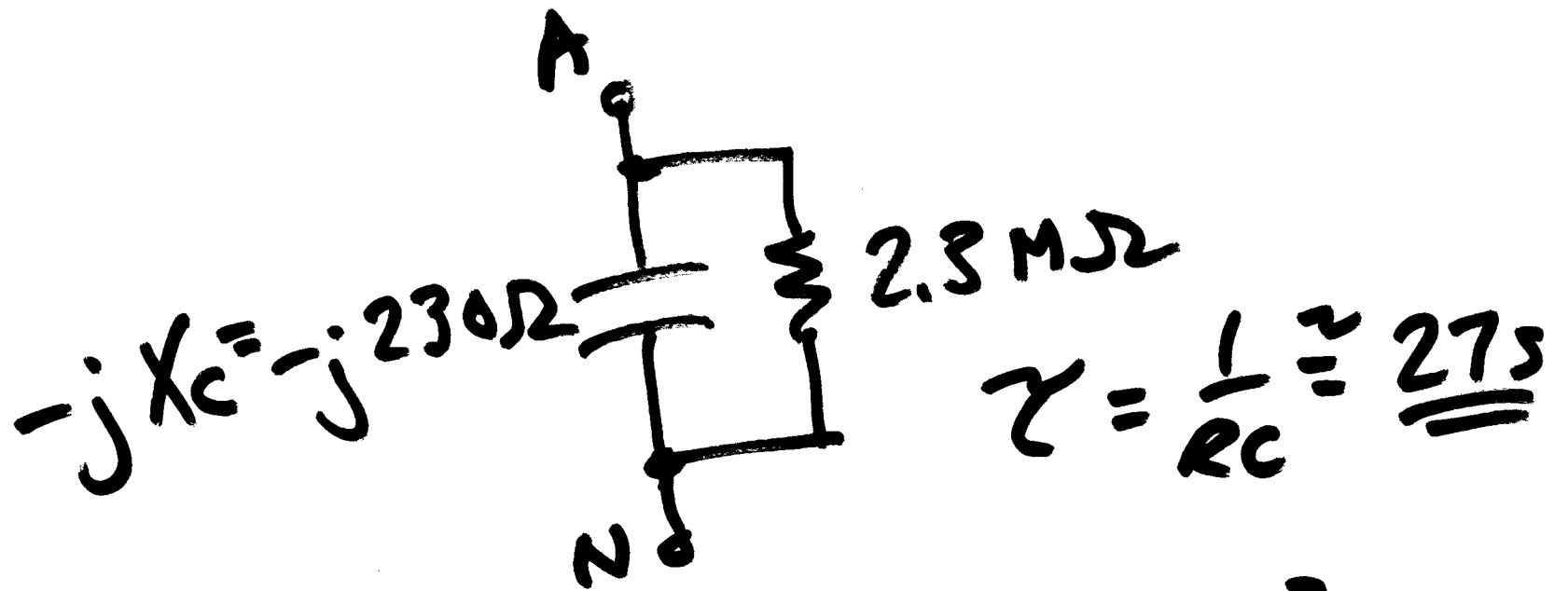


## Ongoing List of Topics:

- URL: <https://pages.mtu.edu/~bamork/EE5223/index.htm>
- Term Project
  - Follow timeline, see posting on web page. Week 12 prototype due Monday.
  - Formal outline w/complete references complete, get/keep cranking...
  - Homework - problem on Cap Bank configuration & protection - work out Monday
- Wrapup on Cap banks issues
  - Recap of Protection of grounded-wye fuseless banks
  - Synchronous Switching to minimize transient overvoltages.
- Next - overview of shunt cap bank 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.

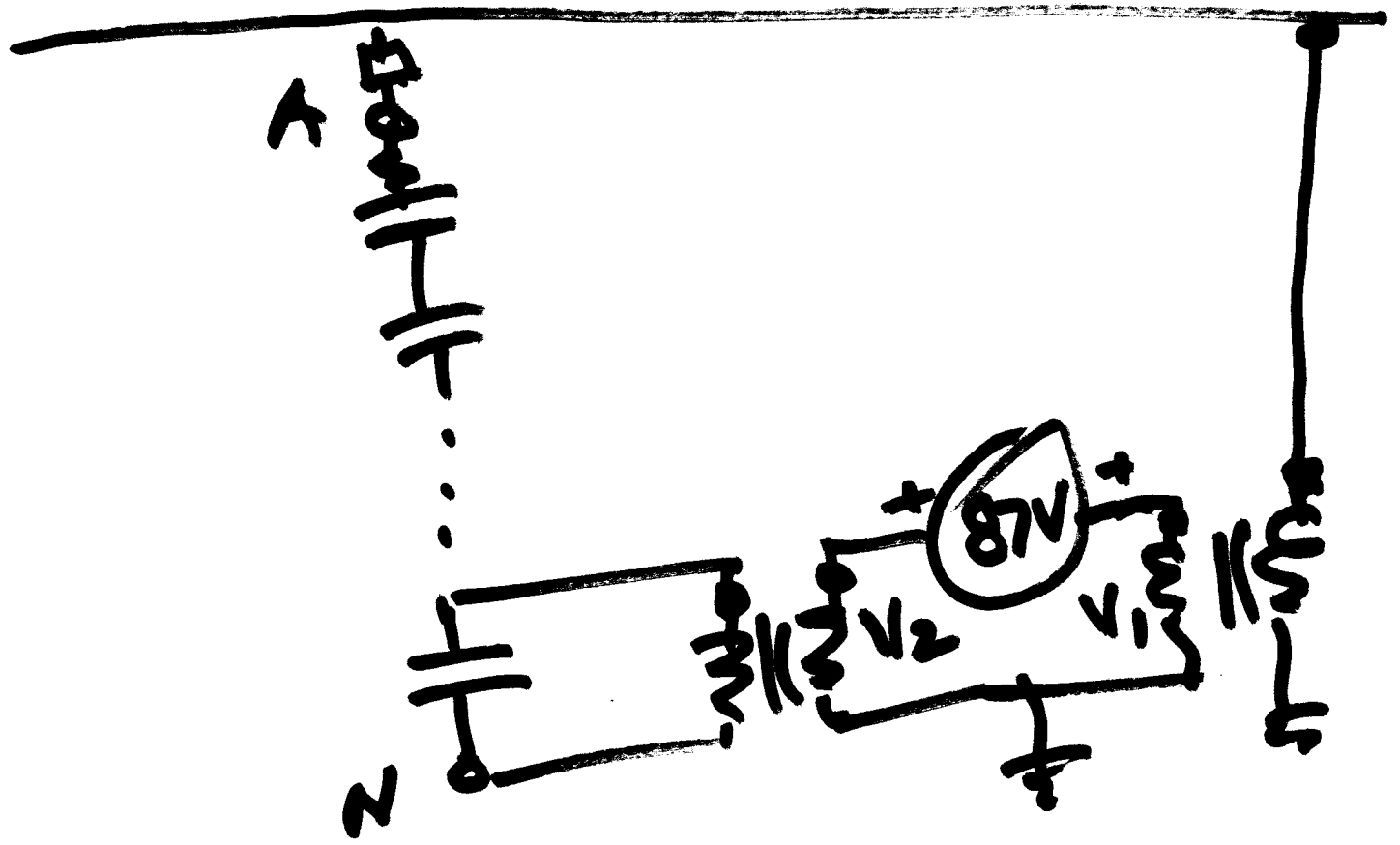
## Control of Cap Banks:

- on/off (CB switching)
  - G3 relays include control.



$$Z = \frac{L}{RC} \approx \underline{\underline{275}}$$

$$Q = 3 \frac{V_{LN}^2}{X_c}$$



$$\sum V_s = K_1 V_1 + K_2 V_2 \equiv 0$$

if  $|\sum V_s| > \epsilon \Rightarrow$  trip.

