Reactor Switching
and
Current Chopping

EMTP Training
Nov. 16th, 2001
Prof. Leonard J Bohmann

MichiganTech

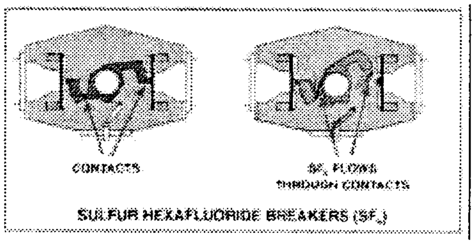
The Short Story

- CB can break currents too quickly
- $V = L\frac{di}{dt}$

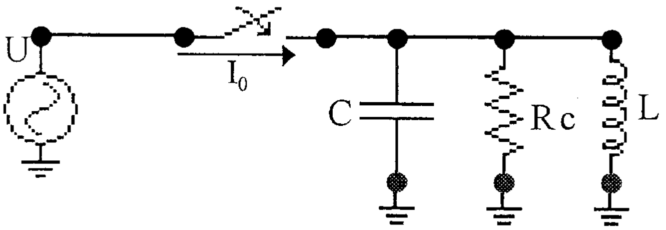
MichiganTech

Circuit Breakers

- Most Often SF6 or Air-Blast
- Happens at low levels of inductive current



Simplistic Equivalent Circuit



- L: inductance of coil
- C: capacitance of coil +bushing capacitance
- Rc: core loss resistance

Overvoltage

- Assumptions:
  No losses, Linear inductance
- Stored energy in inductor:

$$Energy = \frac{1}{2} L_M I_0^2$$

- Capacitor – Inductor Oscillation

$$\frac{1}{2} C V^2 = \frac{1}{2} L_M I_0^2 \Rightarrow V = I_0 \left(\frac{L_M}{C} \right)^{1/2} \approx I_0 Z_0$$

Example

Transformer: : 1 MVA, 13.8 kV,
$I_{exciting}$ =1.5 A rms, C =5000 pF, I_0 =2.5 A

$$L_M = \frac{V}{\omega \; I_{exciting}} = \frac{13{,}800}{\sqrt{3} \times 377 \times 1.5} = 14H$$

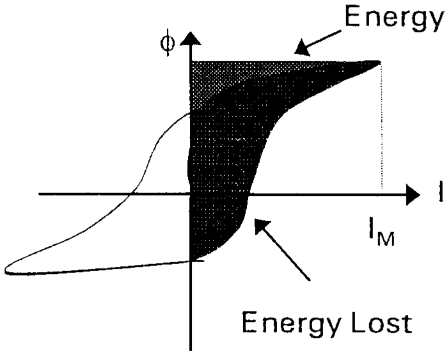
$$Z_0 = \left(\frac{L_M}{C} \right)^{1/2} = \left(\frac{14}{5 \times 10^{-9}} \right)^{1/2} = 53{,}000\Omega$$

Example p.2

$$f = \frac{(1/L_M C)^{1/2}}{2\pi} = 602\ Hz$$

$$V = I_0\left(\frac{L_M}{C}\right)^{1/2} = I_0 \times Z_0 = 2.5 \times 53{,}000 = 132kV$$

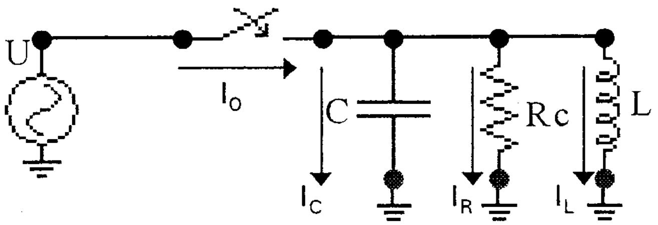
With Saturation



Only about 30% of stored energy is released

$$V \approx I_0\left(0.3\frac{L_M}{C}\right)^{1/2} = 72.7kV$$

Formal Analysis



$$I_C + I_R + I_L = 0$$

$$I_C = C\frac{dV}{dt} \qquad I_R = \frac{V}{R} \qquad I_L = \frac{1}{L_M}\int V \cdot dt$$

