Grid Forming Inverters:

Requirements and Practical Applications

PRESENTED BY

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Outline

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. Q&A

A Definition (IMHO)

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

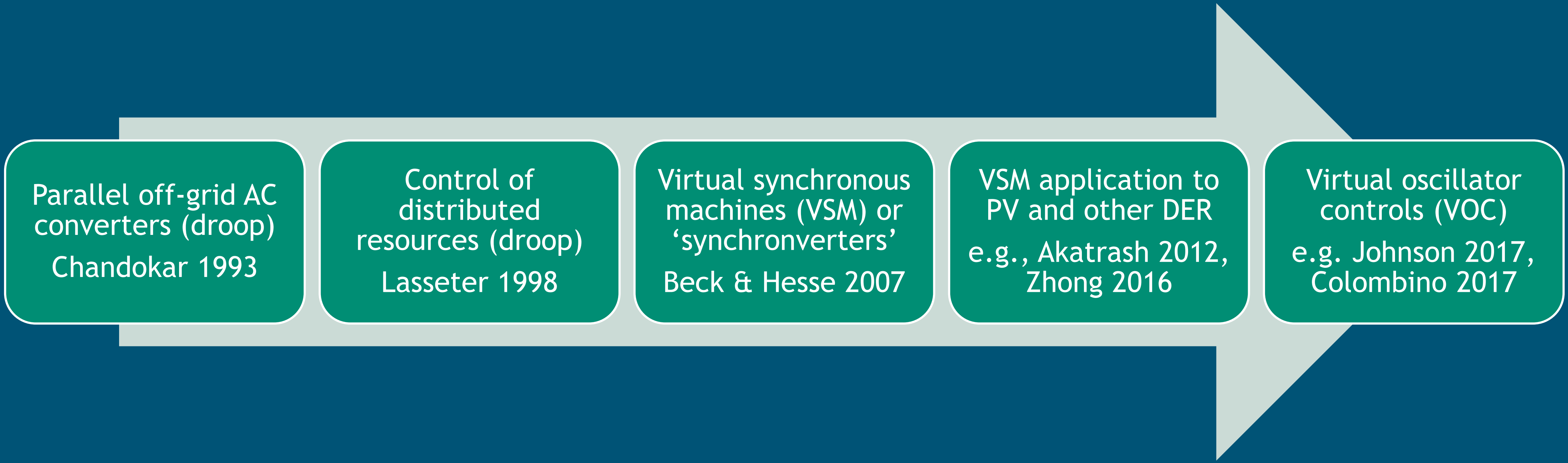
(a) synthesize voltage and frequency without an external reference (no PLL),
(b) share load with other generators without explicit communications,
(c) behave as a good grid citizen when interacting with other generators (synchronous, inverters, and mix)… over a range of system sizes up to continental-scale 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 application to PV and other DER
e.g., Akatrash 2012, Zhong 2016

Virtual oscillator controls (VOC)
e.g. Johnson 2017, Colombino 2017

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

Demonstration, part of DOE/CERTS program, 2010

Power system stats

- 3.0 MW peak load
- 5 x 2.3 kW WTG, 1.2 MW PV, 1 MW fuel cell
- 4 MWh Li-Ion battery with 2.5 MVA GFM PCS
- 2 x 1.2 MW diesel gensets with CERTS droop controls

Demonstrated:

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

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CERTS Microgrid Demonstration With Large-Scale Energy Storage and Renewable Generation

Eduardo Alegria, *Member, IEEE*, Tim Brown, *Member, IEEE*, Erin Minear, *Member, IEEE*, and Robert H. Lasseter, *Fellow, IEEE*

BERKELEY LAB Lawrence Berkeley National Laboratory

Sandia National Laboratories

OAK RIDGE National Laboratory

Pacific Northwest NATIONAL LABORATORY

Electric Power Group

PSERC

Grid Forming Inverters in the Real World – Sint Eustatius, NLD

Commercial pilot deployment, 2018 -

Power system stats:

- 2.3 MW peak load
- 4.1 MW PV
- 5.8 MWh Li-Ion with 2 x 2.2 MW GFM PCS
- 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

