EE 5220 - Lecture 7

Mon Jan 24, 2022

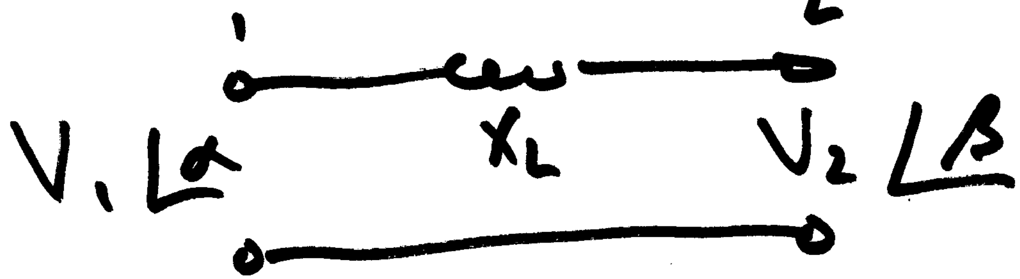
Topics for Today:

- Startup
    - Web page: https://pages.mtu.edu/~bamork/ee5220/
    - Book, references, syllabus, more are on web page.
    - Software - Matlab, ATP/EMTP on remote.mtu.edu (requires VPN)
    - ATP tutorials posted on our course web page
    - Circuit analysis tutorials posted, “Pre-Req Material”
    - EE5220-L@mtu.edu (participation = min half letter grade)

- HW#3 probs 3.2, 3.3, 3.4, 3.6, 3.12 due Feb 1st.
- ATP Simulation pointers
- Cap Bank Switching - 5 main scenarios (continued)
    - First (single) bank energization
    - Back-to-back switching
    - Outrush
    - TRV
    - Voltage Magnification

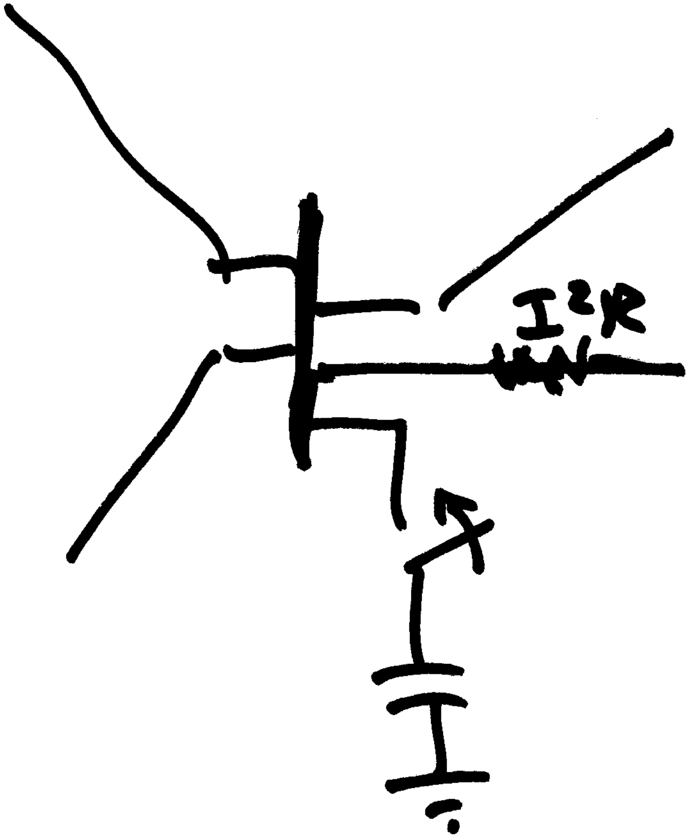
Why have Cap Banks?

