How to choose a contactor for Bank capacitor application ?

I- Type of publication

- [ ] Typical application
- [x] Best know Method (BKM)
- [ ] Troubleshooting guide

- [ ] Level 2 use
- [ ] Internal use
- [x] Customer

II- Product

- Product range : Contactor

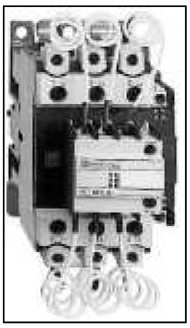
- Product family : LC1D/LC1F

III- Introduction

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 provide a complete offer (you can only go up to 92 kVAR).

Out of this range you can choose Tesys D or Tesys F contactor in association with choke inductance to work with bank capacitor up to 1000 kVAR. This document is made to choose a Tesys D or Tesys F for bank capacitor, we do not describe the range LC1D*K**.

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.

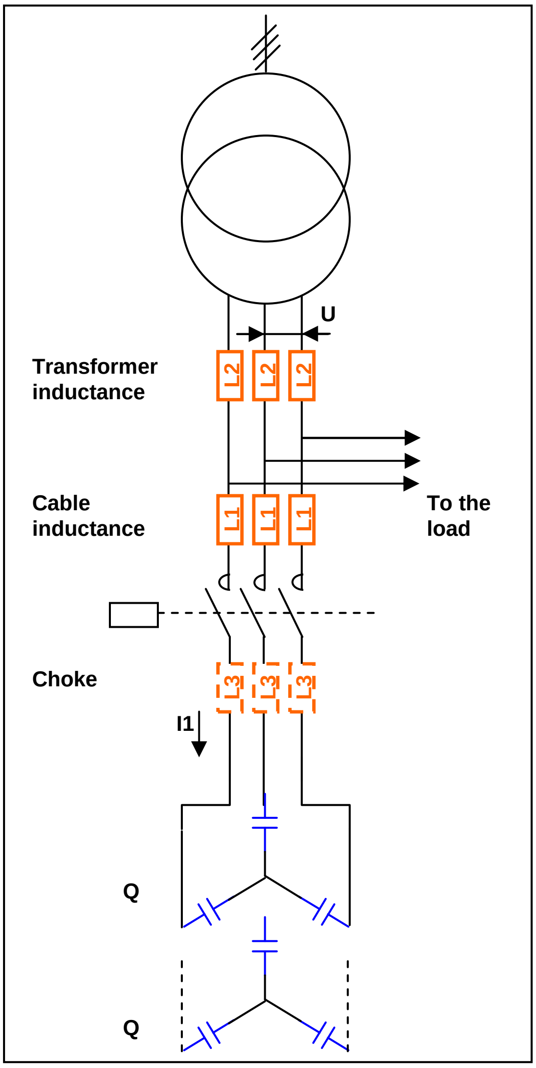


Contactor LC1D*K**

IV- Description

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 %,
δ = ambient temperature around the contactor in ℃



- 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 :

$$Ie(Contactor) = I1 x 1{,}43$$

(standards IEC 70, VDE 560)

- Step 3 : Select a contactor with Ith at δ℃ 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

- Step 5 : Determine the line total inductance L_T 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	LC1D12
0,85	LC1D18
1,6	LC1D25
1,9	LC1D32, D38
2,16	LC1D40
2,16	LC1D50
3,04	LC1D65
3,04	LC1D80, D95
3,1	LC1D115
3,3	LC1D150
3,5	LC1F185
4	LC1F225
5	LC1F265
6,5	LC1F330
8	LC1F400
10	LC1F500
12	LC1F630

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℃

Solution :

- Step 1 : Calculate the line current I1 :

$$I1 = \frac{Q}{U\sqrt{3}} = \frac{50000}{400\,x1,732} = 72A$$

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

$$Ie = 72\,x1,43 = 103A$$

- Step 3 : From the catalogue select on LC1-D80 with Ith at 40℃ = 125 A

- Step 4 : Catalog value of making current is 1100 A, giving :

$$\hat{I}\ peak\ \ for\ capacitor\ \ switching = 1100\,x\,2,7 \cong 2970A$$

(the exact value given in the table is 3040 A)

- Step 5 : The total value of inductance L_T 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 µH. Also L1, adds even further to the inductance value (typical value for a three phase cable ≅ 0,3 to 0,7 µH/meters)

Conclusion

No additional choke is required for this application.

