Self-organizing Microgrids
Virtual Oscillator Control for Voltage Source Inverters

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collaborators
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His research interests include modeling, analysis, and control of power electronics and power systems with a focus on renewable integration.
Challenges:

- Low-inertia
- Minimize communication
- Plug and play
- Intermittency
- Reliability
Capacity of 2012 PV increased by 80% to 3.3 GW

Annual capacity growth rate > 40% for 6 years
Droop Control
- Inverter mimics synchronous machine
- Duplicating bulk power system

Limitations
- Sinusoidal steady-state assumption
- Slow dynamics
- Sensitivity to parameters
- Load-dependent frequency
- Rigid hierarchical control
Synchronization in nature

- Single agent
- Group behavior
Outline

- Controller for single inverter
- Conditions for synchronization
- Single-phase laboratory-scale prototype
- Three-phase microgrid controllers with high PV penetration
- Vision and future work
Nonlinear Oscillator

- Control each inverter to emulate a nonlinear oscillator
- Sinusoidal output voltage at resonant frequency of $\omega_{osc}$
- Nonlinear current source $g(v)$ with gain given by $\sigma = |g'(v)|$

VOC subsumes Droop

VOC stabilizes arbitrary waveforms to sinusoidal steady state

Droop control only acts on sinusoidal steady state
Synchronization

- Robust
- Resilient
- Modular

Resistive Load

Startup

[Diagram of a resistive load system with voltage sources and current measurements]
Resistive Load

Inverter removal

Inverter addition
Resistive Load

Load step down

Load step up
Resistive Load

2:2:1 Load sharing inverter addition

2:2:1 Load sharing inverter removal
Rectifier Load

Startup

Diagram:
Rectifier Load

Inverter addition

Inverter removal
Three-phase controller

45 kW Microgrid

Inverter 1

Inverter 2

Inverter 3
Varying Irradiance

\[ G = 1 \frac{kW}{m^2} \quad G = 0.5 \frac{kW}{m^2} \quad G = 1 \frac{kW}{m^2} \]
Varying Load

\[ \Delta P_{\text{load}} = -5 \text{ kW} \quad \Delta P_{\text{load}} = +5 \text{ kW} \]
Summary

- New paradigm for inverter control
  - Synchronization of coupled nonlinear oscillators
  - Leverage advances in nonlinear systems theory

- Ensuing **Self-organizing Microgrid**
  - **Robust:** load independent
  - **Resilient:** no communication
  - **Modular:** seamlessly connect/disconnect
Questions?

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