Ingeteam

ELECTRIFYING A SUSTAINABLE FUTURE

INGETEAM GFM CAPABILITIES AND PERSPECTIVE ON ERCOT AGS-ESR TESTS

- > About Ingeteam
- > IS Grid-Forming Control
- > ERCOT AGS Test Framework
- > Ingeteam GFM Experience

Ingeteam

Key figures

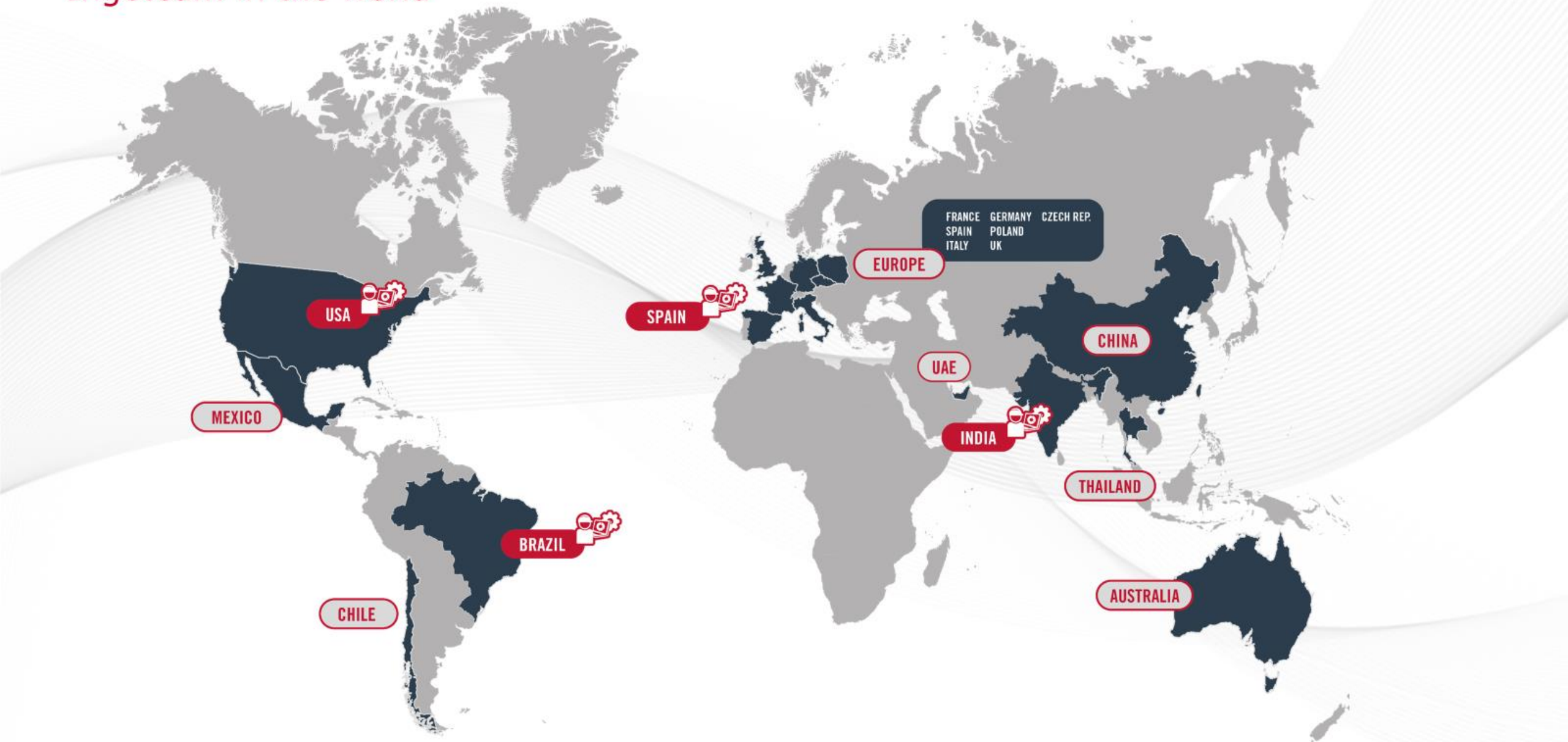
Present in **15 countries** and new markets

3600 + employees around the world

5.5% of turnover invested in R&D every year. 500+ pe.

More than **85 years** in the electrical sector.

Ingeteam in the world



Main manufacturing plants

Converters, Inverters, EV Chargers & Controls
SPAIN (16,800 m²)

- Sesma (Navarra)
- Zamudio (Bizkaia)
- Ortuella (Bizkaia)

Converters, Inverters, EV Chargers & Controls
BRAZIL (5,250 m²)

- Campinas (Sao Paulo)

Electric machines
SPAIN (53,500 m²)

- Beasain (Gipuzkoa)
- Segorbe (Castellón)

Frequency converters
INDIA (5,100 m²)

- Chennai (Tamilnadu)

Automation & Control
Electronic Devices
SPAIN (3,200 m²)

- Zamudio (Bizkaia)

Frequency converters
Electric machines
USA (12,500 m²)

- Milwaukee (Wisconsin)

Milwaukee, WI

138,000 sq ft

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Solar PV Energy

24 years of experience in the solar industry.

35 GW of PV power installed worldwide.

5 GW+ installed in the U.S.

+750 MW of PV plants monitored with our SCADA system worldwide.

10 GW controlled with our PPC worldwide.

- String and central PV inverters.
- Power outputs of up to 7.5 MW.
- MV integration. Turnkey solution.
- PPC and SCADA systems.