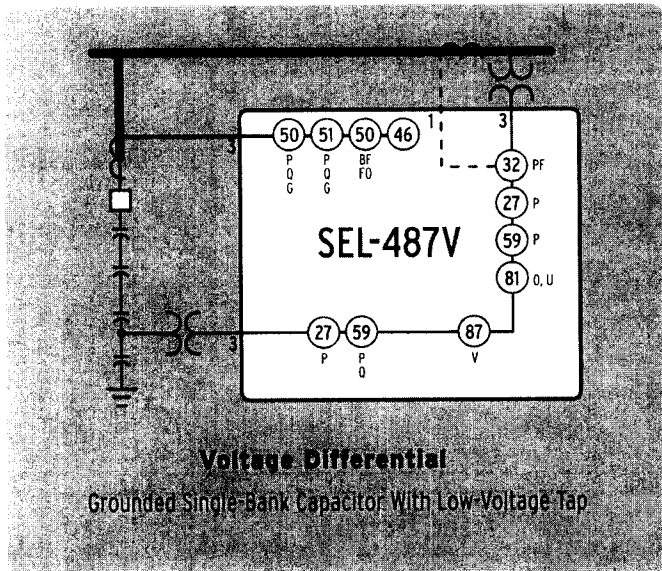
# Applications

## The SEL-487V Provides Comprehensive Protection and Control for All Your Capacitor Bank Applications

Simplify relay settings, application, and inventory by using one relay for all of your capacitor bank needs. The versatile SEL-487V can handle grounded and ungrounded, and single and double-wye capacitor bank applications. It provides sensitive voltage differential and current unbalance protection with compensation adjustment for small voltage differential levels due to variations in individual capacitor elements from manufacturing, potential transformer, or instrument transformer measurement error. Each differential and unbalance element provides three levels of detection (low-set alarm level, trip pickup level, and high-level trip pickup level), each with its own definite-time delay. Instantaneous and time-overcurrent elements, as well as voltage elements, provide backup protection.

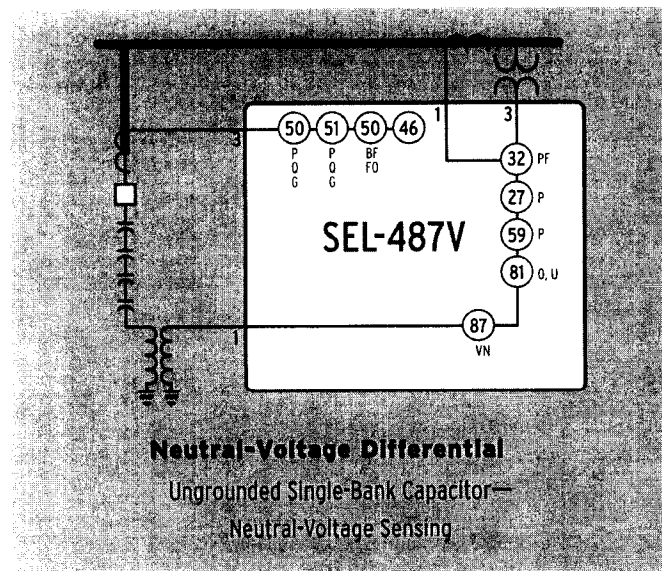
### Differential Protection

The phase differential elements are used to detect variations in capacitor bank impedance due to loss of individual capacitor elements, a single capacitor unit, or an entire group of capacitor units. Filtering minimizes voltage transients due to line-switching operations.



### Phase Voltage Differential Elements

Protect grounded wye capacitor bank configurations with SEL-487V phase voltage differential elements. Three-phase voltage differential elements measure voltage differences between bus or line phase voltages and the tapped voltage of the grounded wye capacitor bank.



### Neutral-Voltage Differential Elements

Protect up to three ungrounded wye capacitor bank configurations with SEL-487V neutral-voltage differential elements. Three neutral-voltage differential elements calculate zero-sequence voltage from three-phase potential inputs provided from the line or bus. The calculated zero-sequence voltage is then compared to the zero-sequence voltage measured by a potential transformer connected between the capacitor bank neutral and ground.

# Faulted-Phase Identification Protection

## Find Faults Faster

Reduce the time needed to identify faulted capacitor bank units with the faulted phase and section identification logic in the SEL-487V. This logic provides discrete indications for the phase and section of the faulted capacitor units. For voltage differential applications, the phase angle of the differential voltage determines the faulted phase and the sign of the differential voltage determines whether the fault is above or below the tap. For current unbalance applications, the phase angle of the unbalanced current determines the phase and bank where the fault is located.



# Control

## Eliminate the Need for a Separate Capacitor Controller—Choose the Optional SEL-487V Control Feature

Obtain full control of your capacitor banks without the additional time, wiring, and installation of an additional device. Maintain system voltage, VAR, or power factor (PF) levels with deadband control functions, which include auto and manual as well as local and remote control capabilities. Apply control instability detection for alarm or blocking of control operations. Implement the time-of-day control feature to synchronize capacitor bank insertion with peak VAR demand periods for any weekday or weekend period.

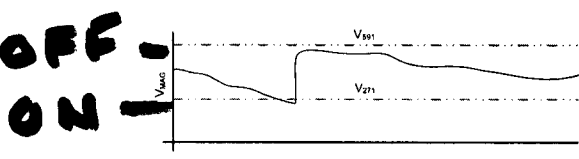


Figure 1. Voltage Control Deadband Characteristics

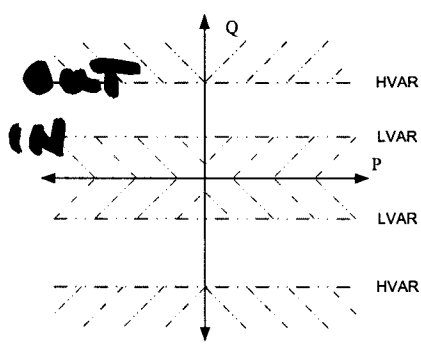


Figure 2. VAR Deadband Control Characteristics

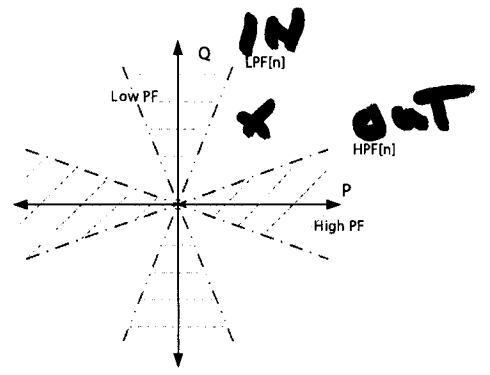


Figure 3. Power Factor Deadband Control Characteristics

# Settings

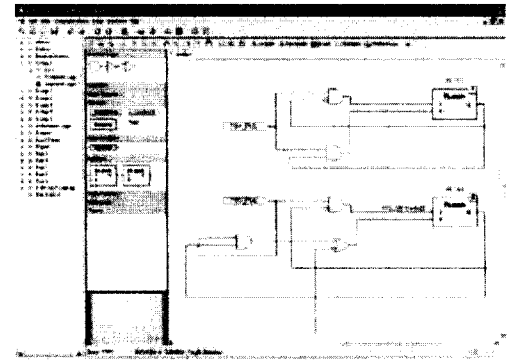
## Minimize Setup Costs and Commissioning Time With Application-Based Settings

The SEL-487V saves time by automatically providing the recommended capacitor bank primary protection elements based upon capacitor bank nameplate and configuration settings. The relay only displays applicable protection elements (differential voltage, differential neutral voltage, neutral-current unbalance, and phase current unbalance protection) for easy setup.

