LARSEN & TOUBRO

POWER QUALITY SOLUTIONS

L&T SWITCHGEAR

SAFE & SURE

Switchgear Factory, Navi Mumbai

Switchgear Factory, Ahmednagar

Switchgear Factory, Vadodara

ABOUT US

Larsen & Toubro is a technology-driven company that infuses engineering with imagination. The Company offers a wide range of advanced solutions in the field of Engineering, Construction, Electrical & Automation, Machinery and Information Technology.

L&T Switchgear, a part of the Electrical & Automation business, is India's largest manufacturer of low voltage switchgear, with the scale, sophistication and range to meet global benchmarks. With over five decades of experience in this field, the Company today enjoys a leadership position in the Indian market with a growing international presence.

It offers a complete range of products including powergear, controlgear, industrial automation, building electricals & automation, reactive power management, energy meters, and protective relays. These products conform to Indian and International Standards.

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POWER CAPACITORS

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1-25 kVAr

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5-50 kVAr

LTXL:
Ultra Heavy Duty
5-50 kVAr

MPP

Advanced APP

HARMONIC FILTERING

Detuned Harmonic Filter Reactor
5-100 kVAr
Copper and Aluminium
7% and 14%

Active Harmonic Filter
30-600A
3Ph 3Wire/4 Wire

CAPACITOR SWITCHING

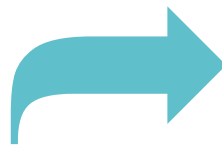Thyristor Switching Modules
10, 25 & 50 kVAr

Capacitor Duty Contactors -
Type MO C
5 – 80 kVAr

POWER FACTOR CONTROLLER

etaCON L series APFC relay
3, 5, 7, 8 and 12-step

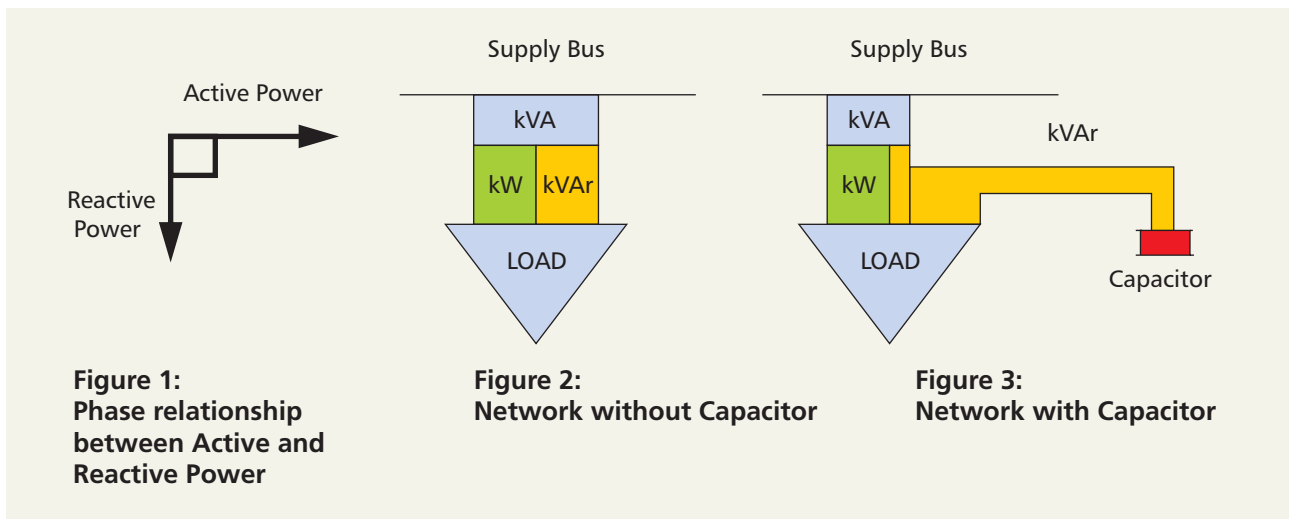# REACTIVE POWER MANAGEMENT SOLUTIONS

etaSYS APFC Panels
35 - 500 kVAr

Principles of Power Factor Correction

A vast majority of electrical loads in low voltage industrial installations are inductive in nature. Typical examples are motors and transformers, which consume both active and reactive power. The active power is used by the load to meet its actual work requirements whereas reactive power is used by the load to meet its magnetic field requirements. The reactive power (inductive) is always 90^0 lagging with respect to active power as shown in figure1. Figure 2 & 3 show the flow of kW, kVAr and kVA in a network.

Figure 1:
Phase relationship between Active and Reactive Power

Figure 2:
Network without Capacitor

Figure 3:
Network with Capacitor

Flow of active and reactive power always takes place in electrical installations. This means that the supply system has to be capable of supplying both active and reactive power. The supply of reactive power from the system results in reduced installation efficiency due to:

- Increased current flow for a given load
- Higher voltage drops in the system
- Increase in losses of transformers, switchgear and cables
- Higher kVA demand from supply system as given in figure 2
- Higher electricity cost due to levy of penalties / loss of incentives

It is therefore necessary to reduce & manage the flow of reactive power to achieve higher efficiency of the electrical system and reduction in cost of electricity consumed.
The most cost effective method of reducing and managing reactive power is power factor improvement through Power Capacitors. The concept of reduction in kVA demand from the system is shown in figure 3.

Benefits of Power Factor Correction

Power factor correction

Cost benefits

Reduction in kVAr demand

- No penalties
- Incentive

Reduction in kVA demand
- Reduction in transformer rating

- Reduced electrical equipment cost

Reduction in line current
- Reduction in power loss
- Reduction in cable size
- Reduction in switchgear rating

- Reduced energy charges
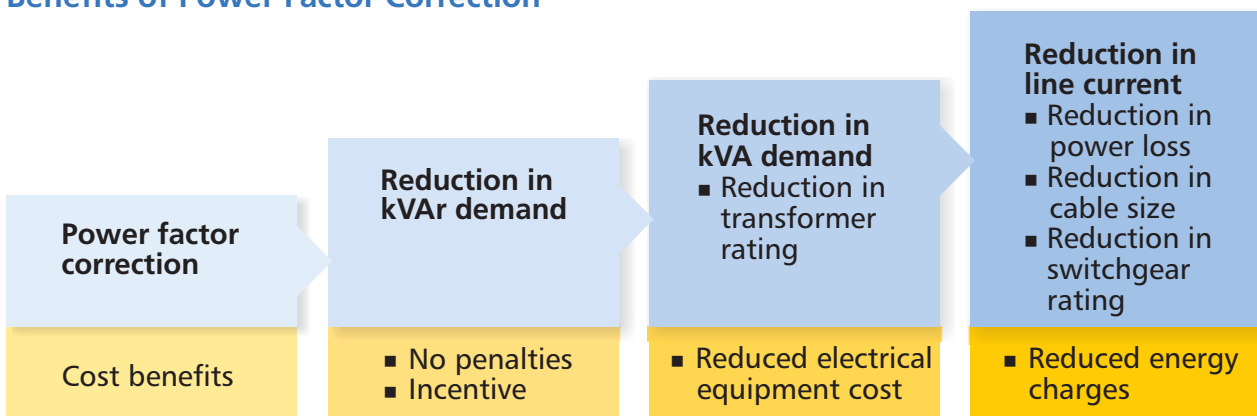
Power factor compensation can be provided on either LT or HT side of the distribution transformer. Often, compensation is done on the HT side as the electricity board measures power factor on HT side for penalty calculation. Also, HT capacitors involve low initial investment as compared to LT capacitors. However, compensation achieved by HT capacitors does not provide the benefits offered by the use of LT capacitors, as discussed in this article.

Consider two cases with compensation provided on HT and LT side respectively as shown in figure 1 and 2.
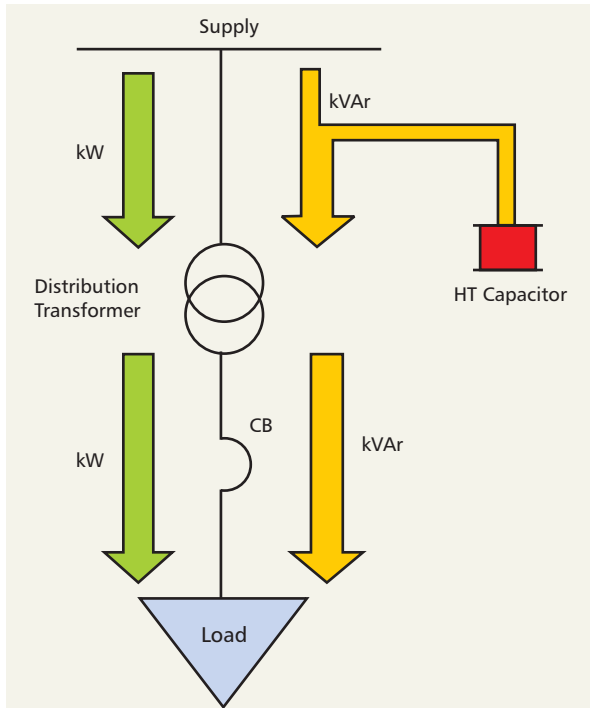
Fig 1: Compensation on HT Side   **Fig 2: Compensation on LT Side**
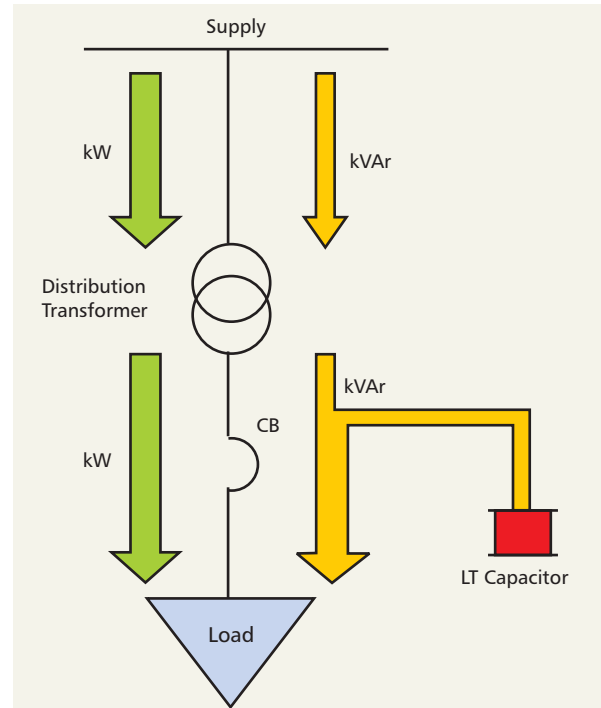
As seen in fig 1, with the capacitor connected on the HT side, the compensated reactive power flow through the transformer does not reduce and hence there is no change in current flow. Although the HT side power factor is improved, the LT side power factor remains same. However, as seen in fig 2, connecting capacitor on LT side reduces the reactive power flow through the transformer and we get improved power factor and reduced current flow on both LT and HT sides.

Reduction in Transformer Copper Losses

Consider a load of 1200 kW connected to a transformer of 2000 kVA. The typical full-load copper losses in a 2000 kVA transformer are 25000 W.

When compensation is provided on HT side, operating power factor of the transformer is 0.75 (same as uncompensated), denoted by $\cos\phi_1$.

When compensation is provided on LT side, operating power factor of the transformer is 0.98 (compensated), denoted by $\cos\phi_2$.

$$\text{Power Saving} = \text{Wf} * \text{K} * \left(\frac{1}{\cos\phi_1} - \frac{1}{\cos\phi_2} \right)$$

Where,

$$W_f = \text{Full Load Copper Losses} = 25000 \text{ W}$$

$$K = \frac{\text{Load in kW}}{\text{kVA rating of transformer}} = 0.6$$

Power Saving (in W)	=	25000*0.6*(1/.75-1/.98)	=	4694 W
Monthly Energy Savings (in kWh)	=	4694 *24*30/1000	=	3380 kWh
Typical Energy Charge (in Rs/kWh)	=	Rs. 6 per kWh		
Monthly Cost Saving (in Rs)	**=**	**6*3380**	**=**	**Rs. 20278/-**
Yearly Cost Savings (in Rs)	**=**	**20278*12**	**=**	**Rs. 243330/-**

Thus, LT compensation provides monthly savings of Rs. 20,278/- for a 2000 kVA transformer. Additionally, the operating temperature of the transformer is relatively less because of reduced copper losses. Hence, apart from monetary benefits, LT compensation also ensures longer life of the transformer.

Capacity Release in Transformer

Consider a 2000 kVA transformer connected to a load.

Cast 1: When compensation is provided on HT side, operating PF of transformer = 0.75

Maximum load that can be connected = 2000*0.75 = 1500 kW

Cast 2: When compensation is provided on LT side, operating PF of transformer = 0.98

Maximum Load that can be connected = 2000*0.98 = 1960 kW

Additional load that can be connected under the same transformer = 460 kW

LT compensation allows release of capacity of 460 kW with the same transformer. Thus, additional load can be easily connected to the system without any additional investments in new transformers.

Optimized Main Incomer Switchgear Rating

LT side capacitor, when connected after the main incomer reduces the current drawn by the same set of loads. Hence incomer switchgear rating can be optimized and the investment cost of the main incomer can be reduced.

Apart from those mentioned above, LT compensation also offers other advantages, such as

- Maintenance of LT capacitors and panels is easier and does not require complex safety measures
- Spares and accessories for the same are easily available and relatively cheaper

Thus, for a factory with all LT loads, power factor compensation with LT capacitors proves to be a better option, with its relatively smaller payback period.

MPP (Metalized Poly-Propylene)

Capacitors are used in diverse applications, and hence different capacitor technologies are available. In low voltage applications, LT cylindrical capacitors which are made in accordance with **metalized polypropylene** technology, have proved to be the most appropriate and the most cost effective amongst all technologies. Depending on the nominal voltage of the capacitor, the thickness of the polypropylene film differs.

Electrodes (metalized)

Poly-propylene Film

Electric Contact

Non-metallized Edge

Design of LT Capacitor
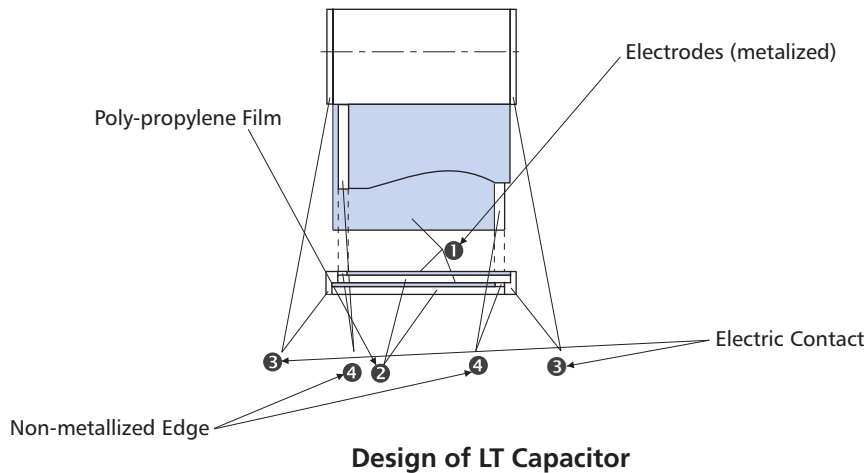
Self - Healing

At the end of service life, or due to inadmissible electrical or thermal overload, an insulation breakdown may occur. This breakdown causes a small arc which evaporates the metal layer around the point of breakdown and hence re-establishes the insulation at the place of perforation. After electric breakdown, the capacitor can still be used. The decrease of capacitance caused by a self-healing process is less than 100 pF. The self-healing process lasts for a few microseconds only and the energy necessary for healing can be measured only by means of sensitive instruments.

Polypropylene Film

Electrodes (metallized)

Point of Breakdown

Non-conductive Insulating Area

Top View

Self - Healing Breakdown
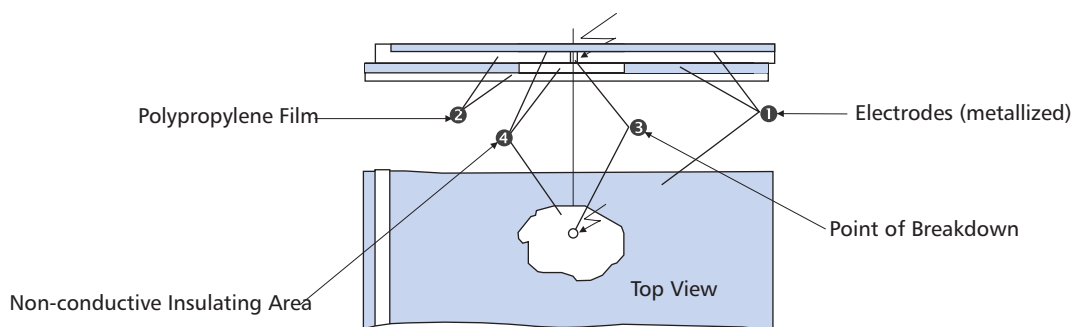
Impregnation

Our LT-type capacitors are impregnated to safeguard from environmental influences and to guarantee reliable, long-term operation. Vacuum impregnation eliminates air and moisture, improves "self-healing" and reduces thermal resistance.

Over Pressure Tear - Off Fuse

At the end of service life or after several self-healing operations or due to inadmissible electrical or thermal overload, over pressure builds up and causes an expansion of the cover. Expansion over a certain limit causes the tear-off of the internal fuses. The active capacitor elements are thus cut-off from the source of supply. The pressure within the casing separates the breaking point so rapidly that no harmful arc occurs.

Operating Condition
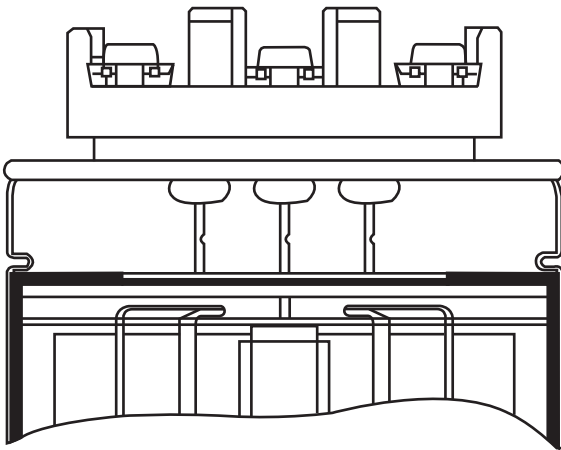
Torn - off Condition
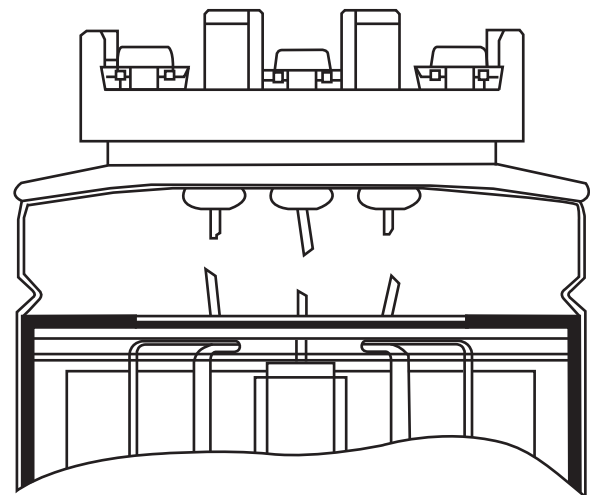
Construction Details

Cylindrical capacitors consist of three units of single phase capacitors connected in delta kept inside an aluminium can. Technologically similar to cylindrical capacitors, box type capacitors consist of three or six single phase cylindrical capacitor cells. The individual cells are wired together and mounted on a steel frame. The steel frame together with the cells is housed in a common sheet steel casing. The enclosure is powder coated and is designed to protect the capacitor cells from dust and moisture. Ease of mounting is ensured by 4 drillings at the bottom of the container.

This design ensures highest safety by:
- Self healing technology
- Over pressure tear - off fuse
- Robust steel container
- Massive connection studs

MPP capacitors are manufactured in two different types such as Standard duty and Heavy duty. The Standard duty capacitors are manufactured using standard thickness of dielectric material with heavy edge metalization. Heavy duty capacitors are manufactured using thicker material and in lower width which increases current handling capacity as well as reduces temperature rise.

LIFE OF POWER CAPACITORS

The life of a capacitor is influenced by the following three parameters:

- Temperature
- Voltage
- Current

Temperature

For a capacitor, the temperature depends upon the following parameters:
- Ambient temperature in which capacitor is being operated
- Amount of over current that flows through the capacitor
- Power loss of the capacitor (dielectric power loss and resistive power loss)

The increase in temperature results in faster degradation of the dielectric. For every 10°C rise in temperature, the life of the capacitor is halved. Faster the degradation of the dielectric, lower will be the life of the capacitor.

Increase in temperature beyond a certain limit may result in expansion of impregnation and dielectric material. This may result in bulging of capacitors. In worst case, capacitor may even burst, if it does not have an over-pressure disconnector.

The capacitor must thus be operated at rated ambient temperature for a long operating life.

Voltage

The increase in system voltage has the following effects on the capacitor:

- **Dielectric degradation**
  If the voltage increases beyond a certain limit, the dielectric material will breakdown. This critical voltage is called the dielectric breakdown voltage. Breakdown can result in an internal short circuit causing the capacitor to fail permanently

- **Increase in current flow through the capacitor**
  As capacitors are linear in nature, with increase in voltage, the capacitor current also increases because X_c remains constant ($I_c = V/X_c$). This results in overloading of the capacitor, which may reduce the life of the capacitor. Over-voltage limits of the capacitors are +10% for 12 hrs in 24 hrs, +15% for 30 min in 24h, +20% for 5 min in 24 hrs and +30% for 1 min in 24 hrs

Current

The parameters that are related to current, which affect the life of the capacitor are:

- **Inrush current**
  Inrush current (100 times rated current) is like a momentary short circuit. Frequent switching of the capacitor without proper inrush current limiting devices will affect the life of the capacitor as it is heavily stressed during each switching operation. Switching frequency thus limits the life of the capacitor

- **Over-load current**
  Continuous overload of capacitor is mainly because of harmonics and continuous over voltage. Overloading results in local hot spots and may lead to an internal short circuit

A generally accepted formula for estimating variation in life of capacitor is:

$$L = L_R \left(\frac{E_R}{E_0} \right)^7 \times 2^{(\Delta T / 10)}$$

Where:
L = operating life under stated temperature and voltage.
L_R = life at rated temperature and voltage.
E_R = rated voltage limit.
E_0 = operating voltage.
ΔT = difference between rated operating temperature and capacitor core temperature in °C.

To conclude, all the above parameters should be within the rated value in order to exploit the maximum life of the capacitor.

A capacitor is a passive device which has two conductors separated by a dielectric of infinite resistance, ideally. Hence, it should offer only capacitive reactance, with zero resistance and zero inductance values. But practically, the dielectric of the capacitor will offer a finite resistance along with the capacitance. This finite resistance is called as **Equivalent Series Resistance (ESR)**, and its equivalent circuit can be represented as below:

$$C_{real} \qquad\qquad C_{ideal} \qquad ESR$$
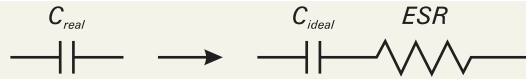
The ESR in the capacitor causes the leakage current to flow through the dielectric of the capacitor. This results in real power loss (I^2 *ESR) called as dielectric loss. Higher the ESR, higher is the power loss, and hence the heat generated by the capacitor is also more. The heat generated should be dissipated properly; otherwise it may result in significant temperature rise. A good quality capacitor has very low ESR value.

In a lossless (ideal) capacitor, the current leads the voltage exactly by 90°. But there is always a small shortfall in the lead angle from 90°, because of the dielectric loss. The difference in angle is called loss angle (δ). The following diagram represents loss angle (δ) in the impedance plane.

The tangent of the loss angle (loss tangent) is defined as the ratio of the capacitor's equivalent series resistance (ESR) to the capacitive reactance (X_c).

Impedance plane

ESR

δ

$-jX_c$
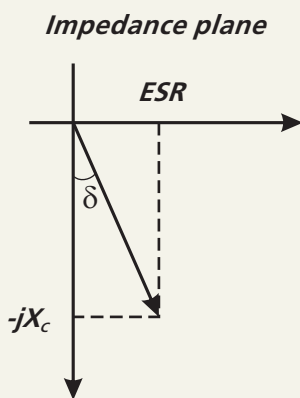
$$\tan\delta = \frac{ESR}{[Xc]} \longrightarrow \text{(Eq 1)}$$

Power loss $= I^2 \times ESR$

$\quad = (\omega CV) \times (\omega CV) \times ESR$ where, $\omega = 2\pi f$

$\quad = (\omega C) \times (\omega CV^2) \times ESR$

$\quad = (\omega C) \times Q \times ESR$

$\quad = Q \times ESR / X_c$

Power loss $= Q \tan\delta$ [from Eq 1]

Where, Q is the reactive power rating of the capacitor (in VAr).

Typically, for good quality power capacitors, tan δ value is less than 0.0002. Power loss of any capacitor can be computed if tan δ value is known as explained in the example below:

For a 10 kVAr capacitor, consider the value of tan δ as 0.0002.

Total watt loss $\quad = 10 \times 1000 \times 0.0002$

$\qquad\qquad\qquad = 2$ watts

Per kVAr power loss $=$ Total watt loss / kVAr

$\qquad\qquad\qquad = 2/10$

$\qquad\qquad\qquad = 0.2$ watts per kVAr

Normally, the tan δ value is available in the routine test certificate of the power capacitor.

The life of a power capacitor is largely dependent upon temperature. Hence, it is a good practice to do the thermal design of APFC panel after computing the capacitor power loss.

Typically, power factor correction capacitors are fitted with discharge resistors connected directly across the terminals (two resistors between three phases). These resistors are mandatory safety requirement recommended by the capacitor standards, to discharge the residual voltage that remains in the capacitor, once it is switched off.

As per IS 13340 (MPP capacitors) and IS 13585 (APP capacitors) the capacitor should discharge to 50 V or below, within 60 seconds, as soon as the capacitor is switched off this is to protect human beings from the risk of electric shock and also for safe re-switching of the same capacitor in APFC panel.

Cylindrical capacitor's terminal block with discharge resistor
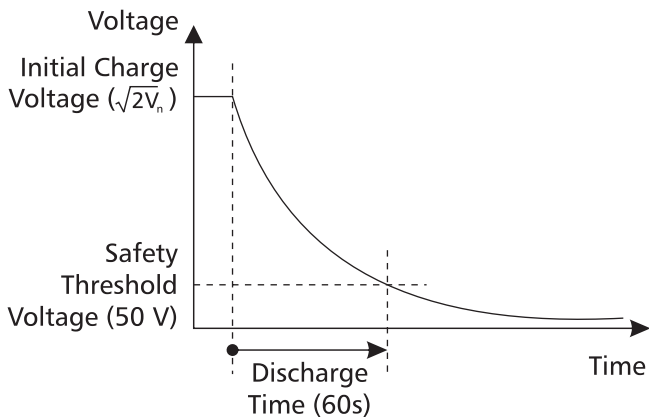
If the capacitor is re-switched without discharging sufficiently, there is a possibility that the voltage difference across the contactor may shoot up to 1000 V. More over, this results in very high peak inrush current as the rate of change of voltage is very high (I_c = C dV/dt). Such frequent switchings reduce the life of the capacitor and/or the contactor, and may cause premature failures. Hence while re-switching the capacitor (either in manual mode or auto mode) it is mandatory to discharge the capacitor to its 10% rated voltage.

In order to ensure the sufficient discharge, it should be ensured that the capacitor is re-switched only after 45 to 60 seconds. This time delay (for re-switching the same capacitor bank) can be set in APFC relay. In case, any application demands frequent switching of capacitors by contactors, time delay can be reduced by faster discharge of the residual voltage. Faster discharging can be achieved by replacing the existing resistors with new resistors of lesser resistance.

Formula to calculate the resistance is:

$$R \leq \frac{t}{3C \times \log_e\left(\sqrt{2}V_n \big/ V_r\right)}$$

Where,
R = Discharge resistance value in Ω
t = time for discharge from $\sqrt{2V_n}$ (ie., peak voltage) to V_r (50 V), in seconds
C = Rated capacitance per phase, in μF
V_n = Rated voltage of capacitor unit, in V
V_r = Permissible residual voltage, in V

The above formula is valid for resistors assembly in the delta connected capacitor (two resistors between three terminals), as shown in the figure.

However, opting for lower resistance for faster discharge will increase the power loss. At the same time, appropriate power rating (wattage) of the resistor should be chosen to ensure sufficient current carrying capacity of the resistor.

$$\text{Power rating of the resistor (in watts)} = 1.3\ V_n I = \frac{1.3 \times V_n^2}{R}$$
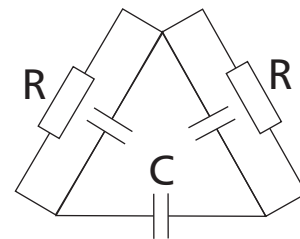
Here, the resistor should withstand the initial peak discharge current even if the capacitor is switched off at the instant of 30% over voltage.

The name plate of a capacitor usually has three kVAr ratings at three different voltages. kVAr rating of the capacitor is directly proportional to square of the applied voltage.

This is evident from the below formula:

$$kVAr = \frac{V^2}{X_c}$$

As capacitance (C in uF) remains same for a capacitor, X_c will remain constant.

For example, if a capacitor is rated for 30 kVAr at 480 V, and if the applied voltage is 440 V, the kVAr output can be calculated as follows:

$$kVAr\ output = Rated\ kVAr \ \times \frac{(Applied\ voltage)^2}{(Rated\ voltage)^2}$$
$$= 30 \times \frac{(440)^2}{(480)^2}$$
$$= 25.2\ kVAr\ at\ 440\ V$$

LTBCH - 30 kVAr

Heavy Duty 30 kVAr Power Capacitor

Un	50 Hz	In
480 V	30.0 kVAr	36.1 A
440 V	25.2 kVAr	33.1 A
425 V	22.4 kVAr	31.2 A

3X138 µF	3 Phase	D	SH	MPP
-40/D	Ui 3/-kV	Case	Max	65°C
NPCB	Non Flammable			55°C

Sr. No.01234567890

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06N13

MADE IN INDIA
DISCHARGE CAPACITOR BEFORE HANDLING

Similarly, if we apply 500 V for the same capacitor, the kVAr output will be 32.5 kVAr. In this case, we are applying voltage more than the rated value and the capacitor will deliver kVAr output more than its rated value. Hence the life of the capacitor may reduce drastically, because of over-voltage and over-current.

To summarize, the product label of a capacitor (for e.g. 30 kVAr, 480 V) has the following details:

Similarly, for 25 kVAr and 440 V capacitor, the name plate contains the respective kVAr ratings and current ratings at 440 V, 415 V and 400 V.

Selection of Capacitors when System Voltage is 415 V

Before deciding the voltage of the capacitor, it is important to understand the percentage impedance of the transformer (% Z). The percentage impedance is the voltage drop on full load due to the winding resistance and leakage reactance of the transformer. This is expressed as a percentage of the rated voltage. For example, if the secondary of the transformer is rated for 433 V and %Z is 4%, the voltage available at the load end, during full load conditions, would be 415 V only. When the load decreases, the voltage drop decreases and hence the voltage at the load end increases. During no-load conditions, the voltage can reach a maximum of 433 V.

If a capacitor is selected with 415 V (in the above case), it would be subjected to over-voltage during partial load or no-load conditions. This would impact the capacitor life drastically. For a normal capacitor, following are the over-voltage limits permitted as per IS:

• 10% over-voltage for 12 hours in every 24 hours
• 15% over-voltage for 30 minutes in every 24 hours
• 20% over-voltage for 5 minutes in every 24 hours
• 30% over-voltage for 1 minute in every 24 hours

Hence, the capacitor should be rated for 440 V, even though the voltage at the load end is measured as 415 V. In general, it is a better practice to select capacitor voltage greater than the rated secondary voltage of the transformer and hence, avoid prolonged over-voltage conditions.
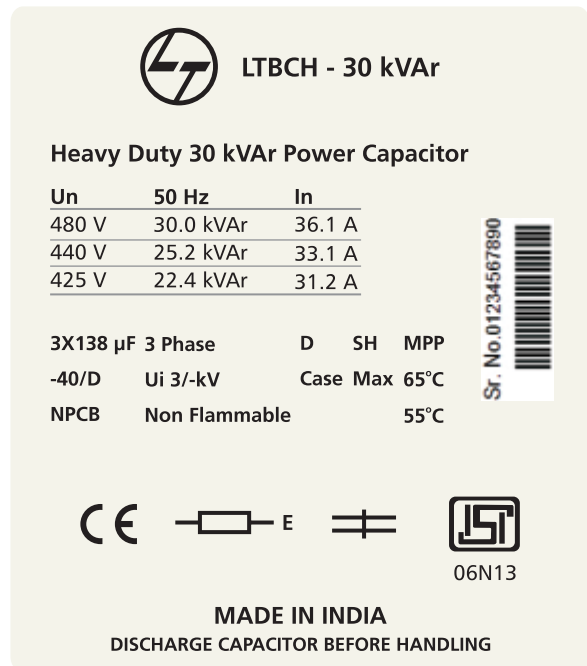
L&T Standard Duty Capacitors are metalized polypropylene capacitors from 1 - 25 kVAr in cylindrical configuration and 1-30 kVAr in box type configuration. These capacitors come with a stacked winding and are impregnated with a biodegradable soft resin. These capacitors are self healing type. The Capacitors come with an over pressure disconnector and finger proof terminals. They can be used to provide effective power factor correction in industrial and semi industrial applications.

For Selection and Application details please refer page no. 74

Technical Details

	Standard Duty	
	Box	**Cylindrical**
Series	LTBCF (1 to 6 kVAr) and	LTCCF (1 to 6 kVAr) and
	LTBCD (7.5 kVAr and above)	LTCCD (7.5 kVAr and above)
Range	1 - 30 kVAr	1 - 25 kVAr
Standards	IS 13340-2012, IS 13341-1992, IEC 60831-1+2	IS 13340-2012, IS 13341-1992, IEC 60831-1+2
Rated Frequency	50Hz	50Hz
Rated Voltage	415 / 440 V	415 / 440 V
Over Voltage	+10% (12h/24h), +15% (30m/24h), +20% (5m/24hrs), +30% (1m/24hrs)	+10% (12h/24h), +15% (30m/24h), +20% (5m/24hrs), +30% (1m/24hrs)
Overcurrent	1.5 x In	1.5 x In
Peak Inrush Current	200 x In	200 x In
Operating Losses (Dielectric)	< 0.2 W/kVAr	< 0.2 W/kVAr
Operating Losses (Total)	< 0.45 W/kVAr	< 0.45 W/kVAr
Tolerance on Capacitance	-5 / +10% as per IS	-5 / +10% as per IS
Test Voltage (Terminal-Terminal)	2.15 Times rated voltage for 10 sec	2.15 Times rated voltage for 10 sec
Test Voltage (Terminal-Casing)	3 kV (AC) for 1 minute	3 kV (AC) for 1 minute
Degree of Protection	IP20, Indoor mounting (IP54 optional)	IP20, Indoor mounting (IP54 optional)
Ambient Temperature	-25 / D Max temperature = +55°C Max mean temperature (24 h) = +45°C Max mean temperature (1 year) = +35°C	-25 / D Max temperature = +55°C Max mean temperature (24 h) = +45°C Max mean temperature (1 year) = +35°C
Cooling	Natural or forced air cooling	Natural or forced air cooling
Permissible Relative Humidity	Max 95%	Max 95%
Maximum Operating Altitude	4000m above sea level	4000m above sea level
Mounting	Upright	Upright
Safety Features	Overpressure disconnector, Self-healing, Finger-proof terminals	Overpressure disconnector, Self-healing, Finger-proof terminals
Impregnation	Non-PCB biodegradable resin	Non-PCB biodegradable resin
Casing	MS Sheet metal	Aluminum extruded can
Dielectric Composition	Metalized polypropylene	Metalized polypropylene
Terminals	Wire (1 - 6 kVAr)	Wire (1 - 6 kVAr)
	Ceramic bushing (7.5 kVAr and above)	Finger-proof clamptite (7.5 kVAr and above)
Discharge Resistors / Time	Discharge resistors fitted, Standard discharge time 60 seconds, Other discharge times on request	Discharge resistors fitted, Standard discharge time 60 seconds, Other discharge times on request
Switching Operations (maximum)	5000 Switchings per year	5000 Switchings per year

Standard Duty Capacitors - Overall Dimensions

Cylindrical Type

Sr. No.	Voltage	Power rating (kVAr)		Capacitance (uF)	Rated current (A)	Dimensions in (mm)		Cat. Nos.
		50 Hz	60 Hz			H	D	
1	440 V	1	1	16.44	1.31	130	45	LTCCF301B2
2	440 V	2	2	32.88	2.62	130	50	LTCCF302B2
3	440 V	3	4	49.32	3.94	165	50	LTCCF303B2
4	440 V	4	5	65.77	5.25	165	63.5	LTCCF304B2
5	440 V	5	6	82.21	6.56	225	63.5	LTCCF305B2
6	440 V	6	7	98.65	7.87	225	63.5	LTCCF306B2
7	440 V	7.5	9	123.31	9.84	195	75	LTCCD307B2
8	440 V	8.33	10	136.96	10.93	195	75	LTCCD308B2
9	440 V	10	12	164.42	13.12	195	85	LTCCD310B2
10	440 V	12.5	15	205.52	16.40	270	85	LTCCD312B2
11	440 V	15	18	246.62	19.68	270	85	LTCCD315B2
12	440 V	20	24	328.83	26.24	345	85	LTCCD320B2
13	440 V	25	30	411.04	32.80	345	90	LTCCD325B2
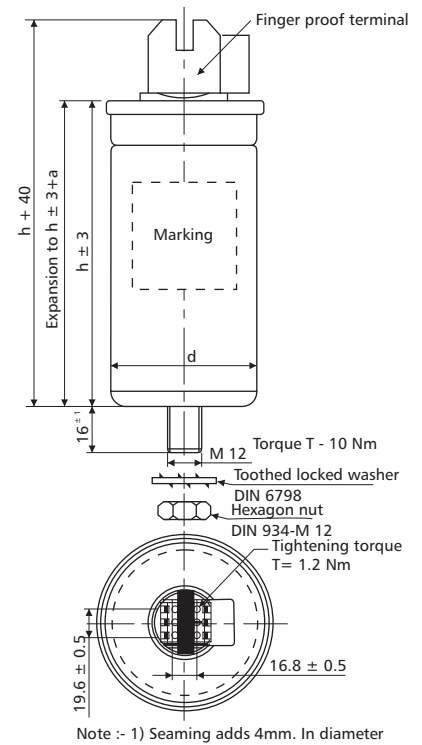
Finger proof terminal

h + 40

Expansion to h ± 3+a

h ± 3

Marking

d

16 ±1

M 12 — Torque T - 10 Nm
Toothed locked washer
DIN 6798
Hexagon nut
DIN 934-M 12
Tightening torque
T= 1.2 Nm

19.6 ± 0.5

16.8 ± 0.5

Note :- 1) Seaming adds 4mm. In diameter

Box Type

Sr. No.	Voltage	Power rating (kVAr)		Capacitance (uF)	Rated current (A)	Dimensions in (mm)			Cat. Nos.
		50 Hz	60 Hz			H	W	D	
1	440 V	1	1	16.44	1.31	125	140	40	LTBCF301B2
2	440 V	2	2	32.88	2.62	125	140	40	LTBCF302B2
3	440 V	3	4	49.32	3.94	145	170	50	LTBCF303B2
4	440 V	4	5	65.77	5.25	145	170	50	LTBCF304B2
5	440 V	5	6	82.21	6.56	175	170	50	LTBCF305B2
6	440 V	6	7	98.65	7.87	175	170	50	LTBCF306B2
7	440 V	7.5	9	123.31	9.84	300	240	80	LTBCD307B2
8	440 V	8.33	10	136.96	10.93	300	240	80	LTBCD308B2
9	440 V	10	12	164.42	13.12	300	240	80	LTBCD310B2
10	440 V	12.5	15	205.52	16.40	300	240	80	LTBCD312B2
11	440 V	15	18	246.62	19.68	300	240	80	LTBCD315B2
12	440 V	20	24	328.83	26.24	300	240	160	LTBCD320B2
13	440 V	25	30	411.04	32.80	300	240	160	LTBCD325B2
14	440 V	30	36	493.25	39.37	300	240	160	LTBCD330B2

7.5 kVAr to 15 kVAr

2 Slot 8x10

W ± 5

D ± 5

H ± 5

EMBOSSING

20 kVAr to 30 kVAr

4 Slot 8x15

75 ±1

W ± 5

D ± 5

Hole Ø30 mm for cable entry

H ± 5

EMBOSSING
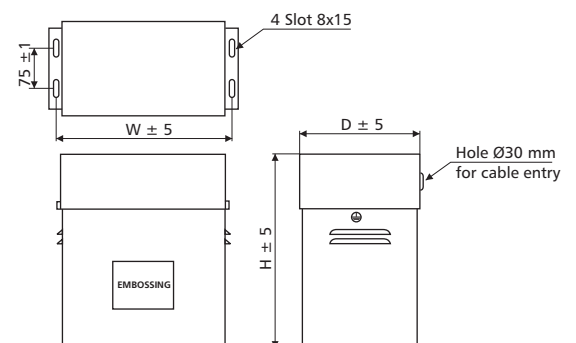
L&T Heavy Duty Capacitors are metalized polypropylene capacitors available from 3-25 kVAr in cylindrical and from 5-50 kVAr in box type construction. These capacitors have an inrush current withstand of 300 In and an overload withstand capacity of 1.8 In. These capacitors have all the features of standard capacitors like over pressure disconnector and self healing.

