# Shunt Active Filters (SAF)

**Operation principle of a Shunt Active Filter.**

Non-linear loads like Variable Speed Drives, Uninterrupted Power Supplies and all kind of rectifiers draw a non-sinusoidal current from the network. Therefore they can be considered to be harmonic current sources. Shunt Active Filter works as a current source which, when properly designed and controlled, produces harmonic currents having opposite phase than those harmonic currents produced by the non-linear load. When such a Shunt Active Filter is connected parallel with a non-linear load its harmonic currents are compensated and the network is loaded with almost fundamental current only.

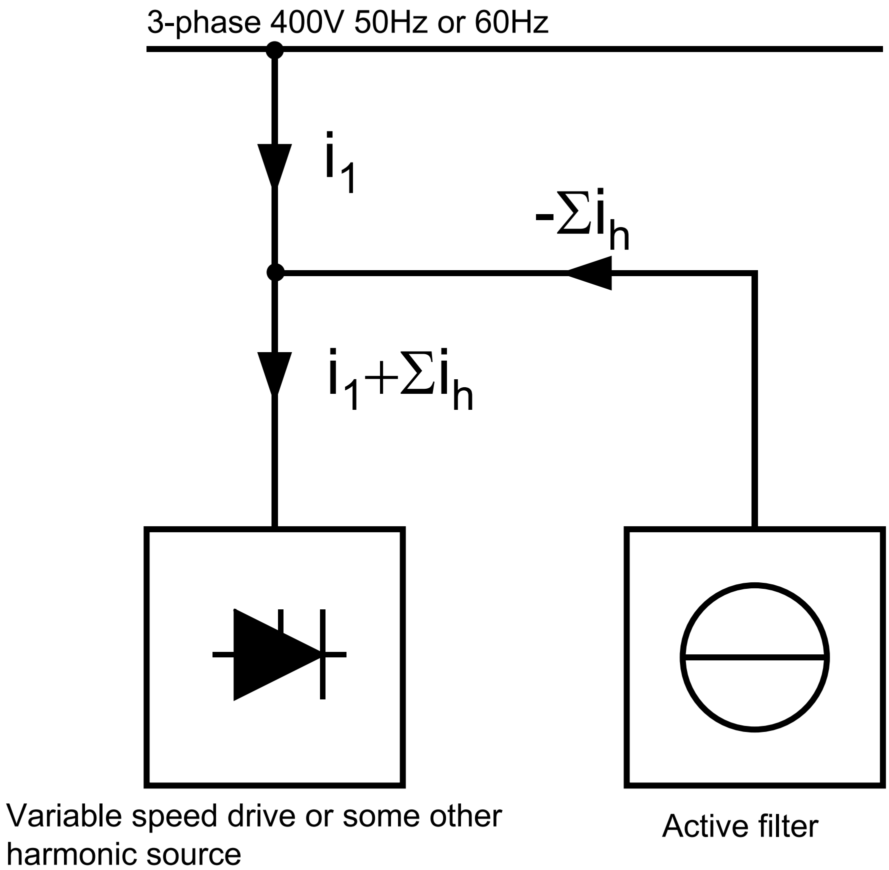



Figure 1. Non-linear load with shunt active filter

**Shunt Active Filter and harmonic producing load**

Considering harmonic current producing load like a typical voltage source Variable Speed Drive with a 4% line side reactor in Figure 2 its AC-side current looks like in Figure 3.