## Simplify the Process of Configuring Your SEL-487V Using the Graphical Logic Editor (GLE)

The GLE allows you to view your SELogic® control equations graphically, so your settings files can be documented for easier validation and commissioning. Convert existing SELogic control equations to easy-to-read diagrams, and save diagrams with your acSELERATOR QuickSet® SEL-5030 Software settings.

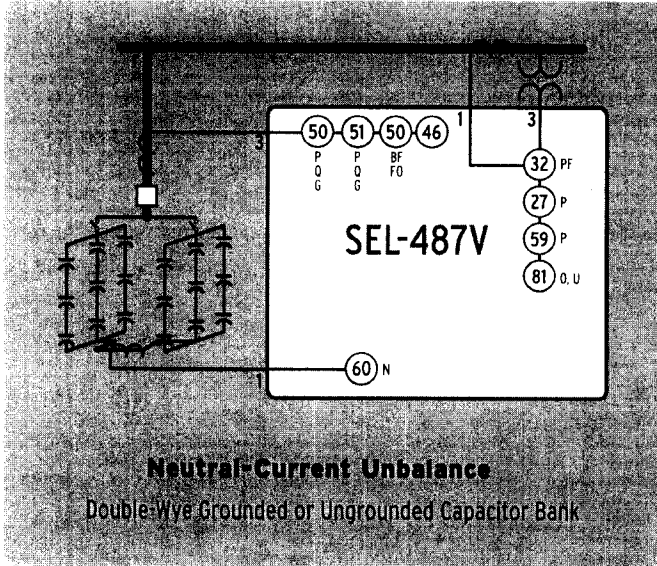
With the GLE capability in QuickSet, design new SELogic control equations using the convenient diagram navigation tool, drag-and-drop interface, function block diagrams, and automatic layout function. Manage your control diagrams with a full element palette. The GLE will aid in reducing design errors as well as time and expense in commissioning relays.



acSELERATOR® graphical logic editor (GLE).

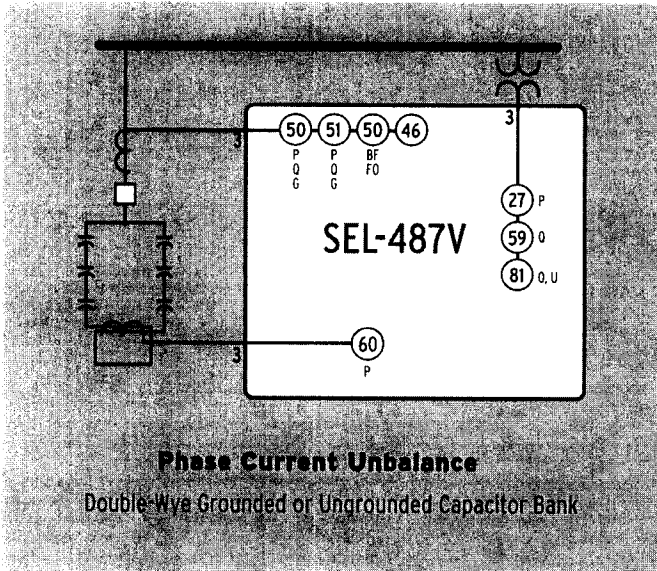
**Unbalance Protection**

The phase current unbalance elements use the positive-sequence voltage as a reference to provide a fault directional indication. Fault direction is based upon the polarity of the phase current to the relay.



**Neutral-Current Unbalance Elements**

Protect ungrounded capacitor bank configurations with the SEL-487V neutral-current unbalance elements. Three elements provide protection for up to three double-wye capacitor banks.

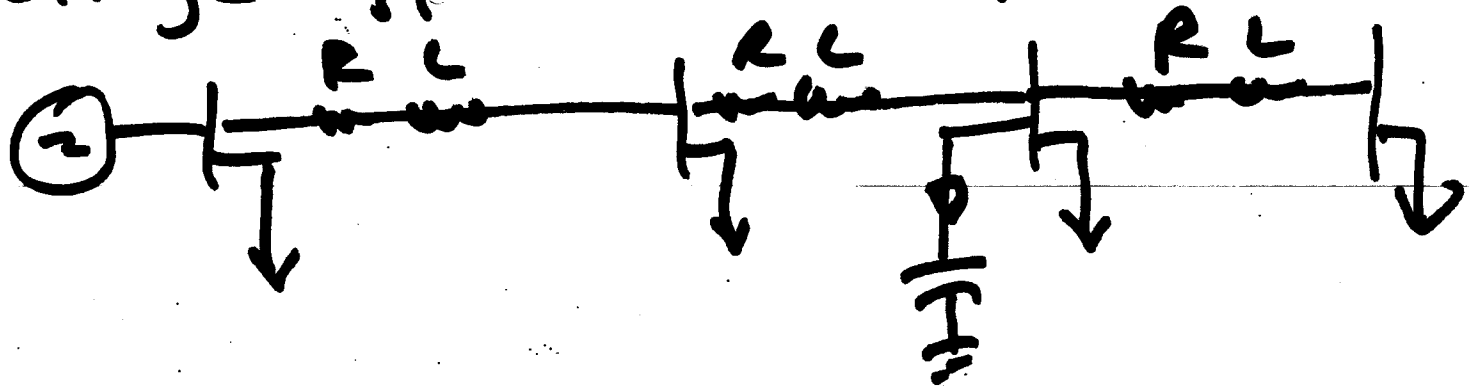


**Phase Current Unbalance Elements**

Protect both grounded and ungrounded double-wye capacitor bank configurations with the SEL-487V phase current unbalance elements. The SEL-487V provides three-phase current unbalance elements with nulling functions.

