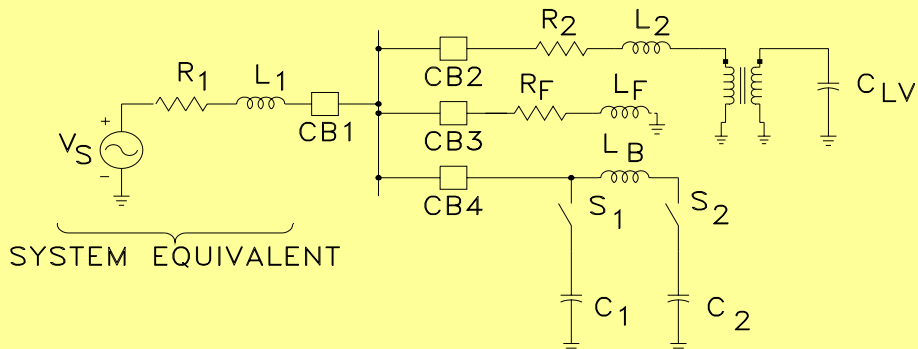
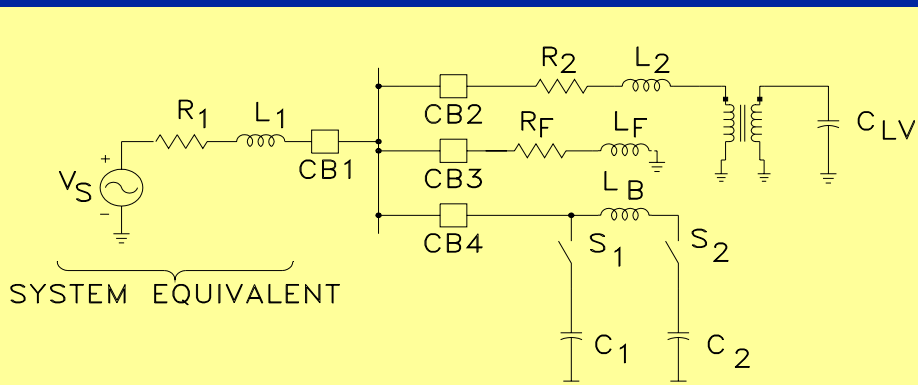


# Learning the Basic Concepts of Capacitor Bank Switching



34.5-kV Per-Phase System

## 1 - Energization Inrush



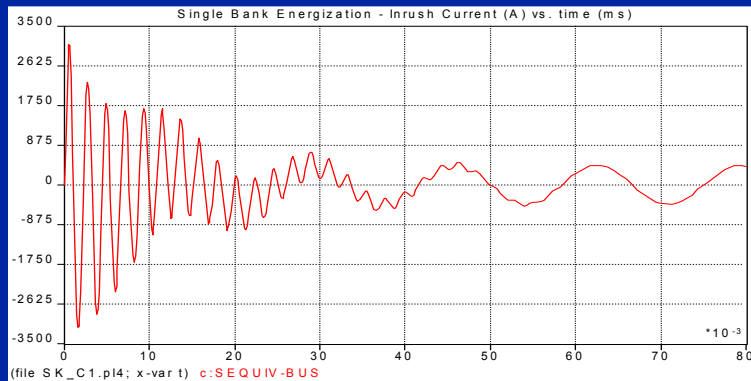
CB1 and CB4 Closed, Close Switch S1.

