Iberdrola Innovation Middle East

Grid-Forming Technology: Supporting the Transition to Resilient Power Grids

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Iberdrola, an international energy leader

Net production
168,599 GWh

Total renewable installed capacity
42,187 MW

Electrical energy
233.7 GWh

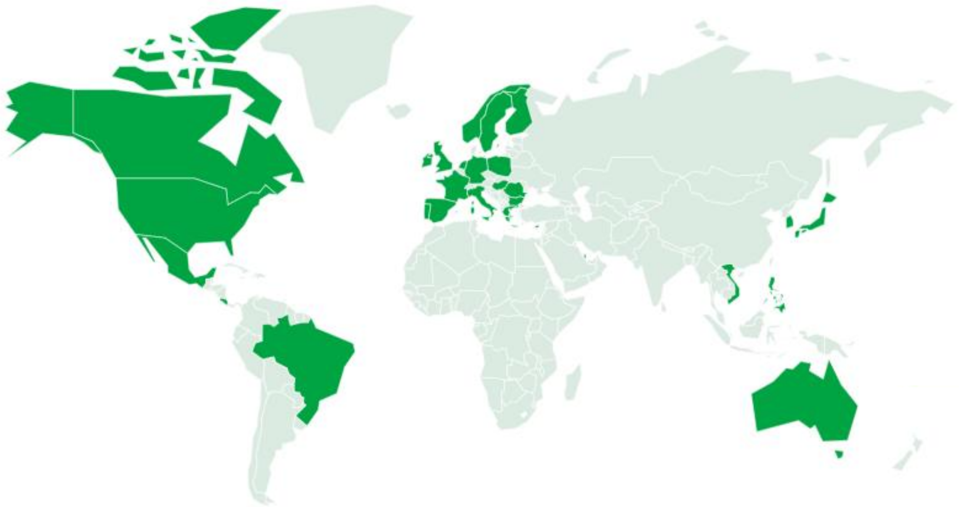
Direct employees
42,276

More than two decades leading the energy revolution

With more than 180 years of history, Iberdrola is a global leader in clean energy, grids and storage, a company that is today more solid, sustainable and diversified than ever

Largest 100% private integrated utility in Europe

+€70 Bn market capitalization (x6 in the last 20 years)



Total installed capacity
62,883 MW

Power lines
1,276,519 km

Gross investments
11,382 M€

Million users
35.9

About Iberdrola Innovation Middle East

Iberdrola Innovation Middle East is a world-leading innovation company, located in Qatar Science & Technology Park. IBME aims at defining 'the digital utility', developing innovative digital solutions for renewable energy integration, smart grids and energy efficiency and conservation.

Iberdrola Innovation ME – develop digital solutions for the energy sector

Networks
Enhancing grid planning, operations and maintenance

Renewables
Enabling the integration of renewables and storage

Customers
Empowering prosumers in the new energy paradigm

People: expertise in Power Systems, full-stack Software Development and Artificial Intelligence

Partners: R&D partnerships with Universities, Start-ups and Industrial companies

Premises: state-of-the-art facilities including Digital Innovation Lab

Through its expertise in the areas of **electrical and electronics engineering, software development, big data, machine learning and artificial intelligence**, the centre searches for new solutions for the following applications:

Iberdrola and Green Hydrogen: The Case of Puertollano

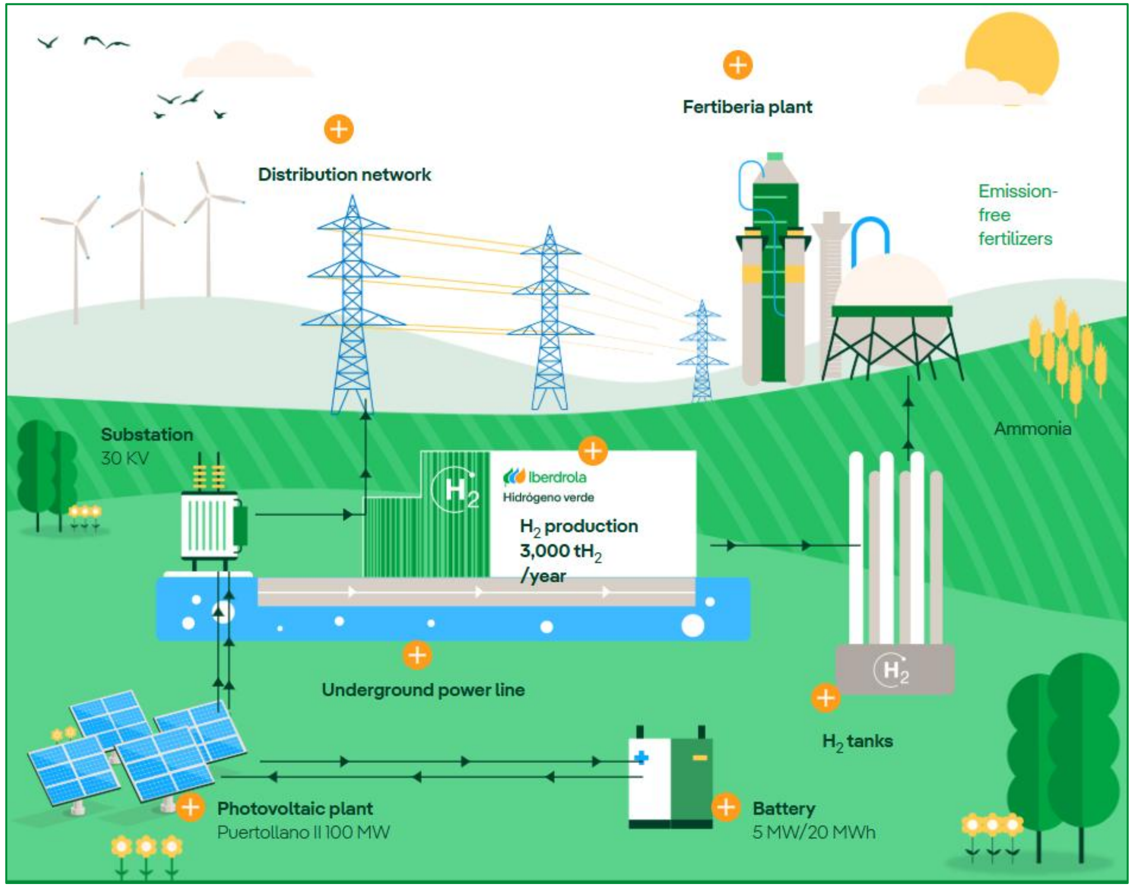
- Iberdrola group has more than 50 green hydrogen development projects (including ammonia and green methanol) in eight countries.
- When commissioned, Puertollano was recorded as Europe's largest green hydrogen plant for zero-emissions fertilisers production.

