Ongoing List of Topics:

- URL: http://www.ece.mtu.edu/faculty/bamork/EE5223/index.htm
- Term Project - last few proj/teams being firmed up and getting moving.
  - Follow timeline, see posting on web page (posted in week 5)
  - Formal outline w/complete references complete, get/keep cranking...
  - Grad students - include journal paper and review in appendices
- Homework - problem on Cap Bank configuration & protection
- Wrapup on Cap banks issues
  - Application of cap banks for system operation
  - Recap of Protection of grounded-wye fuseless banks
  - Synchronous Switching to minimize transient overvoltages.
- Next - overview of switching transients
- Gen Protection - Ch. 8, IEEE Publication 95TP102 - Prot of Synch Gens
  - Basic Protection issues
  - Volts/Hz
  - Overspeed
- Next: Detailed overview - total overall Gen protection.
Application Exercise - Capacitor Bank Protection

Mentioned in Book Section 9.2C p. 332-33

- Capacitor Banks are made of individual "cans"
- Typically connect banks in Grounded-Wye, except for lower distribution (PF) applications.
- On each phase, place enough cans in series for L-N voltage. Connect enough cans in parallel to provide required total MVARs.
- Cans must not exceed 1.1 p.u. voltage
- Harmonics are bad - heat and destroy dielectric

\[ X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C} \]

- Transients can be bad (EE 5220)
  - Energization inrush of first bank
  - Back-to-back energization of parallel banks
  - Outrush into nearby fault can damage OCBs
  - Voltage magnification - new HV bank has same resonant frequency as existing distribution banks.
Cap Banks
- PF Correction (IND MOTORS)
  (LV Ind. Installations).
  - Reduce I^2R losses in Dist Syst.
  - Transmission: Line capacity
- Voltage Support in dist system.

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Power Transfer

- Boost voltage a bit higher, more power can be transferred.

\[
\begin{align*}
\text{Ex:} & \quad V_{1/+} \frac{jX_L}{P} + V_{2/-} \\
\text{1.05}^2 & = 1.22 \times 1.95^2 \\
\frac{V_1 V_2}{X_L} & = \sin(\delta - \beta)
\end{align*}
\]
- Reactive Power Support/Reserve

- Voltage Support

Aug ’03 Blackout
Power Transfer

- Boost voltage a bit higher, more power can be transferred.

\[ \frac{1 - jX_c}{V_{1E} + V_{2E}} \]

\[ \frac{1.05^2}{1.45^2} = 1.22 \times \quad P = \frac{V_{vv}}{X_L} \sin (\delta - \beta) \]

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- Reactive Power Support/Reserve

- Cap Banks
- Synch Mach
- FACTs
- SVCs

- Voltage Support

- Voltage Stability (prevent voltage collapse)

Aug '03 Blackout
Fig. 4—Recommended maximum allowable cyclic variation of voltage.

Table 1—Maximum Allowable Voltage Fluctuations
10.5.1 Limits of Flicker. Frequently, the degree of susceptibility is not readily determinable. Fig 10.3 is offered as a guide for planning for such applications. This curve is derived from empirical studies made by several sources. There are several such curves existing that have approximately the same vertical scale.
Attached are a couple of references on sizing cap banks according to limiting voltage bump, I got this from my former substation section chief at Burns & McDonnel (from when I was a substation design engineer in Kansas City). He was with B&V at the time he made these comments, but he no longer works there.

> Subject: RE: cap bank design
> Date: Fri, 3 May 2002 14:00:15 -0500
> 
> Bruce,
> 
> Concerning voltage flicker/variations I think what is acceptable is some what a matter of opinion. I have attached a couple graphs - one from IEEE 519 and the other from the Westinghouse T&D Reference book.

In addition, I found an e-mail of details that I got from BPA a couple of years back. They said "I checked with a planning engineer on our policy and we use 3% for normal system operation and 8% for an outage condition (N-1) as the maximum voltage "bump" allowed on the transmission system."

Finally, another contact who has been involved in system planning off and on for years commented the following:

I don't believe that there is a explicit delta-V standard, other than the flicker curves. I would assume that the transmission cap switching would be infrequent. The I.f. end of the curve is once per hour, and this is far more frequent than expected cap switchings. At this end, the flicker curve is 3% for visibility, and much higher for irritation.