Battery Energy Storage Systems (BESS)

13 years of experience in utility-scale installations

Over 3.2 GW / 9.9 GWh of BESS installed worldwide in generation and distribution substations

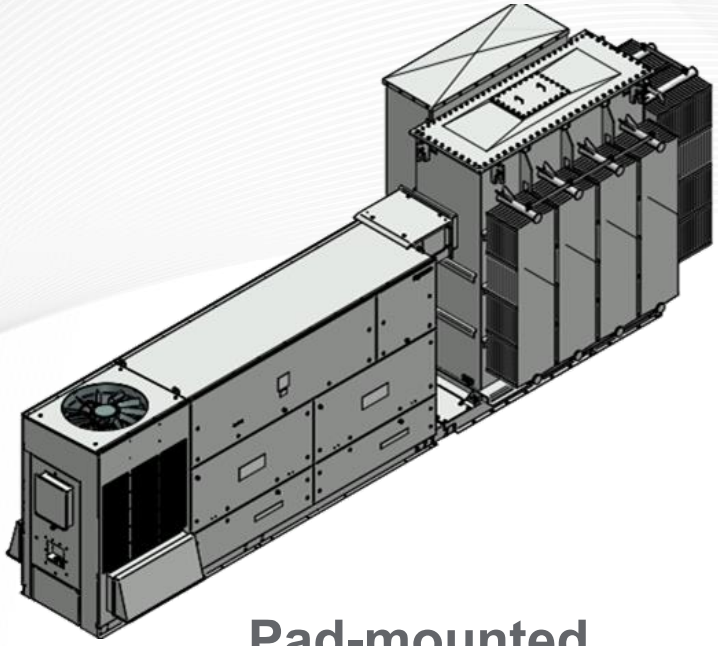
In-house converter technology for residential, industrial and utility scale application.

- DC/AC inverters & DC/DC converters
- DC-coupled and AC-coupled systems
- Full control capabilities (EMS, PPC...)
- ESS for Energy, Industry, Marine and Commercial sectors

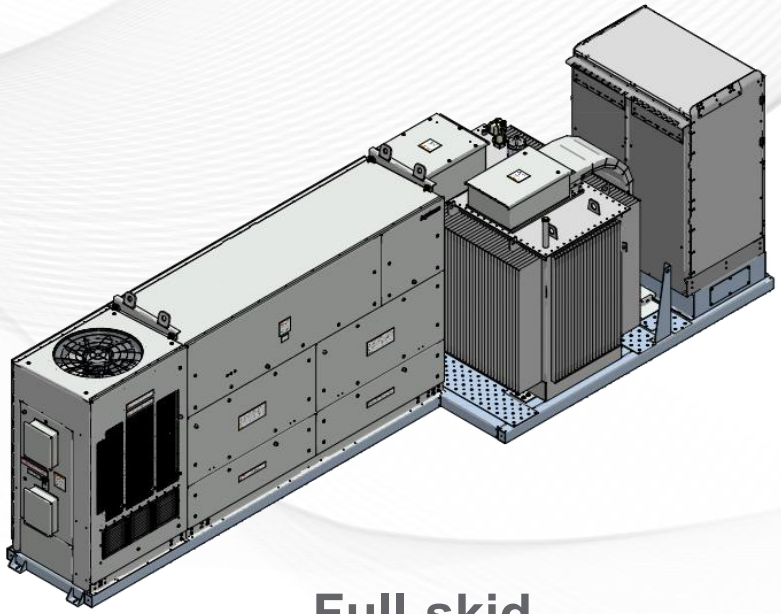
Utility Scale Central Power Stations

Inverter

GFM



Pad-mounted



Full-skid

Ingecon Sun

GFM Control

BACKGROUND

Power system evolution

BEFORE

- High % of synchronous generation
- Small penetration of power electronics generation
- Grid control logics based on synchronous generators characteristics

NOW

- High penetration of renewable energy based on power electronics
- Displacement of synchronous generation
- Reduction of system inertia, short circuit current and system strength

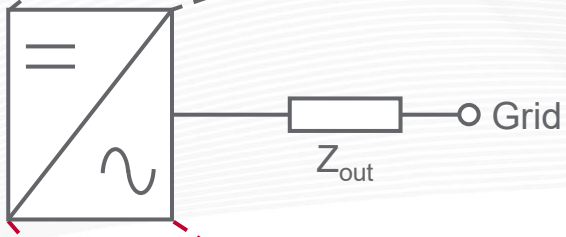
FUTURE

- Advanced control algorithms for power electronics generation
- Provision of services
  - Inertia
  - Short circuit current
  - Voltage support
- Grid codes and grid control logics update

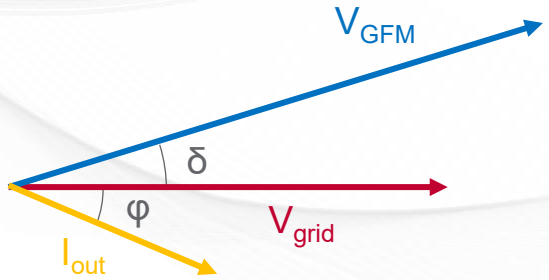
Ingecon Sun GFM Control

What is Grid Forming?

