POWER ELECTRONICS

Grid-Forming Technology Overview

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PE Introduction

About our company

Power Electronics

Since 1987 offering solutions for industrial automation processes.

We are #1 manufacturer of solar inverters in America, Oceania and Europe.

World’s leading manufacturer of energy storage.

Innovative solutions for charging electric vehicles.

Campus

100.000 m²

30GW

Of annual production capacity

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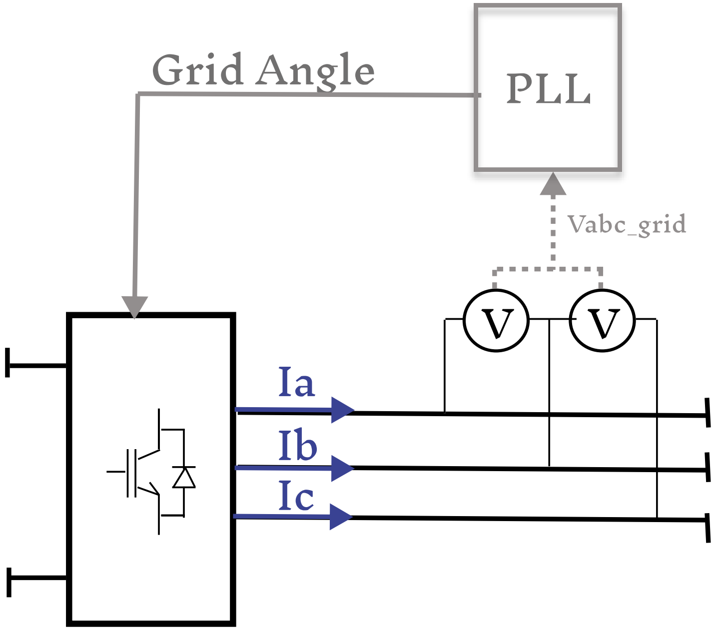
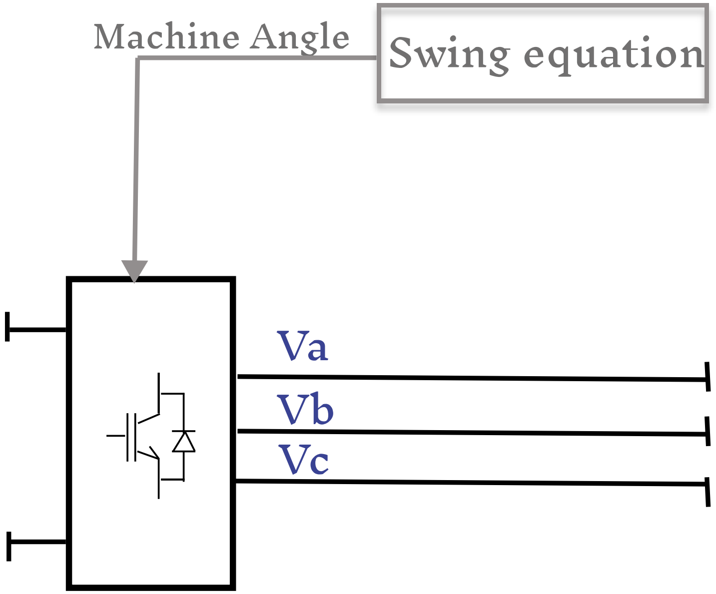
Grid Forming Overview

Grid Forming Inverter

A GFM inverter maintains a constant internal voltage phasor in a short time frame, with magnitude and frequency set locally by the inverter, thereby allowing immediate response to a change in the external grid. On a longer timescale, the internal voltage phasor may vary to achieve desired performance. [1]