MichiganTech

Formal Analysis 2

$$\frac{d^2V}{dt^2} + \frac{1}{RC}\frac{dV}{dt} + \frac{V}{L_M C} = 0$$

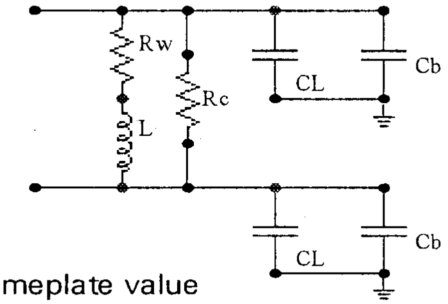
$$V(s) = \frac{sV_0}{s^2 + \left(s/_{RC}\right) + \left(1/_{L_M C}\right)} + \frac{V_0}{RC}\,\frac{1}{s^2 + \left(s/_{RC}\right) + \left(1/_{L_M C}\right)} - \frac{I_0}{C\left[s^2 + \left(s/_{RC}\right) + \left(1/_{L_M C}\right)\right]}$$

MichiganTech

Characteristics of Transients

- Frequency of oscillation is a few kHz for iron core reactors, hundreds of kHz for dry, air-core reactors
- Relatively little energy is trapped
  Surge arrestors can usually deal with it

Detailed Reactor Model



Rc: Core loss; ˜1000 pu for iron core, infinite for air core

Rw: Winding resistance; same value as similar transformer winding, ˜0.5%

L: Reactor inductance, nameplate value

CL: ½ Winding capacitance; iron core - same as similar transformer winding (See Ch 13, Greenwood); air core : 75 – 150 pF

Cb: Bushing capacitance; 150 – 600 pF

Harner & Rodrigues

See also: C37.011
Appendix B
Tables B1 → B7

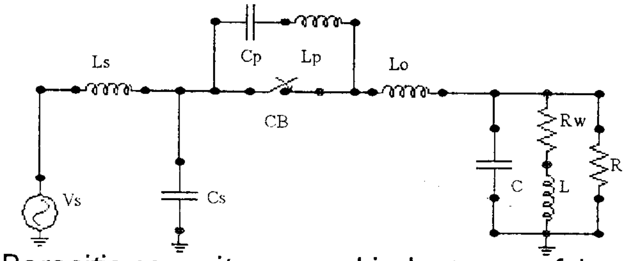
Restrikes

When breaking low level highly reactive currents:

- The arc is weak because the current is not large
- The contacts are not far apart when the arc extinguishes
- The system voltage is near its peak so the recovery voltage can be large