GRID FOLLOWING
- Current Source behaviour
- Relies on grid voltage tracking



GRID FORMING
- Internal voltage generation
- No grid tracking
- Provide synchronous generators functionalities



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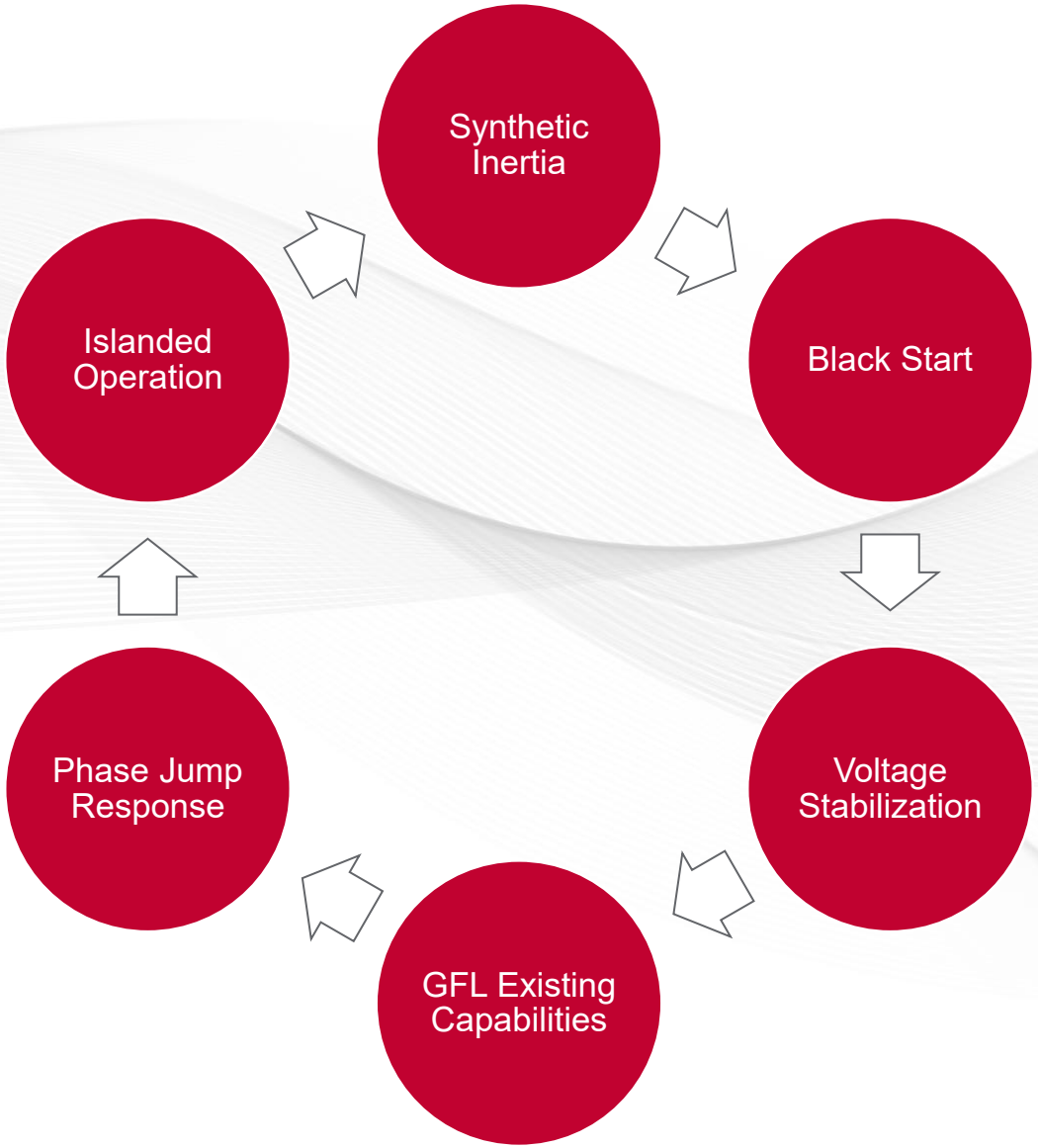
Features



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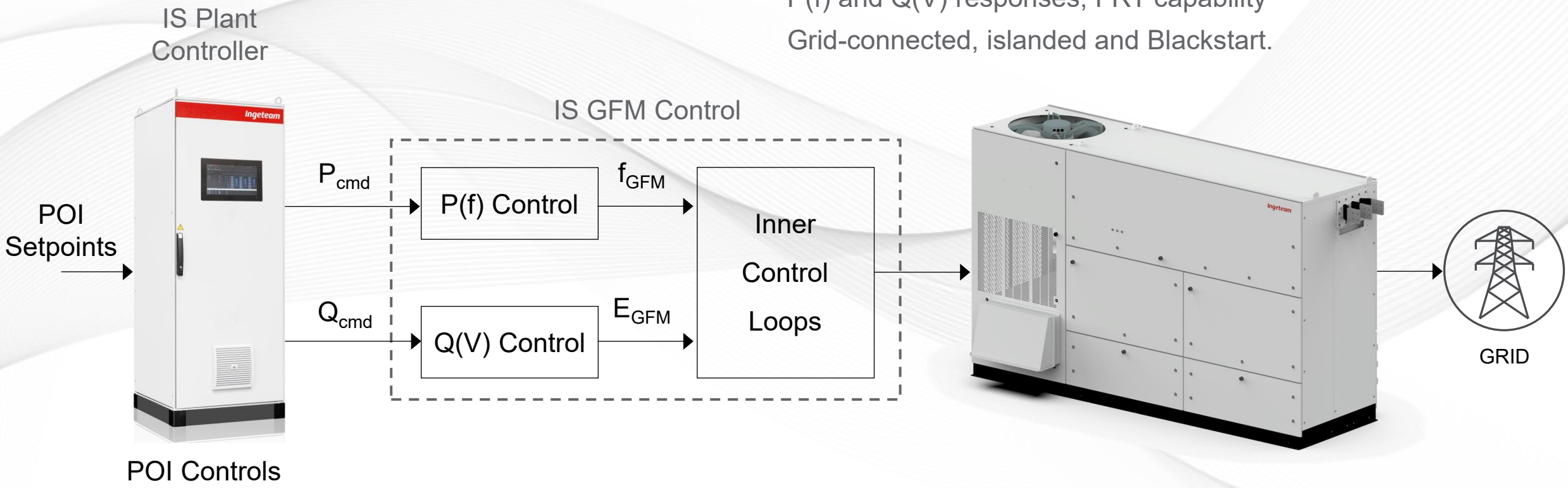
Solution



GFM Features

Voltage source behaviour, no PLL use, configurable P(f) and Q(V) responses, FRT capability

Grid-connected, islanded and Blackstart.