The cylindrical Capacitors are subjected to an extended period of drying after which the casing is filled with an inert gas to prevent corrosion of the winding elements and inner electrical contacts. Compact design ensures space saving. Heavy Duty capacitors have a long life of 150000 hours.

Technical Details

	Heavy Duty	
	Box	**Cylindrical**
Series	LTBCH	LTCCN
Range	5 - 50 kVAr	3 - 25 kVAr
Standards	IS 13340-1993, IS 13341-1992, IEC 60831-1+2	IS 13340-1993, IS 13341-1992, IEC 60831-1+2
Rated Frequency	50Hz	50Hz
Rated Voltage	415 / 440 / 480 / 525 V	415 / 440 / 480 / 525 / 690 V
Over Voltage	+10% (12h/24h), +15% (30m/24h), +20% (5m/24hrs), +30% (1m/24hrs)	+10% (12h/24h), +15% (30m/24h), +20% (5m/24hrs), +30% (1m/24hrs)
Overcurrent	1.8 x In	1.8 x In
Peak Inrush Current	300 x In	250 x In
Operating Losses (Dielectric)	< 0.2 W/kVAr	< 0.2 W/kVAr
Operating Losses (Total)	< 0.35 W/kVAr	< 0.35 W/kVAr
Tolerance on Capacitance	-5 / +10% as per IS	-5 / +10% as per IS
Test Voltage (Terminal-Terminal)	2.15 times rated voltage for 10 sec	2.15 times rated voltage for 10 sec
Test Voltage (Terminal-Casing)	3 kV (AC) for 1 minute	3 kV (AC) for 1 minute
Degree of Protection	IP20, indoor mounting (IP54 optional)	IP20, indoor mounting (IP54 optional)
Ambient Temperature	-25 / D Max temperature = +55˚C Max mean temperature (24 h) = +45˚C Max mean temperature (1 year) = +35˚C	-40 / D Max temperature = +55˚C Max mean temperature (24 h) = +45˚C Max mean temperature (1 year) = +35˚C
Cooling	Natural or forced air cooling	Natural or forced air cooling
Permissible Relative Humidity	Max 95%	Max 95%
Maximum Operating Altitude	4000m above sea level	4000m above sea level
Mounting	Upright	Upright or horizontal
Safety Features	Overpressure disconnector, Self-healing	Dry type (gas filled), Overpressure disconnector, Self-healing
Impregnation	Non PCB Oil, Biodegradable oil	Inert gas
Casing	MS Sheet metal	Aluminum extruded can
Dielectric Composition	Metalized polypropylene	Metalized polypropylene
Terminals	Ceramic bushing	Finger-proof clamptite
Discharge Resistors / Time	Discharge resistors fitted, Standard discharge time 60 seconds, Other discharge times on request	Discharge resistors fitted, Standard discharge time 60 seconds, Other discharge times on request
Switching Operations (maximum)	8000 Switchings per year	8000 Switchings per year

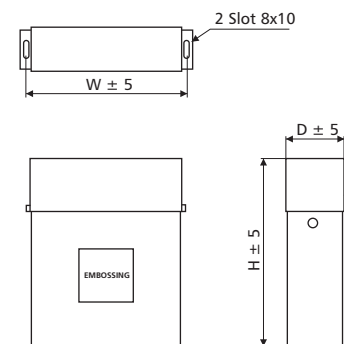# Heavy Duty Capacitors - Overall Dimensions

Cylindrical Type

Torque T = 10 Nm

d₁= 2 ... 6 mm (depending on the capacitor type; for details please refer to the data sheet)
Creepage distance 12.7 mm min. Clearance 9.6 mm min.
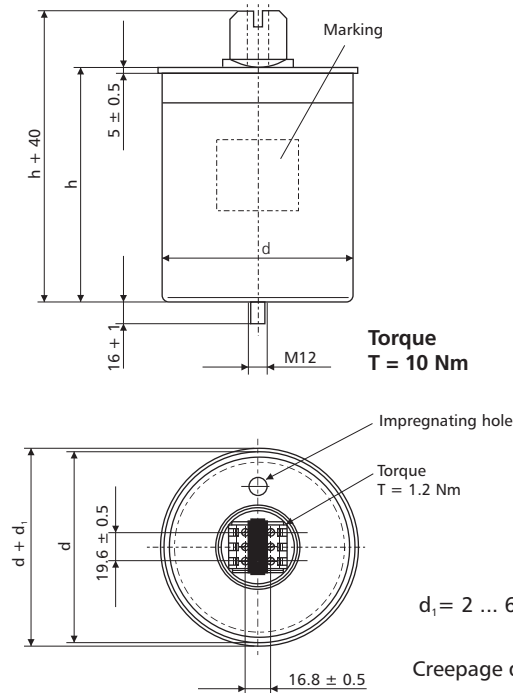
Sr. No.	Voltage	Power rating (kVAr)		Capacitance (uF)	Rated current (A)	Dimensions in (mm)		Cat. Nos.
		50 Hz	60 Hz			H	D	
1	440 V	3	4	49.32	3.94	130	64	LTCCN303B2
2	440 V	4	5	65.77	5.25	190	64	LTCCN304B2
3	440 V	5	6	82.21	6.56	190	64	LTCCN305B2
4	440 V	7.5	9	123.31	9.84	190	64	LTCCN307B2
5	440 V	8.33	10	136.96	10.93	190	64	LTCCN308B2
6	440 V	10	12	164.42	13.12	265	64	LTCCN310B2
7	440 V	12.5	15	205.52	16.40	265	64	LTCCN312B2
8	440 V	15	18	246.62	19.68	190	84.4	LTCCN315B2
9	440 V	20	24	328.83	26.24	265	84.4	LTCCN320B2
10	440 V	25	30	411.04	32.80	265	84.4	LTCCN325B2
11	480 V	7.5	9	103.62	9.02	190	64	LTCCN307C2
12	480 V	10	12	138.16	12.03	190	84	LTCCN310C2
13	480 V	12.5	15	172.69	15.04	190	84	LTCCN312C2
14	480 V	15	18	207.23	18.04	265	84	LTCCN315C2
15	480 V	20	24	276.31	24.06	265	84	LTCCN320C2
16	480 V	25	30	345.39	30.07	265	84	LTCCN325C2
17	480 V	30	36	414.47	36.09	230	116	LTCCN330C2
18	525 V	7.5	9	86.61	8.25	190	64	LTCCN307M2
19	525 V	8.33	10	96.20	9.16	190	64	LTCCN308M2
20	525 V	10	12	115.49	11.00	265	65	LTCCN310M2
21	525 V	12.5	15	144.36	13.75	265	65	LTCCN312M2
22	525 V	15	18	173.23	16.50	265	65	LTCCN315M2
23	525 V	20	24	230.97	21.99	265	84	LTCCN320M2
24	525 V	25	30	288.72	27.49	265	84	LTCCN325M2
25	525 V	30	36	346.46	32.99	230	116	LTCCN330M2

Heavy Duty Capacitors - Overall Dimensions

Box Type

5 to 12.5 kVAr
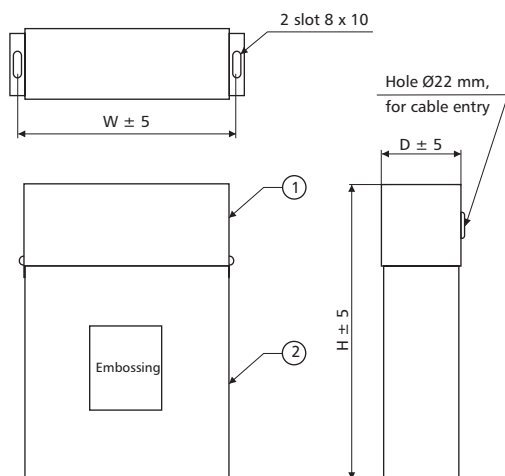
15 to 50 kVAr

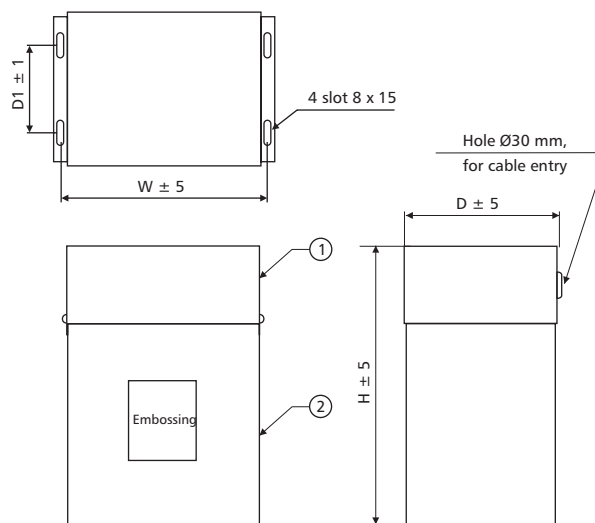| Sr. No.	Voltage	Power rating (kVAr)		Capacitance (uF)	Rated current (A)	Dimensions in (mm)				Cat. Nos.
		50 Hz	60 Hz			W	D	D1	H	
1	440 V	5	6	82.21	6.56	240	80	-	300	LTBCH305B2
2	440 V	7.5	9	123.31	9.84	240	80	-	300	LTBCH307B2
3	440 V	8.33	10	136.96	10.93	240	80	-	300	LTBCH308B2
4	440 V	10	12	164.42	13.12	240	80	-	300	LTBCH310B2
5	440 V	12.5	15	205.52	16.40	240	80	-	300	LTBCH312B2
6	440 V	15	18	246.62	19.68	240	80	75	300	LTBCH315B2
7	440 V	20	24	328.83	26.24	240	160	75	300	LTBCH320B2
8	440 V	25	30	411.04	32.80	240	160	75	300	LTBCH325B2
9	440 V	30	36	493.25	39.37	240	160	75	300	LTBCH330B2
10	440 V	50	60	822.08	65.61	240	320	150	350	LTBCH350B2
11	480 V	7.5	9	103.62	9.02	240	80	-	300	LTBCH307C2
12	480 V	10	12	138.16	12.03	240	80	-	300	LTBCH310C2
13	480 V	12.5	15	172.69	15.04	240	80	-	300	LTBCH312C2
14	480 V	15	18	207.23	18.04	240	80	75	300	LTBCH315C2
15	480 V	20	24	276.31	24.06	240	160	75	300	LTBCH320C2
16	480 V	25	30	345.39	30.07	240	160	75	300	LTBCH325C2
17	480 V	30	36	414.47	36.09	240	160	75	300	LTBCH330C2
18	525 V	7.5	9	86.61	8.25	240	80	-	300	LTBCH307M2
19	525 V	10	12	115.49	11.00	240	80	-	300	LTBCH310M2
20	525 V	12.5	15	144.36	13.75	240	80	-	300	LTBCH312M2
21	525 V	15	18	173.23	16.50	240	80	75	300	LTBCH315M2
22	525 V	20	24	230.97	21.99	240	160	75	300	LTBCH320M2
23	525 V	25	30	288.72	27.49	240	160	75	300	LTBCH325M2
24	525 V	30	36	346.46	32.99	240	160	75	300	LTBCH330M2
25	525 V	33.1	40	382.26	36.40	240	160	75	300	LTBCH333M2

APP (Aluminium Poly-Propylene)

The LTXL range of capacitors are designed for Ultra heavy duty applications and can withstand heavy load fluctuations, high inrush current and harmonics.

Applications

- Applications such as welding, steel rolling, etc., with heavy load fluctuations and high thermal loading
- Systems with high harmonic distortion levels (non linear load >15%)
- Systems with high inrush current
- Best suited for detuned harmonic filter

Features

- Long life expectancy (upto 300000 hrs)
- Maximum inrush current withstand capability (upto 500 times I_R)
- Low power loss (0.35 W/kVAr)
- Protection with internal fuse

The life of a capacitor largely depends upon its operating temperature. LTXL box type capacitors use **advanced APP** technology. By employing thicker aluminum foil, thicker hazy polypropylene film and special impregnates, LTXL box type capacitor is able to operate at lower temperatures and hence achieve a longer life. These capacitors are thus able to withstand stringent operating conditions. The higher surface area and special epoxy based coating also ensures better heat dissipation. The capacitor is designed to operate at case temperature up to 70°C.
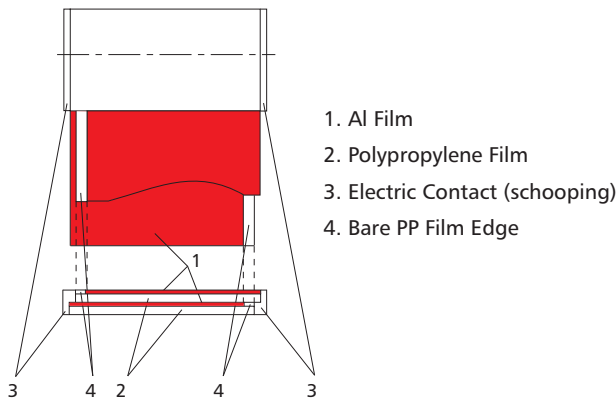
1. Al Film
2. Polypropylene Film
3. Electric Contact (schooping)
4. Bare PP Film Edge

Design of LT Capacitor

Fuse

Capacitor element

Blown fuse
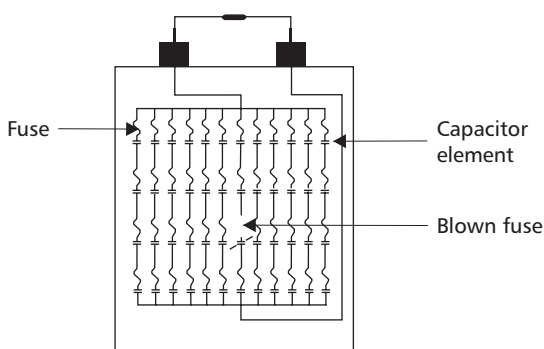
In LTXL box, two polypropylene films and two Al films are grouped together as shown in the figure. The wave-cut and heavy edge metalized films are then rolled to form a capacitor element. Many such capacitor elements are pressed and stacked together and are internally connected in parallel. Depending upon the rating of the capacitor, the number of stacks differ. These stacks are placed inside a case and are vacuum impregnated with non-PCB, biodegradable oil (PXE).

Each capacitor element is protected by an internal fuse as shown in the figure. If there is an internal short circuit in any of the capacitor element, the fuse of that corresponding capacitor element blows.

Technical Details

	LTXL - Ultra Heavy Duty Box
Series	LTBCU
Range	5 - 50 kVAr
Standards	IS 13585 (Part 1)-2012, IEC 60931-1 1996
Rated Frequency	50 Hz
Rated Voltage	415 / 440 / 480 / 525 / 690 / 850 / 1000 V
Over Voltage	+10% (12h/24h), +15% (30m/24h), +20% (5m/24hrs), +30% (1m/24hrs)
Overcurrent	Upto 3 x In
Peak Inrush Current	Upto 500 x In
Operating Losses (Dielectric)	< 0.2 W/kVAr
Operating Losses (Total)	< 0.35 W/kVAr
Tolerance on Capacitance	-5 / +10% as per IS
Test Voltage (Terminal-Terminal)	2.15 times rated voltage for 10 sec
Test Voltage (Terminal-Casing)	3 kV (AC) for 1 minute
Degree of Protection	IP20, Indoor mounting (IP54 optional)
Ambient Temperature	-25 / D (Case temperature 70˚C)
Cooling	Natural or forced air cooling
Permissible Relative Humidity	Max 95%
Maximum Operating Altitude	4000m above sea level
Mounting	Upright
Safety Features	Internal fuse
Impregnation	Non PCB Oil, Biodegradable oil
Casing	MS sheet metal
Dielectric Composition	Biaxially oriented polypropylene film with aluminium foil electrode
Terminals	Ceramic bushing
Discharge Resistors / Time	Discharge resistors fitted, Standard discharge time 60 seconds, Other discharge times on request
Switching operations (maximum)	20000 Switchings per year

LTXL: Ultra Heavy Duty Capacitors - Overall Dimensions
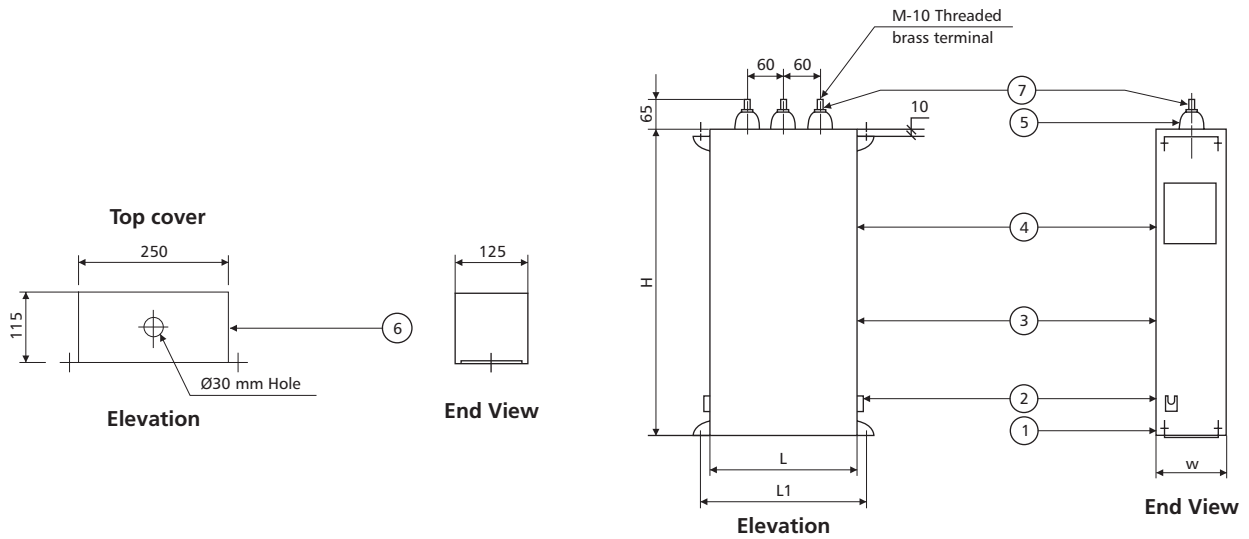
Box Type

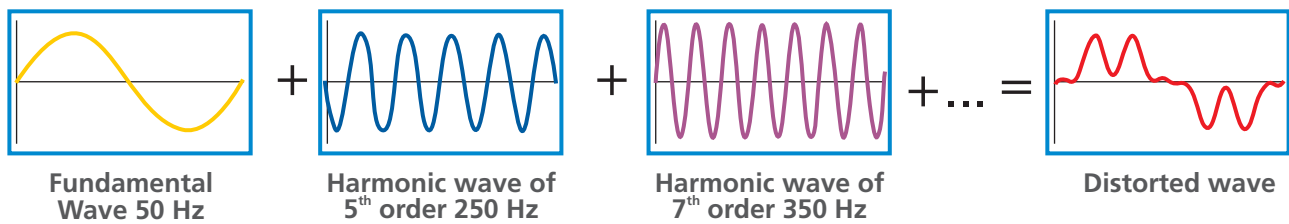| Sr. No.	Voltage	Power rating (kVAr)		Capacitance (uF)	Rated current (A)	Dimensions in (mm)				Cat. Nos.
		50 Hz	60 Hz			L	L1	W	H	
1	440 V	5	6	82.21	6.56	240	270	115	115	LTBCU305B2
2	440 V	7.5	9	123.31	9.84	240	270	115	150	LTBCU307B2
3	440 V	8.33	10	136.96	10.93	240	270	115	150	LTBCU308B2
4	440 V	10	12	164.42	13.12	240	270	115	175	LTBCU310B2
5	440 V	12.5	15	205.52	16.40	240	270	115	200	LTBCU312B2
6	440 V	15	18	246.62	19.68	240	270	115	225	LTBCU315B2
7	440 V	20	24	328.83	26.24	240	270	115	275	LTBCU320B2
8	440 V	25	30	411.04	32.80	240	270	115	325	LTBCU325B2
9	440 V	30	36	493.25	39.37	240	270	115	375	LTBCU330B2
10	440 V	50	60	822.08	65.61	240	270	115	575	LTBCU350B2
11	480 V	7.5	9	103.62	9.02	240	270	115	150	LTBCU307C2
12	480 V	10	12	138.16	12.03	240	270	115	150	LTBCU310C2
13	480 V	12.5	15	172.69	15.04	240	270	115	175	LTBCU312C2
14	480 V	15	18	207.23	18.04	240	270	115	200	LTBCU315C2
15	480 V	20	24	276.31	24.06	240	270	115	250	LTBCU320C2
16	480 V	25	30	345.39	30.07	240	270	115	300	LTBCU325C2
17	480 V	30	36	414.47	36.09	240	270	115	325	LTBCU330C2
18	525 V	7.5	9	86.61	8.25	340	370	115	115	LTBCU307M2
19	525 V	10	12	115.49	11.00	340	370	115	125	LTBCU310M2
20	525 V	12.5	15	144.36	13.75	340	370	115	150	LTBCU312M2
21	525 V	15	18	173.23	16.50	340	370	115	175	LTBCU315M2
22	525 V	20	24	230.97	21.99	340	370	115	200	LTBCU320M2
23	525 V	25	30	288.72	27.49	340	370	115	250	LTBCU325M2
24	525 V	30	36	346.46	32.99	340	370	115	275	LTBCU330M2
25	525 V	33.1	40	382.26	36.40	340	365	115	325	LTBCU333M2

Harmonics is defined as a component of periodic wave (or a signal) whose frequency is integral multiple of the fundamental frequency. Non linear loads such as rectifiers, inverters, variable speed drives, furnaces, etc. create harmonics.

These currents consist of a fundamental frequency component rated at 50 Hz, plus a series of overlapping currents, with frequencies that are multiples of the fundamental frequency. The result is deformation of the current (and, as a consequence, voltage) that has a series of associated secondary effects.

Fundamental Wave 50 Hz	Harmonic wave of 5th order 250 Hz	Harmonic wave of 7th order 350 Hz	Distorted wave

Types of Harmonic Loads

Type of Load	Wave Shape	Harmonic Spectrum THD I
• 6 Pulse and 12 Pulse drive* (VFD & UPS) • Three-phase / Single-phase rectifiers • Arc / Induction furnace		
• Discharge lamps / CFL • Single-phase converters • Computer, IT loads • SMPs • TVs		

* Harmonics are inversely proportional to (n±1) for an n-pulse drive

Effects of Harmonics

Type of Equipment	Effect of Harmonics
Rotating Machines	Increased power losses, over heating due to skin effect as higher frequency current flows on cable periphery increasing cable resistance, pulsating torque due to negative phase sequence harmonics
Transformer, Switch-gear, Power Cables	Over-heating, increased power consumption
Protective Relays	Mal-operation, nuisance tripping
Power Electronics	Mal-operation, failure
Power Capacitors	High currents & failure due to overload

The above malfunctions are not always felt immediately after the system is installed, but the effects may be felt in the long term and are difficult to distinguish from the natural ageing of equipment. Hence it is important to have some basic knowledge about harmonics and find solutions for the same.

Harmonic amplification is an undesired increase in the magnitude of harmonics beyond the level that is being generated in the system. This in turn amplifies the ill effects of the harmonics. The article briefs how the amplification happens in the network and solutions to avoid this amplification.

Power capacitors are added to the network for improving the power factor. The addition of capacitors results in reduction of system impedance. Capacitive impedance is inversely proportional to frequency (as shown in the figure 1).

Capacitive impedance $X_c = \dfrac{1}{2\pi fc}$ ---------> Eq 1

Hence the capacitor offers lower impedance for high frequency (250 Hz, 350 Hz, 550 Hz and so on). This results in increase in the magnitude of harmonic currents. This can be practically seen by measuring harmonics at a particular location in the electrical network with and without power factor correction capacitors (APFC panels).

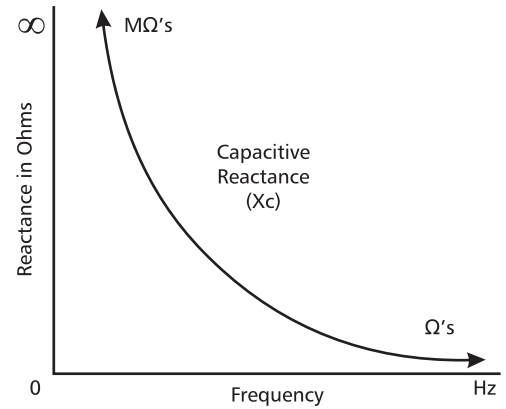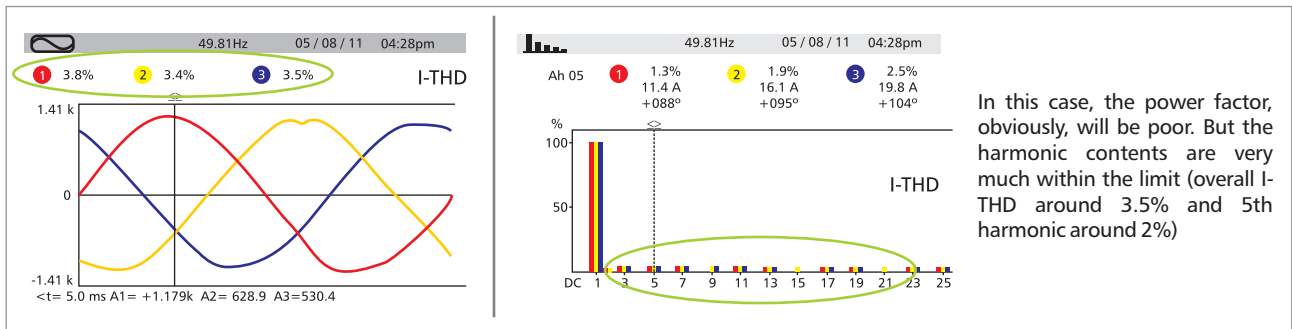Following are the snapshots of harmonic measurement done at the main incomer, with and without capacitors.

Figure 1

Figure 2: Measurement with APFC Panel OFF

In this case, the power factor, obviously, will be poor. But the harmonic contents are very much within the limit (overall I-THD around 3.5% and 5th harmonic around 2%)

Figure 3: Measurement with APFC Panel ON
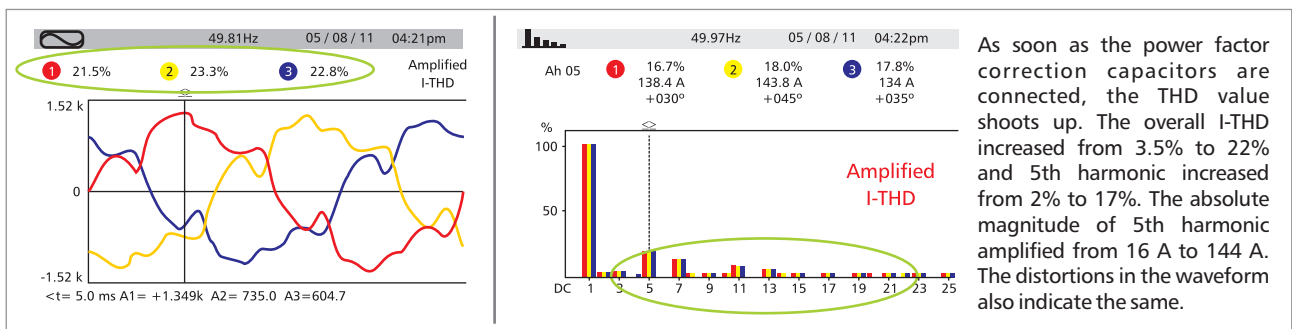
As soon as the power factor correction capacitors are connected, the THD value shoots up. The overall I-THD increased from 3.5% to 22% and 5th harmonic increased from 2% to 17%. The absolute magnitude of 5th harmonic amplified from 16 A to 144 A. The distortions in the waveform also indicate the same.

In the above equation (1), for the same set of harmonic frequencies, on adding more capacitors for PF improvement, the capacitive impedance (X) will drop further. Again this will result in amplification of the harmonics. If the power factor goes to leading, the amplification will be worse. The unnecessary amplification of harmonics damages power capacitors and over heats switchgear, cables and busbars.

The solutions to prevent harmonic amplification are:

- By connecting a series inductor, so as to form a detuned filter (series LC), the impedance increases, when the frequency increases (as $XL = 2\pi fL$). The impedance will be high for high frequency harmonics and no amplification will happen. Hence, the THD (with reactor + capacitor) will be less than or equal to the earlier THD levels with no capacitors

- By strictly avoiding leading power factor, the excess addition of capacitors can be prevented and hence the amplification because of this can also be avoided. The optimum power factor of 0.97 to 0.99 should always be maintained always

Many industries may not generate high harmonics. Sometimes harmonic resonance occurring between power capacitors and transformers causes very high magnification of harmonics. This causes increased rate of failures and over-heating of electrical equipments. This article briefs about the basics of harmonic resonance, a practical case study and solution to avoid resonance.

In a system with inductive (X_L) and capacitive (X_C) impedances, resonance can happen at one particular frequency (resonant frequency, F_R). At this point X_L is equal to X_C and the net impedance is very low. Hence, at resonance point, the magnitude of the current (with frequency F_R) will be maximum and only inherent resistance in the network would limit the current.

Ohms
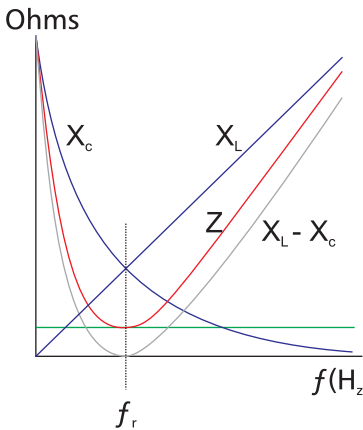
In practical network, the resonance is possible because of one of the following reasons:

- Parallel resonance within a given electrical system, involving internally generated harmonics (in the load) and resonance between local capacitors and the predominantly inductive supply (transformers)
- Series resonance involving external harmonics (in the supply system) and resonance between capacitors within electrical system
- Interactive resonance between different harmonics filters within a given electrical network

Typically, the inductance (L, of the transformer)in the system remains almost constant, but the capacitance(C) is varied (in steps) as per the requirement to maintain higher power factor. So, when the capacitance increases the resonant frequency (F_R) drops, as F_R is inversely proportional to square root of capacitance.

Resonant frequency, $F_R = \dfrac{1}{2\pi\sqrt{LC}}$

The lower resonant frequency is dangerous, as it may match with any of the predominant harmonics and cause more damage. Let us see a practical case study of resonance happening between variable PFC capacitors (C) and transformer.

Consider an industry with 1000 kVA transformer of %Z = 5.67% and 750 kVAr APFC panel. The resonant frequency can be calculated from the formula:

Resonant frequency = $F_S \times \sqrt{\dfrac{kVA_{SC}}{kVAr}}$

Where F_S is the System frequency = 50 Hz

kVA_{SC} is the short circuit power of the transformer $= \dfrac{kVA}{\%Z/100} = \dfrac{1000}{0.0567} = 17636 kVA$

 kVAr is the power rating of the capacitor connected under the transformer for power factor correction.

Case 1: **When 145 kVAr is connected to the system,**

Resonant frequency = $50 \times \sqrt{\dfrac{17636}{145}} = 550Hz$

This frequency exactly matches with 11th harmonic (550 Hz) and results in resonance. Following is the harmonics measurement that depicts the 11th harmonic resonance, where it increases from less than 5% to 25%. This huge amplification will damage the capacitor and other equipments.
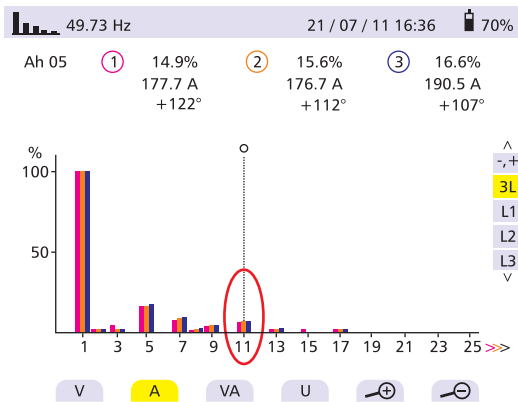
Figure 1: Measurement with APFC Panel OFF
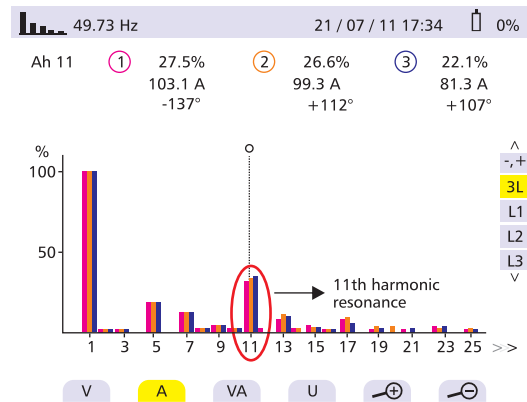
Figure 2: Measurement with APFC PanelON

Case 2: **When 250 kVAr of capacitor is switched on in the same industry,**

$$\text{Resonant frequency} = 50 \ x \sqrt{\frac{17636}{250}} = 420 Hz$$

In this case, no resonance will happen; hence the amplification level will be less than the case1. If harmonics study is carried at this particular moment, the system would reveal relatively lesser harmonics level (%I-THD)

Case 3: **When 700 kVAr is connected to the system,**

$$\text{Resonant frequency} = 50 \ x \sqrt{\frac{17636}{700}} = 250 Hz$$

Once again, this frequency perfectly matches with 5th harmonic. Typically 5th harmonic is the least order harmonic with higher magnitude (6 pulse drives). Resonance at this harmonic order would result in even worse damage than the case 1.

From the above cases it is evident that any peculiar problem like frequent failure of capacitors, nuisance tripping of MCCBs, frequent blowing of fuses and over-heating of busbars is, may be because of harmonic resonance. Resonance or worst case THD may not be revealed at the moment of harmonic measurement or troubleshooting. Hence at times, finding the root cause of any such failures is very difficult.

Solution for harmonic resonance is to detune, by using a reactor in series with each capacitor. This detuned filter will forcefully create one resonant frequency, so that the combination offers higher impedance for high frequency harmonics. For example, installation of 7% reactor with each capacitor in APFC panel, will create tuning frequency at 189 Hz. Hence, resonance at harmonic frequencies (5th harmonics and above) can be avoided. Moreover, all the harmonics having frequency above 189 Hz (i.e., from 5th harmonics onwards) will lie in inductive region, where the impedance increases when the frequency increases ($X_L = 2\pi fL$). One important point to note is that all the capacitors in the industry must have similar series inductor; else the overall tuning frequency may not be at 189 Hz.

It's a known fact that harmonics cause over loading of power capacitors and consequently reduce the life of power capacitors. Normally lot of emphasis is given only to %THD for assessing the harmonics level while the frequency spectrum (5th, 7th, 11th, 13th and so on) of the harmonics are not given due importance.

The over-current (and hence the stress on the capacitors) will not only depend on the %THD value but also on the magnitude of individual harmonics, which can be clearly seen in the frequency spectrum. Following calculations prove the above statement.

