UNIVERSITY OF MINNESOTA

Nonlinear Oscillators & Low-inertia Power Systems

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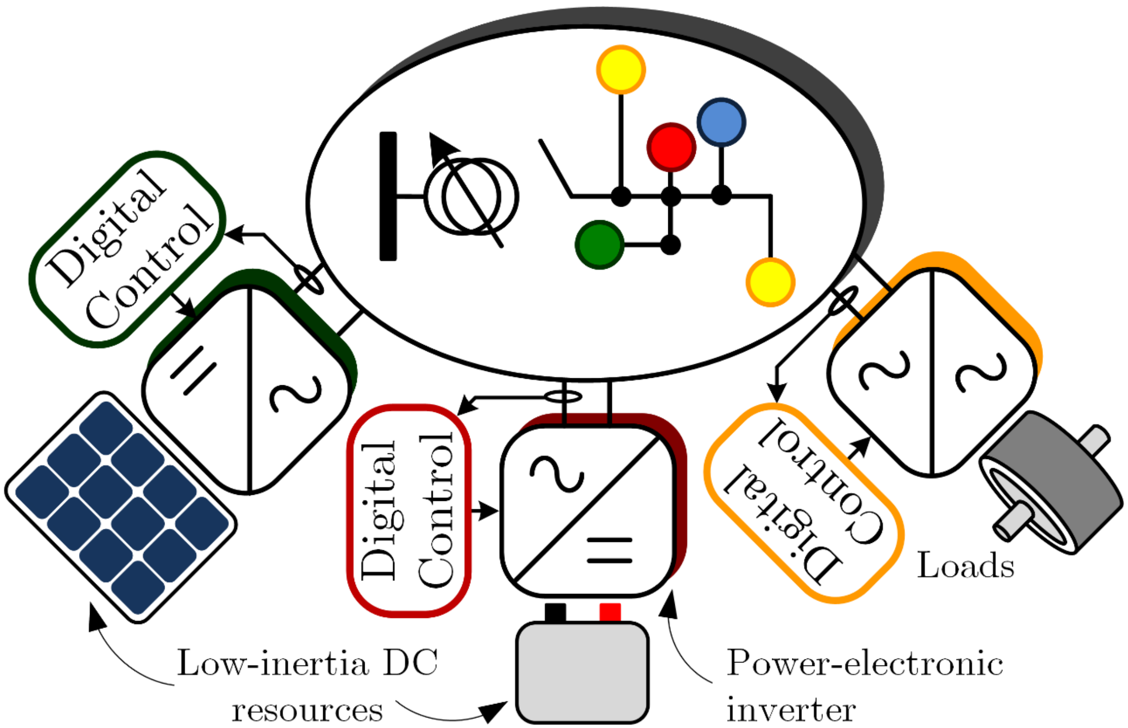
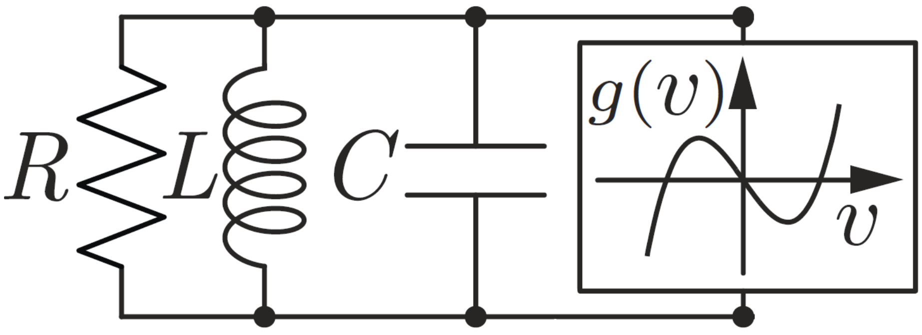
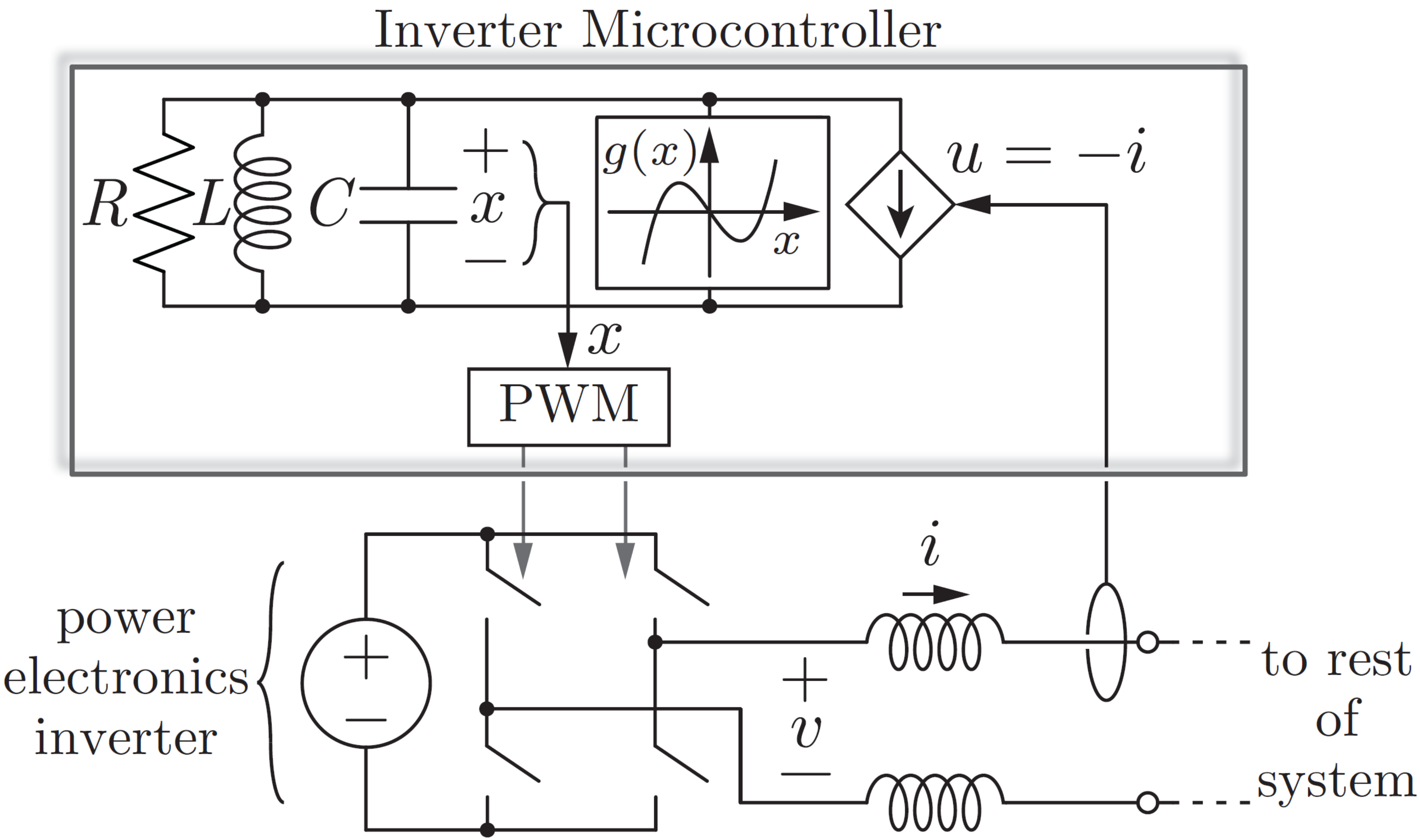
Low-inertia Power System