GFM Plant response coordination

Setpoint tracking and Disturbance rejection

Ingecon Sun GFM Control

Applicability

Typically related to BESS → Can be applied to PV systems

Only difference is the DC Source manageability

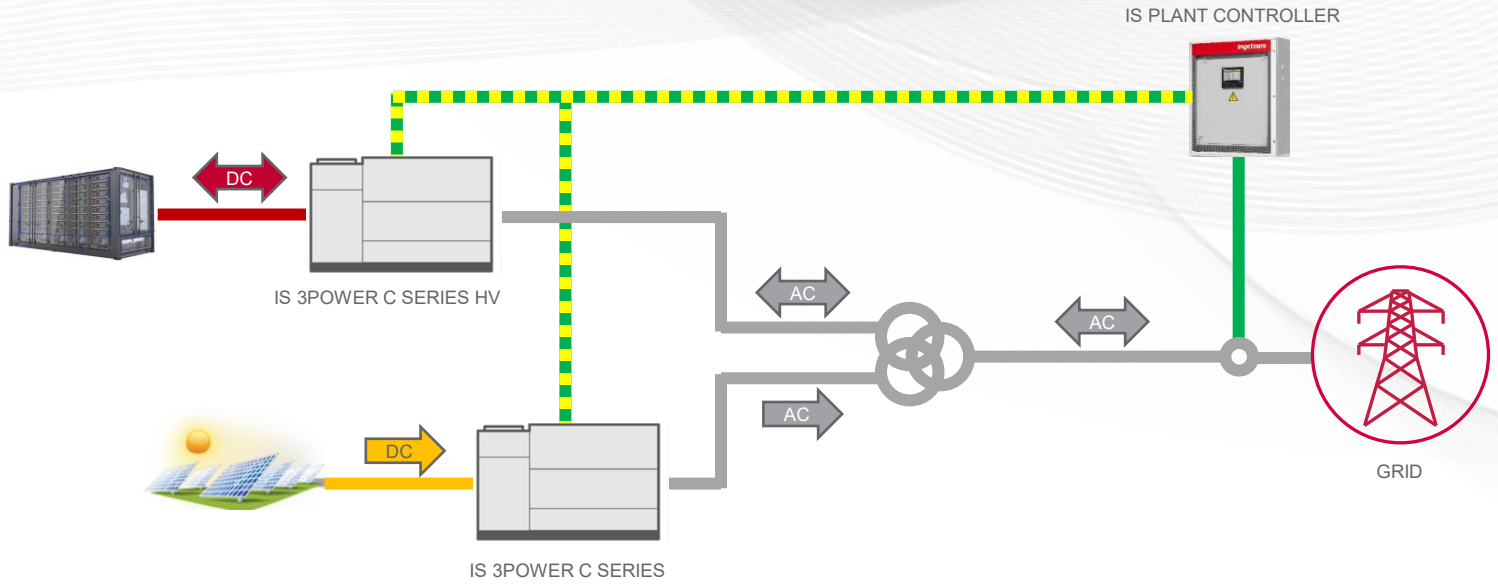
MPPT	ACTIVE POWER RESERVE

• Same GFL features as current solutions
• In addition:
  • Reactive power related responses
  • Active power reduction responses
	• Already available
	• Configurable active power headroom
	• Full GFM capability
	• Ingeteam patented algorithm

Ingecon Sun GFM Control

GFM applied to PV systems

- PV could contribute to Grid Stability
- PV could participate in future markets
- Applicable to hybrid projects
  - Same dynamics in PV and BESS
  - Maximize grid support capabilities



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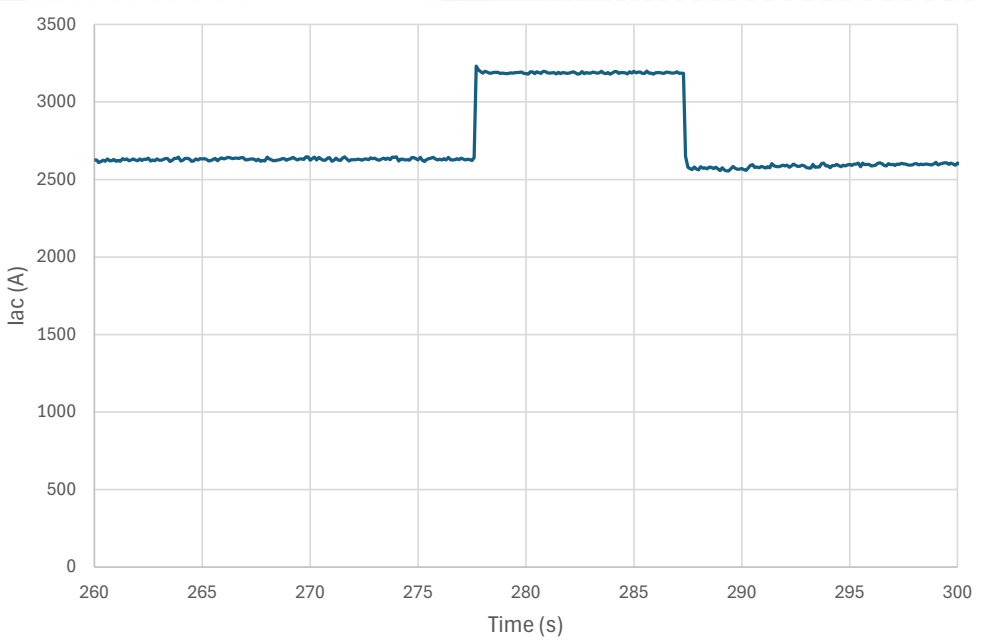
Overloading capability for BESS systems