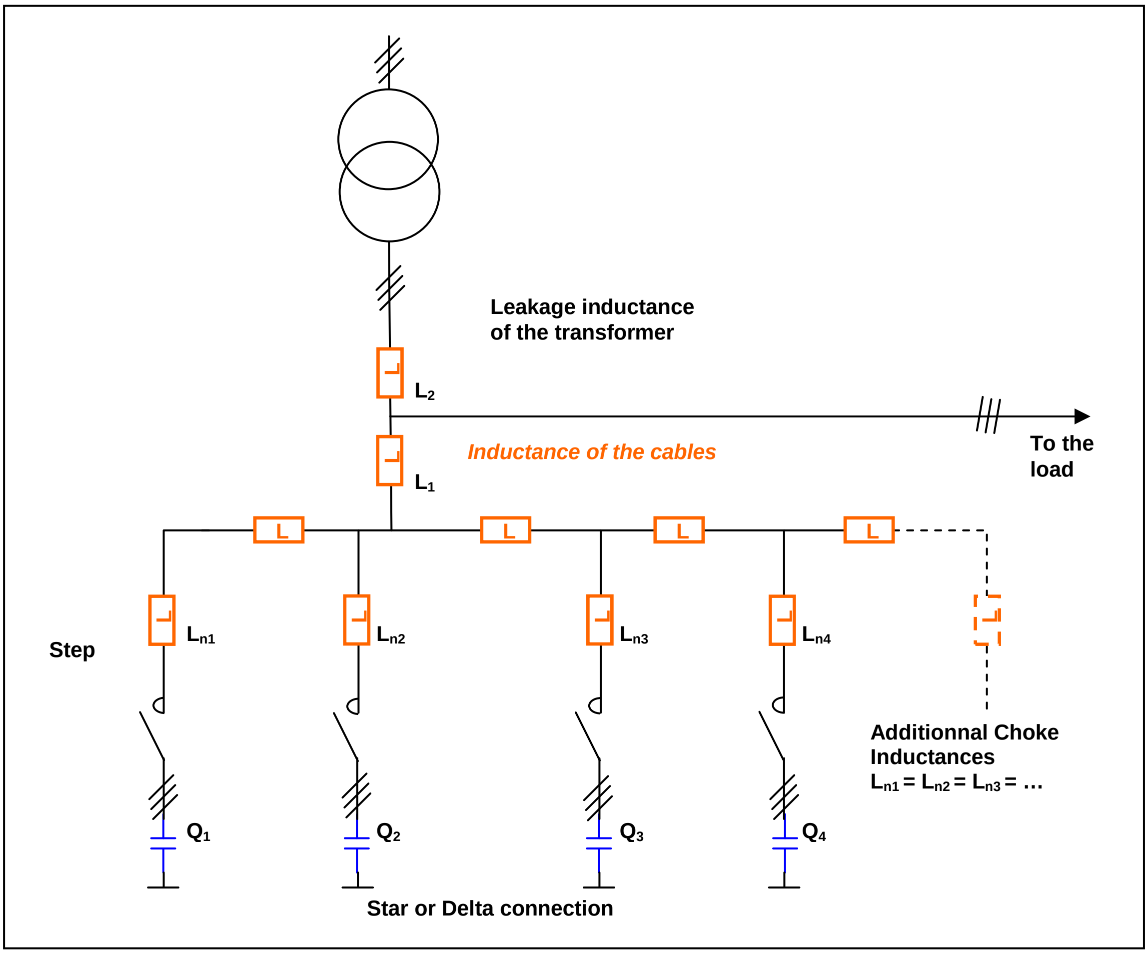
The problem

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,
δ = ambient temperature in ℃.