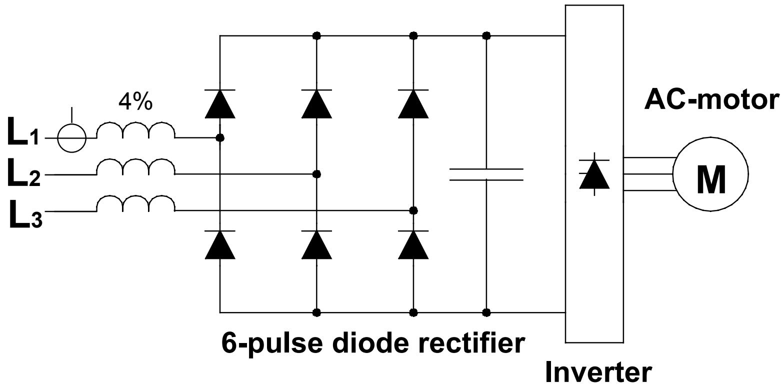
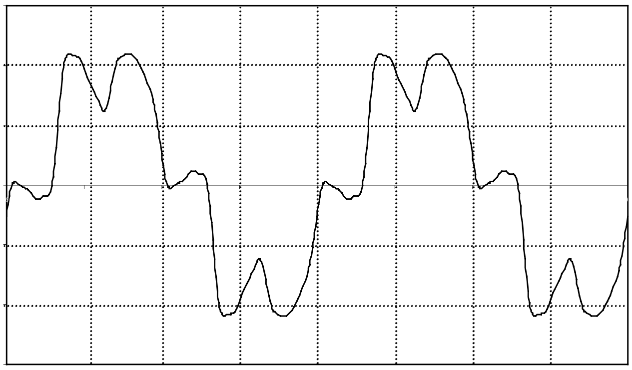


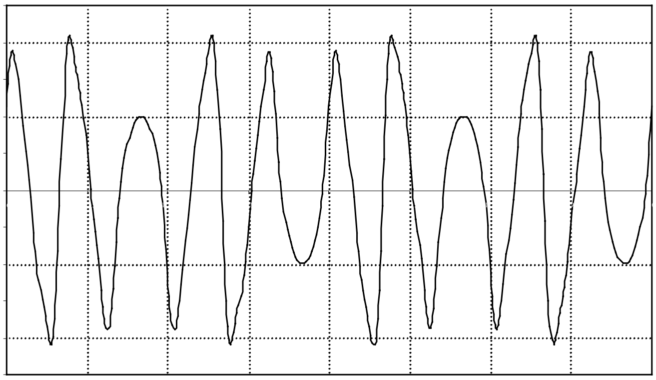

Figure 2. Voltage Source Variable Speed Drive



5th harmonic 32.0%
7th harmonic 9.5%
11th harmonic 6.4%
13th harmonic 3.3%
17th harmonic 2.4%
19th harmonic 1.8%

Figure 3. AC side current of a Voltage Source Variable Speed Drive and its harmonic content

In Figure 4 there is the current produced by an active filter to compensate harmonic currents shown in Figure 3. Please note that in this case active filter is not producing fundamental reactive power and therefore there is no fundamental current but harmonic currents only.



- 5$^{th}$ harmonic 32.0%
- 7$^{th}$ harmonic 9.5%
- 11$^{th}$ harmonic 6.4%
- 13$^{th}$ harmonic 3.3%
- 17$^{th}$ harmonic 2.4%
- 19$^{th}$ harmonic 1.8%

Figure 4. Current of an active filter and its harmonic content

Connecting this active filter parallel with the load harmonics are compensated and the network is loaded by almost fundamental current only like shown in Figure 5.

