Examples of Ferroresonance in a High Voltage Power System

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Outline

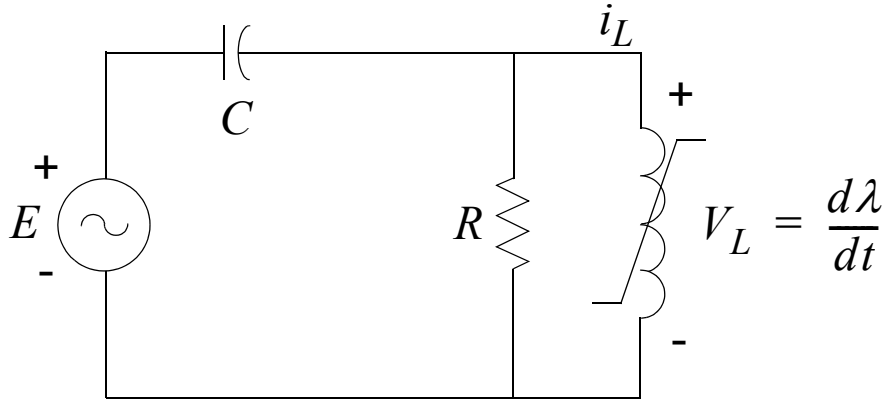
- Ferroresonance Background Information
- Literature Survey
- Case #1: Wound PT-grading capacitor
- Case #2: Transformer-grading capacitor
- Case #3: Open-delta PT
- Case #4: Capacitor Voltage Transformer
- Conclusions

Ferroresonance

- **DEFINITION: term used to describe any unusual oscillations observed in a circuit which contains a nonlinear inductor and a capacitor. Oscillations can be periodic (period-1, period-2 etc.), quasi-periodic or chaotic.**

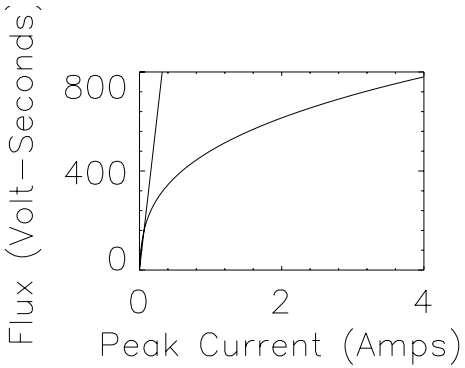
- **KEY FEATURES: co-existence of several different steady state conditions. Small parameter variations or perturbations can cause jumps from one state to another.**