# Cap Banks

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

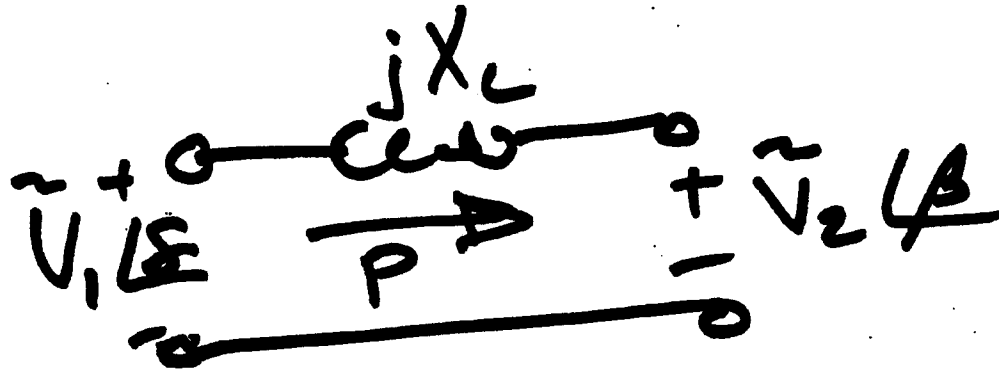




# Power Transfer

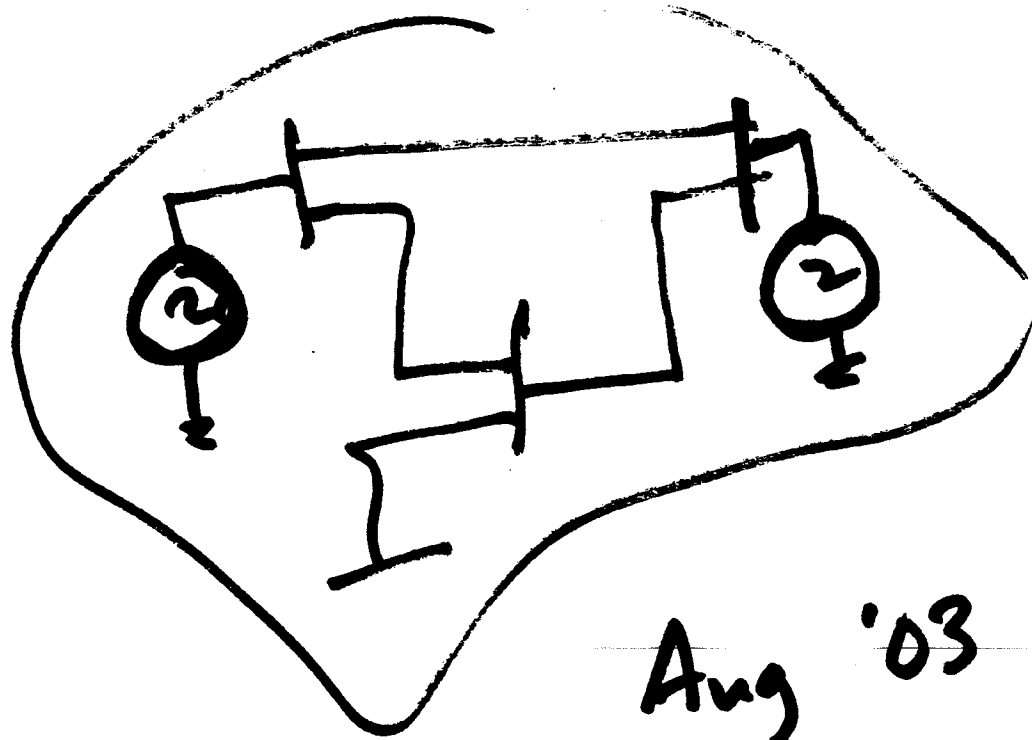
- Boost voltage a bit higher, more power can be transferred.

ex:



$$\frac{1.05^2}{.95^2} = \underline{\underline{1.22x}} \quad P_{1.22} = \frac{V_1 V_2}{X_L} \sin(\delta - \beta)$$

- Reactive Power Support/Reserve

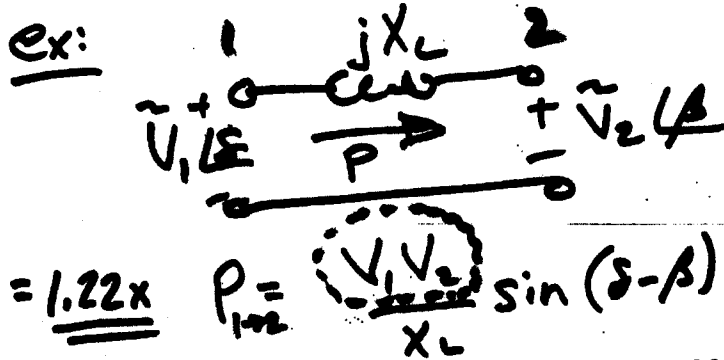


Aug '03 Blackout

- Voltage Support

# Power Transfer

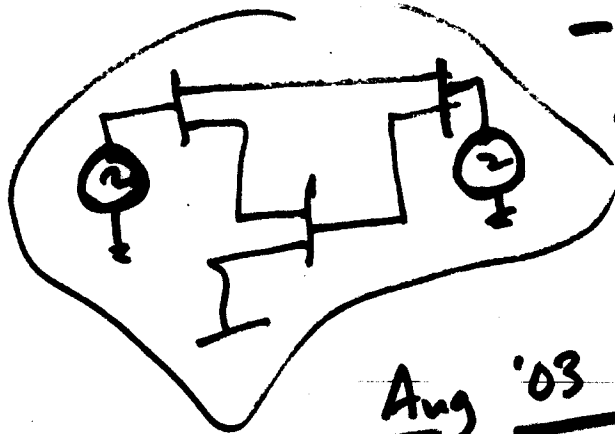
- Boost voltage a bit higher, more power can be transferred.



$$\frac{1.05^2}{.95^2} = 1.22x$$

- Reactive Power Support/Reserve

- Cap Banks
- Synch Mach
- FACTS
- SVCs



Aug '03 Blackout

- Voltage Support

- Voltage Stability (prevent voltage collapse)

