Grid Forming Inverters Voluntary Specifications

Nilesh Modi

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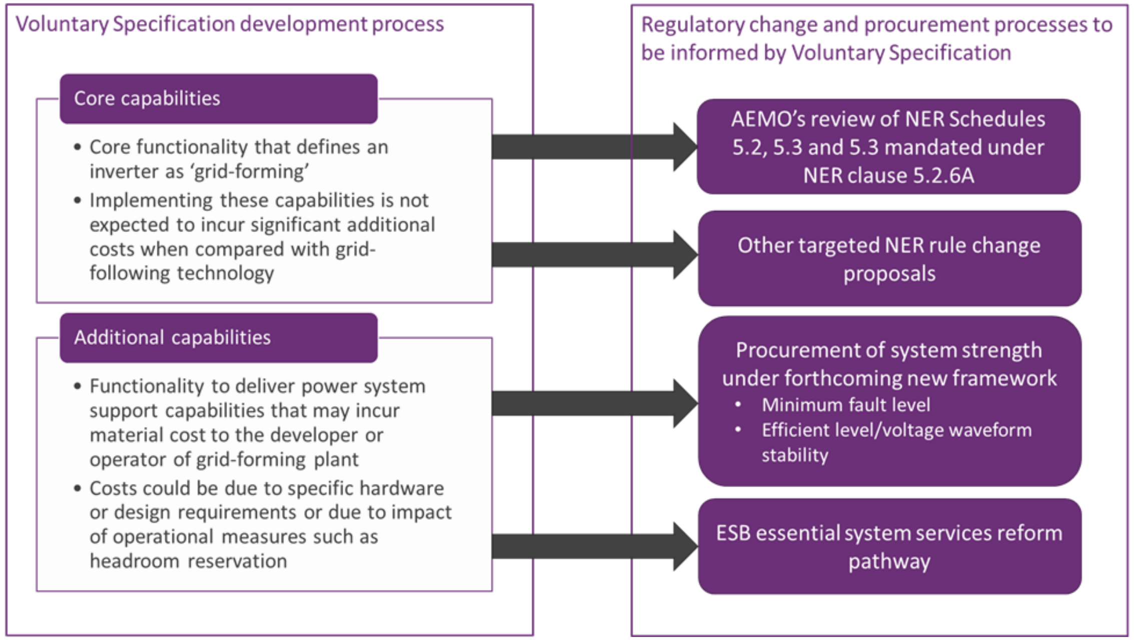
Background

Action ID	Target end-state objective for action	AEMO commitment for financial year 2022-2023
A3	Define necessary power system support capabilities for grid-forming inverters to guide Original Equipment Manufacturers (OEMs) and developers.	Collaborate with industry on a voluntary specification for grid-forming inverters.

- Collaborate with industry to prepare a preliminary document to establish alignment and provide guidance on technical and operational design considerations.
- Could be used to inform future regulatory change in technical standards, service specifications, and procurement processes.



Grid forming inverters – definition(s)

AEMO

Grid forming characteristics as the fundamental capability of maintaining a stable operating point with constant voltage and frequency during hypothetical standalone operation. The stability must also be maintained for defined disturbances with steady-state and dynamic deviations from the operating point.
-- VDE's FNN Guideline, Grid forming & system supporting behaviour of power generating modules' Version 1.0 December 2021

…any inverter controller that regulates instantaneous terminal voltages and can coexist with other grid-following and grid-forming inverters and synchronous generation on the same system. We further restrict our definition to inverter controls that do not require a PLL…..
-- NREL, Research Roadmap on Grid-Forming Inverters

Grid forming technology refers to the inverter control paradigm in which the inverters synthesize a voltage phasor, which is controlled relative to the grid's voltage phasor to achieve the desired current and power flow
-- IEEE

Grid forming inverters are required to behave as voltage sources, and some additional requirements are:

- To be synchronised with other grid forming sources (including synchronous machines)
- Operate in stand-alone mode after seamless islanding
- To smartly limit the output current magnitude to protect the hardware and to control the voltage as much as possible when the current is limited; and
- To be compatible with all devices connected presently on the power system especially synchronous machines and grid-following inverters

-- Migrate project, WP3- Control and Operation of a Grid with 100% Converter-based Devices. Deliverable 3.6: Requirement guidelines for operating a grid with 100% power electronic devices" December 2019

