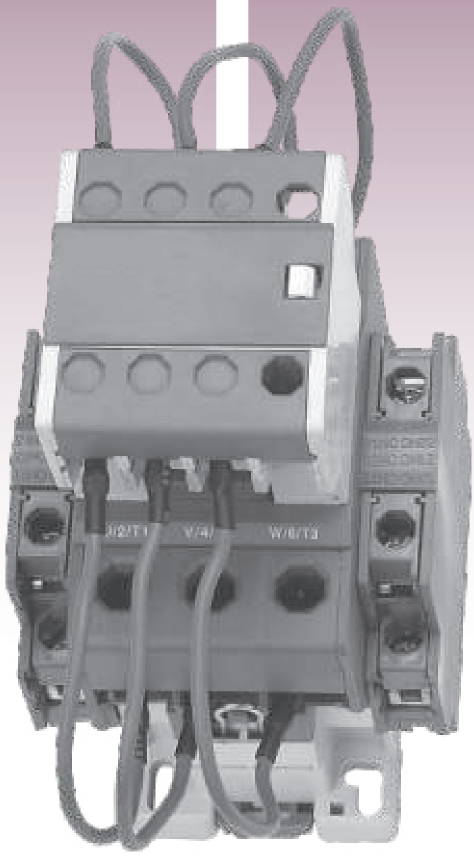


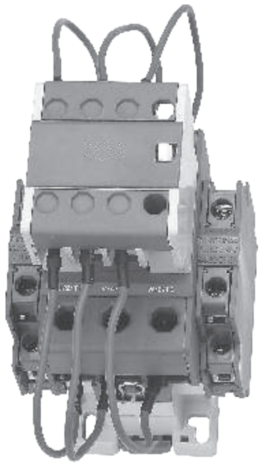

# Contactors for Capacitors Applications

DYNAGEAR

Lakshmi Electrical Control Systems Limited

# Capacitor Duty Contactor

## Introduction & Selection



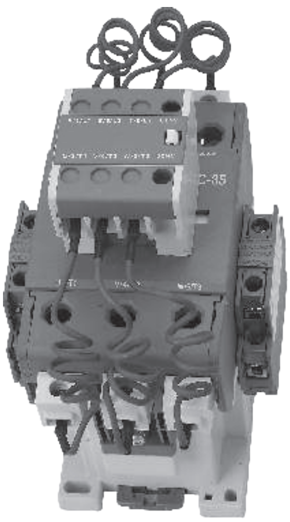
This document describes how to choose a contactor for bank capacitor application. In our offer we already have contactor LC1D*K** for bank capacitor application but this range does not provides up to 85 kVAR in 14 ratings. These contactor having CE and RoHS marking and confirms to IEC 60947-4-1.

Concepts of Operation

Capacitor duty contactor connected the capacitor loads series with resistor for the duration of 5 to 10 milli seconds. After lapse of 10 milli seconds these resistance wire permanently isolate from the supply and main contacts share the load until the coil supply interrupted.

The purpose of adding resistance wire in the capacitor circuit is to limit the heavy inrush current of capacitor and avoid contact welding. This was achieved by specially made integral pre-contacts and fiber glass teflon coated resistance wire.

All capacitor duty contactors are fitted with coil suppressor across the coil terminal to suppress the surge voltage that occurs due to self-inductance of the coil during interruptions. By providing suppressor the malfunction of APFC controller would be totally eliminated, resulting in a better life of the contactor and capacitor.

