OAK RIDGE National Laboratory

Grid-Forming Inverters

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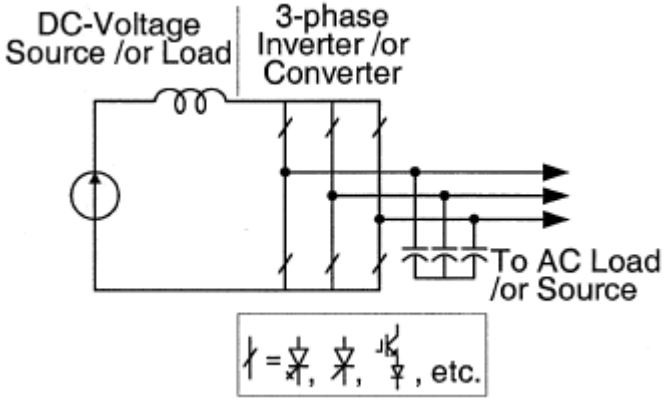
U.S. DEPARTMENT OF ENERGY

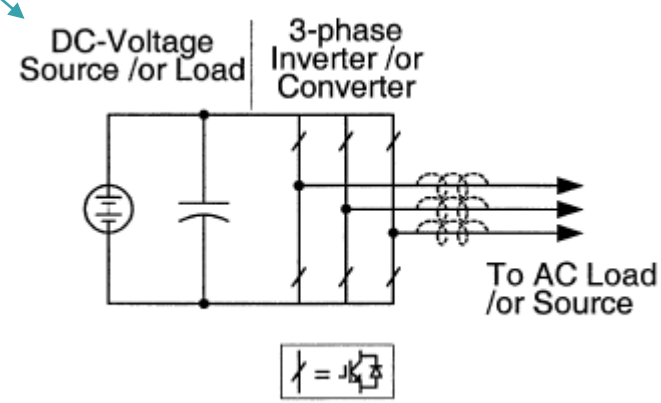
Definition of Grid-Forming Inverter

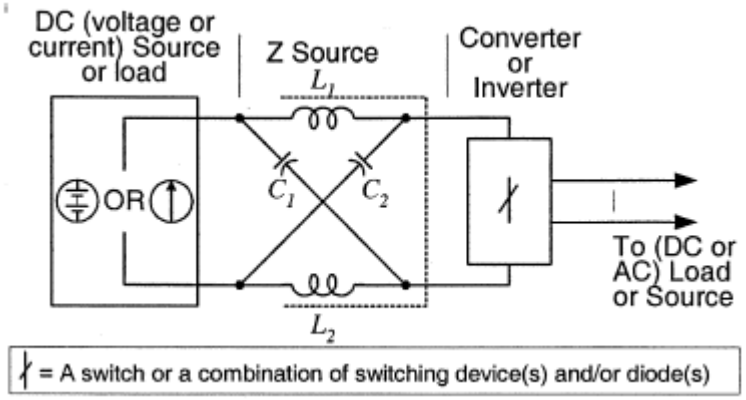
- Grid-forming inverters are essentially the inverters that can establish grid voltage magnitude and frequency, be operated in standalone or island mode, or in applications such as in a microgrid, where one or more inverters are required to form/create the microgrid voltage and frequency.
- Created to be distinguished from conventional solar PV inverters, which are grid-tied or grid-connected inverters.
- Other names – microgrid-ready inverters, smart inverters, multi-functional inverters, etc.
- The fundamental is this type of inverters regulates its ac output voltage, instead of ac currents.

Inverter Classification from Input Side

- Current-source inverter
- Voltage-source inverter
- Z-source inverter







Fang Zheng Peng, "Z-source inverter," in *IEEE Transactions on Industry Applications*, vol. 39, no. 2, pp. 504-510, March-April 2003.