Green hydrogen plant for industrial use

Europe's most ambitious innovation project to promote decarbonization of industrial sectors

100% renewable hydrogen for emission-free ammonia and fertilizer production

Investment	Local jobs	CO_2 emissions avoided
€150 M	700	39,000 tCO_2/year



Read More:
[Iberdrola commissions its largest green hydrogen plant for industrial use in Europe]
[Iberdrola: a pioneer in the development of green hydrogen]

Introduction to GFM Technology

Power Converters in Grid-Connected Systems

Classical Approach

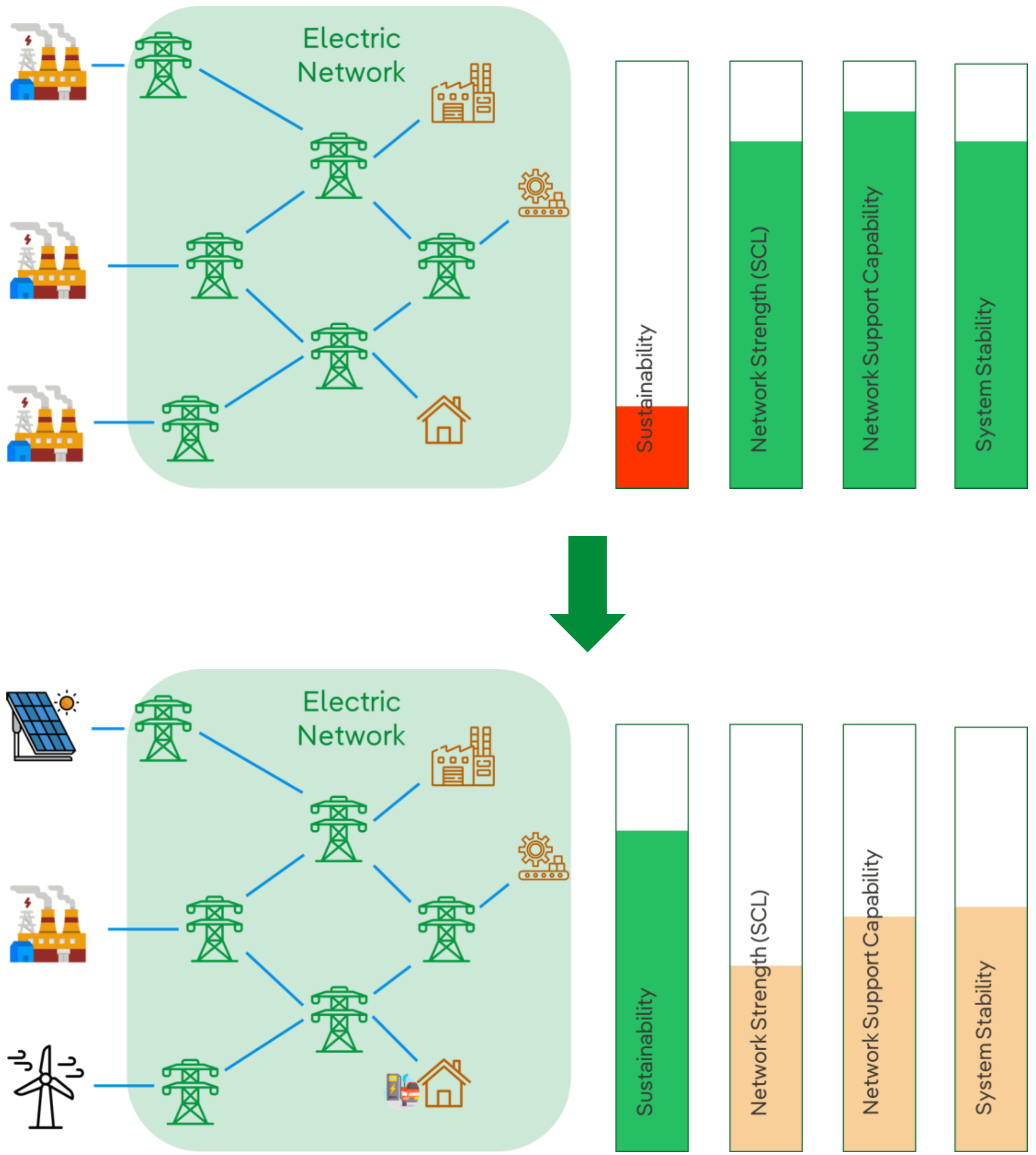
- Reliance on the existence of 'strong-grids' with large Synchronous generators.
- Power converters are controlled in *'grid-following'* mode.
- For decades: successfully achieved the purpose of power injection into the grid.

