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Electrical & Computer ENGINEERING

Stability of Passivity-Based Control for Power Systems and Power Electronics

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The problem

- Passivity-based control
  - Nonlinear control method
  - Exploits the intrinsic energy properties of the system dynamics
  - Robust due to the avoidance of exact cancellation of nonlinearities
- Challenge for under-actuated systems
  - Not all state variables can be regulated
  - Desired state variables cannot be all arbitrarily selected
  - Non-directly controlled desired state variables have dynamics
  - Desired dynamics need to be stable for control to work
  - Stability of desired dynamics can depend on
    - which state variables are chosen to be directly controlled
    - parameters and set points

Description of the Problem

State space model: $\dot{\mathbf{x}} = \mathbf{f}(x,u)$

Closed-loop energy functions: $\tilde{W}_m'(\tilde{\mathbf{x}}),\ \tilde{W}_e(\tilde{\mathbf{x}})$

where $\tilde{\mathbf{x}} = \mathbf{x} - \mathbf{x}^D$

Closed-loop dissipation function: $\tilde{R}(\tilde{\mathbf{x}})$

Set point equations: $\mathbf{f}_r(x^D) = \mathbf{r}^*$

can derive control law in an automated manner

Passivity-Based Control Law:

$$\mathbf{u} = \mathbf{g}_1(x, x^{Dn}, r^*)$$

$$\dot{\mathbf{x}}^{Dn} = \mathbf{g}_2(x, x^{Dn}, r^*)$$

Non-directly controlled desired state variables have dynamics, which can go unstable

Lyapunov function:

$$V(\tilde{\mathbf{x}}) = \tilde{W}_m'(\tilde{\mathbf{x}}) + \tilde{W}_e(\tilde{\mathbf{x}})$$

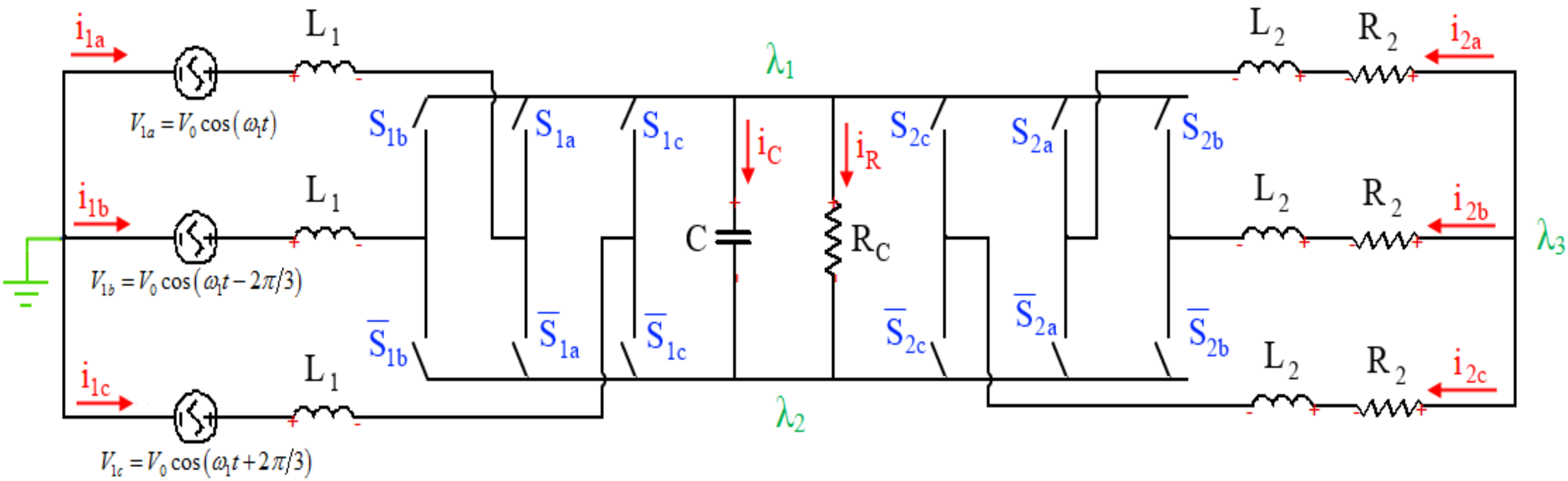
$$\frac{dV(\tilde{\mathbf{x}})}{dt} = \frac{dV(\tilde{\mathbf{x}})}{d\tilde{\mathbf{x}}}\frac{d\tilde{\mathbf{x}}}{dt}$$

If
- $V(\tilde{\mathbf{x}})$ is positive definite
- $\frac{dV(\tilde{\mathbf{x}})}{dt}$ is negative definite

Then $\tilde{\mathbf{x}} \to 0,\ \mathbf{x} \to \mathbf{x}^D$

Source: K. D. Bachovchin, M. D. Ilić, "Automated Passivity-Based Control Law Derivation for Electrical Euler-Lagrange Systems and Demonstration on Three-Phase AC/DC/AC Converter," EESG Working Paper No. R-WP-5-2014, August 2014.