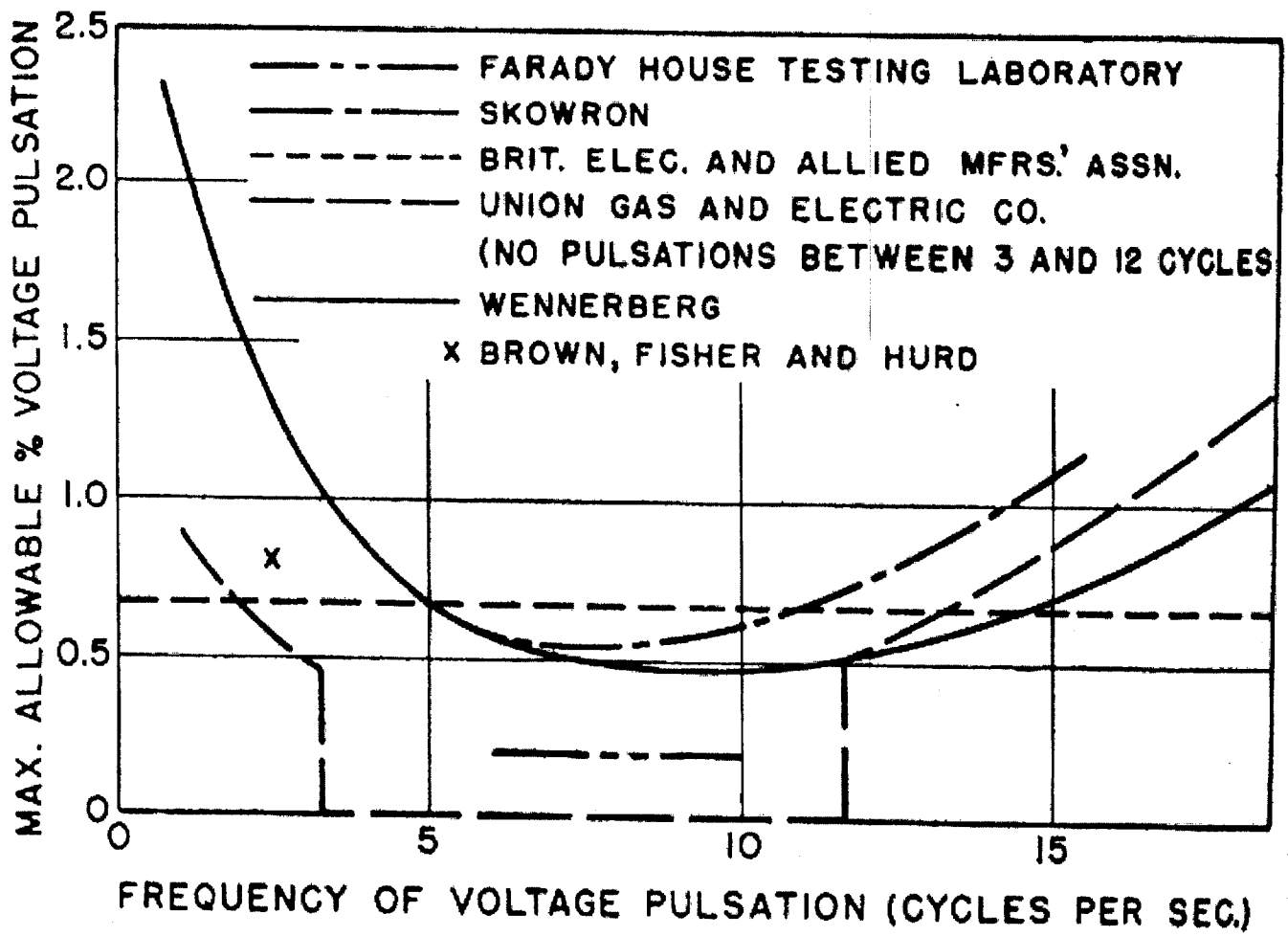
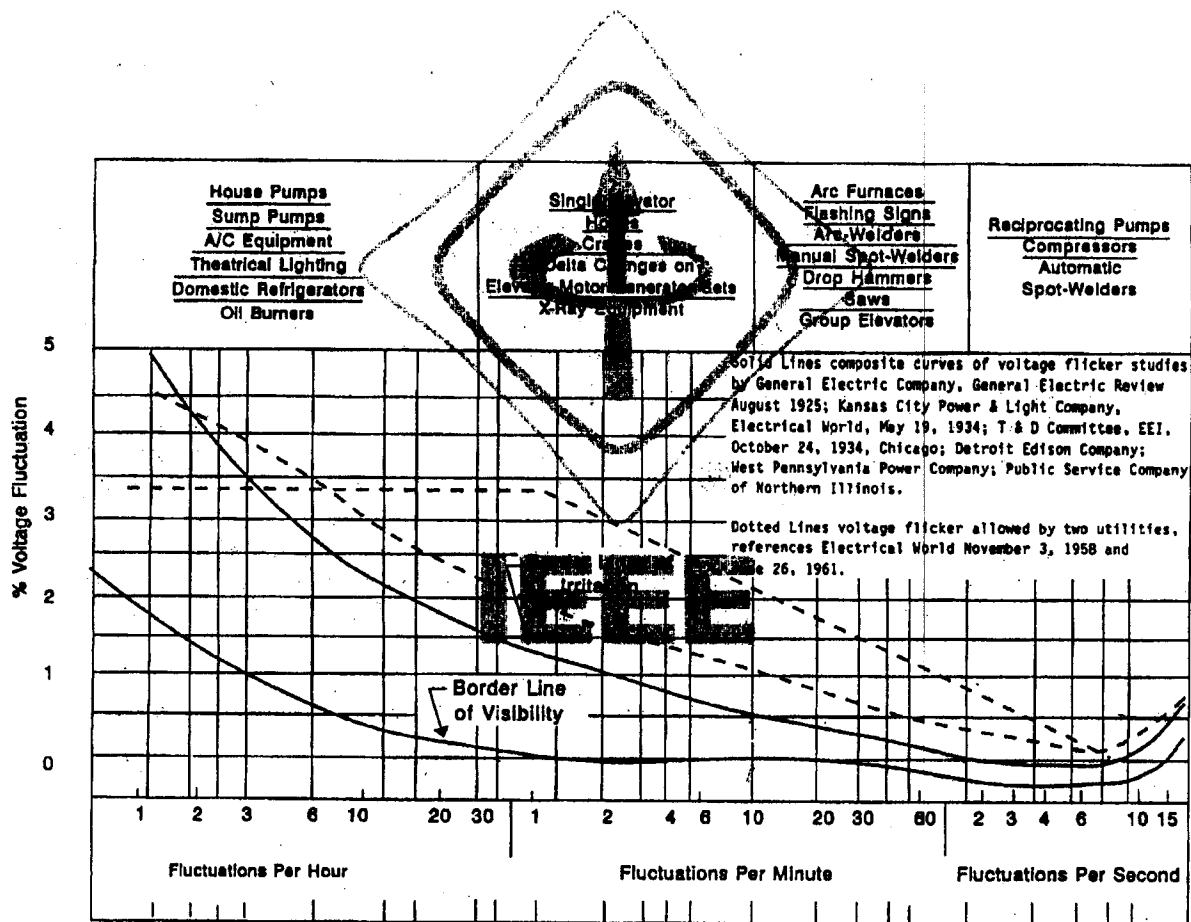


Fig. 4—Recommended maximum allowable cyclic variation of voltage.

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.



→ 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 & McDonnell (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/variatioins 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 an explicit delta-V standard, other than the flicker curves. I would assume that the transmission cap switching would be infrequent. The l.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.