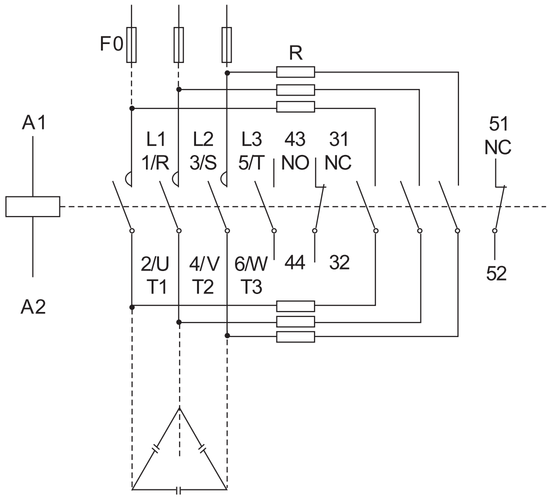


### Selection / Technical Specificatons

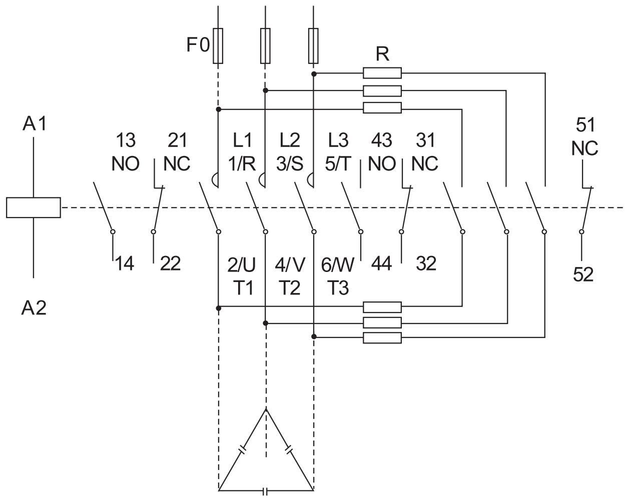
| Type | Maximum Operating Power(kVar) $\theta \leq 55^{\circ}C$ (3) | | | Ith A | Instantaneous Aux | | Max. Operating Hour |
|---|---|---|---|---|---|---|---|
| | 220~240V | 400~440V | 550~600V | | NO | NC | |
| ABNCC0211 | 1.4 | 2.5 | 3.7 | 25 | 1 | 1 | 240 |
| ABNCC0511 | 2.7 | 5 | 7.3 | 25 | 1 | 1 | 240 |
| ABNCC0712 | 4 | 7.5 | 11 | 25 | 1 | 2 | 240 |
| ABNCC1012 | 5.4 | 10 | 14.5 | 25 | 1 | 2 | 240 |
| ABNCC1212 | 6.7 | 12.5 | 18 | 25 | 1 | 2 | 240 |
| ABNCC1612 | 8.5 | 16.7 | 24 | 40 | 1 | 2 | 240 |
| ABNCC2012 | 10.7 | 20 | 30 | 40 | 1 | 2 | 240 |
| ABNCC2512 | 15 | 25 | 36 | 50 | 1 | 2 | 240 |
| ABNCC3323 | 17.7 | 33 | 48 | 60 | 2 | 3 | 240 |
| ABNCC4023 | 22 | 40 | 58 | 80 | 2 | 3 | 100 |
| ABNCC5023 | 27 | 50 | 72 | 100 | 2 | 3 | 100 |
| ABNCC6023 | 37 | 65 | 94 | 110 | 2 | 3 | 100 |
| ABNCC7523 | 40 | 75 | 108 | 135 | 2 | 3 | 100 |
| ABNCC8523 | 45 | 85 | 123 | 135 | 2 | 3 | 100 |

## Circuit Diagram

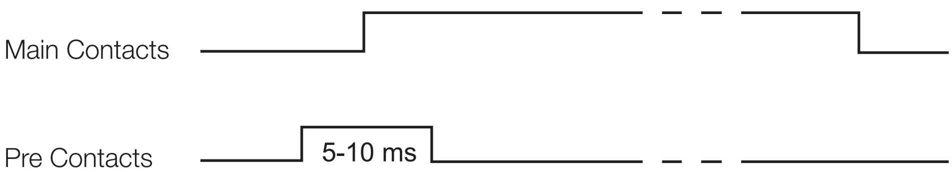
### ABN-CC07 ~CC25




### ABN-CC33 ~CC85




## Function diagram



# Capacitor Duty Contactor

## Case Studies

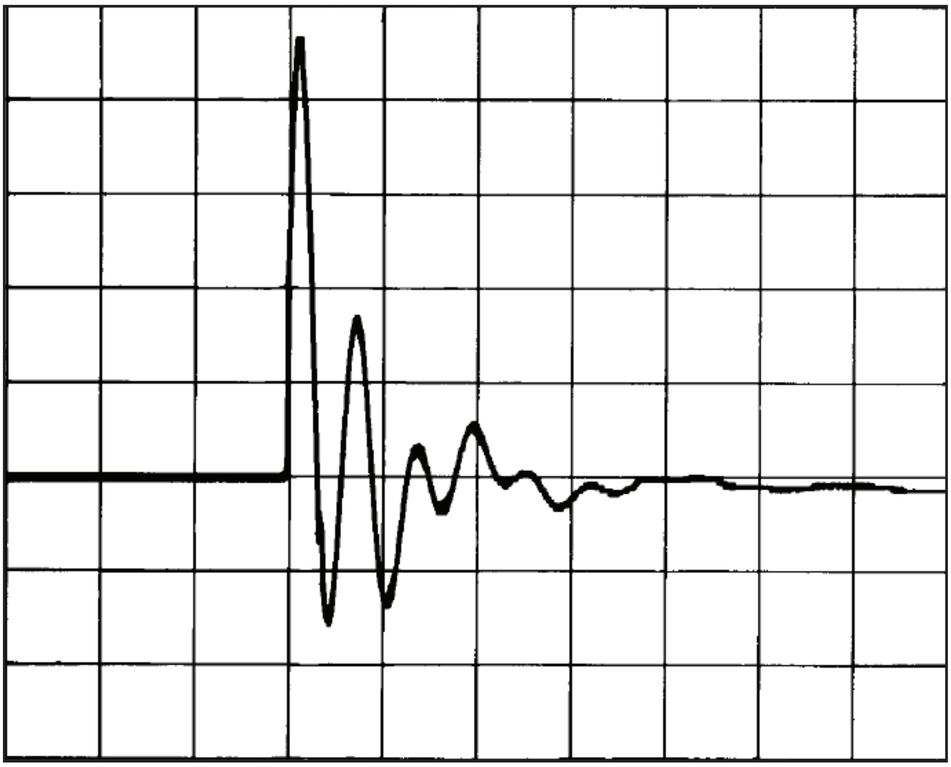
### Case studies with different condition

### 1) Normal contactor

make without pre - contacts / normal contactor

ABNCC12 with 12.5kVAr (18A / 400V)

