Topics for Today:

- Startup
  - Web page:  http://www.ee.mtu.edu/faculty/bamork/ee5220/
  - Book, references, syllabus, more are on web page.
  - Software - Matlab. ATP/EMTP [ License - www.emtp.org ] ATP tutorials posted on our course web page
  - EE5220-L@mtu.edu (participation = half letter grade, 5%)

- ATP Simulation pointers
- Cap Bank Switching (continued)
  - Back-to-back switching
  - Outrush
  - TRV
  - Voltage Magnification
- Discussion - how to carry out HW#4
Sample 34.5-kV system, developed from Fig. 3.4 in Greenwood.

R_1 = 0.5 \text{ Ohms} \quad L_1 = 3 \text{ mH} \quad R_2 = 0.001 \text{ Ohms} \quad L_2 = 12 \text{ mH}

C_1 = 40.1 \mu \text{F} (18 \text{ MVAR}) \quad C_2 = 22.3 \mu \text{F} (10 \text{ MVAR}) \quad C_{LV} = 601 \mu \text{F}

Dist. Transformer: 4:1 ratio \quad L_B = 19 \mu \text{H} \quad C_{BUSH} = 300 \text{ pF} (\text{see p.437})

**Back-to-Back Operative Circuit:**

\[ W_0 = \frac{1}{\sqrt{L_B \cdot \frac{C_1 C_2}{C_1 + C_2}}} \]

\[ Z_0 = \sqrt{\frac{L_B}{C_1 C_2 \frac{C_1 + C_2}{C_1 + C_2}}} \]

(\text{Typical } f_0: 3-15 \text{ KHz})
Sample 34.5-kV system, developed from Fig. 3.4 in Greenwood.

\[ R_1 = 0.5 \text{ Ohms} \quad L_1 = 3 \text{ mH} \quad R_2 = 0.001 \text{ Ohms} \quad L_2 = 12 \text{ mH} \]

\[ C_1 = 40.1 \mu\text{F (18 MVAR)} \quad C_2 = 22.3 \mu\text{F (10 MVAR)} \quad C_{LV} = 601 \mu\text{F} \]

Dist. Transformer: 4:1 ratio \[ L_B = 19 \mu\text{H} \quad C_{BUSH} = 300 \text{ pF (see p.437)} \]

**Outrush** — Cap banks discharge into nearby fault. CBs may not handle it.

**Ratings of CBs:** \( I_p \times f_0 \)

i) General Purpose \( I_p \times f_0 \leq 2 \times 10^7 \)

ii) Definite Purpose: See IEEE Stds!
\[ Z_0 = \sqrt{\frac{LF}{C_1}} \quad \text{or} \quad \sqrt{\frac{LF}{C_1 + C_2}} \]

(One Bank)  (Both Banks)

\[ I_0 = \frac{V(t)}{Z_0} \]

\[ I_0 \times f_0 = ? \]
Sample 34.5-kV system, developed from Fig. 3.4 in Greenwood.

SYSTEM EQUIVALENT

$R_1 = 0.5 \text{ Ohms}$  \hspace{1cm}  $L_1 = 3 \text{ mH}$  \hspace{1cm}  $R_2 = 0.001 \text{ Ohms}$  \hspace{1cm}  $L_2 = 12 \text{ mH}$

$C_1 = 40.1 \mu\text{F (18 MVAR)}$  \hspace{1cm}  $C_2 = 22.3 \mu\text{F (10 MVAR)}$  \hspace{1cm}  $C_{LV} = 601 \mu\text{F}$

Dist. Transformer: 4:1 ratio  \hspace{1cm}  $L_B = 19 \mu\text{H}$  \hspace{1cm}  $C_{BUSH} = 300 \text{ pF (see p.437)}$

5) Voltage Magnification - Usually Low Freq

$$f_1 = \frac{1}{2\pi\sqrt{L_1C_1}} \quad \frac{1}{C_1} \quad f_2 = \frac{1}{2\pi\sqrt{L_2C_{LV}}}$$
Series resonance: \[ Z_{TOT} = jX_L - jX_C \]

\[ X_L = X_C \]

\[ 2\pi f_1 L = \frac{1}{2\pi f_1 C_1} \]

Per Unit Voltage at \( C_L V \) is higher than at \( C_1 \), thus the name "Voltage magnification."
Sample 34.5-kV system, developed from Fig. 3.4 in Greenwood.

Table 13.4

R_1 = 0.5 Ohms  \quad L_1 = 3 \, \text{mH}  \quad R_2 = 0.001 \, \text{Ohms}  \quad L_2 = 12 \, \text{mH}

C_1 = 40.1 \, \mu\text{F} (18 \, \text{MVAR})  \quad C_2 = 22.3 \, \mu\text{F} (10 \, \text{MVAR})  \quad C_{LV} = 601 \, \mu\text{F}

Dist. Transformer: 4:1 ratio  \quad L_B = 19 \, \mu\text{H}  \quad C_{BUSH} = 300 \, \text{pF} \quad \text{(see p.437)}

\[ W_0 = \frac{1}{\sqrt{L_1 C_{BUSH}}} = \frac{1}{\sqrt{0.003 \times 300 \times 10^{-12}}} \]
Numerical Oscillations -
(Trapezoidal Method in EMTP)

Typical: Very small L's
         Very large C's.

Solution: Place a numerical
          damping resistor
          a) In parallel w/L
          b) In series w/C

\[
\begin{align*}
R_{\text{damp}} & \quad \text{Ramp} \\
\text{series} & \quad L_1 \\
\text{parallel} & \quad R_1
\end{align*}
\]

ATP Draw Implementable
\[ V_{\text{peak}} = 39.64 \text{ KV} \]
\[ V_{\text{peak, base}} = \frac{(34,500)(\sqrt{2})}{\sqrt{3}} = 28.1 \text{ KV} \]
\[ V_{\text{pu}} = \frac{39.64}{28.1} = 1.4 \text{ p.u.} \]
\[ W_0 = \frac{1}{\sqrt{L_1 C_{\text{Bush}}}} = 167 \text{ KHz} = 300 \mu\text{F} \]
\[ W_{\text{sim}} = 5 \text{ KHz} \text{ (at 200nF)} \]

Capacitances other than \( C_{\text{Bush}} \) may be present,
- Cap Bank (like single-Bank energization)
- Transformer Coil Capacitances,
- Transformer bushing Cap.
Problem 3.3 - Recovery Voltage

\[ Q = CV \]

\[ Q(0^-) = Q(0^+) = (C_1)(V_s - \text{peak}) \]
\[ = (69.64 \text{ mF})(\frac{\sqrt{2} \times 13,000}{\sqrt{3}}) \]

\[ V(0^+) = \frac{Q}{C_1 + C_2} \Rightarrow V(0^+) = 7042 \text{ V} \]
Voltage oscillations: \( \pm (11,267 - 7044) = \pm 4225 \text{V} \)

\[
W_0 = \frac{1}{\sqrt{L_1 (c_1 + c_2)}} \quad Z_0 = \sqrt{\frac{L_1}{c_1 + c_2}}
\]

What about current oscillations?

\[
V_p \circlearrowleft \quad V(0^+) = 7042
\]
\[ \Delta V = V(\infty) - V(0^+) \]
\[ = 11267 - 7042 \]
\[ = 4225 \text{V} \]

\[ I_p = \frac{\Delta V}{Z_0} = \frac{4225}{3.08} = 1372 \text{A} \]

Bus Overvoltages
- Not usually a concern with B-2-B energization.
- Bigger w/o worried with single bank.