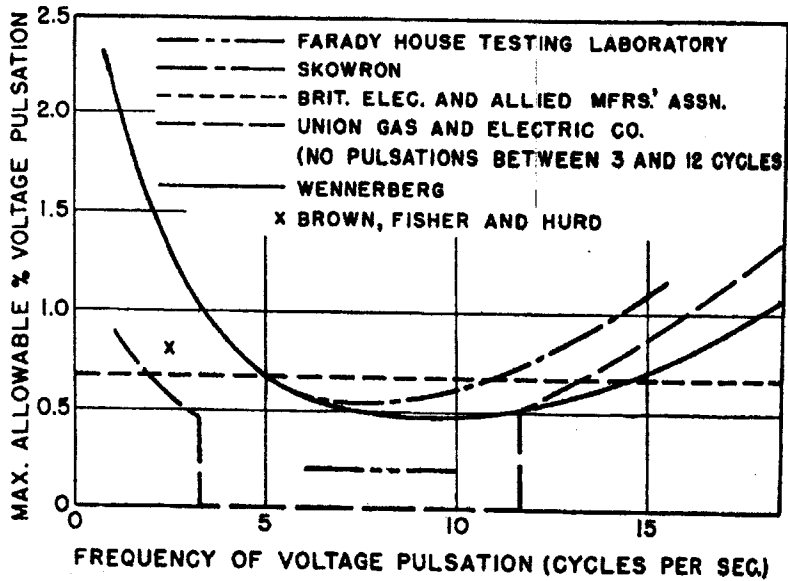
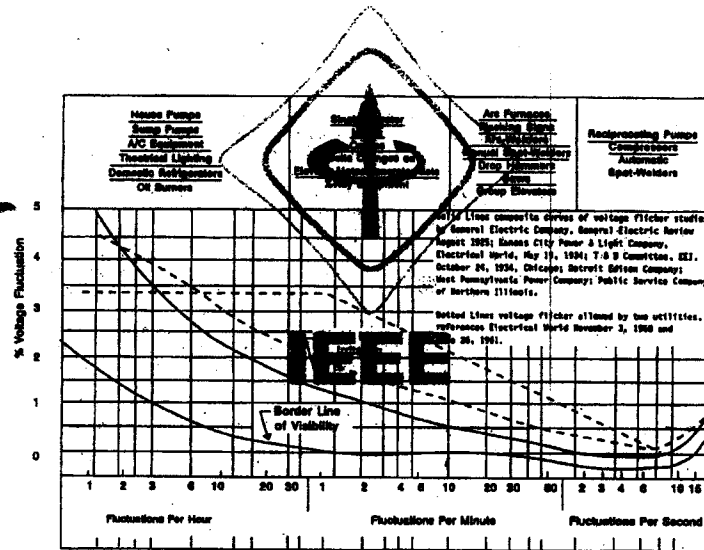


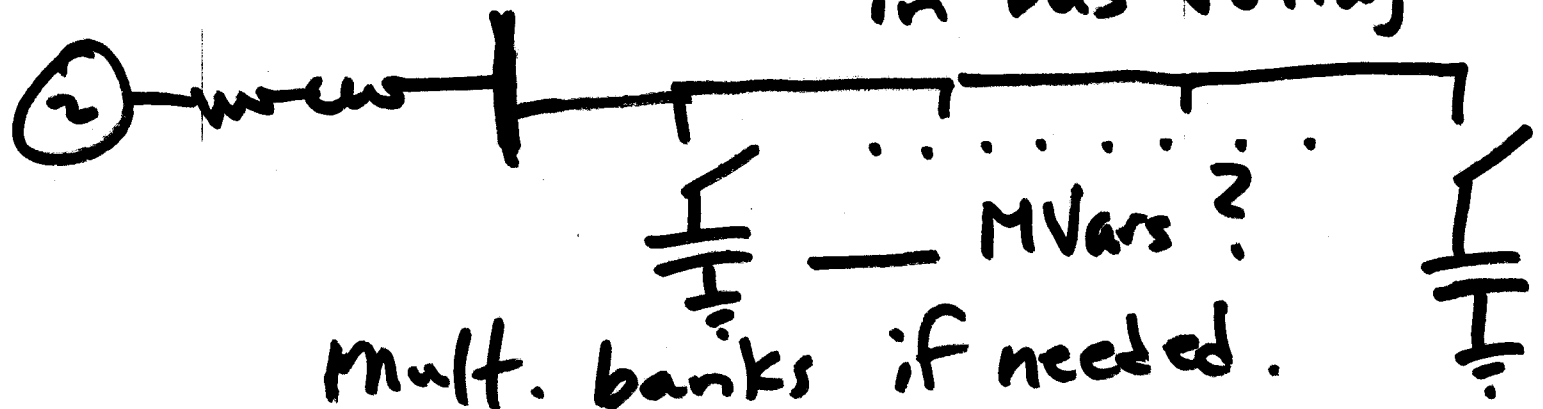
Fig. 4—Recommended maximum allowable cyclic variation of voltage.

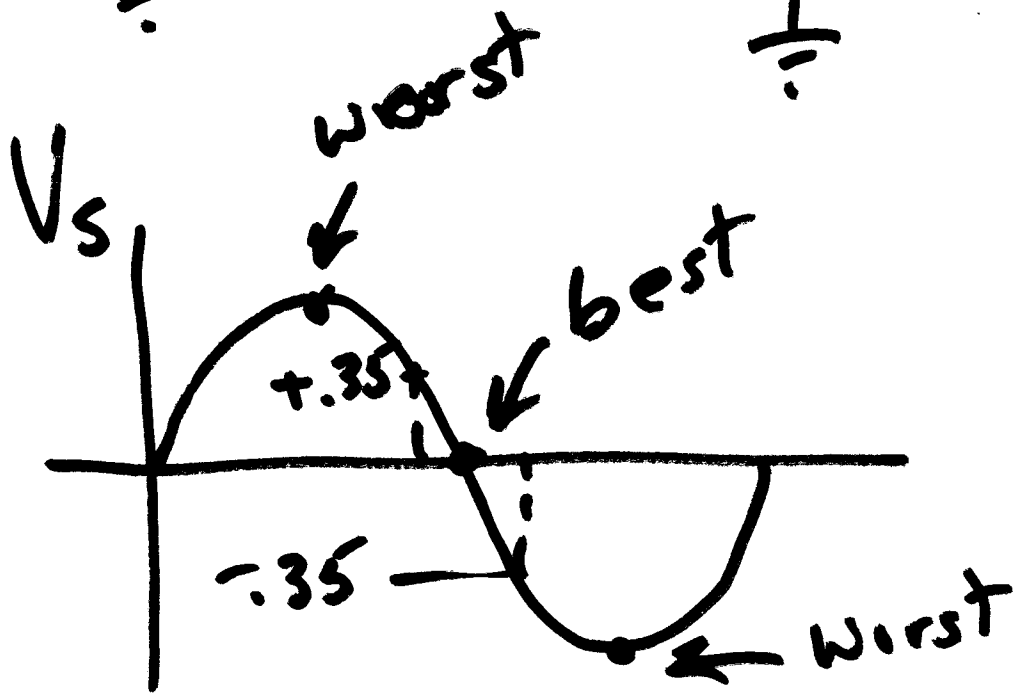
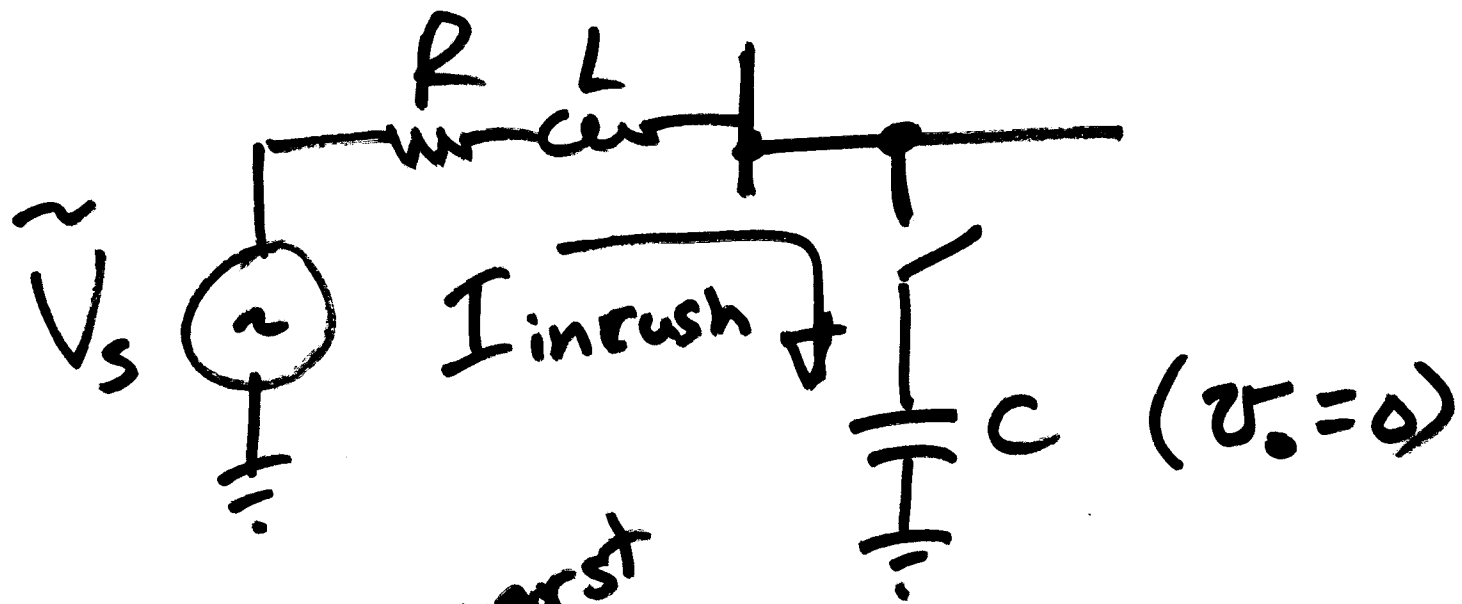
TABLE 1—MAXIMUM ALLOWABLE VOLTAGE FLUCTUATIONS