- Implementation and validation of transient overloading
  - Additional overcurrent without curtailing the inverter in normal operation
- 119% of rated current
- Several seconds duration
  - Useful for synthetic inertia services



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ERCOT AGS

TEST FRAMEWORK

ERCOT Advanced Grid Support

Site-specific Model Quality Tests (MQT)

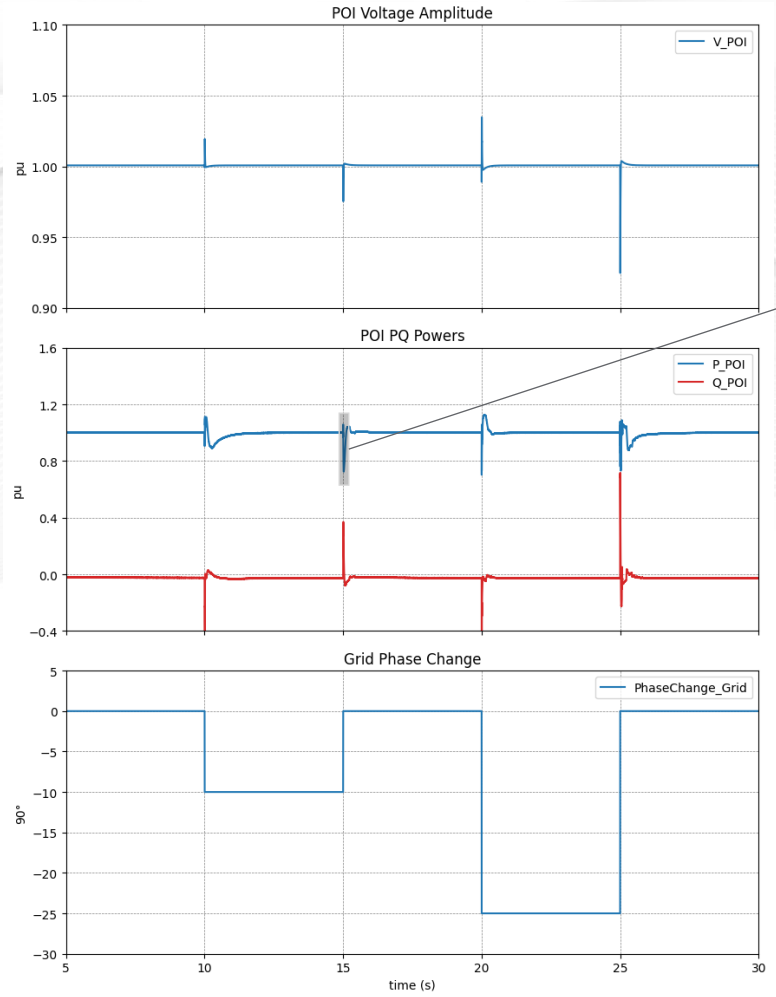
- The IS solution, Plant Controller + GFM inverter, provides satisfactory results in all AGS MQT.
- AGS requirements aim to verify not only GFM-specific capabilities, but also the compliance with current IBR requirements (ERCOT NOG).
- In some cases, the tested conditions are not representative of real-life disturbances and are oriented to verify the GFM withstand capability, rather than its contribution to maintain the grid conditions.

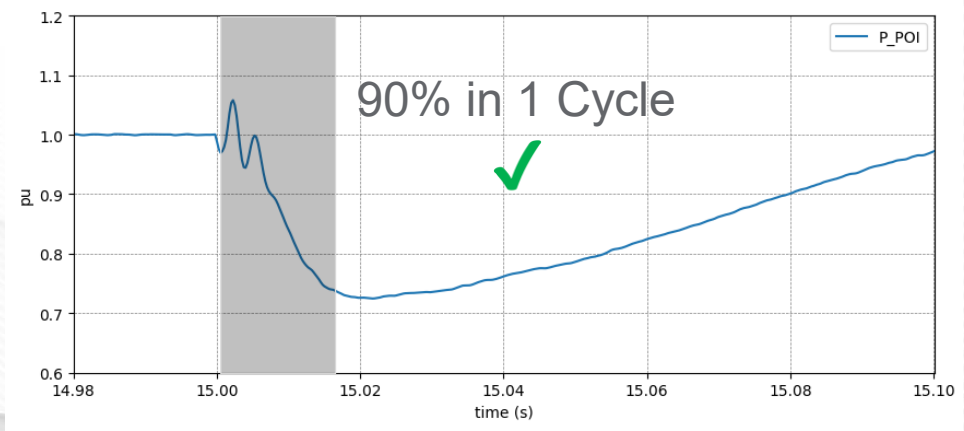
PSCAD MQT RESULTS

	IS Plant Controller + IS GFM Inverter
Test	**Result**
Flat Run	Pass
Phase Angle Jump	Pass
Small Voltage Disturbance	Pass
Frequency change & Inertial response	Pass
System Strength	Pass
Large Voltage Disturbance	Pass
Loss of Synchronous Machine	Pass