This delta-V is a big issue for HVDC stations, where there are many banks, and limiting bank size has a significant cost. A limit in the 2% - 3% range is typical. These banks at HVDC stations, however, tend to be switched more frequently than the typical HV transmission bank because the Q requirement is heavily dependent on Pdc. If the power transfer is load following, there may be many switchings per day, rather than the typical max of twice per day. The delta-V limit is also a proxy for other limitations governed by the ratio of Q to SC capacity, such as transients, VAR flow changes, etc.

However, in a stronger system, the practical limits on MVAR size could [result in] a smaller delta-V. These limits are things like available switchgear ratings, transient currents during switching, blown-can detection schemes, etc.
Chapter 28

10.3.1 Limits of Flicker. Frequently, the degree of susceptibility is not readily determinable. Fig 10.3 is offered as a guide for planning for such applications. This curve is derived from empirical studies made by several sources. There are several such curves existing that have approximately the same vertical scale.

Fig. 4—Recommended maximum allowable cyclic variation of voltage.

Table 1—Maximum Allowable Voltage Fluctuations

\[ \leq 2-3\% \text{ "bump" in bus voltage.} \]

\( \frac{1}{\text{MVars}} \) - Mult. banks if needed.
\( R, L \) current

\( \frac{1}{C} \) charge

\( \frac{1}{T} \) time

\( V_s \) voltage

Worst

Best

+35

-35
$$\vec{V}_b = \vec{V}_s \begin{bmatrix} -jX_c \\ R+jX_L-jX_c \end{bmatrix}$$

$$\vec{V}_b = I_c (R+jX_L-jX_c) = I_c R + I_c jX_L - I_c jX_c$$
\[ V_s - I_c R - I_c jX_L + I_c jX_C = 0 \]

Neg. Voltage Drop
Capacitor Bank Design and Protection

Bank Specification:
Grounded-Wye Bank

L-L System Voltage: 12.52 kV
Size of Bank: 86 MVAR

Can Specs:
Voltage: 12.52 kV
Rating: 2000 kW/kVAR
Loss: 861.79 Ohms
Capacitance: 3.008 µF/Ph
Impedance: 15.06 Amperes
Current: 8.816 MAmperes
Diss Ohms:
Discharge RC Time Constant:

Calc  Chosen
Total No. Cans: 400.00 405 Cans
No. Cans/Phase: 133.33 135 Cans/Ph
Series Groups/Phase: 5.00 5
Parallel Cans/Group: 26.67 27
Impedance/Group:
Impedance/Phase: 32.60 Ohms
Diss Ohms/Phase:
Discharge RC Time Constant: 132.63 Secs

Performance:
System Voltage, pu: 0.95 1.00 1.05
Total MVAR 73.09 80.99 89.26
Line Current, Amps: 386.27 406.60 426.93
Voltage/Group, kV: 12.615 13.279 13.943
Voltage/Group, pu: 0.950 1.000 1.050
Losses, kW: 7.309 8.099 8.929 kW
Dischg Time to 50V 992.95 899.75 1006.22 Seconds

Group Voltages:

Blown Fuses

This Group: 13.000 13.685 14.369 kV
0.979 1.030 1.082 Per Unit
117.48 123.66 129.95 VT Sec Volts

Other Groups: 12.519 13.178 13.837 kV
0.943 0.992 1.042 Per Unit
113.13 119.08 125.04 VT Sec Volts

Blown Fuses

This Group: 13.846 14.575 15.303 kV
1.043 1.097 1.152 Per Unit
125.12 131.71 138.29 VT Sec Volts

Other Groups: 12.307 12.955 13.603 kV
0.927 0.976 1.024 Per Unit
111.22 117.07 122.93 VT Sec Volts

Blown Fuses

This Group: 14.311 15.064 15.818 kV
1.078 1.134 1.191 Per Unit
129.33 136.13 142.94 VT Sec Volts

Other Groups: 12.191 12.833 13.474 kV
0.918 0.966 1.015 Per Unit
110.17 115.97 121.76 VT Sec Volts

Download from Class web page CAPBANK.XLS
Fuseless Cap Banks
- Single Y

\[ \phi_A \rightarrow \text{CB} \rightarrow \phi_B \rightarrow \phi_C \]

- 800V max design for <400V
- For more LV or "next" caps
How to minimize transient?

"Pole Span" - within which all three close

SF6 CB's - can control each pole separately
Can control ±20° (statistical variation)

(Same close sig. time window)

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Spring 2001
CB "timing"

- Statistical close times for each pole:

\[ \pm 20 - 25 \text{ ms} \]

- When closing all 3 poles at once, the "pole span" is the time from 1st close to last.

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