Grid Forming Control for BPS-Connected Inverter-Based Resources are controls with the primary objective of maintaining an internal voltage phasor that is constant or nearly constant in the sub-transient to transient time frame. This allows the IBR to immediately respond to changes in the external system and maintain IBR control stability during challenging network conditions. The voltage phasor must be controlled to maintain synchronism with other devices in the grid and must also regulate active and reactive power appropriately to support the grid
-- NERC "Grid Forming Technology. Bulk Power System Reliability Considerations" December 2021

Grid forming inverters – definition(s)

…within the power park module current limits, the power park module shall be capable of behaving at its connection point as a voltage source behind an internal impedance (Thevenin source), during the normal operating conditions (non-disturbed grid conditions) and quasi immediately after a grid disturbance (including voltage, frequency and voltage phase angle disturbance). ……..

-- ENTSO-e NC RfG 2.0 / Grid forming new Article / Legal Text

- A GFM device maintains an <u>internal voltage phasor</u> on a short timescale following a disturbance, with magnitude and frequency set locally at each device thereby allowing an immediate response to a change in the external grid. On longer timescales, the device's internal voltage source may vary to achieve desired performance.

  - AEMO, ….. At final stage and going through internal discussion ……

Core and additional capabilities

Core capabilities

- Capabilities which are mostly inherent to the GFM inverter control strategy and can be achievable with no or minimal hardware upgrade to the plant

Additional capabilities

- Capabilities which generally require additional cost for hardware upgrade, including an energy buffer and over-current capability – not all GFM inverters need to provide advanced capabilities

Core and additional capabilities

Core

- Voltage source behaviour
- Surviving the Loss of the Last Synchronous Connection
- Weak Grid Operation and System Strength Support
- Inertial Response
- Oscillation Damping

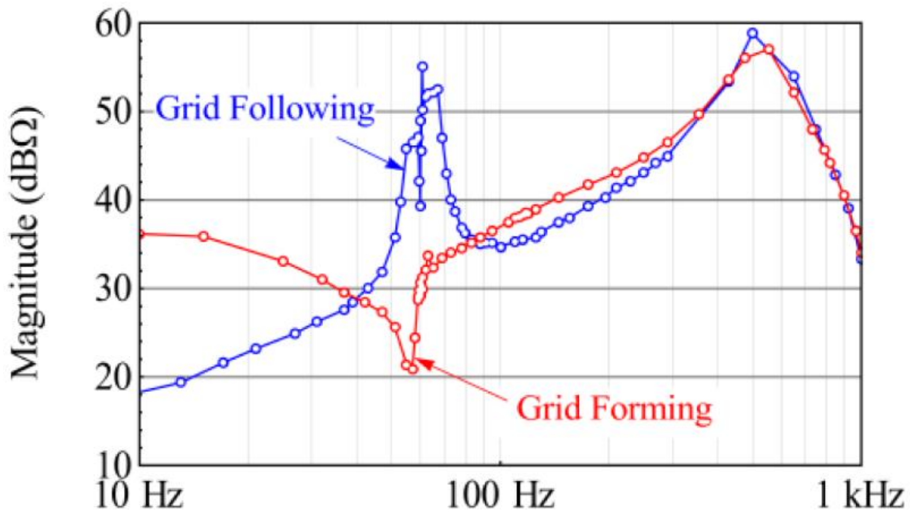
Additional

- High Overload Capability
- System Restart Capability
- High Disturbance Withstand Capability

Voltage source behaviour

- Voltage source behind an impedance
- The internal voltage phasor is constant within the *short* time frame following a disturbance
  - Enables GFM inverter to inherently prevent fast changes in the voltage and phase angle
- Active power output of a GFM inverter is determined by the internal voltage phasor, the PoC voltage phasor, and the sine of the load angle (not via current)
- At the thermal limit, GFM inverters may operate similar to grid-following inverters

- Expected behaviour
  - A small-signal impedance scan test around the fundamental frequency can be used to quantify the voltage source behaviour of the GFM resources.
  - A small impedance magnitude around fundamental frequencies indicates good voltage