Vertical : 250 / div     horizontal : 0.5ms / div

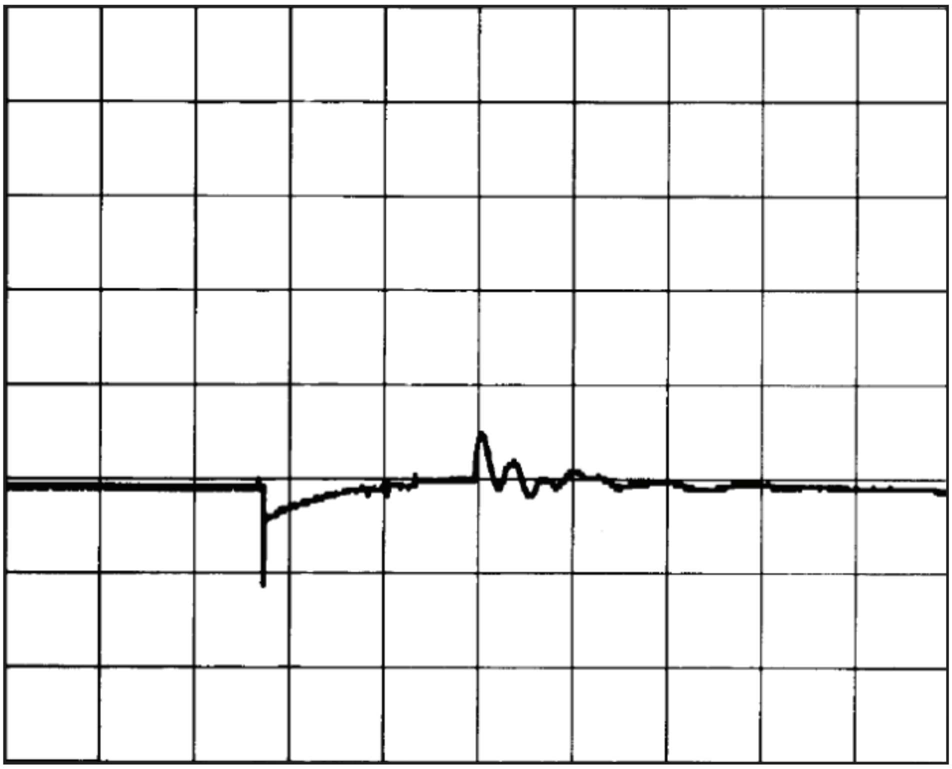


Practical function - Oscillogram

The picture shows a make current peak without pre-contacts with about 1200A with high power in opposite contrast to 280A with low power (power=integrated area). Of course, the contactors endure a few switches without pre-contacts.

### 2) Capacitor duty contactor

Make with capacitor duty contactor  ABNCC12 with 12.5kVAr (18A / 400V)
vertical : 250 / div, horizontal : 0.5ms / div



Practical function - Oscillogram

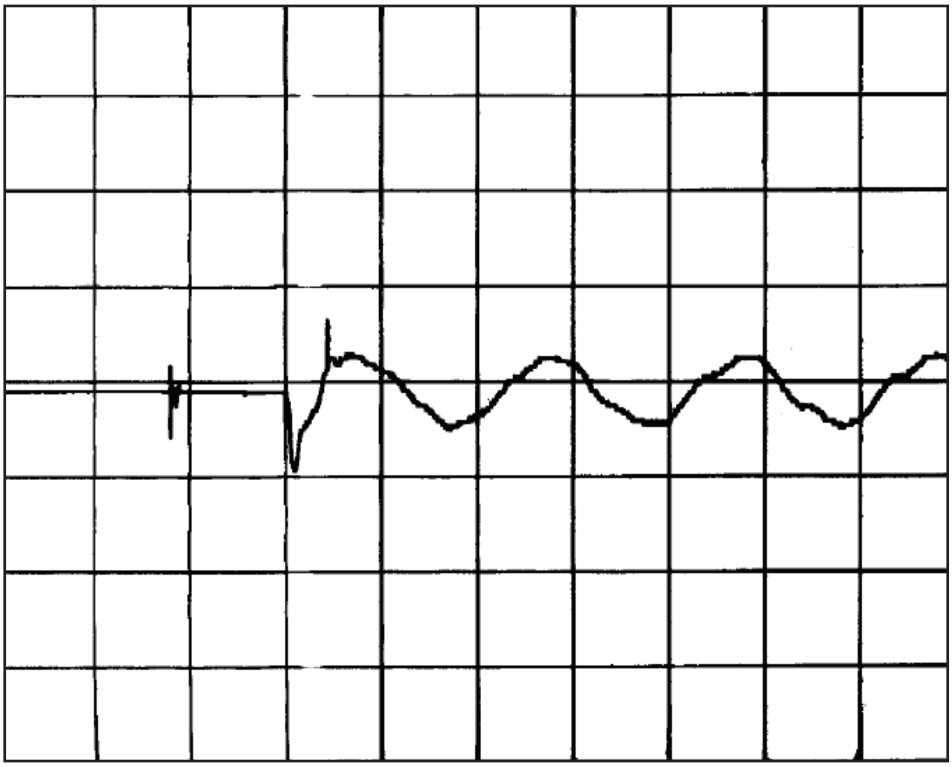
Description:
First current peak is due to make of pre-contacts.
Second current peak due to building-up the main-circuit with notable lower amplitude as the first and not so steep.

## 3) Capacitor duty contactor with choke

Make with pre - contacts with chockes ABNCC50 50kVAr (72A / 690V)
Vertical : 2000A / div, horizontal : 0.625ms / div

# Capacitor Duty Contactor

## Case Studies / Selection



In this care we see the influence of chokes and pre-contacts of the "Capacitor contactor". The peak is reduced to approx. 200A.

Also the sine weave is very clear by the influence of chokes because you have reduced harmonic frequencies.

### Practical function - Oscillogram

From this wave from the influence of choke with capacitor contactor the inrush peak current is maximum 200A for 50kVAR capacitor and the sine wave is clear which reducing the harmonic frequencies.

## Selection or normal capacitor contactors for capacitor application

Out of this range you can choose ref. below normal contactor in association with choke inductance to work bank capacitor up to 1000kVAR. This document is made to choose a ABN..... for bank capacitor, we do not describe the range ABN AC...

The Three last pages is a guide line to choose the right inductance. We do not have inductance offer in our products range but we will explain you how to select the right value of inductance.