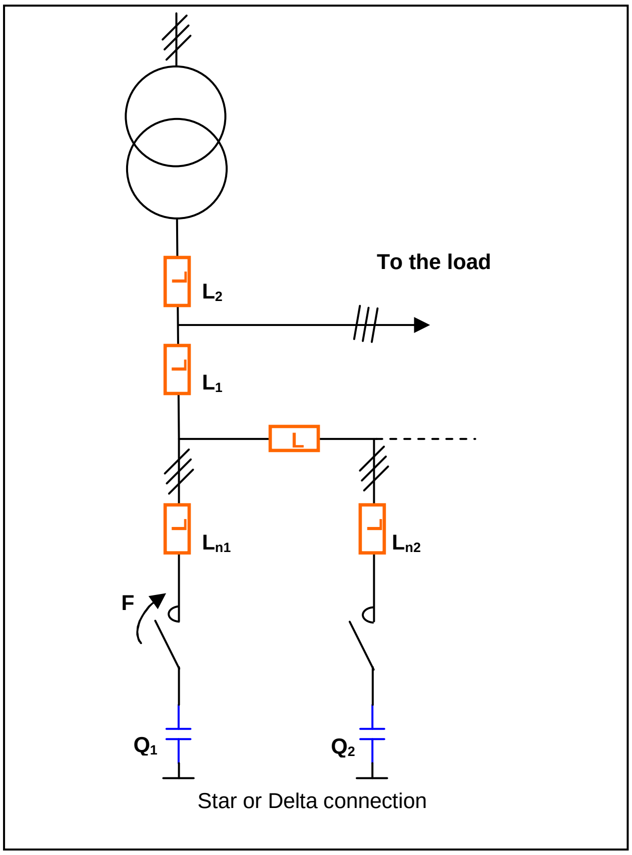
The capacitor bank is associated with a three phase distribution transformer with :
S = apparent power in VA,
Us = secondary voltage between phases (almost identical to Ue),
Usc = short circuit voltage in %,
f = mains frequency in Hz



$$Q1 = Q2 = Q3 = Qn$$

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

- 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 L_T 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 :

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

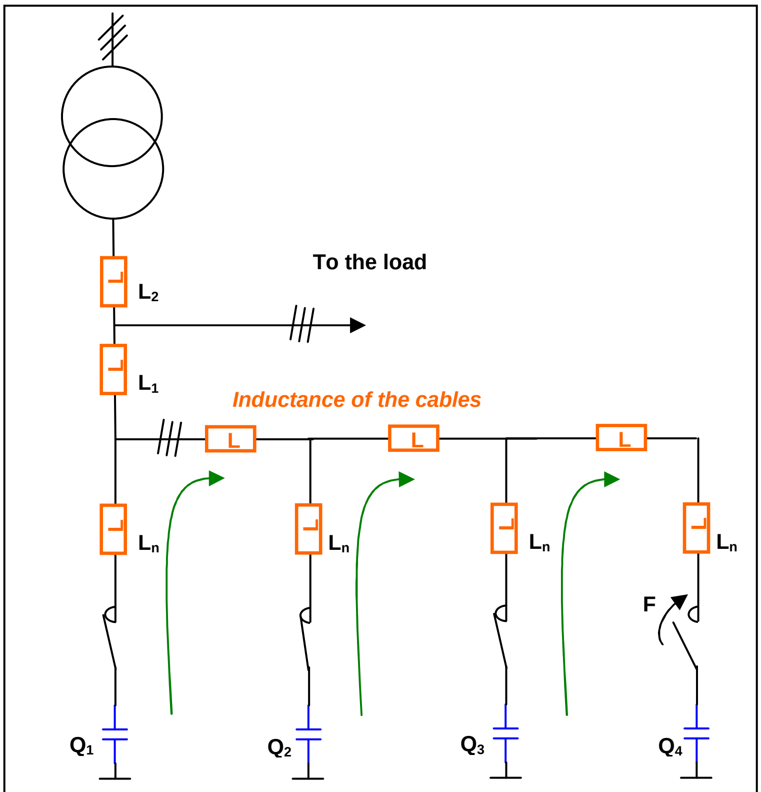
L_T = total inductance in µH
Q_T = total power of the bank in kVAR Î
Î = making capacity of the contactor in kA
n = number of steps

Next check that :

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

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

- 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 :
Ln = choke inductance in µH
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
ω = angular frequency = 2πf = 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 Q_T, 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 example

Power factor improvement for an installation with the following characteristics :

- Distribution transformer	
- Short circuit voltage	S = 1250 kVA
- Secondary voltage between phases	Usc = 5,5 %
- Maximum ambient temperature	Us = 400 V
- Frequency	δ = 40℃
- Total power of the capacity bank	F = 50 Hz
- Operating voltage	Q_T = 360 kVAR
- Number of steps	Ue = 380 V
	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 LC1D115 which has:

Ith at 40℃ = 250 A
Making capacity = 1260 A
Conformity to IEC 158.1

Peak current calculation at switch on :

$$\hat{I} = 1250\ x\ 2{,}2 \cong 2750\ or\ 2{,}7kA$$

- 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 µH
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 µH. As 25 µH > 15, 8 µH the peak current will be limited in proportion and there will therefore be no danger of the contactor welding.