Dependent on how quickly the dielectric strength between the contacts recovers

Restrike Equivalent Circuit



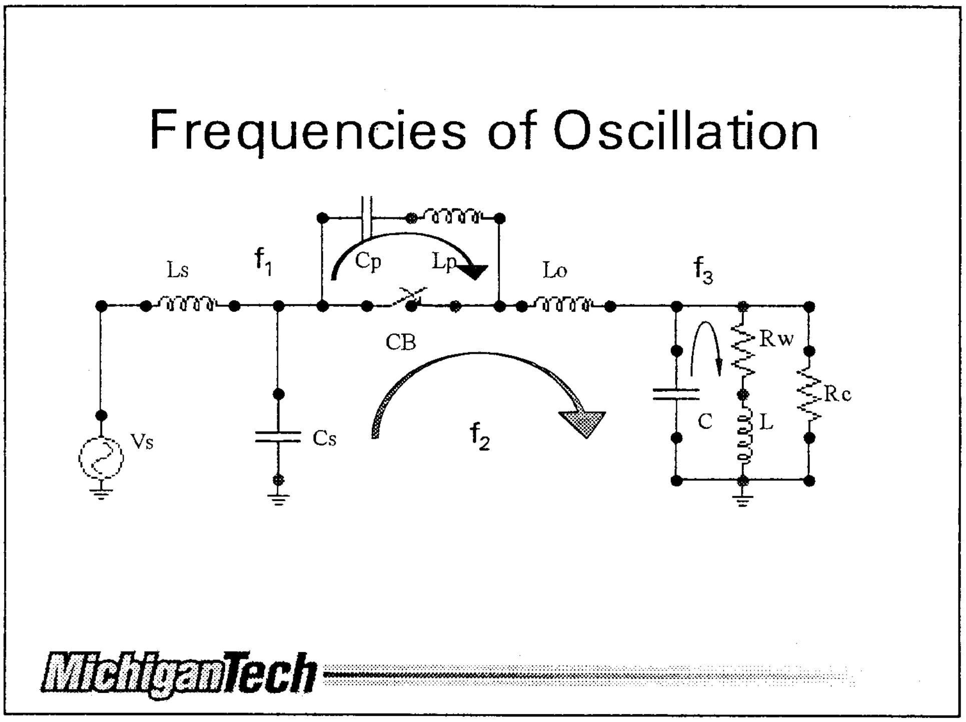
Cp, Lp: Parasitic capacitance and inductance of the CB; value ?, use potential grading cap

Ls: Equivalent system inductance

Lo: bus work inductance

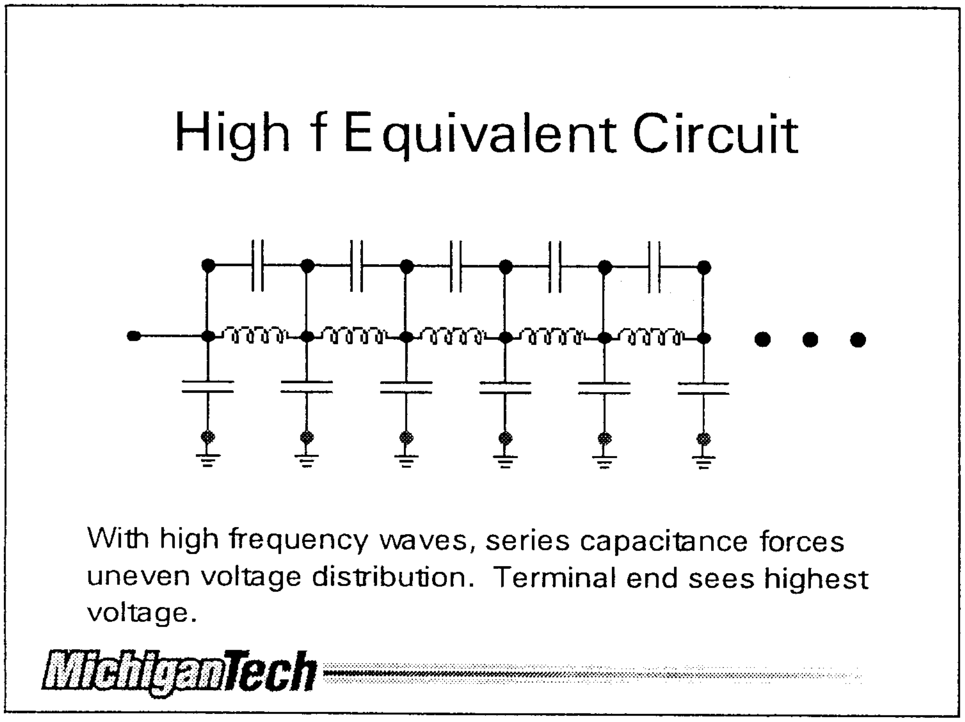
Cs: System capacitance; CB bushing and buswork

C: Reactor equivalent capacitance; CB bushing, reactor bushing, winding cap



Frequencies of Oscillation

MichiganTech



High f Equivalent Circuit

With high frequency waves, series capacitance forces uneven voltage distribution. Terminal end sees highest voltage.