## Method of calculation

Consider switching a single step bank of three phase capacitors (according to the circuit diagram,

below); the following details must be known :

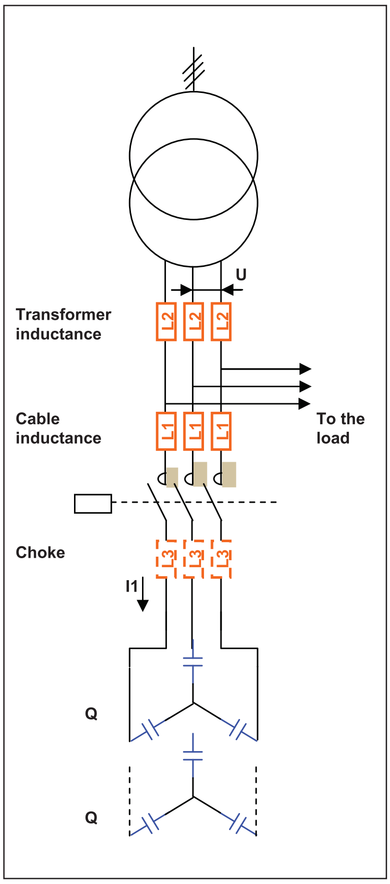
Q = Power of the capacitor bank in kVAR,

U = voltage between phases in Volts,

S = apparent power of the supply in kVA,

Usc = Short circuit voltage in %,

d = ambient temperature around the contactor in °C




- Step 1 : Determine the line current I1 using the formula :

$$I1 = \frac{Q}{U\sqrt{3}}$$

Q = in VAR (in both Y and Δ)
U = in Volts
I1 = in Amps

- Step 2 : Use a safety factor (standard) to take harmonics into account, this gives :

Ie (Contactor) = I1x1,43

(standards IEC 70, VDE 560)

- Step 3 : Select a contactor with Ith at d°C equal to or immediately greater than Ie (contactor).

- Step 4 : Having selected the rating , check the making capacity of the contactor given in the catalogue and calculate the peak current at capacitor switch on using the formula :

$$\hat{I}(kA) = \frac{Catalog\ making\ capacity\ (in\ A)\ x\ k}{1000}$$

where :
k ≅ 2,7 for D range contactors
k ≅ 2,2 for F range contactors

# Capacitor Duty Contactor

## Selection

- Step 5 : Determine the line total inductance LT needed per phase to limit the current peak at switch on.

$$L_T = \frac{Q}{0,5\hat{I}^2}$$

Q = kVAR,
Î = in kA (corresponding to Î of the capacitor),
L = in µH

- Step 6 : This inductance is made up as follows :

$L_T$ = L1 (inductance, conductors, cables)
+ L2 (transformer loss inductance)
+ L3 (choke inductance if required)

- Step 7 : whence L3(choke induct) = $L_T$ - (L1+ L2)

In practice, a choke can be made up on site by winding a few turns of closely coiled wire.

### Appendix

| Î peak in kA for capacitor switching | Type of contactor |
|---|---|
| 0,56 | ABN AC 1203 |
| 0,85 | ABN AC 1803 |
| 1,6 | ABN AC 2203 |
| 1,9 | ABN AC 3203, 4003 |
| 2,16 | ABN AC 5003 |
| 3,04 | ABN AC 6503 |
| 3,04 | ABN AC 7503, 8503 |
| 3,1 | ABN AC 10003 |
| 3,1 | ABN AC 12503 |
| 3,3 | ABN AC 15003 |
| 4 | ABN AC 22003 |
| 6,5 | ABN AC 30003 |
| 8 | ABN AC 40003 |
| 10 | ABN AC 60003 |
| 12 | ABN AC 80003 |

## Calculation of example

Select a contactor for switching a single step bank of three phases capacitors of 50 kVAR fed by an MV/LV transformer 30 kV / 400 V – 50 Hz.

S = 2000 kVA,

Usc = 6%

ambient temperature = 40°C

Solution :

- Step 1 : Calculate the line current I1 :

$$I1 = \frac{Q}{U\sqrt{3}} = \frac{50000}{400\,x\,1,732} = 72\,A$$

- Step 2 : Calculate the operating current Ie (contactor) :

$$Ie = 72\,x\,1,43 = 103\,A$$

- Step 3 : From the catalogue select on ABNAC8503 with Ith at 40°C = 135 A
- Step 4 : Catalog value of making current is 1100 A, giving :

  Î peak for capacitor switching =1100 x 2,7 @ 2970A

  (the exact value given in the table is 3040 A)
- Step 5 : The total value of inductance LT to be connected in series to limit the peak current to 2970 A is given by :

$$L_T = \frac{Q}{0,5\hat{I}^2} = \frac{50}{0,5\,x\,2,97^2} = 11,3\mu H$$

- Step 6 : To determine whether it is necessary to insert a further choke in the circuit, use :

$$L3 = L_T - (L1 + L2)$$

The inductance of the transformer L2 = 15  H. Also L1, adds even further to the inductance value (typical value for a three phase cable @ 0,3 to 0,7  H/meters)

Conclusion

No additional choke is required for this application.

# Capacitor Duty Contactor

## The Problem

Consider switching a multi step bank of three phase capacitors with steps of equal power (according to the circuit diagram, below).

The following details must be known :

$Q_T$ = total power of the capacitor bank in kVAR,

n = number of identical steps (n1, n2, n3, .... $n_n$)

Ue = operational voltage between phases in volts,

$\delta$ = ambient temperature in °C.