- Voltage support
- Var Support (V stab)
- Power Transfer

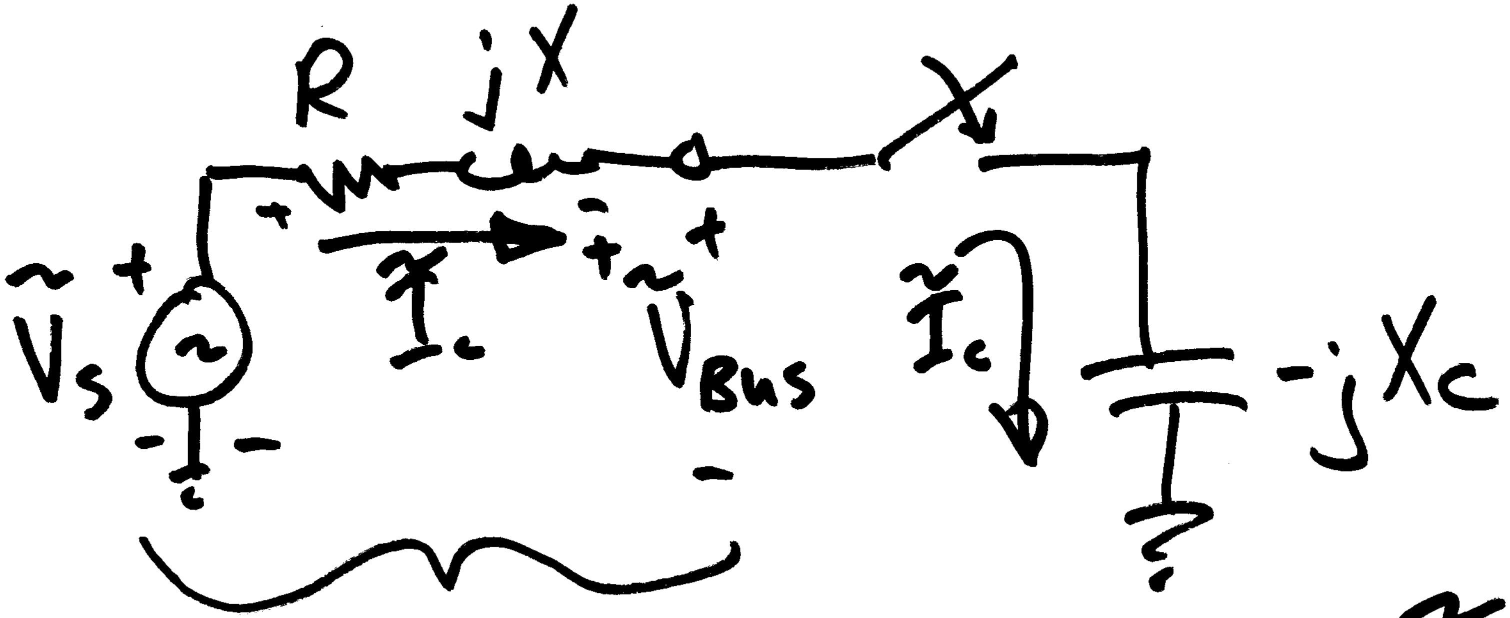


$P_{1-2} \Rightarrow$?

$$P_{12} = \frac{V_1 V_2}{X_L} \sin(\alpha - \beta)$$

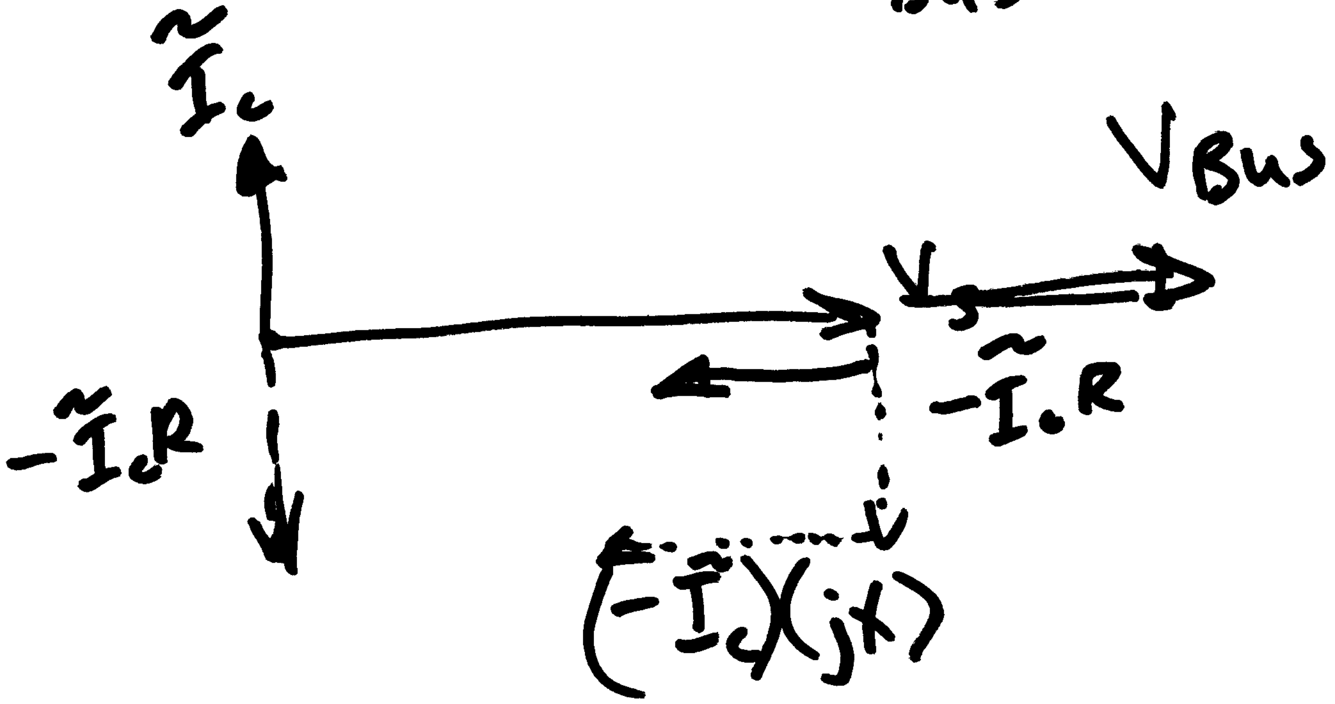


(.95)(.95)
vs.
(1.05)(1.05)



Thev. Equiv.

$$\tilde{V}_{Bus} = \tilde{V}_s - \tilde{I}_c (R + jX)$$



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 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.