## Energization Inrush - First Bank C<sub>1</sub>

$$i(t) = \frac{V(0)}{Z_0} \sin \omega_0 t$$

$$Z_0 = \sqrt{\frac{L}{C_1}}$$

$$\omega_0 = \frac{1}{\sqrt{LC_1}}$$



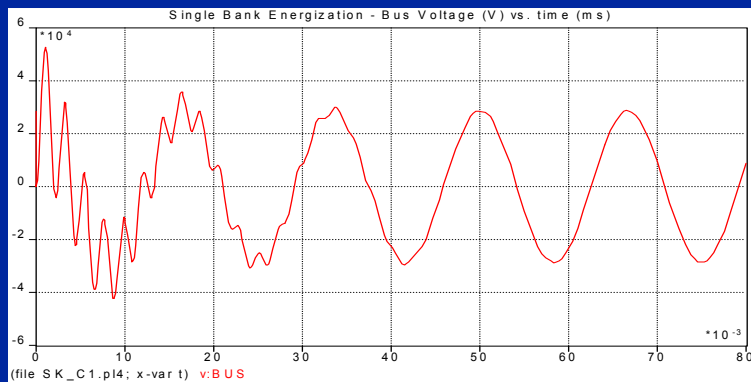
Peak Current = 3041 Amps, Natural Frequency = 500 Hz

## Energization Inrush - First Bank C<sub>1</sub>

$$i(t) = \frac{V(0)}{Z_0} \sin \omega_0 t$$

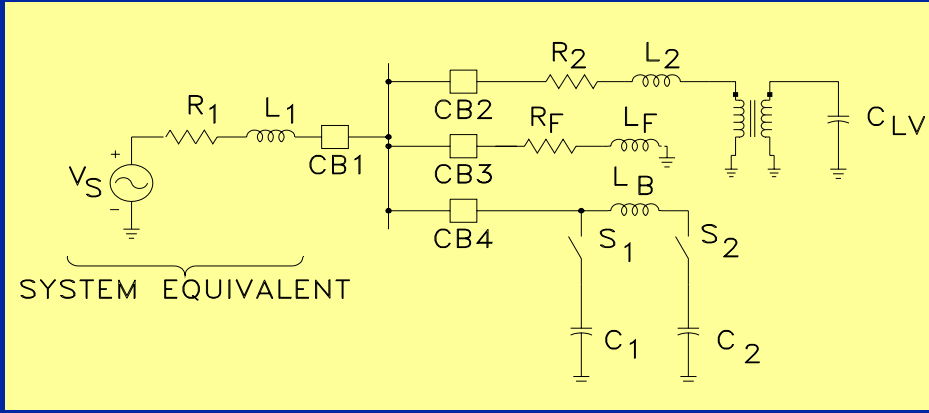
$$Z_0 = \sqrt{\frac{L}{C_1}}$$

$$\omega_0 = \frac{1}{\sqrt{LC_1}}$$



Bus Voltage: Peak Voltage = 1.87 per unit

## 2 - Back-to-Back Energization



CB1, CB4, S1 Closed. Close Switch S2.