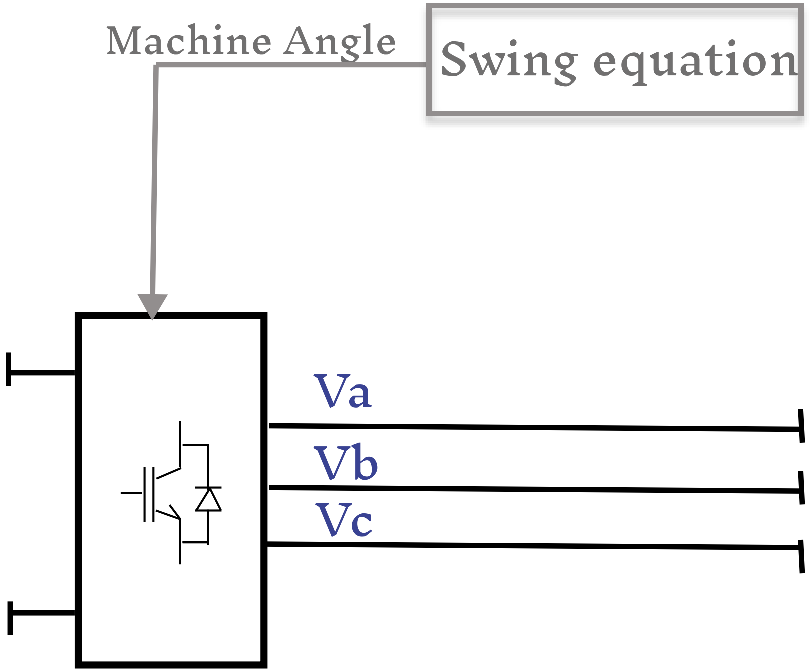


Grid Following -Current source

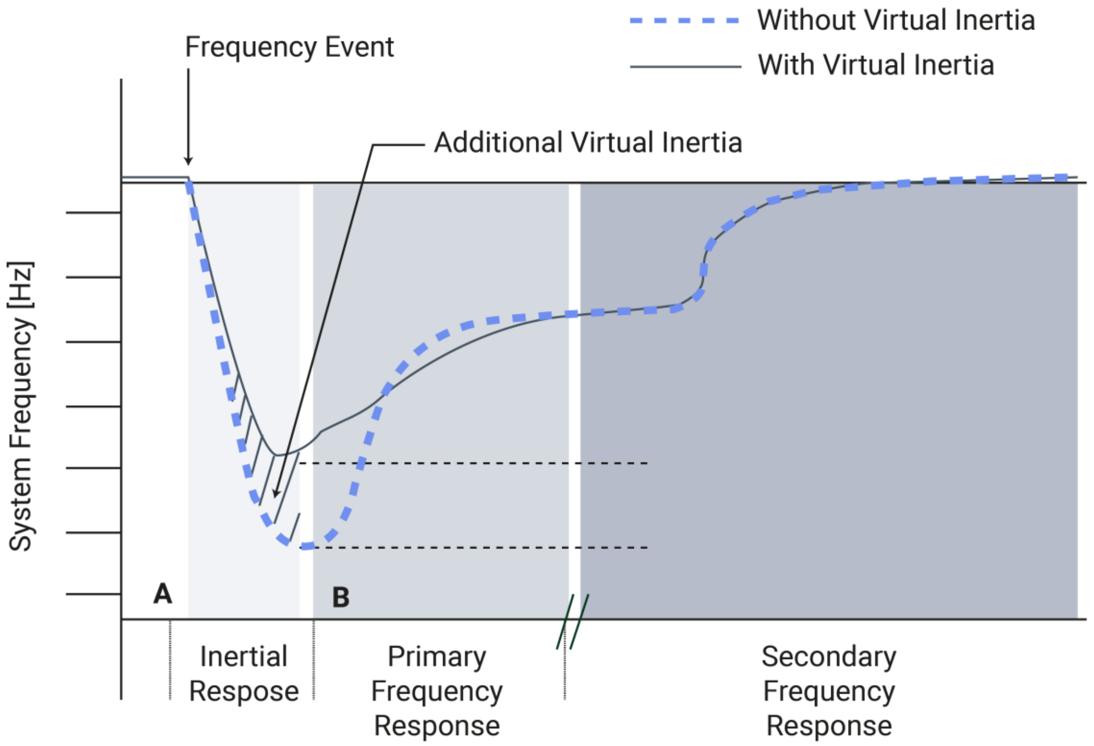


Grid Forming -Voltage source (VISMA)

