Real and Reactive Power Sharing

Shipboard Power System Fundamentals

Revision of 3 February 2026

Dr. Norbert Doerry

Essential Questions

How are real and reactive power shared among generators?	Understand
How are real and reactive power shared among power electronic sources?	Understand
How are real and reactive power shared among combined generator and power electronic source systems?	Understand
How is the operating point calculated for multiple sources operating using droop?	Apply

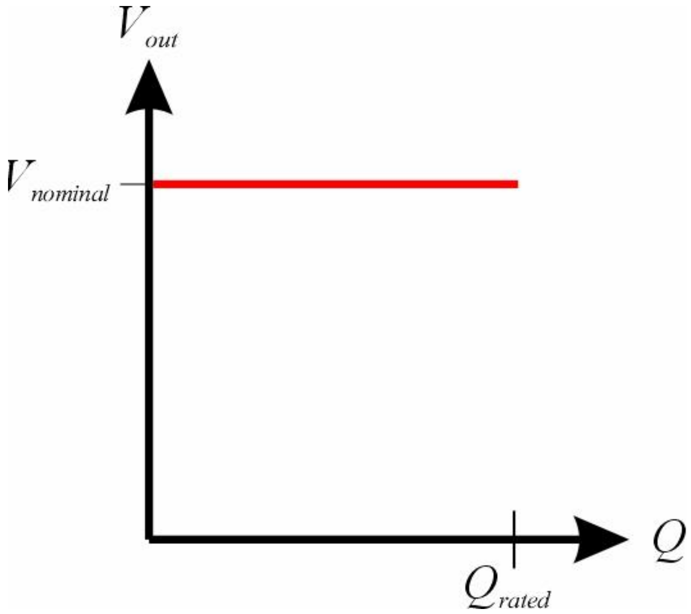
Conditions when two ac power sources operate in parallel

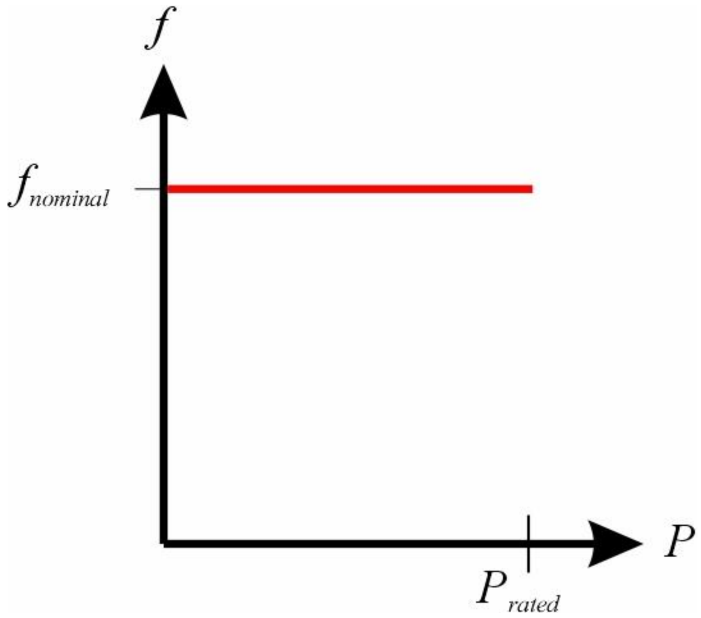
- Voltage magnitudes are equal …
  - If voltage drops in the interconnecting cable are negligible.
  - (Also true for two dc power sources)
- Voltage frequencies are equal.
- Voltage phase angles are equal …
  - If voltage drops in the interconnecting cable are negligible.
- No automatic sharing of real and reactive power.
  - Must be implemented via a control mechanism.
  - (also true of two dc power sources for sharing real power)

Power control modes for individual sources

- Swing source characteristic
  - Regulates voltage / frequency by providing whatever power (reactive or real) necessary to achieve set points.
- Operator or control system input
  - Constant power sources.
  - Sources that provide power independent of load.
- Droop characteristic
  - Voltage / frequency decreases as reactive / real power increases.
- Cross-current compensation signals
  - Analog signals among paralleled sources that modify the voltage / speed reference of controllers.
- Exchange of control signals among paralleled sources
  - Typically, digital signals that enable sharing.