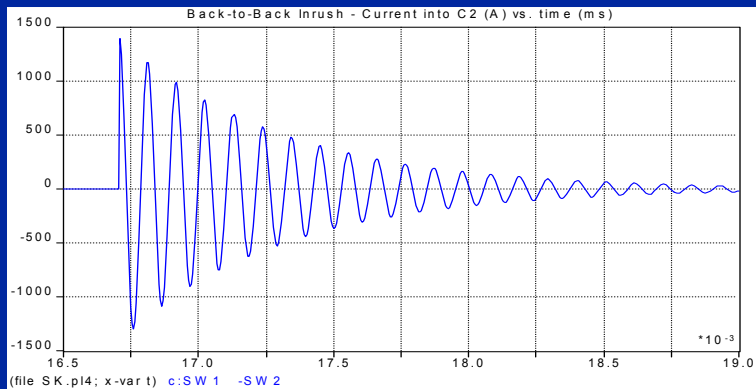
## Back-to-Back Energization

$$i(t) = \frac{V(0)}{Z_{01}} \sin \omega_{01} t$$

$$Z_{01} = \sqrt{\frac{L_B}{C_{EQ}}}$$

$$\omega_{01} = \frac{1}{\sqrt{L_B C_{EQ}}}$$

$$C_{EQ} = \frac{C_1 C_2}{C_1 + C_2}$$



Peak Current = 1400 Amps, Natural Frequency = 9.4 KHz

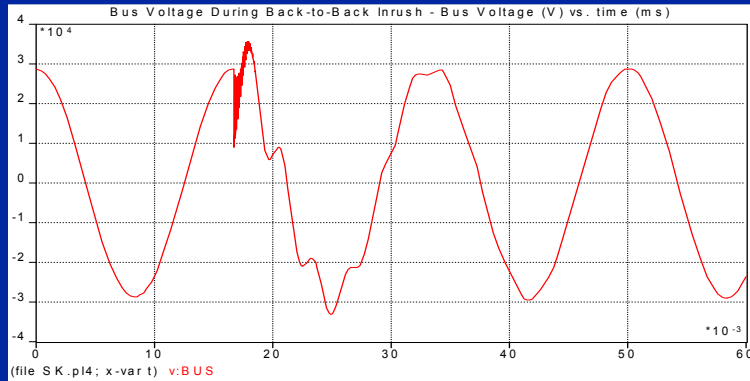
## Back-to-Back Energization

$$i(t) = \frac{V(0)}{Z_{01}} \sin \omega_{01} t$$

$$Z_{01} = \sqrt{\frac{L_B}{C_{EQ}}}$$

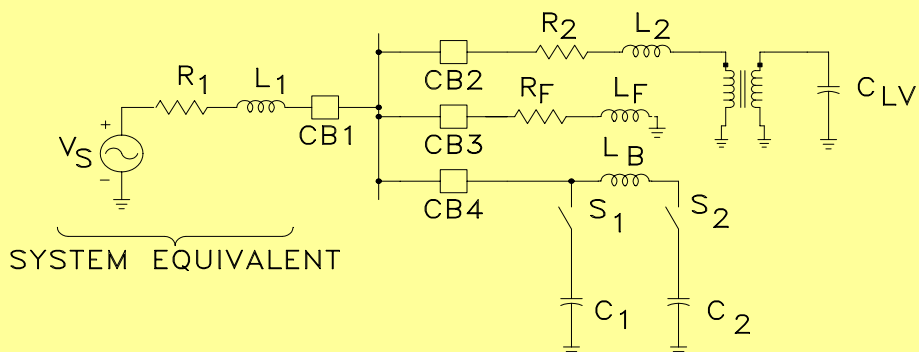
$$\omega_{01} = \frac{1}{\sqrt{L_B C_{EQ}}}$$

$$C_{EQ} = \frac{C_1 C_2}{C_1 + C_2}$$



Peak Bus Voltage = 1400 Amps

## 3 - Outrush Transient



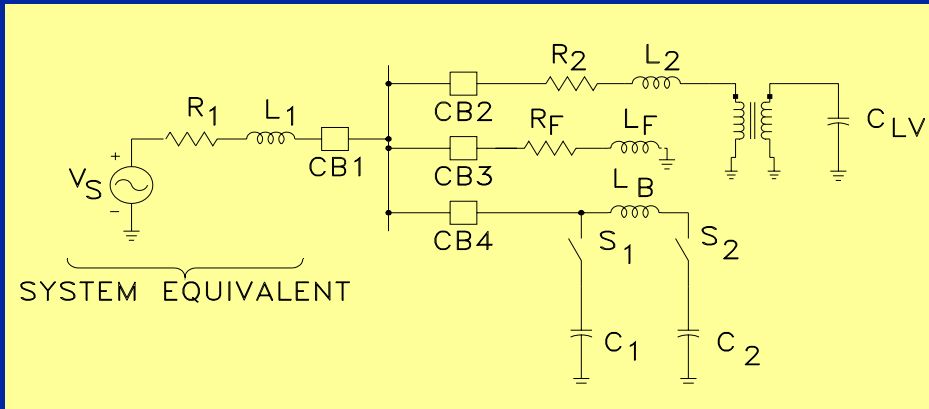
$$i(t) = \frac{V(0)}{Z_{02}} \sin \omega_{02} t$$

$$Z_{02} = \sqrt{\frac{L_F}{C_1}}$$

$$\omega_{02} = \frac{1}{\sqrt{L_F C_1}}$$

CB1, CB3, CB4, S1 Closed. Fault on Feeder or Bus.