Virtual Synchronous Machine (VISMA)



Grid Forming -Voltage source (VISMA)



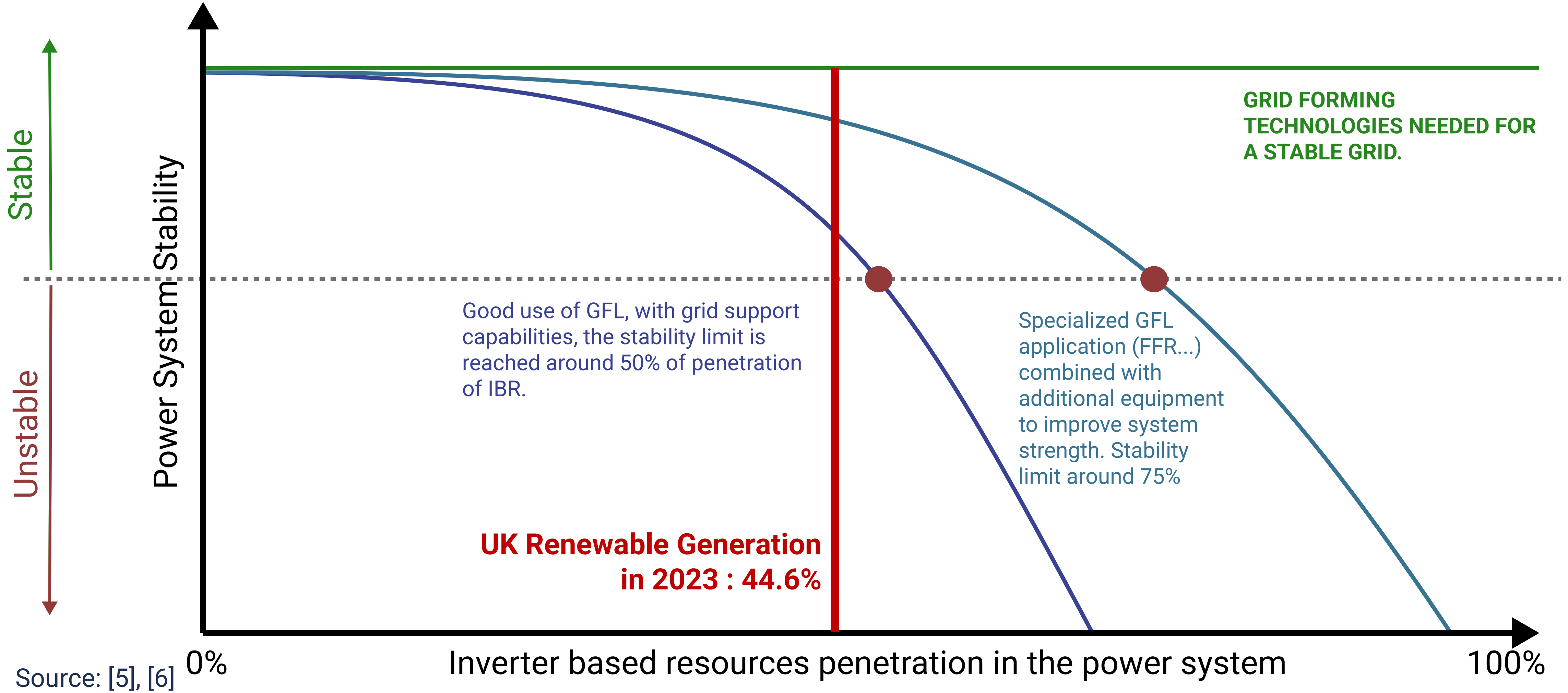
The Need for VISMA Inverters

The UK is legally committed under the **Climate Change Act 2008** to achieve net-zero emissions by 2050. [2]

NGESO already operates the fastest decarbonizing electricity system in the world, with an ambition for zero carbon operation by 2025. And by 2035, NGESO want to run 100% clean, green energy, all the time. [4]

The Need for VISMA Inverters

Power system stability limits depending on the inverter's technology.



