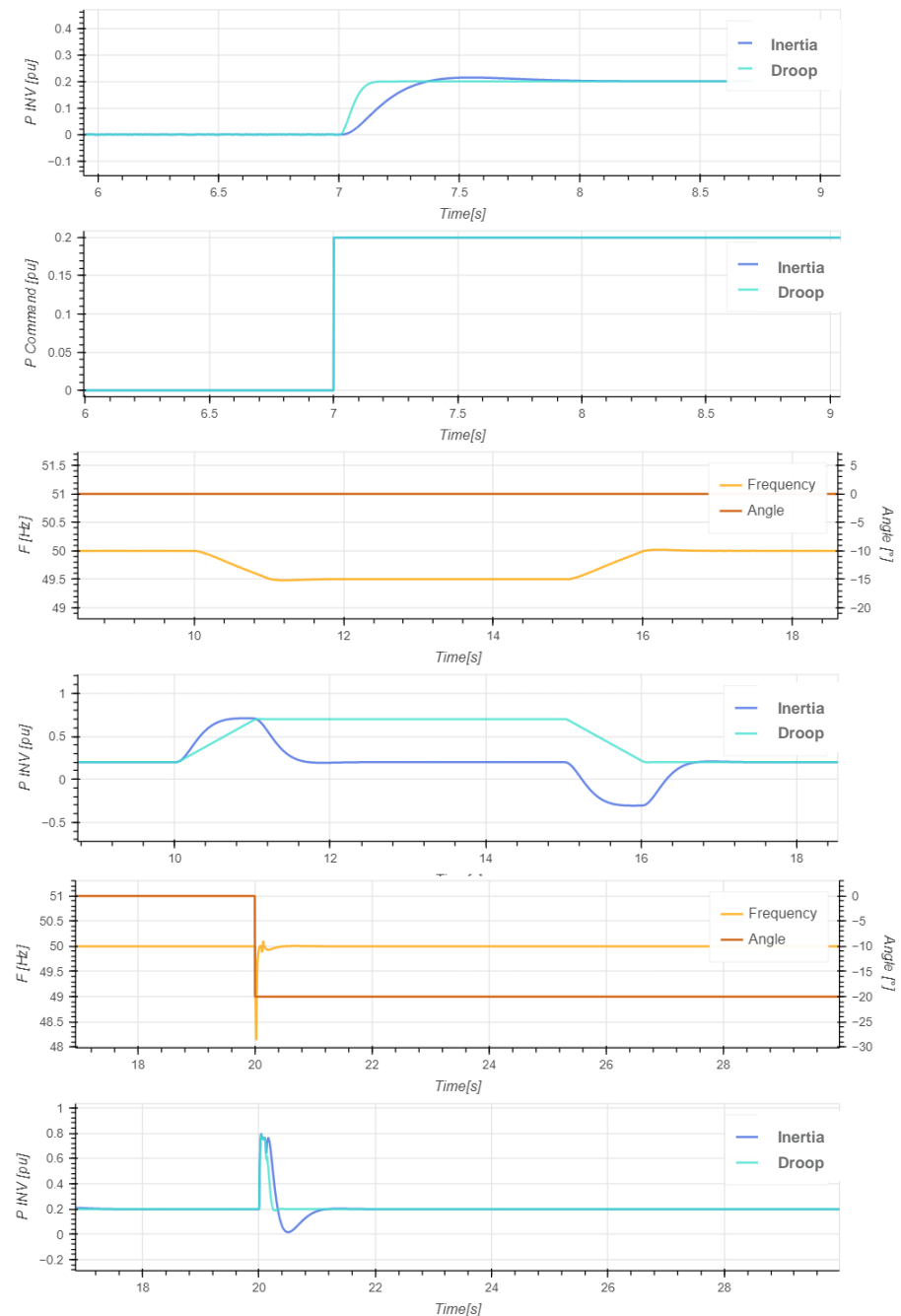
- BESS Island - Ready to resynch to healthy grid
- Subnetwork – Unsignalled/unexpected reduction in Grid size, BESS dominant/solo
- Self-Supply – Intentional low aux mode up to 72h to ensure BS ready at anytime
- Black-Start (per VDE) - Commanded
 - Single PCS at $U=0.1$ p.u.
 - Multi PCS ramp to 1.05 p.u. in 10min
- Grid Restoration – Commanded start to intentionally reduced Grid, BESS is solo