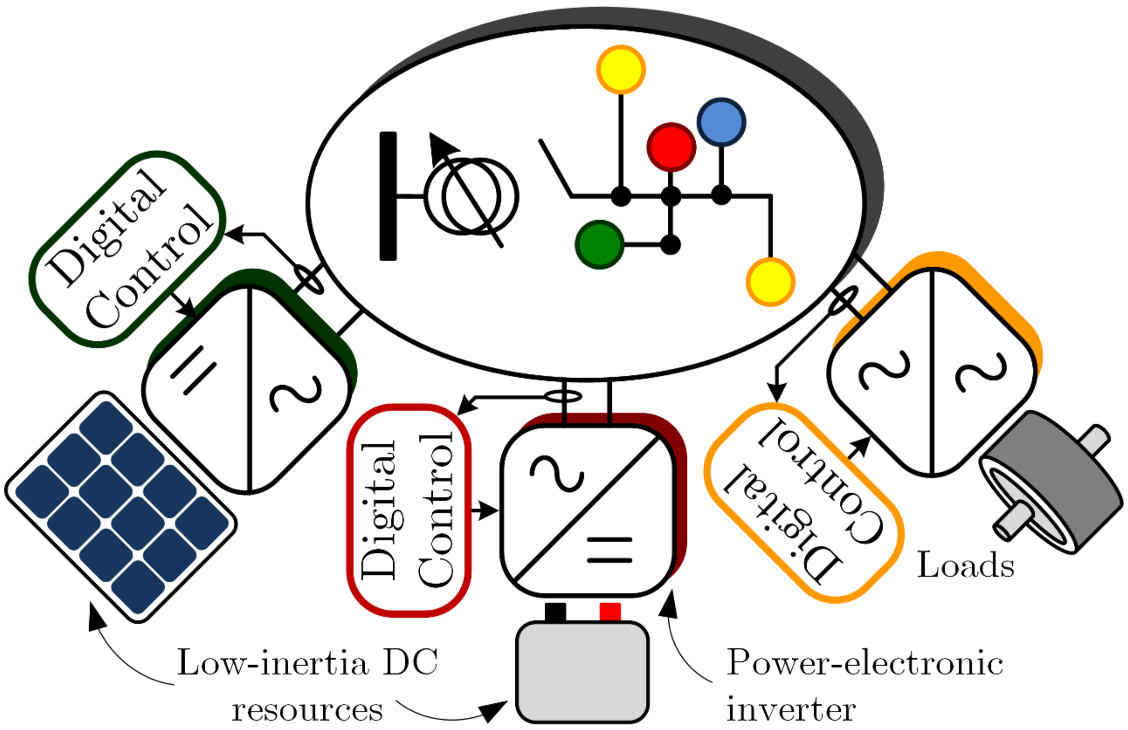
Nonlinear Oscillator

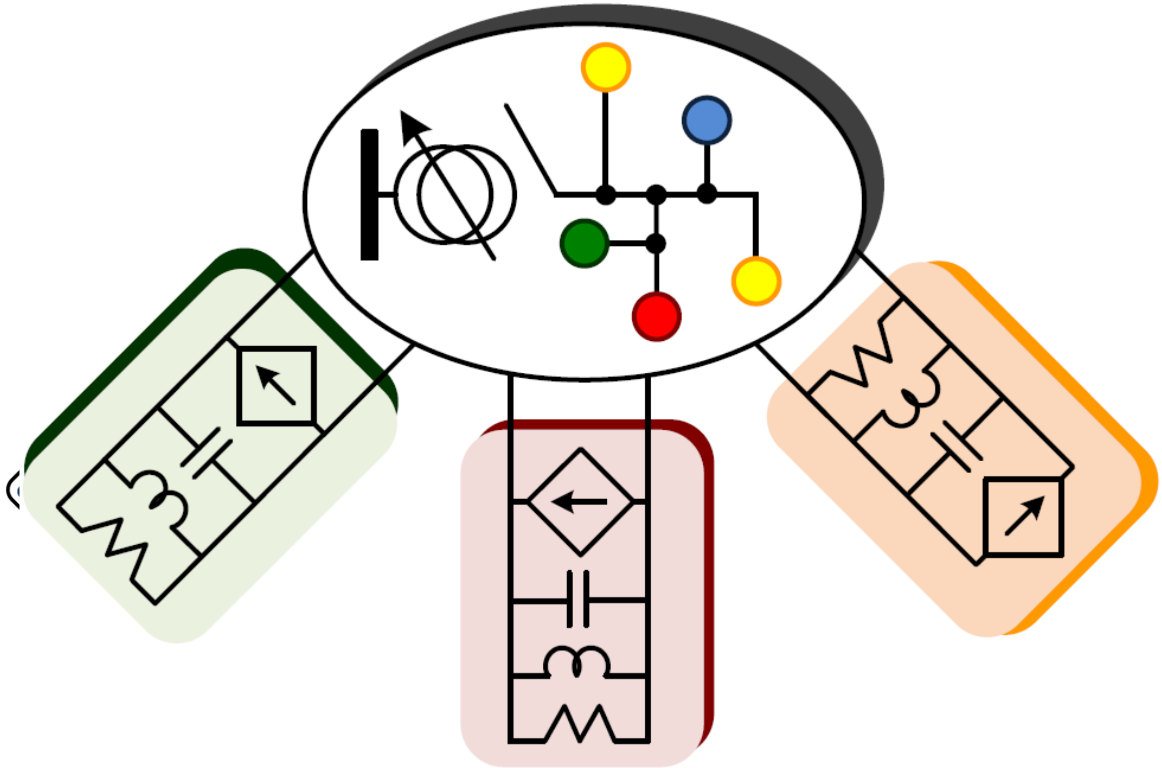


Connecting the two



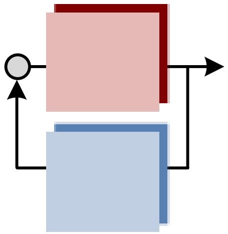
VOC- Virtual Oscillator Control

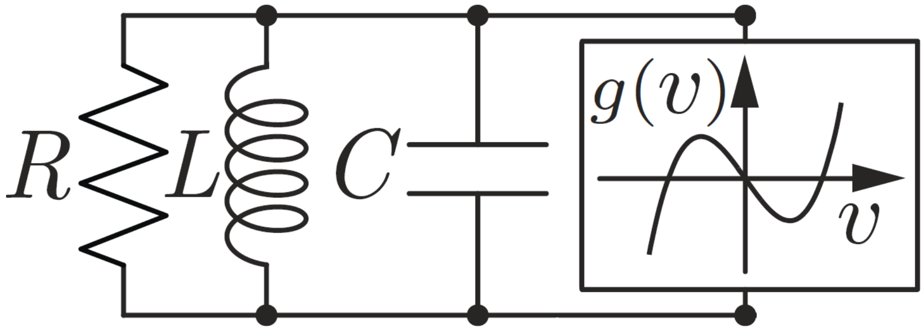

Digital Control
Digital Control
Digital Control
Loads
Low-inertia DC resources
Power-electronic inverter



