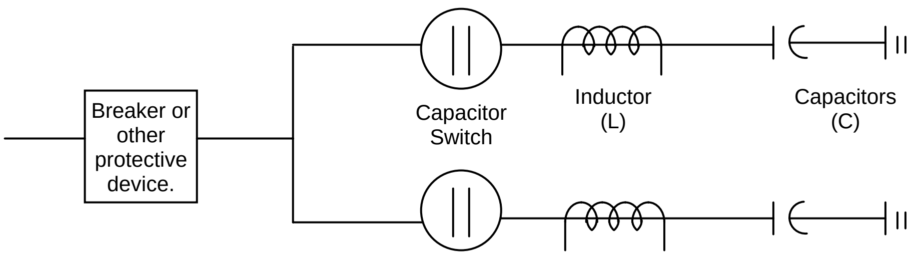
T.D. 750-457
November 2006
Supersedes: July 2002

ENGINEERING MEMO

CONSIDERATION OF INRUSH CURRENT IN BACK-TO-BACK CAPACITOR SWITCHING

When switching "back-to-back" or parallel capacitor banks installed on the same bus or which can be paralleled by closing normally open switches or breakers, consideration must be given to the maximum inrush current that can occur. It may be necessary to add inductance to the system to limit these currents to values which will not damage the capacitors and switches or have other detrimental effects. An uncharged capacitor bank offers practically zero impedance when initially energized, with a resultant passage of a large, high-frequency transient inrush current. When two or more capacitor banks are paralleled within close proximity to each other, the peak transient inrush current into the uncharged bank, may exceed the normal peak steady-state capacitor current by several orders of magnitude. This high frequency release of energy can cause damage to the switching device and capacitors, if it is not limited.



Example of Back-to-Back Capacitor Switching Application

CAUTION! Be certain to consider all banks on the same bus including those already installed. Consideration cannot be limited to only those banks being added in a specific project.

The only significant impedance to limit inrush current is the inherent resistance and inductance of the conductors between banks. The values of resistance and inductance of the conductors may be too low to limit the inrush current to safe values. In these cases, the addition of a current limiting impedance is required. The use of reactors for this purpose has been found to be practical for typical capacitor banks used on power systems.

Current limiting reactors are available from Joslyn, for this purpose, at system voltages through 230kV.

REPRESENTATIVE JOSLYN REACTOR RATINGS

Maximum System Voltage (kilovolts)	Reactor Inductance (Microhenries/Phase)	Continuous Current per Reactor (amperes)	Part Number for Three Phase Set
15	15	400	3059X0016G1*
15	30	400	3059X0050G2*
15	40	400	3059X0050G3*
15	30	600	3059X0050G1*
27	60	400	3059X0050G4*
34.5	30	300	3059X0016G5*
34.5	60	300	3059X0050G6*
34.5	30	400	3059X0016G2
46	30	300	3059X0016G4*
46	30	400	3059X0016G3
69	60	300	3059X0016G6*

NOTES:
*Includes one porcelain insulator per phase to support the free end of the insulator.

4000 East 116th Street Cleveland, Ohio 44105-4398 USA 216-271-6600 FAX 216-341-3615
http://www.joslynhivoltage.com info@joslynhv.com

For longest maintenance-free life of the capacitors and capacitor switches, peak inrush current should be limited to lower values than the maximum rating of the switch. To achieve maximum switch life when applied with the repetitive nature of capacitor switching applications, Joslyn suggests limitation of peak inrush as shown in the table below:

Model	Continuous Current (Amps)	Maximum Peak Inrush Current
VerSaVac (VSV)	200	6000
Varmaster (VBM)	300	8000
Varmaster (VBM)	400, 600	10000
Transmaster (VBT)	600	10000
Faultmaster (VBU)	600	10000

The formulae on the next page from ANSI Standard C37.0731 -1973 enable determination of the inductance needed to limit peak inrush currents to acceptable values. In calculating the required inductance, it is generally appropriate to include a value of 0.3 microhenry per foot of overhead bus or 0.09 microhenry per foot of cable for the electrical separation between the capacitor banks. The resistance per foot is assumed to be negligible. After the necessary inductance is calculated, the inductance of the conductors between the banks is subtracted from the calculated L_{EQ} yielding the size of the required current limiting reactor.