MichiganTech

Example: Parkers Lake

2 dry type, air core reactors on 13.8 kV tertiary

Reactor 1: 7 Ω ->27.2 Mvar ->18.57 mH

Very little capacitance; use 200 pF

Assume $R_{winding}=0.1\%$, $R_{core}=\infty$

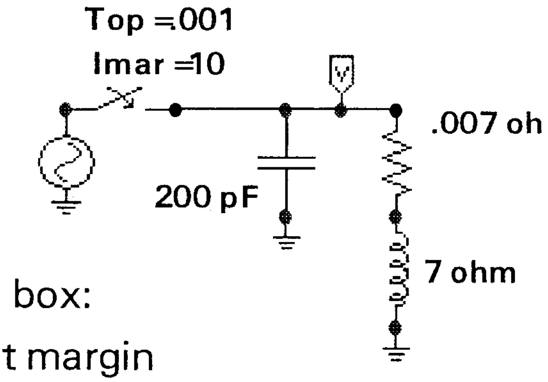
Reactor 1 Predictions

Surge Impedance: $Z_0=\sqrt{L/C}=9.64k\Omega$

Frequency : $f_0=\sqrt{1/LC}\Big/2\pi=82.6kHz$

$_{peak}\approx I_{chop}\times Z_0$

Reactor Opening: Simulation



- Switch dialog box:

  Imar – current margin

  switch opens if t >T-op AND |I| <Imar

Reactor 2

Reactor 2: 12.7 Ω ->15 Mvar ->33.69 mH

Has parallel capacitor to lower surge impedance and frequency.

What's the value?

My guess: 0.2 μF

Assume $R_{winding}$ =0.1%, R_{core} =∞

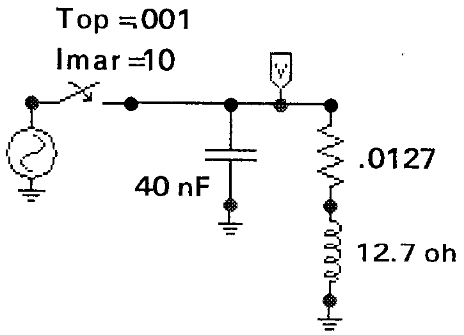
Reactor 2 Predictions

Surge Impedance: $Z_0 = \sqrt{L/C} = 410.4\Omega$

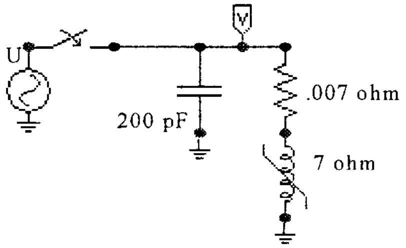
Frequency: $f_0 = \sqrt{1/LC} \big/ 2\pi = 1.94 kHz$

$${}_{peak} \approx I_{chop} \times Z_0$$

Reactor Opening: Simulation



Try using a saturable inductor



Use: L(i) Type 98 – Dialog Box

CURR: peak current in A

FLUX: flux in Volt-sec

Current/Flux Data

Need I_{peak} and magnitude ($\int V\,dt$)