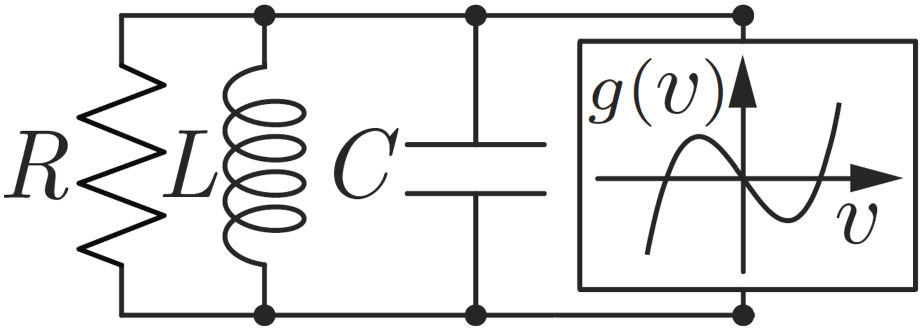
State of the Art

- Droop Control
- Inverters mimic synchronous machines
- Main disadvantages:
  - Slow dynamics (aggressive filtering)
  - Rigid hierarchical control (inner and outer control loops)





- Time-domain control
- System-wide synchrony
- Backward compatibility



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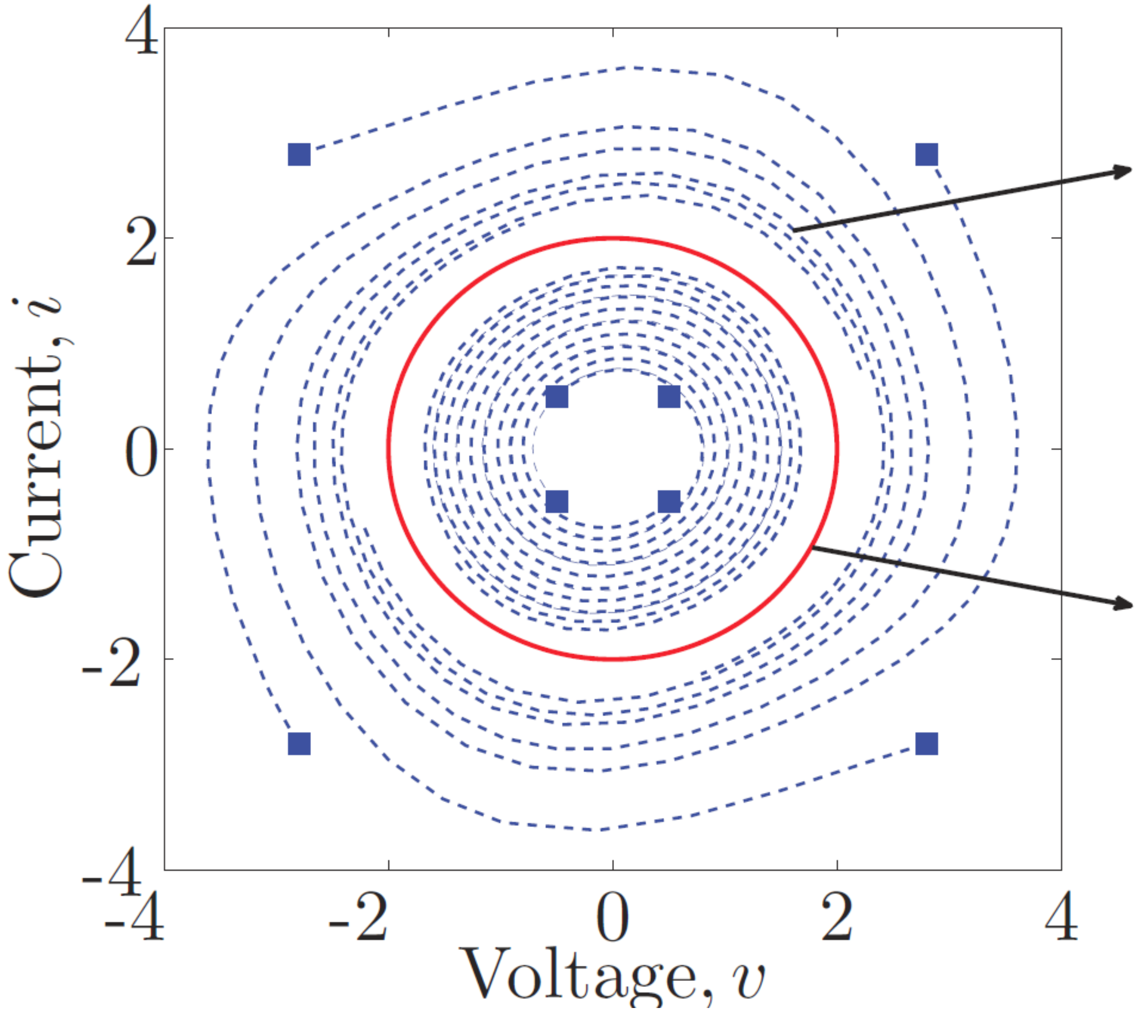
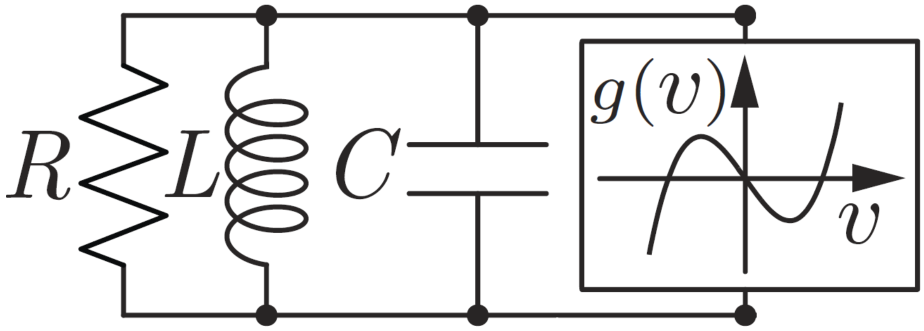
Time-domain Control