ERCOT Advanced Grid Support

Phase Angle Jump Test



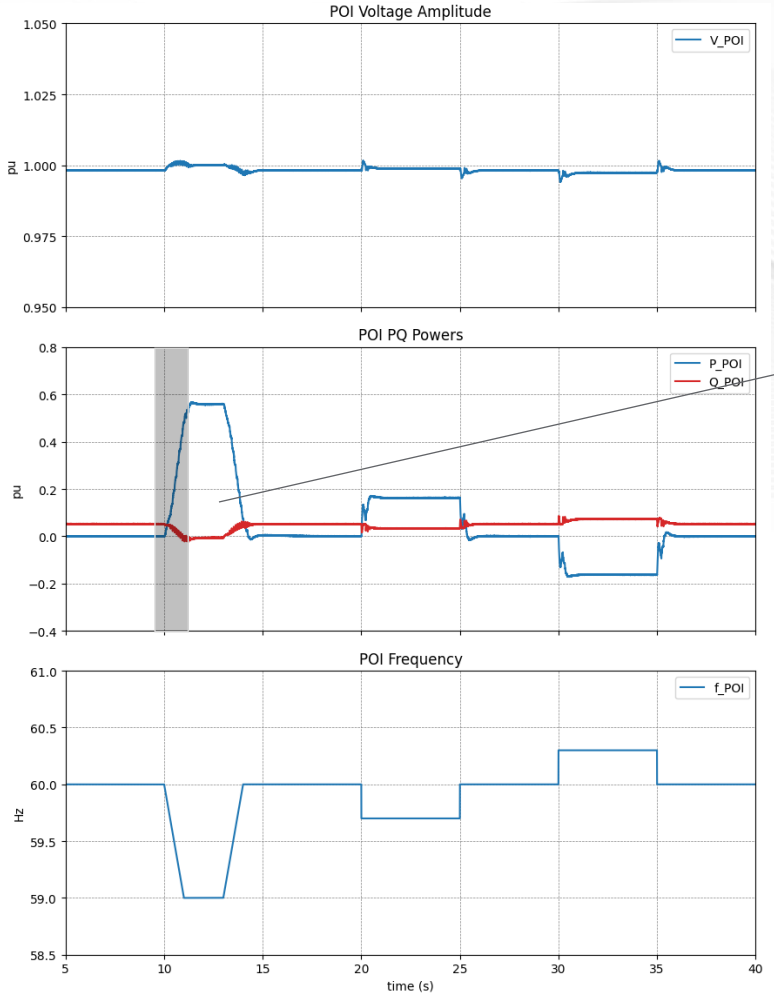


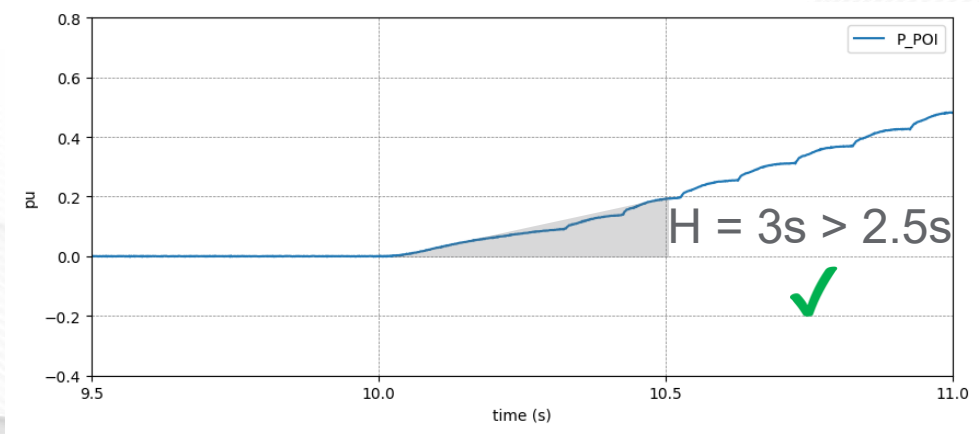
- P variation higher than 0.02 pu/1° when there is current or P headroom to vary it.
- P_POI returns to track the setpoint with stable inertial dynamics.

Depending on the pre-event P_POI value, the GFM plant may exceed the P_POI limits. Is this behaviour allowed?