Note that if reactors are installed in both capacitor banks, the L_{EQ} equals the sum of both reactors.

Inrush current and Frequency Formulae for Switching Capacitors Banks (Reference ANSI Standard C37.0731 -1973)

Energizing an isolated bank

$$I_{max\ peak}\ (\text{amperes}) = 1.41 \bullet \sqrt{I_{SC} \bullet I_1}$$

$$f\ (\text{hertz}) = f_s \bullet \sqrt{I_{SC} / I_1}$$

Energizing a bank with another on the same bus

$$I_{max\ peak}\ (\text{amperes}) = 1747 \bullet \sqrt{\frac{V_{LL}\,(I_1 \bullet I_2)}{L_{EQ}\,(I_1 + I_2)}}$$

$$F\ (\text{kilohertz}) = 9.5 \bullet \sqrt{\frac{f_s \bullet V_{LL}\,(I_1 + I_2)}{L_{EQ}\,(I_1 \bullet I_2)}}$$

EXAMPLE: SOLVING FOR MINIMUM REQUIRED REACTOR SIZE WITH TWO CAPACITOR BANKS OF EQUAL VALUE

RESULT: Install a $\frac{LEQ}{2}$ reactor (minimum) in each phase on both banks.

1) VSV switches ($I_{max\ peak}$ = 6, 000 amperes); $L_{EQ} = \frac{V_{LL} \bullet I_1}{23.6}$

2) VBM switches rated 300 amps ($I_{max\ peak}$ = 8, 000 amperes); $L_{EQ} = \frac{V_{LL} \bullet I_1}{42}$

3) VBM switches rated 400 & 600 amps ($I_{max\ peak}$ = 10,000 amperes); $L_{EQ} = \frac{V_{LL} \bullet I_1}{66}$

JOSLYN Hi-Voltage

GENERAL CASE: For energizing two or more capacitor banks

Solve:

1. $MVAR_{EQ} = \dfrac{\frac{\left(\sum_{}^{N} MVAR\right) MVAR_1}{2}}{\sum_{1}^{N} MVAR}$

2. $L_{EQ} = \dfrac{1767\,(10^6)\,MVAR_{EQ}}{I_{pk}^2}$

3. $L_1 = L_{EQ} - \dfrac{1}{\frac{1}{L_2} + \frac{1}{L_3} \ldots \frac{1}{L_N}}$

Solved Examples: Equal inductance and bank size

Bank Qty.	I_{pk} = 6kA	I_{pk} = 8kA	I_{pk} = 10kA
2	L_1=12.27($MVAR_1$)	L_1 = 6.90($MVAR_1$)	L_1 = 4.18 ($MVAR_1$)
3	L_1=21.85($MVAR_1$)	L_1 = 12.27($MVAR_1$)	L_1 = 7.85 ($MVAR_1$)
4	L_1=27.61($MVAR_1$)	L_1 = 15.53($MVAR_1$)	L_1 = 9.94 ($MVAR_1$)
5	L_1=31.41($MVAR_1$)	L_1 = 17.62($MVAR_1$)	L_1 = 11.27 ($MVAR_1$)

V_{LL} = Rated maximum voltage (RMS kilovolts)

I_{SC} = Symmetric short circuit current (RMS amperes)

$I_{max\ peak}$ = A peak value calculated with-out damping. In practical circuit it will be about 90% of this value. (amperes)

L_{EQ} = Total equivalent inductance (μh – micro-henries) between the capacitor bank being switched and all other banks. (microhenries)
*Example with equal inductance per phase: $L_{EQ} = \dfrac{N}{N-1}(L_1)$

$L_1 \ldots L_N$ = Inductance per phase in banks 1 thru N. (microhenries)

f_s = System frequency (hertz)

I_1 & I_2 = Currents of bank being switched and bank already energized, respectively. Capacitor bank being switched is assumed uncharged with closing taking place at a voltage crest of the source voltage. The current used should include the effect of operating the capacitor bank at a voltage above nominal rating of the capacitors and the effect of a positive tolerance of capacitance. **In the absence of specific information, a multiplier of 1.15 times nominal capacitor current would give conservative results.**

4000 East 116th Street Cleveland, Ohio 44105-4398 USA 216-271-6600 FAX 216-341-3615
http://www.joslynhivoltage.com info@joslynhv.com