Inverter Classification from Output Side

- Grid-forming inverter
  - Like a synchronous generator, but without inertia!
- Grid-feeding, grid–following, or grid-tied inverter
  - Like a current source.
- Grid-supporting inverter
  - Current-source based, also called grid-supporting grid-feeding (GSGFd) inverter
  - Voltage-source based, also called grid-supporting grid-forming (GSGFm) inverter

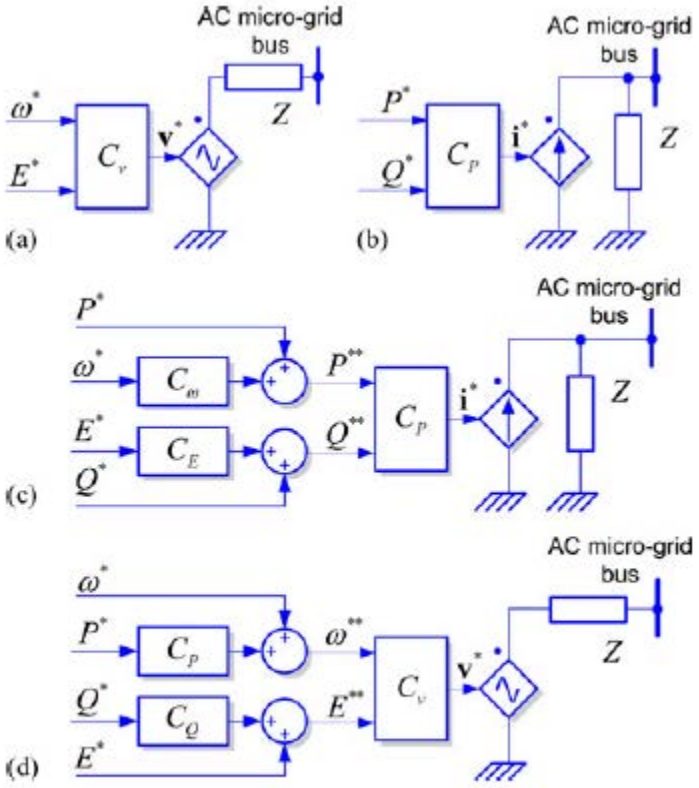
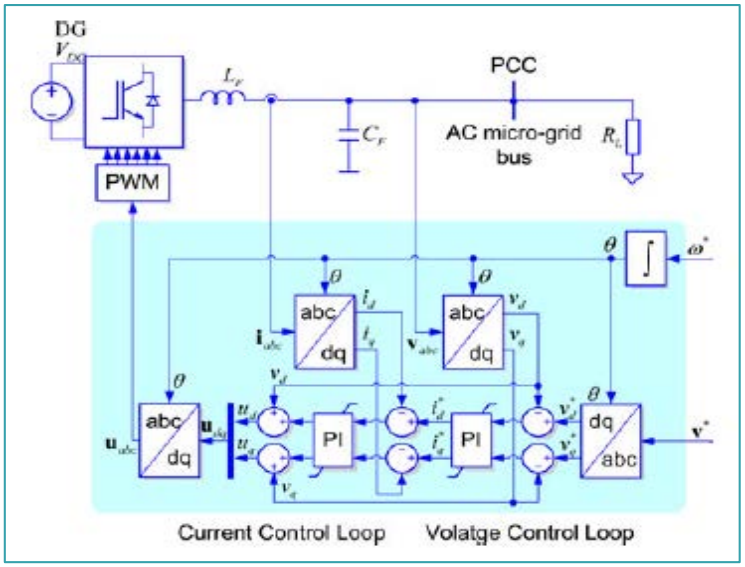


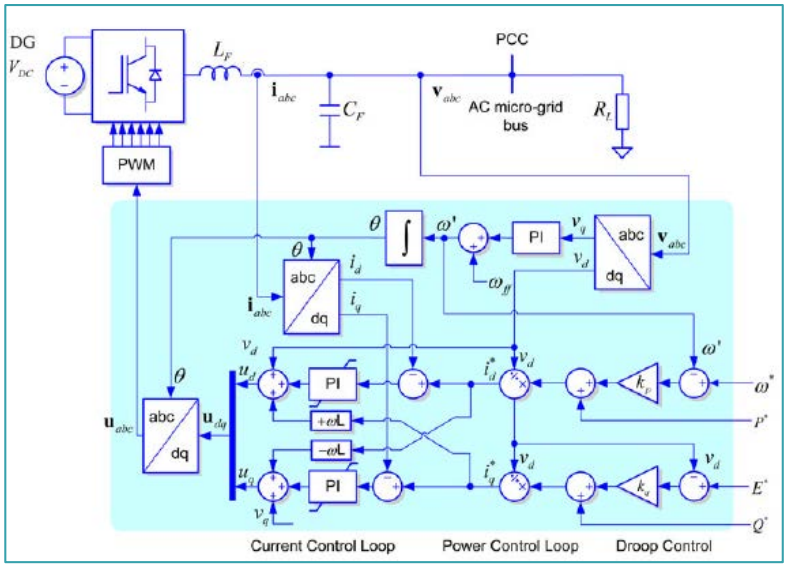
Fig. 1. Simplified representation of grid-connected power converters. (a) grid-forming, (b) grid-feeding, (c) current-source-based grid-supporting, and (d) voltage-source-based grid-supporting.