Case 1:

Assumptions:
1. V_{THD} : 25%
2. Harmonic frequencies considered: 5th (250 Hz), 7th (350 Hz)
3. $V_5 = 20\%V_1$ and $V_7 = 15\%V_1$
4. All other harmonic frequencies are negligible
5. The capacitors are delta connected hence will not provide a path for the third harmonic to flow

Important Formulae:

$$Xc = \frac{1}{(2\pi f C)}$$

where X_c is the capacitive reactance, f is the frequency, C is the capacitance $I_c = V_c / X_c$, where I_c is the capacitive current, V_c is the voltage across the capacitor and X_c is the capacitive reactance

$$V_{THD} = \sqrt{\Sigma (V_i^2) / V_1)}, \text{ where I } = 3 \text{ to } 99$$

Calculations:
Using the superposition theorem, we can calculate the current contribution of individual harmonic voltages.

$I_5 = V_5 / X_{c5} = 0.2V_1/[1/(2 \times \pi \times 5 \times f \times C)] = 0.2 \times 5 \times V_1/X_{c1} = 1 \times V_1/X_{c1} = I_1$

Similarly,

$I_7 = 1.05I_1$

The total current I will be a vector sum of I_1, I_5 and I_7

$$\text{Thus } I = \sqrt{(I_1^2 + I_5^2 + I_7^2)} = \sqrt{(1+1+1.1025)} \times I_1$$

Net current, I = 1.8 I_1 ----------------------> (1)

Case 2:

Assumptions:

1. V_{THD}: 25%
2. Harmonic frequencies considered: 5th (250 Hz), 7th (350 Hz), 11th (550 Hz), 13th (650 Hz)
3. $V_5 = 18\%V_1$, $V_7 = 15\%V_1$, $V_{11} = 8\%V_1$ and $V_{13} = 4\%V_1$

Calculation:

$I_5 = V_5 / X_{c5} = 0.18V_1 / [1/(2 \times \pi \times 5 \times f \times C)] = 0.18 \times 5 \times V_1 / X_{c1} = 0.9 \times V_1 / X_{c1} = 0.9I_1$

Similarly,

$I_7 = 1.05I_1$ $I_{11} = 0.88I_1$ and $I_{13} = 0.52I_1$

The total current I will be a vector sum of I_1, I_5, I_7, I_{11} and I_{13}

$$\text{Thus } I = \sqrt{I_1^2 + I_5^2 + I_7^2 + I_{11}^2 + I_{13}^2} = \sqrt{(1^2 + 0.9^2 + 1.05^2 + 0.88^2 + 0.52^2)} \times I_1$$

Net current, I = 2 I_1 ----------------------->(2)

Thus, in the above two cases, even the THD value remains same (25%), the over current (ref. Eq 1 and Eq 2) value is different depending upon the spectral values.

Hence THD value and detailed information of the frequency spectrum are necessary to predict the capacitor over-current. Harmonics study is the best way to get the frequency spectrum details and hence the exact over current value can be calculated.

Current and voltage harmonics are often used interchangeably. At most places, only harmonics is quoted and whether the values pertain to current or voltage is not mentioned. The differentiation can be done on the basis of their origin.

Understanding Total Harmonic Distortion

The current and voltage harmonics in a system are often expressed as Total Harmonic Distortion (THD). The total harmonic distortion, or THD, of a quantity is a measurement of the harmonic distortion present and is the ratio of all harmonic components to the fundamental component. It is given by the formula as under:

$$THD_Y = \frac{\sqrt{\sum_{h=2}^{\infty} Y_h^2}}{Y_1}$$

Where, Y_1 is the rms value of fundamental

Y_h is the rms value of hth harmonic

Hence, current THD is the ratio of the root-mean-square value of the harmonic currents to the fundamental current.

$$I_{THD} = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1}$$

Where do Current & Voltage Harmonics originate?

Harmonics always originate as current harmonics and voltage harmonics are the results of current harmonics. Current harmonics originate because of the presence of non-linear loads like variable speed drives, inverters, UPS, television sets, PCs, semiconductors circuits, welding sets, arc furnaces in the system. They act as harmonic current sources. The resulting current waveform can be quite complex depending on the type of load and its interaction with other components of the system.

Linear load
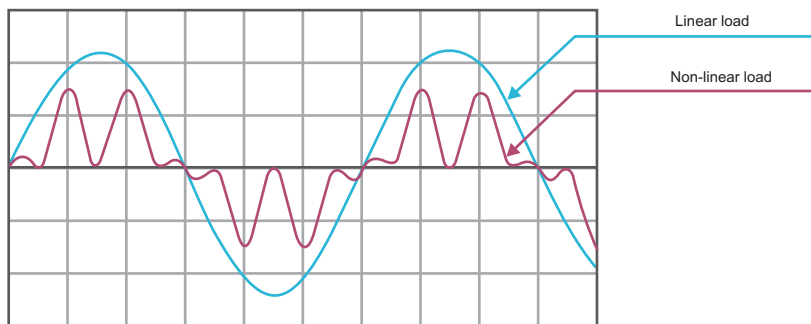
Non-linear load

Fig 1: Linear & Non-Linear Loads

The distorted current waveforms can be represented as the sum of current waveform of fundamental frequency and of its multiples (harmonics):
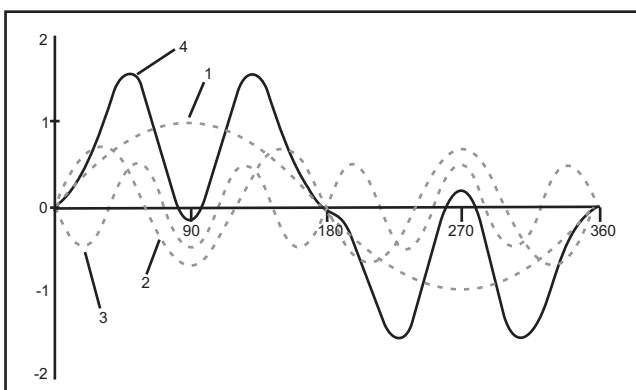
$$f(t) = \sum_{h=1}^{\infty} (c_h \sin(h\omega_0 t + \varphi_h))$$

Where,

c_h - Magnitude of nth order harmonics

φ_h - Phase angle of nth order harmonics

Fig 2: Current waveform as sum of fundamental frequency component and its multiples

Voltage harmonics do not originate directly from non-linear loads. The current harmonics (distorted waveform) flow through system impedance (source and line impedances) and cause harmonic voltage drop across the impedances. This will distort the supply voltage waveform. Thus voltage harmonics are generated. Long cable runs, high impedance transformers, etc. contribute to higher source impedance and hence, higher voltage harmonics.

A typical power system has the following impedances as indicated in the line diagram:
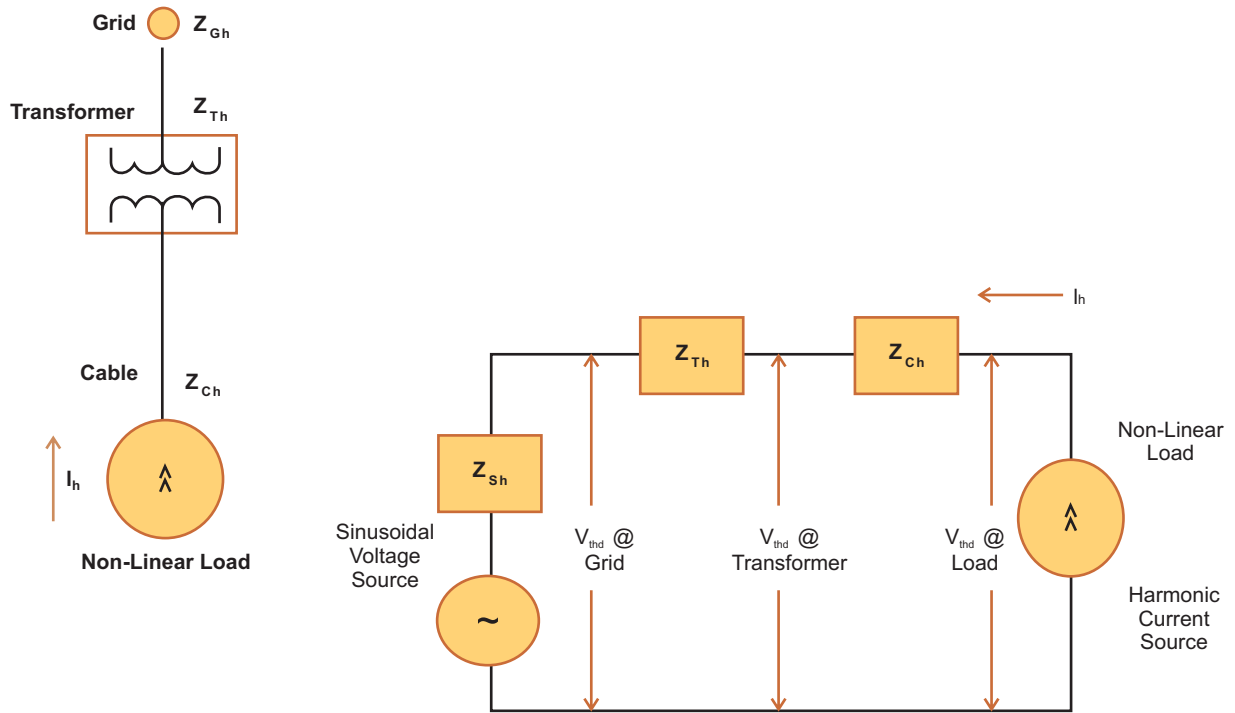
Fig 2: Impedance in a power system

In the above diagram,

V_h = h^{th} harmonic voltage

I_h = h^{th} harmonic current

Z_h = Impedance at h^{th} harmonic

V_{thd} = Voltage total harmonic distortion

At load, $\quad V_h = I_h \times (Z_{Ch} + Z_{th} + Z_{Gh})$

At transformer, $\quad V_h = I_h \times (Z_{Th} + Z_{Gh})$

At grid, $\quad V_h = I_h \times (Z_{gh})$

Usually, grid impedances are very low and hence, the harmonic voltage distortions are also low there. However, they may be unacceptably higher on the load side as they are subjected to full system impedance there. Hence, it becomes important where the harmonics measurements are done.

However, in case of DG sets, the source impedance is large resulting in high voltage harmonics despite small current harmonics. Thus, a clear distinction between current and voltage harmonics becomes important here.

An industry, say industry A, that has large non-linear loads will generate huge current harmonics in its system. A nearby industry, say industry B, connected to the same grid may not have non-linear loads, yet, it may be subjected to high voltage harmonics. These voltage harmonics are the result of high current harmonics of industry A and impedance of grid & transformer. Thus, industry B despite small current harmonics, has high voltage harmonics. However, if industry B goes for power factor correction, then, due to the presence of capacitors, current harmonics may also appear in the system, magnifying voltage hamrmonics further.

How do Current & Voltage Harmonics affect the system?

Current harmonics increase the rms current flowing in the circuit and thereby, increase the power losses. Current harmonics affect the entire distribution all the way down to the loads. They may cause increased eddy current and hysteresis losses in motor and transformers resulting in over-heating, overloading in neutral conductors, nuisance tripping of circuit breakers, over-stressing of power factor correction capacitors, interference with communication etc. They can even lead to over-heating and saturation of reactors.

Voltage harmonics affect the entire system irrespective of the type of load. They affect sensitive equipment throughout the facility like those that work on zero-voltage crossing as they introduce voltage distortions.

Understanding IEEE 519 Guidelines

The purpose of harmonic limits in a system is to limit the harmonic injection from individual customers to the grid so that they do not cause unacceptable voltage distortion in the grid. IEEE 519 specifies the harmonic limits on Total Demand Distortion (TDD) and not Total Harmonic Distortion (THD). TDD represents the amount of harmonics with respect to the maximum load current over a considerable period of time (not the maximum demand current). Whereas, THD represents the harmonics content with respect to the actual load current at the time of measurement.

It is important to note here that a small load current may have a high THD value but may not be significant threat to the system as the magnitude of harmonics is quite low. This is quite common during light load conditions.

TDD limits are based on the ratio of system's short circuit current to load current (I_{sc}/ I_L). This is used to differentiate a system and its impact on voltage distortion of the entire power system. The short circuit capacity is a measure of the impedance of the system. Higher the system impedance, lower will be the short circuit capacity and vice versa.

The Guidelines IEEE – 519-1992 at PCC Level are as under

Current Distortion Limits for General Distribution Systems (120 V Through 69 kV)						
Maximum Harmonic Current Distortion in % I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{sc} / I_L	<11	11≤ h<17	17 ≤ h<23	23 ≤ h< 35	35≤h	TDD
<20	4.0%	2.0%	1.5%	0.6%	0.3%	5.0%
20 - 50	7.0%	3.5%	2.5%	1.0%	0.5%	8.0%
50 - 100	10.0%	4.5%	4.0%	1.5%	0.7%	12.0%
100 - 1000	12.0 %	5.5%	5.0%	2.0%	1.0%	15.0 %
>1000	15.0%	7.0%	6.0%	2.5%	1.4%	20.0%

where
I_{sc} = maximum short-circuit current at PCC [Can be calculated as MVA/(%Z x V)]
I_L = maximum demand load current (fundamental frequency component) at PCC

Systems with higher I_{sc}/I_L have smaller impedances and thus they contribute less in the overall voltage distortion of the power system to which they are connected. Thus, the TDD limits become less stringent for systems with higher I_{sc}/I_L values. In other words, higher the rating of transformer used for the same amount of load, higher will be the allowable current distortion limits.

Voltage Distortion Limits		
Bus Voltage at PCC	Individual Voltage Distortion	V_{THD}
≤ 69 kV	3.0%	5.0%
69 kV < V ≤ 160 kV	1.5%	2.5%
> 160 kV	1.0%	1.5%

The limits on voltage are set at 5% for total harmonic distortion and 3% of fundamental for any single harmonic at PCC level. Harmonics levels above this may lead to erratic functioning of equipment. In critical applications like hospitals and airports, the limits are more stringent (less than 3% V_{THD}) as erroneous operation may have severe consequences. As discussed already, the harmonic voltage will be higher downstream in the system.

Solutions for Current & Voltage Harmonics

Current Harmonics (I_{THD})	Voltage Harmonics (V_{THD})	Recommended Solutions**
High	Low (≤5%)	Detuned Harmonic Filter with 480 V Capacitors and/or Active Harmonic Filter
High	High (>5%)	Active Harmonic Filter and 525 V MPP Capacitors
Low	High (>5%)	Grid may be polluted with imported voltage harmonics. It may not be possible to reduce them at the load side. Check with utility to rectify

**These are typical solutions. However the actual solution may vary depending up on the actual harmonic content in the system.

Triplen harmonics have frequencies in multiples of 3, i.e., 3rd harmonic (150 Hz), 9th harmonic (450 Hz), 15th harmonic (750 Hz) and so on. These harmonics have some peculiar characteristics, which make them very difficult to handle and mitigate. This article explains about the basics, sources, effects and mitigation techniques of triplen harmonics.

Sources of Triplen Harmonics

Triplen harmonics are usually generated by single phase non-linear loads that share a common neutral. Some of them are,

- SMPS in computers, televisions, etc.,
- CFL lamps
- Electronic dimmers and so on

These types of loads are common in IT parks, office, hospital and other commercial buildings. Following are the typical current harmonic spectra of SMPS and CFL lamps, where third harmonic is predominantly high.

Positive sequence   **Zero sequence**
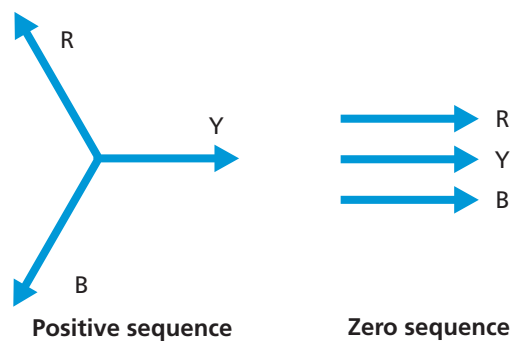
Neutral current is the vector sum of all the three phase (120° phase displaced) and the sum is zero, if the loads are balanced in all the three phase. But the presence of triplen harmonics will result in the flow of neutral current, even if the loads are balanced. This phenomenon explained below:
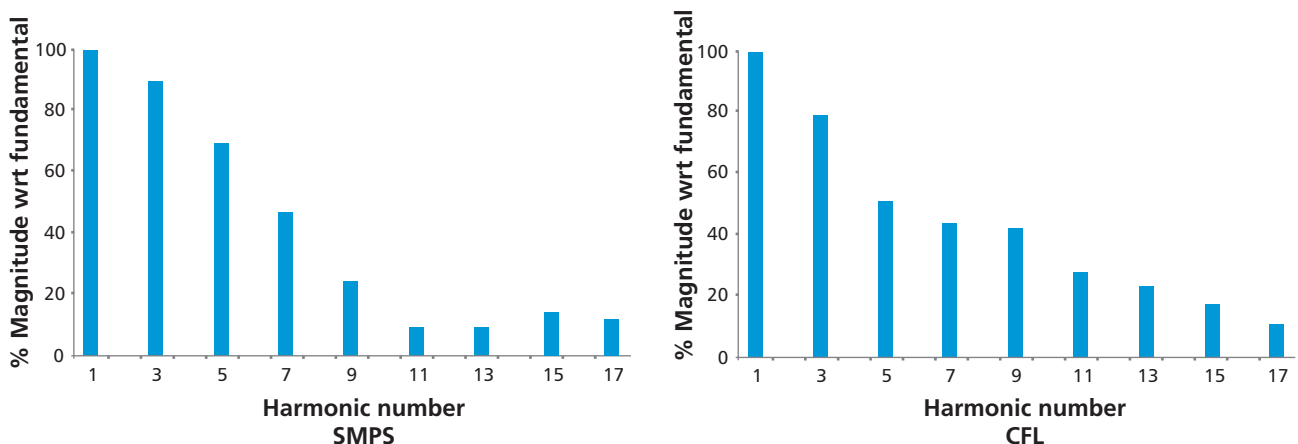
All the triplen harmonics are zero sequence in nature and they are exactly in-phase in all the three phases, where as the fundamental component (50 Hz), has positive phase sequence, displaced by 120° between the three phases.

The accumulated neutral current, because of the additive triplen current, can go up to 200% of the phase current.

Three Phase System

Wave forms of balanced three phase fundamental currents.

R-Phase current with its third harmonic component.

Y-Phase current with its third harmonic component.

B-Phase current with its third harmonic component.

Third harmonic current of R,Y & B Phases are in-phase with each other and hence adds up, without cancellation in the neutral conductor.

▼ Reaching maximum at the same time

Ill Effects of Triplen Harmonics

• The harmonics accumulate in neutral and cause hot neutral or neutral burning due to neutral over-loading. Thus, we need to use a higher sized cable for neutral
• Distribution transformer over heating
• Busbars and cable overheating due to skin effect
• Eddy current losses (as eddy current is proportional to square of the frequency)
• Reduced life of electrical equipments like transformers, power capacitors, switchgear, etc.

Triplen Harmonic Mitigation

Most commonly used passive filter for triplen harmonics is 14% detuned filter. This filter has the tuning frequency of 133 Hz, which is below the 3rd harmonic (150 Hz). This filter is very effective in averting the harmonic amplification of 3rd harmonics & above and thereby protecting power capacitors and other equipments. But detuned filter does not eliminate the harmonics completely. In order to achieve that, active harmonic filters with three-phase four-wire configuration should be used.

Benefits of Harmonics Mitigation

■ **Reduction in operating expenses**
Harmonic mitigation contributes to reduced power losses in transformers, cables, switchgear. Harmonic mitigation helps in reducing the energy losses

■ **Reduction in capital expenditure**
Harmonic mitigation reduces the r.m.s. value of the current and it eliminates the need to oversize transformers and hence switchgear, cables and busbars

■ **Improved business performance**
Harmonics are responsible for increased line currents, resulting in additional power losses and increased temperature in transformers, cables, motors, capacitors. The consequence may be the unwanted tripping of circuit breakers or protection relays. This might cause significant financial losses linked to a process interruption

Solutions for Harmonic Mitigation

For any electrical system, which is expected to be harmonics rich, it is recommended to study the harmonics level, analyze and then a proper solution should be employed.

The different solutions employed are as follows:

Harmonic Filters

Passive

Active **Hybrid**

Detuned **Tuned**

7% **14%**

Active: IGBT-based power converter that reduces harmonic distortion

Hybrid: Combination of passive and active filters

Mitigates harmonics by acting as a sink

Series LC combination helps in avoiding harmonic resonance and amplification

Merits:
✓ Reduces %THD

Merits:
✓ Reduces THD within IEEE limits
✓ Dynamic correction of THD is possible
✓ Improves Distortion PF
✓ Load balancing and Displacement PF improvement possible
✓ Modular – Can be expanded along with the load

Demerits:
✗ Tuning efficiency is susceptible to system frequency & load variations leading to overheating & failure of filter
✗ Extensive harmonic audit is mandatory before installation

Merits:
✓ Simple and economical

Demerits:
✗ Marginal reduction of %THD
✗ High V_{THD} will affect the performance

Detuned Filters are a combination of series inductors and power factor correction capacitors that are meant to:

1. Prevent resonance.
2. Prevent harmonic amplification.
3. Protect power factor correction capacitors from overload.

Typically a detuned filter has a series connected capacitor and reactor. The capacitor terminal voltage varies with respect to the tuning factor (%p) of the reactor. Tuning factor (%p) is the ratio of inductive impedance to the capacitive impedance (X/X). Common tuning factors of detuned filters are 7% and 14%.

Every series LC combination behaves capacitive below its tuning frequency [$f_t = 1 / (2\pi\sqrt{(LC)})$] and inductive above. The inductive element of the detuned filter is selected such that the tuning frequency of the filter is significantly lower than the lowest order harmonic frequency present in the system. The filter is thus 'detuned'. The ratio of inductive reactance (X_L) and capacitive reactance (X_C) is defined as the tuning factor.

Eg : A tuning factor of 7% implies $X_L / X_C = 0.07$.

The tuning frequency using tuning factor can be calculated as

$$f_t = \frac{f_s}{\sqrt{p/100}}$$

Where,
f_s = Supply Frequency = 50 Hz
For tuning factor of 7%, f_t = 189 Hz.
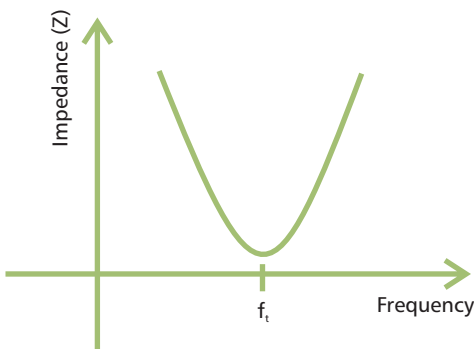
As can be seen from the above graph, for all frequencies above the tuning frequency (f_t), the combination will provide increasing impedance. The combination will not provide a low impedance path for harmonics that the capacitor did earlier, thus preventing harmonic amplification. Further as the tuning frequency of the combination is lower than the lowest order harmonic in the system, there is no question of resonance. At 50 Hz the combination behaves capacitive and power factor correction is achieved

The voltage that appears across the terminals of a capacitor increases the moment you connect an inductor in series with it. This can be illustrated by the below phasor:

V_s : System Voltage; V_C : Voltage across the capacitor;
V_L : Voltage across the inductor; I : current.

As can be seen $V_C > V_s$ by an amount V_L. Thus if reactors are to be added to an existing APFC panel, the capacitors will have to be replaced with those capable of withstanding higher voltages. More over, the output of the capacitors will have to compensate for the reactive power that will be consumed by the reactor.
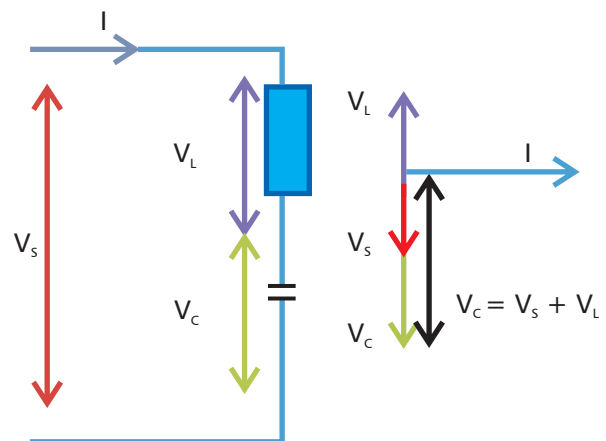
Secondly reactors are a major source of heat. The existing panel may not have sufficient space or cooling arrangement to handle the heat generated by the newly installed reactors. For these reasons, it is not advisable to add detuned reactors to existing APFC panels.

Hence, it is difficult to solve harmonics related problems, once the power factor correcting capacitors are installed. It is thus important to incorporate harmonic mitigation techniques in the system design stage itself.

Selection of Capacitor - Reactor Combination for Detuned Harmonics Filters

Typically a detuned filter has a series connected capacitor and reactor. The capacitor terminal voltage varies with respect to the tuning factor (%p) of the reactor. Tuning factor (%p) is the ratio of inductive impedance to the capacitive impedance (X_L / X_C). Common tuning factors of detuned filters are 7% and 14%.

The voltage that appears across the terminals of a capacitor increases the moment an inductor is connected in series.

The actual amount of voltage increase can be calculated using the following formula:

$$V_C = \frac{V_s}{(1 - \frac{\%p}{100})}$$

➤ For example, the capacitor terminal voltage with 7% detuned reactor shall be calculated using the above formula:

$$V_C = \frac{440}{(1 - \frac{7}{100})} \qquad V_C = 473 \text{ V}$$

Hence the rated voltage of the capacitor should be selected as 480 V when used along with 7% reactor. Sometimes, the voltage variations, as per the electricity board voltage limits, may cause the supply voltage to exceed 480 V. Also, due to harmonics, both peak and rms voltage may go beyond 480 V. In such cases, a 525 V capacitor should be used along with 7% detuned reactor. Selection for both 480 V and 525 V capacitor with 7% reactor is given in the table.

➤ When 14% reactor is used along with the capacitor, the capacitor terminal voltage,

$$V_C = \frac{440}{(1 - \frac{14}{100})} \qquad V_C = 512 \text{ V}$$

Here the capacitor should be rated for 525 V when used along with 14% reactor.

Capacitor voltage and kVAr selection for both 7% and 14% reactors are given below:

Effective kVAr output	With 7% detuned reactor			With 14% detuned reactor	
	Reactor (440 V)	Capacitor (480 V)**	Capacitor (525 V)**	Reactor (440 V)	Capacitors (525 V)**
5 kVAr	5 kVAr	7.5 kVAr 480 V	7.5 kVAr 525 V	5 kVAr	7.5 kVAr 525 V
10 kVAr	10 kVAr	12.5 kVAr 480 V	12.5kVAr 525 V	10 kVAr	12.5 kVAr 525 V
12.5 kVAr	12.5 kVAr	15 kVAr 480 V	15 kVAr 525 V	12.5 kVAr	15 kVAr 525 V
15 kVAr	15 kVAr	20 kVAr 480 V	20 kVAr 525 V	15 kVAr	20 kVAr 525 V
20 kVAr	20 kVAr	25 kVAr 480 V	25 kVAr 525 V	20 kVAr	25 kVAr 525 V
25 kVAr	25 kVAr	30 kVAr 480 V	33.3 kVAr 525 V	25 kVAr	30 kVAr 525 V
50 kVAr	50 kVAr	2 nos of 30 kVAr 480 V	2 nos of 33.3 kVAr 525 V	50 kVAr	2 nos of 30 kVAr 525 V
75 kVAr	75 kVAr	3 nos of 30 kVAr 480 V	3 nos of 33.3 kVAr 525 V	75 kVAr	3 nos of 30 kVAr 525 V
100 kVAr	100 kVAr	4 nos of 30 kVAr 480 V	4 nos of 33.3 kVAr 525 V	100 kVAr	4 nos of 30 kVAr 525 V

** Capacitor kVAr selection is done considering the tuning frequency (189 Hz with 7% and 133 Hz with 14%), reactor current and standard capacitor ratings available.

Electrical netwroks often contain significant levels of harmonic distortion, which has led the large majority of manufacturers of automatic capacitor banks to unanimously include detuned filter units in their offerings. In this article, we will try to explain the impact of different detuned filters and the consequences of a poor choice, as well as the recommendation for avoiding these possible risks.

Importance of Tuning Frequency in Capacitor Banks

However, there is no such unanimity in the choice of the tuning frequency of the detuned filter offered as standard.

In case the network has predominant 3rd order harmonics (150 Hz in 50 Hz networks), the use of detuned filters tuned at 134 Hz is more common (over voltage factor of p = 14%).

However, a large majority of installations require capacitor bank fitted with detuned filters appropriate for 5th order harmonics (250 Hz in 50 Hz networks) or higher, which are normally produced by the more usual harmonic current sources, such as, drives, AC/DC rectifiers, induction ovens, etc. In such cases, there are two options available, that corresponding to an over voltage factor of p = 7% (tuning frequency of 189 Hz in 50 Hz networks) and p = 5.67% (tuning frequency of 210 Hz in 50 Hz networks).

It may seem from the above that the choice of a value of p = 7% or p = 5.67% might be indifferent and that both should give the same result when they are connected to the electrical network, but this is not strictly true.

Detuned Filters and their Effect on Installations

To follow the arguments of this, we will briefly go through the operating principle of detuned filters.
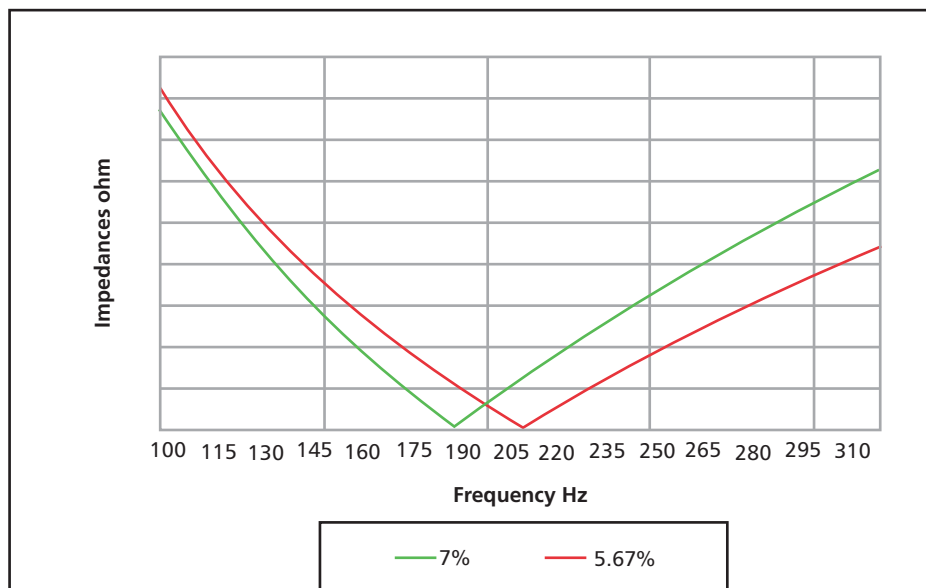
Fig. 1 Impedance-frequency graph of a detuned filter with p = 7% (189 Hz) and p = 5.67% (210 Hz)

Observing the impedance-frequency graph at rated current of a standard reactor-capacitor unit with p = 7% (green line in Fig. 1), we see that it offers least impedance at 189 Hz, whereas that corresponding to p = 5.67% (red line in Fig. 1) offers the least impedance at 210 Hz. In both cases, the impedance gradually increases on either side of it. The impedance is capacitive at frequencies under 189 Hz for 7% and 210 Hz for 5.67% respectively, and inductive at higher frequencies. It is this inductive character with harmonic frequencies of the 5th order or higher that prevents the possibility of a resonance phenomenon being produced at any of those frequencies. However, another key parameter for the correct operation of the detuned filter is the value of impedance at the different harmonic frequencies. Therefore, at said impedance-frequency in Fig. 1 the impedance difference of each tuning can clearly be seen at a harmonic frequency of 250 Hz.

Main Consequence of Difference in Impedance

For p = 5.67%, the value of the impedance is around half of the value for p = 7%. Hence its ability to filter of 5th Harmonic and above is only half that of a 7% detuned filter.

The result will be that the absorption of harmonic currents by the capacitor will be higher for p = 5.67% than for p = 7% as it is providing less impedance to the harmonic frequency.

Other Effects on Filtering

One basic point is the fact that if, to start with, a reactor with p = 5.67% is going to have a larger harmonic current consumption, then the reactor and the associated capacitor, must be designed to withstand the overload to which they are to be subjected on the level of intensity and temperature. However, in the particular case of a similarly-designed reactor with p = 7%, the result is a smaller and lighter reactor, and a lower cost.

In short, in case of reactor with p=5.67%, there is a risk that the capacitor bank might have to withstand higher levels of harmonic overloading, which would inevitably cause faster wear than in case of a capacitor with filter of p = 7%.

The other essential point to be considered, which is the most important, is the influence of the capacitor capacity in tuning the reactor-capacitor series group according to the formula for tuning frequency:

$$f_{res} = \frac{1}{2\pi\sqrt{LC}}$$

A decrease in the capacitor capacity will result in an increase in the unit's resonance frequency. Capacitors are elements that lose capacity with time either due to their conditions of use (voltage, temperature, connection operation rate, etc.), or due to the natural deterioration of the polypropylene of their dielectrics. A same loss of capacity in a p = 5.67% filter and in one of p = 7% , means that the first will come much closer to the 5th order frequency than the second, and the closer it comes, the greater harmonic current absorption it will present, the greater overloading it will suffer, leading to greater deterioration.

In other words, the safety margin given with this loss of capacity is considerably higher in a filter with p = 7%

Conclusions for the Correct Choice of a Reactor

The conclusion in this case is clear, and is the unequivocal recommendation of the use of filters with p = 7% instead of p = 5.67% in all installations where they have to be applied due to the level of harmonic distortion.

The purpose of this recommendation is none other than to reduce the obvious risk that a loss of capacitor capacity could cause as a result of overcurrent in the capacitor bank much earlier. Thus, 7% detuned reactors allow a longer reaction time through pertinent maintenance actions and the application of corrective measures before the damage is definitive and, therefore, avert worse economic conditions.

An industry whose load includes a high proportion of non-linear load (harmonic generating loads), with poor power factor, requires capacitor with de-tuned filter. This performs the function of power factor improvement while preventing harmonic amplification.
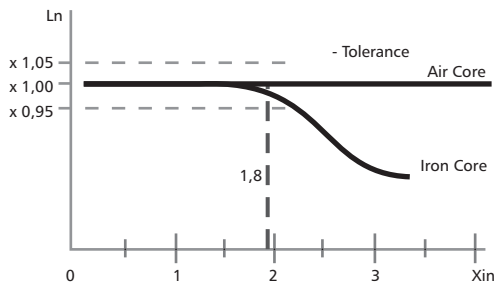
Relation between inductance (L_N) and inductor current (I_N)

Normally, the inductance of the series reactor (of de-tuned filter) connected is chosen such that the tuning frequency of the de-tuned filter is 10% below the lowest harmonic frequency with considerable current/voltage amplitude. Therefore, resonance does not happen in the system and reactor offers high impedance for higher frequency harmonics.

Normally, 7% detuned reactors are designed considering typical industrial loads such as drives that have the following harmonic voltages: V_3= 0.5% V_N, V_5= 6% $V_N V_7$= 5% V_N and so on. However, if the individual harmonic voltages increase, the following phenomenon happens:

The magnitude of net current (through LC) increases

If the current increases beyond certain limit, the reactor may be driven into its saturation region

Once the reactor saturates, inductance value (L, in henry) of the reactor starts decreasing (as $L = N\phi/I$)

Therefore, the resonant frequency (f_R) of the LC rises as resonant frequency = $1/(2\pi\sqrt{LC})$

The new resonant frequency may match the fifth harmonic frequency and may result in resonance

As the resonant frequency rises, the capacitor-reactor combination may offer lower impedance to the fifth harmonic component and the current through the combination may increase further

Thus the resonant frequency of the reactor capacitor combination may increase continuously resulting in a thermal runaway

Normally, reactors are designed with predefined linearity. A reactor having a higher linearity does not saturate for higher harmonic currents and prevents the system from a thermal run away as described above.

The quality factor or Q-factor is a dimensionless parameter that characterizes a resonator's bandwidth relative to its center frequency. It also describes the damping nature of a resonant circuit. Higher Q indicates a lower rate of energy loss relative to the stored energy of the oscillator; i.e., the oscillations die out more slowly. For example, a pendulum suspended from a high-quality bearing, oscillating in air, has a high Q, while a pendulum immersed in oil has a low one. Oscillators with high quality factors have low damping making them ring longer.

The Q-factor is the ratio of the reactance to the resistance in the circuit. In other words, it is the absolute value of the ratio of reactive power to real power

$$\tilde{Z} = R + jX$$

$$Q = \left| \frac{X}{R} \right|$$

Thus, we can also calculate the Q-factor, just by knowing the power factor of the circuit

$$Q = \frac{|\sin\phi|}{|\cos\phi|} \frac{\sqrt{1 - PF^2}}{PF} \sqrt{\frac{1}{PF^2} - 1}$$

or just the tangent of the phase angle

$$Q = |\tan \phi|$$

While selecting a detuned filter, it is important to give due consideration to its band-width. The bandwidth will decide the extent of impendence the filter offers to higher order harmonics. The bandwidth of the filter is a function of the resistance of the system. The resistance largely depends upon material and construction of the filter inductor.

Bandwidth $= F_2 - F_1 = F_r / Q$

Where, F_2 is the upper cut off frequency
F_1 is the lower cut off frequency and
F_r is the resonant frequency
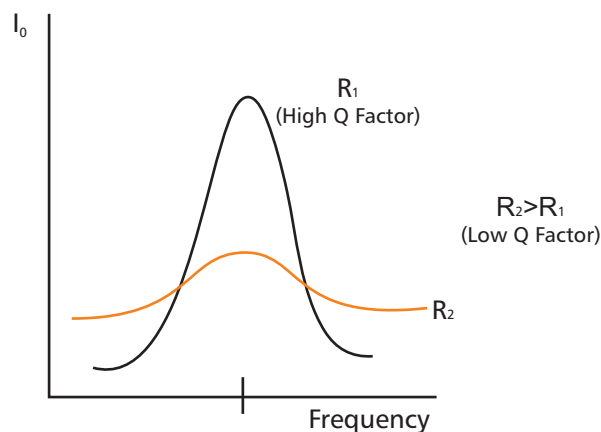
For an electrically resonant system, the Q-factor represents the effect of electrical resistance, as shown in the figure. When resistance is low (R_1), the system will have a low bandwidth. When the resistance is increased gradually (say to R_2), its bandwidth increases. Thus while selecting De-tuning reactors, care should be taken that the Q factor of the same is adequate.