Max "bump" in $\tilde{V}_B$

Printed for Bruce Mork <bamork@mtu.edu> 4/1/2005

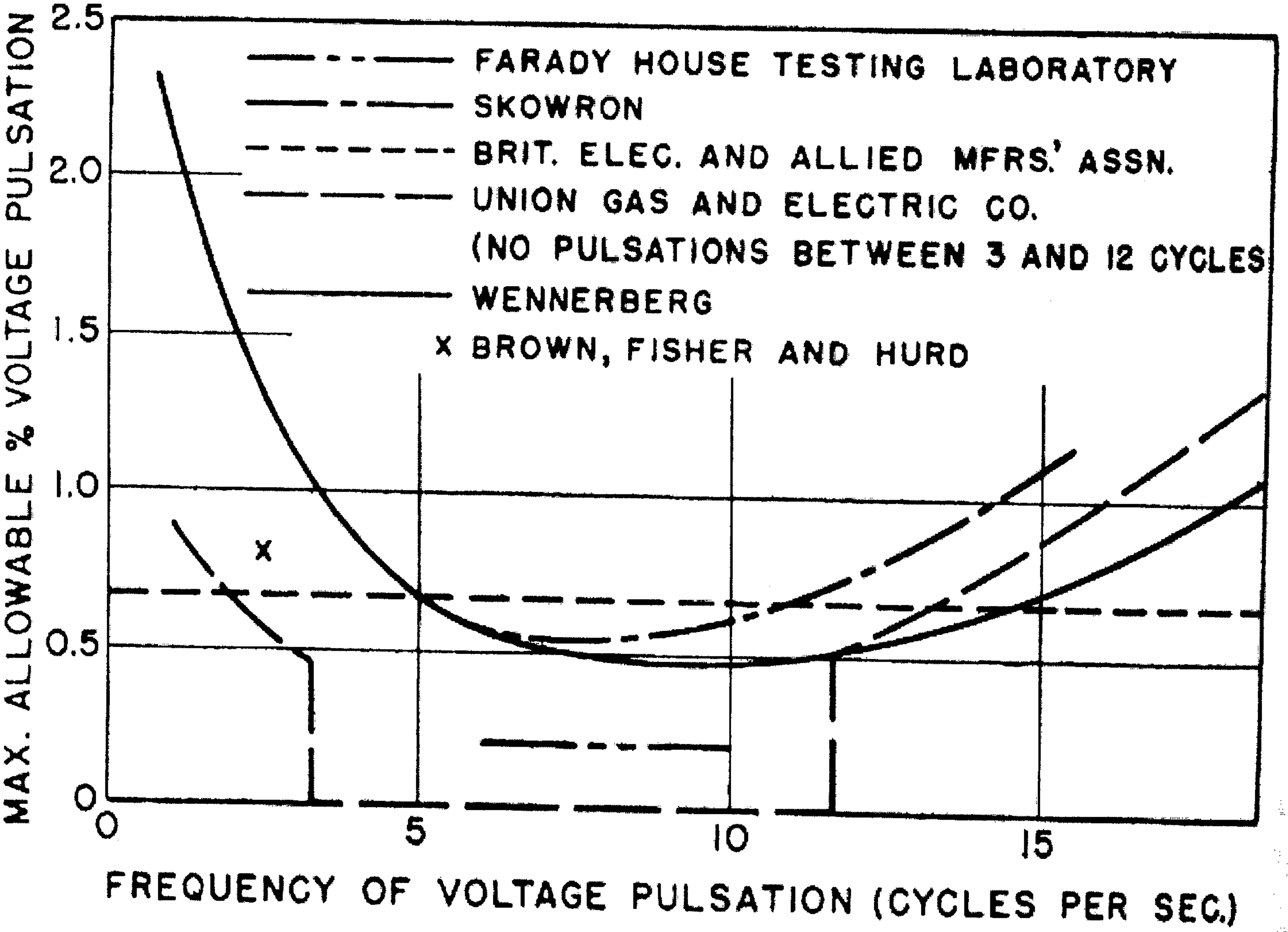
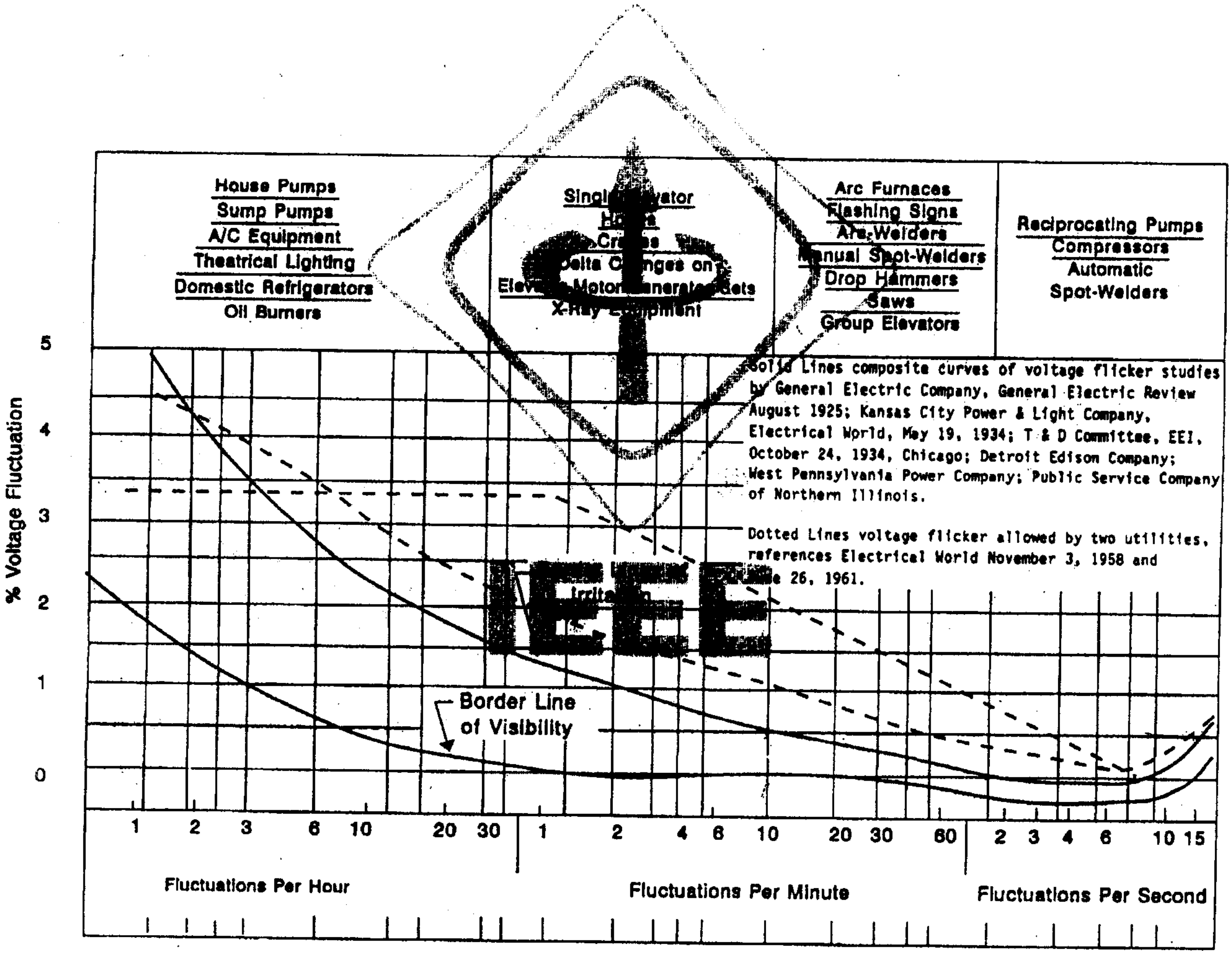