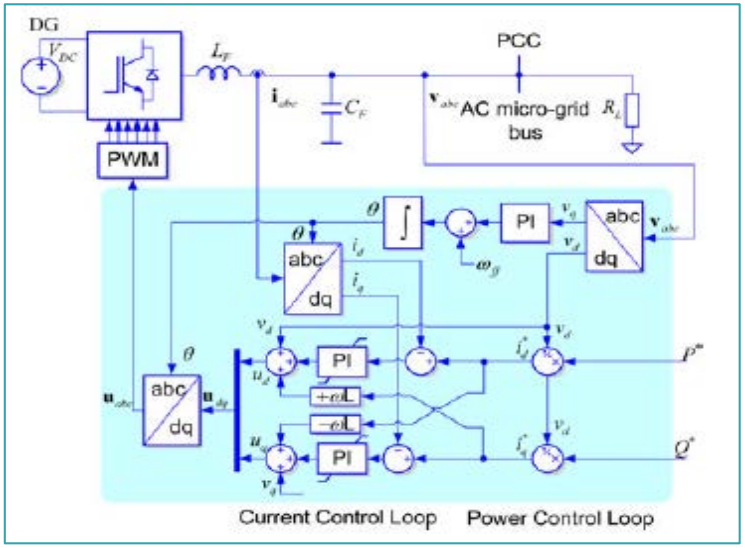
[1] J. Rocabert, A. Luna, F. Blaabjerg and P. Rodríguez, "Control of Power Converters in AC Microgrids," in *IEEE Transactions on Power Electronics*, vol. 27, no. 11, pp. 4734-4749, Nov. 2012.

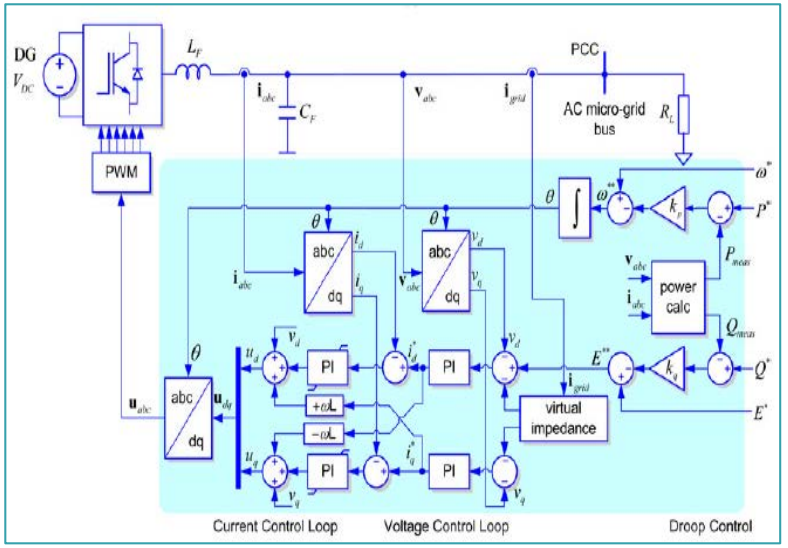
[2] A. D. Paquette, M. J. Reno, R. G. Harley and D. M. Divan, "Sharing Transient Loads : Causes of Unequal Transient Load Sharing in Islanded Microgrid Operation," in *IEEE Industry Applications Magazine*, vol. 20, no. 2, pp. 23-34, March-April 2014.