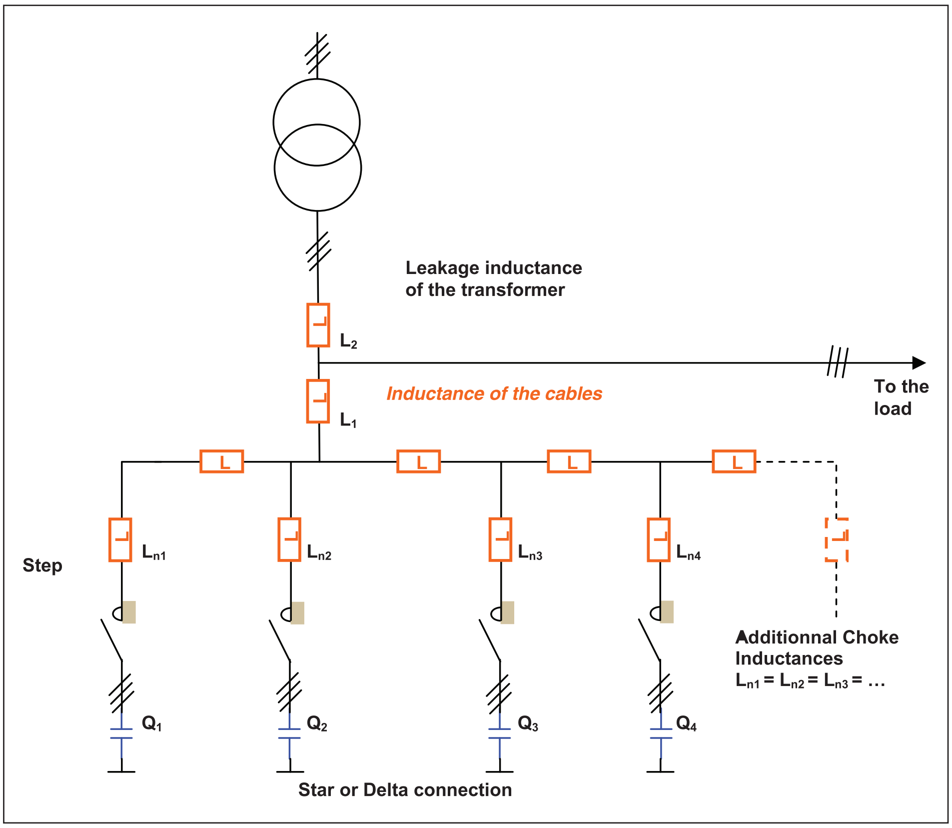
The capacitor bank is associated with a three phase distribution transformer with :

S = apparent power in VA,

Us = secondary voltage between phases (almost identical to Ue),

Usc = short circuit voltage in %,

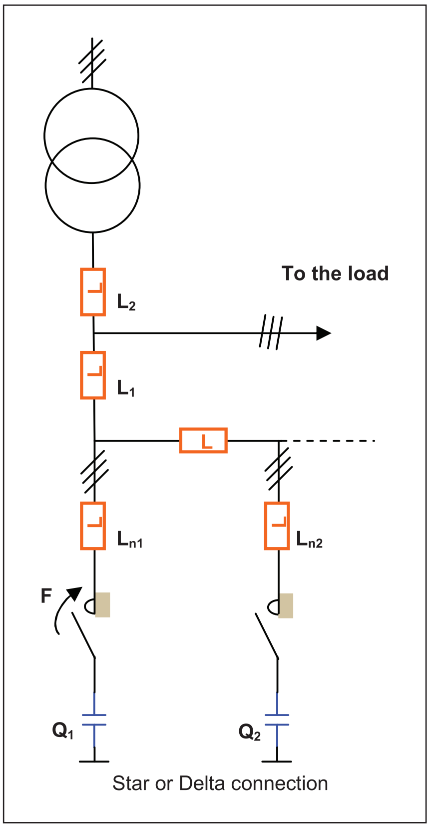
f = mains frequency in Hz




$$Q1 = Q2 = Q3 = Qn$$

$$Q_T = \sum Q1 + \sum Q2 + \sum Q3 + \ldots Qn \text{ giving} \qquad Qn = \frac{Q_T}{n}$$

- 1st Stage




At the first switching operation, the peak current is limited almost entirely by the leakage inductance of the transformer L2.

Note : it should be remembered that at the initial switch on, during the first microseconds, as discharged capacitor is almost equivalent to a short circuit.

It is therefore more practical to consider the total inductance LT which will limit the value given as peak for the making capacity of the contactor selected. This avoids the welding of the contactor.

The total inductance is given by the formula :

$$L_T = \frac{Q_T}{0{,}5\hat{I}^2 \; x \; n}$$

$L_T$ = total inductance in μH

$Q_T$ = total power of the bank in kVAR Î

Î = making capacity of the contactor in kA

n = number of steps

Next check that :

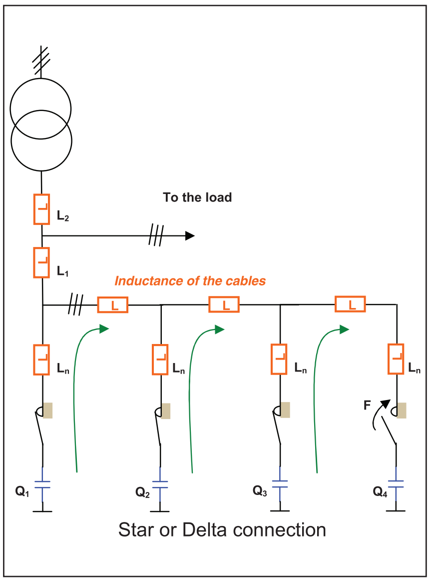
$$\begin{aligned} L_T \leq \quad & L2 \quad \text{Leackage induct. of the transformer} \\ & + L1 \quad \text{Induct. of the cables or conductors} \\ & + L_{n1} \quad \text{Choke Induct., to be calculated later} \\ & \quad (\text{see following page}) \end{aligned}$$

Note : in practice this first stage rarely presents a problem as the value of L2 is often greater than $L_T$.