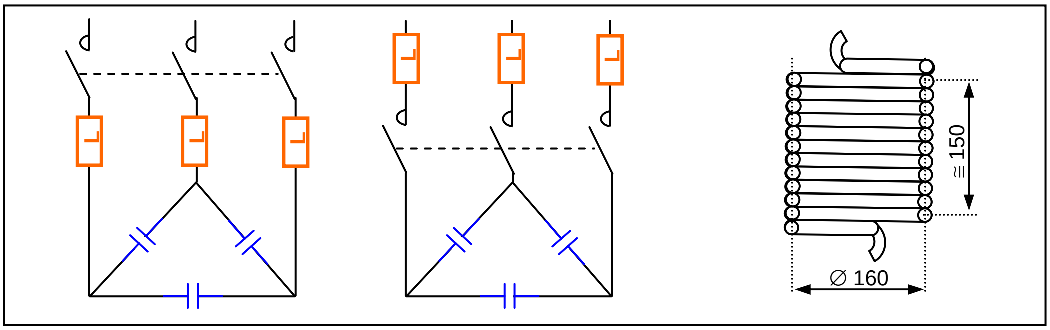
- 2nd Stage

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

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

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 mm^2 cable could be used, approximately 12 turns would be required at a mean diameter of 160 mm.



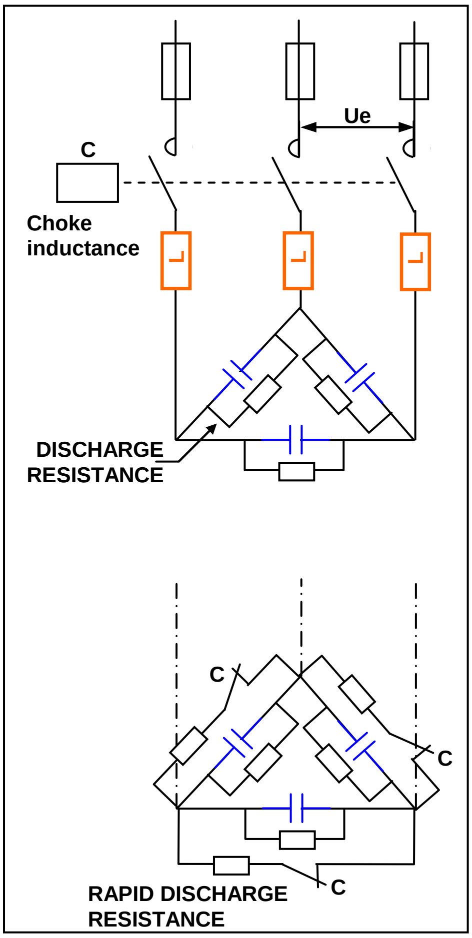
Precautions relating to the sequence of operation

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

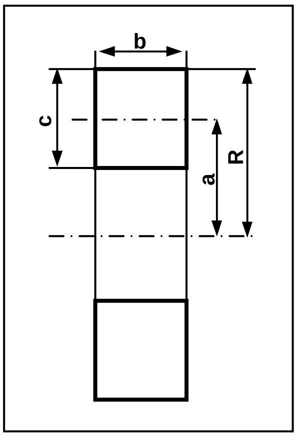
Short circuit protection

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 :

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

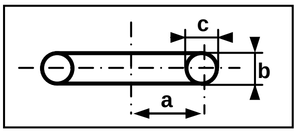
$$F'' = 0{,}5\log_{(10)}\left(100 + \frac{14R}{2b+3c}\right)$$

b, c and R being expressed in the same units

- ***For a long coil***

If b ≥ 4R, F' and F'' are close to unity, therefore F' x F'' ≅ 1

- ***For a single turn coil***

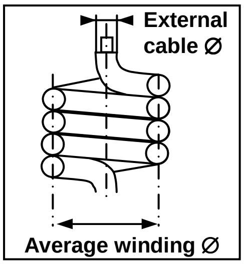


b = c = ∅ of the wire
a is the radius of the turn

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 µH
- 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
		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

V- Limitation

This document is made for TeysD or TesysF contactor you cannot use these informations for other contactors. We do not have reference for inductance because this kind of product is not sold by Schneider electric. We just gave you a guide line to choose your inductance.