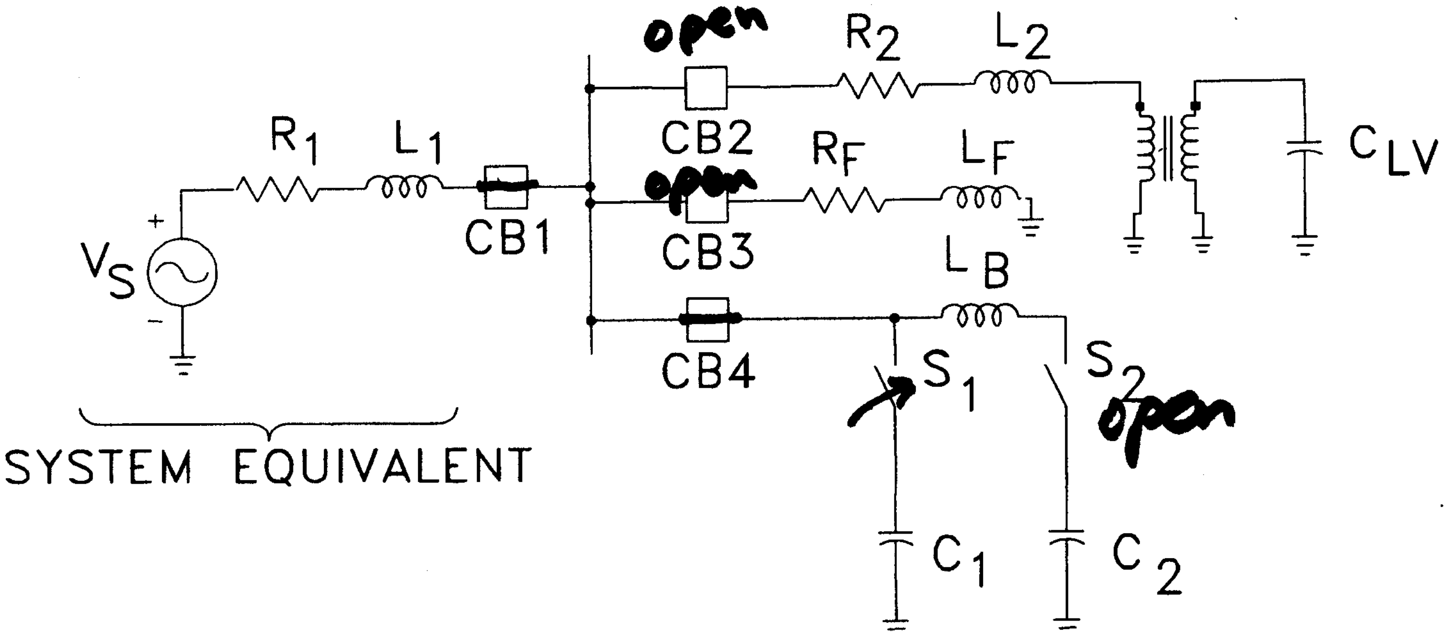
Fig. 4—Recommended maximum allowable cyclic variation of voltage.

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.



Sample 34.5-kV system, developed from Fig. 3.4 in Greenwood.



R_1 = 0.5 Ohms

L_1 = 3 mH

R_2 = 0.001 Ohms

L_2 = 12 mH

C_1 = 40.1 μF (18 MVAR)

C_2 = 22.3 uF (10 MVAR)

C_{LV} = 601 μF

Dist. Transformer: 4:1 ratio

L_B = 19 μH

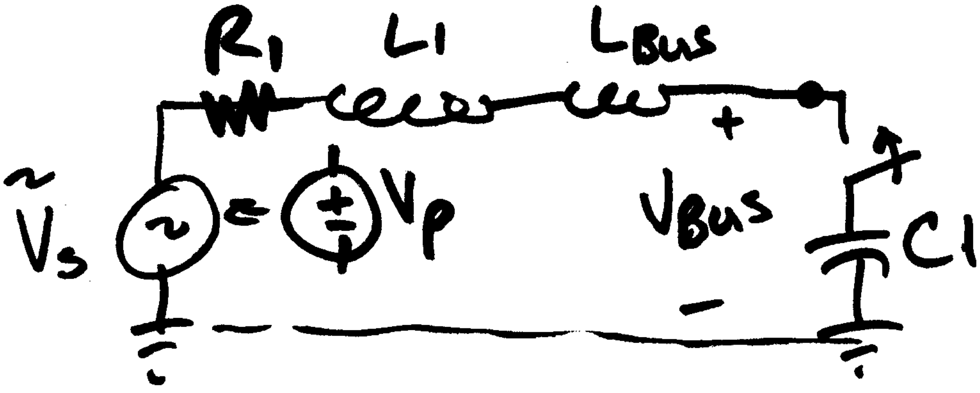
C_{BUSH} = 300 pF (see p.437)