Increased RES penetration

- Decreased network strength.
- Impact on ancillary services provision and system stability.

Innovation Areas

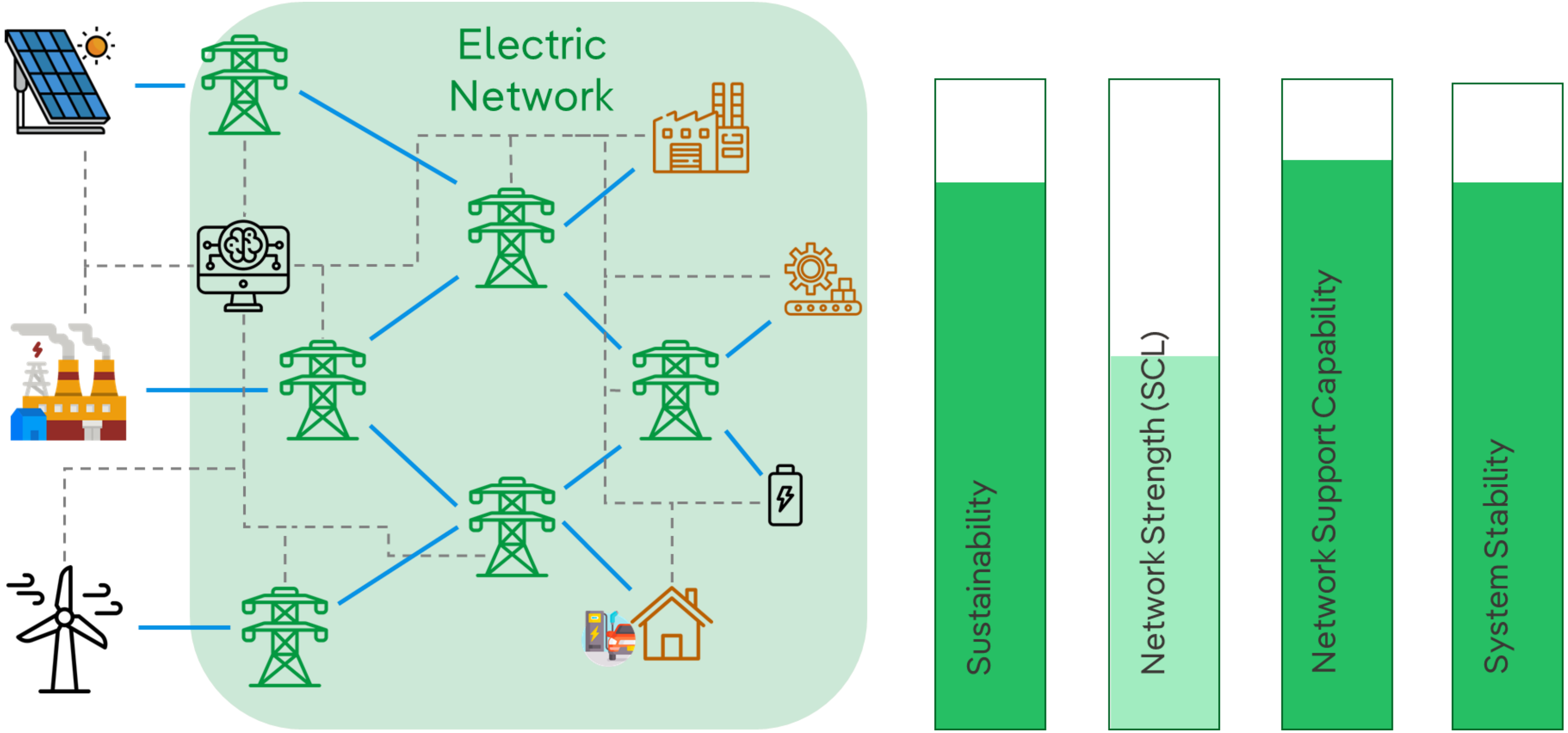
- Control and assets management/coordination.
- System optimization and *smart-grid* integration.



Power Converters in Grid-Connected Systems

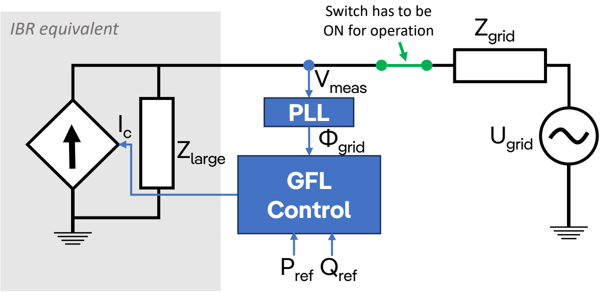
But how can converters control help here?