VOC stabilizes arbitrary waveforms to sinusoidal steady state

Droop control only acts on sinusoidal steady state



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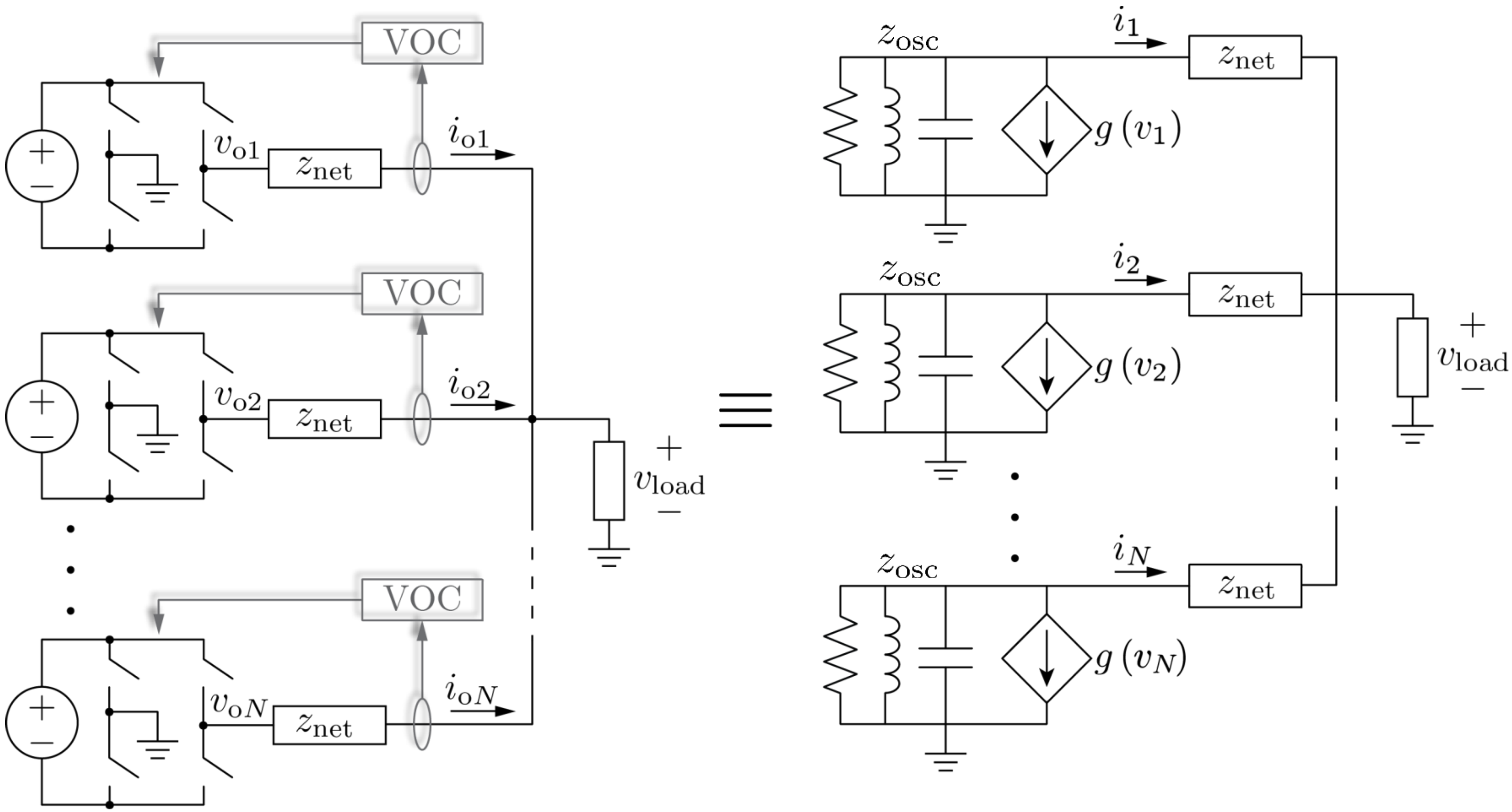
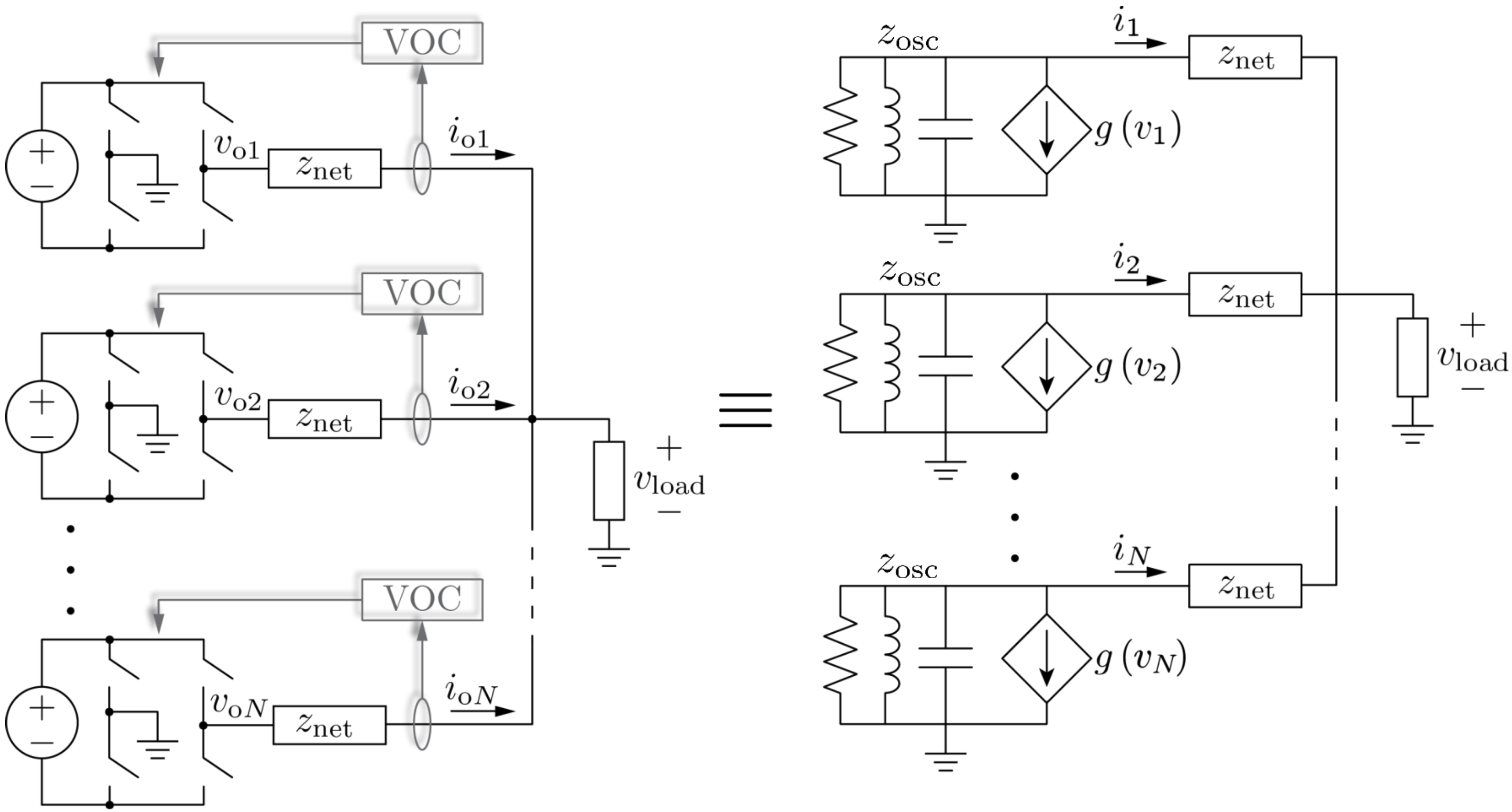
System-wide Synchrony