The increasing use of modern power electronic apparatus (drives, uninterruptible power supplies, etc) produces nonlinear current and thus influences and loads the network with harmonics (line pollution).

The capacitance of the power capacitor forms a resonant circuit in conjunction with the feeding transformer. Experience shows that the self-resonant frequency of this circuit is typically between 250 and 500 Hz, i.e. in the region of the 5th and 7th harmonics. Such a resonance can lead to the following undesirable effects:

- Overloading of capacitors
- Overloading of transformers and transmission equipment
- Interference with metering and control systems, computers and electrical gear
- Resonance elevation, i.e. amplification of harmonics
- Voltage distortion

These resonance phenomena can be avoided by connecting capacitors in series with filter reactors in the PFC system. These so called "detuned" PFC systems are scaled in a way that the self-resonant frequency is below the lowest line harmonic and the detuned PFC system is purely inductive as seen by harmonics above this frequency. For the base line frequency (50 or 60 Hz usually), the detuned system on the other hand acts purely capacitive, thus correcting the reactive power.

Features

- Copper and Aluminium wound reactors
- Very low operating losses - 3 to 5 W / kVAr
- High linearity - 1.8 times the rated current
- Low noise
- Auto-thermal cutoff**

Reactor Tuning Factor	Tuning Frequency	Application (Harmoic Orders)	Typical Loads
7%	189 Hz	5th harmonic (250 Hz) and above	6 pulse drives (AC / DC), 3 phase UPS, frequency converters
14%	133 Hz	3rd harmonic (150 Hz) and above	Single phase UPS, CFL lamps, SMPS, dimmers

Technical Details (Copper and Aluminium)

Standards	IEC 60289, IS 5553
Rated Voltage (V)	440 V
Rated Frequency (F)	50 Hz
Max Permissible Operating Voltage	1.05 Un Continuously, 1.1 Un for 8 hours
Max Permissible Operating Current (Linearity)	1.8 In Continuously
Duty Cycle	100%
Class of Protection	I
Ambient Temperature	40°C
Winding	Cu / Al
Insulation Class	Class H
Protection	Thermal Switch**
De-Tuning	5.67%, 7% & 14%
Harmonics Limit	V_3 = 0.5% V_R (duty cycle = 100%) V_5 = 6.0% V_R (duty cycle = 100%) V_7 = 5.0% V_R (duty cycle = 100%) V_{11} = 3.5% V_R (duty cycle = 100%) V_{13} = 3.0% V_R (duty cycle = 100%)
Effective Current	$I_{rms} = \sqrt{(I_1^2 + I_3^2 + I_5^2 + \dots)}$
Fundamental Current	I_1 = 1.06 x I_R

** In NC, to be connected in series with contactor coil. When temperature exceeds 130° C, NC opens and disconnects the reactor from the circuit.

7% Detuned Reactor (Copper) 440 V - Overall Dimensions

connect well
terminal type
cmst 2.5 mm sq. / 400 V
(Thermistor - NC contact)

Open Slot
d1 X d2 - 4 Nos.

Elevation

R. H. Side View

Mounting Plan
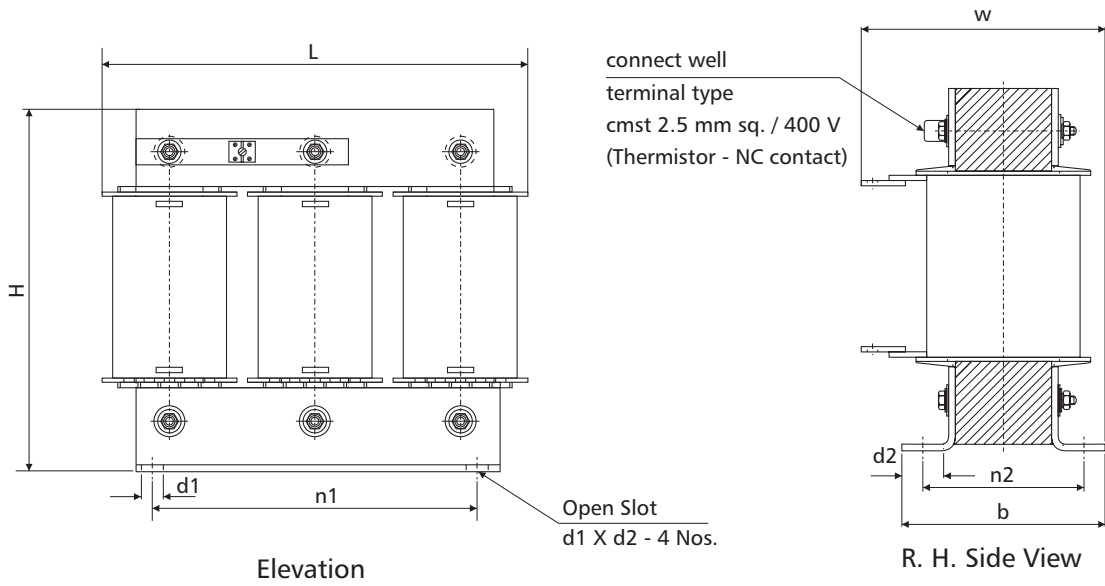
kVAr	Cat. No.	Rated Current	I rms	Inductance	Terminal Hole	L	W	H	n1	n2	b	d1	d2
						All Dimensions in mm							
5	LTFR0705B2	6.6A	7.5A	9.280 mH	6Ø	175	96 ± 5	157	100	55 ± 3	73	10.5	18
10	LTFR0710B2	13.12A	14.9A	4.641 mH	6Ø	178	125 ± 5	161	100	75 ± 3	93	10.5	20
12.5	LTFR0712B2	16.5A	18.7A	3.71 mH	6Ø	178	125 ± 5	161	100	75 ± 3	93	10.5	20
15	LTFR0715B2	19.8A	22.35A	3.1 mH	8Ø	225	150 ± 5	230	150	73 ± 3	93	10.6	21.5
20	LTFR0720B2	26.4A	29.8A	2.328 mH	8Ø	226	152 ± 5	205	150	96 ± 3	109	10.8	22
25	LTFR0725B2	32.8A	37.2A	1.86 mH	8Ø	226	152 ± 5	205	150	96 ± 3	109	10.8	22
30	LTFR0730B2	39.6A	44.7A	1.552 mH	8Ø	226	152 ± 5	205	150	96 ± 3	109	10.8	22
50	LTFR0750B2	65.61A	74.45A	0.93 mH	8Ø	260	207 ± 5	240	150	167 ± 3	185	10.6	55
75	LTFR0775B2	99A	112.2A	0.62 mH	6Ø	300	200 ± 5	265	150	151 ± 3	181	12	20
100	LTFR0700B2	131.2A	148.9A	0.464 mH	6Ø	330	225 ± 5	300	240	160 ± 3	195	12	20

7% Detuned Reactor (Aluminium) 440 V - Overall Dimensions

Elevation

R. H. Side View

Mounting Plan
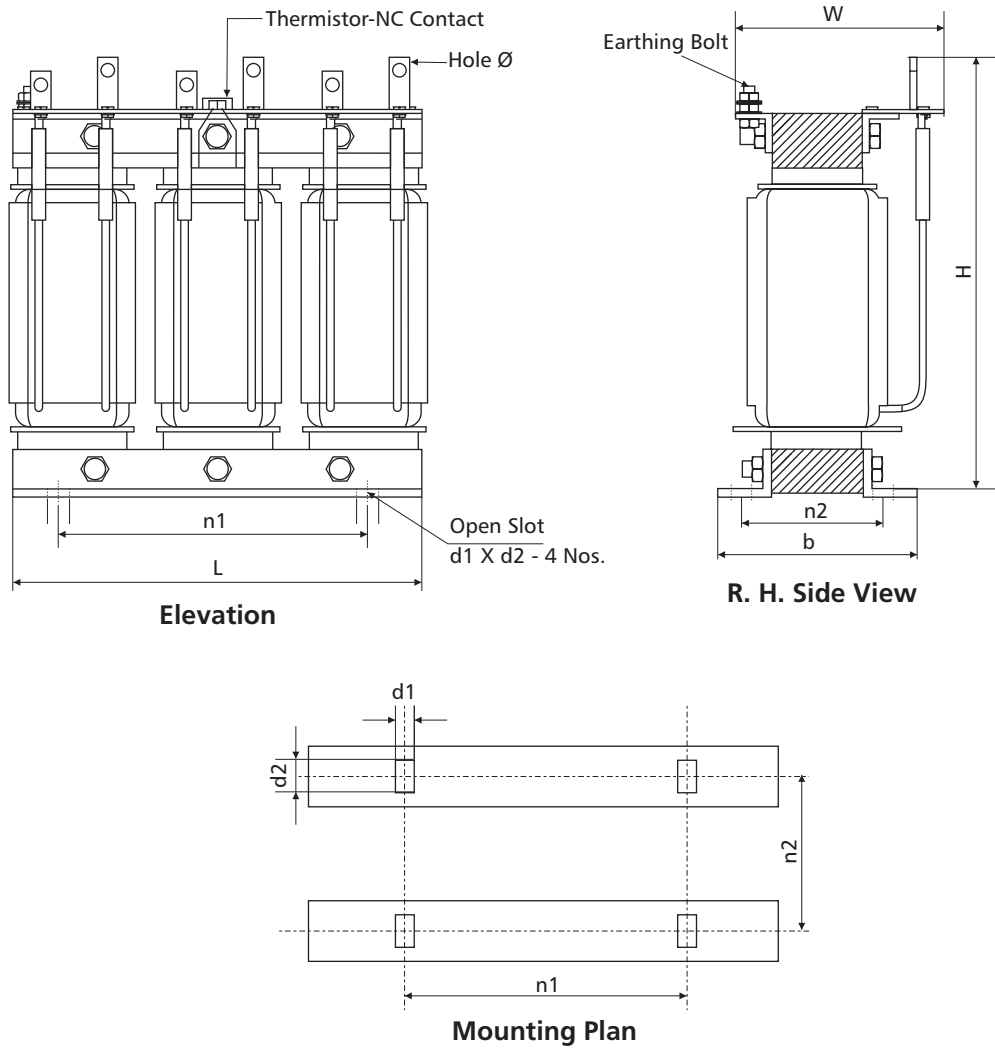
kVAr	Cat. No.	Rated Current	I rms	Inductance	Terminal Hole	L	H	W	n1	n2	b	d1	d2
						All Dimensions in mm							
5	LTAL0705B2	6.6A	9A	9.28 mH	6Ø	215	185	130 ± 3	203	80 ± 3	100 ± 3	8	12
10	LTAL0710B2	13.2A	18A	4.64 mH	6Ø	215	185	155 ± 3	203	92 ± 3	110 ± 3	8	12
12.5	LTAL0712B2	16.5A	21A	3.97 mH	6Ø	215	185	170 ± 3	203	105 ± 3	123 ± 3	8	12
15	LTAL0715B2	19.8A	26A	3.21 mH	6Ø	215	185	196 ± 3	203	130 ± 3	150 ± 3	8	12
20	LTAL0720B2	26.4A	35A	2.32 mH	6Ø	250	225	170 ± 3	150	110 ± 3	140 ± 3	12	20
25	LTAL0725B2	33A	43A	1.85 mH	6Ø	270	265	165 ± 3	150	110 ± 3	140 ± 3	12	20
50	LTAL0750B2	66A	86A	0.92 mH	10Ø	270	375	210 ± 5	150	110 ± 5	140 ± 5	12	20
75	LTAL0775B2	99A	129A	0.62 mH	10Ø	270	385	210 ± 5	150	110 ± 5	140 ± 5	12	20
100	LTAL0700B2	132A	172A	0.46 mH	10Ø	370	305	205 ± 5	180	145 ± 5	185 ± 5	12	20

The increasing use of energy saving power electronics based loads (adjustable speed drives, switch mode power supplies, etc.) to improve system efficiency and controllability, is increasing the concern for harmonic distortion levels in end use facilities and on the overall power system. Active filter is the apt device for reducing harmonic levels in industrial and commercial facilities to meet IEEE 519 guidelines. The concept of active filter, what many try to explain is, it senses harmonics and generates 180° phase shifted harmonics that cancels out the unwanted harmonics. This article, specifically describes the basic operation of active filters in a little more detailed way.

Principle of Operation

An active harmonic filter is based on the following principle:

$$I_{FILTER} = I_{MAIN} - I_{LOAD}$$

It detects the difference between the ideal current sine wave (I_{MAIN}) and the actual current which has been deformed by harmonics (I_{LOAD}). It, then, injects this difference (I_{FILTER}), which is the negative of the harmonic currents present in the load current, into the system on a real-time basis. This cancels out the high frequency harmonics and results in almost pure sine wave.
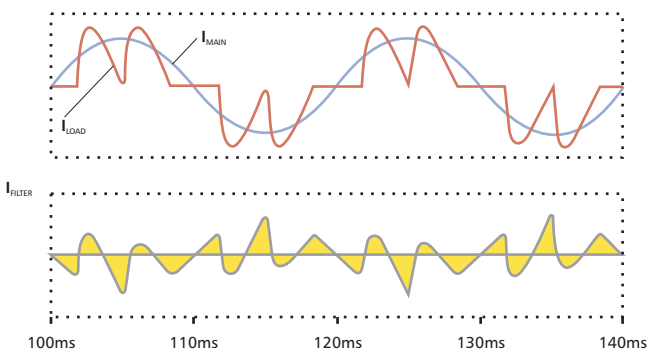
Wave Shapes of The Currents - I_{MAIN}, I_{LOAD} & I_{FILTER}
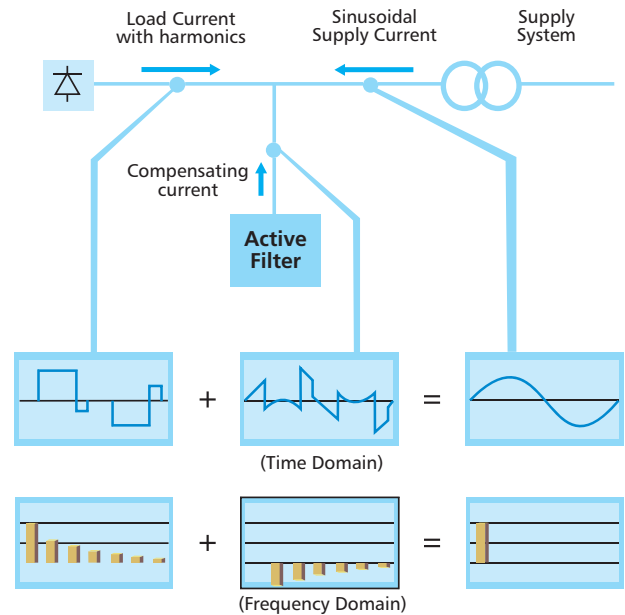
Line Diagram of Active Harmonic Filter

The use of active harmonic filters helps in reducing harmonics as can been seen under:
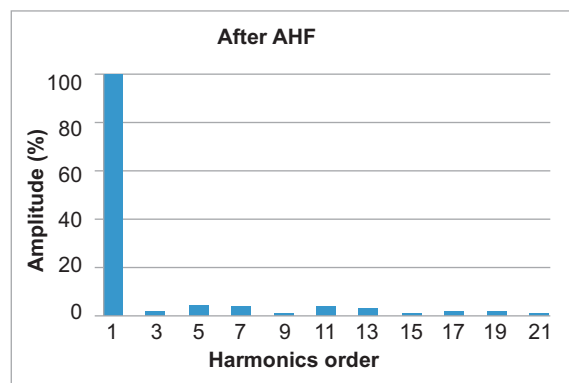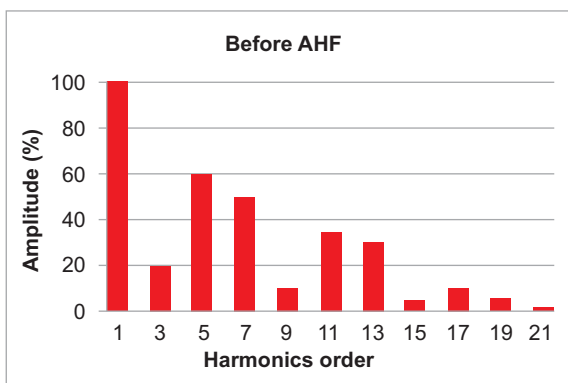
Frequency Spectrum of Current Before and After Active Harmonic Filtering

Some of the areas where active harmonic filters can be used are:
- In areas with critical loads like automobile industry, precision equipment manufacturing etc., the harmonic load may vary frequently. This may have immediate adverse impacts like poor quality of manufactured products and equipment failures leading to huge monetary losses. Active filters prove to be suitable as they provide real-time reduction of THD
- Certain segments like textile industry, having huge VFD loads suffer from high harmonics. Due to this, the use of detuned filters may not be adequate, resulting in frequent capacitor failures and overheating or saturation of reactors. Only active harmonic filters provide necessary solutions in such cases
- Active harmonic filters have an added advantage of providing unsymmetrical reactive power compensation and also, provide load balancing
- Even usage of 14% reactor may not be sufficient to reduce neutral overloading due to triple-N harmonics. However, 3 phase, 4 wire active filter helps in achieving the same more effectively

Active Harmonic Filters - Concepts & Connections

The active filter uses power electronic switching to generate harmonic currents that cancel the harmonic currents from a nonlinear load. The active filter configuration is based on a Pulse-Width Modulated (PWM**) voltage source inverter that interfaces to the system through an Interface Filter as shown in Figure 1. In this configuration, the filter is connected in parallel with the load being compensated. Therefore, the active filter with this configuration is often referred to as shunt active filter. Figure 1 illustrates the concept of the harmonic current cancellation so that the current being supplied from the source is sinusoidal.
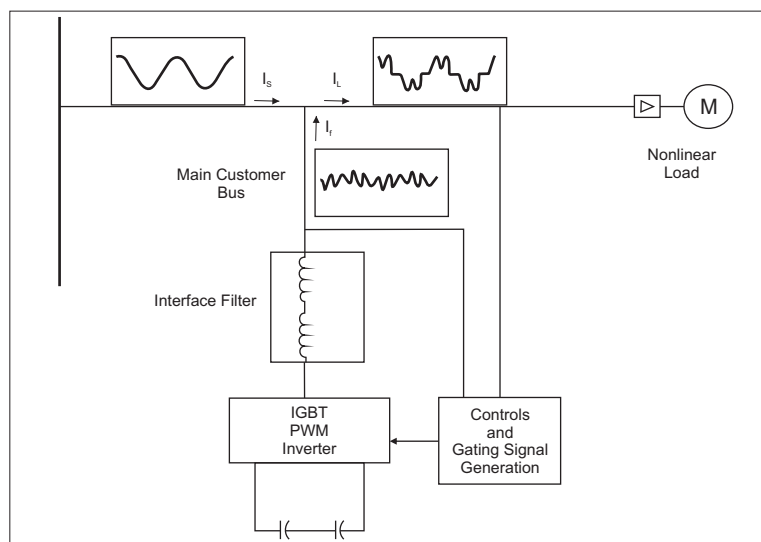
**Pulse Width Modulation is a technique used to generate the effect of any wave-form by varying the width of the DC pulse. The width (duty cycle) is varied by employing faster switching devices (IGBT with switching frequency in kHz). Higher the switching frequency, better will be the intended wave-form but higher will be the power losses.

The voltage source inverter used in the active filter makes the harmonic control possible. This inverter uses DC capacitors as the supply and can switch at a high frequency to generate a signal which will cancel the harmonics from the nonlinear load. One leg of the inverter is shown in Figure 2 to illustrate the configuration.
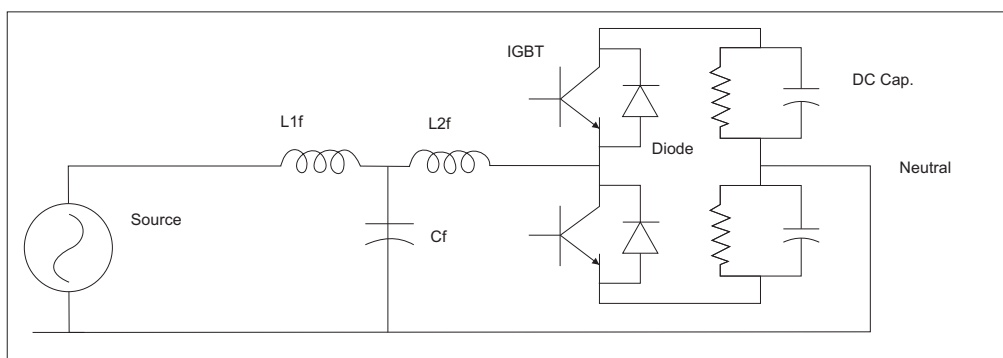
The current waveform for cancelling harmonics is achieved with the voltage source inverter and an interfacing filter. The filter consists of a relatively large isolation inductance to convert the voltage signal created by the inverter to a current signal for cancelling harmonics. The rest of the filter provides smoothing and isolation for high frequency components. The desired current waveform is obtained by accurately controlling the switching of the IGBTs in the inverter. Control of the current wave shape is limited by the switching frequency of the inverter and by the available driving voltage across the interfacing inductance.

The active filter does not need to provide any real power to cancel harmonic currents from the load. The harmonic currents to be cancelled show up as reactive power.

Connections & CT installations of Active Harmonic Filters

For the stable operation of active harmonic filter and for the expected reduction of harmonics, the physical connection & location of power cables & CTs plays a critical role. Let us understand the connections through the below two cases.

Case 1: In case any industry faces severe problems due to harmonics like over-heating of equipments, failure of power capacitors, frequent card failures, etc., it is advisable to arrest the harmonics right at the source. The connection shall be as below:
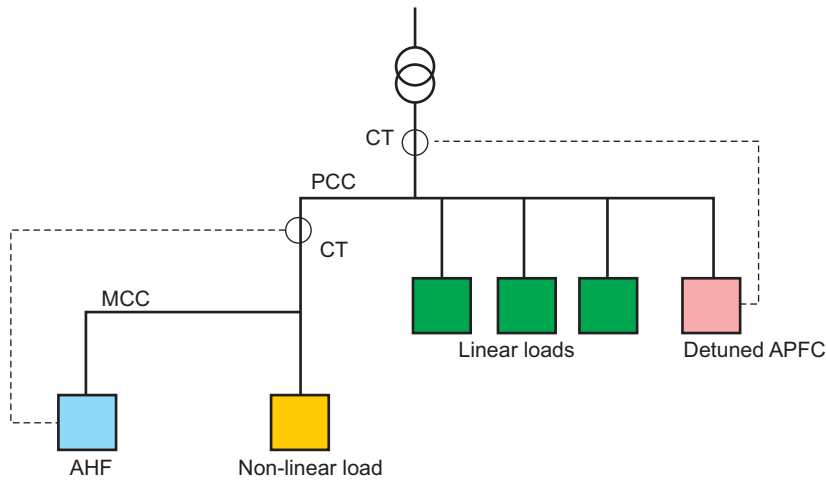
Make sure that the APFC panels are detuned and are connected in the upstream of the AHF. Detuning of APFC panel helps in optimising the AHF rating, as detuning avoids the harmonic amplification. Connecting AHF below the APFC avoids the AHF being overloaded due to unwanted harmonic resonances. Also make sure that the CT of AHF shall be connected below the CT of APFC panel.

Case 2: If almost all the main feeders from PCC generates high harmonics, ideally each feeder shall be compensated with individual AHF. But this will increase the installation cost and requires more space. Also managing all the AHF will be difficult. In such cases, a common AHF can be connected for harmonics compensation, as shown below:
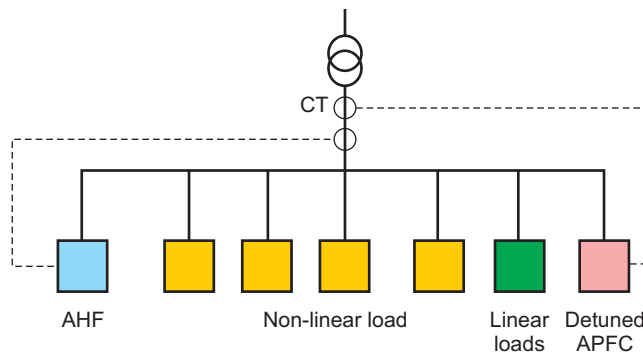
Also make sure that the APFC panels are detuned and the AHF CT shall be below the CT of detuned APFC panels. This method is also simple enough, especially for industries where harmonics need to be reduced at the HT side, in order to meet utility regulations (like Tamil Nadu Electricity Board).

In some rare cases, there may be multiple sources, like two or more synchronised transformers. In such cases, individual CTs shall be connected to each sources and the common signal can be given to AHF through a summation CT.

Open Loop Connection Vs Closed Loop Connection

The open loop or closed loop connection is indicated by the location, where harmonics are measured by the AHF. In simple words, CT position states whether the connection is open loop or closed loop connection.

In **open loop connection,** CT is installed close to load, as indicated in the above figure. AHF senses the harmonics that are being generated by the load and generates the compensating harmonics based on that data. Advantage of this connection is faster harmonic compensation. But a drawback in this connection is, the AHF won't get any feedback from the system and does not know whether the harmonics compensation is happening properly or not. Also, as no feedback exists, the resulting line current may typically contain error components that are not detected by the control system. This connection works better when AHF is connected close to the load and not at PCC / main incomer.

Open Loop Connection
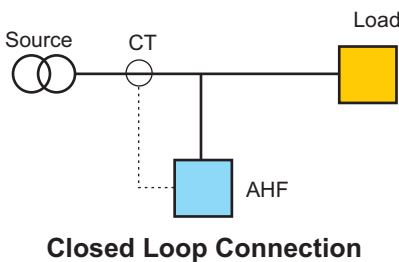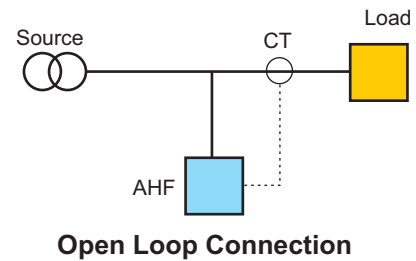
In **closed loop connection** the CT is installed close to source. Here, CT actually measures the compensated current. In other words, AHF senses the difference between load current and the AHF compensating current. If CT senses any harmonics, corrective action is taken by the AHF, till CT senses close to sine wave. In this method of connection, the AHF gets system feedback and any measurement or other inaccuracies can be automatically cancelled out. Even though, closed loop connection is not as fast as open loop, closed loop ensures better harmonics compensation. This type of connection works better, anywhere in the system, than the open loop

Closed Loop Connection

Selection / Sizing of Nominal Current of Active Harmonic Filter

Active harmonic filter is rated in Amperes. The current rating is decided on the basis of harmonic content (THD) in the system which can be obtained from harmonic study. The required nominal current can be obtained by multiplying the initial current of harmonics measured in the load by a safety factor (SF_h) of 20%. In other words,

$$I_{filter} \text{ (AHF)} = 1.2 \times I_{load} \times \%THD \text{ (I)}$$

Where,

I_{filter} (AHF) : Nominal Current of Active Filter (A)
I_{load} : Maximum Load Current (A)
% THD(I) : Load Current Harmonic Distortion (%)

Majority of the energy saving devices are non-linear in nature. Consequently, the problem of harmonics has become inevitable. Advanced devices like active harmonic filter provide an ideal solution to this problem. These filters help in maintaining a stable and healthy power system thereby increasing productivity and efficiency.

Active Harmonic filters are the most ideal solution for power quality problems caused, in either industrial or commercial facilities, for harmonic filtering, phase balancing and reactive power compensation.

Without AHF   With AHF

Function

• **Harmonic Filtering:**

The filters reduce harmonics up to the 50th order (2500 Hz) reducing distortion power factor. Selection of specific harmonic order for filtering helps in optimizing filtering efficiency.

3 Phase 4 Wire filter configuration ensures reduction in neutral current that can reach up to 200% of rated value due to triple-N harmonics.

THD TOTAL

	LOAD	MAINS
L1	21%	5%
L2	18%	5%
L3	19%	5%

Harmonic Filtering

VOLTAGE & CURRENT

	VOLTAGE	CURRENT	
		LOAD	MAINS
L1	232 V	199 A	220 A
L2	231 V	206 A	221 A
L3	231 V	255 A	221 A
FREQUENCY	50 Hz		

Phase Balancing

• **Phase Unbalance Correction:**

This function ensures balanced current on the supply side in 3 Phase 4 Wire filter configuration.

• **Power Factor Correction:**

This filter ensures close to unity displacement power factor for both lagging (inductive) and leading (capacitive) current systems. With improvement in both distortion and displacement power factor, true power factor is also improved.

POWER MAINS

	P	Q	S	PF
L1	41.6 kW	5.92 kVAr	42.02 kVA	0.99
L2	38.9 kW	5.52 kVAr	39.29 kVA	0.99
L3	48.0 kW	6.80 kVAr	48.48 kVA	0.99

Reactive Compensation

Features & Benefits

Features	Advantages	Benefits
Employs floating Point 32 bit Digital Signal Processor	High accuracy & high attenuation up to 96% of individual harmonics	Effective harmonic mitigation
Programmable selective harmonic elimination		
Any number of units of different ratings can be connected in parallel	Modularity & expandability	Reduced Mean Time to Repair; Filter can be expanded as per future load requirements
Employs high speed IGBTs in power circuit	Faster response to change in THD and very high speed of operation	THD can be maintained even in case of very frequently changing load
Provision of Alarms	Easy diagnosis of fault conditions	Safety to devices and operators
7" TFT touch screen HMI	Easy configuration and parameter monitoring	Ease of installation and maintenance, User-friendly
Ethernet based communication	Remote monitoring	Ease of monitoring
Configuration in both open loop (load side sensing) and closed loop (source side sensing)	Faster response & higher attenuation of harmonics	Flexibility of configuration

The active filter is ideal in any application that has a large variation of loads, a wide spectrum of harmonics that must be compensated. Non-linear loads that are heavily distributed in the form of small network loads, so that it is not possible to use individual passive filters.

The most common applications are:
• Variable frequency drives
• Computer loads
• UPS
• CFL Lamps

In other words, its application is in any industry where large non-linear loads are present with high THD. Such high THD are prevalent in the following industries:

• Automotive Industry	• Textile Industry	• Cement Industry
• Data Centres	• Paper Mills	• Oil & Gas Exploration
• Wind Turbines	• Sugar Plants	• Water Treatment
• Building & Infrastructure	• Pharmaceutical Industry	• Granite & Stone Polishing

Connection Diagram

LOAD SIDE   MAINS SIDE
L1
L2
L3
N

L1 L2 L3 N

Active Filter

Close Loop Connection

LOAD SIDE   MAINS SIDE
L1
L2
L3
N

L1 L2 L3 N

Active Filter

Open Loop Connection

Technical Specifications

INPUT									
Model	AHF - 4W/3W								
Normal Voltage	400V AC ±10%, 3Ph 4 Wire/3 Wire (690V optional)								
Current Rating	30A	60A	75A	150A	100A	200A	300A	400A	600A
Frequency	50Hz,+/-5%								

FILTER									
Harmonic Range	2nd to 50th order								
Harmonic Selection	Any 20 Harmonic can be selected at a time								
Harmonic Attenuation Ratio	Up to 96% at rated current								
Response Time	<1 ms								
Function Selection	Harmonic filtering, Power factor correction, Load balancing								
Overload (peak value)	125% for 10 msec								
Current Transformer	30A	60A	75A	150A	100A	200A	300A	400A	600A
	500A:5A	1000A:5A		3000A:5A			5000A:5A		6000A:5A
	Class 1, 15VA rating								

PHYSICAL CHARACTERISTICS	
Protection Class	IP20 (IP31 or IP41 optional)
Cooling	Forced air
Cable Entry	Front - Bottom

ENVIRONMENTAL		
Operating Temperature	0 to 40 Deg C	
Relative Humidity	95% (Non condensing)	
Maximum Operating Altitude without De-rating	1000 m	
Acoustic Noise at 1m From Panel Front (Ref ISO3746)	< 65 db	< 68 db	< 70 db

USER INTERFACE	
User Parameter Setting	LCD touch screen HMI

PROTECTIONS AND STANDARDS	
Protections	MCCB & fast acting semiconductor fuses
Alarms	DC over voltage, Over load trip, Over temperature alarm & trip, Over current, No synchronisation, Mains abnormal, DC under voltage, Active filter trip, Wrong phase, No faults, Fast DC overvoltage, Inductor over temperature trip
Reference Design Standard	IEC 60146
Safety Standard	EN 50178
Electromagnetic Compatibility	EN 55011, IEC EN 50081-2, IEC 61000-4-2, IEC 61000-4-3, IEC 61000-4-4, IEC 61000-4-5, IEC 610004-6, IEC 61000-6-2

Overall Dimensions

AHF - 3W/4W 30/60/75/100
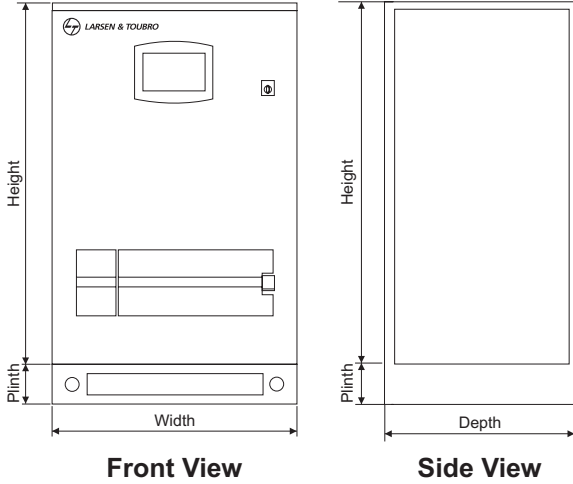
Front View **Side View**

3 Ph 3 Wire / 4 Wire, 400 V Active Filter						
Cat. No.	Model No.	Dimensions (mm)				
		Weight (kg)	Width	Depth	Height	Plinth
AHF030331D2	AHF - 3W- 30A	45	550	300	800	Wall-Mounting
AHF030341D2	AHF - 4W - 30A	48				
AHF060331D2	AHF - 3W- 60A	65	620	450	1000	100
AHF060341D2	AHF - 4W - 60A	70				
AHF075331D2	AHF - 3W- 75A	75	620	450	1000	100
AHF075341D2	AHF - 4W - 75A	80				
AHF100331D2	AHF - 3W- 100A	85	620	450	1000	100
AHF100341D2	AHF - 4W - 100A	90				

AHF - 3W/4W 200/300/400/600

3 Ph 3 Wire / 4 Wire, 400 V Active Filter						
Cat. No.	Model No.	Dimensions (mm)				
		Weight (kg)	Width	Depth	Height	Plinth
AHF150331D2	AHF - 3W- 150A	175	800	850	1600	150
AHF150341D2	AHF - 4W- 150A	205				
AHF200331D2	AHF - 3W- 200A	225	800	850	1600	150
AHF200341D2	AHF - 4W - 200A	265				
AHF300331D2	AHF - 3W- 300A	310	800	850	1600	150
AHF300341D2	AHF - 4W - 300A	365				
AHF400331D2	AHF - 3W- 400A	430	1000	900	1600	150
AHF400341D2	AHF - 4W - 400A	*	*	*	*	*
AHF600331D2	AHF - 3W- 600A	600	1000	900	1600	150
AHF600341D2	AHF - 4W - 600A	*	*	*	*	*

* Please contact nearest branch

Front view **Side view**
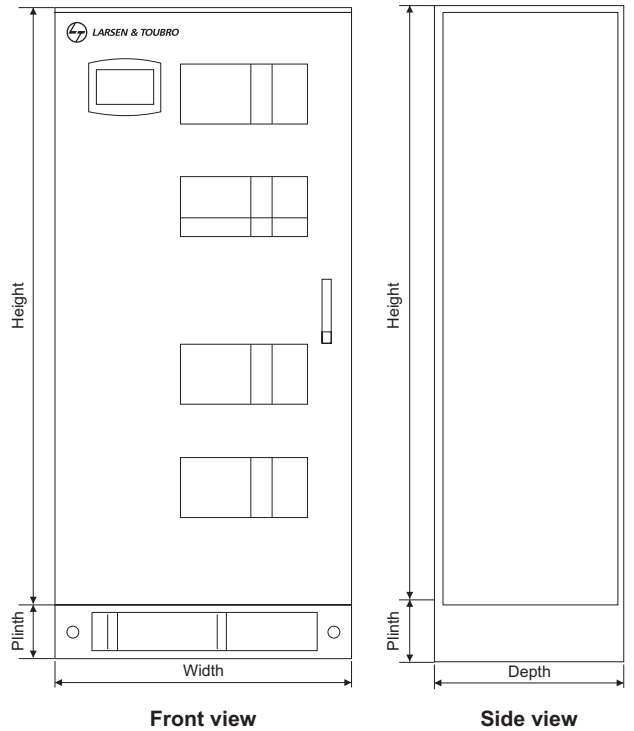
The switching of capacitor banks is a special and challenging task in Automatic Power Factor Correction (APFC) panels. The selection of appropriate switching device for such application is based on two criteria:

- Ability to carry rated capacitor current continuously
- Ability to withstand the peak-inrush current of capacitor

It is simple to calculate the capacitor rated current and select the switching device to be able to carry rated capacitor current (2.5 to 3 times the capacitor rated current to take care of overload, harmonics, supply voltage variation and capacitor value tolerance). However, it is little difficult to select the switching device which is able to withstand the peak-inrush current. This is because the peak inrush current for capacitor switching application depends upon various factors such as:

- The inductance of the network (including cables, switchgears and transformer)
- The transformer power rating and percentage impedance
- Method used for power factor correction
  - ➢ Fixed capacitor bank
  - ➢ Multi-stage capacitor bank with steps of equal ratings
  - ➢ Multi-stage capacitor bank with steps of unequal ratings
- In multi-stage capacitor bank, the numbers and rating of steps already switched on

In most of the installations, the multi-stage capacitor banks are used as steps of unequal ratings. The bigger steps of higher kVAr ratings being switched on initially and smaller steps are switched on periodically, for achieving the targeted power factor. In such cases, the value of inrush-current peak will be far higher and hence the smaller capacitors will be heavily stressed.

