



Sandia
National
Laboratories

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Grid Forming Inverters: Requirements and Practical Applications



PRESENTED BY

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Much of this material is based on work by a National Lab / University team tasked with defining an R&D roadmap for grid forming inverters.

- Yashen Lin, Gabsu Seo, Hugo Villegas – National Renewable Energy Laboratory
- Jack Flicker, Brian Pierre, Ryan Elliott, Javier Hernandez-Alvidrez – Sandia National Laboratories
- Joseph Eto – Lawrence Berkeley National Laboratory
- Brian Johnson – University of Washington - Seattle
- Robert Lasseter – University of Wisconsin - Madison



1. Definition (IMHO), types of grid forming (GFM) controls, and abridged timeline
2. Examples of GFM inverters in the real-world... almost!
3. Thoughts on GFM inverters in large interconnected systems
 - What do we know?
 - What are the challenges?
 - What is the path forward?
4. An opportunity to join the conversation

A Definition (IMHO)



Grid Forming (GFM) refer to a class of controls that give inverters the ability to ...

- (a) synthesize voltage and frequency without an external reference (no PLL),
- (b) share load with other generators without explicit communications,
- (c) behave as a good grid citizen when interacting with other generators (synchronous, inverters, and mix)...
over a range of system sizes up to continental-scale interconnections.

NOTE: Standalone inverters may be grid forming, but not necessarily grid interactive in GFM mode.

Grossly Abridged GFM Controls Timeline



Three broad classes of GFM controls:

1. Droop controls (with virtual inertia for systems with low X/R)
2. Virtual synchronous machines (VSM) controls
3. Virtual oscillator controls (VOC)

Parallel off-grid AC
converters (droop)
Chandokar - 1993

Control of
distributed
resources (droop)
Lasseter, 1998

Virtual synchronous
machines (VSM) or
'synchronverters'
Beck & Hesse, 2007

VSM for PV inverters
and other DER
e.g., Akatrash 2012,
Zhong 2016

Virtual Oscillator
Controls
e.g. Johnson 2017,
Colombino 2017

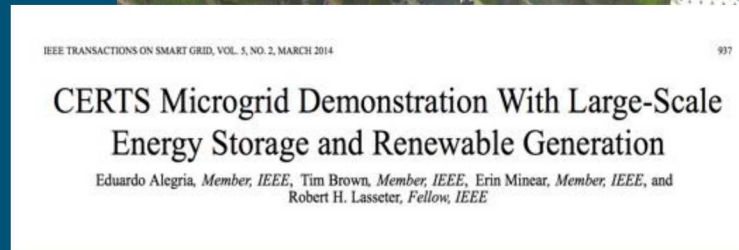
Grid Forming Inverters in the Real World – Santa Rita Jail, Dublin, CA



Demonstration, part of DOE/CERTS program, 2011

Power system stats

- System Stats:
- 5 x 2.3 kW wind turbines
- 1.2 MW PV plant
- 1 MW fuel cell
- 4 MWhr Li-Ion battery with 2 MW GFM inverter
- 1 x 1.2 MW diesel gensets (GFM inverter interface)



Demonstrated:

- Seamless switching between grid and island operation and back (static switch)
- Stability and load sharing without communications
- Plug-and-play sources





Commercial pilot deployment, 2018 -

Power system stats:

- 2.3 MW peak load
- 4.1 MW PV
- 5.8 MWh Li-Ion via 2 x 2.2 MW GFM inverters
- 9 gensets

Demonstrated:

- Diesel-off mode (100% solar + storage)
- Immediate load transfer after generator contingency: simultaneous loss of all gensets at peak load, no load shed
- VRT for various faults and operating modes



Photo: Robert Kenney, 2016

Reference: Experiences with Large Grid Forming Inverters on the island of St Eustatius, Oliver Schömann, SMA Solar Technology, AG



Commercial pilot deployment

Power system stats (combined)

- ~1.1 MW peak load, ~150 kW minimum load
- 900 kW wind generator
- 6 diesel gensets
- Limited refueling options for most of the year
- Planned: Grid bridging system (GBS) consisting of battery and GFM inverter

Goals:

- Carry spinning reserve on GBS
- Diesel-off mode
- Stable, reliable, resilient operation across wide operating range, difficult environment.