Detailed but Basic Control Block Diagrams









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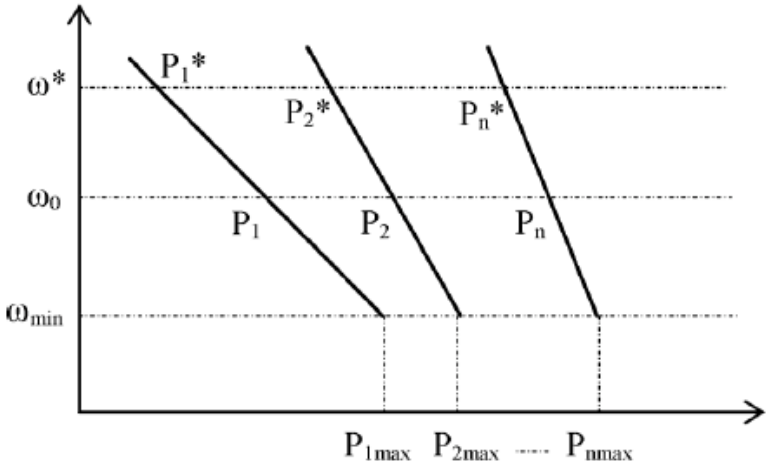
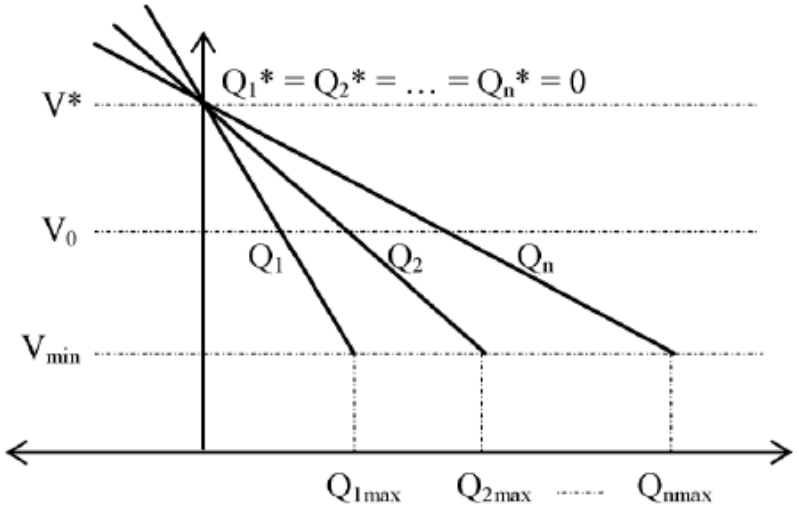
Power Sharing by Droop Method

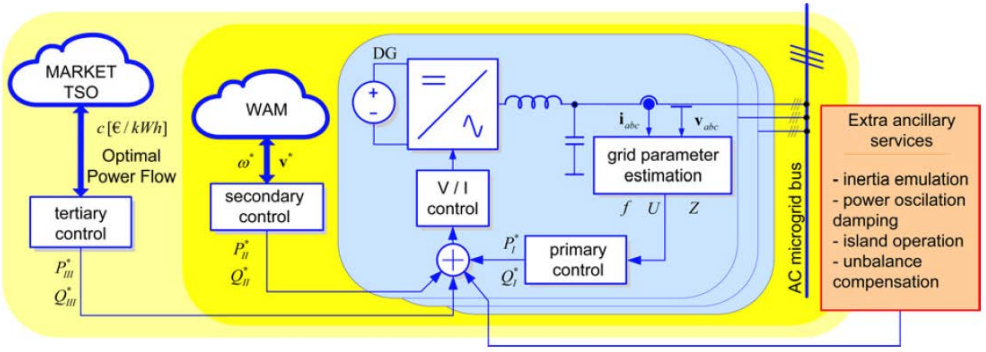
- In a microgrid, there will likely be multiple inverters or converters.
- Load power sharing is necessary, based on converter ratings.
- This is (typically) achieved by the droop method, emulating sync. gen.
- Droop methods inherently cause voltage and frequency deviations.





So, Need Secondary Control

- Secondary control corrects voltage and frequency deviations
  - Centralized
  - Decentralized