Capacitor switching can be done by various ways like:

Power Contactor

- Normal power contactors simply allow the inrush current to flow through it. Because of this, contactors and capacitors are heavily stressed. So the contactor selection should be such that it withstands the heavy inrush current. Hence, power contactors need to be heavily de-rated
- This inrush current also stresses the power capacitors and may result in their premature failure
- Power contactors should be used along with inrush current limiting resistors, for reducing the magnitude of inrush current. However, this increases the cost & size of the APFC panel along with extra power losses

Capacitor Duty Contactor

- Capacitor duty contactors can be used to limit the inrush current to less than $10*I_N$
- Capacitor duty contactors have pre-contacts/auxiliary contacts with current limiting resistors (of $4\,\Omega$). At the moment of switching, the pre-contacts (with resistors) close first. This reduces the inrush current to less than $10*I_N$. After a few milliseconds, main contacts are closed and the pre-contacts will open and go out of the circuit
- Capacitor duty contactors are employed where the frequency of switching is less i.e., the load fluctuation is not very fast. The capacitor requires atleast 60 seconds to discharge to a nominal value (50 V). So capacitor duty contactors cannot be used when load fluctuation is heavy

Thyristor Switching Module (TSM)

- TSM is a static switching device that is used specially for switching capacitors (dynamic power factor correction), wherever the load fluctuation is heavy (like welding, steel rolling, etc.)
- Rapid switching (5 ms to 20 ms) is possible with TSM along with Quick Discharge Resistor (QDR)
- There is no inrush current while using TSM (zero voltage switching). So frequent switching does not affect the life of capacitors and there is no need for extra current limiting resistors
- TSM has thermal cutoff, which switches off the module when temperature exceeds beyond a certain limit. It automatically switches on when optimum temperature is attained

MO C Capacitor Duty Contactors are specially designed for capacitor switching applications. As capacitor switching is associated with high inrush current, the contactors are provided with damping resistors which limit the value of inrush current to a safe value. The contactors are used in APFC panels for switching power capacitors depending upon the amount of reactive power compensation required.

Benefits of using Capacitor Duty Contactors

Since switching of capacitor banks involves high transient inrush currents, the size of the contactor required to switch these high currents becomes higher. Hence, current limiting inductors are used in series to attenuate this inrush current. This increases the system cost and panel space.

A typical case below illustrates the magnitude of transient inrush current for switching of a capacitor bank. For a 12.5 kVAr capacitor bank:

Rated current of 12.5 kVAr 415 V Capacitor = 18A
Peak Inrush current without Damping Resistors = 1200A

Capacitor Duty Contactors are designed to limit this high transient inrush current by introducing damping resistors with early make auxiliary contacts. The current limiting due to damping resistors protects the APFC system from harmful effects of the capacitor charging inrush current.

Peak Inrush current with Damping Resistors = 260A
It is observed that peak inrush current with damping resistors is one fifth of that without damping resistors.
As the contactor is now required to switch the rated capacitor current, the size of the contactor required is smaller. Thus the system cost and panel space are significantly lower when Capacitor Duty Contactors are used.

MO C Capacitor Duty Contactors

MO C Capacitor Duty Contactors are designed for switching 3 phase, single or multi-step capacitor bank. In conventional capacitor switching contactors, early make auxiliary contacts used for insertion of damping resistors used to remain in the circuit continuously. During current breaking these auxiliary contacts would also carry and break the currents due to higher arc resistance in the main pole during arcing. This current breaking by auxiliary contacts at higher transient recovery voltage causes unreliable product performance and premature product failures.

MO C range of capacitor switching contactors have patented mechanism which disconnects the early make auxiliary contacts after the main contacts are closed. This completely eliminates the possibility of auxiliary contacts carrying and breaking the currents during breaking operation. This enhances the product switching performance and improves the product life.

Features and Benefits of MO C Capacitor Duty Contactors

Feature	Customer Benefits
De-latching auxiliary contacts	Improved switching performance
	Reduced losses in auxiliary contacts
Dual contact gap for auxiliary contacts	Higher electrical life
Encapsulated resistor assembly	Enhanced product safety
	No flash over between phases
Separate termination of damping resistors	Ease if wiring
	Enhanced operational reliability
Wide and chatter-free operating band	Improved switching performance
	Higher electrical life
	Higher product reliability

Ordering Information
Contactors

Product Designation	kVAr Rating @ 415V 50Hz	In Built Aux contacts	Cat. No.*
MO C5	5	1 NO	CS96127
MO C5	5	1 NC	CS96128
MO C8.5	8.5	1 NO	CS96320
MO C8.5	8.5	1 NC	CS96337
MO C12.5	12.5	1 NO	CS96321
MO C12.5	12.5	1 NC	CS96338
MO C15	15	1 NO	CS90019
MO C15	15	1 NC	CS90020
MO C20	20	1 NO	CS90021
MO C20	20	1 NC	CS90022
MO C25	25	1 NO	CS96322
MO C25	25	1 NC	CS96339
MO C33.5	33.5	1 NO	CS96323
MO C33.5	33.5	1 NC	CS96340
MO C50	50	1 NO	CS96324
MO C50	50	1 NC	CS96341
MO C70	70	1 NO	CS96325
MO C70	70	1 NC	CS96342
MO C80	80	1 NO	CS96326
MO C80	80	1 NC	CS96343

* : Add four digit suffix as per coil voltage

Accessories & Spares
Add on Blocks

Mounting Position	Contacts	Cat. No.
First Left	1 NO + 1 NC	CS94580OOOO
First Right	1 NO + 1 NC	CS94581OOOO
Second Left	1 NO + 1 NC	CS94582OOOO
Second Right	1 NO + 1 NC	CS94583OOOO

Spare Coils

For Contactor	Cat. No.
MO C5 - C25	CS96317
MO C33.5 - 50	CS96318
MO C70 - 80	CS96319

* Add four digit suffix as per coil voltage

MO C Spreader Link Kit

For Contactor	Cat. No.
MO C5-25	CS94274OOOO

Note:1) Spreader Link Kit consists of six terminals
2) Use above Spreader Link when using MO C 25 16 sq. mm cable

Ordering Suffix for Coil Voltages

Std Coil Voltage	110	220	240	415
Ordering Suffix - 50 Hz	AOOO	KOOO	BOOO	DOOO
Ordering Suffix - 60 Hz	YOOO	VOOO	-	SOOO

Technical Specification

- Available for capacitor range from 5 - 80 kVAr
- Modular design saving precious panel space
- De-Latching auxiliary contacts
- Separate termination of damping resistors
- Encapsulated resistor assembly ensuring safety
- In-built surge supressor with the coil
- Lugless termination

Type Designation			MO C5	MO C8.5	MO C12.5	MO C15	MO C20	MO C25	MO C33.5	MO C50	MO C70	MO C80
Catalogue No.	Built in Aux Contacts	1 NO	CS96127	CS96320	CS96321	CS90019	CS90021	CS96322	CS96323	CS96324	CS96325	CS96326
		1 NC	CS96128	CS96337	CS96338	CS90020	CS90022	CS96339	CS96340	CS96341	CS96342	CS96343
Conformance to Standards			IS/IEC 60947-4-1, IEC 60947-4-1, EN 60947-4-1									
Rated Operational Current I (AC - 6b) 3 Phase Delta Connected Capacitor Bank at 440 V, 50 Hz	I_e	A	7	11	16	20	26	33	44	66	92	105
Short Circuit Protection			gG type fuses rated at 1.5 - 2 I_e									
kVAr Rating	230 V AC	kVAr	3.0	5.0	7.5	8.5	11	14.5	20	30	40	45
	440 V AC	kVAr	5.0	8.5	12.5	15	20	25	33.5	50	70	80
Max. Operational Voltage	U_e	V	690	690	690	690	690	690	690	690	690	690
Rated insulation Voltage	U_i	V	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Rated Impulse Withstand Voltage	U_{imp}	kV	8	8	8	8	8	8	8	8	8	8
Degree of Protection			IP20									
Main Terminal Capacity	Solid Conductor	mm^2	2 x 10	2 x 10	2 x 10	2 x 10	2 x 10	2 x 10	-	-	-	-
	Stranded Conductor	mm^2	2 x 10	2 x 10	2 x 10	2 x 10	2 x 10	2 x 10	2 x 35	2 x 35	2 x 70	2 x 70
	Finely Stranded Conductor	mm^2	2 x 6	2 x 6	2 x 6	2 x 6	2 x 6	2 x 6	2 x 25	2 x 25	2 x 50	2 x 50
Coil Operating Band	Pick-up	% U_c V	65 - 110	65 - 110	65 - 110	65 - 110	65 - 110	65 - 110	75 - 110	75 - 110	75 - 110	75 - 110
	Drop-off	% U_c V	35 - 65	35 - 65	35 - 65	35 - 65	35 - 65	35 - 65	35 - 65	35 - 65	35 - 65	35 - 65
Coil Consumption	Pick-up	VA	77	77	77	77	77	77	144	144	240	240
	Hold-on	VA	9	9	9	9	9	9	15	15	25	25
		W	3	3	3	3	3	3	6	6	9	9
Life (Operating Cycles)	Mechanical	Million	10	10	10	10	10	10	10	10	10	10
	Electrical	Million	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Max. Operating Frequency	Operations / Hr		240	240	240	240	240	240	240	240	240	240
Operating Sequence	Making		Early Make / Main									
	Breaking		Main Contacts Break									
Overall Dimensions	Height	H mm	87	87	87	87	87	87	123.5	123.5	135	135
	Width	W mm	45	45	45	45	45	45	55	55	70	70
	Depth	D mm	133.5	133.5	133.5	133.5	133.5	133.5	163.0	163.0	175.0	175.0
	Mounting Dimensions	mm	35 x 60 - 65 - 70	35 x 60 - 65 - 70	35 x 60 - 65 - 70	35 x 60 - 65 - 70	35 x 60 - 65 - 70	35 x 60 - 65 - 70	45 x 100 - 105	45 x 100 - 105	60 x 115 - 120	60 x 115 - 120

* Accessories and Spares same as that of MO contactor.
Note: Contact replacement is not permitted in MO C contactors

Technical Details

MO C
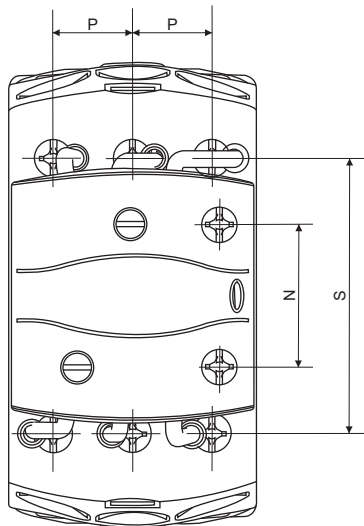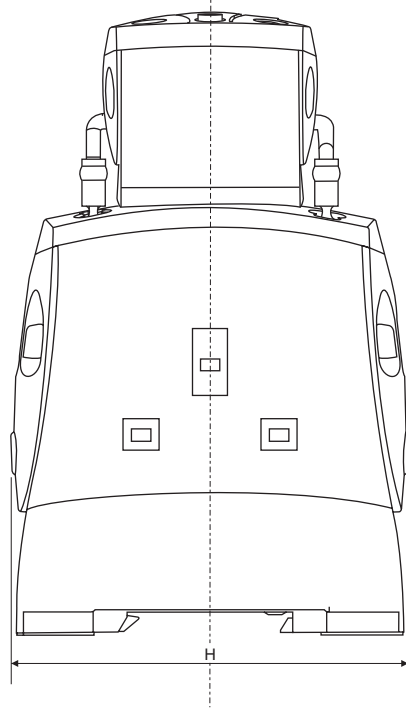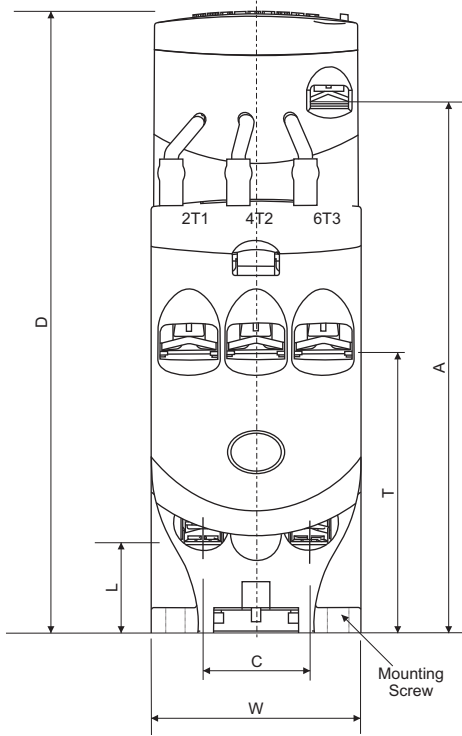
Label	MO C		
	5 - 25	**33.5 - 50**	**70 - 80**
W	45	55	70
D	133.5	163	175
H	87	123.5	135
N	26	26	26
T	60	68	68
C	22.8	27	35
L	19.6	29.5	30
S	50	82	93
P	14.4	18	23
A	113	142	154

All dimensions in mm.

Conventionally, power factor correction systems consist of power factor correction capacitors switched using capacitor duty contactors. The re-switching time is the sum of capacitor discharge time (within 60 seconds as per IS 13340) and response time of contactor. Such arrangement is suitable for applications where few switching operations take place per day.

Many applications increasingly require real-time reactive compensation. With this, the demand for dynamic power factor correction arises and faster switching of capacitors becomes inevitable.
This article discusses the need for thyristor switching module and the care to be taken when designing systems with thyristor switching modules.

Need for Dynamic Power Factor Correction

Faster response is needed when the demand for reactive power is rapidly fluctuating either due to rapidly changing load conditions or process requirements. For certain loads, like,

• Welding equipment
• Injection moulding equipment
• Industrial presses
• Loads such as, lifting cranes, elevators, lifts etc.

the demand for reactive power comes frequently and for short duration of time.

Large reactive power demand for very short durations has severe ill-effects, such as,

• Rapid fluctuations in voltage which may lead to system instability.
• High voltage transients may result in insulation breakdown or damage to other loads
• Malfunctioning of sensitive electrical and electronic equipment such as relays, PLCs
• Oversizing of electrical instillation is needed since kVA capacity needs to be provided for maximum power demand

Why Not Contactors?

Contactors are electro-mechanical devices which switch capacitors after a lag. Also, due to discharge time of capacitors, the re-switching time of contactors becomes longer than 60 seconds. This makes contactor a slow device.

In-rush current in capacitor switching are reduced to 10 times the rated current if capacitor duty contactors are used. However, a certain pulse element is inevitable as can be seen in figure 1.
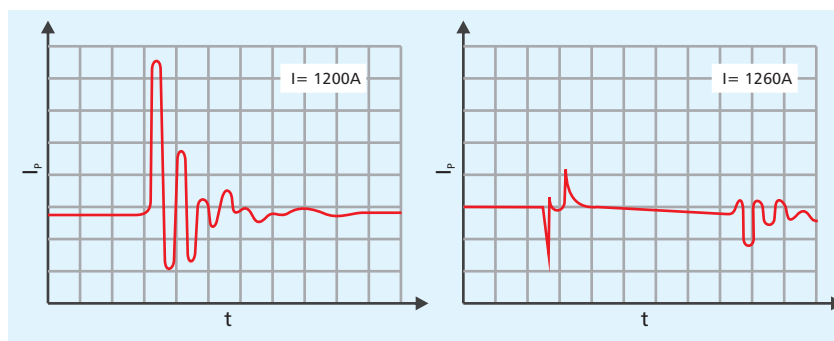
Figure : Transient during capacitor switching by a) Normal contactor b) Capacitor-duty contactor

Inrush current occurences cause high eletromechanical forces within the capacitor. The dielectric inside the capacitor is highly stressed due to this high current. This could lead to reduction in the life of capacitors.

In order to obviate the above shortfalls, the thyristor switching modules are used.

Principle of Operation of TSM

A thyristor switching module (TSM) is a fast, electronically controlled thyristor switch for switching capacitor loads within a few milliseconds as often and as long as required.

First of all, being a thyristor-based switch, the thyristor switches the capacitor without delay. A thyristor switching module works on the principle of zero-voltage switching, i.e., the capacitor is switched ON only when the voltage waveform is at its zero crossing. The current through a capacitor is given by:

$$I_c = C\ \frac{dV_c}{dt}$$

Where, I_c is capacitor current, C is capacitance and V_c is voltage across capacitor. This current is directly proportional to the rate of change of voltage across the capacitor. Thus, when capacitors are switched ON at zero crossing of supply voltage, the voltage applied to the capacitor is almost zero and grows steadily following the sine wave. Thus, the inrush current becomes equal to the rated current.
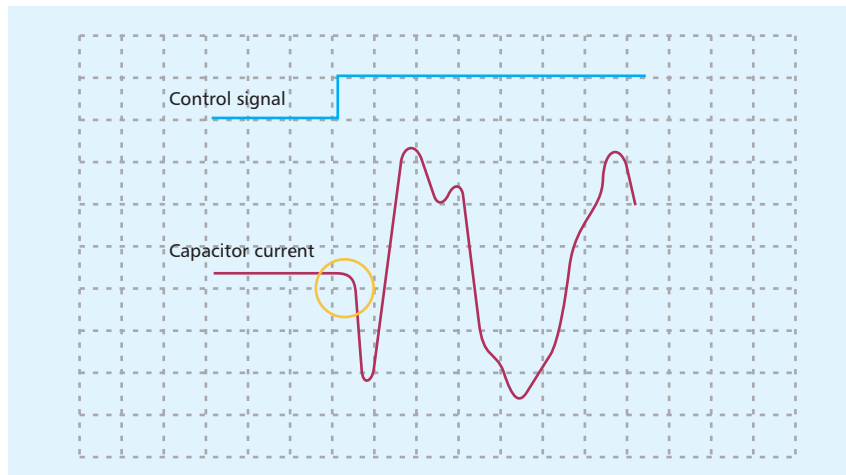
Figure : Zero in-rush current during capacitor switching by TSM

Importance of QDR

Another point to be noted here is that the capacitors used with TSM should be fitted with quick discharge resistors (QDR). If the capacitors are used with the usual discharge resistors, then, the capacitor may not get fully discharged at the time of re-switching. In such a situation, there will still be a significant voltage across the capacitor resulting in high inrush current. Quick discharge resistors ensure that the capacitor is completely discharged before its re-switching. The typical discharge time of normal resistors is to reach less than 50 V within 60 seconds (as per IS 13340/1). However, for QDR, the discharge time is reduced to as low as 5 ms making the capacitors suitable to be used with thyristor switching modules.

PIV Rating of TSM

The typical arrangement of thyristor switches in a thyristor switching module is given in figure 3. Two terminals of a delta connected-capacitor are connected to the line via TSM while the third is connected directly to the line (all three phases have high speed fuses for branch protection). This configuration obviates the need to use three switch-pairs while ensuring that the three-phase capacitor is connected only when both switch pairs are ON or the module is ON. Each switches pair is a combination of two thyristors connected in anti-parallel for operation with ac voltage.

Peak Inverse Voltage (PIV) rating of a thyristor switch is the maximum peak voltage that the thyristor can withstand in the reverse biased condition. It is the maximum voltage that it must block when it is in OFF condition. A module with thyristors of lower PIV, say 1600 V, is likely to fail in presence high voltage surges. Hence, higher values of PIV are desirable. Typically, in capacitor switching applications, the PIV ratings are up to 2200 V.

Figure 1 Arrangement of thyristor in a TSM

Advantages of TSM

- Faster switching of capacitors with response time from 5-40 ms can be achieved.
- No delay due to capacitor discharge
- No inrush current ensures that there are no resulting voltage fluctuations or transients. Thus, we get transient-free smooth switching and stable voltage and increased life of capacitors.
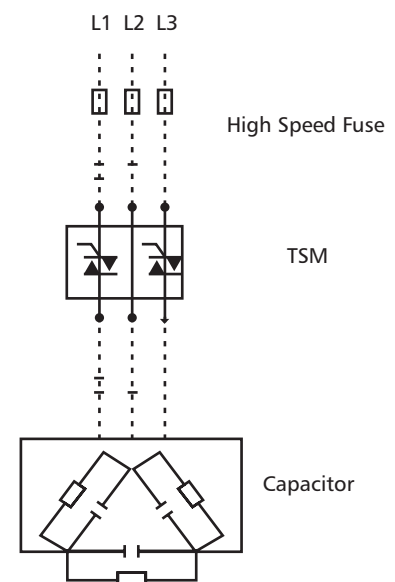- No arching owing to a static switch
- Thyristor switches allow any number of switching operations as they are not subjected to any mechanical wear. Thus, a longer service life as compared to contactors.
- With dynamic compensation, reactive power is more efficiently compensated resulting in further lowering of energy costs.
- With reduced peak of inrush current, cables and equipment used can be of smaller short circuit rating reducing capital expenditure.

High Speed Fuse for Branch Protection

For short circuit protection of a thyristor switching module, a faster protection device is needed so that it will act before the thyristor switch in case of a short circuit. Normally, an HRC fuse has a time characteristics based on the I^2t characteristics of cables as per IEC 60269-2. In case of a short circuit, the thyristor will blow before the fuse. However, a semiconductor back-up (or a high speed) fuse has a time characteristics based on I^2t characteristics of a thyristor. Hence, semiconductor fuse or high speed fuse can protect the thyristor module.

Forced Colling for TSM

Being electronic switches, the heat generated due to losses needs to be dissipated quickly. The thyristor switching modules are generally designed with fins for better heat dissipation. They should be mounted in a position so that maximum air flow is possible. Additionally, it is always recommended to use an adequately-sized fan in the compartment where TSMs are mounted in an APFC panel.

Some thyristor switching modules come with in-built fans for cooling. Practically, it is difficult to spot a fan failure in such a case and an undetected fan failure may lead to failure of TSM. The TSM module becomes unnecessarily bulky in such cases. Hence, it is best to use fan-less modules with an adequately-sized fan on panel ceiling.

How to Connect
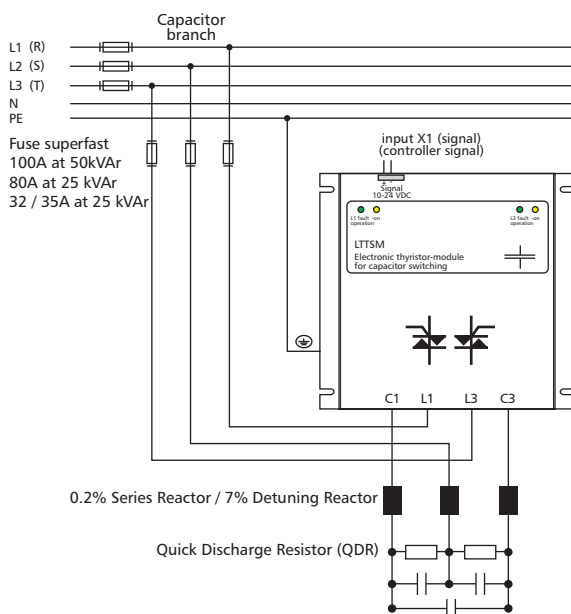
Figure 4 Connection Diagram of TSM

A TSM is connected to the line via a semiconductor fuse and its output is given to the three-phase capacitor or a detuned filter (in case harmonics are present). Triggering of a TSM can be done by means of dynamic power factor controllers. Triggering can be done by a controller which has a transistor output. Typically, a TSM has a 24 V or/and a 12 V input and the respective currents required for triggering are approximately 15 mA and 20 mA respectively. Sometimes, more than one TSM is required to be connected to the same controller output for making a larger step, say, 100 kVAr. In such a case, more than one TSM can be connected to one output of the controller. The maximum number of TSMs that can be connected to a controller is restricted by the dc supply available and the maximum current limit of a stage output of the controller output.

Another point to be noted here is that in case of TSM, there is no electrical isolation. Due to the switching principle of the thyristor-modules the PFC-capacitors are permanently loaded at the peak value of the grid voltage (DC current) even when they are disconnected. Even when the thyristor switches are off, no electrical isolation is given. Hence, even after switching off the incomer of the APFC system, parts should only be touched after the standard discharge time of the capacitors.

Combination of Contactor-based & Thyristor-based Panels

Thyristor switching modules being expensive is often a concern for industry. An economical solution without compromising the performance of power factor correction panel can still be devised in many applications. Typically, an industry consists of a variety of loads – some fixed loads that are always running, some varying motor loads that run for some part of the day and some highly fluctuating loads.

The following solution is suggested:

APFC CONTROLLER

Fixed Compensation
for fixed load

Contactor-based switching
for variable load

Thyristor-based switching
for fluctuating load
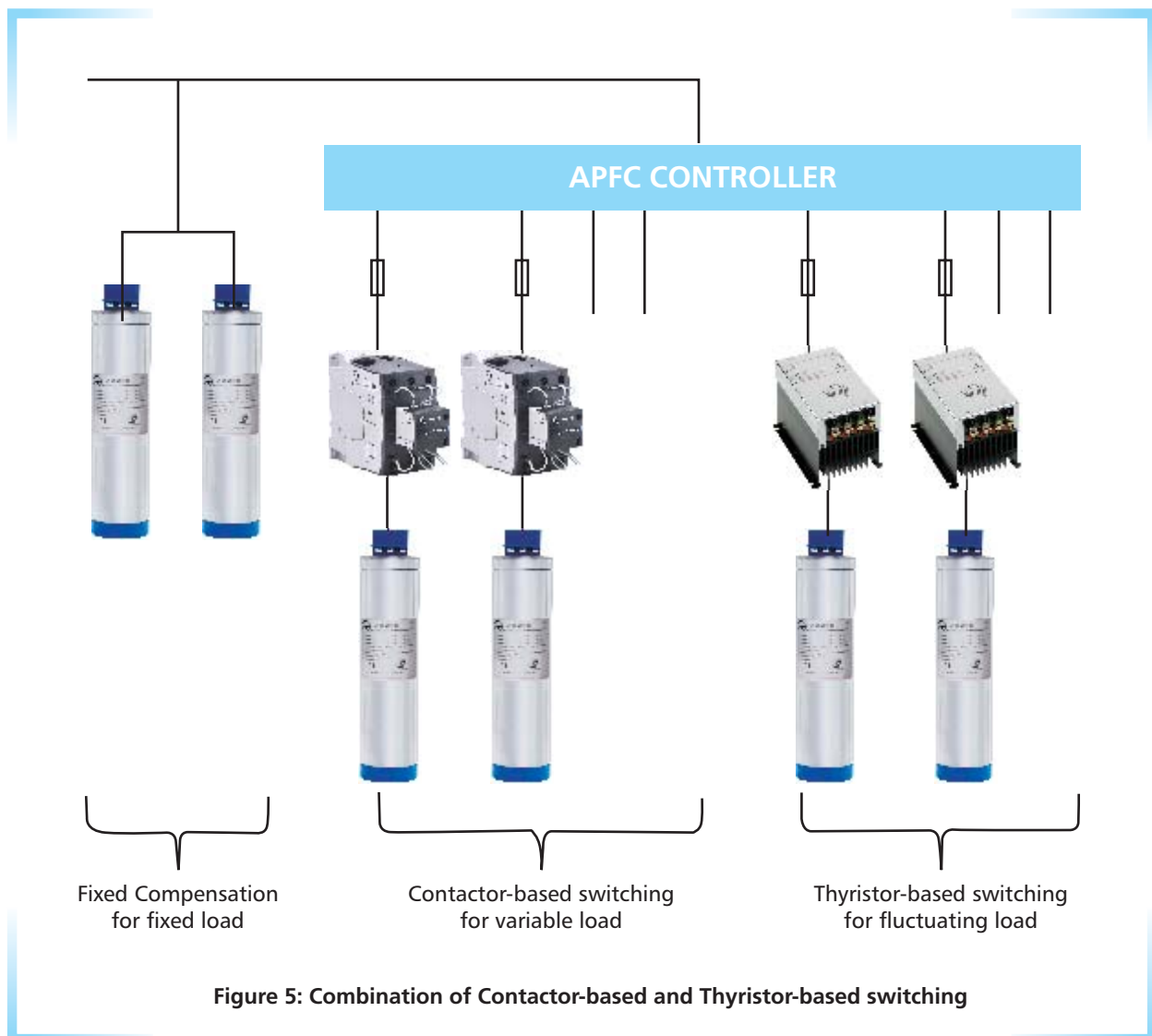
Figure 5: Combination of Contactor-based and Thyristor-based switching

The most economical solution can be to provide some fixed capacitors for the loads that are ON throughout the day, a contactor-based switching for capacitors providing compensation to varying motor loads and a thyristor-based switching for capacitors providing compensation to highly fluctuating loads.

In some modern industries, due to special processes with rapidly fluctuating loads, the demand for reactive power also fluctuates rapidly. Usage of mechanical switch (contactors) has the following negative impacts:

- Average unity power factor cannot be maintained due to delay in capacitor switching
- Reduction in the life of capacitors, contactors and other equipments
- Power quality issues due to current and voltage transients

The solution is dynamic power factor correction system.

With the thyristor module we provide the main component - "The Electronic Switch"- for dynamic power factor correction. The LT-TSM series offers fast electronically controlled, self-observing thyristor switches for capacitive loads up to 50 kVAr, that are capable to switch PFC capacitors within a few milliseconds nearly without a limitation to the number of switchings during the capacitor lifetime. These switching modules are easy to install, have a fast reaction time of 5 msec and come with built-in indications of operations, faults and activation. These thyristor modules are very compact and operate at lower power losses.

Features

- High peak inverse voltage (2.2 kV) ensures long operational life
- Automatic thermal cut-off
- Monitoring of voltage, phase sequence, faults and display of status via LED
- Faster response time - 5 ms
- No system perturbation caused by switching operations (no transients)
- No auxiliary supply needed
- Maintenance free
- Long operational life
- High switching speed
- No noise during switching
- Compact design ready for connection and easy installation

Application

Industries and applications with high load fluctuations, where the demand for reactive power is also very dynamic:

- Welding
- Elevators and cranes
- Presses
- Wind turbines

Technical Details

	LT TSM 10	LT TSM 25	LT TSM 50
Rated Voltage (V)	440 V		
Frequency (Hz)	50 / 60		
Rating (kVAr)	10	25	50
Power Losses (W)	35	75	150
LED Display Per Phase	2	2	2
Ambient Temperature (^{0}C)	-10 to 55		
Signal Voltage Required	10-24 Vdc (20 mA)		
Peak Inverse Voltage (PIV)	2.2 kV		
Reaction Time	5 ms		
Re-switching Time	60 ms		
Indication / Display	**2 LEDs Per Phase** **LED (Green/Red) Fault / Operation** Green : Operating voltage activated, thyristor module standby Flashing Red - Fast : Temperature failure Flashing Red - Slow : Net voltage L1-L3 too low (under-voltage < 300 V) Permanent Red : Phase L2 missing or under-voltage or phase L1 or L3 missing or capacitor without capacitance or not existent **LED (Yellow)** Yellow : "Module ON"		
Monitoring	Permanent monitoring of net voltage, temperature and operation status (Note: Before re-switching after temperature fault, heat sink temperature must be below 50°C)		
Termination	Connection from bottom; Cable lug: 25 sq. mm. D: 8 mm		
Protection	Semiconductor fuse (High speed fuse) is mandatory for short circuit protection.		
	10 kVAr : 32 A	25 kVAr : 80 A	50 kVAr : 160 A
Capacitor Discharge Resistor	Quick discharge resistors (Default capacitor discharge resistors shall be interchanged with QDR)		
Mounting Position	Vertical, minimum 100 mm space clearance around the module		

Selection of TSM and Semiconductor Fuse

Capacitor Step (kVAr)	Rated Current (A)	TSM Rating (kVAr)	Semiconductor Fuse Rating (A)
5	6.6	10	16
10	13.1	10	32
12.5	16.4	25	40
15	19.7	25	47
20	26.2	25	63
25	32.8	25	80
30	39.4	50	94
35	45.9	50	110
40	52.5	50	126
50	65.6	50	160
75	98.4	3 nos. of 25	9 nos. of 80 A
100	131.2	2 nos. of 50	6 nos. of 160 A

Network of Thyristor Switching Modules
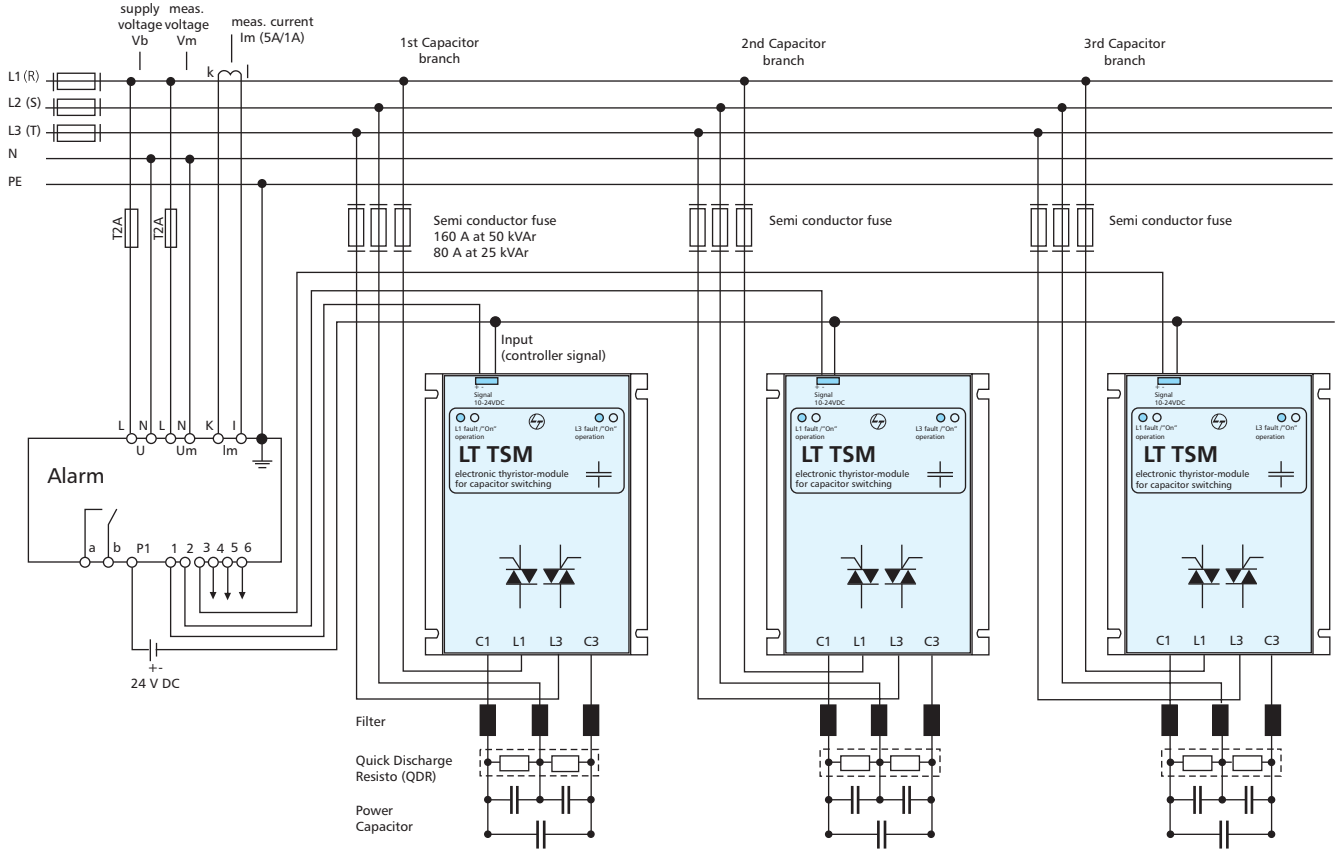
Thyristor Switching Modules - Dimensions

Front View

Side View

Top View
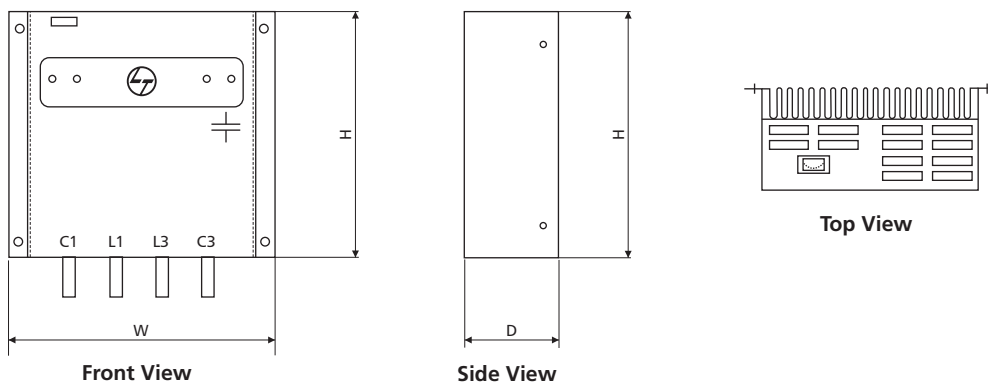
Rating (kVAr)	Max. RMS Current (A)	Dimensions in (mm)			Cat. Nos.
		W	D	H	
10	20	153	75	153	LTTSM10B2
25	50	156	171	200	LTTSM25B2
50	100	156	171	200	LTTSM50B2

Trouble-free Power Factor Correction

The *etaCON* L series digital Power Factor Controllers are microprocessor-based controllers which automatically correct power factor, with the help of contactors by switching capacitor banks. The series comes in 3, 5, 7, 8 and 12-step versions.

The *etaCON* controller offers power factor correction without any need for manual intervention. It decides the optimum configuration of capacitor banks to achieve desired power factor by taking into consideration the kVAr of each step, the number of operations, total usage time, re-connection time of each step, etc. The intelligent adjustment interface helps in achieving balanced capacitor usage ensuring longer life for switchgear and capacitors. Besides, manual switching of capacitors is also possible directly through the controller.

Automatic Programming

With automatic programming at start-up, there is no need for manual feeding of parameter values. In this mode, the controller automatically senses the kVAr rating of each step and configures the controller, ready to be placed in service.

By pressing just two buttons simultaneously, the automatic controller set-up can be activated.

Feature	Description
3 Digit 7 Segment LED Display	Display of V, A, Δ kVAr, Average Weekly PF, Capacitor overload & Panel temperature
4 Key Membrane Keypad	Selecting & configuring parameters
Internal Temperature Sensor	Temperature sensing for control of fan and alarm
Programmable Relay O/Ps	Programmable for normal contact / alarm / fan control

Salient Features

COMPACT RELAY

Compact relay of 96 x 96 x 71 mm for 3, 5 and 7 stage for space economy.