Example: AC/DC/AC Converter



- Choose to directly regulate the direct and quadrature components of the load and source currents
- Desired capacitor charge has dynamics

$$\frac{dq_C{}^D}{dt} = -\frac{\left(q_C{}^D\right)^2 - C^2 R_C\left(V_{1d} i_{1d}{}^* + V_{1q} i_{1q}{}^*\right) + C^2 R_C R_2\left(i_{2d}{}^{*2} + i_{2q}{}^{*2}\right) + C^2 R_C R_1\left(i_{1d}{}^{*2} + i_{1q}{}^{*2} - i_{1d} i_{1d}{}^* - i_{1q} i_{1q}{}^*\right)}{C R_C q_C{}^D}$$

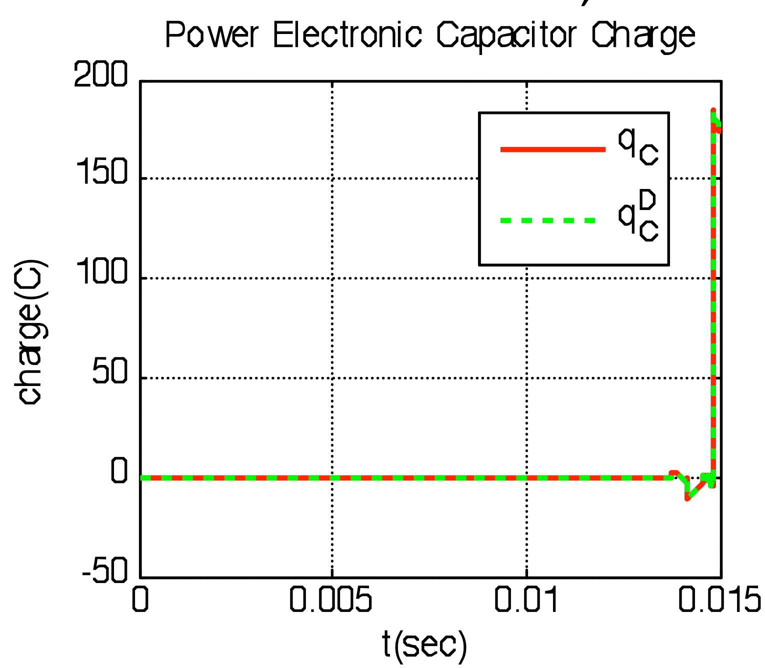
Source: K. D. Bachovchin, M. D. Ilić, "Automated Passivity-Based Control Law Derivation for Electrical Euler-Lagrange Systems and Demonstration on Three-Phase AC/DC/AC Converter," EESG Working Paper No. R-WP-5-2014, August 2014.