Typical: 0.2 - 0.4 μH/ft

Tube Bus

Strain Bus

① Inrush - CB1 - Closed
CB4 - Closed
SW1 - Closing

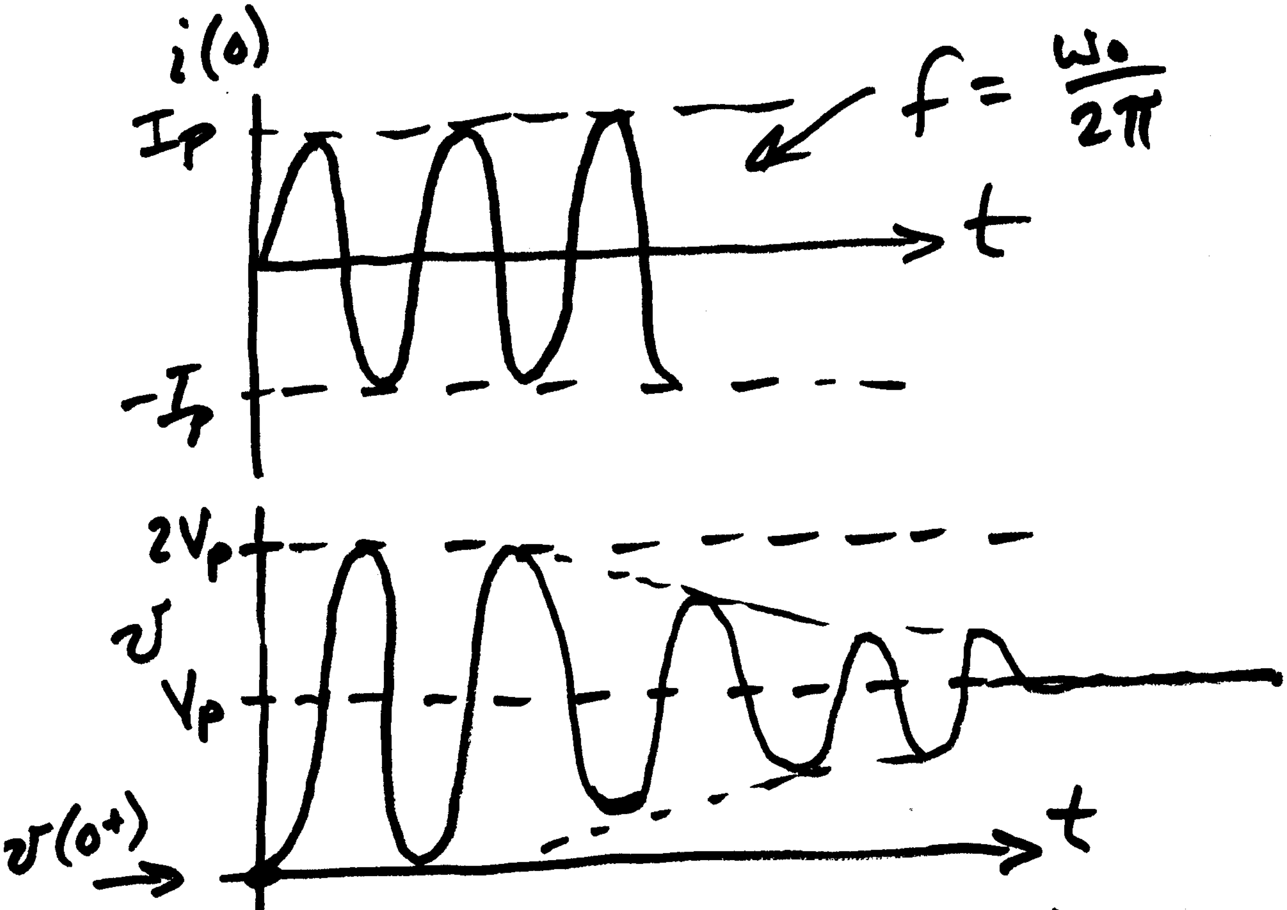


@ $t = 0^+$
V_{Bus} ↓ 0V

$$\omega_0 = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{(L_1 + L_{Bus})(C1)}}$$

Typical to see $\underline{\omega_0 \text{ as } 400\text{-}800\text{ Hz}}$

$$I_p = ? = \frac{V_p}{Z_0} = \frac{V_p}{\sqrt{\frac{(L_1 + L_{Bus})}{C1}}}$$



$$f_0 = \left[\frac{4.43 - 0.89}{2}\right]^{-1} = \underline{563\text{ Hz}}$$

$$\omega_0 = \frac{1}{\sqrt{(.002)(40.1\times10^{-6})}} = \frac{1}{\sqrt{LC}}$$

$$= \text{[illegible]}\ s^{-1} = \text{[illegible]}\ 562\ \text{Hz}$$

$$I_p = \frac{V_p}{Z_0} = \frac{28{,}170}{\sqrt{\frac{.002}{40.1\times10^{-6}}}} = \text{[illegible]}\ \underline{3989\ A}$$

$$\boxed{Z_0 = 7.06\ \Omega}$$

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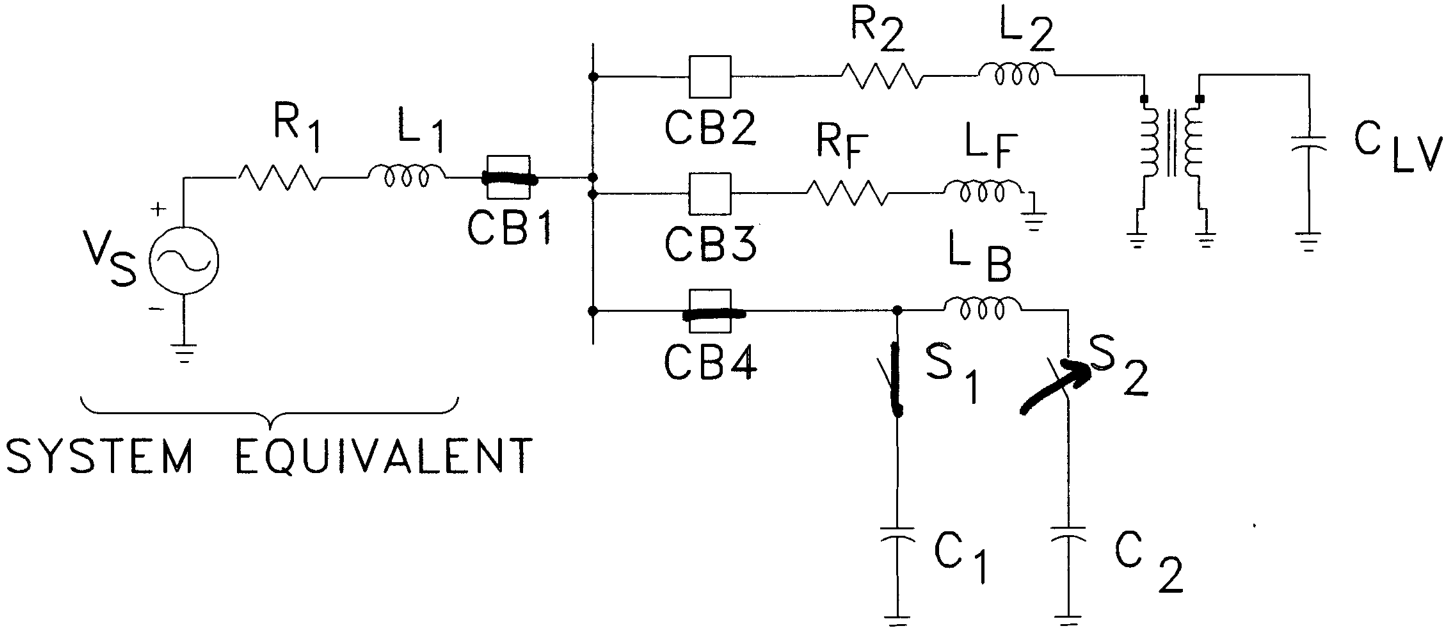
2) Back-to-Back