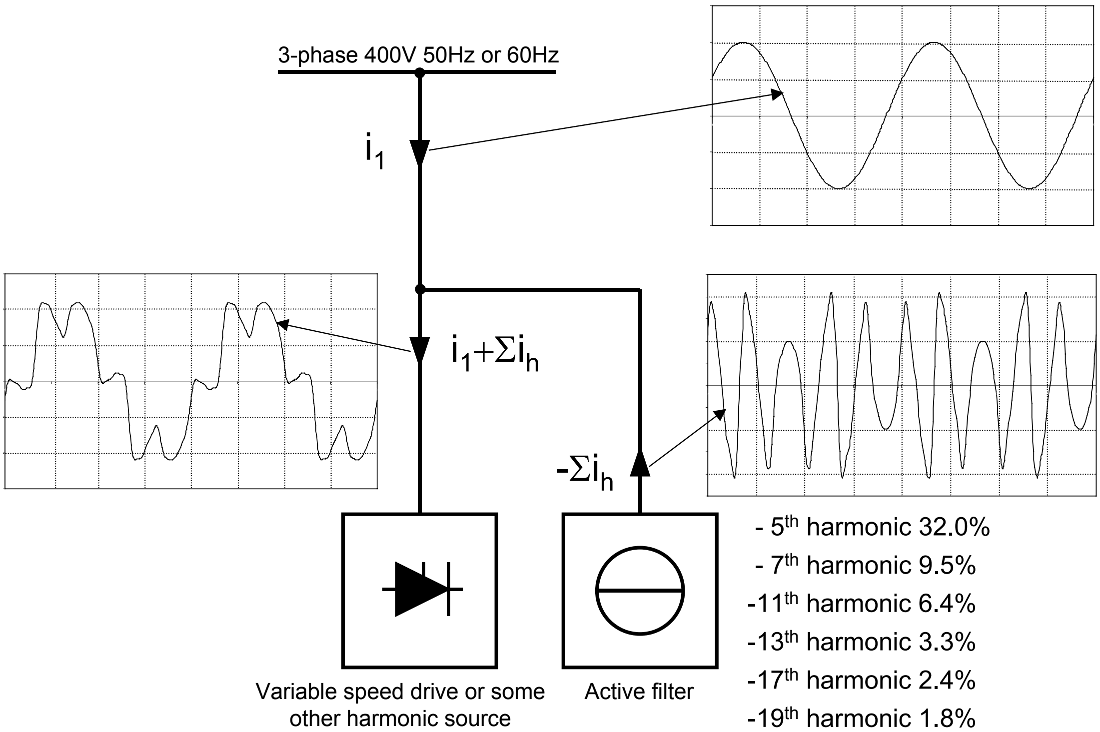



Figure 5. The effect of the connection of an active filter parallel to the harmonic producing load.

It should be noted that the output current of an active filter has a continuous spectrum of all harmonics due to the accuracy of the control system. Therefore in the network current there are still some harmonic currents.

**Connection of Shunt Active Filters**

In case of 3-phase 3-wire system current of the load is measured from two phases and the current of the third phase is derived from two others. Measured currents are used to control the output of the active filter. In Figure 6 there is the connection of an active filter in 3-phase 3-wire supply system.

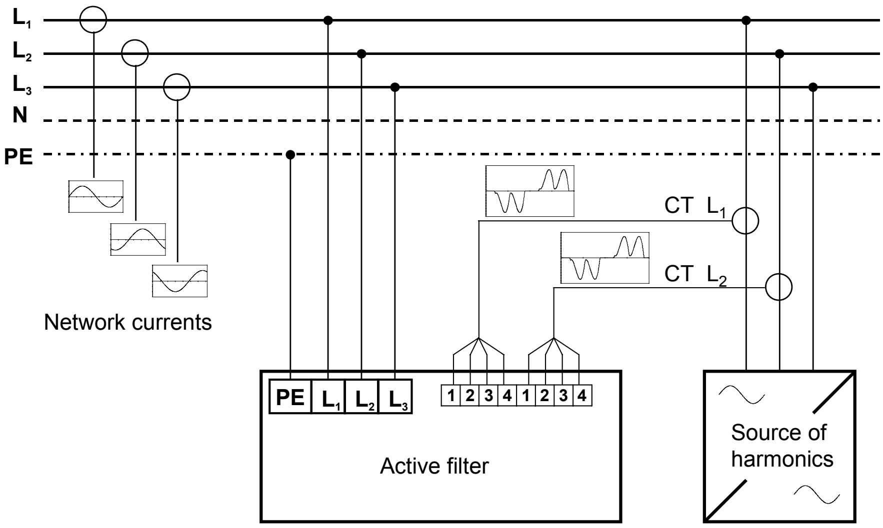



Figure 6. Connection of the active filter to 3-phase 3-wire supply system.