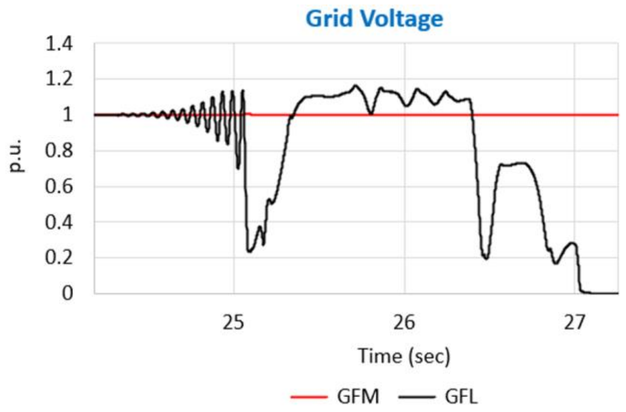


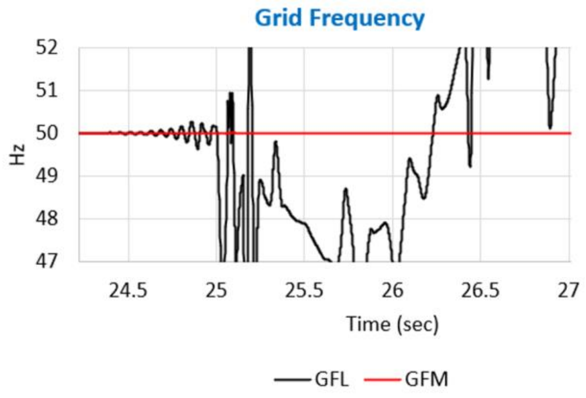
Reference: NREL (https://www.esig.energy/event/webinar-impedance-scan-tools-for-stability-analysis-of-ibr-grids/)

Surviving the loss of the last synchronous connection

- Capable of standalone and stable operation when it loses the last synchronous connection to the main grid.
  - This is owing to the GFM inverter's capability to generate its own voltage reference.
- Seamlessly switch between grid-connected and islanded operation.
- Under islanded conditions, it should have a capability to share the active and reactive power load with other online generators (wind, solar, GFM, GFL, synchronous machines etc.)

- Expected behaviour
  - Both voltage and frequency should be stable and settle back within a nominal range after disconnecting the last synchronous connection