6

Sample 34.5-kV system, developed from Fig. 3.4 in Greenwood.



R_1 = 0.5 Ohms L1 = 3 mH R2 = 0.001 Ohms L2 = 12 mH

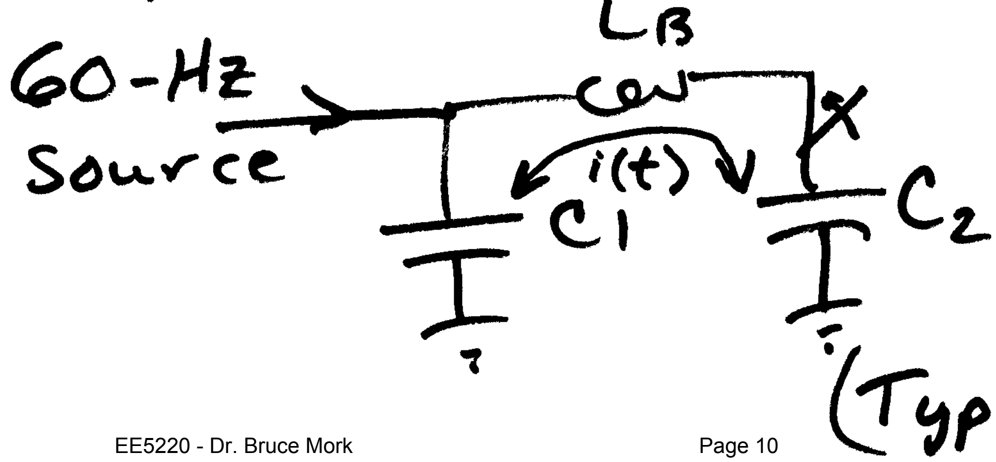
C_1 = 40.1 μF (18 MVAR) C_2 = 22.3 uF (10 MVAR) C_{LV} = 601 μF

Dist. Transformer: 4:1 ratio L_B = 19 μH C_{BUSH} = 300 pF (see p.437)

Back-to-Back

Operative Circuit:

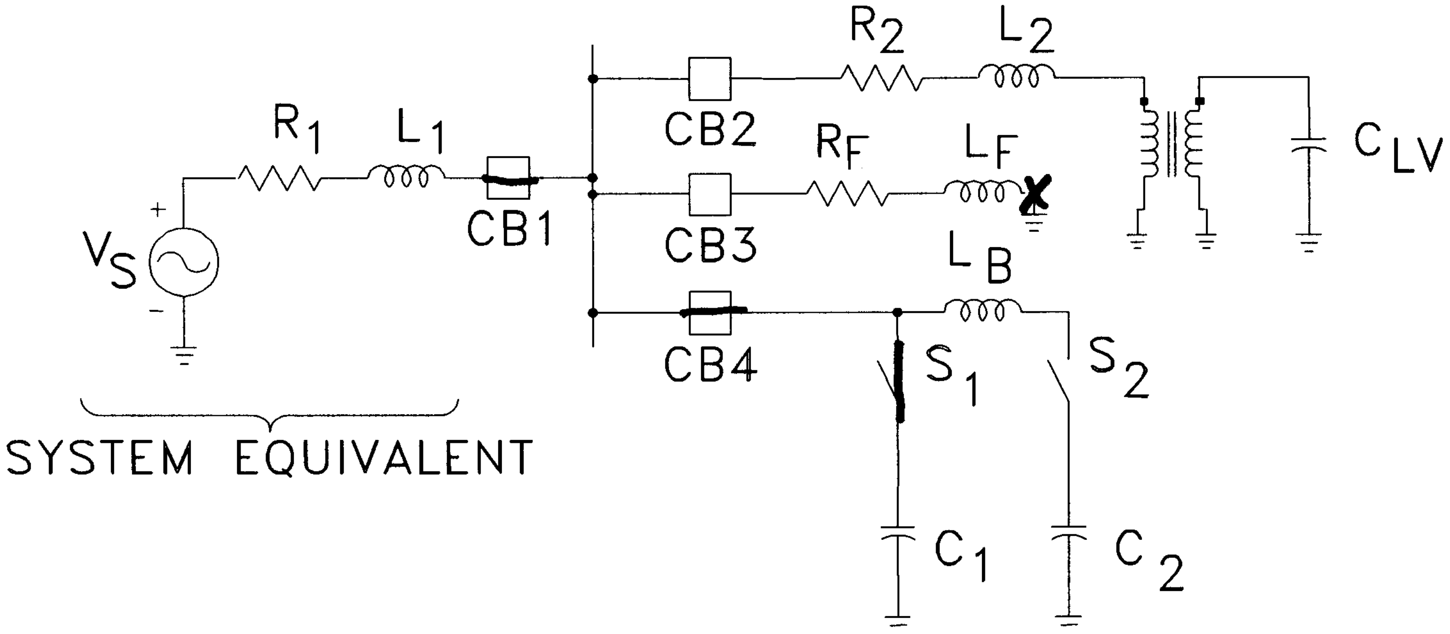
$$\omega_0 = \frac{1}{\sqrt{L_B \cdot \frac{C_1 C_2}{C_1 + C_2}}}$$



$$Z_0 = \sqrt{\frac{L_B}{\frac{C_1 C_2}{C_1 + C_2}}}$$

(Typ f_0: 3-15 KHZ)