Swing Source





Acts as a grid forming source (establishes voltage and frequency)

A set of paralleled sources should at most have one swing source

The shore power connection typically acts as a swing source

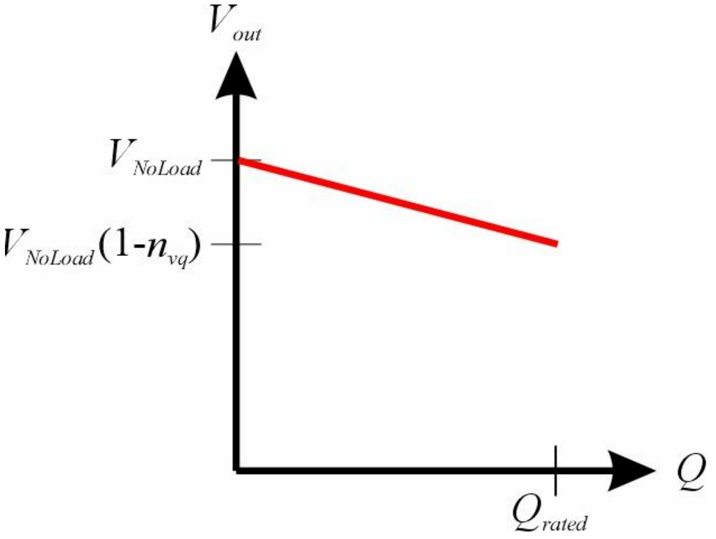
Operator or control system input

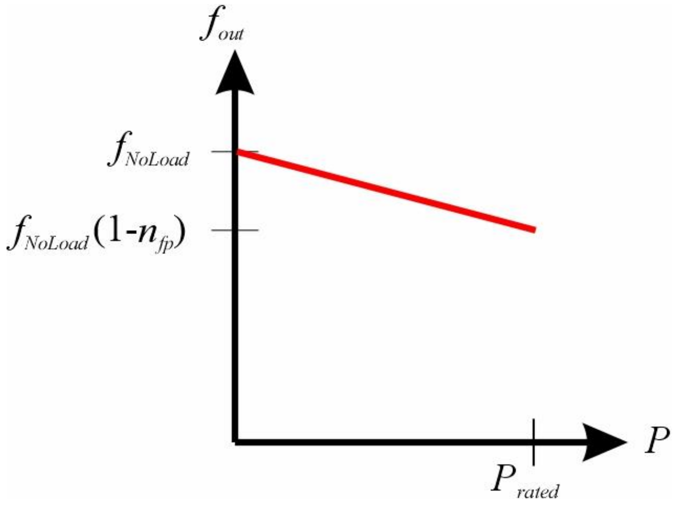
- Constant power source
  - Operator or control system specifies the amount of real or reactive power to provide.
  - May be employed by power system to minimize overall fuel consumption.
- Grid following converters
  - Controlled current sources.
    - Cannot regulate a voltage magnitude or frequency
  - Amount of power provided is determined by the operator, power management system, or by the converter itself.
  - Examples …
    - Waste heat recovery systems
    - Photovoltaic systems
    - Regenerative braking converters (in lieu of dynamic braking resistors)
  - Requires at least one paralleled grid-forming source to establish voltage magnitude and frequency.

Acts as a grid forming source

Droop characteristic

- AC systems
  - The reactive power provided is a linear function of voltage.
  - The real power provided is a linear function of frequency.
- DC systems
  - The real power provided is a linear function of voltage.
- Multiple paralleled droop sources
  - The voltage (frequency) is determined by the combined droop characteristic of all paralleled sources.
- Paralleled with a swing source
  - The real (reactive) power provided depends on the voltage or frequency set point established by the swing source.





Combined Droop Characteristic (ac)

Droop equations for a single droop source

$$V_{out\_i} = V_{NoLoad\_i} - n_{vq\_i}\left(\frac{Q_i}{Q_{rated\_i}}\right)V_{NoLoad\_i}$$

$$f_i = f_{NoLoad\_i} - n_{fp\_i}\left(\frac{P_i}{P_{rated\_i}}\right)f_{NoLoad\_i}$$

Droop equations for m paralleled droop sources

$$V = \frac{\sum_i^m\left(\frac{Q_{rated\_i}}{n_{vq\_i}}\right)}{\sum_i^m\left(\frac{1}{V_{NoLoad\_i}}\right)\left(\frac{Q_{rated\_i}}{n_{vq\_i}}\right)} - \frac{Q}{\sum_i^m\left(\frac{1}{V_{NoLoad\_i}}\right)\left(\frac{Q_{rated\_i}}{n_{vq\_i}}\right)}$$