Simple Example



linear: $i_L(\lambda) = \lambda / L$

nonlinear: $i_L(\lambda) = a_1\lambda + a_3\lambda^3$

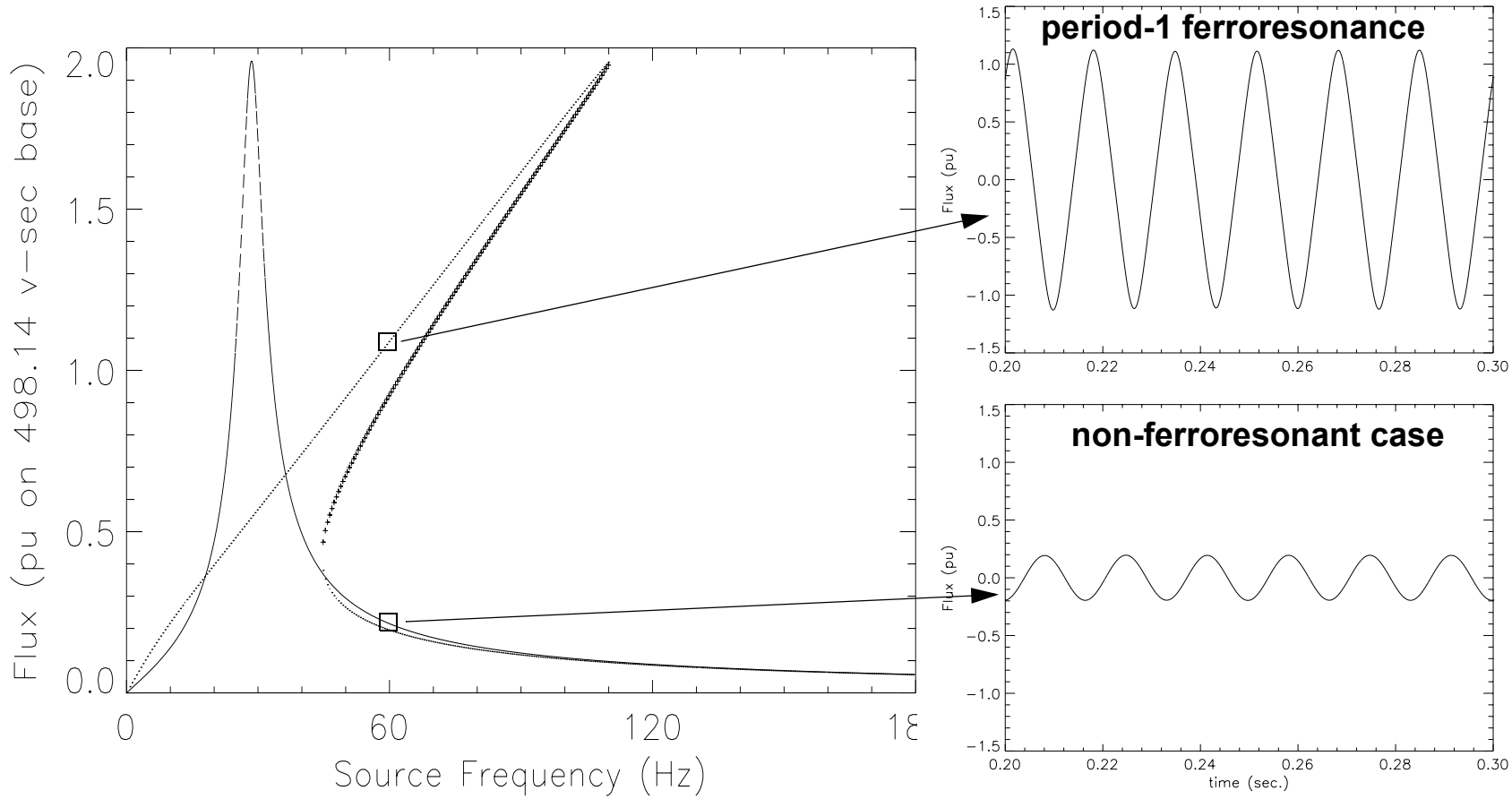


- **linear case: use frequency domain analysis**

$$|\lambda| = \frac{E}{\sqrt{\left(\frac{1}{RC}\right)^2 + \left(\omega - \frac{1}{\omega LC}\right)^2}} \qquad (1)$$

- **nonlinear case: use harmonic balance method**

Resonance vs. Ferroresonance



fixed parameters: C=12450 pF, R=2.5 MΩ, E=0.167 pu, L=2500 H, a_1=0.1, a_3=1.0

Why is there a need to study ferroresonance?

- **Prevent catastrophic equipment failures.**
- **Develop a study methodology that may be adopted by the industry.**
- **Becoming more important at transmission level voltages (> 66 kV) because of changes in circuit breaker and transformer technology.**

Circuit Breaker Technology

- **1940-1960 bulk oil breakers: no grading capacitance.**
- **1950-1980 air blast breakers: (30-800 pF) grading capacitance**
- **1970-1990 minimum oil breakers: (800-1350 pF)**
- **1988-2000 150 SF_6 breakers: (1500-1600 pF)**
- **TREND: Number of interrupting chambers decreasing and grading capacitance increasing.**

Literature Survey: Top 7 Circuits

1. TF supplied on 1 or 2 phases (39 papers)

2. *TF supplied through CB grading cap. (25 papers)

3. TF connected to series compensated t/l (15 papers)

4. *VT connected to isolated neutral system (15 papers)

5. TF supplied through a long t/l or cable with low short circuit power (14 papers)

6. *CVT (11 papers)