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

Photo: Robert Kennesy, 2016

Grid Forming Inverters in the Real World St. Mary’s & Mtn. Village, AK

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

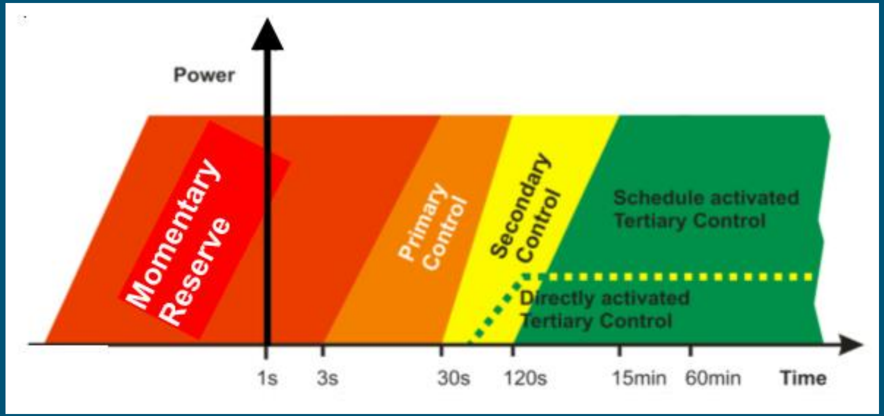
Goals:

- 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. Technology maturation process

- Microgrids and Islands → Interconnected Systems

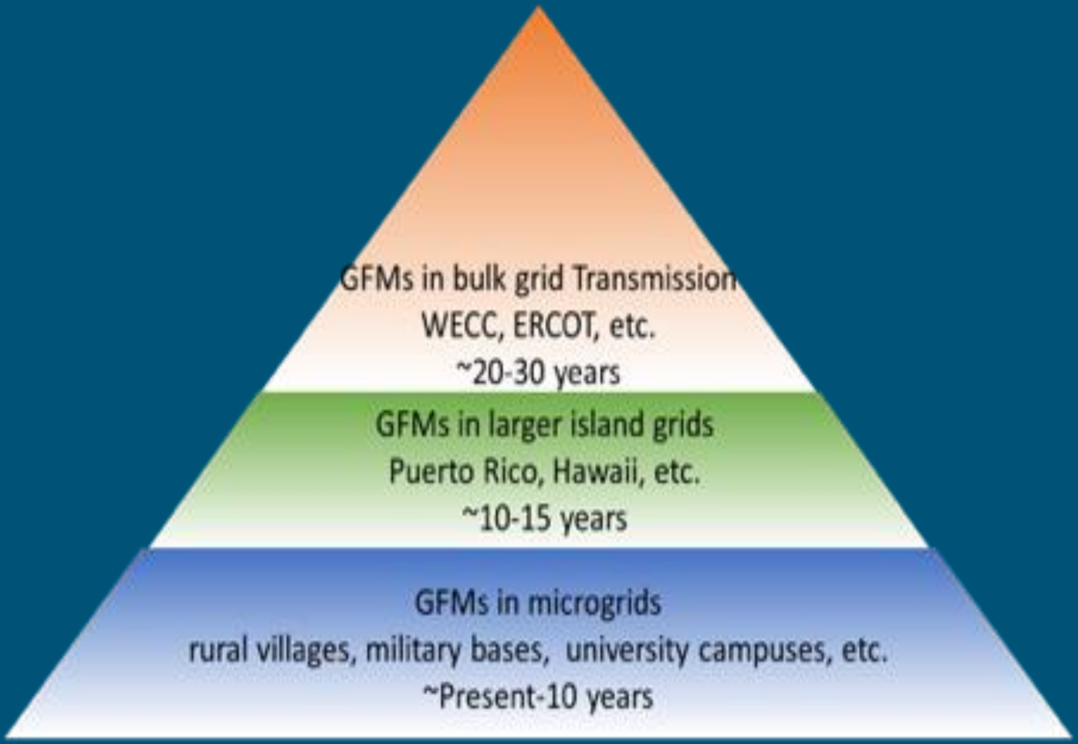
2. Pursue Standardization

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

3. 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!



Speaking of engagement…

ELECTRICAL & COMPUTER ENGINEERING
CLEAN ENERG INSTITUTE

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 Chakrabortty (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)

Organized by

- Brian Johnson (U Washington)
- Yashen Lin (NREL)
- Joe Eto (LBNL)
- Bob Lasseter (U Wisconsin)
- Abraham Ellis (Sandia)
- Daniel Kirschen (U Washington)

More information on the event:
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