Ongoing List of Topics:

- URL: http://www.ece.mtu.edu/faculty/bamark/EE5223/index.htm
- Term Project - last few proj/teams being formed up and getting moving.
  - Follow timeline, see posting on web page (posted in week 5)
  - Formal outline w/complete references complete, get/keep cranking...
- Homework set 11
- Problem 10.1 - complete by next Tuesday 5pm.
- Bus protection - 87B (print out "Bus Prot" at Week 11)
- Low Impedance relays
- High-Impedance relays - CT considerations
- Partial bus protection using 51 relay (distribution bus w/radial feeders)
- Protection of Shunt Capacitor Banks (print out "Cap Bank Prot" at Week 11)
- Basic application, reason for using shunt cap banks
- Cap bank configurations - delta, wye, sectionalized wye
- Basic Methods of protection
Application Exercise - Capacitor Bank Protection

Mentioned in Book Section 9.26 p. 352-35
IEEE Std. C57.99-2000

- 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

\[ X_c = \frac{1}{\omega C} = \frac{1}{2\pi fC} \text{ as \, f \uparrow} \]

- 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.

[Diagram of capacitor bank connection]
Cap Banks

- PF Correction (IND MOTORS)
  (LV Ind. Installations),
  - Reduce $I^2R$ losses in Dist Syst.
  - Transmission: Line capacity

- Voltage Support in Dist System.
$$V_B = V_s \left[ \frac{-jX_c}{R+jX_L-jX_c} \right]$$

$$V_s = I_c (R+jX_L-jX_c)$$

$$= I_c R + I_c jX_L - I_c jX_c$$
\[ V_s - I_c R - I_c j X_L + I_c j X_C = 0 \]

\[ \uparrow \]

Neg Voltage Drop
Power Transfer

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

\[ \text{Ex:} \quad \vec{V}_{1,LE} \xrightarrow{\Delta} \vec{V}_{2} \]

\[
\frac{1.05^2}{0.95^2} = 1.22x \quad P_{1+2} = \frac{V_1 V_2}{X_L} \sin (\delta - \beta)
\]

EE 5210 - Power Systems Protection  Spring 2001
- Reactive Power Support/Reserve

- Voltage Support

Aug '03 Blackout
1) 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.

2) 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."

3) 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.
Fig. 4—Recommended maximum allowable cyclic variation of voltage.

Table 1—Maximum Allowable Voltage Fluctuations

<table>
<thead>
<tr>
<th>Frequency of Voltage Pulsation (Cycles per Sec.)</th>
<th>Max. Allowable % Voltage Pulsation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>1.0</td>
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<tr>
<td>1.5</td>
<td>1.5</td>
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<tr>
<td>2.0</td>
<td>2.0</td>
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<tr>
<td>2.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Skowron, Brit. ELEC. and Allied Mfrs' Assn. (No pulsations between 3 and 12 cycles)
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.
280-KV L-C
80 MVAR

→ 13.8-KV

400-KVAR → 200-KVAR

Mfr. Tolerance on Capa:
±5%
7+1 total
±10%
247 Cans/phase

13-series sections
19 in parallel each group

Could lose up to 5

2400 → 21,600 Volts

100, 150, 200 KVAR

EE 5210 - Power Systems Protection  Spring 2001

MichiganTech  Instructor: Bruce Mork  Phone (906) 487-2857  Email: bamork@mtu.edu
Capacitor Bank Design and Protection

Bank Specification:
Grounded-Wye Bank
L-L System Voltage: 115 kV
Size of Bank: 80 MVAR

Can Specs:
Voltage: 13.28 kV
Rating: 200 kVAR
Loss: 0.1 W/KVAR
Capacitance: 3.008 uF
Impedance: 881.79 Ohms
Current: 15.06 Amps
Diss Ohms: 8.818 MOhms

Configuration:
Total No. Cans: 400.00
No. Cans/Phase: 133.33
Series Groups/Phase: 5.00
Parallel Cans/Group: 26.67
Impedance/Group: 32.66 Ohms
Impedance/Phase: 163.29 Ohms
Diss Ohms/Phase: 1.633 MOhms
Discharge RC Time Constant: 132.63 Secs

Performance:
System Voltage, pu: 0.95 1.00 1.05
Total MVAR: 73.09 80.99 89.29
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
Disch Time to 50%: 992.95 999.75 1006.22

Group Voltages:

1. Blown Fuses
This Group: 13.000 13.685 14.369 kV
0.979 1.030 1.082 Per Unit
117.48 123.66 129.85 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

2. 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

3. 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
CASCaded Failure

Look at one L-N phase

\[ V_{LN} = \frac{1}{N_{ser}} V_A \]

EE 5210 - Power Systems Protection

Spring 2001