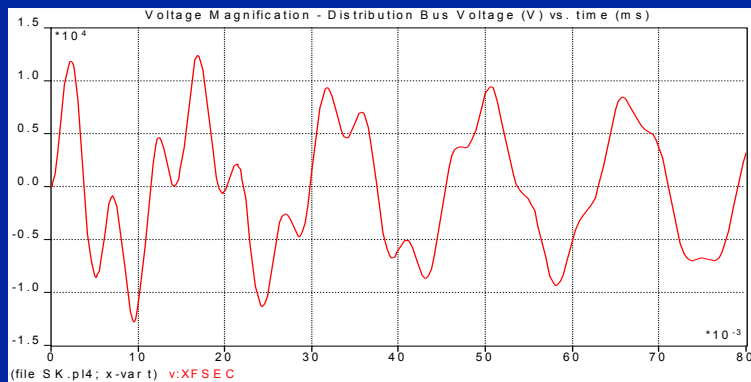
## 4 - Voltage Magnification



CB1, CB2, CB4 Closed. Close Switch S1 or S2.

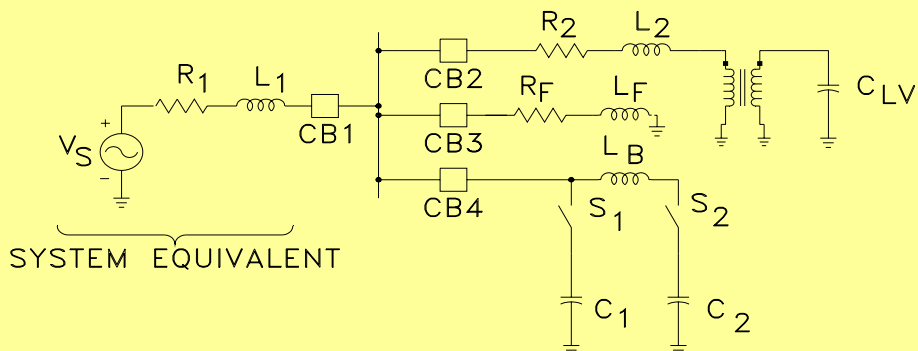
## Voltage Magnification

$$\omega_0 = \frac{1}{\sqrt{L_2 C_{LV}}} = \frac{1}{\sqrt{L_1 C_1}}$$



Peak Distribution Bus Voltage = 1.76 per unit.

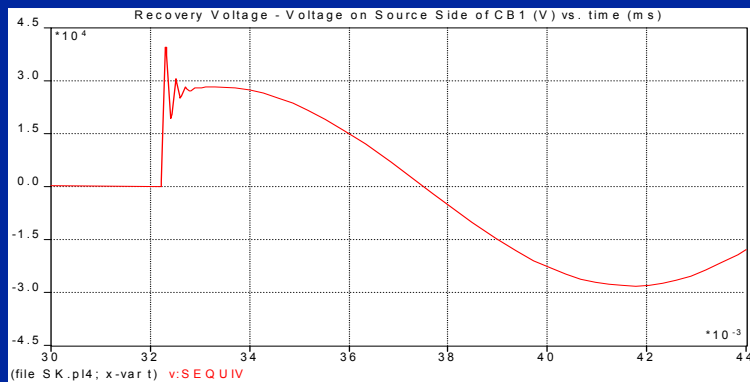
## 5 - Transient Recovery Voltage



**CB1 Closed, Fault on Bus. Open CB1 to Clear Fault.**

## Transient Recovery Voltage

**Oscillation between Circuit Breaker Bushing Capacitance and Source Inductance.**



**Peak Bus Voltage = 1.4 per unit, Frequency = 5 KHz.**