- Well-coordinated network with optimal design and robust controls → Improved operational reliability.



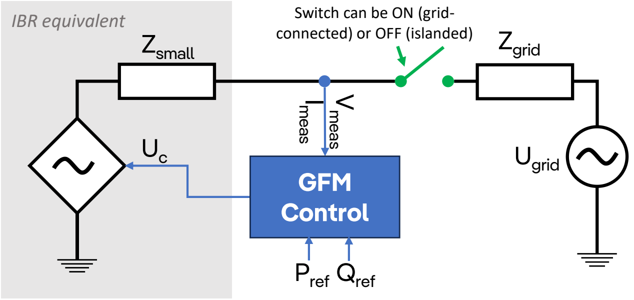
Grid-Following to Grid-Forming: Emerging Ancillary Services Paradigm

Controllers' equivalent behaviour



- Controls current magnitude and phase
- Requires a PLL
- Stable under high SCR
- No black-start capabilities

Demonstration of grid-following control mode



- Controls terminal voltage and frequency
- Doesn't use PLL
- Stable under low SCR
- Black-start capabilities

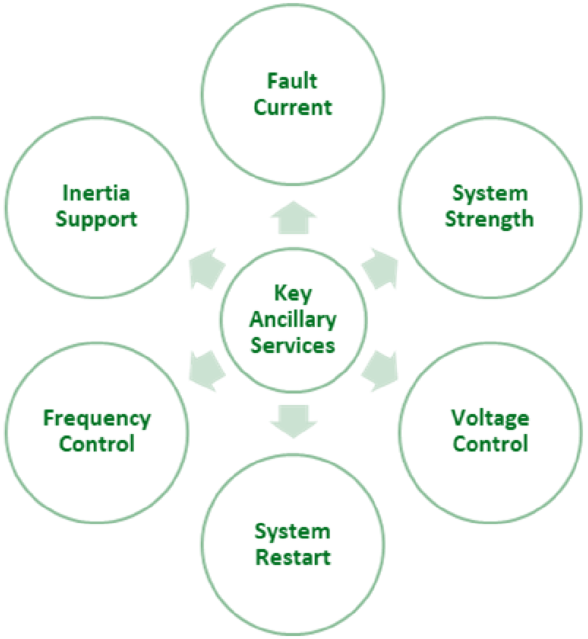
Demonstration of grid-forming control mode

Grid-codes development

- Classical view: IBRs disconnections during faults.
- Revised view: Cannot afford disconnecting large IBRs during faults!

Impact on the array of provided ancillary services

- Impact of source configuration.
- Dispatchable vs. non-dispatchable sources.
- Energy buffer availability.



Key network-support services

Grid-forming Technology Overview

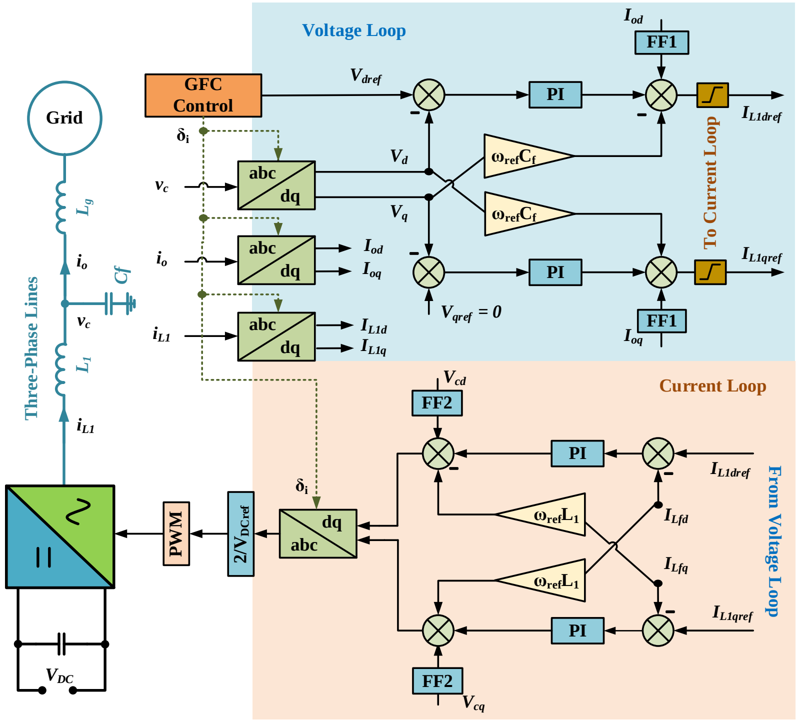
So, how does it work?

