Boost Controller Design

ECE 482 Lecture 7
February 3, 2014

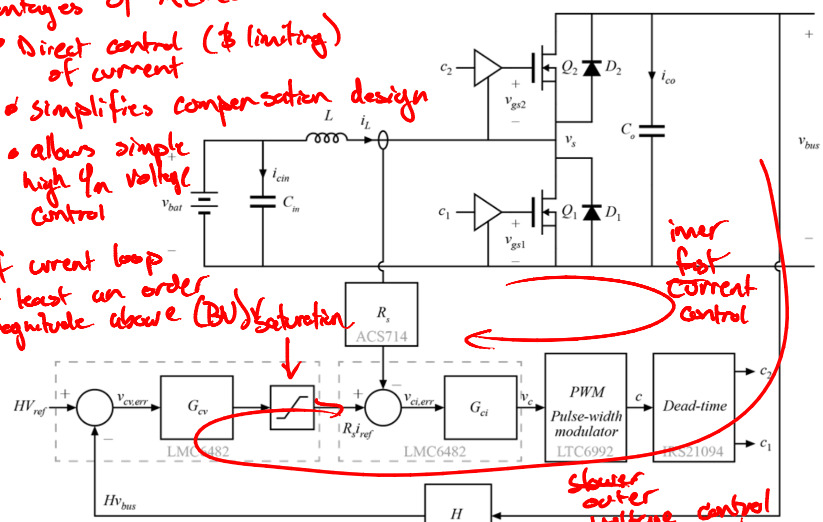
Announcements

- Experiment 1 Reports
  - Give all parameters needed to repeat
  - Reference *specific* features in figures/tables from text
- Experiment 2 Report due Friday
  - Demo full power in lab Wednesday
- Exp.3 prelab moved to Wednesday 2/12

Controller Implementation

Advantages of ACMC
- Direct control ($ limiting) of current
- simplifies compensation design
- allows simple high fn voltage control

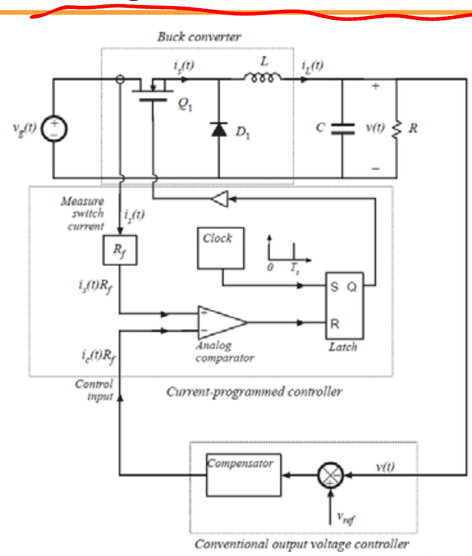
BW of current loop is at least an order of magnitude above (BW) saturation



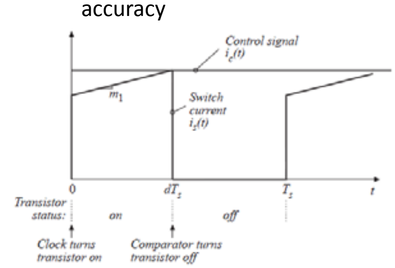
inner fast current control

slower outer voltage control loop

Average Current Mode Control (ACMC) vs. CPM



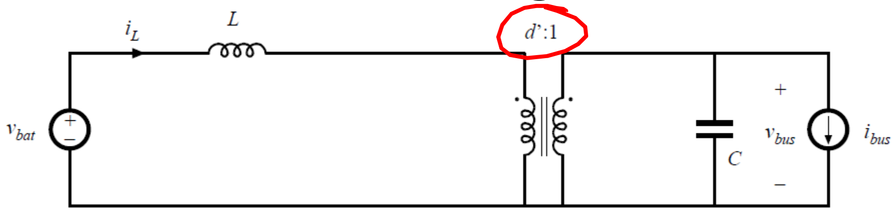
- Current Programmed Control (CPM) from Chapter 12 is **not** ACMC
- Both possess many of the same benefits, but ACMC has:
  - Simpler compensation
  - Better noise immunity and accuracy