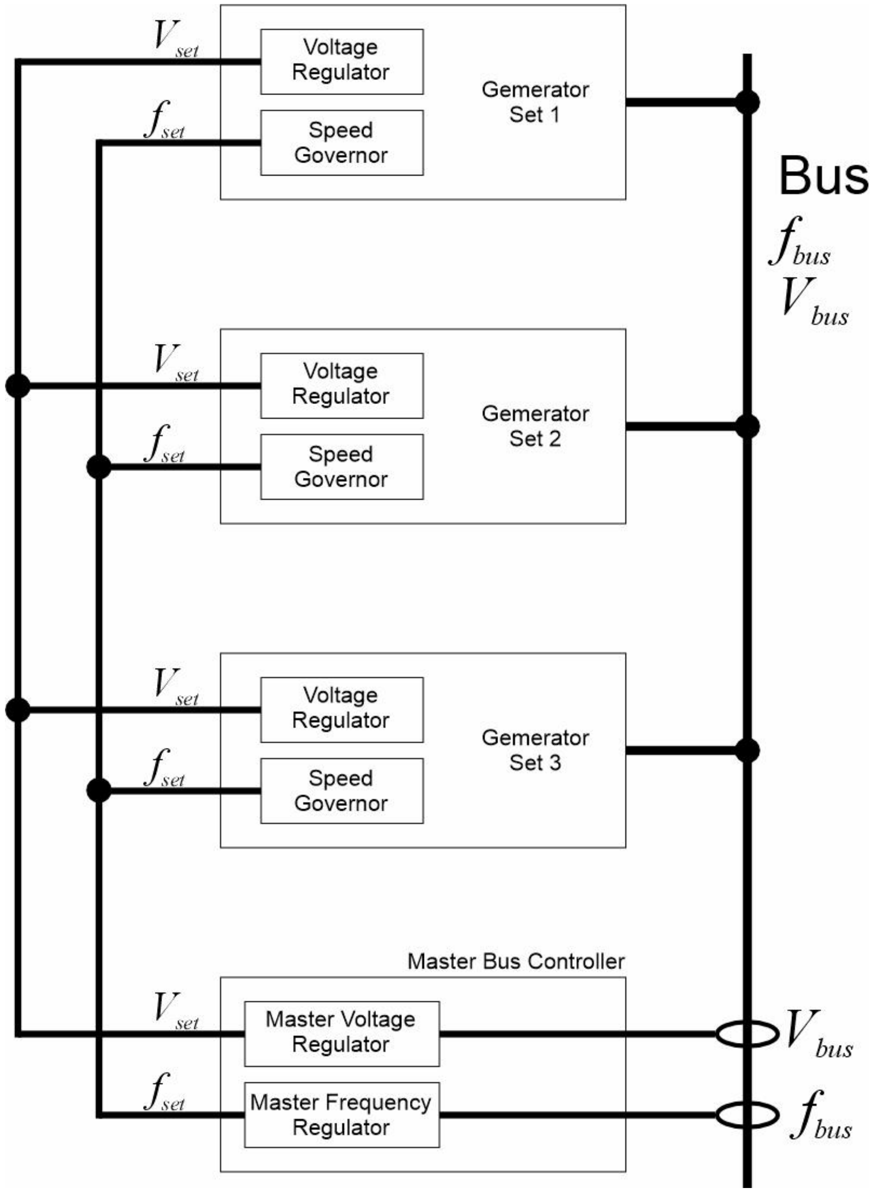
$$f = \frac{\sum_i^m\left(\frac{P_{rated\_i}}{n_{fp\_i}}\right)}{\sum_i^m\left(\frac{1}{f_{NoLoad\_i}}\right)\left(\frac{P_{rated\_i}}{n_{fp\_i}}\right)} - \frac{P}{\sum_i^m\left(\frac{1}{f_{NoLoad\_i}}\right)\left(\frac{P_{rated\_i}}{n_{fp\_i}}\right)}$$

The voltage and frequency equations for a paralleled set of droop sources also have droop characteristics.

Power electronic inverters may implement droop through a virtual synchronous generator (VSG) by emulating a physical synchronous generator in controls.