Condition for global asymptotic synchronization

$$\sup_{\omega \in \mathbb{R}} \left\| \frac{z_{\mathrm{net}}(\mathrm{j}\omega) z_{\mathrm{osc}}(\mathrm{j}\omega)}{z_{\mathrm{net}}(\mathrm{j}\omega) + z_{\mathrm{osc}}(\mathrm{j}\omega)} \right\|_2 \sigma < 1$$

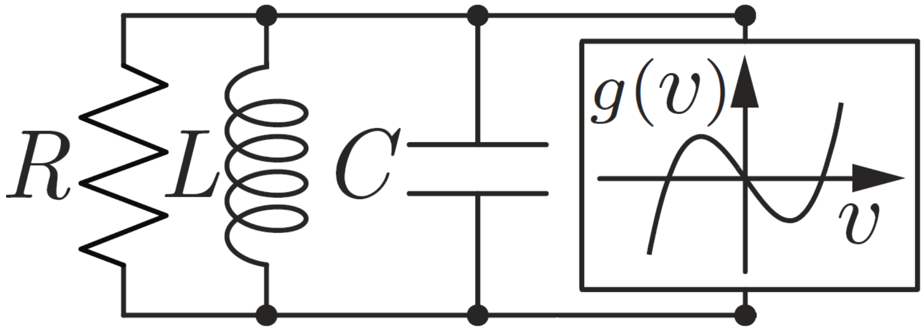
System-wide Synchrony



Condition for global asymptotic synchronization

$$\sup_{\omega \in \mathbb{R}} \left\| \frac{z_{net}(j\omega) z_{osc}(j\omega)}{z_{net}(j\omega) + z_{osc}(j\omega)} \right\|_2 \sigma < 1$$