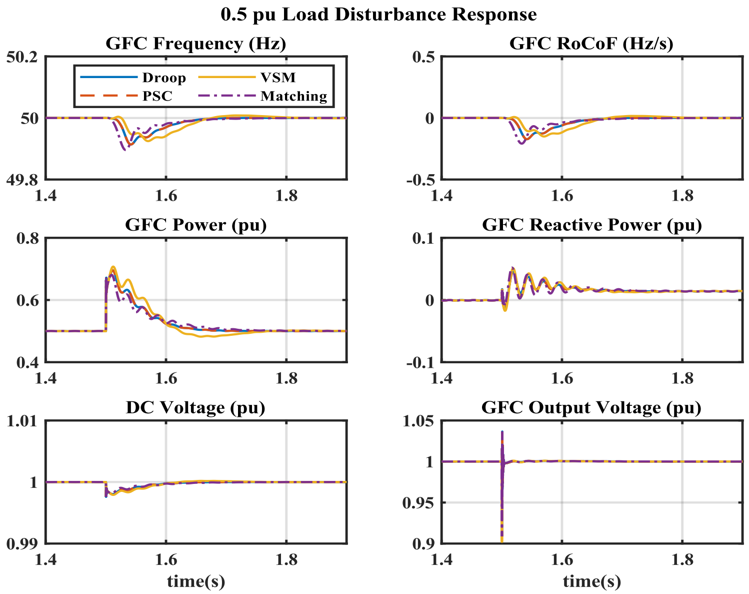
- Self-generated voltage and angle reference.
- Power-based grid-synchronization.
- Ability to ‘mimic’ the behaviour of synchronous generators.
- Different attainable control structures.

Different ‘methods’ to achieve a common objective

Droop Control	Power Synchronizing Control	Virtual Synchronous Machine (VSM)	Matching Control

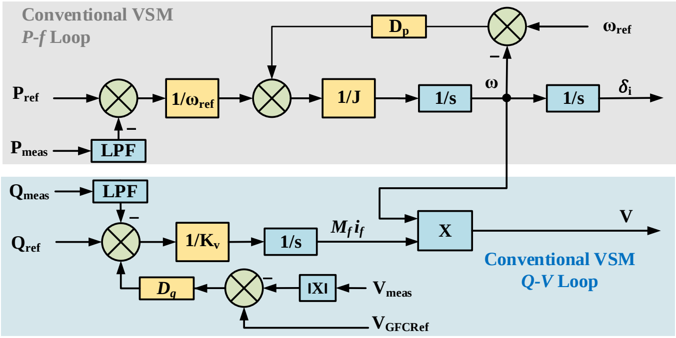
GFM control ‘in-action’





Grid-forming controls performance benchmark

- Internal protective loops compatible with different controllers.



Sample implementation: VSM

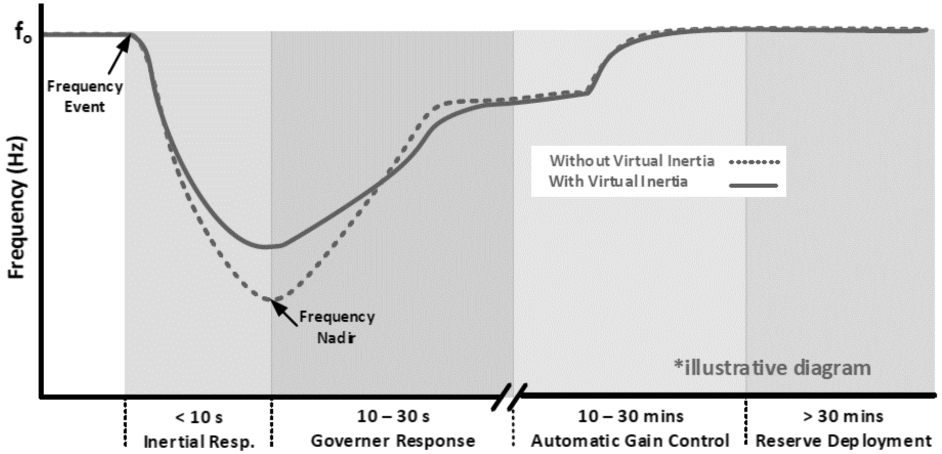
- Analogy to synchronous generators.
- Mimics swing equation.
- Virtual inertia and droop parameters.

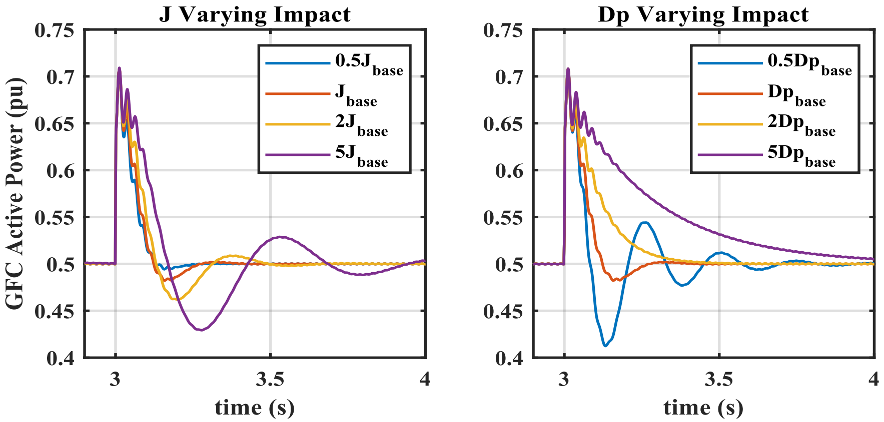
$$J\frac{d\omega}{dt} = \frac{1}{\omega_{ref}}(P_{ref} - P) + D_p(\omega_{ref} - \omega)$$