Source: [5], [6]

PE Solution

PE Inverters

-**Power Electronics GEN 2 and GEN 3 PCSK/M** Inverters prepared to be updated to operate in Grid Forming – Voltage Source Mode (VISMA)

-PE GEN 3 Inverter with overload capacity when operating in VISMA mode.

NEW POWER RATINGS DURING VISMA OPERATION!

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NOGRR-272 Advanced Grid Support Requirements for Inverter Based ESR

NOGRR272/PGRR121 Advanced Grid Support Requirements for Inverter Based ESRs

- The potential benefits observed in the ERCOT assessment include:
- (1) improvement of voltage and frequency response during events, which would reduce events' impact to the ERCOT Transmission Grid,
- (2) reduction in the risk of IBRs tripping or unstable operations,
- (3) increase in GTC limits which could reduce generation curtailment due to stability constraints.

2.14 Advanced Grid Support Requirements for Inverter-Based ESR

s

(1) An Energy Storage Resource (ESR) that interconnects to the ERCOT Transmission Grid pursuant to a Standard Generation Interconnection Agreement (SGIA) executed on or after April 1, 2025 shall comply with the requirements of this Section.

(a) An ESR shall maintain an internal voltage phasor that is constant or near-constant in the sub-transient to transient timeframe. An ESR shall immediately respond to changes in the external system and maintain ESR control stability during normal and disturbance conditions. The voltage phasor must be controlled to maintain synchronism with the ERCOT Transmission Grid and regulate real power and Reactive Power appropriately to support the ERCOT Transmission Grid.

PE Compliance – Constant Voltage Phasor

- **Constant Voltage Phasor**: The ESR must maintain a stable internal voltage phasor (a representation of voltage in terms of amplitude and phase angle).

- *Inverter Performance is characterized by:*
  - *Active power phase jump*
  - *Active power inertia*
  - *Reactive Power Voltage jump*
  - *Reactive power response*
  - *Power Oscillation Damping*
  - *Fast Current Injection*

PE Response – Response to External Changes

- **Responsive to External Changes**: The ESR should be able to quickly react to changes in the external electrical system (like fluctuations in demand or generation) and ensure operational stability during both normal operations and during disturbances (such as faults).
- o *This section 2.1 of the technical note “**SIAN0091OI_VISMA_GEN3.pdf**” describes the performance characteristics of the inverter while operating in both disconnected and connected modes. It includes aspects like active power phase jumps and transient responses, which indicate the inverter's ability to react to fluctuations in demand or generation.*
- On Grid functions
    - Active and Reactive power commands
    - Volt-Var response
    - Frequency droop curve
    - LVRT and HVRT Algorithm

Synchronism with the Grid

- **Synchronism with the Grid**: The voltage phasor must be carefully controlled to ensure that the ESR stays in sync with the overall ERCOT Transmission Grid.
- o Emulate behavior of synchronous generators to maintain synchronization with the grid.
- *Active power phase jumps and reactive power response as required to achive synchronizaed operation.*
- o On Grid operation include response to P & Q setpoints while Grid forming mode responds to changes and V & F at the inverter terminals.
- Grid functions like OVERT and LVRT algorithms provide rapid response to grid events.

Regulation of Power

- **Regulation of Power**: The ESR must regulate both real power (actual electricity consumed) and reactive power (used for voltage control in the system) effectively. This regulation helps support the stability and reliability of the ERCOT grid, especially during varying load conditions or disturbances.