AUTOMATIC RECOGNITION OF CURRENT FLOW DIRECTION

The *etaCON* detects the CT reversal and automatically corrects the same. This saves the effort put into the detection/correction of CT polarity at site.

DISPLAY OF AVERAGE WEEKLY POWER FACTOR

Average value of power factor of last seven days is displayed and updated every day for assessment of APFC panel performance.

INTELLIGENT SWITCHING SENSITIVITY

Hunting of capacitors is avoided by faster switching of step in case of higher kVAr demand and more delay in case of smaller demand

KEYPAD LOCK

The keypad lock function eliminates unauthorized modification of operating parameters.

PROVISION OF ALARMS

Alarms for Under / Over compensation, Low/ High current, Low / High voltage, Capacitor overload due to harmonic voltage, Over temperature, No-voltage release.

PROTECTION OF CAPACITOR

Capacitors are protected from overload due to harmonics, over-voltage and over-temperature. If threshold value is exceeded, alarm is triggered and steps are disconnected either immediately or after some delay depending upon the different settings

PROTECTION OF PANEL FROM OVER-HEATING

An inbuilt temperature sensor monitors temperature variation of the panel. Alarm is triggered in case of over-heating. Fan start & stop temperature can be set to operate cooling fans.

Technical Specifications

Auxillary Supply	etaCON L3	etaCON L5	etaCON L7	etaCON L8	etaCON L12
Rated Voltage Ue	415 - 440 VAC				
Operating Limit	-15% to +10% Ue				
Rated Frequency	50 or 60 Hz± 1%				
Maximum Consumption	6.2 VA			5 VA	
Maximum Dissipation	2.7 W			3 W	
Maximum Power Dissipation by Output Contacts	0.5 W with 5 A				
Immunity Time for Micro Breakings	$\leq$ 30 ms				
No-Voltage Release	$\geq$ 8 ms				
Current Input					
Rated Current Ie	5 A				
Operating Limit	0.125 - 6 A				
Constant Overload	+ 20%				
Type of Measurement	True RMS				
Short-time withstand Current	10 Ie for 1 sec				
Dynamic Limit	20 Ie for 10 ms				
Burden on CT	0.65 VA				
Control Range					
Power Factor Setting	0.8 ind - 0.8 cap				
Reconnection Time of the Same Step	5 - 240 secs				
Sensitivity	5 - 600 s/step				
Relay Outputs	etaCON L3	etaCON L5	etaCON L7	etaCON L8	etaCON L12
Number of Outputs*	3	5	7	8	12
Type of Output	3NO	4 +1 NO	6 +1 NO	7NO +1C/O	11NO +1C/O
Maximum Current at Contact Common	12 A				
Rated Current Ith	5 A				
Rated Capacity of NO Contact	1.5 A 250 VAC (AC15) - 1.5 A 400 VAC (AC15)				
Rated Capacity of NC Contact	1.5 A 250 VAC (AC15) - 0.75 A 400 VAC (AC15)				
Electric Life at 0.33A, 250 VAC and AC11 load conditions	5000000 ops				
Electric Life at 2A, 250 VAC and AC11 load conditions	400000 ops				
Electric Life at 2A, 400 VAC and AC11 load conditions	200000 ops				

Ambient Conditions	
Operating Temperature	-20 to +60°C
Storage Temperature	-30 to +80°C
Relative Humidity	<90%
Overvoltage Category	3
Maximum Pollution Degree	3**

Connections	
Type of Terminal	Removable / Plug-in
Conductor Cross Section (min-max)	0.2 - 2.5 sq mm (24 - 12 AWG)
Tightening Torque	0,5 Nm (4.5 l bin)
UL Rating - Conductor Cross Section (min -max)	18-12 AWG

Housing					
Mounting	Flush mount				
Material	Thermoplast NORYL SE1 GN F2			Thermoplast LEXAN 3412R	
Degree of Protection	IP54			IP41	
Weight	420 g	440 g	460 g	740 g	770 g

Compliance

IEC/EN 61010-1, IEC/EN 61000-6-2, ENV 50204, CISPR 11/EN55011, IEC/EN 61000-3-3, IEC/EN 60068-2-61, IEC/EN 60068-2-27, IEC/EN 60068-2-6, UL 508, CSA C22.2n°14

Certifications

Use 60°C/75°C CU conductor and wire size range 18-12 AWG, stranded or solid

Other Features	
Measurement	Instantaneous PF, V, I, & ΔkVAr, Capacitor overload Panel temperature, Average weekly PF
Metering / Logging	Average weekly PF, Maximum values of voltage, Current, Overload & temperature
Alarms	Under / Over compensation, Low/ High current, Low / High voltage, Capacitor overload due to harmonic voltage, Over temperature, No-voltage release

* 1 output contact is Galvanically isolated
** Pollution degree 2 when outputs used with 400 VAC load

Wiring Diagrams

etaCON L3 / L5 / L7
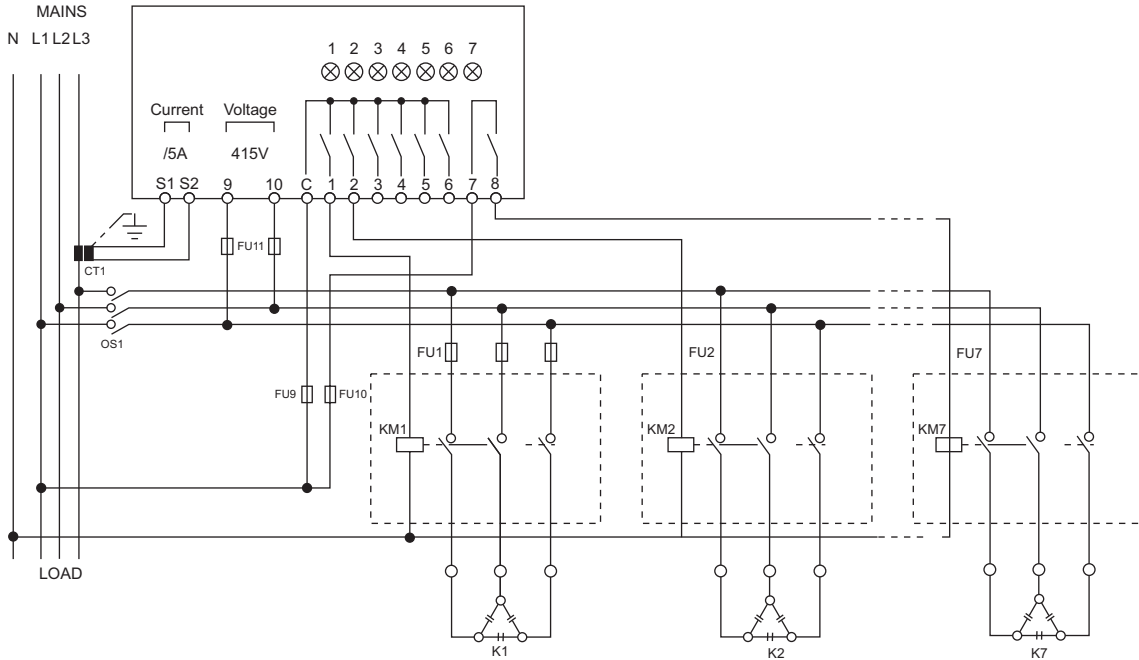
etaCON L8 / L12
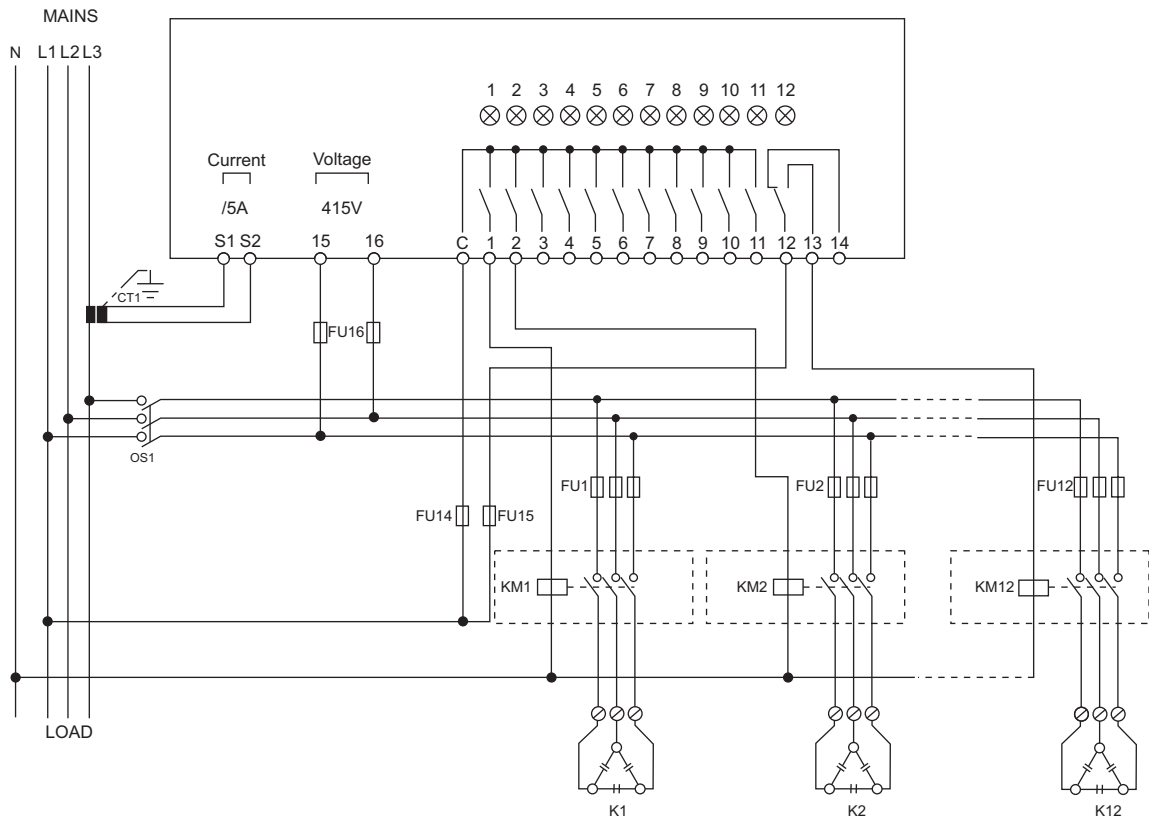
Overall Dimensions

etaCON L3 / *etaCON* L5 / *etaCON* L7
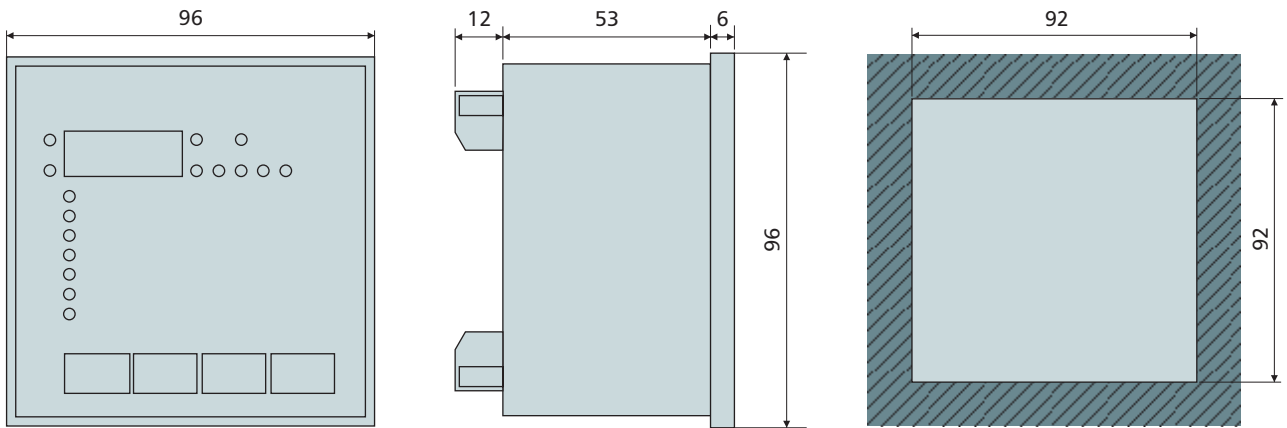
etaCON L8 / *etaCON* L12
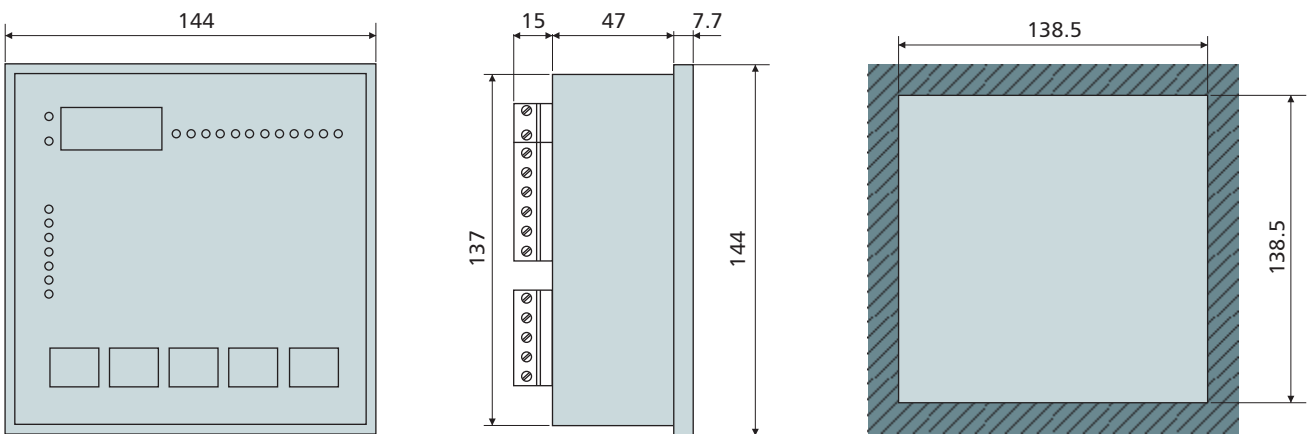
Dimensions in mm

Product		Steps	CT / Voltage Input	Dimensions (mm)			Panel Dimensions (mm)		Cat. Nos.
				L	H	D	L	H	
etaCON L3	3 stage APFC relay	3	5 A / 415 V	96	96	71	92	92	ERPML03D500
etaCON L5	5 stage APFC relay	4+1*	5 A / 415 V	96	96	71	92	92	ERPML05D500
etaCON L7	7 stage APFC relay	6+1*	5 A / 415 V	96	96	71	92	92	ERPML07D500
etaCON L8	8 stage APFC relay	7+1*	5 A / 415 V	144	144	69.7	138.5	138.5	ERPML08D500
etaCON L12	12 stage APFC relay	11+1*	5 A / 415 V	144	144	69.7	138.5	138.5	ERPML12D500

* Last contact can be programmed for capacitor switching / alarm function / fan control

Power Factor Correction Capacitors have been used for many years as the most cost effective solution for PF improvement. Modern electrical networks are continuously evolving into more complex installations due to the increasing usage of non-linear loads, sophisticated control & automation, UPS systems, energy efficiency improvement devices etc.

This evolution is also accompanied by increased dependency on captive power generation as well as growing concerns about incoming supply power quality.

In this background, it is necessary to evolve the Power Factor Correction solution also to a higher level so as to ensure sustainable achievement of high PF & acceptable harmonic distortion levels.
The selection of the correct type of PFC capacitors & filter reactors thus needs better understanding of the various issues involved.

This publication outlines a "5 Step" technology based approach, simplified for easier understanding to enable the correct selection of PFC Capacitors & Filter Reactors.

STEP 1
Calculation
of kVAr Required

STEP 2
Selection of
Capacitor Duty

**SELECTION
OF CAPACITORS**

STEP 5
Achieving Dynamic
and Transient
Free Unity PF

STEP 3
Avoiding the Risk of
Harmonic Application
and Resonance

STEP 4
Methods of Power
Factor
Correction
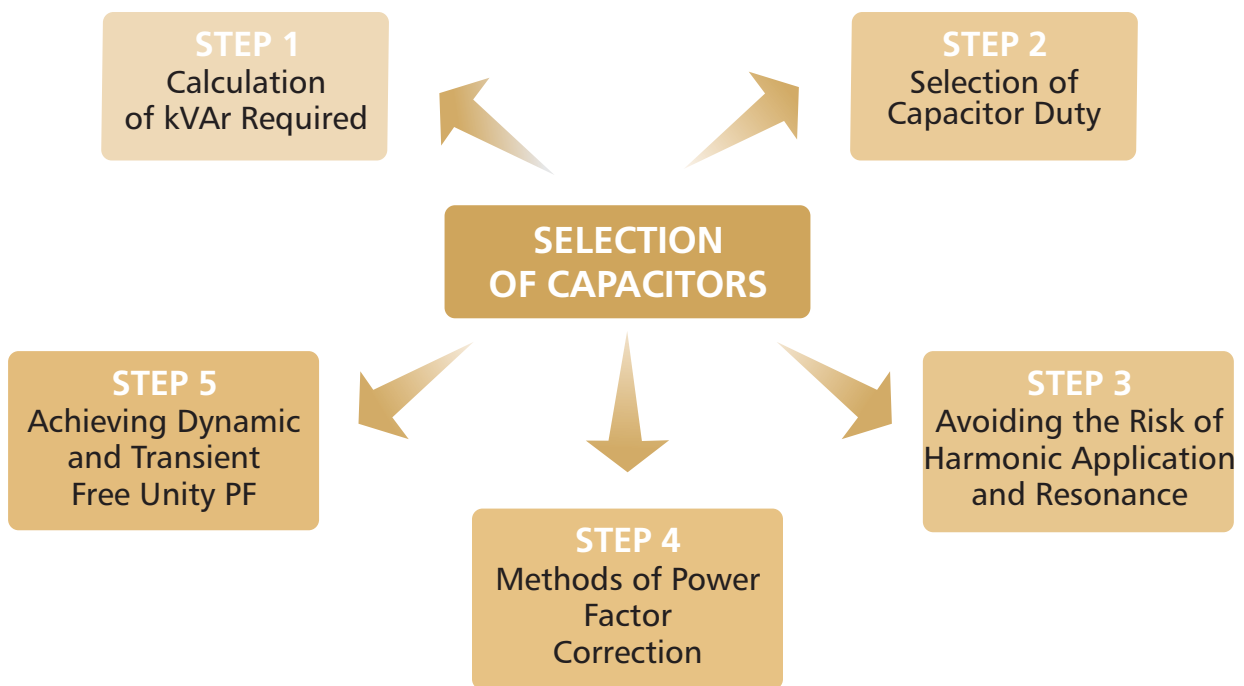
STEP 1: Calculation of kVAr Required for Industries & Distribution Networks

In electrical installations, the operating load kW and its average power factor (PF) can be ascertained from the electricity bill. Alternatively, it can also be easily evaluated by the formula:

Average PF = kW/kVA
Operating load kW = kVA Demand x Average PF

The average PF is considered as the initial PF and the final PF can be suitably assumed as target PF. In such cases, required capacitor kVAr can be calculated as explained in the example below:

Example: To calculate the required kVAr compensation for a 500 kW installation to improve the PF from 0.75 to 0.96

kVAr = kW x multiplying factor from table = 500 x 0.590 = 295 kVAr

Note: Table is based on the following formula:

kVAr required = kW (tanØ₁ - tanØ₂)

where
$\emptyset_1 = \cos^{-1}(PF_1)$ and $\emptyset_2 = \cos^{-1}(PF_2)$.

Initial PF \ Target PF	0.9	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99
0.4	1.807	1.836	1.865	1.896	1.928	1.963	2.000	2.041	2.088	2.149
0.42	1.676	1.705	1.735	1.766	1.798	1.832	1.869	1.910	1.958	2.018
0.44	1.557	1.585	1.615	1.646	1.678	1.712	1.749	1.790	1.838	1.898
0.46	1.446	1.475	1.504	1.535	1.567	1.602	1.639	1.680	1.727	1.788
0.48	1.343	1.372	1.402	1.432	1.465	1.499	1.536	1.577	1.625	1.685
0.5	1.248	1.276	1.306	1.337	1.369	1.403	1.440	1.481	1.529	1.590
0.52	1.158	1.187	1.217	1.247	1.280	1.314	1.351	1.392	1.440	1.500
0.54	1.074	1.103	1.133	1.163	1.196	1.230	1.267	1.308	1.356	1.416
0.56	0.995	1.024	1.053	1.084	1.116	1.151	1.188	1.229	1.276	1.337
0.58	0.920	0.949	0.979	1.009	1.042	1.076	1.113	1.154	1.201	1.262
0.6	0.849	0.878	0.907	0.938	0.970	1.005	1.042	1.083	1.130	1.191
0.62	0.781	0.810	0.839	0.870	0.903	0.937	0.974	1.015	1.062	1.123
0.64	0.716	0.745	0.775	0.805	0.838	0.872	0.909	0.950	0.998	1.058
0.66	0.654	0.683	0.712	0.743	0.775	0.810	0.847	0.888	0.935	0.996
0.68	0.594	0.623	0.652	0.683	0.715	0.750	0.787	0.828	0.875	0.936
0.7	0.536	0.565	0.594	0.625	0.657	0.692	0.729	0.770	0.817	0.878
0.72	0.480	0.508	0.538	0.569	0.061	0.635	0.672	0.713	0.761	0.821
0.74	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.706	0.766
0.75	0.38	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739
0.76	0.371	0.400	0.429	0.460	0.492	0.526	0.563	0.605	0.652	0.713
0.78	0.318	0.347	0.376	0.407	0.439	0.474	0.511	0.552	0.699	0.660
0.8	0.266	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.608
0.82	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.556
0.84	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503
0.85	0.135	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477
0.86	0.109	0.138	0.167	0.198	0.230	0.265	0.302	0.343	0.390	0.451
0.87	0.082	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424
0.88	0.055	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397
0.89	0.028	0.057	0.086	0.117	0.149	0.184	0.221	0.262	0.309	0.370
0.9		0.029	0.058	0.089	0.121	0.156	0.193	0.234	0.281	0.342
0.91			0.030	0.060	0.093	0.127	0.164	0.205	0.253	0.313
0.92				0.031	0.063	0.097	0.134	0.175	0.223	0.284
0.93					0.032	0.067	0.104	0.145	0.192	0.253
0.94						0.034	0.071	0.112	0.160	0.220
0.95							0.037	0.078	0.126	0.186

Step 2: Selection of Capacitor Duty

To select the type of capacitor to be used.
Power Factor Correction Capacitors can be classified as follows:
- Standard Duty
- Heavy Duty
- LTXL: Ultra Heavy Duty

The criteria for this classification is based on the following:
- Operating life
- Permissible over voltage & over current coupled with the time duration
- Number of switching operations per year
- Peak inrush current withstand capability
- Operating ambient temperature

Duty	Over Current	Permissible Over Voltage @ Rated Voltage 440V	Peak Inrush Currents	Ambient Temperature	Maximum Switching Operations / Year
Standard Duty	1.5 x In	1.1 Un (12h/24h)	200 x In	-25°C to 55°C	5000
Heavy Duty	1.8 x In	1.1 Un (12h/24h)	300 x In	-25°C to 55°C	8000
LTXL: Ultra Heavy Duty	3 x In	1.1 Un (12h/24h)	500 x In	-25°C to 70°C	20000

It is strongly recommended that the above table be followed as a guideline for selecting the appropriate capacitor for a given application. While choosing the type of duty it is also very important to identify the % age non-linear load in the system. The method of calculating the % age non-linear load is shown below:

Calculation of Non - linear Load:

Example:
Installed transformer rating = 1000 kVA

Non - linear loads = 100 kVA
% non - linear loads = (non - linear loads / transformer rating) x 100
= (100 / 1000) x 100
= 10%

Examples of non - linear load
UPS, Arc / induction furnace, Rectifiers, AC / DC Drives, Computer, CFL lamps, CNC machines, etc.

% Age Non - linear Load	Type of Duty
$\leq$10%	Standard Duty
Upto 15%	Heavy Duty
Between 15 and 25%	Ultra Heavy Duty
Between 25% and 30%	Use Capacitor + Reactor (detuned filters)
Above 30%	Hybrid filters (Active filter + detuned filters)*

*For solutions contact L&T

In addition to the above, a simplified way of using capacitor duty based on type of industry is given in the following table**:

Standard Duty	Heavy Duty	Ultra heavy Duty
Steady Uniform Inductive Loads Like	Variable Inductive Loads, THD < 5%	Variable and Fluctuating Inductive Loads, THD < 8%
Agricultural pump sets	Commercial buildings with CFL lamps, SMPS, UPS, etc	Steel rolling mills
Commercial establishments	Garment industries	Cement Industries
Small scale Industries etc.,	Fabrications shops	Textiles
	Welding shops	Heavy chemical industries
	Machine & Tool shops	Pharmaceutical industries
	Steel wire drawings	Sugar plants
	Bakeries	Automobile plants
	Flour mills	Paper industries
	Coffee curing works	Food processing plants
	Oil mills	Granites & Stone polishing units
	Steel melting	IT industries
	Glass industries	Wind mills
		Heavy welding equipments
		Power frequency induction furnaces

** The above table is for illustration; actual selection of capacitors & reactors shall be carried out based on THD or % non-linear load.

Step 3: Avoiding the Risk of Harmonic Application and Resonance

To make a choice between the use of Capacitors or Capacitors + Filter reactors.
In a system with inductive (X_L) and capacitive (X_C) impedances, resonance can happen at one particular frequency (resonant frequency, f_R).

$$\text{Resonant frequency,} \quad f_R = \frac{1}{(2\pi\sqrt{LC})}$$

At this point X_L becomes equal to X_C and the net impedance becomes very low. Hence, at resonance point, the magnitude of the current (with frequency f_R) is very high and only inherent resistance in the network would limit the current. Typically, the resonance may create major problem in harmonics rich industry. The resonant frequency may match with any of the harmonic frequency and create very high harmonic amplification, which can create huge damage to the electrical equipment.
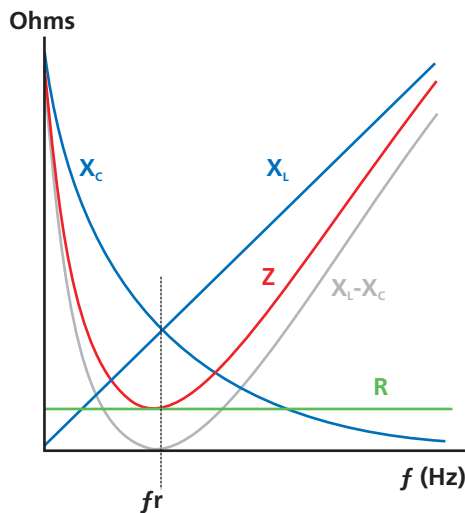
Addition of detuned reactors (in series to capacitors) forcefully shifts the resonant frequency to a safer level.

For example, combination of capacitor and 7% detuned filter reactor has the resonant frequency of 189 Hz, which will avoid resonance with 5th harmonic and above.

Step 4: Methods of Power Factor Correction

To estimate whether fixed compensation or automatic compensation is to be used.

In order to achieve high power factor i.e., close to unity PF, the following guideline may be adopted to make a decision. If the total kVAr required by the installation is less than 15% of the rating of the incoming supply transformers, then the use of fixed capacitors may be adopted at various points in the installation.

If the kVAr required by the installation is more than 15% of the rating of the incoming supply transformers, then automatic power factor correction solution needs to be adopted.

APFC panels with suitable kVAr outputs may be distributed and connected across various points within the installation.

Note: De-tuned filter APFC panels must be selected if non-linear loads exceed as per previous table.

Methods of Power Factor Compensation

	Individual Compensation	Group Compensation	Central Compensation
Control	Manual / Semi-automatic	Manual / Semi-automatic	Automatic
Elimination of penalties due to low PF	Yes	Yes	Yes
Achievement of Unity PF	No	No	Yes
Optimization of the kVA demand of the installation to the installed load in kW	Yes	Yes	Yes
Reduction of transformer loading	Yes	Yes	Yes
Reduction of transformer losses	Yes	Yes	Yes
Reduction of circuit breaker rating	Yes	Yes	Yes
Reduction of switchgear ratings and cable sizes down the line	Yes	Partial reduction	No
Reduction in I^2R losses	Yes	Partial reduction	No
Chance of leading PF	No	Yes	No
Advantages	Simple and inexpensive for few number of motors	Relatively better management of loads	Best suited for industries with large and variable loads
Disadvantages	Managing becomes difficult if the number of motors are more	Difficult to manage, if there is load variation in the group	Relatively expensive
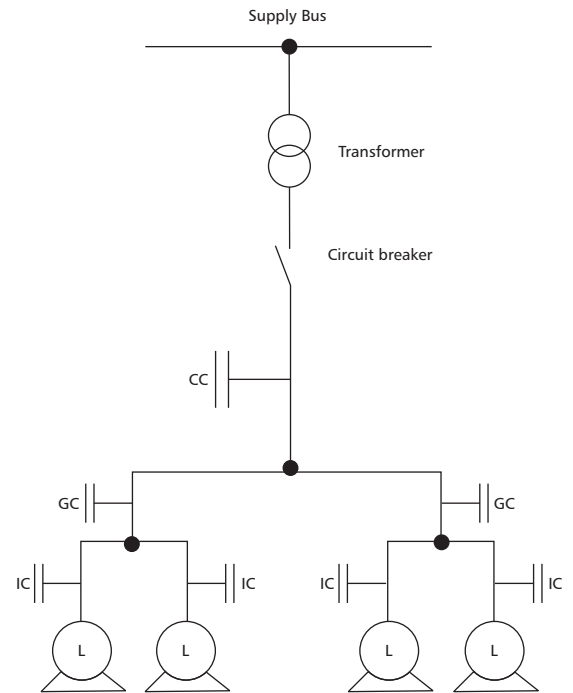
L : Inductive load
IC : Individual Compensation
GC : Group Compensation
CC : Central Compensation

Step 5: Achieving Dynamic and Transient-Free Unity PF

To decide whether transient free PF correction is required.

Conventional switching techniques of capacitors involving electro-mechanical contactors may give rise to transient phenomena. This transient phenomena can interact with impedances present in the installation to create "Surges". This occurrence of surges can cause serious damage to sensitive electronics and automation resulting in either their malfunction or permanent damage. The transient phenomenon is a sudden rise in voltage or current at the point of switching.

In this background, it is important to ensure that all the capacitors installed are switched in a transient free manner so as to ensure reliable performance of the installation.

In such a situation, it is necessary to specify the use of Thyristor switches for transient free switching of Capacitors.

Note: Thyristor switching can also be used for dynamic compensation which is needed if the fluctuation of loads is very high; such as lifts, welding load is very high; fast presses etc.

The various methods of power factor correction are direct compensation, group compensation and centralized compensation. Depending upon the size and the rate of change of loads in an industry, any one or combination of the above methods can be employed. Specifically, in case of agricultural pump-sets and some small scale industries with a few motor loads, the power factor correction can be done by connecting shunt capacitors directly to the motors. This method of compensation is called direct compensation. This is simple and ideal method for reactive power compensation, as this results in rating optimization of all the upstream switchgear and cables, which reduces overall system losses.

Direct motor compensation can be done by two methods:

Method – 1:

As shown in the figure, the capacitor is connected directly to the motor terminals, after the starter. The capacitors would start supplying reactive power, as soon as the motor is switched ON. This method of compensation can be used for motors with Direct on-line starters. Usually the kVAr rating for a particular motor is given by the respective motor manufacturers, as the kVAr ratings are motor specific.
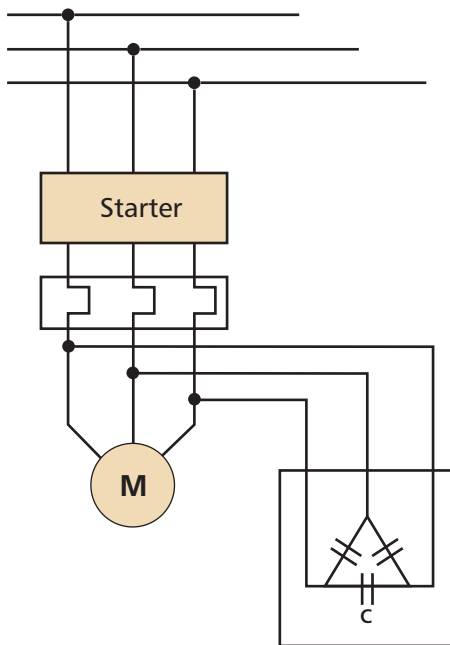
Motor (hp)	3000 rpm	1500 rpm	1000 rpm	750 rpm	500 rpm
2.5	1	1	1.5	2	2.5
5	2	2	2.5	3.5	4
7.5	2.5	3	3.5	4.5	5.5
10	3	4	4.5	5.5	6.5
15	4	5	6	7.5	9
20	5	6	7	9	12
25	6	7	9	10.5	14.5
30	7	8	10	12	17
40	9	10	13	15	21
50	11	12.5	16	18	25
60	13	14.5	18	20	28
70	15	16.5	20	22	31
80	17	19	22	24	34
90	19	21	24	26	37
100	21	23	26	28	40
110	23	25	28	30	43
120	25	27	30	32	46
130	27	29	32	34	49
140	29	31	34	36	52
145	30	32	35	37	54
150	31	33	36	38	55
155	32	34	37	39	56
160	33	35	38	40	57
165	34	36	39	41	59
170	35	37	40	42	60
175	36	38	41	43	61
180	37	39	42	44	62
185	38	40	43	45	63
190	38	40	43	45	65
200	40	42	45	47	67
250	45	50	55	60	70

Even though this is the effective method of power factor compensation, there is a limitation in sizing of the capacitors. That is, the maximum kVAr should be decided such that, the rated capacitor current is less than 90% of the motor's no-load current. If this condition is not met, self-excitation may occur, in which the motor acts as a generator. This happens when a motor has enough inertia to keep rotating even after being disconnected from the power system and the capacitor is large enough to supply the reactive power needs of the motor. Self-excitation may result in high voltage at the terminals of the motor and this can damage the contactor and the capacitor. As this method has the limitation in the sizing of maximum kVAr rating, it is not possible to achieve unity power factor.

Method – 2:

In this method, the capacitor is connected to the motor before the starter and it is switched through a separate capacitor-duty contactor. The capacitors are disconnected as soon as the motor is switched off hence, self-excitation is avoided. There is no need of any limitations in capacitor sizing and unity power factor can be achieved by this method.

The capacitor size (in kVAr) can be calculated by the below formula:

$$kVAr = kW (\tan\phi_1 - \tan\phi_2)$$

$$\text{where, } \Phi_1 = \cos^{-1} \text{(Initial PF) and } \Phi_2 = \cos^{-1} \text{(Target PF)}$$

The limitations are the manual switching of the capacitors and the extra cost incurred for the contactors. Moreover, when the number of motors increase in future, managing all at a time would be difficult.

Motors with Star-Delta Starter

Specifically for motor with star-delta starter, it is recommended to use method-2. If capacitors are directly connected to the terminals of the motor, the life of the capacitor drops drastically because of the voltage spikes that happen during every star to delta transition. So it is safer to connect the capacitor before the star-delta starter, as shown in the above figure.

Points to Remember

- The operating power factor varies with respect to the percentage loading of the motors. Hence with the varying load, the fixed capacitors may not be able to maintain the unity power factor continuously

- After switching off the capacitor, it is very important to maintain a minimum time delay of 60 seconds, for switching ON the capacitor again. Else, there are more chances of contactor damage because of charged capacitor

- If the motor is operated with drives/converters, it is recommended to detune the capacitors by adding series reactors

- It is recommended to use capacitor duty contactors for minimizing the inrush current and hence to maximize the life of contactors and the capacitors

In order to achieve near unity power factor, all sources of reactive power need to be identified and fully compensated. One such element that consumes reactive power is the transformer. Reactive power is consumed by transformers through the no load magnetizing current and through the leakage reactance. This issue is aimed at helping customers size capacitor banks for transformer compensation.

Basics

The power factor on the HT side (source side) of a transformer depends upon the following:
• LT Side (Load side) power factor
• Real power consumed by transformer
• Reactive power consumed by transformer

The load side power factor is compensated by employing APFC panels and/or by providing individual compensation to connected loads. Transformer compensation on the other hand needs a different approach.

The equivalent circuit of a transformer is as shown below:
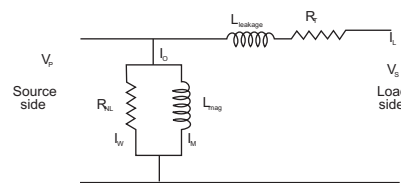
Where: V_P is the source voltage, V_s is the load voltage, Io is the no load current, I_W is the no load watt loss current, I_M is the magnetizing current, R_{NL} is the no load resistance, L_{mag} is the magnetizing inductance, $L_{leakage}$ is the leakage inductance, R_T is the windingresistance.
As can be seen from the equivalent circuit, the inductive elements, namely L_{mag} and $L_{leakage}$ contribute to the VAR consumption of the transformer

Magnetizing VAR Requirement of a Transformer

The magnetizing VAR consumption is a function of the rated voltage and the magnetizing current of the transformer. The no load current of a transformer varies between 0.5 % and 2.5% of the full load current depending on the design of the transformer and the operating flux level. The magnetizing current is around 80% of the no load current and thus varies between 0.4% and 2%. It is safe to assume a value of 1-1.2% for distribution transformers.

Thus the VAR required to compensate for the magnetizing current of the transformer is around 1- 1.2% of the transformer kVA rating.

VAR Requirement due to Leakage Reactance

The VAR requirement due to leakage reactance is a function of the square of the current and the leakage reactance. At full load the voltage drop across the leakage reactance is equal to the impedance voltage (%Z impedance). The reactive VAR consumption is equal to the product of impedance voltage and load current.

$Q_X = I_L^2 \times X_{Leakage};$
Where I_L is the load current and X$_{Leakage}$ is the leakage reactance; Q_X is the kVAr

Power Requirement

Typically, for a 3 phase transformer,

$$X_{leakage} = \frac{V_2^2}{kVA} \times (\%Z);$$

Where V2 is the secondary voltage.

$Q_X = (\% Z) \times (kVA) \times (\% load)^2$
% loading is assumed to be 50% to 75%. Thus for %Z=5%, Q works out to 5%* (75%) i.e. 3%

Thus the VAR requirement to compensate for the leakage reactance of the transformer is around 3% of the kVA rating of the transformer.

The total VAR required to compensate for the reactive power consumed by the transformer is around 4% to 4.25% of the kVA rating of the transformer.