Grid-forming Technology Overview: Challenges & Opportunities

Example 1: Frequency Support

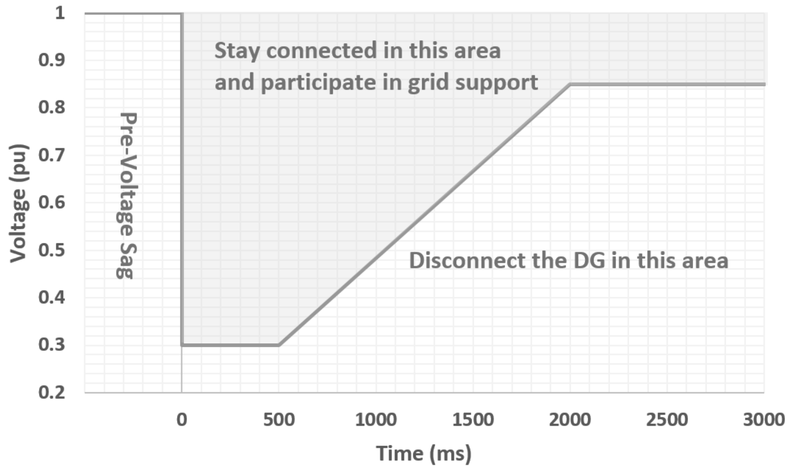
- Virtual-inertia role in frequency support.
- Parameters tuneability impact.





Example 2: FRT & Protection

- Requirement: maintain connection during faults.
- Grid-code compliance.



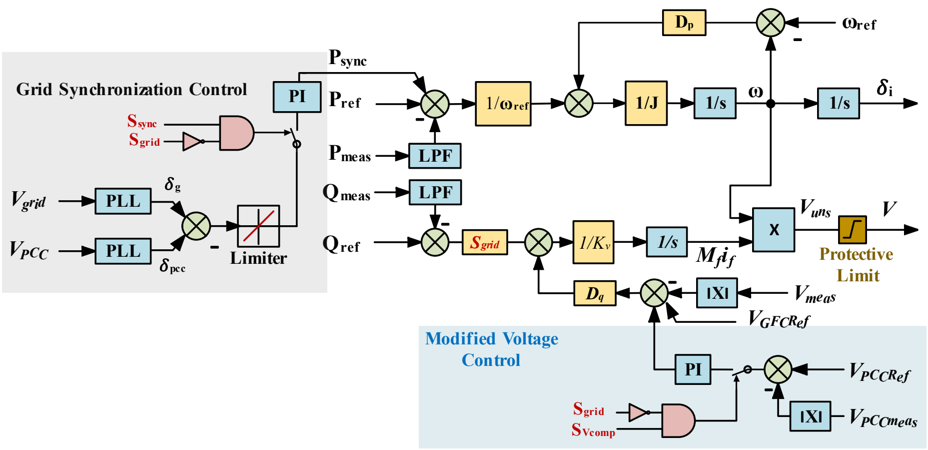
- For GFM, protection is a challenge, but attainable!
- Points to consider:
  - Converter overcurrent limits.
  - Voltage control function.

Innovative schemes are continuously emerging in the literature to maximize compatibility and protection.

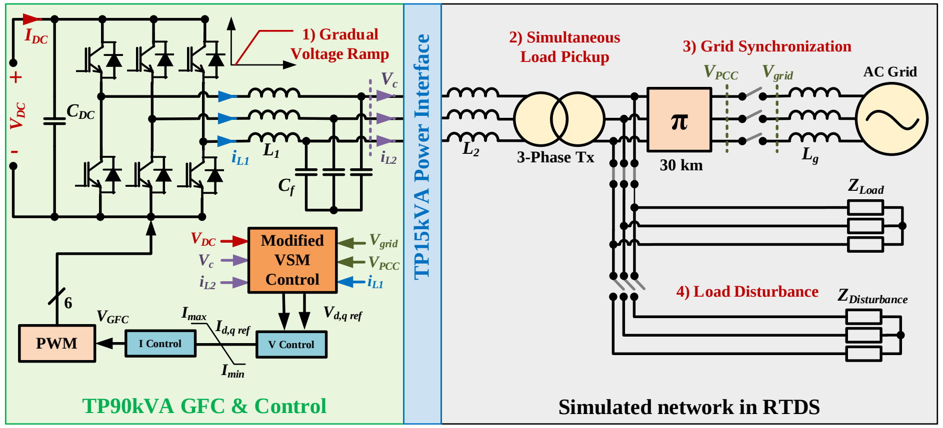
Grid-forming Technology Application: Network Restoration