GFM-PCS: Droop vs. Inertia

- Inertial controls on PCS impede fast response of external power commands
- Instantaneous P response from both controls to ROCOF and Angle Jumps
- Inertia Power pulls back post ROCOF
- Inertia power undershoots post-Angle Jump

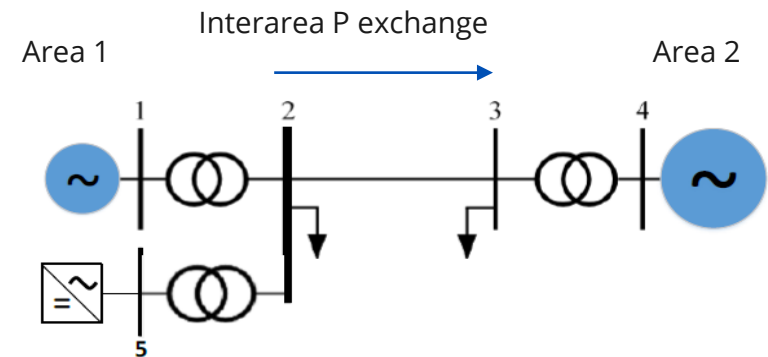
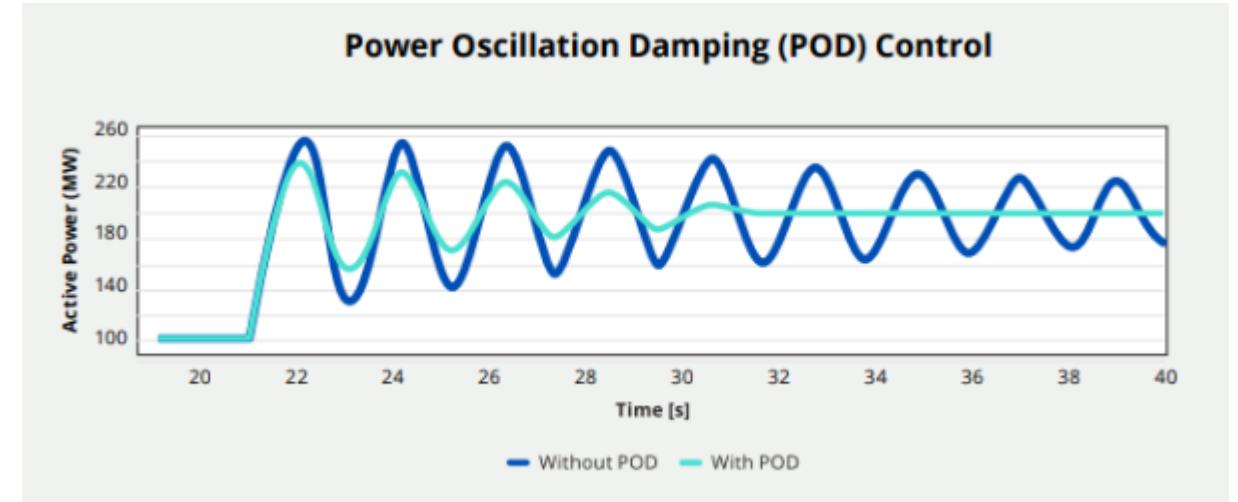
Note: Droop and H intentionally tuned to provide similar output thus aiding generalized comparison



Power Oscillation Damping (POD)

- TSOs require POD capabilities for GFL+GFM
- GFM Controls provide inherent damping
- Quantification/Specification of POD is complex

POD is crucial for safe operation
→ PPC needed to enhance POD capabilities of GFM-BESS at plant level.



Define to Refine

COMPONENT STANDARDS

- PPC Specific Standards and Tests
- Carve out for „Pro-Islanding“ clause
- Standardize SC Anatomy for PCS
- Adapt GFL performance tests for GFM
 - Max loading (P/Q, cont. and dynamic)
 - Voltage/Frequency Accuracy/Stability
 - Response Speed in Droop vs Inertia
 - etc...
- Update Safety Requirements
- High-Resolution, Time Synched Logging
- Firmware/Parameter Persistence and Tracking

GRID CODES

- Form follows function (MWs or SCL or Both?)
- Determine applicable metrics e.g.:
SCR vs. ESCR vs. Voltage “Stiffness”/Sensitivity
- Focus on plant performance
- Don’t overprescribe implementation, instead...
- Drive plant level test/validation criteria
- Define specific sub-applications
- Collaborate and Harmonize



Thank you!