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.

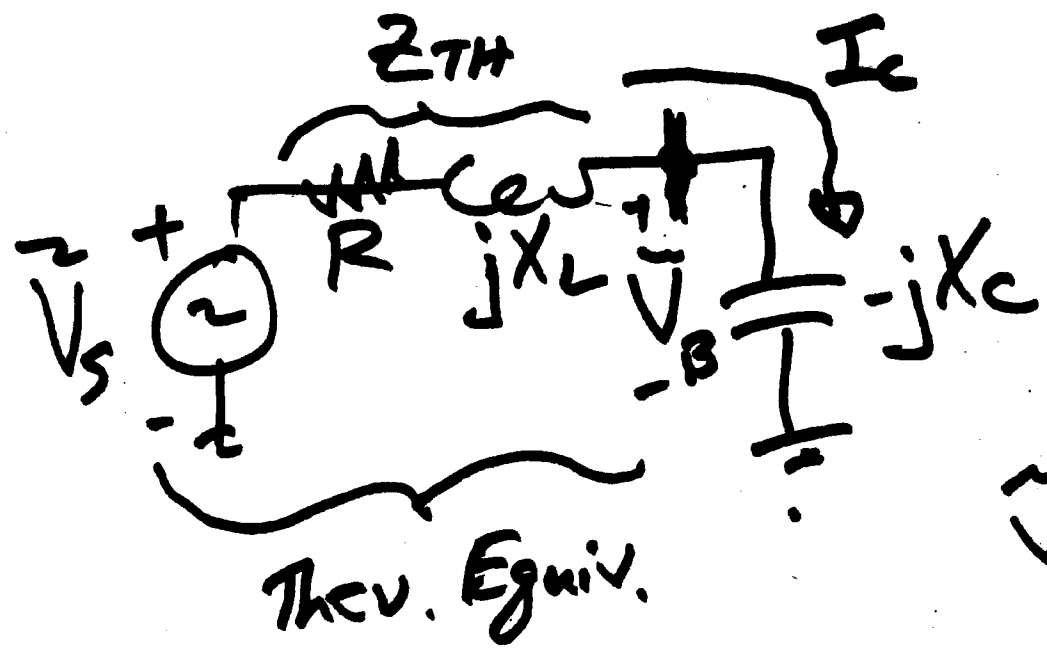


← 2-3% "bump" in bus voltage.









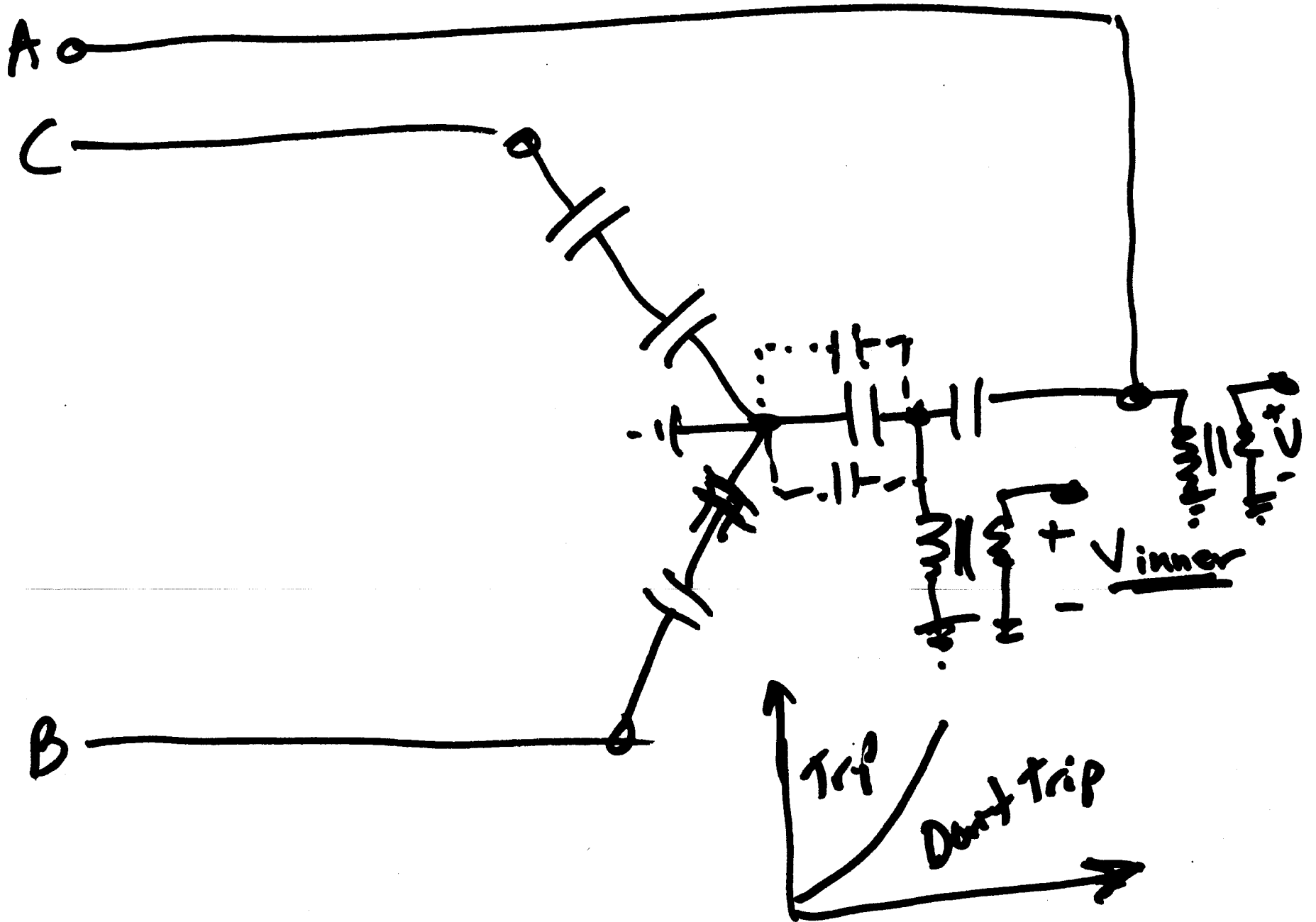
$$\begin{aligned} \tilde{V}_B &= I_c (R + jX_L - jX_C) \\ &= I_c R + I_c jX_L - I_c jX_C \end{aligned}$$