Control & Validation Setup

Grid-forming Virtual Synchronous Machine Control

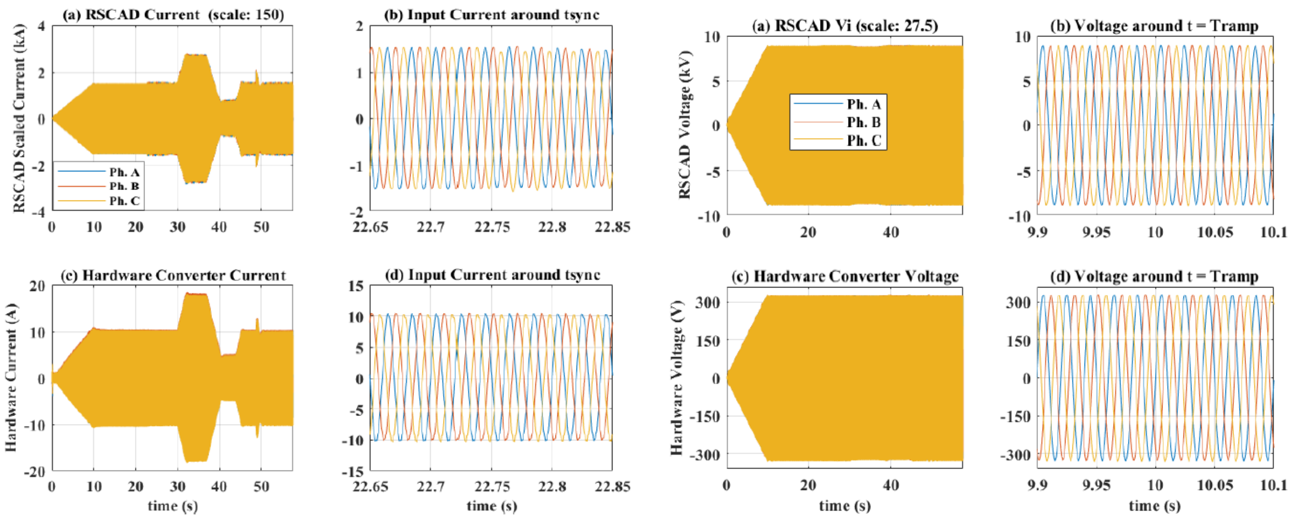


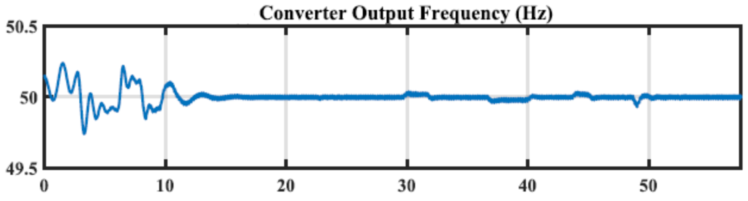
Power Hardware in the Loop Configuration



Network Energization and Synchronization

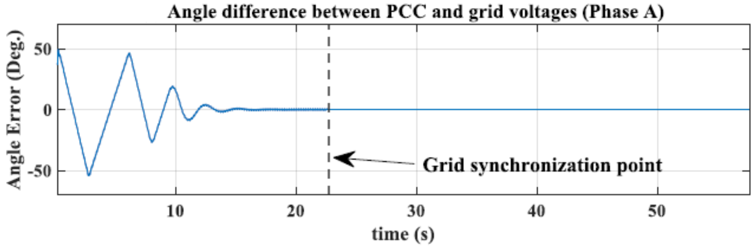
Comparison between real-time hardware and software results





Grid-forming converter frequency

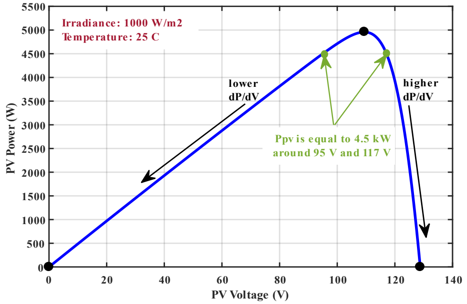
Synchronizing voltage angles error



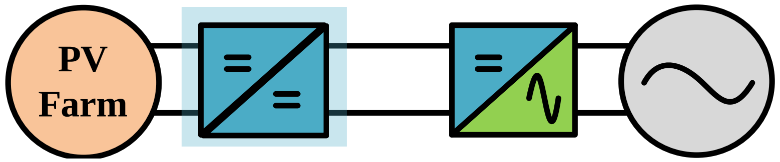
What Enables True Grid-Forming Capability?

What does it take to optimally operate in GFM mode?

- An infinite, dispatchable, DC source – ideal scenario. *Does not exist!*
- In this slide, we look at some practical implementations.

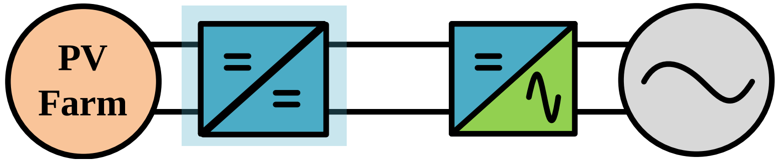


Scenario 1: MPPT Operation - GFM



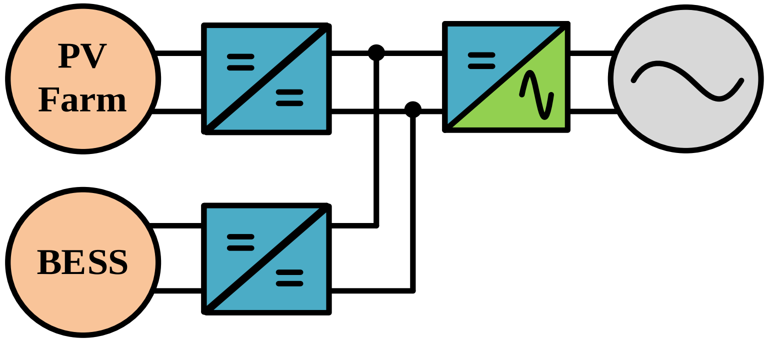
- **Maximum power injection.**
- **Cannot effectively react to bidirectional disturbances.**
- **Limited dispatchability.**

Scenario 2: Sub-MPPT Operation - GFM



- **Reduced steady-state power injection.**
- **Able to dispatch power in both directions.**
- **Increases the array of provided services.**

Scenario 3: Solar PV coupled with BESS



- **Improved operation range with higher flexibility.**
- **Able to couple MPPT and dispatched power operation.**

Finding the 'sweet-spot' trade-off

- Operation in GFM mode may range from simple software to extensive hardware upgrades.
- Key factor: cost and size optimization.