13.8 kV ->7967V l-n

I =V/Z ->I =1138 A rms ->1610 A peak

$$\text{Volt-sec} = \frac{7967 \times 2^{1/2}}{2\pi 60} = 29.888 \text{ V-sec}$$

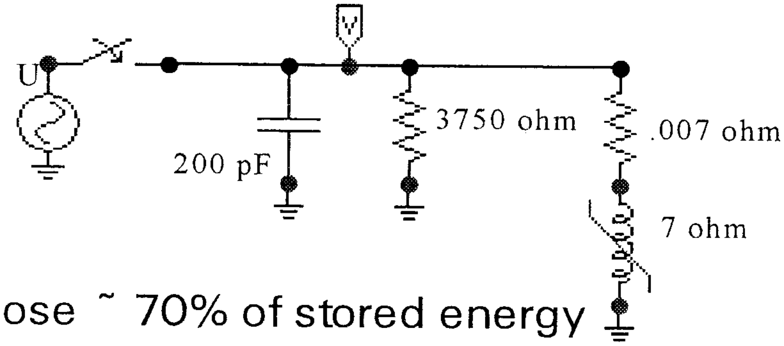
Saturation Data

V (pu)	Peak Current (A)	Flux (Volt-sec)
1.0	1610	29.888
1.1	5506	32.877

"Characteristic" tab in "Component" dialog box

MichiganTech

Add excitation losses

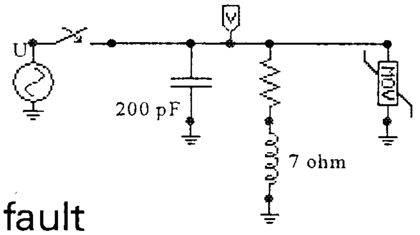


Lose ~ 70% of stored energy

Gives R =3750 Ω

MichiganTech

Add a surge arrestor



Use "MOV Type 92"

Attributes: change default

Vref =2 x system V

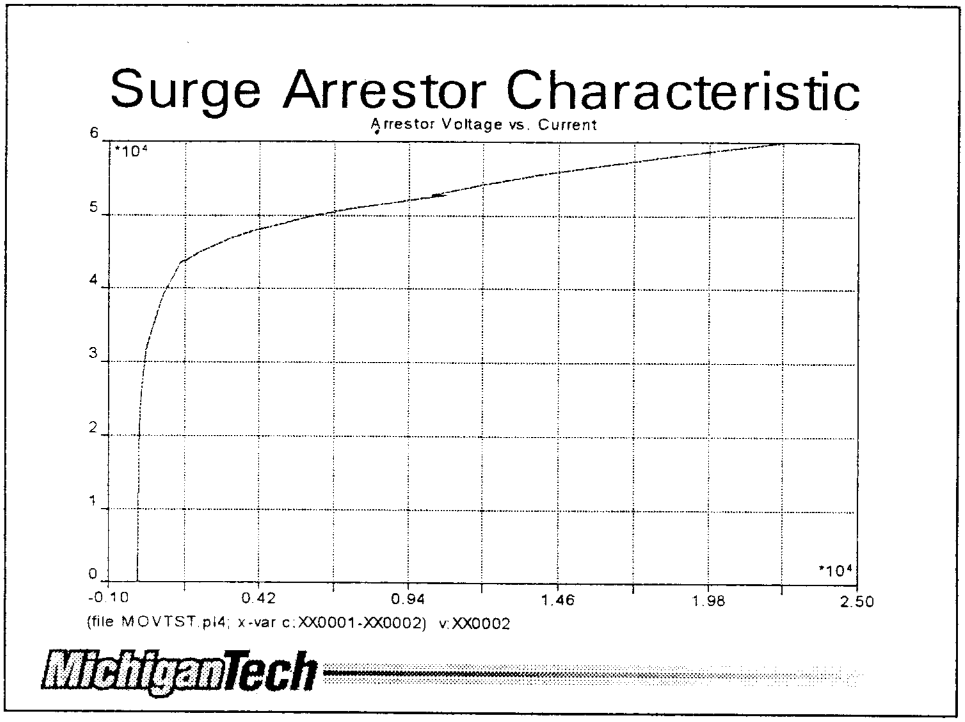
MichiganTech

Surge Arrestor Data

Current (A)	Voltage (V)
5*	13800*
1500	43700
3000	46400
5000	48500
10000	52900
20000	58500
40000	65900

Need to know low current characteristic
Difficult to find (I made it up)

MichiganTech



Surge Arrestor Characteristic

(file MOVTST.pl4; x-var c:XX0001-XX0002) v:XX0002

MichiganTech