ERCOT Advanced Grid Support

Frequency change & Inertial Response Test

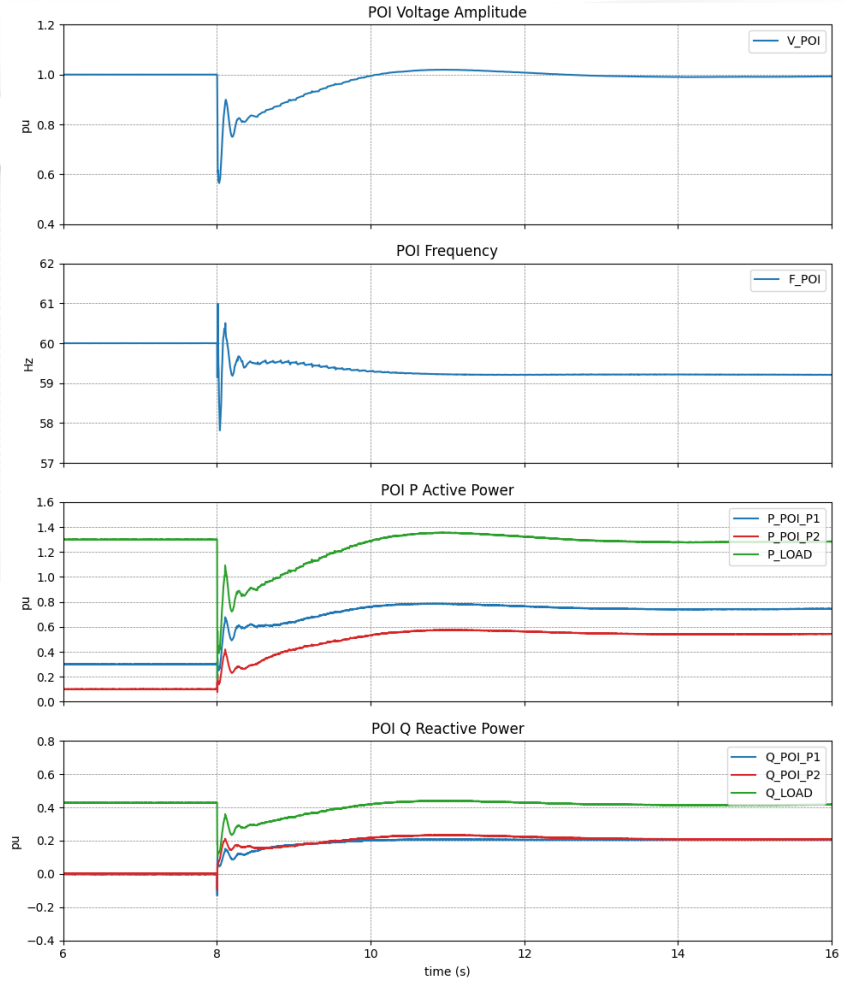




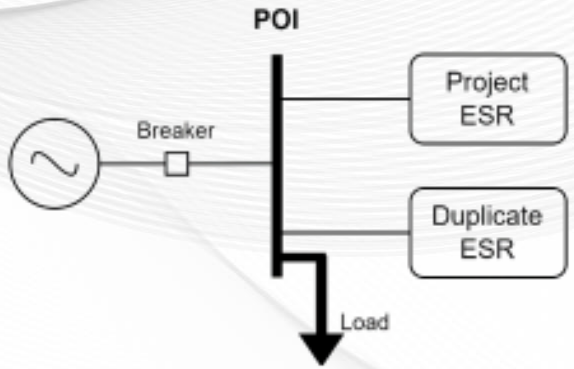
- Inertial response – Configurable parameter of IS GFM Inverter.
- Coordinated P response of the plant at POI.

ERCOT Advanced Grid Support

Loss of synchronous machine – Scenario 1



- Capability to operate in islanded mode.
- Final steady-state operating point is determined by the connected loads and configured PvsF and QvsV droops.



Why is this ultimate scenario used to assess the GFM capability in supporting the maintenance of the grid network?

Ingeteam GFM Experience

INGETEAM GFM EXPERIENCE

Australia

- Hybrid project
  - Existing 150 MW PV plant
  - Addition of 60 MW BESS GFM
- 1.3 GW undergoing connection process in Grid Forming in different regions
  - Queensland
  - New South Wales
  - South Australia
  - Victoria

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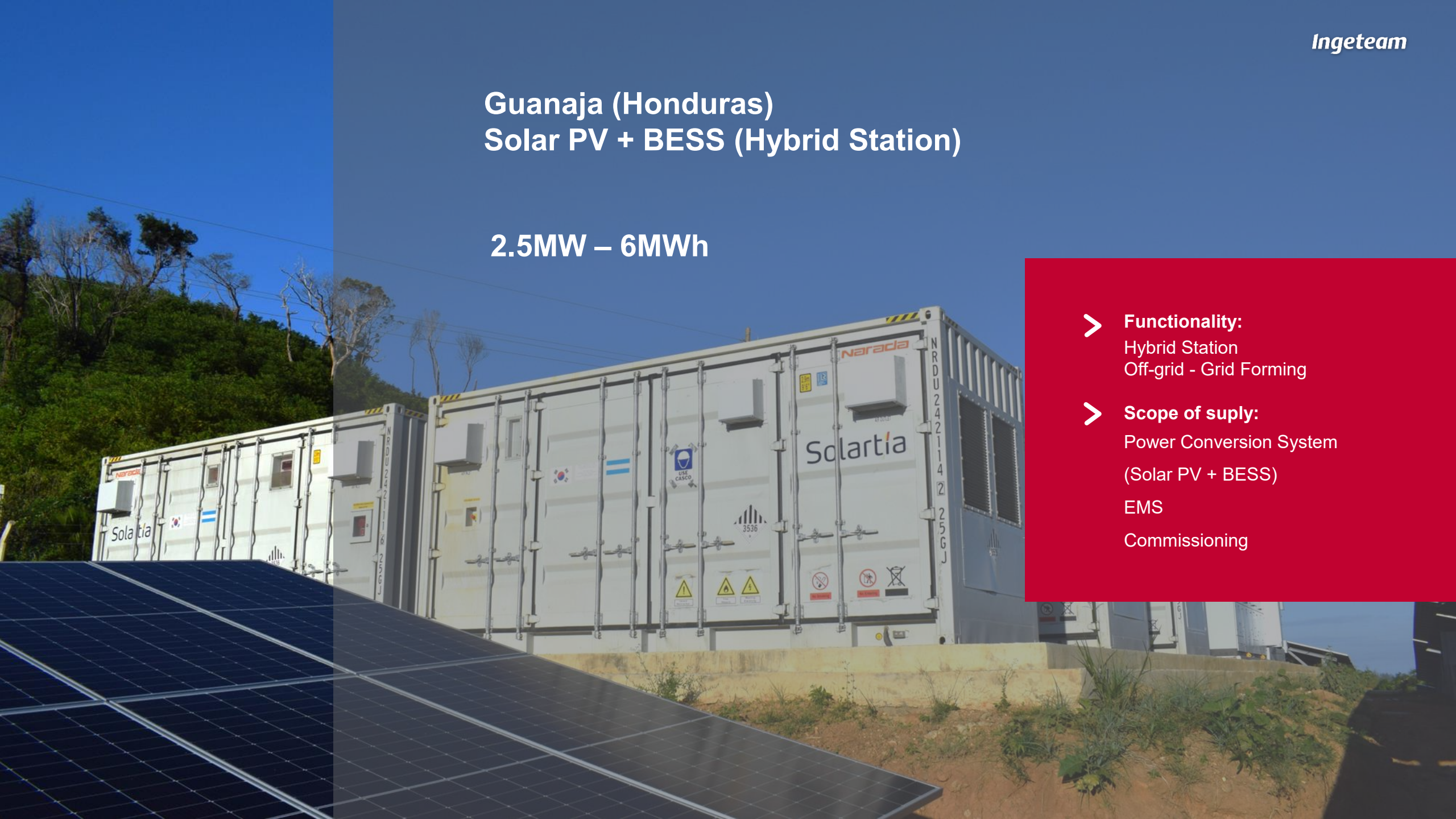
Guanaja (Honduras)
Solar PV + BESS (Hybrid Station)