Whenever an industry is drawing power from utility, there are no major complications in managing the reactive power and power factor close to unity can be maintained. However, when diesel generators are operating, some precautions are needed to be taken for managing reactive power. This article briefs the performance of the DG sets at various power factors and thereby shows the optimal manner of power factor compensation of generators with the help of some examples.

Normally DG sets are rated in apparent power (kVA) along with power factor and typical rated power factor is 0.8 lag (considering the power factor of motors, without any capacitors) irrespective of alternator's apparent power. The diesel engine's mechanical output power (bhp/kW) is designed to match the electrical real power (kW = kVA x PF) of the alternator.

For example, consider a generator rated for 1000 kVA and lagging power factor of 0.8. The maximum possible real power (kW) the generator can supply is 800 kW (rated current = 1739 A). Thus, the diesel engine will also be rated to deliver 800 kW equivalent mechanical power to the alternator. The following cases show the operation of the alternator at different power factor.

Case 1:

Apparent power = 1000 kVA; connected load = 800 kW; power factor = 0.8
Current drawn, I_1 = 1000 x 1000 / (1.732 x 415 x 0.8) = 1739 A
- Here, the generator is operated at the rated name plate values. The load draws maximum rated current from the generator and the generator draws the maximum permissible mechanical power (800 kW) from the diesel engine

Case 2:

Apparent power = 1000 kVA; connected load = 800 kW; power factor = 0.6
Current drawn, I_2 = 1000 x 1000 / (1.732 x 415 x 0.6) = 2318.9 A
- In case 2, the connected load is 800 kW (operated at 0.6 PF) which is equal to the maximum mechanical power that the engine can deliver. But the actual current drawn by the load is greater than the rated alternator current. This results in generator overloading. In order to avoid generator overloading, the maximum load (at the same PF) that can be connected to the generator is 600 kW at 0.6 PF
- Conversely, if the connected load is 600 kW and if the power factor is at 0.6, the entire generator capacity (1000 kVA) is blocked for this partial load. If the power factor was to be improved to 0.8, then as in case 1 additional 200 kW load could have been connected to the same generator, thereby increasing the capacity and productivity of the industry. Moreover, if 600 kW load is operated at unity power factor, the load current (1391 A) will be reduced by 40%, thereby significant reduction in the copper loss/cable loss. This will result in fuel savings of the engine. This is what is described in case 3 below

Case 3:

Apparent power = 1000 kVA; connected load = 800 kW; power factor = 1.0
Current drawn, I_3 = 1000 x 1000 / (1.732 x 415 x 1.0) = 1391 A
- The genset is connected to its full capacity of 800 kW operating at unity power factor. Unlike case 1, the load draws 20% less current at UPF (1391 A). This in turn results in significant reduction in copper loss/cable loss and thereby saving some fuel
- Here, at UPF, even though the generator can support a load of 1000 kW, the diesel engine is rated to deliver a maximum mechanical power of 800 kW
- Even though the current drawn is less than the rated current (1739 A), the genset is delivering its maximum real power (800 kW)
- Hence at UPF, utmost care should be taken such that the total connected electrical load must not exceed 800 kW. Otherwise the diesel engine will be overloaded

Summary

- Close to unity power factor shall be maintained for the loads connected to the DG sets by using capacitors. This will result in the reduction of copper loss and hence savings in fuel
- The load (active power) connected to the generator must not exceed the engine's equivalent kW rating

Modern power networks cater to a wide variety of electrical and power electronics loads, which create a varying power demand on the supply system. In case of such varying loads, the power factor also varies as a function of the load requirements.

It therefore becomes practically difficult to maintain consistent power factor by the use of fixed compensation i.e. fixed capacitors which shall need to be manually switched to suit the variations of the load. This will lead to situations where the installation can have a low power factor leading to higher demand charges and levy of power factor penalties.

In addition to not being able to achieve the desired power factor it is also possible that the use of fixed compensation can also result in leading power factor under certain load conditions. This is also unhealthy for the installation as it can result in over voltages, saturation of transformers, mal-operation of diesel generating sets, penalties by electricity supply authorities etc.

Consequently the use of fixed compensation has limitations in this context. It is therefore necessary to automatically vary, without manual intervention, the compensation to suit the load requirements. This is achieved by using on Automatic Power Factor Correction (APFC) system which can ensure consistently high power factor without any manual intervention. In addition, the occurrence of leading power factor will be prevented.

APFC panels are fully automatic in operation and can be used to achieve:

- Consistently high power factor under fluctuating load conditions
- Elimination of low power factor penalty levied by electrical supply authorities
- Reduced kVA demand charges
- Lower energy consumption in the installation by reducing losses
- Preventive leading power factor in an installation

Basic Operation

- To continuously sense and monitor the load condition by the use of external CT (whose output is fed to the control relay)
- To automatically switch ON and OFF relevant capacitor steps on to ensure consistent power factor
- To ensure easy user interface for enabling reliable system operations
- To protect against any electrical faults in a manner that will ensure safe isolation of the power factor correction equipment

Salient Features and Advantages

- Pre-selected optimal number of steps and step sizes, for better step resolution and hunt free capacitors switching
- Ideal switchgear selection for reliable short circuit protection, without nuisance tripping
- Right capacitor-reactor combination selection to prevent harmonic amplification and resonance
- Option of capacitor duty contactor or thyristor switch for transient free switching
- Panels with better electrical, mechanical and thermal design for longer life of capacitors and other components
- Panels are with advanced microcontroller based APFC relay that offers reliable switching operation with four quadrant sensing

etaSYS Standard APFC Panel Range

Product	Description	kVAr ratings	Capacitors	Main Incomer	Branch Protection	Switching	Harmonic Filter
etaSYS - MH1	Contactor switched standard APFC Panels	35 to 500 kVAr	Heavy Duty Gas filled Capacitors	MCCB - upto 350 kVAr; ACB - 400 to 500 kVAr	MCCB	MO C Capacitor duty contactor	-
etaSYS - MH2	Contactor switched standard APFC Panels with harmonic filters	100 to 500 kVAr	Heavy Duty Gas filled Capacitors	MCCB - upto 350 kVAr; ACB - 400 to 500 kVAr	MCCB	MO C Capacitor duty contactor	7% copper reactor
etaSYS - FH1	Contactor switched standard APFC Panels	35 to 500 kVAr	Heavy Duty Gas filled Capacitors	MCCB - upto 350 kVAr; ACB - 400 to 500 kVAr	HRC Fuse	MO C Capacitor duty contactor	-
etaSYS - FH2	Contactor switched standard APFC Panels with harmonic filters	100 to 500 kVAr	Heavy Duty Gas filled Capacitors	MCCB - upto 350 kVAr; ACB - 400 to 500 kVAr	HRC Fuse	MO C Capacitor duty contactor	7% copper reactor
etaSYS - FH3 (RTPFC)	Thyristor switched standard APFC Panels with harmonic filters	100 to 500 kVAr	Heavy Duty Gas filled Capacitors	MCCB - upto 350 kVAr; ACB - 400 to 500 kVAr	Semiconductor Fuse	Thyristor switching modules	7% copper reactor
etaSYS - MU1	Contactor switched standard APFC Panels	100 to 500 kVAr	LTXL - Ultra Heavy Duty capacitor	MCCB - upto 350 kVAr; ACB - 400 to 500 kVAr	MCCB	MO C Capacitor duty contactor	-
etaSYS - MU2	Contactor switched standard APFC Panels with harmonic filters	100 to 500 kVAr	LTXL - Ultra Heavy Duty capacitor	MCCB - upto 350 kVAr; ACB - 400 to 500 kVAr	MCCB	MO C Capacitor duty contactor	7% copper reactor
etaSYS - FU1	Contactor switched standard APFC Panels	35 to 500 kVAr	LTXL - Ultra Heavy Duty capacitor	MCCB - upto 350 kVAr; ACB - 400 to 500 kVAr	HRC Fuse	MO C Capacitor duty contactor	-
etaSYS - FU2	Contactor switched standard APFC Panels with harmonic filters	100 to 500 kVAr	LTXL - Ultra Heavy Duty capacitor	MCCB - upto 350 kVAr; ACB - 400 to 500 kVAr	HRC Fuse	MO C Capacitor duty contactor	7% copper reactor
etaSYS - FU3 (RTPFC)	Thyristor switched standard APFC Panels with harmonic filters	100 to 500 kVAr	LTXL - Ultra Heavy Duty capacitor	MCCB - upto 350 kVAr; ACB - 400 to 500 kVAr	Semiconductor Fuse	Thyristor switching modules	7% copper reactor

etaSYS Basic Design Specifications

Power Range	35 kVAr to 500 kVAr
Rated System Voltage	440 V / 415 V / 400 V / 380 V
Rated Frequency	50 Hz
Incomer Short Circuit Rating	> 36 kA
Altitude	1000 m
Duty	Continuous
Ambient Temperature	-5°C to 45°C
Power Supply	Three phase, four line
Relay Current Input Signal	– / 5A, from CT on line
Enclosures	The load bearing structure is made of 2 mm sheet steel
	The front door and partition are made of 1.6 mm sheet steel
	The internal components are accessible on opening the front door
	Ingress protection - IP42
Installation	Indoor, wall mounted (upto 100 kVAr), floor mounted (100 kVAr and above) in a well-ventilated, non-dusty environment, cable entry from bottom
Incomer	3 Pole MCCBs upto 630 A, 3 Pole ACBs above 630 A
Capacitors	1. Heavy duty cylindrical gas filled capacitors.
	2. LTXL Ultra Heavy Duty Capacitors (see below table for step ratings).
Reactors	1. Without Reactors
	2. With 7% Detuned Reactors
Switching	1. 3 Pole MO C Capacitor duty contactors of adequate ratings for respective steps.
	2. Thyristor Switching Modules of suitable ratings.
Branch Protection	1. MCCBs for providing short circuit protection and isolation.
	2. HRC Fuses of adequate ratings.
	3. High speed fuse / semiconductor fuse for thyristor switched APFC panels.

Front view

Side view

Air filter unit

Cut out at bottom

Gland plate

Top view
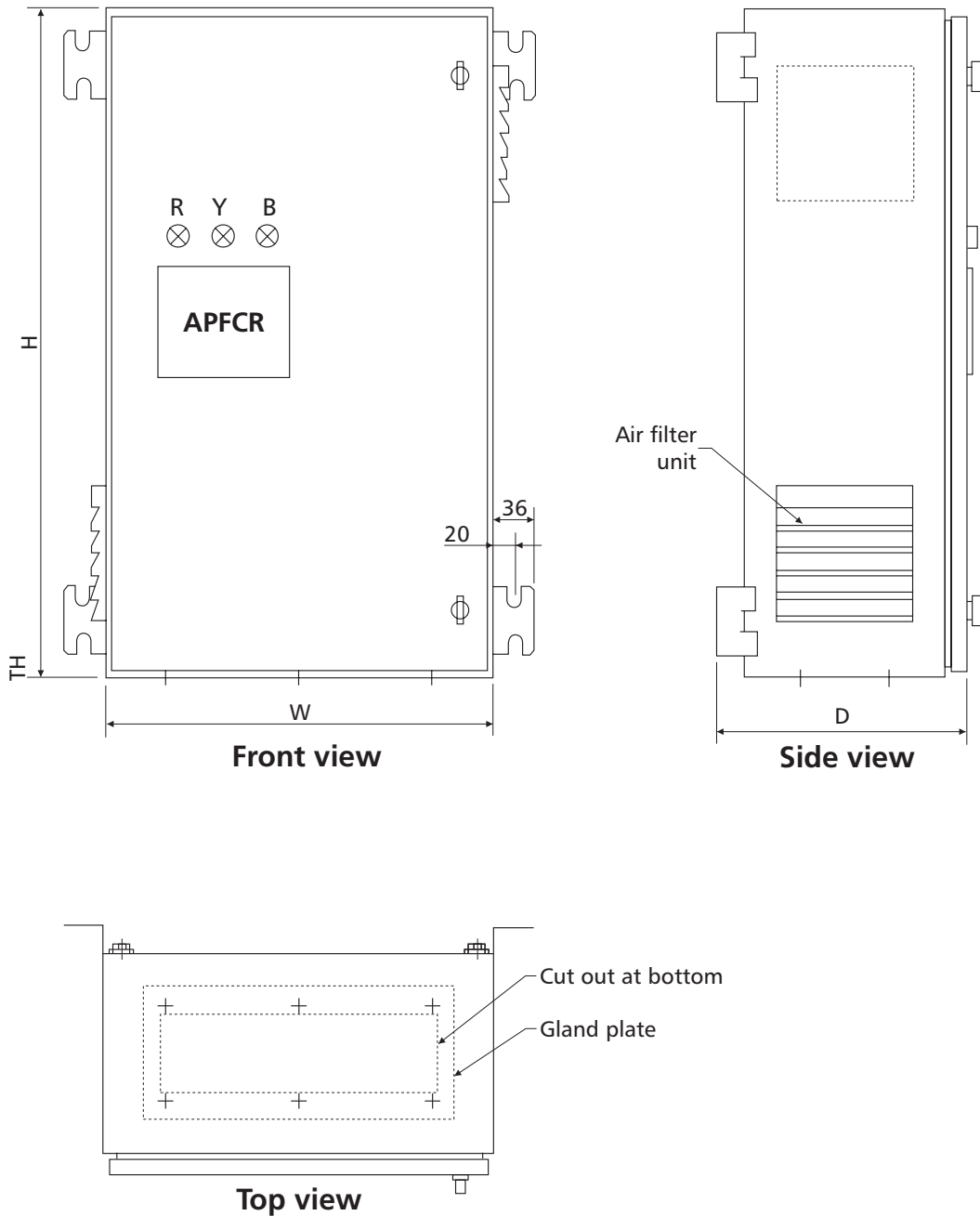
Notes:

- Wall mounted : upto 100 kVAr
- Floor mounted : above 100 kVAr
- Recommended front access : 1000 mm
- Recommended side clearance : 1000 mm
- Paint shade : RAL 7032 Powder coated
- Tolerance on dimensions : ±10 mm
- Cable entry : bottom

etaSYS - MH1 Standard APFC with a combination of Heavy Duty Capacitors & MCCB

Cat. Nos.	Panel Rating (kVAr)	Step size (kVAr)	Steps	Switching Device	Type of Capacitor	Reactor	Branch Protection	Main Incommer	Dimension (mm) (H x W x D)
LTAPMH0351B2	35	2 x 12.5 + 2 x 5	4	Contactor	MPPH	-	DU MCCB	dsine MCCB	1100 x 600 x 400
LTAPMH0501B2	50	2 x 12.5 + 2 x 10 + 1 x 5	5	Contactor	MPPH	-	DU MCCB	dsine MCCB	1100 x 600 x 400
LTAPMH0751B2	75	2 x 25 + 2 x 10 + 1 x 5	5	Contactor	MPPH	-	DU MCCB	dsine MCCB	1200 x 800 x 400
LTAPMH1001B2	100	50 + 25 + 15 + 5 + 5	5	Contactor	MPPH	-	DU MCCB	dsine MCCB	1500 x 1000 x 600
LTAPMH1251B2	125	2 x 12.5 + 2 x 25 + 50	5	Contactor	MPPH	-	DU MCCB	dsine MCCB	1500 x 1000 x 600
LTAPMH1501B2	150	2 x 12.5 + 3 x 25 + 50	6	Contactor	MPPH	-	DU MCCB	dsine MCCB	1800 x 1000 x 600
LTAPMH1751B2	175	2 x 12.5 + 2 x 25 + 2 x 50	6	Contactor	MPPH	-	DU MCCB	dsine MCCB	1800 x 1000 x 600
LTAPMH2001B2	200	2 x 12.5 + 25 + 3 x 50	6	Contactor	MPPH	-	DU MCCB	dsine MCCB	1800 x 1000 x 600
LTAPMH2251B2	225	2 x 12.5 + 4 x 50	6	Contactor	MPPH	-	DU MCCB	dsine MCCB	1800 x 1000 x 600
LTAPMH2501B2	250	2 x 25 + 4 x 50	6	Contactor	MPPH	-	DU MCCB	dsine MCCB	1800 x 1000 x 600
LTAPMH2751B2	275	1 x 100 + 3 x 50 + 2 x 12.5	6	Contactor	MPPH	-	DU MCCB	dsine MCCB	2100 x 1200 x 600
LTAPMH3001B2	300	1 x 100 + 3 x 50 + 2 x 25	6	Contactor	MPPH	-	DU MCCB	dsine MCCB	2100 x 1200 x 600
LTAPMH3501B2	350	1 x 100 + 3 x 50 + 4 x 25	8	Contactor	MPPH	-	DU MCCB	dsine MCCB	2100 x 1200 x 600
LTAPMH4001B2	400	2 x 100 + 2 x 50 + 4 x 25	8	Contactor	MPPH	-	DU MCCB	ACB	2000 x 1600 x 800
LTAPMH4501B2	450	2 x 100 + 4 x 50 + 2 x 25	8	Contactor	MPPH	-	DU MCCB	ACB	2000 x 1600 x 800
LTAPMH5001B2	500	3 x 100 + 3 x 50 + 2 x 25	8	Contactor	MPPH	-	DU MCCB	ACB	2000 x 1600 x 800

etaSYS - MH2 Standard APFC with a combination of Heavy Duty Capacitors, MCCB & 7% Detuned Reactor

Cat. Nos.	Panel Rating (kVAr)	Step size (kVAr)	Steps	Switching Device	Type of Capacitor	Reactor	Branch Protection	Main Incommer	Dimension (mm) (H x W x D)
LTAPMH1002B2	100	50 + 25 + 15 + 5 + 5	5	Contactor	MPPH	7%	DU MCCB	dsine MCCB	1600 x 1000 x 800
LTAPMH1252B2	125	2 x 12.5 + 2 x 25 + 50	5	Contactor	MPPH	7%	DU MCCB	dsine MCCB	1600 x 1000 x 800
LTAPMH1502B2	150	2 x 12.5 + 3 x 25 + 50	6	Contactor	MPPH	7%	DU MCCB	dsine MCCB	2100 x 1000 x 800
LTAPMH1752B2	175	2 x 12.5 + 2 x 25 + 2 x 50	6	Contactor	MPPH	7%	DU MCCB	dsine MCCB	2100 x 1000 x 800
LTAPMH2002B2	200	2 x 12.5 + 1 x 25 + 3 x 50	6	Contactor	MPPH	7%	DU MCCB	dsine MCCB	2100 x 1000 x 800
LTAPMH2252B2	225	2 x 12.5 + 4 x 50	6	Contactor	MPPH	7%	DU MCCB	dsine MCCB	2100 x 1000 x 800
LTAPMH2502B2	250	2 x 25 + 4 x 50	6	Contactor	MPPH	7%	DU MCCB	dsine MCCB	2100 x 1000 x 800
LTAPMH2752B2	275	1 x 100 + 3 x 50 + 2 x 12.5	6	Contactor	MPPH	7%	DU MCCB	dsine MCCB	2100 x 1200 x 800
LTAPMH3002B2	300	1 x 100 + 3 x 50 + 2 x 25	6	Contactor	MPPH	7%	DU MCCB	dsine MCCB	2100 x 1200 x 800
LTAPMH3502B2	350	1 x 100 + 3 x 50 + 4 x 25	8	Contactor	MPPH	7%	DU MCCB	dsine MCCB	2100 x 1400 x 800
LTAPMH4002B2	400	2 x 100 + 2 x 50 + 4 x 25	8	Contactor	MPPH	7%	DU MCCB	ACB	2000 x 1600 x 1200
LTAPMH4502B2	450	2 x 100 + 4 x 50 + 2 x 25	8	Contactor	MPPH	7%	DU MCCB	ACB	2000 x 1600 x 1200
LTAPMH5002B2	500	3 x 100 + 3 x 50 + 2 x 25	8	Contactor	MPPH	7%	DU MCCB	ACB	2000 x 1600 x 1200

etaSYS - FH1 Standard APFC with a combination of Heavy Duty Capacitors & HRC Fuse

Cat. Nos.	Panel Rating (kVAr)	Step size (kVAr)	Steps	Switching Device	Type of Capacitor	Reactor	Branch Protection	Main Incommer	Dimension (mm) (H x W x D)
LTAPFH0351B2	35	2 x 12.5 + 2 x 5	4	Contactor	MPPH	-	HRCF	dsine MCCB	1100 x 600 x 400
LTAPFH0501B2	50	2 x 12.5 + 2 x 10 + 1 x 5	5	Contactor	MPPH	-	HRCF	dsine MCCB	1100 x 600 x 400
LTAPFH0751B2	75	2 x 25 + 2 x 10 + 1 x 5	5	Contactor	MPPH	-	HRCF	dsine MCCB	1200 x 800x 400
LTAPFH1001B2	100	50 + 25 + 15 + 5 + 5	5	Contactor	MPPH	-	HRCF	dsine MCCB	1500 x 1000 x 500
LTAPFH1251B2	125	2 x 12.5 + 2 x 25 + 50	5	Contactor	MPPH	-	HRCF	dsine MCCB	1500 x 1000 x 500
LTAPFH1501B2	150	2 x 12.5 + 3 x 25 + 50	6	Contactor	MPPH	-	HRCF	dsine MCCB	1800 x 1000 x 600
LTAPFH1751B2	175	2 x 12.5 + 2 x 25 + 2 x 50	6	Contactor	MPPH	-	HRCF	dsine MCCB	1800 x 1000 x 600
LTAPFH2001B2	200	2 x 12.5 + 25 + 3 x 50	6	Contactor	MPPH	-	HRCF	dsine MCCB	1800 x 1000 x 600
LTAPFH2251B2	225	2 x 12.5 + 4 x 50	6	Contactor	MPPH	-	HRCF	dsine MCCB	1800 x 1000 x 600
LTAPFH2501B2	250	2 x 25 + 4 x 50	6	Contactor	MPPH	-	HRCF	dsine MCCB	1800 x 1000 x 600
LTAPFH2751B2	275	1 x 100 + 3 x 50 + 2 x 12.5	6	Contactor	MPPH	-	HRCF	dsine MCCB	2100 x 1200 x 600
LTAPFH3001B2	300	1 x 100 + 3 x 50 + 2 x 25	6	Contactor	MPPH	-	HRCF	dsine MCCB	2100 x 1200 x 600
LTAPFH3501B2	350	1 x 100 + 3 x 50 + 4 x 25	8	Contactor	MPPH	-	HRCF	dsine MCCB	2100 x 1200 x 600
LTAPFH4001B2	400	2 x 100 + 2 x 50 + 4 x 25	8	Contactor	MPPH	-	HRCF	dsine MCCB	2000 x 1600 x 800
LTAPFH4501B2	450	2 x 100 + 4 x 50 + 2 x 25	8	Contactor	MPPH	-	HRCF	dsine MCCB	2000 x 1600 x 800
LTAPFH5001B2	500	3 x 100 + 3 x 50 + 2 x 25	8	Contactor	MPPH	-	HRCF	dsine MCCB	2000 x 1600 x 800

etaSYS - FH2 Standard APFC with a combination of Heavy Duty Capacitors, HRC Fuse & 7% Detuned Reactor

Cat. Nos.	Panel Rating (kVAr)	Step size (kVAr)	Steps	Switching Device	Type of Capacitor	Reactor	Branch Protection	Main Incommer	Dimension (mm) (H x W x D)
LTAPFH1002B2	100	50 + 25 + 15 + 5 + 5	5	Contactor	MPPH	7%	HRCF	dsine MCCB	1600 x 1000 x 800
LTAPFH1252B2	125	2 x 12.5 + 2 x 25 + 50	5	Contactor	MPPH	7%	HRCF	dsine MCCB	1600 x 1000 x 800
LTAPFH1502B2	150	2 x 12.5 + 3 x 25 + 50	6	Contactor	MPPH	7%	HRCF	dsine MCCB	2100 x 1000 x 800
LTAPFH1752B2	175	2 x 12.5 + 2 x 25 + 2 x 50	6	Contactor	MPPH	7%	HRCF	dsine MCCB	2100 x 1000 x 800
LTAPFH2002B2	200	2 x 12.5 + 1 x 25 + 3 x 50	6	Contactor	MPPH	7%	HRCF	dsine MCCB	2100 x 1000 x 800
LTAPFH2252B2	225	2 x 12.5 + 4 x 50	6	Contactor	MPPH	7%	HRCF	dsine MCCB	2100 x 1000 x 800
LTAPFH2502B2	250	2 x 25 + 4 x 50	6	Contactor	MPPH	7%	HRCF	dsine MCCB	2100 x 1000 x 800
LTAPFH2752B2	275	1 x 100 + 3 x 50 + 2 x 12.5	6	Contactor	MPPH	7%	HRCF	dsine MCCB	2100 x 1200 x 800
LTAPFH3002B2	300	1 x 100 + 3 x 50 + 2 x 25	6	Contactor	MPPH	7%	HRCF	dsine MCCB	2100 x 1200 x 800
LTAPFH3502B2	350	1 x 100 + 3 x 50 + 4 x 25	8	Contactor	MPPH	7%	HRCF	dsine MCCB	2100 x 1400 x 800
LTAPFH4002B2	400	2 x 100 + 2 x 50 + 4 x 25	8	Contactor	MPPH	7%	HRCF	dsine MCCB	2000 x 1600 x 1200
LTAPFH4502B2	450	2 x 100 + 4 x 50 + 2 x 25	8	Contactor	MPPH	7%	HRCF	dsine MCCB	2000 x 1600 x 1200
LTAPFH5002B2	500	3 x 100 + 3 x 50 + 2 x 25	8	Contactor	MPPH	7%	HRCF	dsine MCCB	2000 x 1600 x 1200

etaSYS - FH3 Standard APFC with a combination of Heavy Duty Capacitors, Thyritor Switching & 7% Detuned Reactor

Cat. Nos.	Panel Rating (kVAr)	Step size (kVAr)	Steps	Switching Device	Type of Capacitor	Reactor	Branch Protection	Main Incommer	Dimension (mm) (H x W x D)
LTAPFH1003B2	100	50 + 25 + 15 + 5 + 5	5	Thyristor	MPPH	7%	HSF	dsine MCCB	1800 x 1000 x 800
LTAPFH1253B2	125	2 x 12.5 + 2 x 25 + 50	5	Thyristor	MPPH	7%	HSF	dsine MCCB	1800 x 1000 x 800
LTAPFH1503B2	150	2 x 12.5 + 3 x 25 + 50	6	Thyristor	MPPH	7%	HSF	dsine MCCB	2100 x 1000 x 800
LTAPFH1753B2	175	2 x 12.5 + 2 x 25 + 2 x 50	6	Thyristor	MPPH	7%	HSF	dsine MCCB	2100 x 1000 x 800
LTAPFH2003B2	200	2 x 12.5 + 1 x 25 + 3 x 50	6	Thyristor	MPPH	7%	HSF	dsine MCCB	2100 x 1000 x 800
LTAPFH2253B2	225	2 x 12.5 + 4 x 50	6	Thyristor	MPPH	7%	HSF	dsine MCCB	2100 x 1000 x 800
LTAPFH2503B2	250	2 x 25 + 4 x 50	6	Thyristor	MPPH	7%	HSF	dsine MCCB	2100 x 1000 x 800
LTAPFH2753B2	275	1 x 100 + 3 x 50 + 2 x 12.5	6	Thyristor	MPPH	7%	HSF	dsine MCCB	2200 x 1200 x 800
LTAPFH3003B2	300	1 x 100 + 3 x 50 + 2 x 25	6	Thyristor	MPPH	7%	HSF	dsine MCCB	2200 x 1200 x 800
LTAPFH3503B2	350	1 x 100 + 3 x 50 + 4 x 25	8	Thyristor	MPPH	7%	HSF	dsine MCCB	2100 x 1600 x 800
LTAPFH4003B2	400	2 x 100 + 2 x 50 + 4 x 25	8	Thyristor	MPPH	7%	HSF	dsine MCCB	2000 x 1600 x 1200
LTAPFH4503B2	450	2 x 100 + 4 x 50 + 2 x 25	8	Thyristor	MPPH	7%	HSF	dsine MCCB	2000 x 1600 x 1200
LTAPFH5003B2	500	3 x 100 + 3 x 50 + 2 x 25	8	Thyristor	MPPH	7%	HSF	dsine MCCB	2000 x 1600 x 1200

etaSYS - MU1 Standard APFC with a combination of LTXL Capacitors & MCCB

Cat. Nos.	Panel Rating (kVAr)	Step size (kVAr)	Steps	Switching Device	Type of Capacitor	Reactor	Branch Protection	Main Incommer	Dimension (mm) (H x W x D)
LTAPMU1001B2	100	50 + 25 + 15 + 5 + 5	5	Contactor	LTXL	-	DU MCCB	dsine MCCB	1500 x 1000 x 700
LTAPMU1251B2	125	2 x 12.5 + 2 x 25 + 50	5	Contactor	LTXL	-	DU MCCB	dsine MCCB	1500 x 1000 x 700
LTAPMU1501B2	150	2 x 12.5 + 3 x 25 + 50	6	Contactor	LTXL	-	DU MCCB	dsine MCCB	1800 x 1000 x 700
LTAPMU1751B2	175	2 x 12.5 + 2 x 25 + 2 x 50	6	Contactor	LTXL	-	DU MCCB	dsine MCCB	1800 x 1000 x 700
LTAPMU2001B2	200	2 x 12.5 + 25 + 3 x 50	6	Contactor	LTXL	-	DU MCCB	dsine MCCB	1800 x 1000 x 700
LTAPMU2251B2	225	2 x 12.5 + 4 x 50	6	Contactor	LTXL	-	DU MCCB	dsine MCCB	1800 x 1000 x 700
LTAPMU2501B2	250	2 x 25 + 4 x 50	6	Contactor	LTXL	-	DU MCCB	dsine MCCB	1800 x 1000 x 700
LTAPMU2751B2	275	1 x 100 + 3 x 50 + 2 x 12.5	6	Contactor	LTXL	-	DU MCCB	dsine MCCB	2100 x 1200 x 700
LTAPMU3001B2	300	1 x 100 + 3 x 50 + 2 x 25	6	Contactor	LTXL	-	DU MCCB	dsine MCCB	2100 x 1200 x 700
LTAPMU3501B2	350	1 x 100 + 3 x 50 + 4 x 25	8	Contactor	LTXL	-	DU MCCB	dsine MCCB	2100 x 1200 x 700
LTAPMU4001B2	400	2 x 100 + 2 x 50 + 4 x 25	8	Contactor	LTXL	-	DU MCCB	dsine MCCB	2000 x 1600 x 1200
LTAPMU4501B2	450	2 x 100 + 4 x 50 + 2 x 25	8	Contactor	LTXL	-	DU MCCB	dsine MCCB	2000 x 1600 x 1200
LTAPMU5001B2	500	3 x 100 + 3 x 50 + 2 x 25	8	Contactor	LTXL	-	DU MCCB	dsine MCCB	2000 x 1600 x 1200

etaSYS - MU1 Standard APFC with a combination of LTXL Capacitors, MCCB & 7% Detuned Reactor

Cat. Nos.	Panel Rating (kVAr)	Step size (kVAr)	Steps	Switching Device	Type of Capacitor	Reactor	Branch Protection	Main Incommer	Dimension (mm) (H x W x D)
LTAPMU1002B2	100	50 + 25 + 15 + 5 + 5	5	Contactor	LTXL	7%	DU MCCB	dsine MCCB	2100 x 1000 x 800
LTAPMU1252B2	125	2 x 12.5 + 2 x 25 + 50	5	Contactor	LTXL	7%	DU MCCB	dsine MCCB	2100 x 1000 x 800
LTAPMU1502B2	150	2 x 12.5 + 3 x 25 + 50	6	Contactor	LTXL	7%	DU MCCB	dsine MCCB	2100 x 1000 x 800
LTAPMU1752B2	175	2 x 12.5 + 2 x 25 + 2 x 50	6	Contactor	LTXL	7%	DU MCCB	dsine MCCB	2100 x 1000 x 800
LTAPMU2002B2	200	2 x 12.5 + 1 x 25 + 3 x 50	6	Contactor	LTXL	7%	DU MCCB	dsine MCCB	2100 x 1000 x 800
LTAPMU2252B2	225	2 x 12.5 + 4 x 50	6	Contactor	LTXL	7%	DU MCCB	dsine MCCB	2100 x 1000 x 800
LTAPMU2502B2	250	2 x 25 + 4 x 50	6	Contactor	LTXL	7%	DU MCCB	dsine MCCB	2100 x 1000 x 800
LTAPMU2752B2	275	1 x 100 + 3 x 50 + 2 x 12.5	6	Contactor	LTXL	7%	DU MCCB	dsine MCCB	2100 x 1200 x 1200
LTAPMU3002B2	300	1 x 100 + 3 x 50 + 2 x 25	6	Contactor	LTXL	7%	DU MCCB	dsine MCCB	2100 x 1200 x 1200
LTAPMU3502B2	350	1 x 100 + 3 x 50 + 4 x 25	8	Contactor	LTXL	7%	DU MCCB	dsine MCCB	2100 x 1400 x 1200
LTAPMU4002B2	400	2 x 100 + 2 x 50 + 4 x 25	8	Contactor	LTXL	7%	DU MCCB	dsine MCCB	2000 x 1800 x 1200
LTAPMU4502B2	450	2 x 100 + 4 x 50 + 2 x 25	8	Contactor	LTXL	7%	DU MCCB	dsine MCCB	2000 x 1800 x 1200
LTAPMU5002B2	500	3 x 100 + 3 x 50 + 2 x 25	8	Contactor	LTXL	7%	DU MCCB	dsine MCCB	2000 x 1800 x 1200

etaSYS - FU1 Standard APFC with a combination of LTXL Capacitors & HRC Fuse

Cat. Nos.	Panel Rating (kVAr)	Step size (kVAr)	Steps	Switching Device	Type of Capacitor	Reactor	Branch Protection	Main Incommer	Dimension (mm) (H x W x D)
LTAPFU1001B2	100	50 + 25 + 15 + 5 + 5	5	Contactor	LTXL	-	HRCF	dsine MCCB	1500 x 1000 x 700
LTAPFU1251B2	125	2 x 12.5 + 2 x 25 + 50	5	Contactor	LTXL	-	HRCF	dsine MCCB	1500 x 1000 x 700
LTAPFU1501B2	150	2 x 12.5 + 3 x 25 + 50	6	Contactor	LTXL	-	HRCF	dsine MCCB	1800 x 1000 x 700
LTAPFU1751B2	175	2 x 12.5 + 2 x 25 + 2 x 50	6	Contactor	LTXL	-	HRCF	dsine MCCB	1800 x 1000 x 700
LTAPFU2001B2	200	2 x 12.5 + 25 + 3 x 50	6	Contactor	LTXL	-	HRCF	dsine MCCB	1800 x 1000 x 700
LTAPFU2251B2	225	2 x 12.5 + 4 x 50	6	Contactor	LTXL	-	HRCF	dsine MCCB	1800 x 1000 x 700
LTAPFU2501B2	250	2 x 25 + 4 x 50	6	Contactor	LTXL	-	HRCF	dsine MCCB	1800 x 1000 x 700
LTAPFU2751B2	275	1 x 100 + 3 x 50 + 2 x 12.5	6	Contactor	LTXL	-	HRCF	dsine MCCB	2100 x 1200 x 700
LTAPFU3001B2	300	1 x 100 + 3 x 50 + 2 x 25	6	Contactor	LTXL	-	HRCF	dsine MCCB	2100 x 1200 x 700
LTAPFU3501B2	350	1 x 100 + 3 x 50 + 4 x 25	8	Contactor	LTXL	-	HRCF	dsine MCCB	2000 x 1600 x 1200
LTAPFU4001B2	400	2 x 100 + 2 x 50 + 4 x 25	8	Contactor	LTXL	-	HRCF	dsine MCCB	2000 x 1600 x 1200
LTAPFU4501B2	450	2 x 100 + 4 x 50 + 2 x 25	8	Contactor	LTXL	-	HRCF	dsine MCCB	2000 x 1600 x 1200
LTAPFU5001B2	500	3 x 100 + 3 x 50 + 2 x 25	8	Contactor	LTXL	-	HRCF	dsine MCCB	2000 x 1600 x 1200

etaSYS - FU1 Standard APFC with a combination of LTXL Capacitors, HRC Fuse & 7% Detuned Reactor

Cat. Nos.	Panel Rating (kVAr)	Step size (kVAr)	Steps	Switching Device	Type of Capacitor	Reactor	Branch Protection	Main Incommer	Dimension (mm) (H x W x D)
LTAPFU1002B2	100	50 + 25 + 15 + 5 + 5	5	Contactor	MPPH	7%	HRCF	dsine MCCB	2100 x 1000 x 800
LTAPFU1252B2	125	2 x 12.5 + 2 x 25 + 50	5	Contactor	MPPH	7%	HRCF	dsine MCCB	2100 x 1000 x 800
LTAPFU1502B2	150	2 x 12.5 + 3 x 25 + 50	6	Contactor	MPPH	7%	HRCF	dsine MCCB	2100 x 1000 x 800
LTAPFU1752B2	175	2 x 12.5 + 2 x 25 + 2 x 50	6	Contactor	MPPH	7%	HRCF	dsine MCCB	2100 x 1000 x 800
LTAPFU2002B2	200	2 x 12.5 + 1 x 25 + 3 x 50	6	Contactor	MPPH	7%	HRCF	dsine MCCB	2100 x 1000 x 800
LTAPFU2252B2	225	2 x 12.5 + 4 x 50	6	Contactor	MPPH	7%	HRCF	dsine MCCB	2100 x 1000 x 800
LTAPFU2502B2	250	2 x 25 + 4 x 50	6	Contactor	MPPH	7%	HRCF	dsine MCCB	2100 x 1000 x 800
LTAPFU2752B2	275	1 x 100 + 3 x 50 + 2 x 12.5	6	Contactor	MPPH	7%	HRCF	dsine MCCB	2100 x 1200 x 1200
LTAPFU3002B2	300	1 x 100 + 3 x 50 + 2 x 25	6	Contactor	MPPH	7%	HRCF	dsine MCCB	2100 x 1200 x 1200
LTAPFU3502B2	350	1 x 100 + 3 x 50 + 4 x 25	8	Contactor	MPPH	7%	HRCF	dsine MCCB	2100 x 1400 x 1200
LTAPFU4002B2	400	2 x 100 + 2 x 50 + 4 x 25	8	Contactor	MPPH	7%	HRCF	dsine MCCB	2000 x 1600 x 1200
LTAPFU4502B2	450	2 x 100 + 4 x 50 + 2 x 25	8	Contactor	MPPH	7%	HRCF	dsine MCCB	2000 x 1600 x 1200
LTAPFU5002B2	500	3 x 100 + 3 x 50 + 2 x 25	8	Contactor	MPPH	7%	HRCF	dsine MCCB	2000 x 1600 x 1200

etaSYS - FU3 Standard APFC with a combination of LTXL Capacitors, Thyritor Switching & 7% Detuned Reactor

Cat. Nos.	Panel Rating (kVAr)	Step size (kVAr)	Steps	Switching Device	Type of Capacitor	Reactor	Branch Protection	Main Incommer	Dimension (mm) (H x W x D)
LTAPFU1003B2	100	50 + 25 + 15 + 5 + 5	5	Thyristor	MPPH	7%	HSF	dsine MCCB	2100 x 1000 x 800
LTAPFU1253B2	125	2 x 12.5 + 2 x 25 + 50	5	Thyristor	MPPH	7%	HSF	dsine MCCB	2100 x 1000 x 800
LTAPFU1503B2	150	2 x 12.5 + 3 x 25 + 50	6	Thyristor	MPPH	7%	HSF	dsine MCCB	2100 x 1000 x 800
LTAPFU1753B2	175	2 x 12.5 + 2 x 25 + 2 x 50	6	Thyristor	MPPH	7%	HSF	dsine MCCB	2100 x 1000 x 800
LTAPFU2003B2	200	2 x 12.5 + 1 x 25 + 3 x 50	6	Thyristor	MPPH	7%	HSF	dsine MCCB	2100 x 1000 x 800
LTAPFU2253B2	225	2 x 12.5 + 4 x 50	6	Thyristor	MPPH	7%	HSF	dsine MCCB	2100 x 1000 x 800
LTAPFU2503B2	250	2 x 25 + 4 x 50	6	Thyristor	MPPH	7%	HSF	dsine MCCB	2100 x 1000 x 800
LTAPFU2753B2	275	1 x 100 + 3 x 50 + 2 x 12.5	6	Thyristor	MPPH	7%	HSF	dsine MCCB	2200 x 1200 x 1200
LTAPFU3003B2	300	1 x 100 + 3 x 50 + 2 x 25	6	Thyristor	MPPH	7%	HSF	dsine MCCB	2200 x 1200 x 1200
LTAPFU3503B2	350	1 x 100 + 3 x 50 + 4 x 25	8	Thyristor	MPPH	7%	HSF	dsine MCCB	2100 x 1600 x 1200
LTAPFU4003B2	400	2 x 100 + 2 x 50 + 4 x 25	8	Thyristor	MPPH	7%	HSF	dsine MCCB	2000 x 1800 x 1200
LTAPFU4503B2	450	2 x 100 + 4 x 50 + 2 x 25	8	Thyristor	MPPH	7%	HSF	dsine MCCB	2000 x 1800 x 1200
LTAPFU5003B2	500	3 x 100 + 3 x 50 + 2 x 25	8	Thyristor	MPPH	7%	HSF	dsine MCCB	2000 x 1800 x 1200

Major part in the design of APFC panels is the selection of step size of capacitor banks and number of steps. The right selection of step size and number of steps plays a significant role in the performance as well as cost of the APFC panel. This section focuses on the need and ways of good step size (maximum and minimum sizes) selection and number of steps.