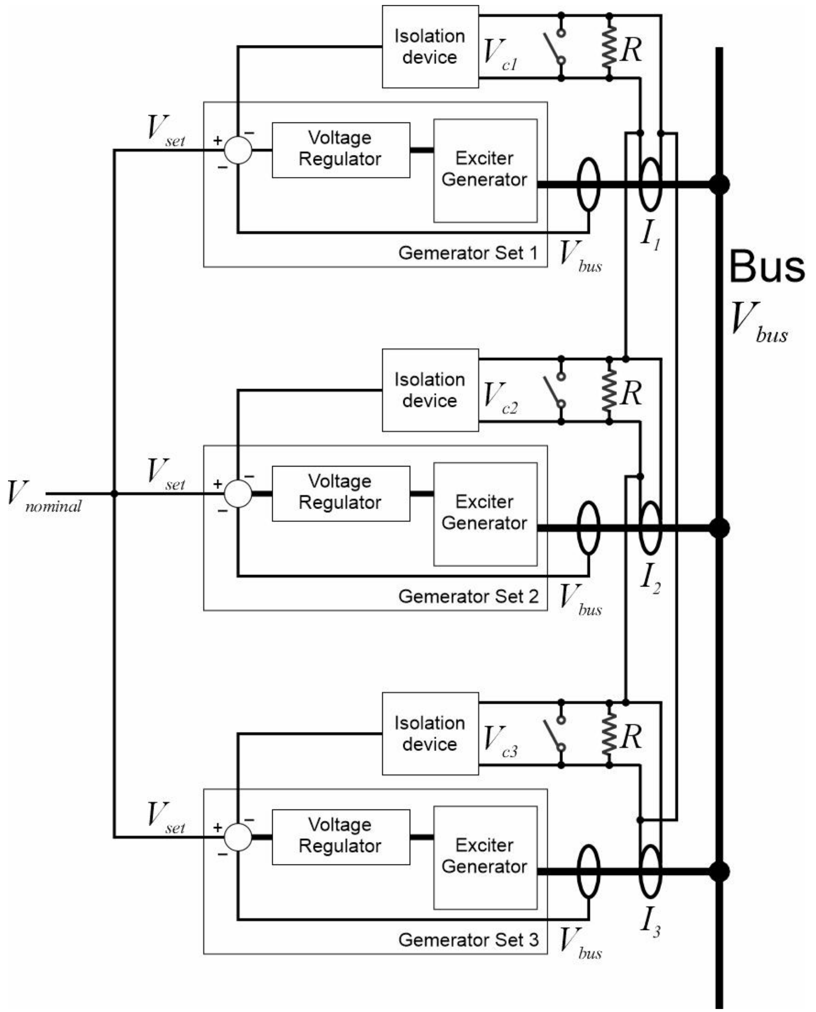
Master voltage (frequency) control for paralleled droop sources

- A linear droop controller is specified by a no load value and the slope of the droop characteristic.
- A master controller can adjust the no load value of all the paralleled droop sources so that the resulting bus voltage (frequency) is at its nominal value.



Cross Current Compensation

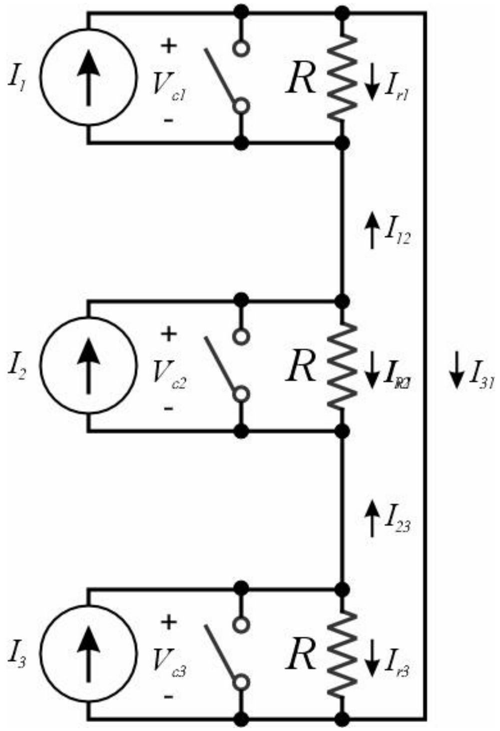
- Allows sharing reactive power while still regulating the voltage to its nominal value.
- Each source has …
  - Current transformer
  - Burden Resistor
  - Switch (closed when source is not online)
- Voltage across the burden resistor is used as feedback to regulator.
  - When all currents are equal, voltage is zero.



$$V_{c1} = \frac{R}{3}(2I_1 - I_2 - I_3)$$

$$V_{c2} = \frac{R}{3}(-I_1 + 2I_2 - I_3)$$

$$V_{c3} = \frac{R}{3}(-I_1 - I_2 + 2I_3)$$



Exchange of control signals among paralleled sources

- Digital controls enable exchange of data at high speeds.
- Individual sources may be grid forming or grid following.
- Standard protocols to enable digital control signal exchange among sources have not been established.
  - Proprietary protocols do exist, but currently cannot guarantee interoperability among sources from different manufacturers.
- Lack of standard protocols complicates modeling and simulation.
- Control signals may use a separate subnetwork.
  - Controller Area Network (CAN).
  - Power line communication (PLC).

Typical implementations

- Generator sets only
  - Voltage regulation using droop or cross-current compensation.
  - Frequency regulation using droop with possible master frequency regulator.
- Power electronic sources
  - May use droop or exchange control information.
  - AC sources may use the VSG concept to implement droop.
- Combined generator sets and power electronic sources
  - May use droop or exchange control information.
  - AC power electron ic sources may use the VSG concept to implement droop.