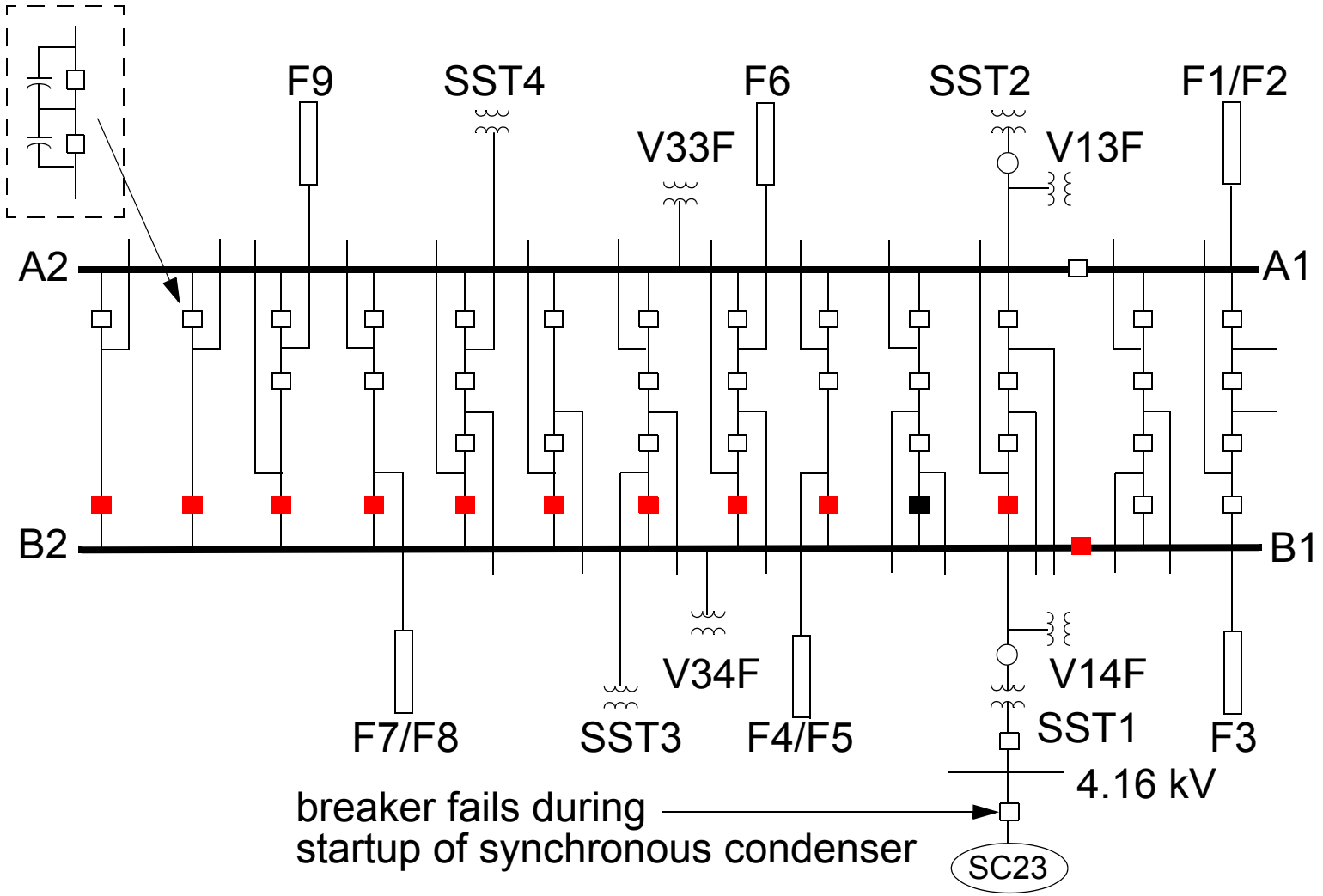
7. TF connected to de-energized t/l running in parallel with energized t/l (6 papers)

Dorsey 230 kV Breaker Replacement

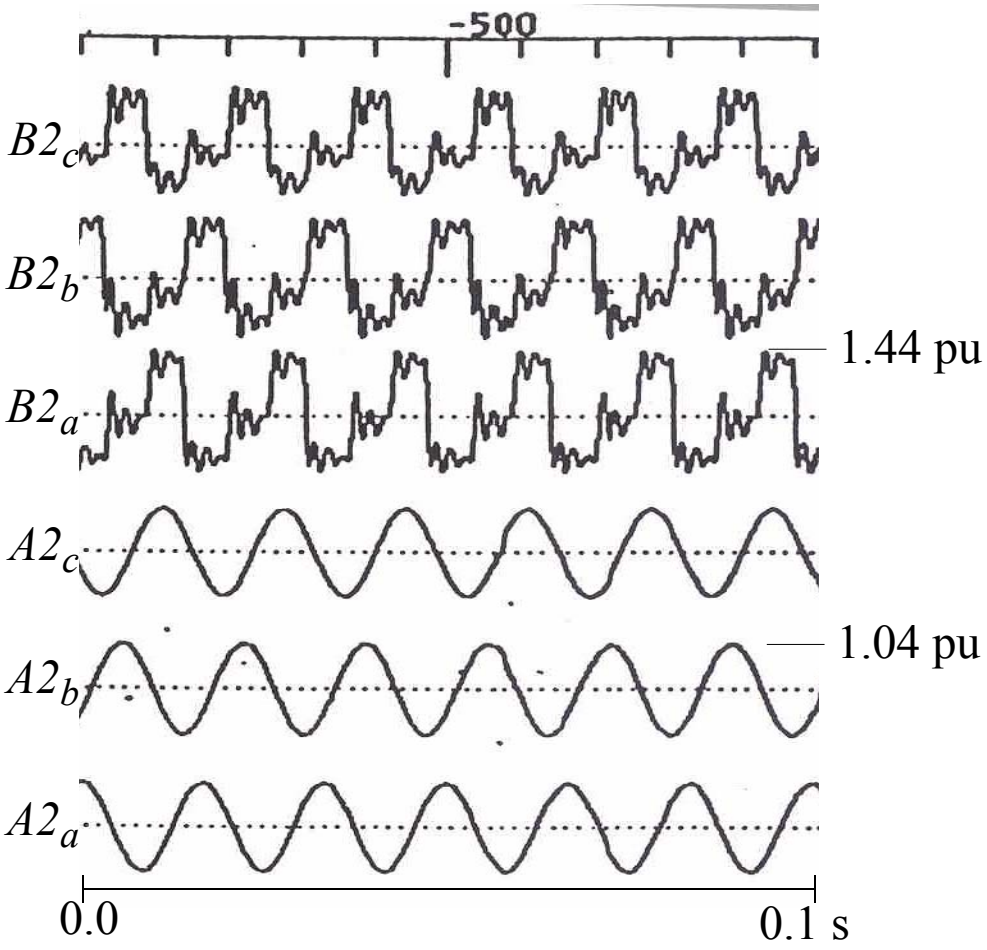
- **Consisted of 25 breaker & ct replacements**
- **Project Duration: April 1992 - April 1996**
- **Circuit Breaker Specifications**
  - **63.5 kA interrupting rating at -550 C**
  - **Clear short line faults at 90% Isc (IEC Test)**
- **Consequences of Upgrade:**
  - **SF_6/CF_4 breakers with 2 breaks/phase and 1500 pF/break**
  - **Total grading capacitance increased from 2000 pF to 7500 pF**
  - **Ferroresonant events: May 20, 1995 and August 4, 1995**