$$\tilde{V}_B = \tilde{V}_s \left[ \frac{-jX_C}{R + jX_L - jX_C} \right]$$

$$V_s - \underline{I_c R} - \underline{I_c j X_L} + \underbrace{I_c j X_C}_{\text{Neg Voltage Drop}} = 0$$

Neg Voltage Drop

# Externally Fused or Internally Fused



Capacitor Bank Design and Protection

Bruce Mork  
Michigan Tech University

25 Apr 1998

6

Bank Specification:

Grounded-Wye Bank

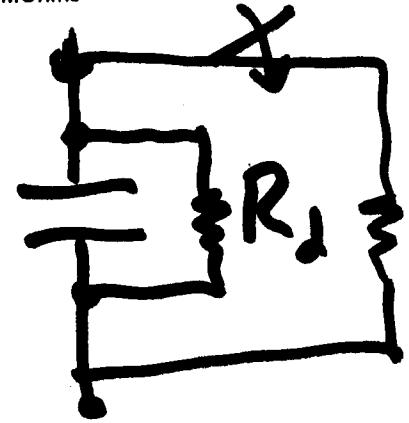
L-L System Voltage: 13.8 kV  
Size of Bank: 80 MVAR

Can Specs:

Voltage: 13.2 kV  
Rating: 200 KVAR  
Loss: 0 W/KVAR  
Capacitance: 3.008 uFarads  
Impedance: 881.79 Ohms  
Current: 15.06 Amps  
Diss Ohms: 8.818 MOhms

Configuration:

	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:		32.66	Ohms
Impedance/Phase:		163.29	Ohms
Diss Ohms/Phase:		1.633	MOhms
Discharge RC Time Constant:		132.63	Secs



550V  
5 mins

Performance:

	0.95	1.00	1.05
System Voltage, pu:			
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
Dischg Time to 50V:	992.95	999.75	1006.22

Group Voltages:

VT Ratio:  $\frac{kV}{V}$   
13.279 / 120

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

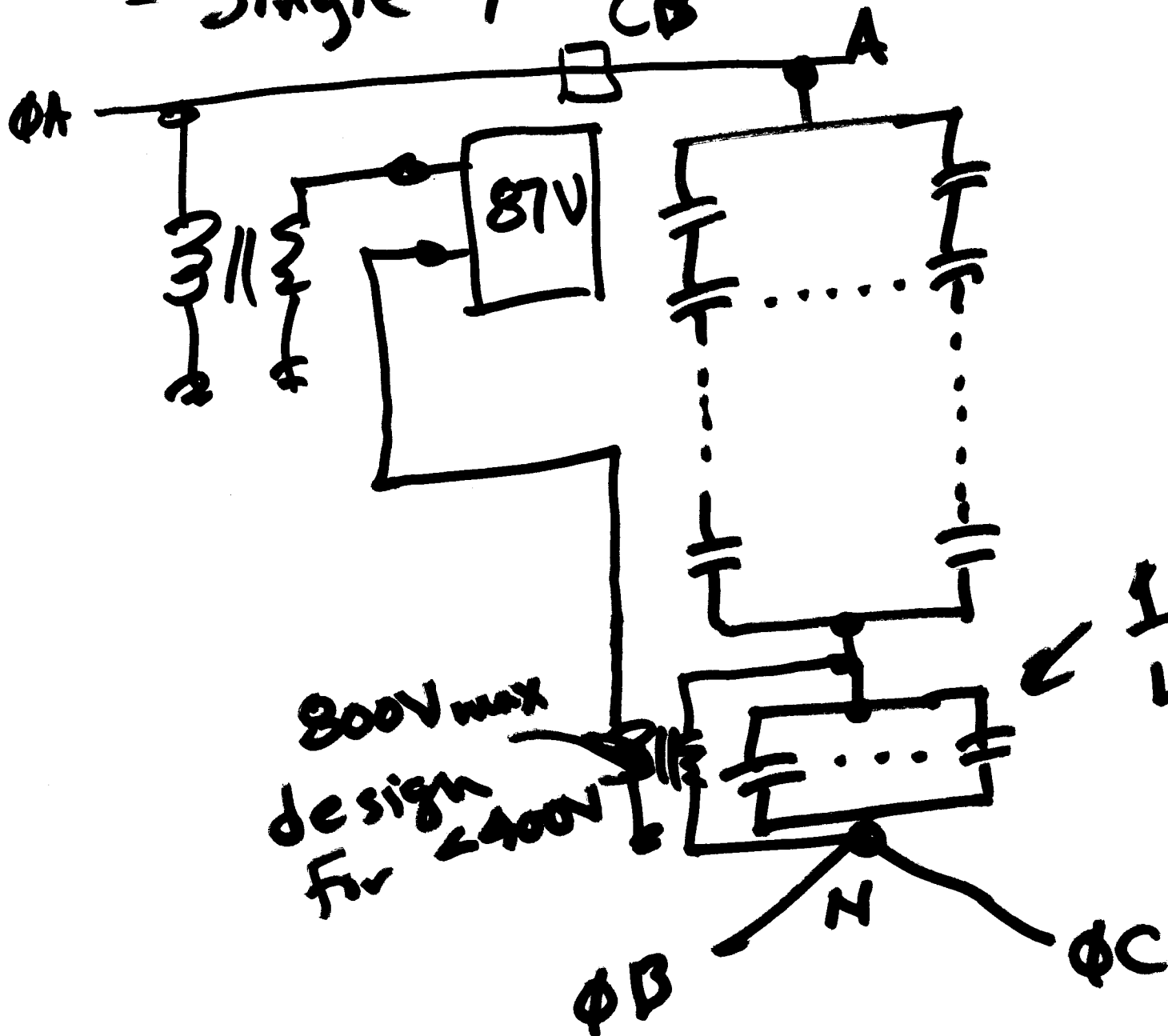
This Group:	14.311	15.064	15.818 kV
	1.078	1.134	1.191 Per Unit
	129.33	136.13	142.94 VT Sec Volts
Other Groups:	12.191	12.833	13.474 kV
	0.918	0.966	1.015 Per Unit
	110.17	115.97	121.76 VT Sec Volts

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from Class  
web page

CAPBANK.XLS

# Fuseless Cap Banks

- Single Y CB



800V max  
design  
for 2400V

1 or more  
LV or "newt"  
caps