In Figure 7 there is the connection of the active filter to 3-phase 4-wire supply system. In this case current is measured from each phase to allow also unsymmetrical operation of the active filter. This version of the active filter can compensate zero sequence harmonics too.

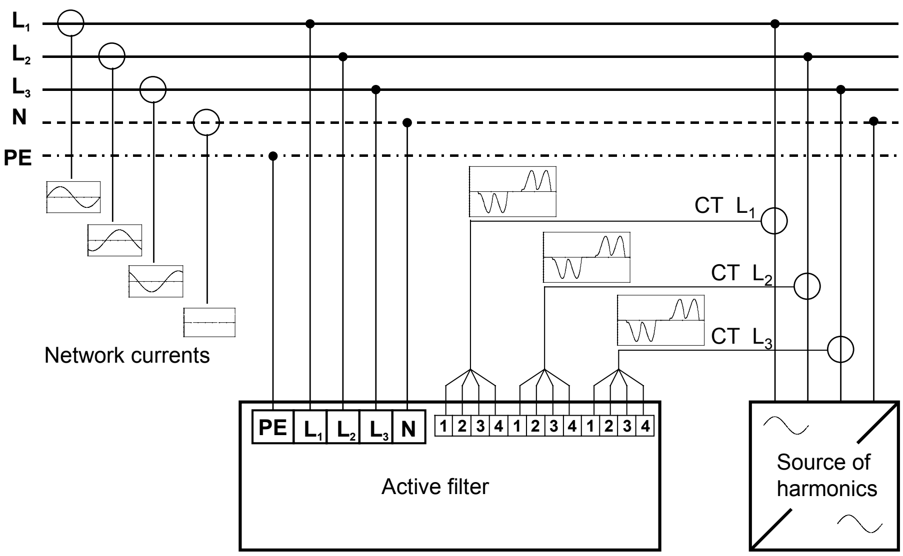



Figure 7. Connection of the active filter to 3-phase 4-wire supply system.

Figure 8 shows the block diagram of the active filters with its main components.

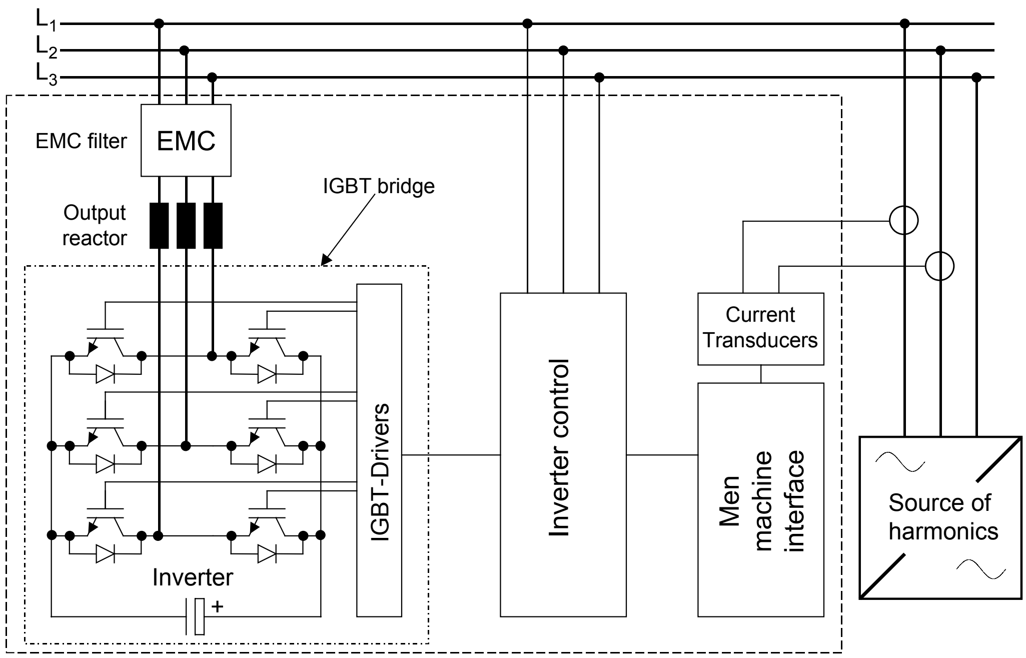



Figure 8. Connection of the active filter to 3-phase 4-wire supply system.