Photograph of VT Destruction (May 20, 1995)
Led to replacement of wound VTs with CCVTs.

Disturbance of Aug. 4, 1995



Field Recordings of Bus Voltages



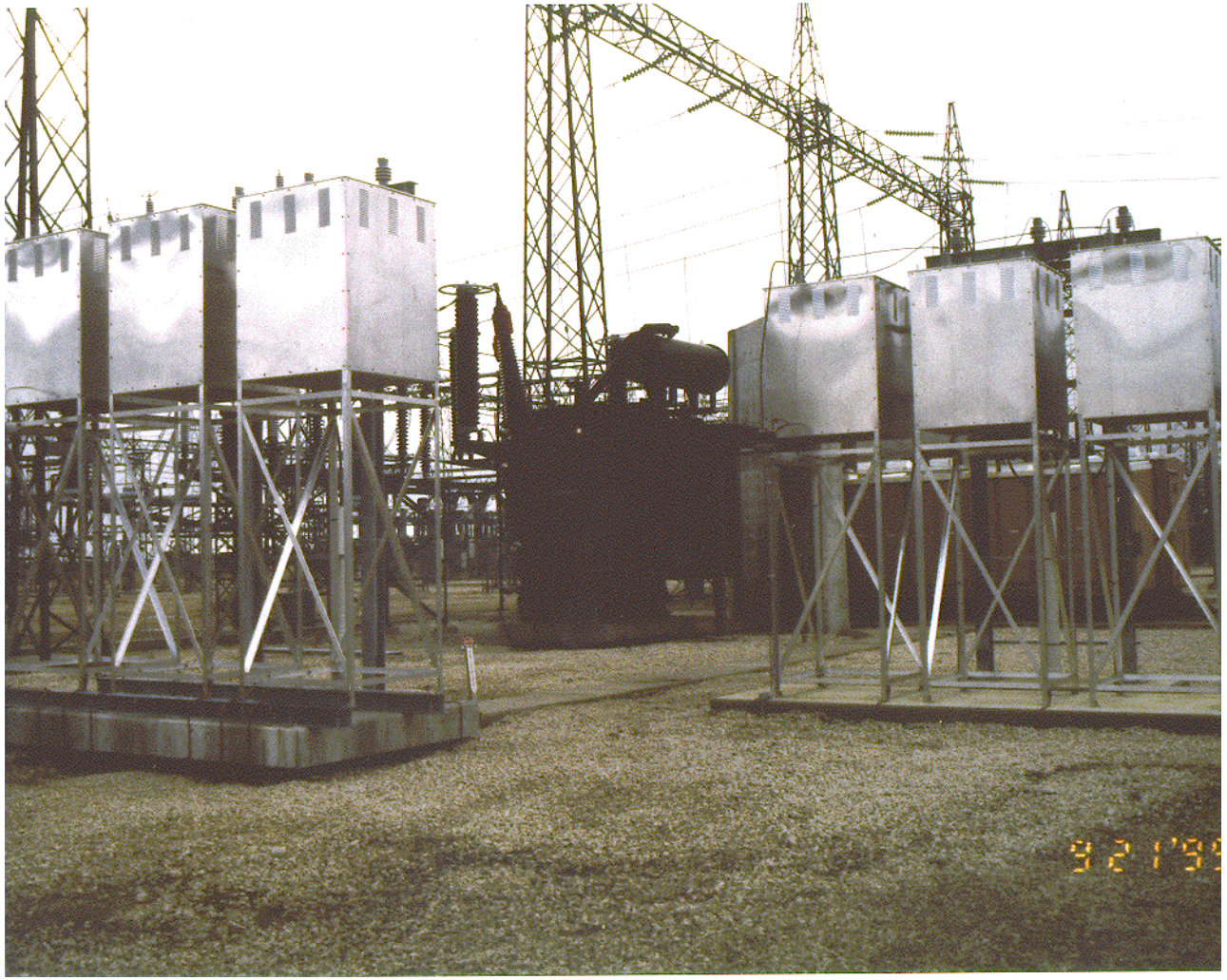
Sequence of Events:

- **14:18 Dorsey bus B2 trips**
- **14:18 synchronous condenser JVC uses VT on bus B2 as ref. and reduces var output to zero.**
- **MH voltage stabilized at 0.93 pu after 1 min.**
- **14:58 filter switched manually onto bus B2. Ferroresonance eliminated. JVC reference voltage switches to VTs on healthy A2 bus.**

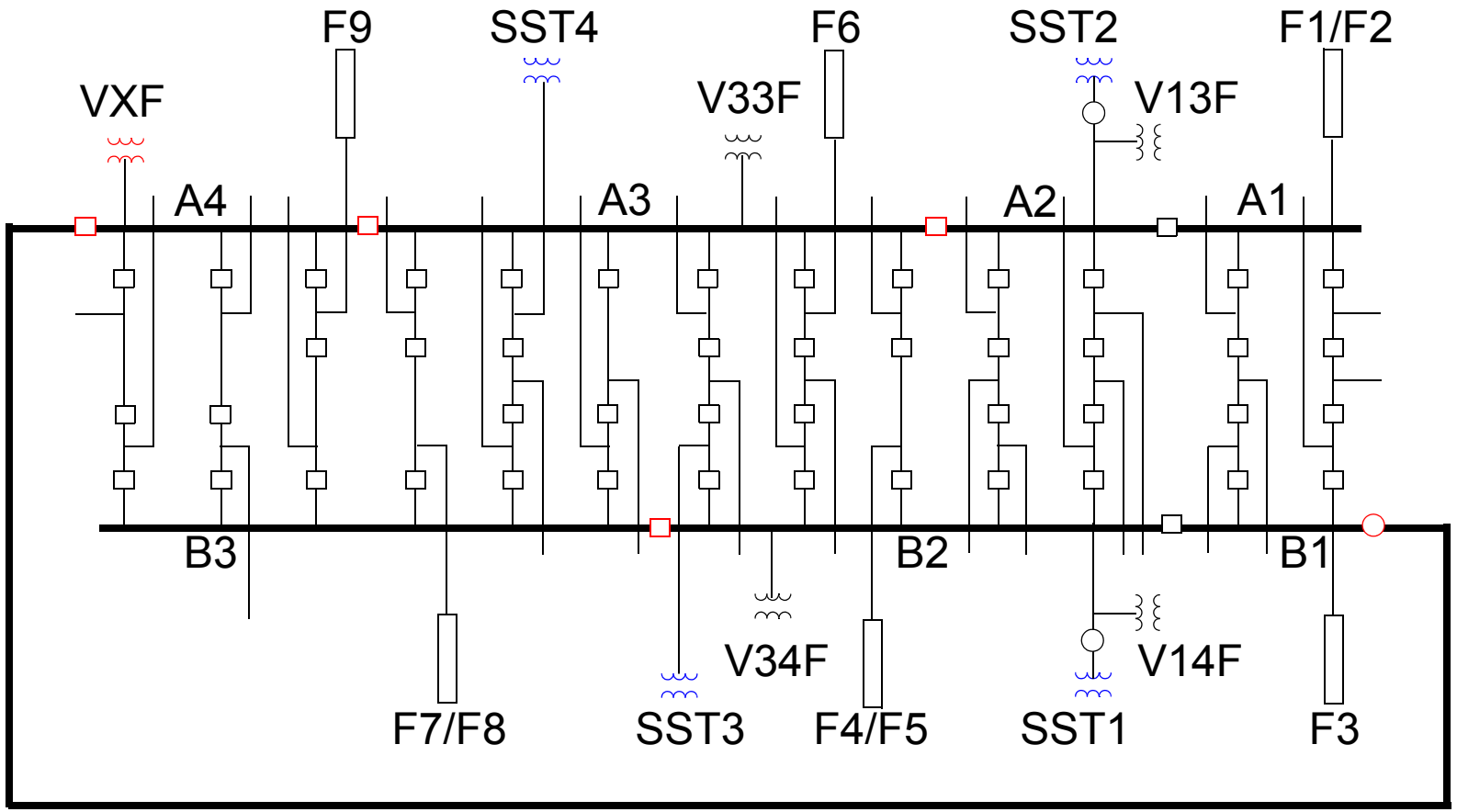
Consequences:

- **1000 MW dc reduction required to prevent voltage collapse. Wound VTs damaged.**

Photograph of six 200 ohm resistors (Sept. 21, 1995)