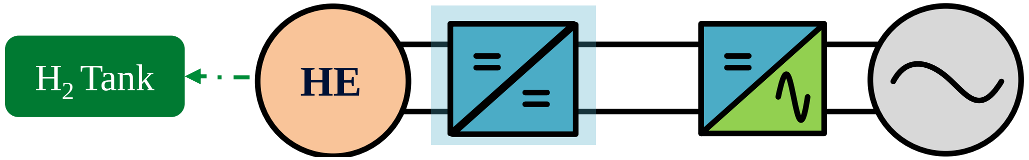
What about flexible loads? (e.g., hydrogen electrolysers)

Grid-forming and Hydrogen Electrolysers

How Can Electrolysers Participate in GFM Systems?

- Standalone versus co-located configurations.
- Array of services influenced by investment cost and the mix of technologies used.
- Any configuration must consider the units operational limits such as power ramp-rates, impact on the equipment lifetime … etc.

Scenario 1: Standalone Electrolyser

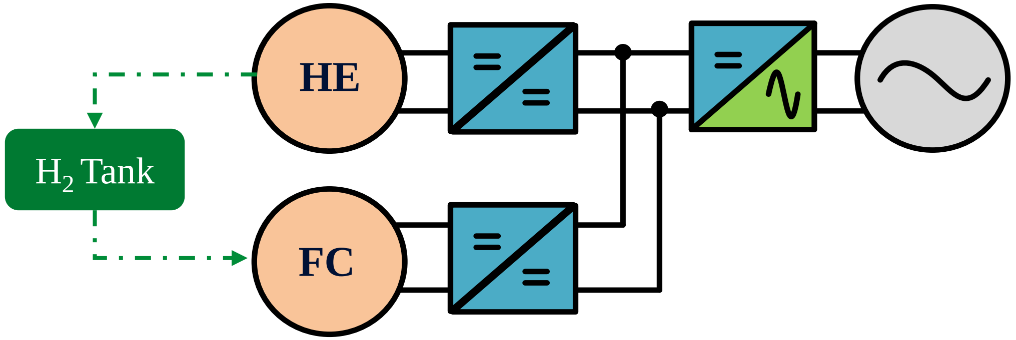


- **Operation with up/down flow regulation (load-mode only).**
- **Highly dependent on H_2 tank storage.**
- **Limited array of ancillary services.**
- **No internal energy buffer: not a 'true' grid-former.**

Points of discussion:

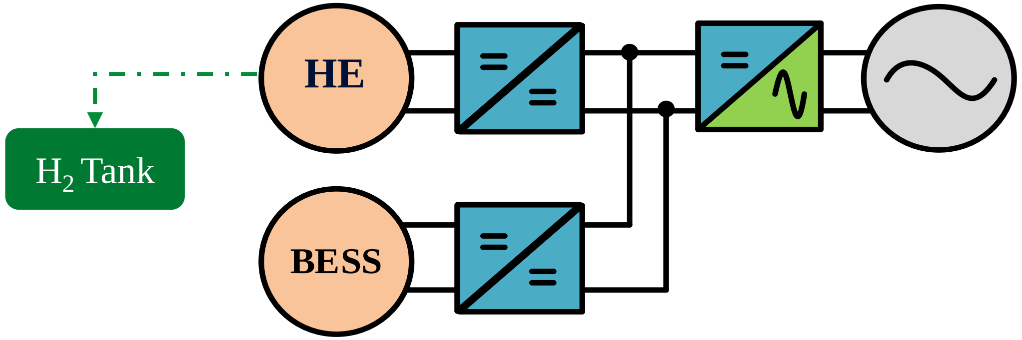
- Scale/size of hydrogen electrolysers and their GFM impact.
- Technology status and maturity.
- Unlocked benefits to the grid versus operational risks.

Scenario 2: Electrolyser with fuel cell *(dispatchability unlocked)*



- **The addition of fuel cell provides the 'energy-buffer' element.**
- **In theory, can be used as an integrated unit for 'power-in & power-out' ancillary services.**

Scenario 3: Electrolyser with external resource



- **Similar to scenario 2 in terms of electrical operation principle.**
- **FC can be replaced/complimented with other resources such as BESS and solar PV … etc.**

Takeaway Messages

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Grid-forming Control

- Increased converter-based generation grid-integration offers wide array of benefits, and presents a set of interesting challenges.
- Innovative schemes are required to unlock the full converters control flexibility.
- Grid-forming control provides a favourable operation range, extended to weak grid conditions.
- The connected assets to the converter DC side play a crucial role in its operation.
- Mimicking the operation of synchronous generators requires having dispatchable resources with up/down regulation and active energy buffers.

Hydrogen Electrolysers Context

- Standalone electrolysers can operate within GFM systems, but cannot 'form' the grid themselves.
- Coupling electrolysers to other resources maximizes the range of services they can provide.
- Incorporating the resource limits into the control is critical to maintain system reliability.

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