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Transient Inrush Reactors

Standard Features

Medium Voltage Metal Enclosed Capacitor Banks

NEPSI's Transient Inrush Reactors are designed to increase the life expectancy of capacitor switches by limiting both the magnitude and frequency of the transient inrush currents associated with back-to-back capacitor bank switching. These reactors are most commonly applied in multi-stage medium voltage (2.4kV through 34.5kV) capacitor banks or in fixed medium voltage capacitor banks that are connected on the same switch-gear bus as other fixed capacitor banks, as shown in figure 2.

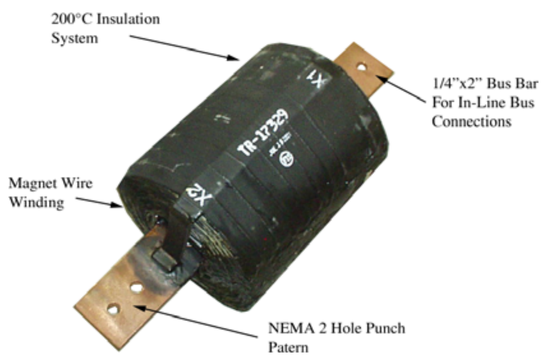


Figure 1
TI Reactor—Transient Inrush Reactor.

Product Benefits and Features

- Increased capacitor switch life.
- Wide range of inductance and current ratings to meet application requirements.
- Designed for 2.4kV through 34.5kV Pad-Mounted and Metal Enclosed Capacitor Banks.
- Compact, low loss efficient design.
- Simple to install.
- Decreased possibility of nuisance capacitor fuse blowing from transient inrush currents.

Specifications

Winding
Low loss all Copper or Aluminum Magnet Wire or Foil for longer reactor life.

Insulation System
200°C Insulation System.

Terminals
NEMA two hole bolt patterns on 1/4"x2" Bus Bar for inline bus connections.

Impregnation
Complete epoxy resin impregnation system to reduce noise, promote heat dissipation and provide protection in harsh environments.

Bobbin
GPO-3 high strength, open profile, epoxy resin bobbin for rigidity and heat dissipation.

Bulletin: 100-06 Rev. Date: 11/26/2013

Application Considerations

Medium voltage multi-stage capacitor banks with voltages of 2.4kV through 34.5kV are typically switched by single phase or three phase capacitor switches that are tested in accordance with ANSI Standard C37.77. These switches are usually rated 200, 400 and 600 amps, with the 200 amp single phase group operated switch being the most common. ANSI C37.77 requires that the switch be tested for switching at a high frequency transient making current of 12,000 amps (peak) at 6000 Hertz. This equates to an IT Product of $7.2x10^7$ amps/second. In many back-to-back capacitor bank switching applications, either the 12,000 amps or the 6,000 Hertz rating or both are exceeded. The TI Reactor when placed in line with the capacitor switch as shown in Figure 2 will decrease the IT Product, inrush frequency, and inrush current magnitude through the energizing switch.

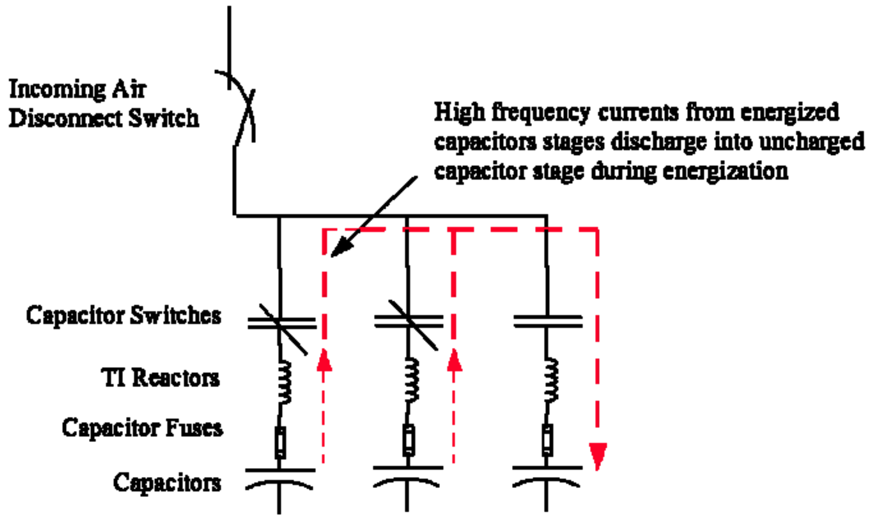


Figure 2
High Frequency Inrush Currents Associated with Back-to-Back Capacitor Bank Switching Are Reduced With NEPSI's TI-Reactors.

As a conservative approach, NEPSI recommends the TI Reactor be sized to limit the IT product of the capacitor inrush current to $3.6x10^7$ amps/second. This is 50% of the maximum tested value. Table 1 shows the total inductance requirements for this IT Product level at various voltage levels.