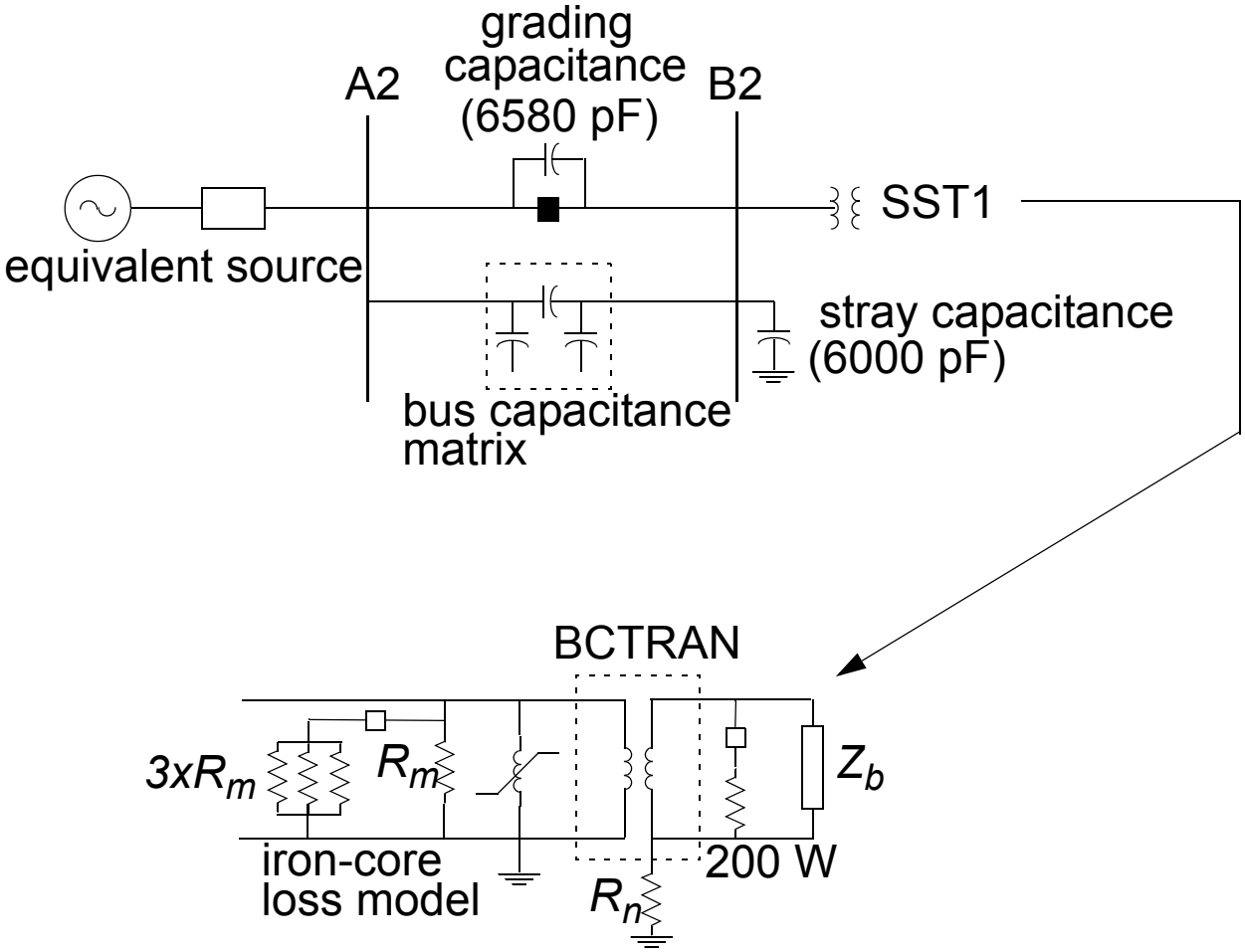


Dorsey Bus Enhancement Project

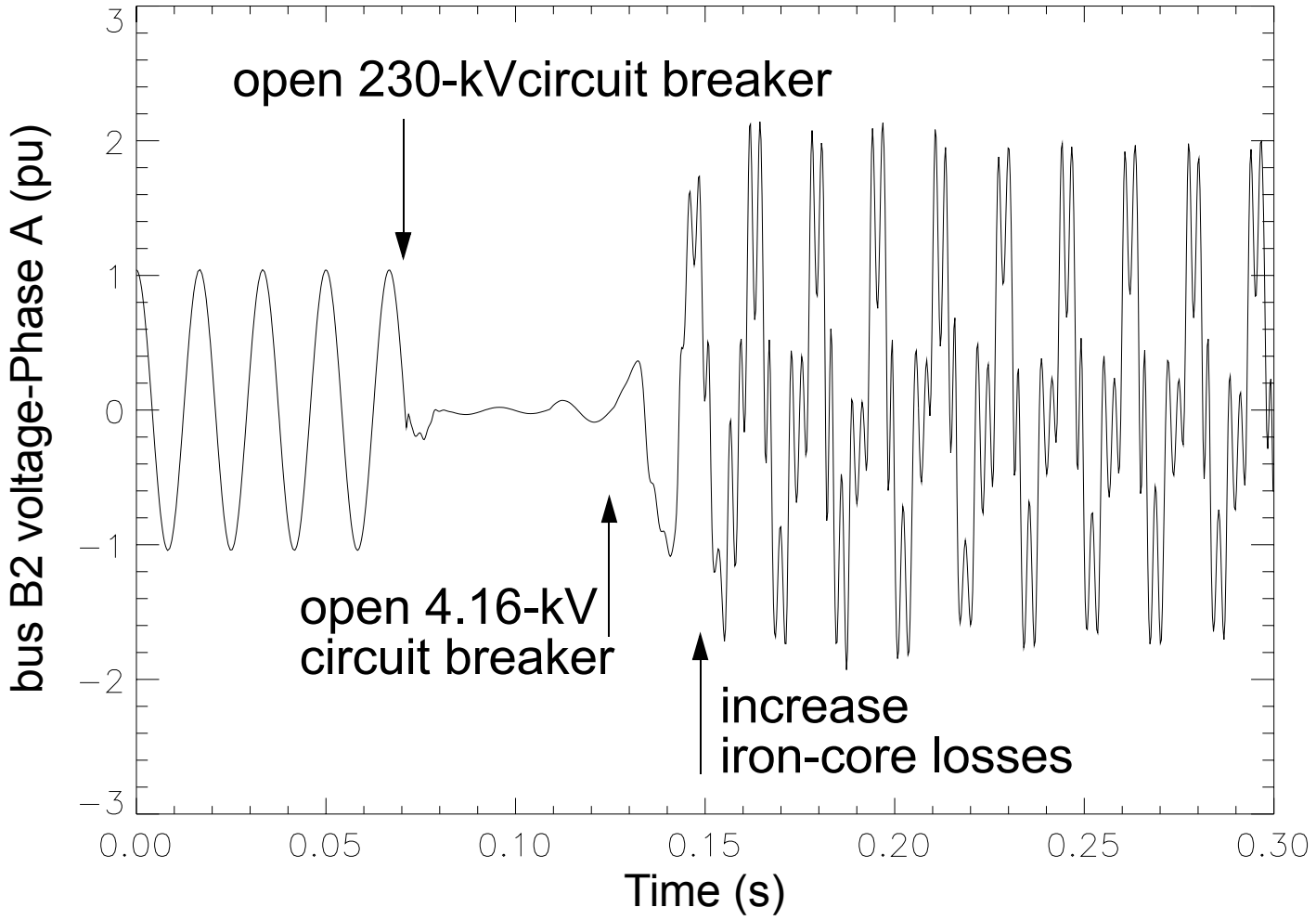


ISD: September 2004

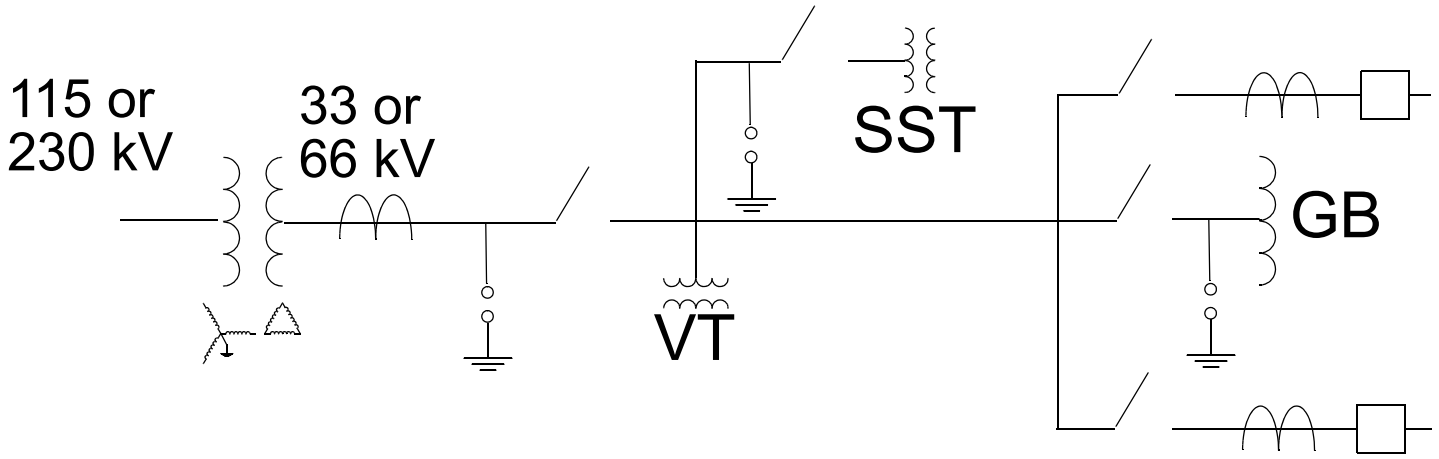
EMTP Model


grading
capacitance
(6580 pF)
A2
B2
SST1
equivalent source
stray capacitance
(6000 pF)
bus capacitance
matrix
BCTRAN
3xRm
Rm
Zb
iron-core
loss model
200 W
Rn