Maximum Step Size Selection
The maximum capacitor rating in an APFC panel depends up on the following:

I.   Maximum amount of load variation that happens in the industry at a time: Large load variations demand bigger capacitor steps so that target power factor is achieved in short time, by less number of switching operations.

ii. Current and voltage transient withstand capabilities of the system:

   • Current transients: Switching of big capacitors (usually above 100 kVAr) introduces large magnitude of inrush current (current transients) for a small duration. This results in high thermal and electrical stress on capacitors, short circuit protection devices and mainly, the switching device. This may lead to their nuisance tripping and premature failures

   • Voltage transients: Switching of big capacitors may cause transient over voltages, which might result in failure of sensitive electronic devices

Thus, the maximum size of the capacitor step is a trade-off between the points i and ii. Practically acceptable maximum possible rating in any APFC panel shall be 100 kVAr. If this 100 kVAr rating capacitor is switched using power contactor, the peak inrush current may reach as high as 75 kA. Hence, the capacitors should be switched using either capacitor duty contactors or thyristor switching module.

However, thyristor switching module or capacitor duty contactor for 100 kVAr rating is not readily available. Hence, the best way to switch a 100 kVAr bank is by connecting two 50 kVAr TSM / contactor in parallel, each with a separate physical 50 kVAr capacitor banks. The control supply to both the 50 kVAr TSM/contactors shall be common (one relay output of the controller), so that both of the devices are triggered at the same time. To achieve this, the common output of the APFC relay should be programmed as 100 kVAr. Hence, physically they are two separate 50 kVAr banks, whereas electrically they behave as a single 100 kVAr bank.

A sample connection diagram for switching a step of 100 kVAr capacitor using two 50 kVAr capacitor duty contactors / TSM is shown as under:
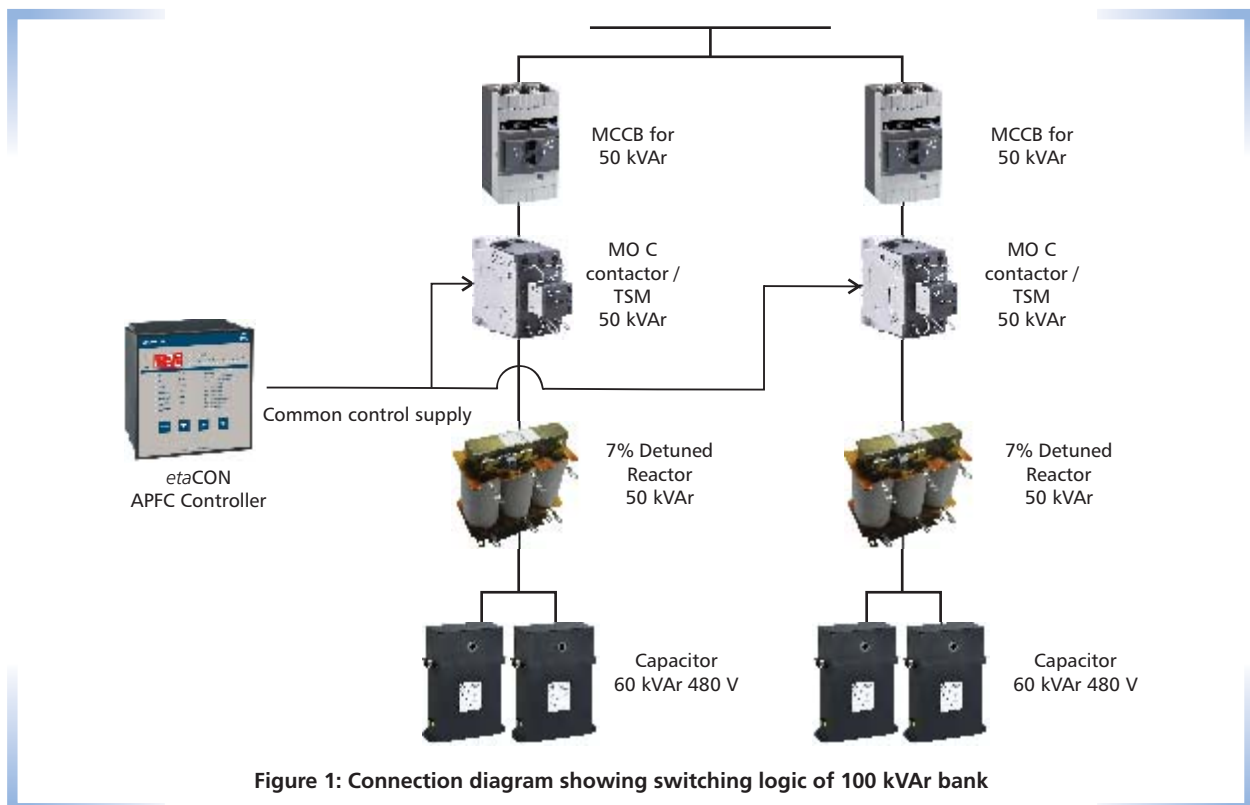

Figure 1: Connection diagram showing switching logic of 100 kVAr bank

Minimum Step Size Selection

The minimum capacitor rating depends on how precise the power factor needs to be maintained. This minimum kVAr rating depends upon the minimum current sensitivity (typically around 2.5%) of the APFC controller. However the change in PF due to these minimum selected kVAr rating would be usually in the 3rd or 4th decimal places (depending on panel size or kVAr requirement), whereas the electricity board is concerned only with the first two digits of PF (like 0.99).

Typically many industries want the desired target PF to be unity (exactly 1.00), in order to get incentives from some EBs. But practically, the optimum target PF has to be 0.96 to 0.99. These are healthy levels of power factor as it will have safety margin that avoids the leading power factor as well as any dangerous harmonic amplification (due to more capacitance in the system).

Hence, as a rule of thumb, the minimum kVAr rating in an APFC panel can be chosen to be 5-10% of overall rating of APFC panel. For smaller rating APFC panels (up to 100 kVAr), the smallest step can be 5 kVAr and for bigger rating APFC panels (above 600 kVAr and up to 1000 kVAr) the minimum rating can be 25 kVAr.

Number of Steps / Branches in APFC Panels

Once the minimum and maximum kVAr rating of the APFC panel is selected, the number of branches can be decided upon based of the following:

I. Technology of APFC controllers: Latest APFC controllers like etaCON L Series employ self-optimized intelligent switching where the controller calculates the exact kVAr requirement and switches ON / OFF the appropriate capacitors irrespective of the capacitors already in circuit. Traditional controllers employing linear or circular switching require more number of smaller steps (like 1:2:2:…) for effective power factor correction. Whereas the latest controllers like etaCON can have a mix of large and small steps reducing the number of steps in capacitor bank as well as the cost of associated switchgear.

ii. Size & cost of APFC panel: More the number of steps more will be the cost of APFC panel, due to more number of switchgear, bigger size of panel and others.

An APFC panel should have:
   a. Maximum number of <u>electrical steps</u> (combination of physical steps) to ensure more accurate and flexible power factor correction
   b. Minimum number of <u>physical steps</u> to reduce the size and cost of the panel

Let us consider a few examples of step size selection in APFC panels.

I. 100 kVAr APFC panel

	Case A	Case B
Step configuration	10 + 10 + 10 + 10 + … 10 times	50 + 25 + 15 + 5 + 5
Step resolution	10 kVAr	5 kVAr
Electrical Steps	10, 20, 30, 40, 50, … 100	5, 10, 15, 20, 25, 30, … 100
Physical Steps	10	5
No. of Electrical Steps	10	20

In case B, 20 electrical steps are possible with only 5 physical steps; whereas in case A, 10 physical steps are required to achieve 10 electrical steps.

II. 300 kVAr APFC panel

	Case A	Case B
Configuration	25 + 25 + 25 + 25 + … 12 times	1x100 + 3x50 + 2x25
Step resolution	25 kVAr	25 KVAr
Electrical Steps	25, 50, 75, 100, 125, … 275, 300	25, 50, 75, 100, 125, … 275, 300
Physical Steps	12	6
No. of Electrical Steps	12	12

Case B is better as same electrical steps are achieved with just 6 physical steps.

III. 600 kVAr APFC panel

	Case A	Case B
Configuration	50 + 50 + 50 + 50 + … 12 times	3x100 + 5x50 + 2x25
Step resolution	50 kVAr	25 KVAr
Electrical Steps	50, 100, 150, 200, 250, … 600	25, 50, 75, 100, 125, … , 600
Physical Steps	12	10
No. of Electrical Steps	12	24

In Case B, 24 electrical steps are possible with only 10 physical steps; whereas in Case A, 12 physical steps are required to achieve 12 electrical steps.

Summary

APFC panels with more number of steps (more than 12) does not always mean better step resolution. With the latest APFC controller technology, fewer steps are sufficient to achieve better step resolution and control of power factor. Hence, usually a combination of large, small and very small ratings is used in steps of capacitor banks, as given below:

1. Large rating capacitors (100 kVAr maximum) are required to PF compensation of base load and coarse power factor compensation
2. Medium rating capacitors are meant for variable part of the reactive power compensation.
3. Small rating capacitors (usually 5 to 10% of total kVAr or 25 kVAr for panels above 500 kVAr) are meant for fine tuning of the power factor.

Considering the above points, following table suggests optimum number of steps and step sizes from 35 kVAr to 1000 kVAr. Beyond 1000 kVAr, it is always better to split the APFC panels and install them at different PCC/MCC levels.

Panel Rating (kVAr)	Physical Step Size (kVAr)	No. of Physical Steps	Electrical / Logical Steps (all possible combination of physical steps)	No. of Electrical Steps
35	2x12.5 + 2x5	4	5, 10, 12.5, 17.5, 22.5, 25, 30, 35	8
50	2 x 12.5 + 2x10 + 1x5	5	5, 10, 12.5, 15, 17.5, 20, 22.5, 25, 27.5, 30, 35, 37.5, 40, 45, 50	15
75	2 x 25 + 2x10 + 1x5	5	5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, … 70, 75	15
100	50 + 25 + 15 + 5 + 5	5	5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, …95,100	20
125	2 x 12.5 + 2 x 25 + 50	5	12.5, 25, 37.5, 50, 62.5, 75, 87.5, 100, 112.5, 125	10
150	2 x 12.5 + 3 x 25 + 50	6	12.5, 25, 37.5, 50, 62.5, 75, 87.5, … 137.5, 150	12
175	2 x 12.5 + 2 x 25 + 2 x 50	6	12.5, 25, 37.5, 50, 62.5, 75, 87.5, … 162.5, 175	14
200	2 x 12.5 + 25 + 3 x 50	6	12.5, 25, 37.5, 50, 62.5, 75, 87.5, … 187.5, 200	16
225	2 x 12.5 + 4 x 50	6	12.5, 25, 37.5, 50, 62.5, 75, 87.5, … 121.5, 225	18
250	4 x 50 + 2 x 25	6	25, 50, 75, 100, 125, 150, 175, 200, 225, 250	10
275	5 x 50 + 1 x 25	6	25, 50, 75, 100, 125, 150, 175, 200, … 250, 275	11
300	1 x 100 + 3 x 50 + 2 x 25	6	25, 50, 75, 100, 125, 150, 175, 200, … 275, 300	12
350	1 x 100 + 3 x 50 + 4 x 25	8	25, 50, 75, 100, 125, 150, 175, 200, … 325, 350	14
400	2 x 100 + 2 x 50 + 4 x 25	8	25, 50, 75, 100, 125, 150, 175, 200, … 375, 400	16
450	2 x 100 + 4 x 50 + 2 x 25	8	25, 50, 75, 100, 125, 150, 175, 200, … 425, 450	18
500	3 x 100 + 3 x 50 + 2 x 25	8	25, 50, 75, 100, 125, 150, 175, 200, … 475, 500	20
550	3 x 100 + 3 x 50 + 4 x 25	10	25, 50, 75, 100, 125, 150, 175, 200, … 525, 550	22
600	3 x 100 + 5 x 50 + 2 x 25	10	25, 50, 75, 100, 125, 150, 175, 200, … 575, 600	24
650	4 x 100 + 4 x 50 + 2 x 25	10	25, 50, 75, 100, 125, 150, 175, 200, … 625, 650	26
700	3 x 100 + 5 x 50 + 6 x 25	12	25, 50, 75, 100, 125, 150, 175, 200, … 675, 700	28
750	5 x 100 + 3 x 50 + 4 x 25	12	25, 50, 75, 100, 125, 150, 175, 200, … 725, 750	30
800	5 x 100 + 5 x 50 + 2 x 25	12	25, 50, 75, 100, 125, 150, 175, 200, … 775, 800	32
850	6 x 100 + 4 x 50 + 2 x 25	12	25, 50, 75, 100, 125, 150, 175, 200, … 825, 850	34
900	7 x 100 + 2 x 50 + 4 x 25	12	25, 50, 75, 100, 125, 150, 175, 200, … 875, 900	36
950	8 x 100 + 2 x 50 + 4 x 25	12	25, 50, 75, 100, 125, 150, 175, 200, … 925, 950	38
1000	9 x 100 + 1 x 50 + 2 x 25	12	25, 50, 75, 100, 125, 150, 175, 200, … 975, 1000	40

The above table is for illustration only, which may be applicable for majority of industries. For accurate compensation, step ratings shall be decided after studying the load profile of the industry.

Disclaimer

For accurate compensation, the load profile of the industry needs to be studied. This gives an indication of the size of peak loads, base loads, possible harmonics, power factor and thus, helps determine step sizes based on load variations. In some cases, the load requirements can also be established from equipment lists.

For any APFC panel, fuses are required for faster short circuit protection and overload protection of capacitors. Fuse selection for capacitive load is critical because of heavy inrush current, high overload capacity and continuous full load. These inherent traits of a capacitor, complicates the selection process. Hence the selection should be such that even during these permissible abnormalities, the fuse should not blow.

Normally, the maximum permissible current in a capacitor branch is **2** times the rated current. This factor is comprised of the following:

• Harmonics overload and over voltage - 30%
• Capacitance tolerance -10%
• Frequency variation - 2%
• Fuse deration factor - 35%

The fuse used for branch protection must be capable of carrying this current continuously. Hence the fuse should be sufficiently rated so as to avoid the deterioration of the fuse element. Further the fuse should not blow during switching of the capacitors because of the inrush current (more than 100 times the rated capacitor current under normal conditions). In order to prevent nuisance operation of fuse, its time-current characteristic should cover the peak inrush current of the capacitor. Hence for the optimal selection of fuses, the inrush current must be limited by using either **capacitor duty contactor** or **inrush current limiting reactor.**

The following table** shows the selection of Fuses and Capacitor switching contactors for an APFC panel:

kVAr	Rated Current* (A)	O/C Factor	Allowed O/C for Capacitor (A)	Recommended Contactor*	Fuse Rating (A)
10	13.12	2	26.24	MO C12	32
15	19.68	2	39.36	MO C15	40
20	26.24	2	52.48	MO C20	63
25	32.80	2	65.60	MO C25	80
50	65.61	2	131.22	MO C50	160

* Selection principle is same for other family of fuses
** The table is valid only for L&T switchgear and capacitors +at 440 V

The rated current of a capacitor can be calculated as.

$$\frac{(1000 \times kVAr)}{(\sqrt{3} \times V)}$$

For any capacitor bank, permissible overload is 2 times rated capacitor current. Hence, fuses should be rated to carry continuous overcurrent as given in the above table. In case Thyristor Switching Modules are used instead of capacitor duty contactors, it is highly recommended to use High Speed Fuses (semiconductor fuse).

Above selection chart is valid only if fuses are used along with capacitor duty contactor or inrush current limiting reactor (0.2% reactor). Please consider the above table purely as a guideline for selection. Actual selection needs to be done based on considerations of connected load and the electrical network properties.

For any APFC panel, MCCBs are required for short circuit protection, overload protection and for isolation of capacitors. MCCB selection for capacitive load is tricky because of heavy inrush current, high overload capacity and continuous full load. These inherent traits of a capacitor, complicates the selection process. The selection should be such that the MCCB should not nuisance trip during inrush current and should withstand continuous flow of overload current.

Whenever we use MCCB in an APFC panel, proper measures need to be taken against the ill effects of the inrush current. Normally the inrush current (more than 100 times the rated capacitor current) will remain for a few micro-seconds and will not be sensed by the MCCB. However the contacts of MCCB may repel and bounce because of the current limiting feature, causing micro-arcs between the contacts of MCCB. This multiple bounce can result in premature failure of MCCB contacts. In order to reduce the magnitude of the peak inrush current, MCCBs must be used along with **capacitor duty contactors or inrush current limiting reactors.**

The maximum permissible current in a capacitor branch is 1.46 times the rated current. This factor is comprised of the following:

• Harmonics overload and over voltage - 30%
• Capacitance tolerance - 10%
• Frequency variation - 2%

The branch MCCB must be capable of carrying this current continuously.
The following table** shows the selection of MCCBs and Capacitor switching contactors for an APFC panel:

kVAr	Rated Current*A	O/L Factor	Permissible Capacitor O/L (A)	Recommended Contactor+	MCCB*	Thermal Setting (A)		Magnetic Setting (6 to 10*I_R)
						I_N	I_R (100% I_N)	
10	13.12	1.46	19.16	MO C12	DH / DU / DN	19	19	171
15	19.68	1.46	28.74	MO C15	DH / DU / DN	29	29	261
20	26.24	1.46	38.32	MO C20	DH / DU / DN	38	38	342
25	32.80	1.46	47.90	MO C25	DH / DU / DN	48	48	432
30	39.37	1.46	57.47	MO C30	DH / DU / DN	58	58	513
50	65.61	1.46	95.79	MO C50	DH / DU / DN	96	96	864

* Selection principle is same for other family of MCCBs
**The table is valid only for L&T switchgear and capacitors + at 440 V

The rated current of a capacitor can be calculated as

$$(1000 \times kVAr) / (\sqrt{3} \times V)$$

For any capacitor bank, permissible overload is 1.46 times rated capacitor current. Hence, MCCB should be rated to carry continuous over current as given in the above table.

Above selection chart is valid only if MCCB is used along with capacitor duty contactor or inrush current limiting reactor (0.2% reactor). Please consider the above table purely as a guideline for selection. Actual selection needs to be done based on considerations of connected load and the electrical network properties.

Switchgear and cable selection for capacitor application is quite challenging. The reason is the capacitive networks are more prone to over-current, high peak inrush current and continuous flow of full load current. Usually the capacitors are designed to withstand and operate normally, even during the above said abnormalities, for a finite amount of time. Hence, the switchgear and cables in the capacitor network should be rated accordingly, so as to withstand & operate normally during these abnormalities.

The capacitors draw over-current because of the harmonics, capacitance tolerances, voltage variation and frequency variation. The permitted over-current isup to 146% of the rated current, which comprises the following:

- Harmonics overload and over voltage – 30%
- Capacitance tolerance – 10%
- Frequency variation – 2%

Accordingly, the cables should also be derated, to continuously withstand permitted over-current. The derated cable will also help in withstanding the electrical and thermal stresses that occur during every switching cycle because of high inrush current.

Following is the recommended cable selection chart:

Capacitor Rating (kVAr)	Current at the Rated Voltage (in A)		Derated Current at the Rated Voltage (in A)		Minimum Recommended Copper Cable Size** (sq.mm)
	440 V	415 V	440 V	415 V	
1	1.31	1.39	1.92	2.03	0.5
2	2.62	2.78	3.83	4.06	0.5
3	3.94	4.17	5.75	6.09	0.75
4	5.25	5.56	7.66	8.12	1
5	6.56	6.96	9.58	10.16	1
6	7.87	8.35	11.49	12.19	2.5
7.5	9.84	10.43	14.37	15.23	2.5
8.3	10.89	11.55	15.90	16.86	2.5
10	13.12	13.91	19.16	20.31	4
12.5	16.40	17.39	23.95	25.39	4
15	19.68	20.87	28.74	30.47	6
20	26.24	27.82	38.32	40.62	10
25	32.80	34.78	47.90	50.78	16
30	39.37	41.74	57.47	60.94	25
50	65.61	69.56	95.79	101.56	50.0 / 2x25*
75	98.41	104.34	143.69	152.34	70
100	131.22	139.12	191.58	203.12	95

**Cross section values mentioned above are guidelines that are valid for operation under normal conditions and at ambient temperature of 40°C.

Busbar selection in APFC panels can be done with the standard calculations for short circuit withstand capability and temperature rise (current density). The only assumption is that the rated current should be considered as 146% of the total capacitor rated current.

It is recommended to use capacitor duty contactors to reduce the magnitude of peak inrush current. This will reduce the thermal and electrical stress in the capacitors, cables and switchgear, which happens during each switching cycle. This also prevents the premature failure of capacitors and nuisance tripping of short circuit protection device. The above special selection for cables will also overcome the heating and losses that happen because of skin effect.

The life of the power capacitors and other equipments in APFC panels depend very much on the operating temperature. In panels with detuned harmonic filter reactors and thyristor switches, the chances of elevated temperature are high, as these equipments generate relatively more heat.

Hence in order to maximise the life of the capacitors and other important equipments in the APFC panel, the temperature must not be allowed to increase beyond certain limit. This article briefs some guidelines about the thermal design of APFC panels and thereby dissipating the generated heat effectively.

For any panel, the temperature rise can be reduced by the following three ways:
- Operating at lower ambient temperature
- Using devices with lower power loss
- Dissipating the excess heat, so that temperature rise is controlled

There is minimal control over the first two conditions. But the third condition completely depends upon the design of the panel. By offering effective cooling methods, the excess heat generated by the equipments can be dissipated.

Selection of the cooling methods can decided based on the internal temperature rise inside the panel. The maximum internal temperature can be calculated using the following formula:

$$\textbf{Internal Temperature } (T_i) = \frac{P_d}{k \times S} + T_a$$

Where, P_d = Total power dissipated in the panel (in watts)
  k = constant defined by the material used to manufacture the enclosure
  For painted sheet-steel enclosure, $k = 5.5$ W/m^2 °C
  S = effective surface area of the panel (in m^2)
  T_a = Ambient temperature (in °C)

If the temperature rise ($T_i - T_a$) is within the acceptable limits, natural cooling would be sufficient; else forced cooling method should be employed for dissipating excessive heat.

1. Natural Cooling

In most of PCCs and MCCs, the temperature rise remains under desirable limits with natural circulation of air (through natural convection and radiation). The air circulation happens through some slots in the enclosure, called the louvers. When temperature rises inside the panel, the pressure of the air increases and the density reduces.

Hence the hot air tends to move upwards. The hot air would go out through the louvers provided at the top side of the panel. Fresh cold air would enter the panel through the louvers provided at the bottom. This is represented in **Figure 1.**

Figure 2 represents the common usage of extra louvers in-between the top and bottom louvers.
The common misconception behind this is that, extra louver would increase the volume of air flow. Practically, this does not happen because the volume of the panel is fixed.

This results in the reduced air flow at the bottom section of the panel, as some air enters through the middle louvers. Hence, the temperature of the lower section of the panel will be higher than the upper section.

It is recommended to follow the panel design as per the Figure 1.

Figure 1

LOUVERS

Hotl Air Outlet

Cool Air Inlet

PLINTH

SIDE VIEW

Figure 2

LOUVERS

Reduced rate of air flow, hence, over heating
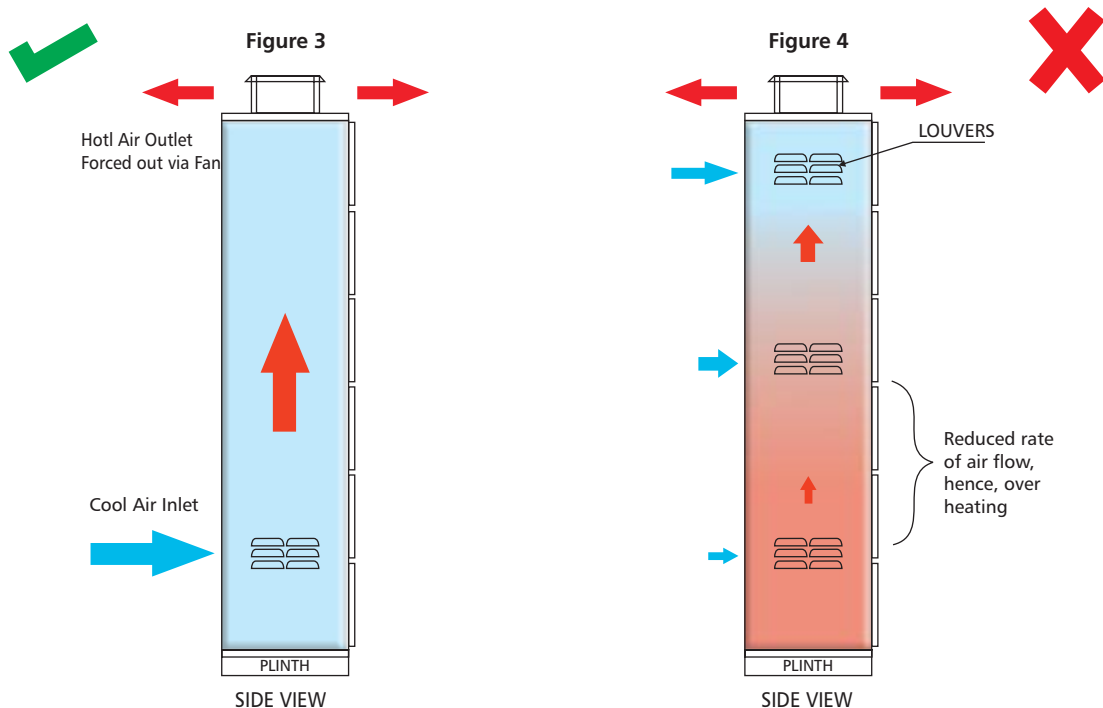
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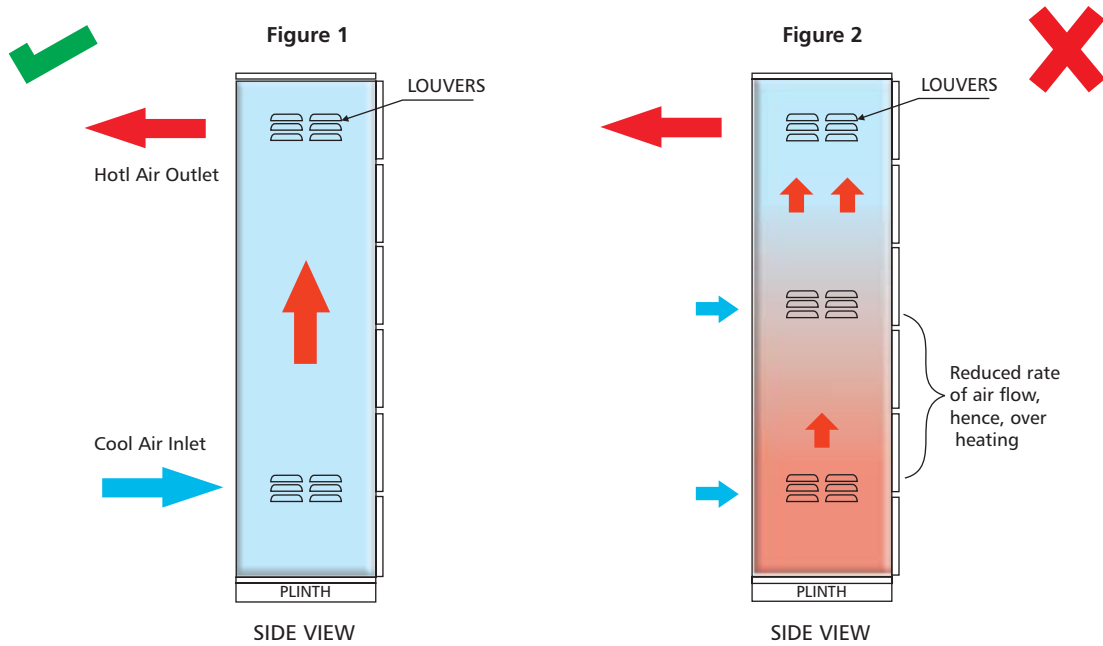
2. Forced Cooling

In most of the APFC panels and in some MCC and PCC panels, the above method would not offer sufficient cooling. In order to maintain the desired temperature levels (ambient temperature + allowed temperature rise), forced cooling methods (using fans at the top) should be employed, which would increase the rate of air flow.

In **Figure 3** the cold air enters through the bottom louvers, flows through all the equipments and they are forced out of the panel through fans. Hence, temperature rise in the panel is kept under check and there are no hot spots/sections.

In **Figure 4** provision of additional louvers, actually disturbs the uniformity of the flow. Major chunk of cold air would enter through the top louver and result in "short cycling". So the bottom section of the panel would see higher temperature rise.

Figure 3

Hotl Air Outlet Forced out via Fan

Cool Air Inlet

PLINTH

SIDE VIEW

Figure 4

LOUVERS

Reduced rate of air flow, hence, over heating

PLINTH

SIDE VIEW

Fan Selection for Forced Cooling

Fan selection is based on the rate of air flow, which is measured in m³/h or Cubic Feet per Minute (CFM), where 1 CFM = 1.7 x 1 m³/h. Following is the formula to calculate air flow rate:

$$Q = C_x \frac{P_d - [k \times S (T_d - T_a)]}{(T_d - T_a)}$$

Where,

Q = Air flow rate (in m³/h)

C = Coefficient related to the altitude above the sea level

Altitude (in meters)	C
0 to 100	3.1
101 to 250	3.2
251 to 500	3.3
501 to 750	3.4
751 to 1000	3.5

P_d = total power loss (watts) inside the panel, by summing up the power loss of individual devices like capacitors, reactors, thyristor switches, contactors, bus bars, joints and so on.

k = constant defined by the material used to manufacture the enclosure.

For painted sheet-steel enclosure, k = 5.5 W/m² °C

S = Open surface area of the panel (in sq. m) can be calculated using one of the below formulas:

Position of the Enclosure	Formula for Calculating S (in sq. m) as per IEC 890
accessible on all sides	S = 1.8 x H x (W + D) + 1.4 x W x D
placed against a wall	S = 1.4 x W x (H + D) + 1.8 x D x H
end of a row of enclosures	S = 1.4 x D x (H + W) + 1.8 x W x H
end of a row of enclosures with back against the wall	S = 1.4 x H x (W + D) + 1.4 x W x D
intermediate in a row of enclosures	S = 1.8 x W x H + 1.4 x W x D + D x H
intermediate in a row of enclosures with the back against the wall	S = 1.4 x W x (H + D) + D x H
intermediate in a row of enclosures back against the wall with top part covered	S = 1.4 x W x H + 0.7 x W x D + D x H

Td = Desired Maximum temperature inside the enclosure

Ta = Ambient temperature

This is a simple method of thermal management and fan selection, which is suitable for majority of the panels. At the same time, some other aspects like position of mounting various equipments in the APFC panel should be taken care.

Recommendations

- Capacitors should be kept below the reactors, which are the major heat sources. This is because the elevated temperature would reduce the life of the capacitors
- The reactors should be mounted in the zigzag position (as shown in the below figure), in order to ensure better heat flow. If the reactors are kept one above other, the bottom most reactors would heat up the other reactors that are mounted above them
- Thyristor switching modules should be mounted vertically (position of heat sink should be parallel to the air flow direction) and in zigzag positions
- It is recommended to use copper reactors, which have lower power loss than aluminium reactors
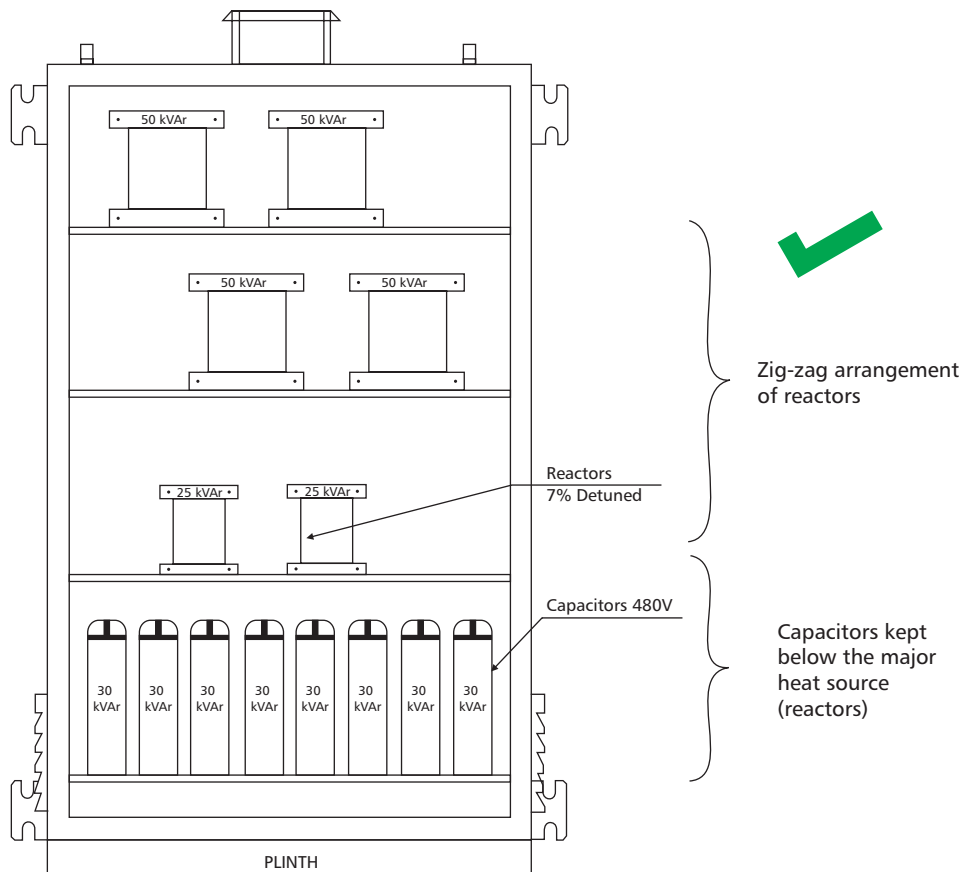
Hence, in APFC panels, a proper thermal design would pave way for maximising the life of important equipments like capacitors, thyristor switches, reactors and other switchgear.

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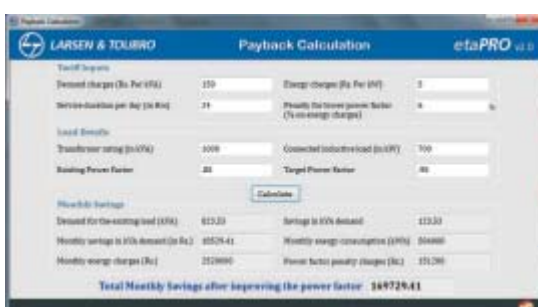

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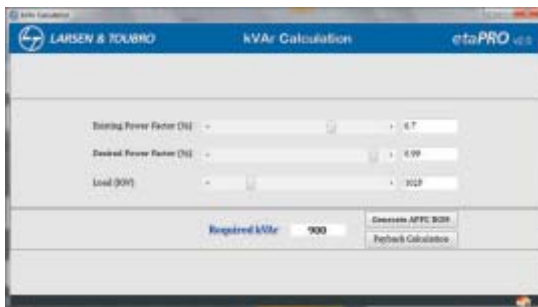
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