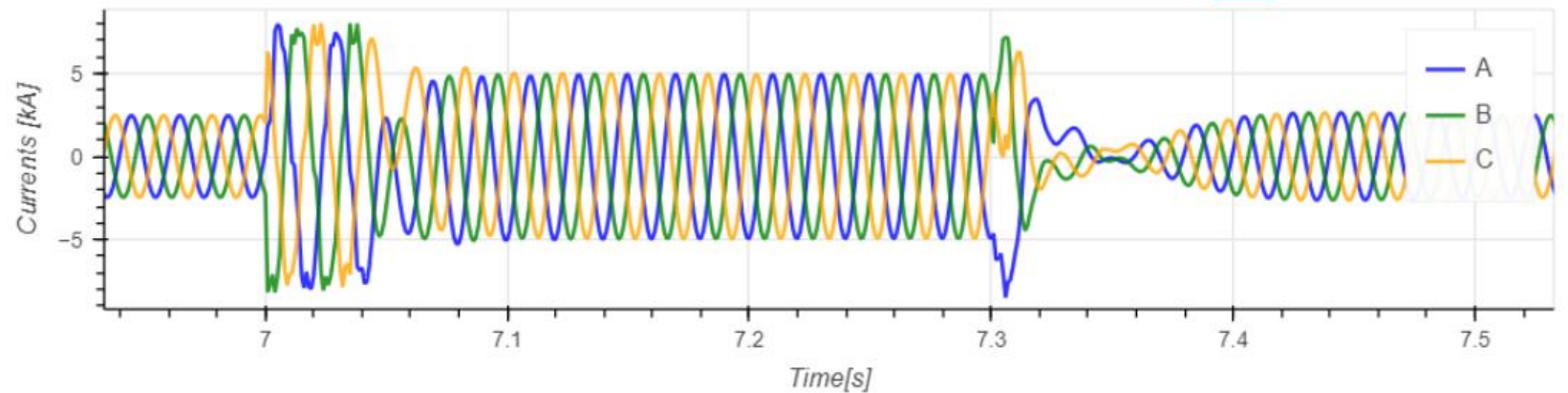
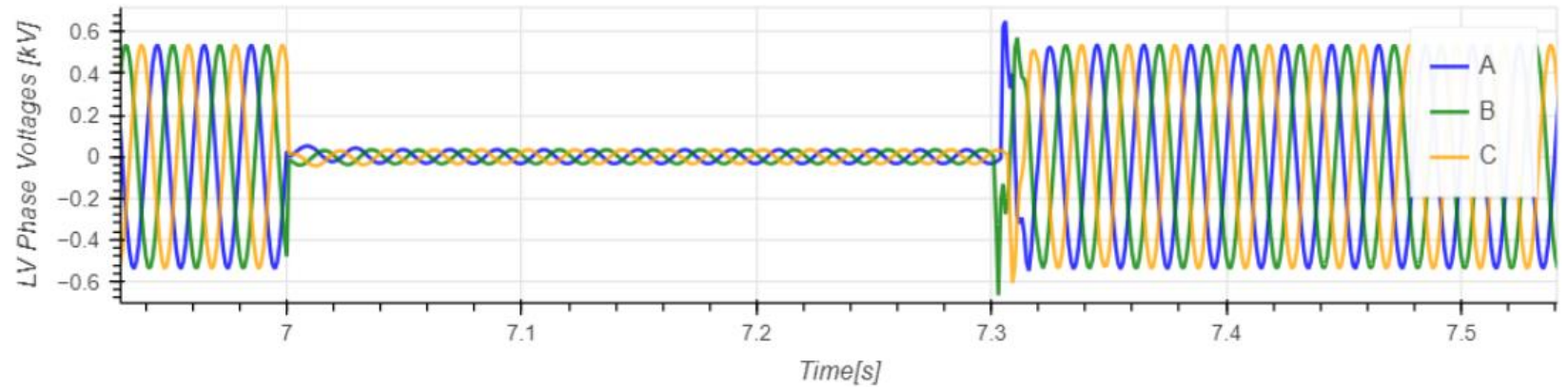
Benjamin Joseph Braun