GFM Inverters in Large Interconnected Systems

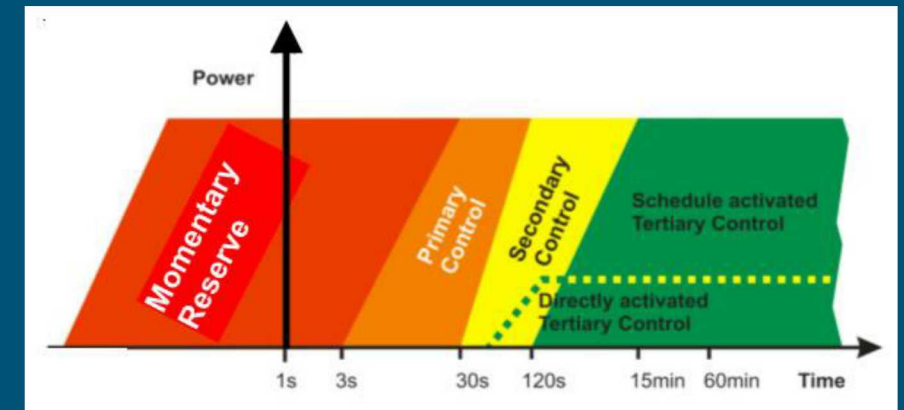
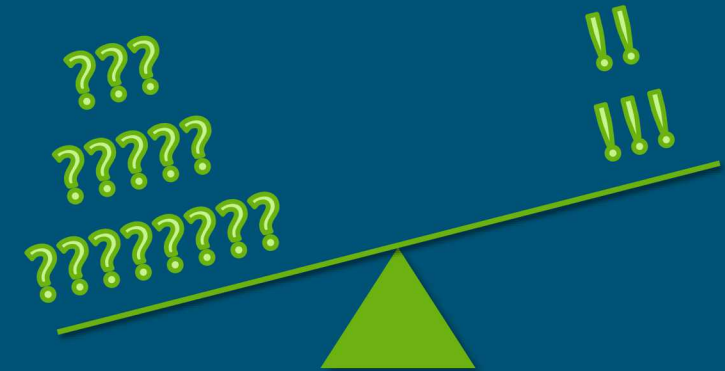


Fundamentally, massive deployment of inverters likely means:

- Lower system inertia
- Lower short circuit power
- Faster voltage and frequency dynamics
- Much more distributed generation
- Complex and emergent behavior

Many questions, few answers ...

- Frequency and voltage control?
- System stability margins?
- Network protection?
- Compatibility with what's there: synchronous machines, grid following inverters, AGC, etc.
- ...
- How do we even study all this?



Reference: Grid Control 2.0 – Control and Stability in Inverter Dominated Power Systems. P. Strauss, 2018

GFM Inverters in Large Interconnected Systems



How to get started, in no particular order:

1. Support technology maturation process

- Microgrids and Islands → Interconnected Systems

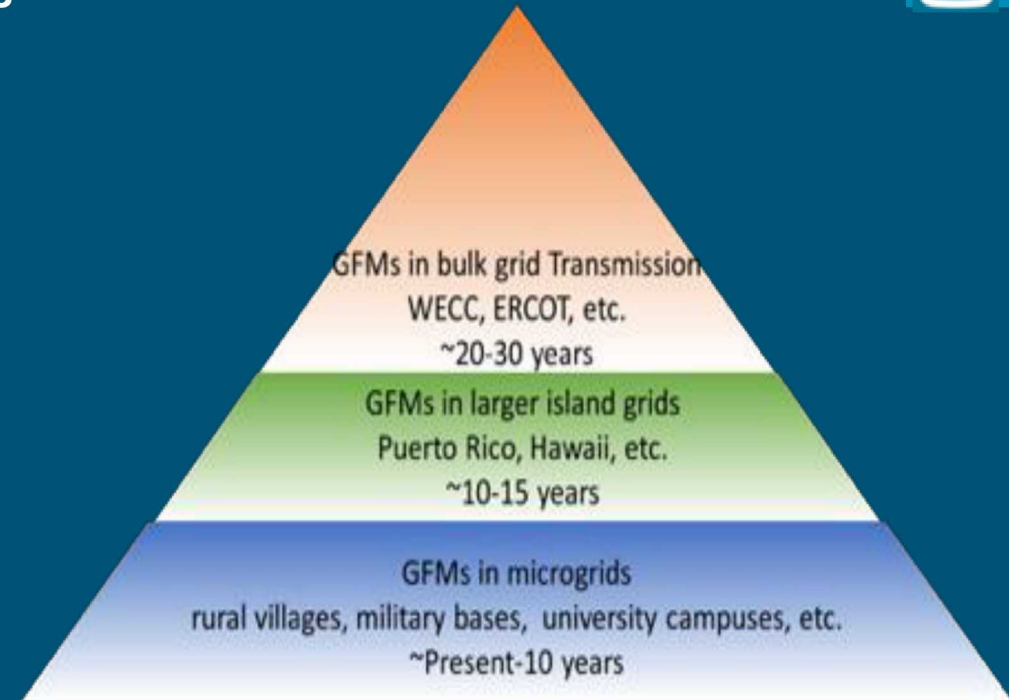
2. Pursue standardization

- Terminology
- Technical requirements
 - Interconnection: (e.g., negative sequence injection? Anti-islanding?)
 - System performance requirements (e.g. stability margins?)
- Interoperability, security

3. Start modeling development and validation

- Device and system models (e.g., reference systems, model aggregation, manufacturer/laboratory/field validation, HIL methods)
- Simulation tools (e.g., numerical integration algorithms for low SCC/inertia systems)

4. Engage!





Workshop on

Grid-Forming Inverters for Low-Inertia Power Systems

April 29 - 30

HUB 250

University of Washington

Invited speakers

Josep Guerrero (Aalborg U)
Mark Ahlstrom (NextEra Energy)
Donny Zimmanck (Enphase)
Thibault Prevost (RTE, France)
Ben Kroposki (NREL)
Aranya Chakraborty (NCSU)
Marcello Colombino (NREL)
Scott Manson (SEL)
Wei Du (PNNL)

Duncan Callaway (UC Berkeley)
Francesco Bullo (UCSB)
David Porter (S&C Electric)
Deepak Ramasubramanian (EPRI)
Greg Kern (Outback Power Systems)
Guohui Yuan (DOE)

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More information on the event:
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