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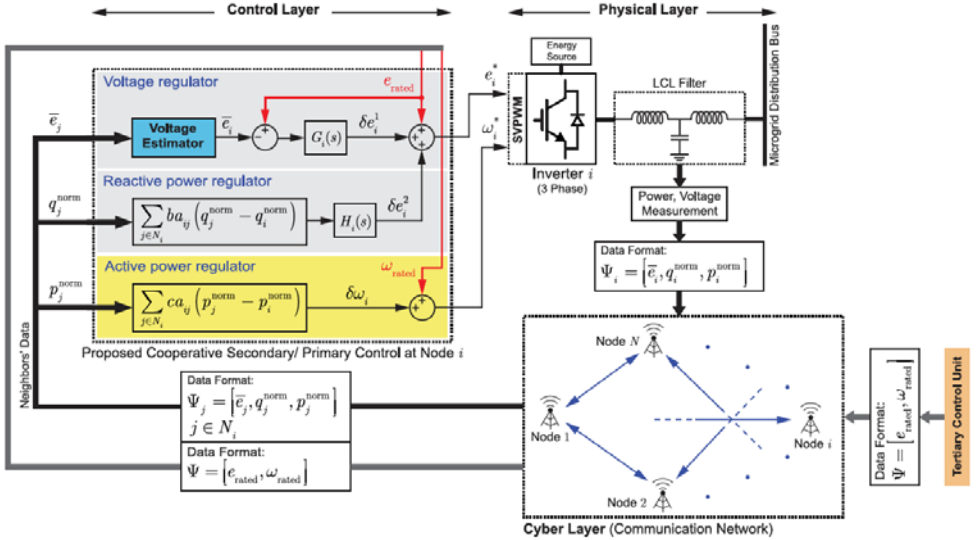


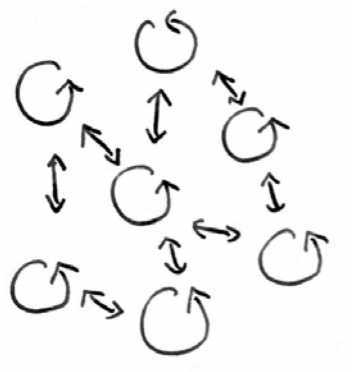
V. Nasirian, Q. Shafiee, J. M. Guerrero, F. L. Lewis and A. Davoudi, "Droop-Free Distributed Control for AC Microgrids," in *IEEE Transactions on Power Electronics*, vol. 31, no. 2, pp. 1600-1617, Feb. 2016.

Various Concepts of Grid-Forming Inverters

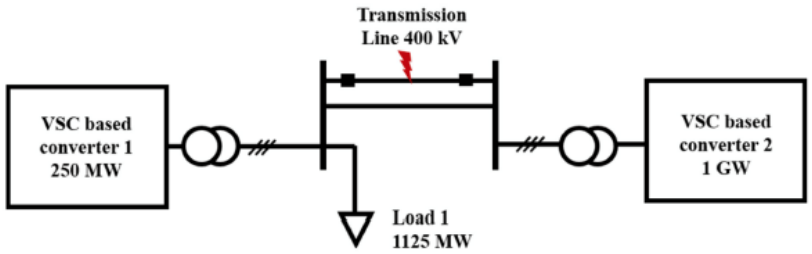
- Virtual synchronous machine/generator (VISMA/VSG)
- Synchronverters
- Static synchronous generator (SSG)
- Virtual inertia with ROCOF control
- Partial grid-forming inverter
  - Frequency-forming only
  - Voltage-forming only

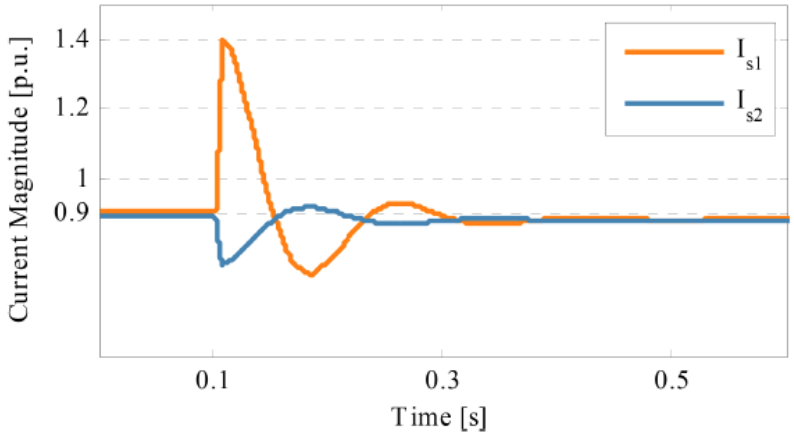
Research Trends on Grid-Forming Inverters

- Parallel operation of multiple GFIs
- Synchronization
- Transient current sharing and limiting solutions
- Overloading capability



A problem of coupled oscillator network





G. Denis, T. Prevost, M. Debry, F. Xavier, X. Guillaud and A. Menze, "The Migrate project: the challenges of operating a transmission grid with only inverter-based generation. A grid-forming control improvement with transient current-limiting control," in *IET Renewable Power Generation*, vol. 12, no. 5, pp. 523-529, 9 4 2018.