## Experiences with shunt active filter

To demonstrate the operation of shunt active filter measurement was made at a DC-drive without and with shunt active filter Figure 9. As can be seen the curve form of the supply current is almost fundamental current only when active filter is on. It should also be noted that the fast changes of the supply current can be followed easily.

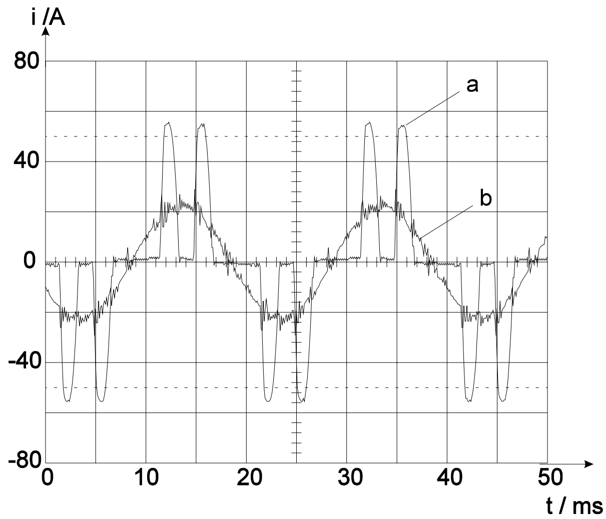



Figure 9. Network current of a DC-drive without active filter (a) and with shunt active filter (b).

Another example shows the high dynamics of the shunt active filter when compensating fast changing harmonic producing loads. In Figure 10 there is the current of a lift drive while accelerating without shunt active filter with the typical 6-pulse rectifier current curve form. In Figure 11 there is the same current when active filter is on. Comparison of the Figures 10 and 11 reveals that harmonics are effectively compensated and the system being loaded with fundamental current only.

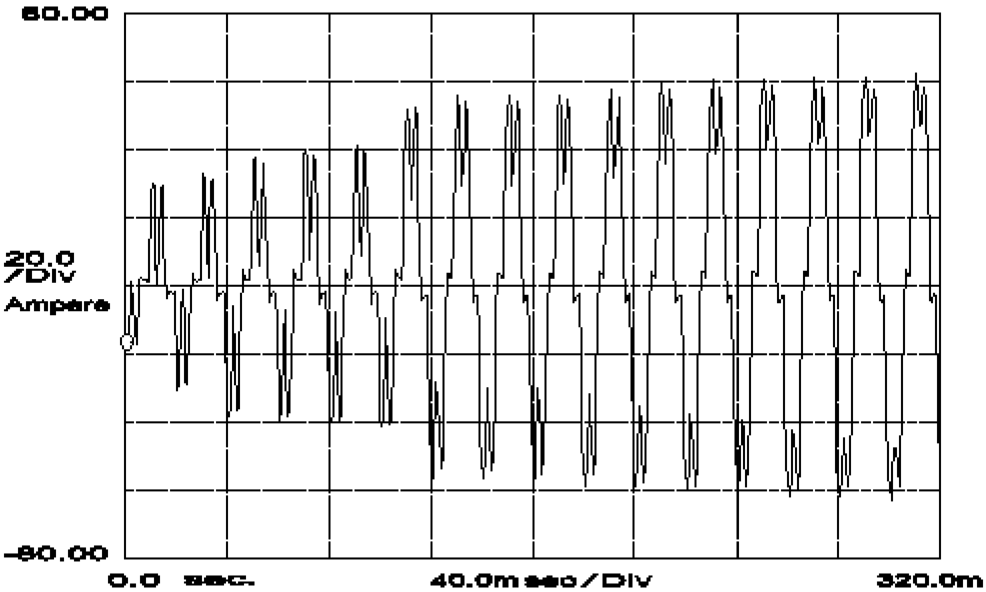



Figure 10. Supply current of a lift drive while accelerating without active filter.