- Modular
- Robust
- Resilient



- Time-domain control
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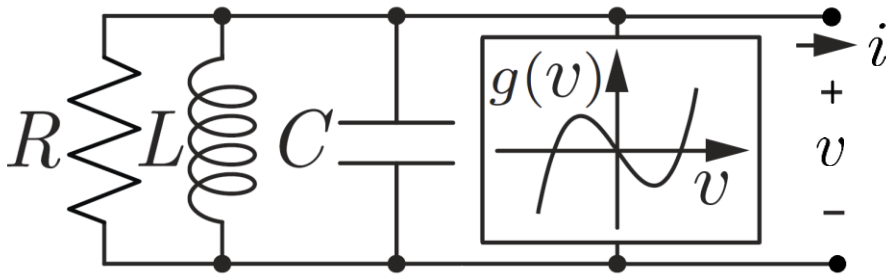
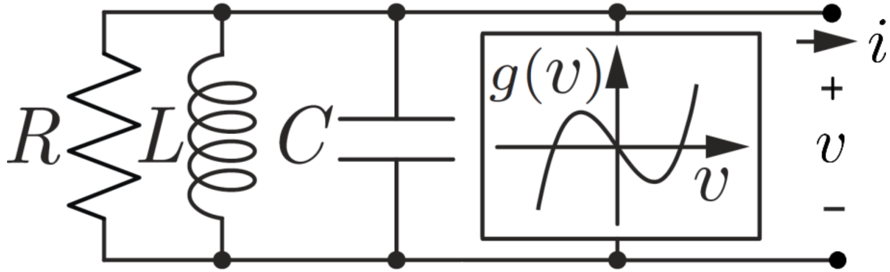
Original Dynamics



$$\frac{d^2 v}{dt^2} + \left(\frac{1}{RC} - \frac{g'(v)}{C} \right) \frac{dv}{dt} + \frac{v}{LC} = -\frac{1}{C} \frac{di}{dt}$$

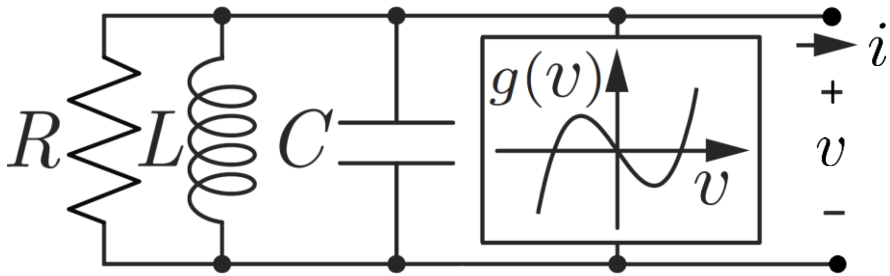
Averaged Dynamics



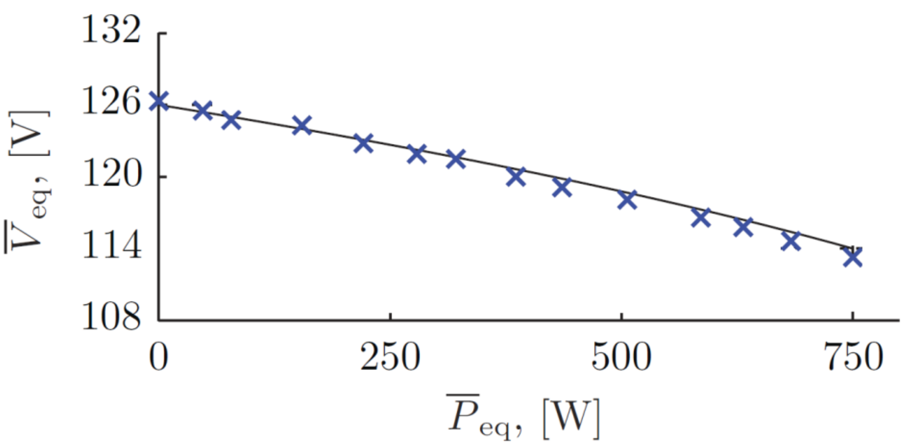
$$\frac{d^2v}{dt^2} + \left(\frac{1}{RC} - \frac{g'(v)}{C}\right)\frac{dv}{dt} + \frac{v}{LC} = -\frac{1}{C}\frac{di}{dt}$$