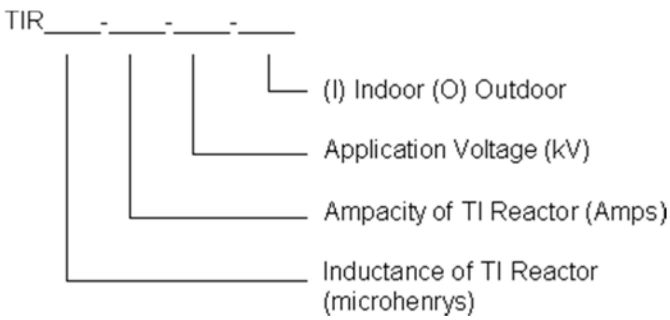
Table 1
Typical Inductance Requirements for Medium Voltage Capacitor Banks

L-L Voltage KV	Leq* (µH)
2.4	8.6
4.16	14.9
4.8	17.1
6.9	24.6
8.32	29.7
12	42.9
12.47	44.5
13.2	47.1
13.8	49.3
20.78	74.2
22.8	81.6
23	82.1
24.94	89.1
34.5	123.2

The transient inrush reactor application table on the next page can be used to aid the capacitor bank design engineer in sizing and specifying the proper NEPSI TI-Reactor for single step and multi-step capacitor banks. The values in the table are based on Table 1 and the use of 200 amp single-phase capacitor switches. For contactors and circuit breakers, or other switch ratings, consult the manufacturer for ratings and recommended inductance. The values listed in Table 1 and 2 are conservative in nature, and lesser values are possible with detailed calculations or EMTP simulations. For single-step and two-step automatic capacitor banks, the equations listed in Table 4 can be used to calculate the magnitude and frequency associated with capacitor switching. Contact NEPSI's Engineering Services Group for more complex systems requiring EMTP simulations.

TI Reactor Ordering Guide

The TI Reactor has inductance rating, current rating, and application voltage. The proper inductance, if not known can be sized from the transient inrush reactor application table (Table 3) in the following section or from the equations listed in Table 4. With proper inductance known, the ampacity is chosen based on the capacitor stage current. An additional 35% of current should be added to the stage current to account for capacitor kvar, voltage variations, and harmonic currents. Fill in the part number below (if not a standard NEPSI part number) for quotations and ordering.



As standard, NEPSI stocks many of the transient inrush reactors listed in Table 2. Any rating, however, can be developed from the above figure on the left. Contact NEPSI for price quote on part numbers that are not listed in Table 2.

Table 2 - *Stock Inrush Reactors*

Part Number	Induct-ance Rat-ing (µH)	Amp Rating	Application Voltage (kV)	List Price Each	Enviroment	Price Adder For Outdoor Rating *
TIR40-50-15-I	40	50	15	$462	Indoor	$110
TIR40-100-15-I	40	100	15	$510	Indoor	$115
TIR40-150-15-I	40	150	15	$607	Indoor	$125
TIR40-200-15-I	40	200	15	$705	Indoor	$135
TIR40-300-15-I	40	300	15	$905	Indoor	$150
TIR40-400-15-I	40	400	15	$1,275	Indoor	$190
TIR150-800-15-I	150	800	15	$3,885	Indoor	$250
TIR47-50-35-I	47	50	35	$751	Indoor	$120
TIR47-100-35-I	47	100	35	$825	Indoor	$135
TIR47-150-35-I	47	150	35	$890	Indoor	$140
TIR47-200-35-I	47	200	35	$940	Indoor	$160

* Note: For Outdoor Ratings, Change “-I” in Part Number To “-O” and Add Price Adder for Outdoor Rated Insulation.

TI Reactor Application Table

The chart below can be used to determine the amount of equivalent inductance required between capacitor banks to keep the IT Product of the transient inrush current to 3.6×10^7 amps/second. This is 50% of the ANSI tested capacitor switch capability since they are tested for 12000 amps of inrush at a frequency of 6000 hertz as specified in ANSI C37.66 (American National Standard, "Requirements for Oil-Filled Capacitor Switches for Alternating-Current Systems).

Table 3
Transient Inrush Reactor Table for Multi-Stage Banks

L-L Voltage (kV)	2 Stage	3 Stage	4 Stage	5 Stage	6 Stage
2.4	4.3	12.9	11.4	10.7	10.3
4.16	7.4	22.3	19.8	18.6	17.8
4.8	8.6	25.7	22.9	21.4	20.6
6.9	12.3	37.0	32.9	30.8	29.6
8.32	14.9	44.6	39.6	37.1	35.7
12	21.4	64.3	57.1	53.6	51.4
12.47	22.3	66.8	59.4	55.7	53.4
13.2	23.6	70.7	62.8	58.9	56.6
13.8	24.6	73.9	65.7	61.6	59.1
20.78	37.1	111.3	98.9	92.8	89.0
22.86	40.8	122.4	108.8	102.0	98.0
23	41.1	123.2	109.5	102.7	98.6
24.94	44.5	133.6	118.7	111.3	106.9
34.5	61.6	184.8	164.3	154.0	147.8

***** *Inductance Requirements of Each Stage to limit inrush to 50% of Capacitor Switch Rating***

TI Reactor Design

The design of the NEPSI TI-Reactor will closely follow the reactor specification plots shown in figure 3. For example, a 101 µH reactor with a 6" diameter would require approximately 28 turns.