Sample 34.5-kV system, developed from Fig. 3.4 in Greenwood.



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Dist. Transformer: 4:1 ratio L_B = 19 μH C_{BUSH} = 300 pF (see p.437)

Outrush – Cap banks discharge into nearby fault.

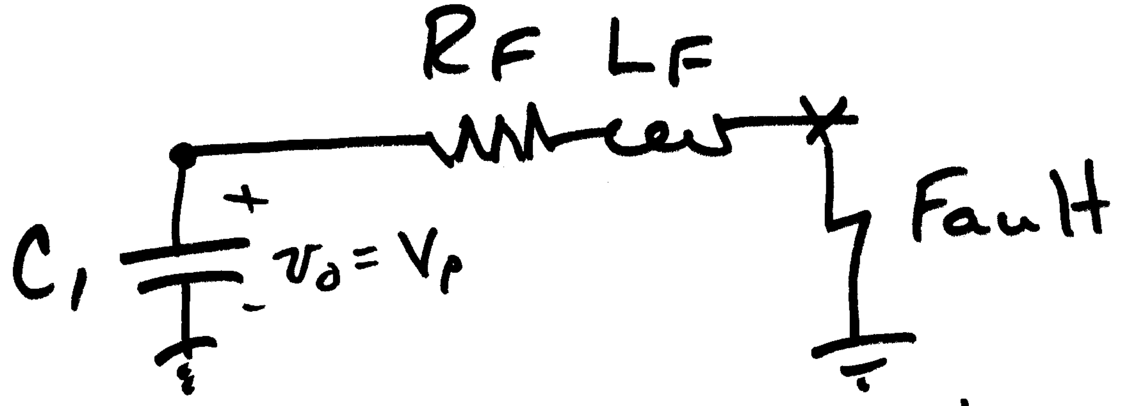
(Close CB3)

CBs may not handle it.

$\boxed{\text{Ratings of CB's: } I_p \times f_0}$

i) General Purpose
$I_p \times f_0 = 2\times10^7$

ii) Definite Purpose:
See IEEE Stds!

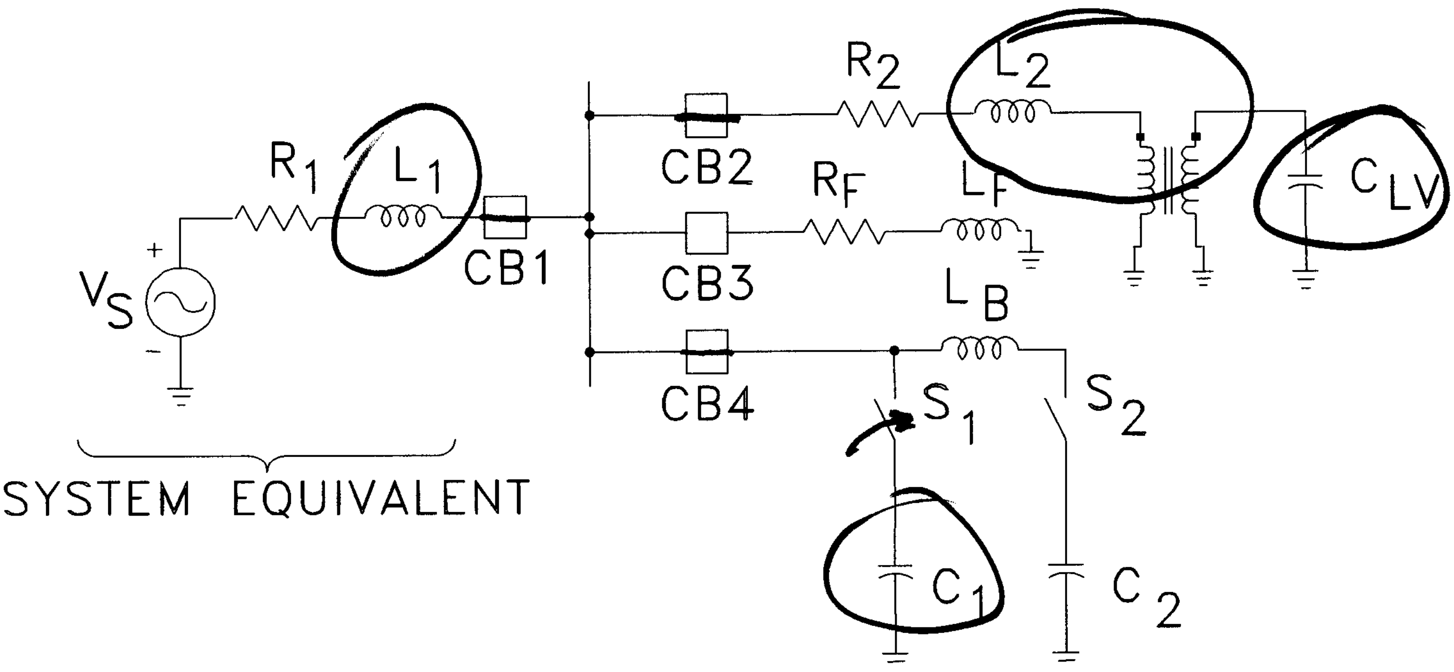


$$\omega_0 = \frac{1}{\sqrt{C_1 L_F}} \ * \quad \text{or} \quad \frac{1}{\sqrt{(C_1+C_2)L_F}}$$

$$Z_0 = \sqrt{\frac{L_F}{C_1}} \quad \text{or} \quad \sqrt{\frac{L_F}{C_1+C_2}}$$

(one Bank) (Both Banks)

Sample 34.5-kV system, developed from Fig. 3.4 in Greenwood.