- *The section 2.3 of the technical note "**SIAN0091OI_VISMA_GEN3.pdf**" discusses the inverter's capability to follow active (real) and reactive (Q) power setpoints. It highlights how the inverter can adjust its power output in response to grid conditions, which is essential for maintaining stability and responsiveness in the ERCOT grid.*

- *Within the section 2.1 of the technical note "**SIAN0091OI_VISMA_GEN3.pdf**", the inverter's ability for active and reactive power control is touched upon. The section outlines various transient responses and control mechanisms that enable effective power regulation during operational changes.*
- *The section 2.4 of the technical note "**SIAN0091OI_VISMA_GEN3.pdf**" details the strategies for injecting reactive power during low and high voltage ride-through events, demonstrating how the inverter can support voltage control through reactive power regulation during disturbances.*

NOGRR-272 Summary

	GEN3 Compliance
Constant Voltage Phasor	Yes
Responsive to External Changes	Yes
Synchronism with the Grid	Yes
Regulation of Power	Yes

Table 1. NOGRR 272 Compliance for GEN3 Inverter Family

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Grid Following vs Grid Forming

Grid Following vs Grid Forming

	Grid Following	Grid Forming	Black Start
Gradients (Ramps)	Same ramps for GFL vs GFM		
Harmonics	< 3% per IEEE-519	>3% below 0.9pf	
EMC/EMI	No difference		
Voltage and Frequency protections	Same protection settings apply		Protections temporarily disabled
LVRT/OVRT Algorithms	Same protection settings apply		
Setpoints	P & Q	V & F	V_setpoint, F_setpoint, Ramp (%/sec), Timer

Grid Following vs Grid Forming Continued

	Grid Following	Grid Forming	Black Start
Start Conditions	Faults cleared DC in Range Vac and Frequency in range Start Command Received Delay timers complete	Faults cleared DC in Range Vac and Frequency optional Start Command Received	Faults cleared DC in Range Vac and Frequency may/may not be in range Start Command Received Switchgear operational
Stop Operation	Stop Command	Stop Command	Timer exceeded

Grid Following vs Grid Forming Continued

	Grid Following	Grid Forming	Black Start
Hardware		Grid forming hardware kit required	
Models	PSCAD, PSSE	PSCAD , PSSE	
Power Rating Steady State	100%	90%	
Overload	100% (No overload capability)	150% / 0.2 seconds 130%/ 0.8 seconds At 25 `C	

PE References

Grid Forming References

SOUDA BAY – CRETE (GREECE)

- PCSK Storage inverter – VISMA mode
- HEMK Solar inverter –Grid Following mode
- PE Micro-Grid Controller

FUNCIONALITIES

- On-Grid Operation
- Off-Grid Operation
- Black Start
- On-Grid / Off-Grid seamless transition

Grid Forming References

Groton School (Groton, Massachusetts)

- PCSM Storage inverter – GFL/ GFM
- 3rd Party Microcontroller

FUNCIONALITIES

- On-Grid Operation
- Off-Grid Operation
- Black Start

Grid Forming Confirmed Projects

Region	Confirmed Projects
North America	31 MW
South America	20 MW
UK	761 MW
APAC	3607 MW
Total	**4.42 GW**

PCSK

Battery Inverter

- Grid-forming and grid-following capable
- Overload capacity for grid-forming applications
- NGESO Stability Pathfinder ready
- Noise reduction kit available

#1 World Storage Leader

Over 4GW Installed Inverters in UK

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POWER SUPPORT

Thank you!

Bibliography

[1] Australian Energy Market Operator (AEMO), “Voluntary Specification for Grid-forming Inverters,” 2023.

[2] UK Government, “Climate Change Act 2008,” 2008.

[3] International Energy Agency, “IEA,” [Online]. Available: https://www.iea.org/.

[4] National Grid Energy System Operator, “NGESO,” [Online]. Available: https://www.nationalgrideso.com/.

[5] Energy System Integration Group, “Grid Forming Technology in Energy Systems Integration,” 2022.

[6] UK Government, “Energy Trends UK, July to September 2023,” 2023.