# Capacitor Duty Contactor

## The Problem

- 2nd Stage




As one or more steps are already connected, the peak current caused by the discharge of these capacitors when switching in the next page is only limited by the inductance of the cables plus the choke inductance if one is required.

It is interesting to note that, in this particular case, the leakage inductance of the transformer L2 is no longer a factor.

Calculation of the choke inductance Ln according to the formula :

$$L_n = \frac{665 \; x \; Q_T \; x \left(\frac{n-1}{n}\right)^2}{\omega \; x \; \hat{I}^2 \; x \; n}$$

where :

$L_n$ = choke inductance in MH

$Q_T$ = total power of the bank in kVAR

Î = making capacity at peak current of the selected contactor in kA

n = number of steps

w = angular frequency = 2pf = 314 at 50 Hz (= 376 at 60 Hz)

The above relationship brings out two interesting aspects of this application. For a given bank of capacitors of power QT, the choke inductance Ln will be all the lower (and therefore less expensive):

a) The fewer the number of steps

In effect $\left(\frac{n-1}{n}\right)^2$ is equal to 0, 56 for 4 steps (0, 69 for 6 steps and 0, 76 for 8 steps)

b) The higher the rating of the contactor selected, as it will then have a higher peak making capacity Î

**- In short**

If the customer has not settled on a fixed number of capacitor bank steps, a technical design study can lead to an economic choice between:

- The number of steps ( to avoid welding problem we suggest to do not exceed 6 to 8 steps )
- The ratings of the contactors
- The cost of the choke inductance

## Calculation of example

Power factor improvement for an installation with the following characteristics :

| | |
|---|---|
| - Distribution transformer | S = 1250 kVA |
| - Short circuit voltage | Usc = 5,5 % |
| - Secondary voltage between phases | Us = 400 V |
| - Maximum ambient temperature | d = 40°C |
| - Frequency | F = 50 Hz |
| - Total power of the capacity bank | QT = 360 kVAR |
| - Operating voltage | Ue = 380 V |
| - Number of steps | n = 6 |

Determination of the contactor rating

Value of the line current I1

$$I1 = \frac{Q1}{Ue\sqrt{3}\ x\ n} = \frac{360000}{380\sqrt{3}\ x\ 6} = 91A$$

$Q_T$ = in var

Ue = in volts

n = number of steps

Value of the contactor operational current Ie

Ie = I1 x 1,43 which gives 90 x 1,43 = 130A

From the catalogue, select the ABN AC 12503 which has:

Ith at 40°C = 250 A

Making capacity = 1260 A

Conformity to IEC 158.1

Peak current calculation at switch on :

Î = 1250 x 2,2 @ 2750 or 2,7kA

- 1st Stage

Decide whether or not a choke inductance is required for the initial switch on:

$$L_T = \frac{Q_T}{0{,}5\hat{I}^2\ x\ n} = \frac{360}{0{,}5\ x\ 2{,}75^2\ x\ 6} = 15{,}8\ \mu H$$

$L_T$ = total inductance in MH

$Q_T$ = total power of the bank in kA

Î = making capacity of the contactor in kA

n = number of steps

CONCLUSION = NO

In effect, a 1250 kVA transformer with Us : 400 V, Usc : 5,5 % has an inherent leakage inductance of 25 MH.

As 25 MH > 15, 8 MH the peak current will be limited in proportion and there will therefore be no danger of the

contactor welding.

- 2nd Stage

For switching the next steps a choke inductance will be required at each step with a value of :

$$L_n = \frac{665\ x\ Q_T\ x\left(\frac{n-1}{n}\right)^2}{\omega\ x\ \hat{I}^2\ x\ n} = \frac{665\ x\ 360\ x\left(\frac{6-1}{6}\right)^2}{314\ x\ 2{,}75^2\ x\ 6} = 11{,}6\mu H$$

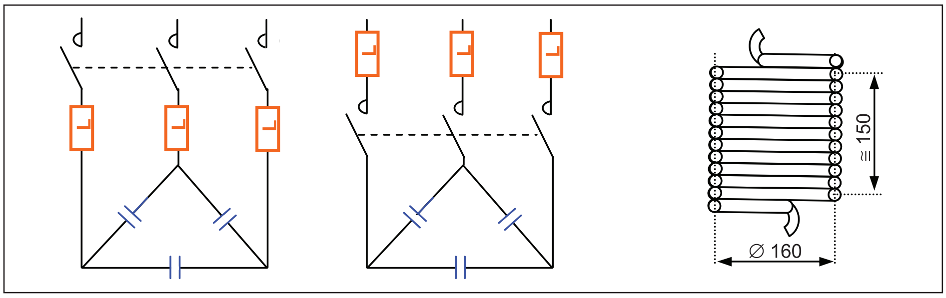
# Capacitor Duty Contactor

## Installation

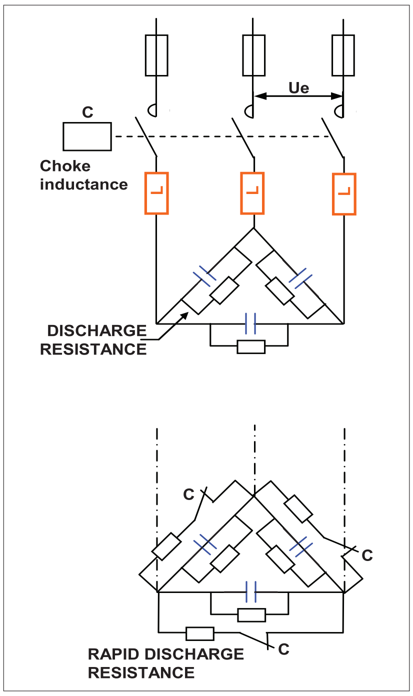
### Practical installation of choke inductances

These are placed in each phase upstream or downstream of the contactor and can simply comprise a number of turns in connecting cables.