Fundamentals of Power Electronics 1

Chapter 12: Current Programmed Control

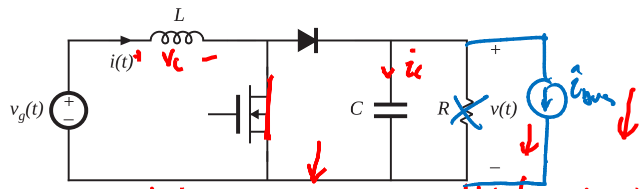
Nonlinear, Averaged Circuit



$$\begin{cases} L\dfrac{d\langle i_L\rangle}{dt} = \langle v_{bat}\rangle - (1-d)\langle v_{bus}\rangle \\ C\dfrac{d\langle v_{bus}\rangle}{dt} = (1-d)\langle i_L\rangle - \langle i_{bus}\rangle \end{cases}$$

<u>suitable for simulation</u>

Nonlinear, Large-Signal Equations



$$\langle v_L\rangle = L\frac{d\langle i_L\rangle}{dt} = d(t)\langle v_g(t)\rangle + d'(t)\left(\langle v_g(t)\rangle - \langle v(t)\rangle\right)$$

$$\langle i_c\rangle = C\frac{d\langle v(t)\rangle}{dt} = -\frac{\langle v\rangle}{R}d(t) + d'(t)\left(\langle i_L(t)\rangle - \frac{\langle v(t)\rangle}{R}\right)$$

DC

Averaged AC

<u>DC only</u>

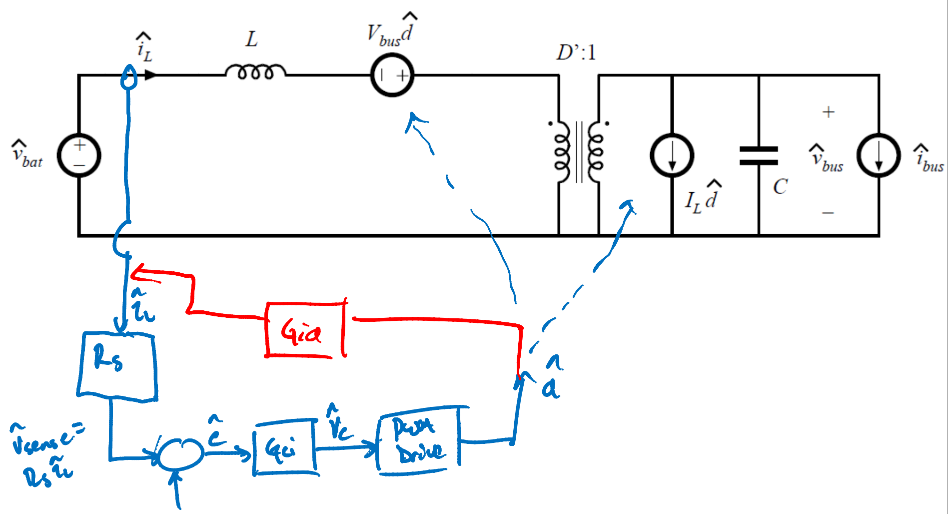
$$\emptyset = V_g - D'V$$
$$\emptyset = D'I_L - \frac{V}{R}$$