Note, that as diameter and the number of turns increase, so does the reactance. If a specific diameter or length is required, please specify with RFQ.

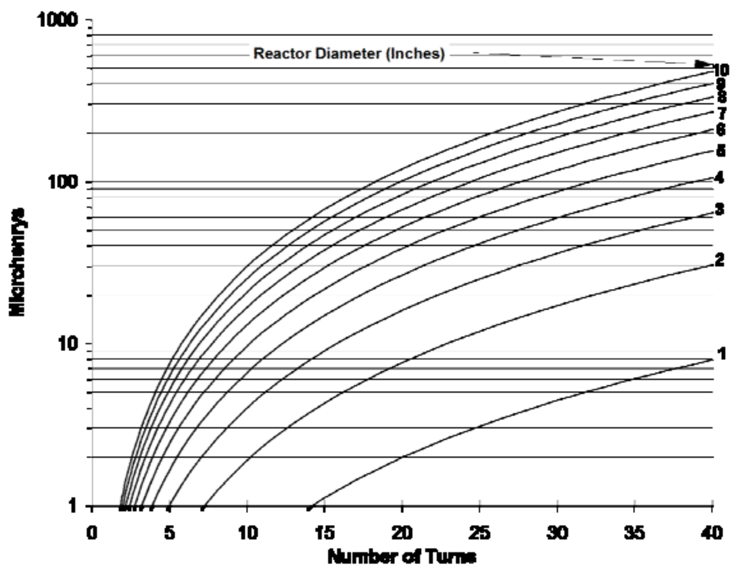


Figure 3
Reactor Design Details

Inrush Current Formulas

Table 4 – *Formulas for Calculating Transient Magnitude and Frequency Associated with Capacitor Bank Switching*	
Switching Conditions	Equation
Energizing an isolated capacitor bank or capacitor bank stage.	$I_{\text{max peak (amperes)}} = 1.41\sqrt{I_{sc} x I_1}$
	$f_{\text{(hertz)}} = \sqrt{\frac{I_{sc}}{I_1}}$
Energizing a capacitor bank or capacitor bank stage with another capacitor bank or stage on the same bus.	$I_{\text{max peak (amperes)}} = 1747\sqrt{\frac{V_{LL}(I_1 x I_2)}{L_{eq}(I_1 + I_2)}}$
	$f_{\text{(hertz)}} = 9.5\sqrt{\frac{(f_s)(V_{LL})(I_1+I_2)}{L_{eq}(I_1 x I_2)}}$

f_s = System Frequency.

L_{eq} = Total equivalent inductance per phase between capacitor banks or stages, in µH.

I_1, I_2 = Currents of bank or stages being switched and of bank or stage already energized, respectively.

$I_{\text{max peak}}$ = A peak value calculated without damping. In practical circuits it will be about 90 percent of this value.

V_{LL} = Rated maximum voltage in kilovolts.

I_{sc} = Symmetrical rms short-circuit current, in amperes.

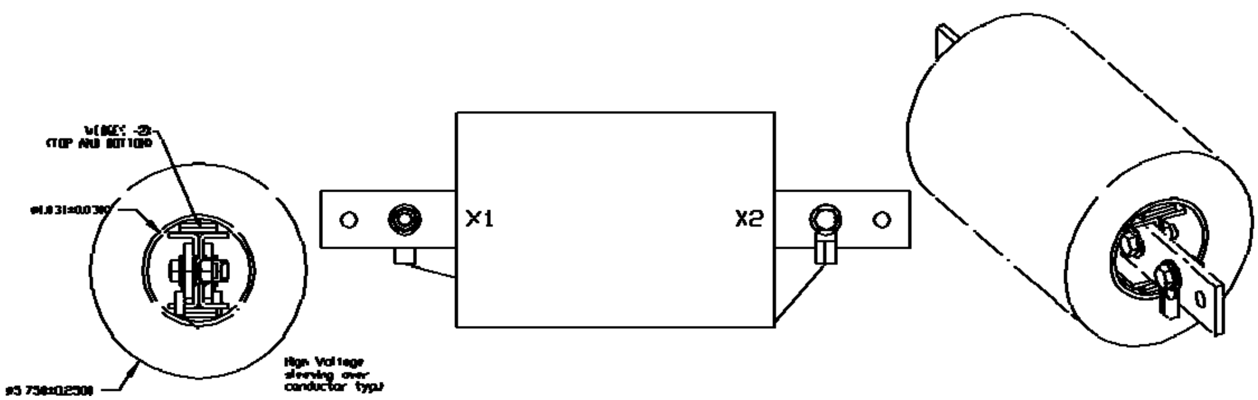


Figure 4
Typical Assembly—Designs Vary Based On Voltage, Current, and Inductance