In the above example, the operational current Ie is 130 A. 50 mm2 cable could be used, approximately 12 turns would be required at a mean diameter of 160 mm.




### Precautions relating to the sequence of operation




To conform to IEC 70, NF C 54 100 and VDE 0560, capacitors should be fitted with a discharge device (resistance) to reduce the residual voltage from peak Un to 50 volts in a time of :

- one minute for Ue £ 660 V
- five minutes for Ue > 660 V

As a result, in order to avoid premature reclosing of the contactors on to capacitors charged in phase opposition, the contactors should be delayed on reclosing. The operating rate is therefore low and presents no problem.

Nevertheless if a faster operating sequence is required, then fast discharge resistors should be used, connected as shown in the circuit diagram on the right.

The contactor should be fitted with three suitably rated N/C contacts.

#### Electrical life

At present a standard test circuit does not exist for this application.

It is therefore suggested that, based on the above selection methods, the following figures can be given :

D range : 100 000 electrical operating cycles

F range : 300 000 electrical operating cycles

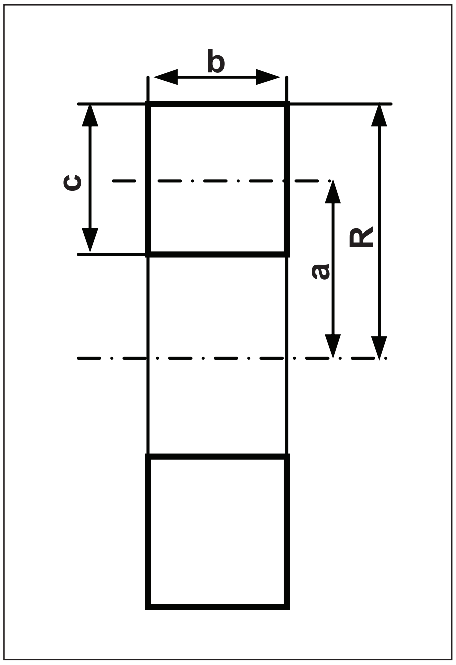
#### Short circuit protection

This is normally provided by g1 distribution fuses rated for 1,3 to 1,4 Ie.

## Calculation of inductance using the brooks and turner formula

### General

This formula enables calculation of the approximate value of the inductance of the tightly wound cylindrical coils (+/- 5%). It can be applied to long or short coils, single or multiple turn and with one or more layers.




$$L = \frac{10^{-4}\ x\ 4\ x\ \pi^2\ x\ a^2\ x\ N^2}{b\ x\ c\ x\ R} = F'\ x\ F''$$

L = in µH
a, b, c, R = in mm
N = number of turns

F' and F" are coefficients which depend on the shape of the coil. They are given by the following formula which enables the geometry of the coil to be taken into account :

$$F' = \frac{10b\ x\ 12c\ x\ 2R}{10b\ x\ 10c\ x\ 1{,}4R}$$

$$F'' = 0{,}5\ \log_{(10)}\left(100 + \frac{14R}{2b + 3c}\right)$$

b, c and R being expressed in the same units

# Capacitor Duty Contactor

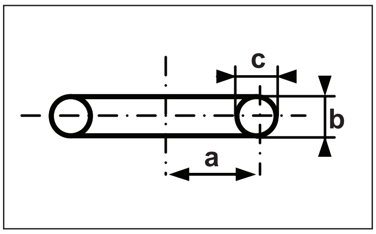
## Case Studies

### Calculation of inductance using the brooks and turner formula

**For a long coil**

If b ³ 4R, F' and F" are close to unity, therefore F' x F" @ 1

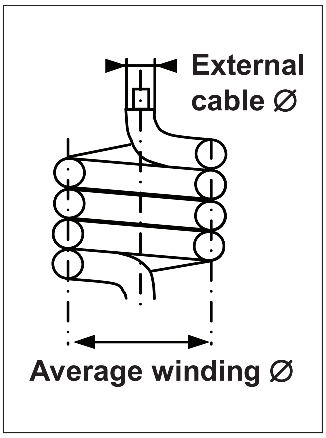
**For a single turn coil**




b = c = Ø of the wire
a is the radius of the turn
Suppose the wire diameter to be very small compared with a ( radius of the choke ).

**For choke inductance**

Choke inductances are normally made from coils of the connecting cable wound in a single layer side by side.




We need to know the following values :

- the inductance L in H
- the cross section of wire in mm² (this value depends on the operating current Ie at a given ambient temperature)
- the external diameter of the wire in mm (determined by the rating of the installation).

Nevertheless to avoid calculations and the consequent risk of error, a table of precalculated values is given below to cover the most common cases.