Equiv. circuit model

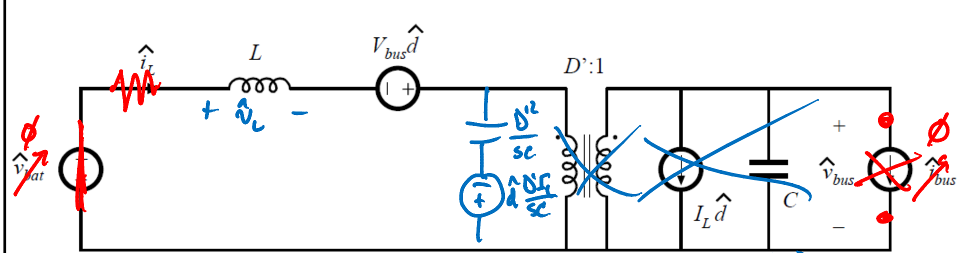
$$\begin{cases} L\dfrac{d\hat{i}_L}{dt} = \hat{v}_g - D'\hat{v} + V\hat{d} \\ C\dfrac{d\hat{v}}{dt} = \dfrac{-\hat{v}}{R} + D'\hat{i}_L - I_L\hat{d} \end{cases}$$

$$-\frac{\hat{v}}{R} = \hat{i}_{bus}$$

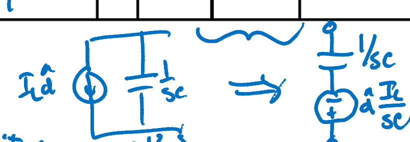
Small-Singal AC Averaged Equic. Circuit Model



Open-Loop Control-to-Current TF



Find $G_{id}(s) = \left.\frac{\hat{i}_L}{\hat{d}}\right|_{\hat{v}_{bat}=0,\, \hat{i}_{bus}=0}$



$$\hat{i}_L = \frac{1}{sL}\hat{v}_L = \frac{1}{sL}\left(V_{bus}\hat{d} + \frac{D'I_L}{sC}\hat{d} - \hat{i}_L\frac{D'^2}{sC}\right)$$

$$\hat{i}_L\left(1+\frac{D'^2}{s^2LC}\right) = \hat{d}\left(\frac{V_{bus}}{sL}+\frac{D'I_L}{s^2LC}\right)$$

$$G_{id} = \frac{\frac{V_{bus}}{sL}+\frac{D'I_L}{s^2LC}}{\left(1+\frac{D'^2}{s^2LC}\right)}\,\frac{\left(\frac{s^2LC}{D'I_L}\right)}{\left(\frac{s^2LC}{D'I_L}\right)} = \frac{\left(1+\frac{CV_{bus}}{D'I_L}s\right)}{\left(\frac{s^2LC}{D'I_L}+\frac{D'}{I_L}\right)}$$

Open-Loop Control-to-Current TF

$$\boxed{G_{id} = \frac{I_L}{D'} \frac{\left(1 + s\frac{CV_{bus}}{D' I_L}\right)}{\left(1 + s^2 \frac{LC}{D'^2}\right)}}$$

$$= G_{ido} \frac{\left(1 + \frac{s}{\omega_{zi}}\right)}{\left(1 + \frac{s^2}{\omega_o^2}\right)}$$

DC solution:

$D' I_L = I_{bus}$

$\omega_{zi} = \frac{I_{bus}}{C V_{bus}}$

Open-Loop Control-to-Current TF

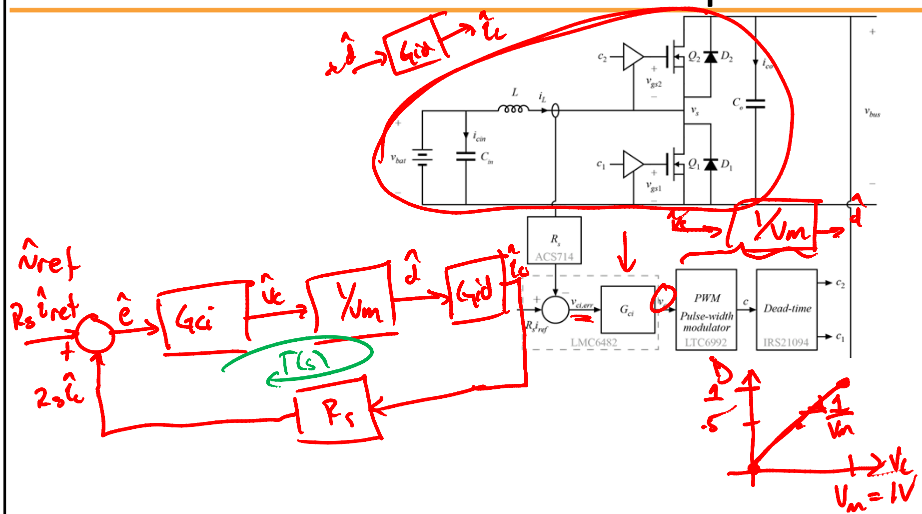
$$G_{id}(s) = \left.\frac{\hat{i}_L}{\hat{d}}\right|_{\hat{v}_{bat}=0,\, \hat{i}_{bus}=0} = G_{ido} \frac{1 + \frac{s}{\omega_{zi}}}{1 + \frac{s^2}{\omega_o^2}}$$