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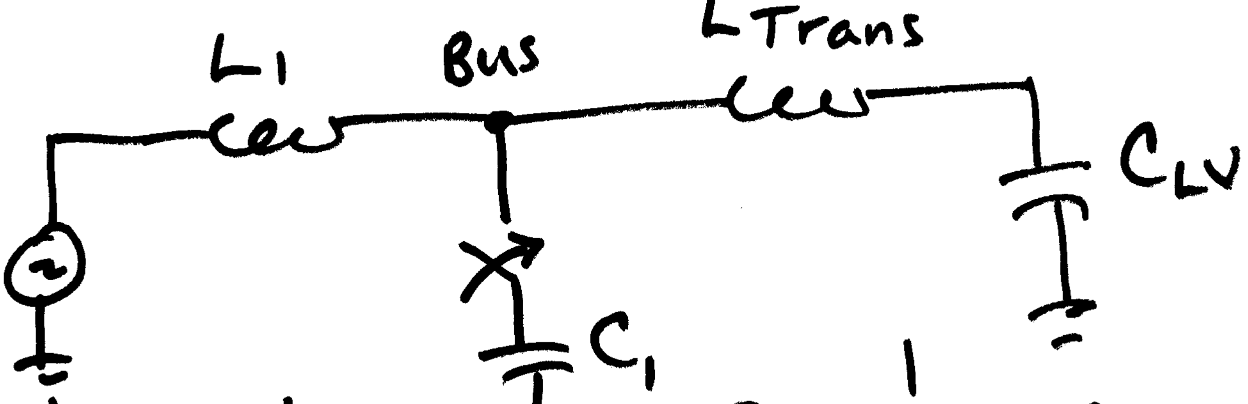
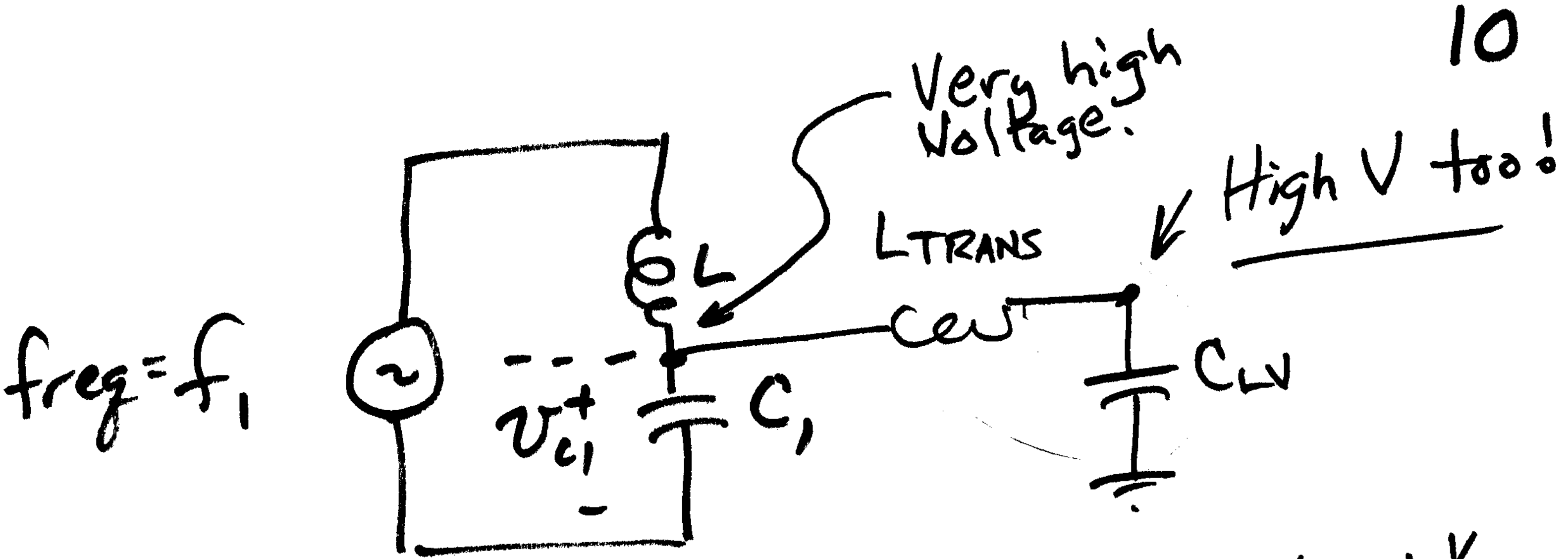
C_1 = 40.1 μF (18 MVAR) C_2 = 22.3 uF (10 MVAR) C_{LV} = 601 μF

Dist. Transformer: 4:1 ratio L_B = 19 μH C_{BUSH} = 300 pF (see p.437)

5) Voltage Magnification – Usually Low Freq



$$f_1 = \frac{1}{2\pi\sqrt{L_1 C_1}} \qquad f_2 = \frac{1}{2\pi\sqrt{L_T C_{LV}}}$$



Series resonance: $Z_{TOT} = jX_L - jX_c$

$= 0$

$$X_L = X_{C1}$$

$$\boxed{2\pi f_1 L = \frac{1}{2\pi f_1 C_1}}$$

$I \rightarrow \infty$

$V_L \rightarrow \infty$

$V_C \rightarrow \infty$

Per Unit voltage at CLV is higher than at C1, thus the name "voltage magnification."