## Inductance (µH)

**Single Core cable U 1000 R02V**

| Average winding ∅ (mm) | | 80 | 100 | 160 | 200 | 250 | 300 | 80 | 100 | 160 | 200 | 250 | 300 | 80 | 100 | 160 | 200 | 250 | 300 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ext cable** | **c.s.a.** | **5 turns** | | | | | | **10 turns** | | | | | | **15 turns** | | | | | |
| 6.4 | 1.5 | 2.1 | 3.0 | | | | | 5.9 | 8.5 | | | | | 10.2 | 15.0 | | | | |
| 6.8 | 2.5 | 2.1 | 2.9 | | | | | 5.7 | 8.2 | | | | | 9.7 | 14.3 | | | | |
| 7.2 | 4 | 2.0 | 2.8 | | | | | 5.4 | 7.9 | | | | | 9.3 | 13.7 | | | | |
| 8.2 | 6 | | 2.6 | 5.4 | | | | | 7.2 | 15.6 | | | | | 12.5 | 27.9 | | | |
| 9.2 | 10 | | 2.5 | 5.1 | | | | | 6.7 | 14.6 | | | | | 11.4 | 25.8 | | | |
| 10.5 | 16 | | 2.3 | 4.8 | 6.6 | | | | 6.1 | 13.4 | 19.3 | | | | 10.3 | 23.5 | 34.3 | | |
| 12.5 | 25 | | | 4.3 | 6.1 | | | | | 12.0 | 17.3 | | | | | 20.7 | 30.4 | | |
| 13.5 | 35 | | | 4.1 | 5.9 | 8.2 | | | | 11.4 | 16.5 | 23.7 | | | | 19.5 | 28.8 | 42.1 | |
| 15 | 50 | | | 3.9 | 5.5 | 7.8 | 10.2 | | | 10.6 | 15.4 | 22.2 | 29.8 | | | 18.0 | 26.7 | 39.1 | 53.2 |
| 17 | 70 | | | | 5.2 | 7.3 | 9.6 | | | | 14.1 | 20.5 | 27.6 | | | | 24.3 | 35.8 | 48.9 |
| 19 | 95 | | | | 4.8 | 6.9 | 9.1 | | | | 13.1 | 19.1 | 25.8 | | | | 22.3 | 33.0 | 45.2 |
| 23 | 150 | | | | | 6.2 | 8.2 | | | | | 16.7 | 22.7 | | | | | 28.6 | 39.4 |
| 28.5 | 240 | | | | | | 7.2 | | | | | | 19.6 | | | | | | 33.4 |

| Average winding ∅ (mm) | | 80 | 100 | 160 | 200 | 250 | 300 | 80 | 100 | 160 | 200 | 250 | 300 | 80 | 100 | 160 | 200 | 250 | 300 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ext cable** | **c.s.a.** | **20 turns** | | | | | | **25 turns** | | | | | | **30 turns** | | | | | |
| 6.4 | 1.5 | 15 | 22 | | | | | 19 | 29 | | | | | 24 | 36 | | | | |
| 6.8 | 2.5 | 14 | 21 | | | | | 18 | 28 | | | | | 23 | 34 | | | | |
| 7.2 | 4 | 13 | 20 | | | | | 18 | 26 | | | | | 22 | 33 | | | | |
| 8.2 | 6 | | 18 | 41 | | | | | 24 | 55 | | | | | 29 | 69 | | | |
| 9.2 | 10 | | 16 | 38 | | | | | 22 | 50 | | | | | 27 | 63 | | | |
| 10.5 | 16 | | 15 | 34 | 51 | | | | 19 | 45 | 68 | | | | 24 | 57 | 85 | | |
| 12.5 | 25 | | | 30 | 44 | | | | | 39 | 59 | | | | | 49 | 74 | | |
| 13.5 | 35 | | | 28 | 42 | 62 | | | | 37 | 55 | 83 | | | | 46 | 69 | 104 | |
| 15 | 50 | | | 26 | 39 | 57 | 79 | | | 34 | 51 | 76 | 105 | | | 42 | 64 | 95 | 132 |
| 17 | 70 | | | | 35 | 52 | 72 | | | | 45 | 69 | 96 | | | | 57 | 86 | 120 |
| 19 | 95 | | | | 32 | 48 | 66 | | | | 42 | 63 | 88 | | | | 52 | 78 | 110 |
| 23 | 150 | | | | | 41 | 57 | | | | | 54 | 75 | | | | | 67 | 94 |
| 28.5 | 240 | | | | | | 48 | | | | | | 63 | | | | | | 78 |

Note : the winding diameter should be less than 10 to 12 times the external diameter of the cable, according to the cable manufacterer's specifications

# Capacitor Duty Contactor

## Instruction

### Useful informations at user end

If you are using 220/240V coil by giving single phase supply (Phase and neutral) to the capacitor duty contactors through controller, please ensure a proper termination and connection at the neutral terminals, both at panel and main supply. Any weak neutral / loose connections would result in low voltage and lead to coil melting and resistance wire burn out. In such cases please incorporate low voltage monitoring option, to isolate the supply at the coil terminals.

We suggest using 415/440V coils, to eliminate the coil melting due to weak neutral and to obtaintrouble free operation of the capacitor duty contactors.

Please check the main terminal connection at least once in two months, to avoid melting and short circuit in the power terminals of the capacitor duty contactors.

Use proper lugs at the correct side of the main terminals of the contactor as per our recommendation in the instruction sheet. Preferably use fork/round type lugs for easy wiring connection and proper grip in the termination.

Don't try to manually push and hold the contact carrier either in the contactor or in the aux. block when power is on, which may result in burning of resistance wire.

Whenever the coil is changed in the contactor or remounting of aux. block for whatever reason, please checks manually for the free movement of contact carrier before switch on power supply.

Do not tamper with resistance wire connections.

Ensure the use of proper VA burden to the coil in case you are using control transformer. To calculate VA burden of the transformer consider the pickuop vA of the highest rated contactor in the system plus the sum of the holding VA of all other contactors together.

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