ECE 529
Utility Applications of Power Electronics

Session 16
Closed loop control using VSC

**Old Way**

\[ V_{TA} = k \frac{V_{dc}}{2} \]

Drawback: No current limiting

Similar to exciter in a synch generator
MODERN CONTROL STRUCTURE

⇒ Grid Following Control

→ Build in current limiting

From outer loop or manual set-point

Imeas

P I

Error

Proportional Integral

Vr

→ Single loop -

But converter has two degrees of freedom (|Vr|, Ωr)
To design control, go back to dc/dc converter.
\[ \text{Input} = V_T \]

\[ i_{out}(t) = \frac{V_T - V_{out}}{R - sL} \text{ just } R \]

- when not in steady state

\[ V_T = V_{out} + I_{out} R + L \frac{dI_{out}}{dt} \]

\[ L \]

\[ V_T(s) = V_{out}(s) + I_{out}(s)(R + sL) \]

\[ I_{out}(s) = \frac{V_T(s) - V_{out}(s)}{R + sL} \]

- dictates system response

R/L Time constant
Choose $K_i, K_p$ (PSCAD/EMTDC $\frac{K_i}{s} \Rightarrow \frac{1}{sT_i}$)

$\rightarrow$ Desired time constant (response we want)

PI control to cancel pole associated with $R+\frac{1}{S}L$ and override that with desired constant
To choose $k_i + k_p$:

\[
\text{Set } k_i = \frac{1}{k_p} \quad \text{and } \quad k_p = \frac{1}{k_i}.
\]
Closed-Loop Grid-Following Control

**ATP Version**

**DC-DC Converter Example**

- The $k_i$ and $k_p$ should be tuned for the $R_s$ and $L_s$ values of this system.

As per page 51 in the textbook by Yazdani and Iravani:

- Desired time constant: $\tau_i := 0.005$

  \[ R_s := 0.00588 \quad L_s := 0.69 \times 10^{-3} \]

We know that:

\[ \frac{k_i}{k_p} = \frac{R_s}{L_s} \quad \text{and} \quad \frac{k_p}{L_s} = \frac{1}{\tau_i} \]

So:

\[ k_p := \frac{L_s}{\tau_i} \quad k_i := k_p \frac{R_s}{L_s} \quad k_i = 1.176 \]

- Switching and averaged models match, but
- Poor current tracking at startup and for changes
- And for changing conditions
- Here are the current reference and current from the averaged model.

- Add feedforward term, VS2.

- Now much better tracking at startup.
- Can see the effect of time constant in the transition between setpoints.

It get rid of this... (large disturbance)
- modulation function

- output of PI (red)
- output of PI + voltage feedforward input (green)
DC-AC Application

Create sinusoidal i_ref(t) function

- Significant tracking problem
- Trying to track a time varying reference

![Graph showing current and i_ref(t)]
- Try lowering the time constant of the PI loop:
  \[ \tau_1 := 0.0005 \]
  \[ k_i := \frac{R_S}{L_S} \]
  \[ k_p = 1.38 \]

- New desired time constant:
  \[ \tau_i := \frac{L_S}{\tau_1} \]

- New gain constant:
  \[ k_p = 1.38 \]

- Now tracks magnitude still have a phase error that would require additional compensation.
- There are other PWM schemes we could use as well.
• Note that modulating function hits limits during the higher current output state
• Due to the high current reference

• Converter terminal voltage from switched and averaged models