$$G_{ido} = \frac{I_L}{D'} = \frac{I_{bus}}{(D')^2}$$

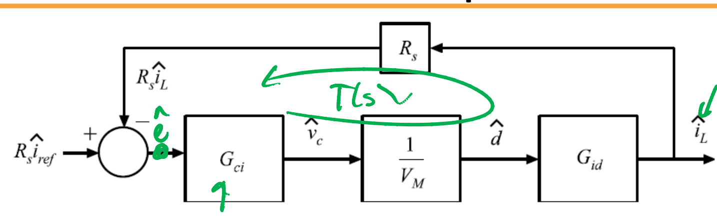
$$f_{zi} = \frac{1}{2\pi} \frac{1}{C} \frac{I_{bus}}{V_{bus}}$$

$$f_o = \frac{1}{2\pi} \frac{D'}{\sqrt{LC}}$$

Current Control Loop



Current Loop Gain



$$T(s) = G_{ci} \frac{1}{V_m} G_{id} R_s$$

$$\hat{e} = R_s \hat{i}_{ref} - R_s \hat{i}_L = R_s \hat{i}_{ref} - \underbrace{R_s G_{id} \frac{1}{V_m} G_{ci}}_{T(s)} \hat{e}$$

$$\hat{e} = R_s \hat{i}_{ref} - T(s)\hat{e}$$

$$\boxed{\hat{e} = \frac{R_s \hat{i}_{ref}}{1 + T(s)}}$$

→ Design goal #1

Large T(s) over wide range of freqs.

$T(s \to 0) \to \infty$

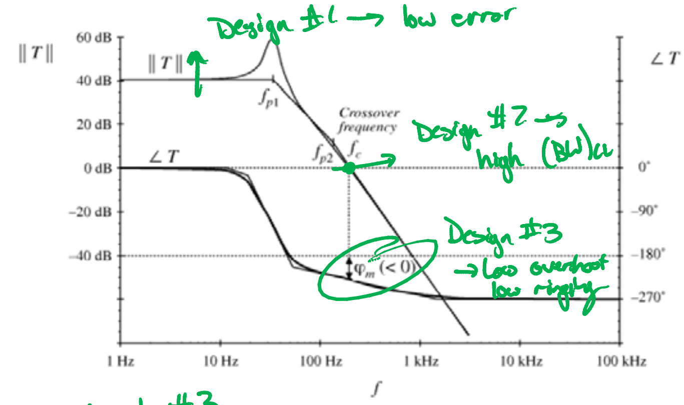
$$\hat{i}_L = \hat{e}\, G_{ci} \frac{1}{V_m} G_{id}$$

$$\hat{i}_L = \hat{i}_{ref} \frac{T}{1+T}$$

→ Design Goal #2

Extend range of freq w/ $|T(s)| > 1$

Loop Gain & Stability



Design Goal #3

system well stabilized
→ Large φ_m

Phase Margin Test

System stable if

$\varphi_m = 180° + \angle T(j\omega_c) > 0°$

$(\omega_c \ni \|T(j\omega_c)\| = 1 = 0\text{dB})$

Closed-Loop Response