2.5MW – 6MWh



Functionality:
Hybrid Station
Off-grid - Grid Forming

Scope of suply:
Power Conversion System
(Solar PV + BESS)
EMS
Commissioning

Isle of Wight (Southern UK)
Linked to gas generation

8,5MW – 4,72MWh

Functionality:

BESS in GTG for Black Start –
Synthetic inertia
Grid code fullfilment

Scope of suply:

Power Conversion System

Control

Orion (Ireland)
Linked to thermal generation

10MW – 10MWh

Functionality:

BESS in GTG for Black Start – Synthetic inertia – Grid code fullfilment

Scope of suply:

Power Conversion System

Control

INGETEAM GFM EXPERIENCE

Full on-field validation

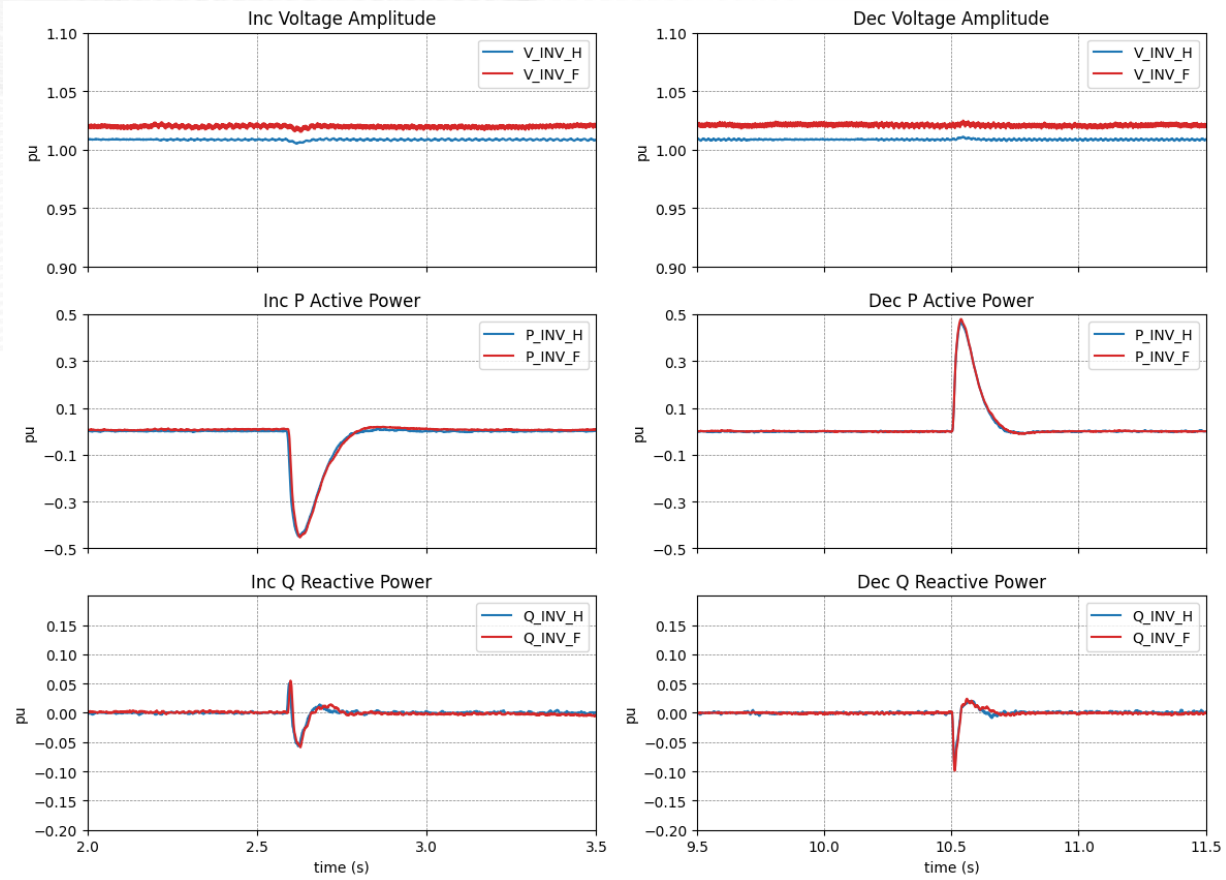
- Updated inverter from existing project
- Full validation on site of GFM based on NESO GC0137 and GBGF Best Practice Guide
  - Setpoint tracking
  - Frequency steps
  - ROCOF
  - Phase angle jump
  - Frequency oscillations
  - Voltage oscillations
- Parallel validation of HIL platform

INGETEAM GFM EXPERIENCE

Full on-field validation

- Overlay of site and HIL results

Phase jump
Δδ = ±15° and Pinit = 0%



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