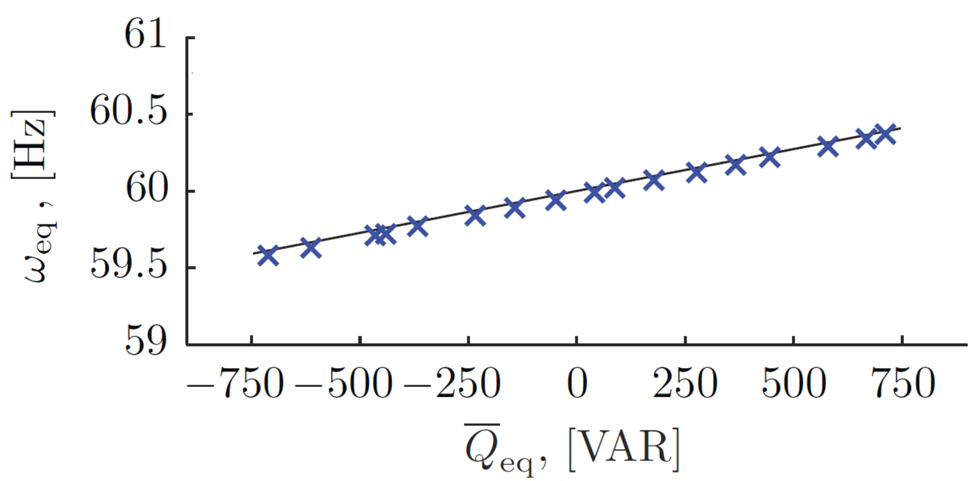
$$\frac{d}{dt}r = \overline{g}(r) - \frac{1}{rC}P, \quad \frac{d}{dt}\theta = +\frac{1}{r^2C}Q$$

Backward Compatibility



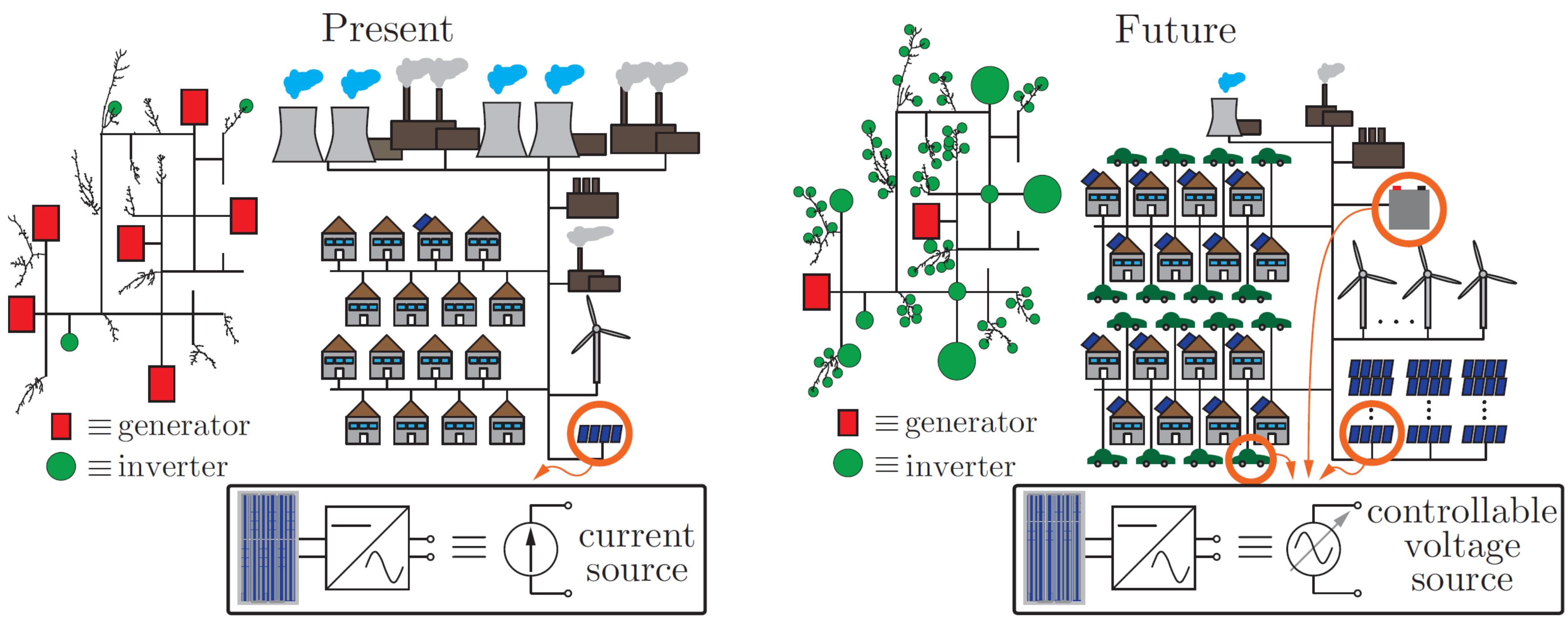
$$\frac{d}{dt}r = \overline{g}(r) - \frac{1}{rC}P, \qquad \frac{d}{dt}\theta = +\frac{1}{r^2C}Q$$





✖ Experimental —— Analytical

Context



Present
≡ generator
≡ inverter
current source
Future
≡ generator
≡ inverter
controllable voltage source

Comments?

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