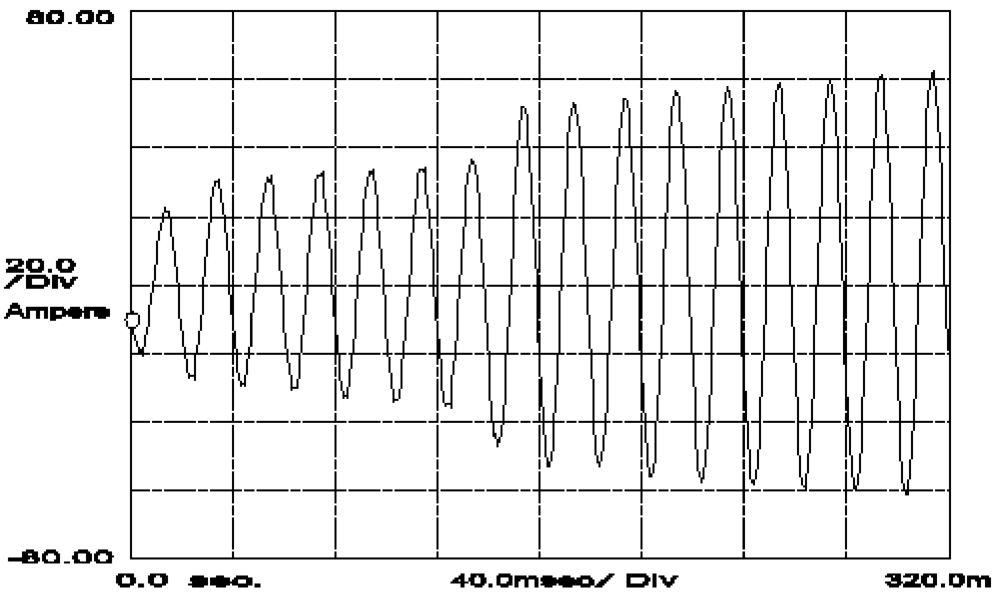



Figure 11. Supply current of a lift drive while accelerating with active filter.

**Comparison of shunt active and passive filters.**

When there is a need to compensate significant fundamental reactive power of relatively stabile harmonic producing loads the passive filters have turned out to be economically justified. With passive filters both reactive power compensation and harmonic filtering can be made at the same time.

When there is a need to compensate fast changing harmonic currents and fundamental reactive power active filters are the right solution. Very short response time of the active filters allows the better utilization of the supply system in respect of the voltage fluctuations.

**The range of available shunt active filters**

| **Current $I_{RMS}$:** | 3-phase 3-wire systems 400V, 50/60Hz | 3-phase 4-wire systems 3x230V, 50/60Hz |
|---|---|---|
| **25 A** | 3L/*17 kVA (40 A)* | 4L/*17 kVA (40 A)* |
| **30 A** | 3L/*20 kVA (45 A)* | 4L/*20 kVA (45 A)* |
| **35 A** | 3L/*25 kVA (50 A)* | 4L/*25 kVA (50 A)* |
| **40 A** | 3L/*28 kVA (60 A)* | 4L/*28 kVA (60 A)* |
| **50 A** | 3L/35 *kVA (75 A)* | 4L/35 *kVA (75 A)* |
| **60 A** | 3L/42 *kVA (100 A)* | 4L/42 *kVA (100 A)* |
| **70 A** | 3L/*50 kVA (110 A)* | 4L/*50 kVA (110 A)* |
| **85 A** | 3L/6*0 kVA (130 A)* | 4L/6*0 kVA (130 A)* |
| **100 A** | 3L/*70 kVA (150 A)* | 4L/*70 kVA (150 A)* |
| **140 A** | 3L/*100 kVA (200 A)* | 4L/*100 kVA (200 A)* |
| **200 A** | 3L/*140 kVA (300 A)* | 4L/*140 kVA (300 A)* |
| **260 A** | 3L/*180 kVA (400 A)* | 4L/*180 kVA (400 A)* |

Legend:

3L: for 3-phase 3-wire systems
4L: for 3-phase 4-wire systems with zero sequence harmonics and asymmetrical loads

In brackets: the peak value of the current to be compensated

Please note that in case one active filter is not big enough it is possible to connect several active filters parallel to reach required rated current.