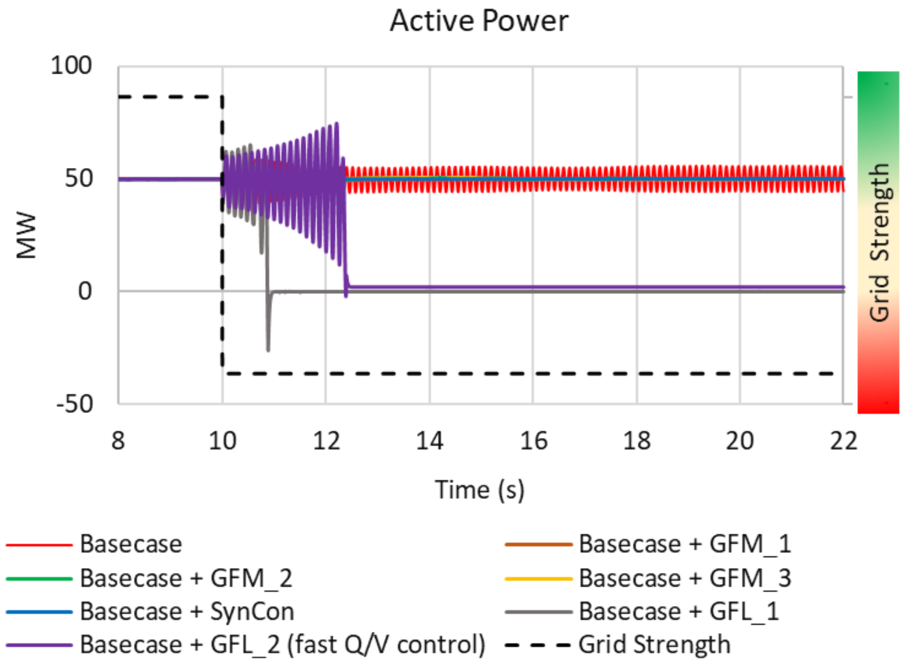


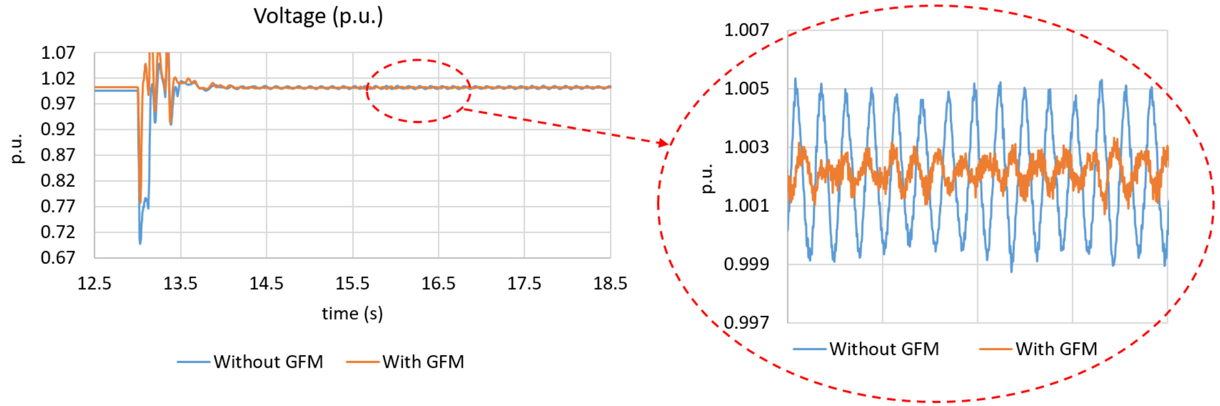
Weak grid operation and system strength support

- Operate stably under very low short circuit ratios, under normal operating condition and when exposed to network disturbances
  - Recognising its contribution to system strength
- Provide support to nearby GFL inverters and enhance their stable operation during grid disturbances

Weak grid operation and system strength support

- Expected behaviour
  - An example of system strength improvement by GFM inverters is shown. The figure shows that GFM plant can stably operate under weak grid condition and also provides support to GFL plants

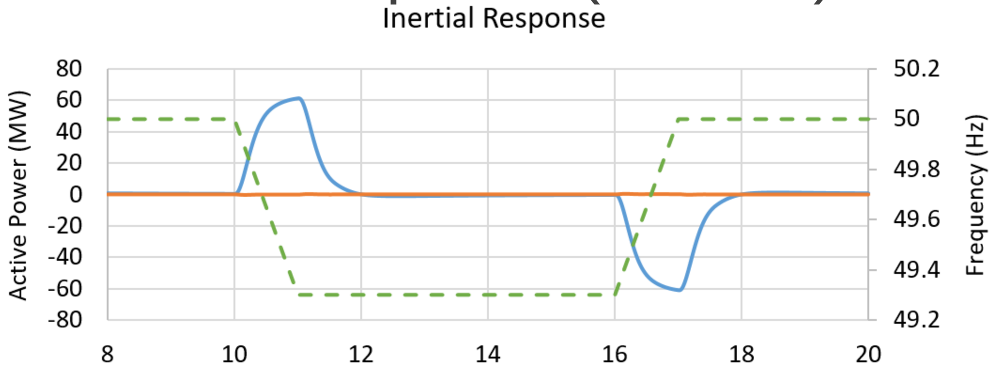


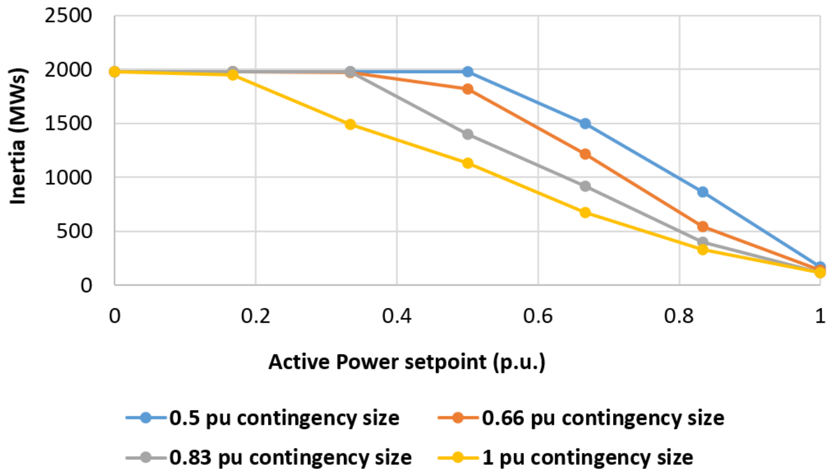


Inertial response

- Inject an immediate, inertia-like *response* of active power upon a change in the outer network frequency
  - For more effective inertial response inverters need power and energy buffers
- Limited by current rating
- Configurable inertia constant

- Expected behaviour
  - Inertial Response (no FFR):





Additional capabilities

- High overload
  - Notionally between 1.5 pu to 3 pu. Duration is yet to be decided
  - Need for appropriate sequence components?
  - High overload can be complimentary during system restoration
- System restart
  - Restart source or support services?
  - Need for energy storage

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