Principal Engineer – Power Controls
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Anatomy of GFM-SC Current

Standard Structure

- Pre-Fault Load
 - No-Load
 - Full Load
- HW Protection
 - Peak Current (i_p, I_k'')
 - Duration X cycles
- Control (Virtual Impedance)
 - Max Current (I_k', I_k, I_b)
 - Time to I_k, I_b
- Sustain
 - No „re-firing“
- Clear
 - Recover Voltage
 - Re-magnetization



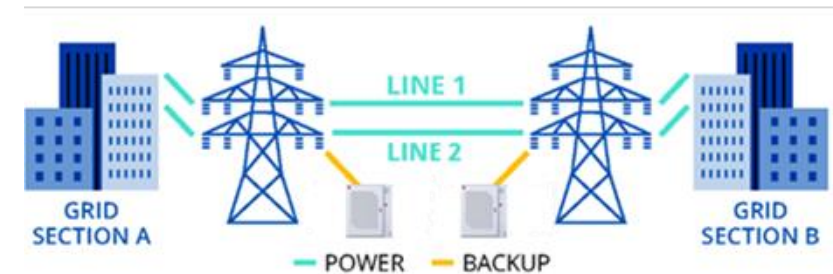
Changing conditions create new challenges for grid operators

Storage is emerging as a valuable resource in this transition

Network Utilization

Changing generation resources and renewable intermittency causes transmission line congestion, which results in asset curtailment and re-dispatching

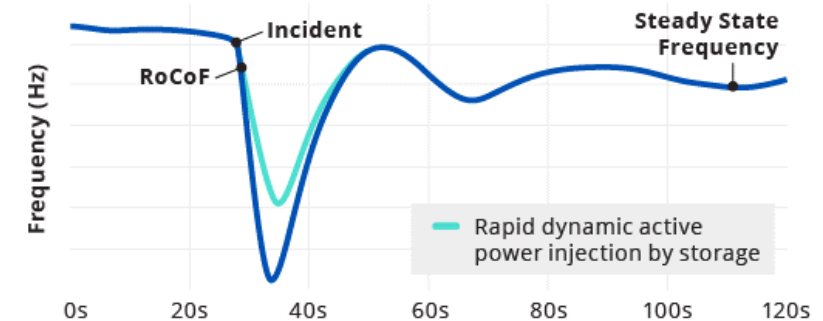
Energy storage can be deployed quickly on the grid to increase capacity on transmission lines through energy shifting or n-1 contingency reserves



System Stabilization

A growing share of inverter fed resources and changing load profiles create new system stability issues for grid operators

Energy storage with advanced grid forming controls supports grid stability and power system operation with complex applications, such as inertia, black start, oscillation damping control, and more



Fluence Ultrastack

Purpose built to meet the unique operational needs and technology requirements of T&D asset owners



Flexibility

Cost effective solution with rapid installation compared to alternatives



Scalability

Supports 50MW+ system sizes and complex grid requirements



Technology

Advanced grid services and critical asset IT security



Architecture

Fast system response and redundant controls



Availability

99%+ asset uptime and availability



Sustainable

Supports rapid grid transition to renewables



CASE STUDY

A powerful asset for European grid interconnection and renewables transition

EPSO-G (Lithuania)

Energy Cells – 200 MW / 200 MWh (50 MW per site)

SERVICES

- Inertia Contribution
- Renewable Integration
- Grid Restoration

IMPACTS

- Increase Grid Resilience today
- Ensure stable operation during synchronization with European Grid
- One of the largest energy storage project of its kind



CASE STUDY

Strengthening energy security and renewable integration in Germany

TransnetBW (Germany)
250 MW / 250 MWh

SERVICES

- Grid stability
- Congestion relief

IMPACTS

- Ease bottlenecks transporting wind energy from northern Germany
- Avoids derating of lines
- Reduces redispatch cost & lowers end user energy cost



CASE STUDY

Better utilisation of existing power lines and lower cost for customers in Germany

TenneT TSO (Germany)

2 x 100 MW / total 200 MWh across two strategically positioned sites in the North and in the South

SERVICES

- Grid stability & increase utilisation
- Congestion relief

IMPACTS

- Ease bottlenecks transporting wind energy from northern Germany
- Reduces redispatch cost & lowers end user energy cost
- Reducing the need for grid expansion measures