Duplicating Field Measurements



Open-Delta VT

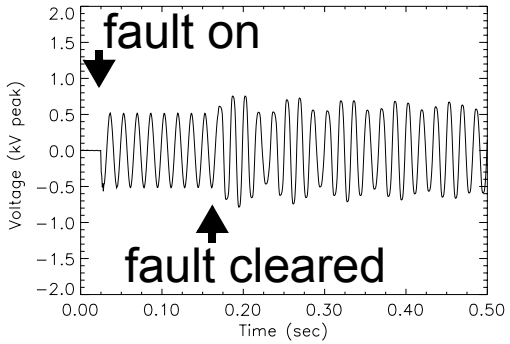


GB: grounding bank (X_0: 120 Ω)

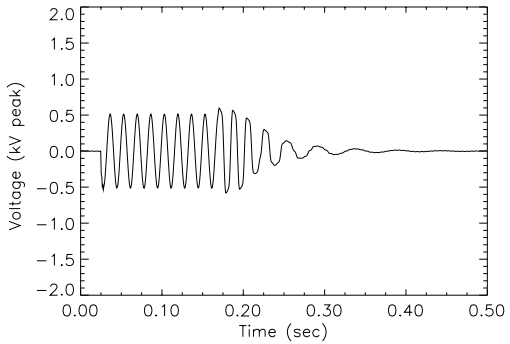
SST: station service transformer

VT: open-delta wound voltage transformer

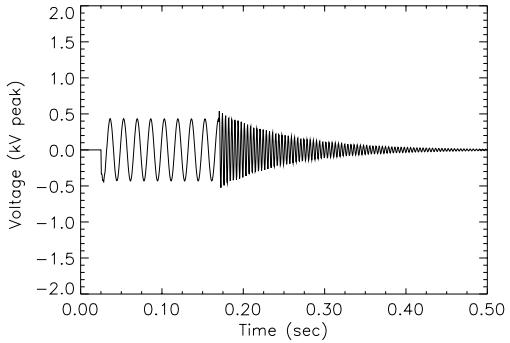
Typical Voltage Oscillations



No Mitigation

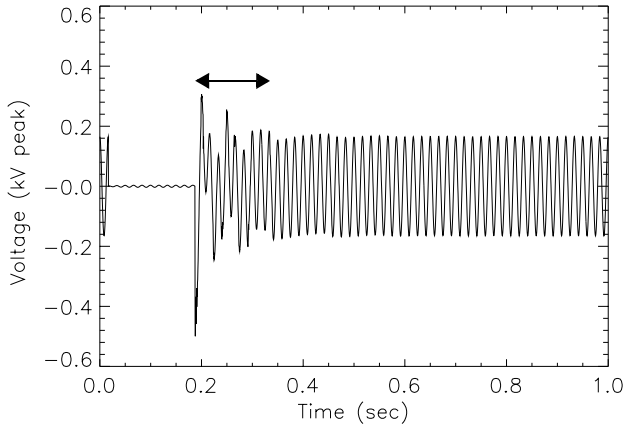


83 Ω resistor
(25% PT rating)

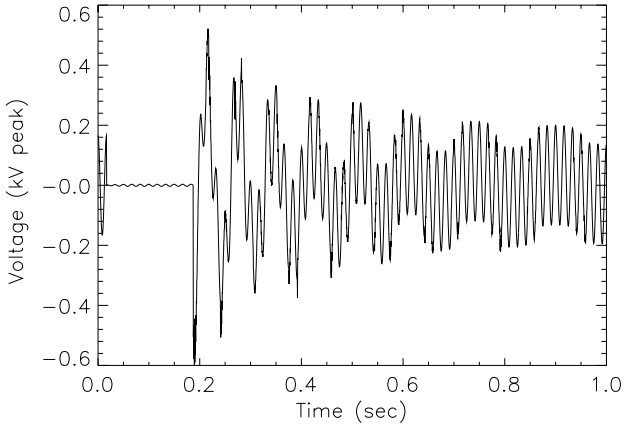


GB connected

CSA Ferroresonance Test



FSC Enabled:
transients damp within
10 cycles



FSC Disabled

Conclusions

- **TF-grading capacitance: Ferroresonance eliminated with CVT replacement and loading resistors. CB specs can be modified to require no grading capacitance (or minimal values).**

- **Open-delta VT: loading resistors of 25% of thermal rating across opening eliminates ferroresonance. Grounding banks also work. Special studies required with cables.**

- **CVT: Manufacturer's FSC eliminates ferroresonance. Required performance should be specified. Use higher voltage auxiliary VTs.**