The four wire active filters are available in three different variations:
Neutral current can be 1-time, 2-times or 3-times line current.

**Application of shunt active filters**

It should be noted that active filters can be designed to compensate both harmonic currents and fundamental reactive power.

Additionally to the system voltage $U_L$ the following parameters of the current to be compensated have to be determined to be able to design the capacity of the shunt active filter:

1. The root-mean-square of the current to be compensated $I_{RMS}$
2. The amplitude $I_S$
3. The rate of rise of the current $\frac{di}{dt}$
4. The harmonic coefficient $k_i$
5. For the 4-wire shunt active filter: The geometric sum of all harmonics divisible by 3.

Rated output of the shunt active filter for 3-wire and 4-wire application for the compensation of the harmonic currents:

$$D_{MAX} = \sqrt{3} \times U_L \times I_{RMS} \times k_i$$

Rated output capacity of the shunt active filter for single phase application for the compensation of the harmonic currents:

$$D_{MAX} = U \times I_{RMS} \times k_i$$

Rated output of the shunt active filter for 3-wire and 4-wire application for the compensation of the harmonic currents and reactive power:

$$Q_{MAX} = \sqrt{D_{MAX}^2 + Q_{1MAX}^2} = \sqrt{(\sqrt{3} \times U_L \times I_{RMS} \times k_i)^2 + Q_{1MAX}^2}$$

Rated output of the shunt active filter for single phase application for the compensation of the harmonic currents and reactive power:

$$Q_{MAX} = \sqrt{D_{MAX}^2 + Q_{1MAX}^2} = \sqrt{(U \times I_{RMS} \times k_i)^2 + Q_{1MAX}^2}$$

Please note that the standard crest factor of the current of the shunt active filter is $\sqrt{2}$.

Definitions:

Active power P: $P = U \times I_1 \times \cos\varphi_1$, where $I_1$ is fundamental current and $\varphi_1$ is the angle between voltage and fundamental current

Apparent power $S_1$: Fundamental apparent power $S_1 = U \times I_1$

Reactive power $Q_1$: Fundamental reactive power $Q_1 = U \times I_1 \times \sin\varphi_1$

Displacement factor $\cos\varphi_1$: $\cos\varphi_1 = \frac{P}{S_1}$

Total apparent power S: $S = U \times I = U \times \sqrt{I_1^2 + I_2^2 + I_3^2 + .....}$

Total reactive power Q: $Q = \sqrt{S^2 - P^2}$

$$Q = \sqrt{(U \times I_1 \times \sin\varphi_1)^2 + U^2 \times (I_2^2 + I_3^2 + ....)}$$

The reactive power consists of fundamental reactive power Q1 and distortion reactive power D.

Distortion reactive power D: $D = U\sqrt{I_2^2 + I_3^2 + I_4^2 ....} = U\sqrt{\sum_{h>1}^{oo} I_h^2}$

Content of the fundamental frequency $g_i$: $g_i = \frac{I_1}{I}$

Harmonic coefficient $k_i$: $k_i = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 ....}}{I}$

$$k_i = \frac{\sqrt{I^2 - I_1^2}}{I}$$

$$k_i = \sqrt{1 - g_i^2}$$

$$k_i^2 + g_i^2 = 1$$

Power factor $\lambda$: $\lambda = \frac{P}{S} = g_i \times \cos\varphi_1$

Current harmonic total distortion $THD_i$: $THD_i = \frac{\sqrt{\sum_{n>1}^{\infty} I_n^2}}{I}$