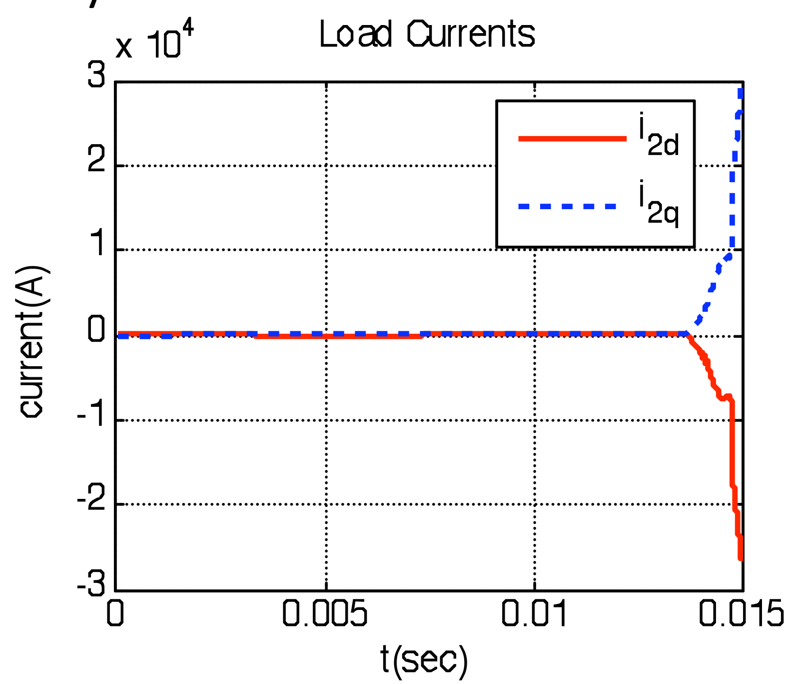
Example: AC/DC/AC Converter

- A stable equilibrium for $q_C^{\,D}$ only exists when

$$\underbrace{V_{1d} i_{1d}^{\;*} + V_{1q} i_{1q}^{\;*}}_{\text{power input by source}} \geq \underbrace{R_2 i_{2d}^{\;*2} + R_2 i_{2q}^{\;*2}}_{\text{power dissipated by load}}$$

- If this condition is violated, then the passivity-based controller will be unstable





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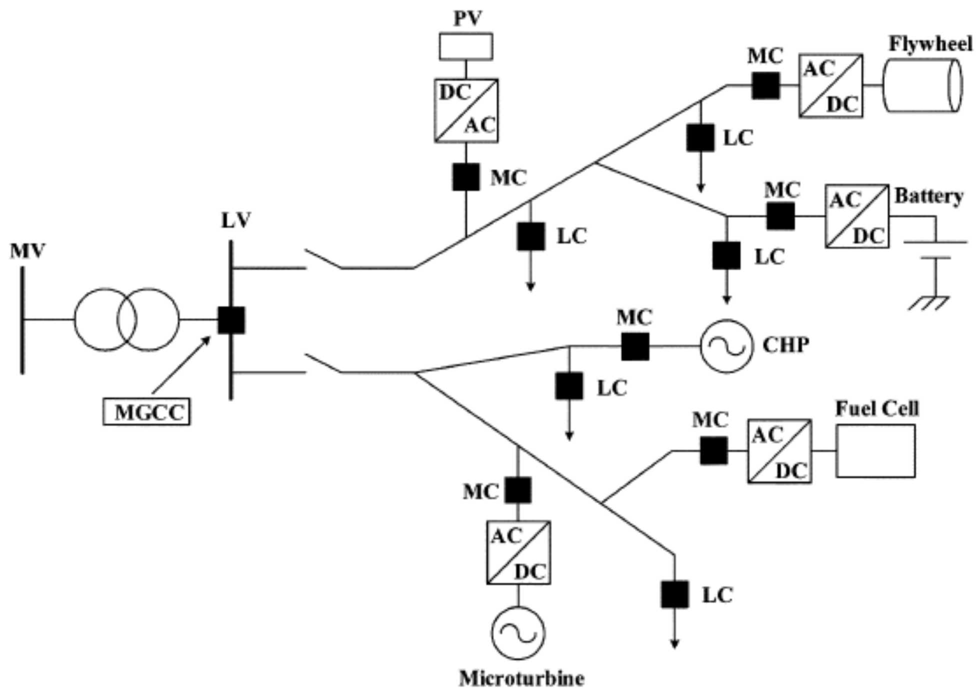
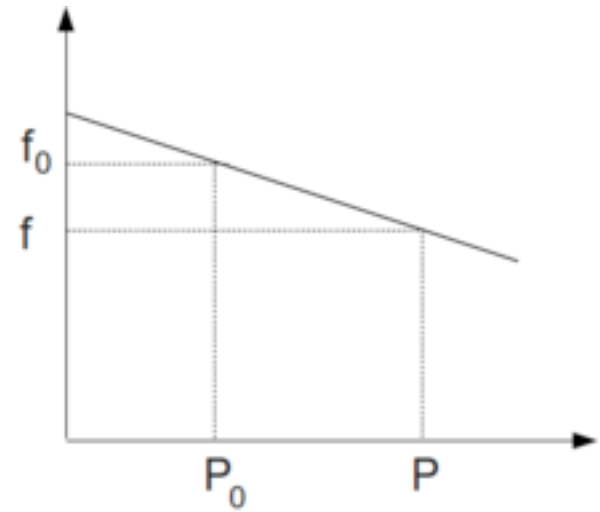
Motivation

- Analysis and control of microgrids often begin with droop characteristic





$$f = f_0 - k_p \left(P - P_0 \right)$$

- Before droop characteristic analysis can be used, the fast dynamics must be stabilized using control with provable performance

Source: J.A. Pecas Lopes, C.L. Moreira, A.G. Madureira., "Defining control strategies for MicroGrids islanded operation," *IEEE Transactions on Power Systems*, vol.21, no.2, pp.916,924, May 2006