Ongoing List of Topics:

- URL: http://www.ece.mtu.edu/faculty/bamork/EE5223/index.htm
- Term Project
  - Follow timeline, see posting on web page (posted in week 5)
  - Formal outline w/complete references complete, get/keep cranking...
- Homework
  - Problem 10.1 - complete by Tues 5pm. See e-mail re. typos, helpful hints.
- Protection of Shunt Capacitor Banks (print out "Cap Bank Prot" at Week 12)
  - Basic protection concerns.
  - Capacitor “can” design - externally fused, internally fused, fuseless.
  - Cap bank configuration, design calculations.
  - Implications of failure of individual capacitor elements.
  - Cascading failure.
  - Protection strategies for wye-connected cap bank.
- Next:
  - Overview of Cap Bank protection strategies for various configurations
  - Example - calc spreadsheet set up for externally fused grounded-wye.
More information concerning the different linking techniques under the design label.

The choice of technology:

- **Series:**
  - More series links are needed as the voltage and power are shown in the diagram below.

- **Parallel:**
  - Parallel links are needed as the voltage and power are shown in the diagram below.

- **Mixed:**
  - Mixed links are needed as the voltage and power are shown in the diagram below.

Fusing:

- **High-voltage fuses:**
  - High-voltage fuses are needed as the voltage and power are shown in the diagram below.

Different fuse technologies:

- **Current:**
  - Current links are needed as the voltage and power are shown in the diagram below.

- **Voltage:**
  - Voltage links are needed as the voltage and power are shown in the diagram below.

- **Protection:**
  - Protection links are needed as the voltage and power are shown in the diagram below.

- **Reliability:**
  - Reliability links are needed as the voltage and power are shown in the diagram below.

- **Economy:**
  - Economy links are needed as the voltage and power are shown in the diagram below.

- **Safety:**
  - Safety links are needed as the voltage and power are shown in the diagram below.

- **Environmental:**
  - Environmental links are needed as the voltage and power are shown in the diagram below.

- **Revenue:**
  - Revenue links are needed as the voltage and power are shown in the diagram below.

- **Service:**
  - Service links are needed as the voltage and power are shown in the diagram below.
The elements are connected in parallel strings which has the benefits of less stress design based on a different thermal connection of the element matrix. As an alternative to the conventional busbar concept, ABB has developed a fuseless concept – internal strings.

The concept was developed by ABB in the late 1980s and is a result of the high installation and maintenance costs.

Installation and maintenance costs

have many years of experience in the development of fuseless concepts. The high initial investment provides a significant reduction in maintenance and repair costs. A fuseless design reduces the number of labor-intensive tasks required for fuse replacement and reduces the risk of human error."

Extremely fused concept

and fewer the parts.

Include higher efficiency, lower space, lower installation and maintenance costs.

Fundamental concept is to design a large system into small, individually disconnected members that can be disconnected and connected to isolated elements. The disconnected members are isolated and maintain a fuseless connection. When two or more members are connected, a fuseless connection is made of remote shuntless steel and paired with high-performance fuseless concepts. ABB fuseless concepts are designed to provide a fuseless and long lifetime. The fuseless design allows for easy maintenance and repair.

Different fuse technologies

The positive busbars are welded onto the conductor to prevent flashovers. The ABB fuseless concept is made of remote shuntless steel and paired with high-performance fuseless concepts. ABB fuseless concepts are designed to provide a fuseless and long lifetime. The fuseless design allows for easy maintenance and repair.
The capacitor unit size
unit and normal bank connection can be used. This technology does not restrict

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ABB Advantages:
- Externally fused unit
- Internally fused unit
- Welded bushing and solid terminal stud prevents fluid leaks
- Extended tabs are soldered, providing superior internal connections
- Fused for coil electrodes reduce partial discharge generation
- Suppressor plate system with over current process
- Nameplates includes microfused for easy field testing
- Needlepoint positioning on cover for easy reading
- Impregnation process under vacuum to ensure lowest possible humidity

\[
\frac{1}{\sum_{c} + \frac{1}{\frac{1}{\frac{1}{c}} + \frac{1}{\frac{1}{c}}} = C_{eq}}
\]
$N_p = 3$

Internally fused:

$N_p = 2$

$Z_{\text{parall}} = \frac{1}{j \omega 2C}$

$Z_{\text{parall}} = \frac{1}{j \omega \frac{1}{C}}$

$-jX_c = \frac{1}{\text{(indv)} \cdot j \omega C}$

$V_{\text{parall}} = \frac{V_{\text{Tot}}}{N_s}$

$Z$ increases with loss of caps $Z \uparrow$ as $N_p \downarrow$
Cascading Failure:

- Voltage on remaining C's > 110% of voltage rating.
"Fuseless"
Cap bank
Shunt Cap Banks
- P.F. Correction (Customer Side of meter).
- Voltage Support
- Power Transfer

\[ P_{12} = \frac{V_1 V_2}{X} \sin (\delta_1 - \delta_2) \]

\[ (\frac{1.05}{0.95})^2 = 1.22 \]
- Limit increment $\Delta Q$
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Protection Issues

- Fused - interrupt w/fuse (ext. or int.)
- Fuseless or unfused - hope they "fail open" fail shorted.
- Major Problems to protect Bank against
  - Harmonics
  - Cascaded Failure
  - Be aware of transients
  - S.S. overvoltages $\geq 1.10$ p.u. of can's rating.
Sound Strategy

- Monitor bank for shifts in voltages on series sections.
- Issue alarm for change in V.
- Trip if V is too close to 1.1 p.u. for comfort (or exceeds).

Note: FIRST, print out "CAP BANK PROT" from week on course web page!
\[ Q_{\text{phase}} = \frac{Q_{\text{series}} \times N_p}{Q_{\text{series \ string}}} = N_s Q_{\text{can}} \]

\[ Q_{\text{can}} = \frac{V^2}{X_{\text{can}}} \left( \frac{V_{\text{LN}}}{N_s} \right)^2 \]

\[ C_{\text{can}} = \frac{V_{\text{LN}}}{V_{\text{Rated}}} \]

Cap Bank MVAR

\[ \frac{\sqrt{3}}{3} \text{ of Total MVAR} \]
Cap Units or "cans"
Externally Fused:

---

fuse

with or w/o bushing.
Internally Fused

\[ C_{\text{tot}} = n \times C \]

\[ C_{\frac{1}{n}} \text{ if we lose one or more indiv. Cs.} \]
Fuseless Cops

Unit shorts if dielectric fails.

\[ C_{\text{TOT}} = \frac{C}{n} = \frac{C}{6} \]

Ex: if \( n = 6 \) and we "lose" one, then \( C_{\text{TOT}} = \frac{C}{5} \)
Fused:

\[ X_c = \frac{1}{\omega C} \]

\[ Z = jX_c \]

Conclusion:

VI on parallel group that loses one or more caps!

\[ X_{c,\text{phase}} = \left[ \frac{X_c}{N_p} \right] N_s \]

\[ X_{c,\text{phase}} = \left[ \frac{X_c}{N_p} \right] (N_s-1) + \frac{X_c}{(N_p-1)} \]
Cascading Failure:

Parallel group

Remaining caps stressed more than before, i.e. \( V_p \) increases. \( V_p \) increase is much less for int. fused.
Fuseless

36 Caps Elements in series.

\[ N_s = 6, \quad N_{int} = 6, \quad N_p = 6 \]

Ex: 120-kV