Application Notes

PQS

Power Factor Correction
Detuned Filtering in Paper Mills

Power Quality Solutions

www.epcos.com/pfc

The collection of “PQS Application Notes” is a library with in-depth information on PFC applications, case studies and reference projects. It also serves as a helpdesk for all topics relating to PFC and PQS, is suitable for training purposes and is designed to answer frequently asked questions.

Each issue focuses on a particular application, a specific solution or a topic of general interest. The aim is to share the extensive knowledge gained globally by EPCOS PFC experts with regional staff who deal with PFC and PQS. The authors of the PQS Application Notes have extensive experience in the field of PFC and PQS and a professional background as electrical/design engineers or product marketing managers throughout the world.

These PQS Application Notes are issued from time to time and can be downloaded from the EPCOS Internet under www.epcos.com/pfc

Please contact the EPCOS PM department in Munich if you wish to receive the latest issue of the PQS Application Notes automatically by e-mail. A list with available titles may also be obtained from the PM department in Munich.

Important Notes

Some parts of this publication contain statements about the suitability of our products for certain areas of application. These statements are based on our knowledge of typical requirements that are often placed on our products for a particular customer application. It is incumbent on the customer to check and decide whether a product is suitable for use in a particular application. This Application Note may be changed from time to time without prior notice. Our products are described in detail in our data sheets. The Important Notes (www.epcos.com/ImportantNotes) and the product specific warnings and cautions must be observed. All relevant information is available through our sales offices.

Foreword

Even in times when paperless communication is becoming increasingly important, the paper industry is booming. Almost no area of social or industrial life can dispense with paper: it is needed everywhere, for instance for banknotes, newspapers, tissues and books.

Paper production started in China almost 2000 years ago. So it's no wonder that one of the largest paper mills in the world is now also located in China: Dongying Huatai (Shandong) Paper Industry Co. Ltd. was founded in 1976; its production reached 150,000 tons of paper in 2006, with a rising trend.

Huatai has two targets that seem to be contradictory at first glance: they are investing in expansion and in environmental protection. In order to increase its power quality – thus stabilizing and enhancing its production output – Huatai has implemented detuned systems for PFC.

By reducing the harmonic content in the power line and the consumption of reactive power, not only have the economic targets been realized, but a major contribution was also made to reducing hazardous greenhouse gases.

The Author

Chen Gang

EPCOS Senior Technical Engineer with more than ten years design experience in electronics and electrical engineering. He is responsible for PFC technical support in Greater China and is located in Shanghai.

Contents

Power Factor Correction

PFC in Paper Mills – Detuned Filtering at Dongying Huatai

1. The history

In the year 105 AD, the Chinese minister of agriculture Tsai Lun was the first to report about the **complicated production** of paper. The material used was made of silk scrap, mixed with old rags, fishing nets and bast fibers from the mulberry tree. These ingredients were soaked, cleaned, mashed and boiled. The resulting mixture was skimmed, dried and pressed – a sheet of paper ready to use not only for writing but also for house decoration and even for clothing.

Fig. 1: Paper making in old China

Paper-making was a very **tough handicraft**. Not until the end of the 18th century did the production process become automated. French inventor Nicholas-Louis Robert opened the gates to mechanical paper production – the machine he developed could produce a roll of paper of any length. More and more people from different countries enhanced the paper-making process – culminating in **today's paper industry**. And this industry is booming: there is hardly any other product that is used as widely as paper: for banknotes, newspapers, books, wallpaper, tissues, business cards etc. even in times when the call for a paperless office is omnipresent, the paper industry is growing.

2. The company

1,871 years after paper production was first documented in China, **Dongying Huatai (Shandong) Paper Industry Co. LTD.** was founded. Huatai has now become the largest base for newspaper production in the world. Its exports reached a volume of 150,000 tons of paper in 2006. But Huatai is not only trying to achieve higher shareholder value and turnover – it also endeavors to deal fairly and responsibly with the environment.

Li Jianhua, Chairman of the Huatai Group, says: **"**Huatai is involved in the **global economic wave**. So it does its best to be an energy-saving and environmentally friendly enterprise whose ecological strategies include international alliances."

In an application with such a wide variety of loads as those found in a paper mill, harmonics and their negative impact on power quality are the major problem.

Economy and ecology – two targets that seem to be contradictory at first glance. The economy calls for more – more expansion, more output, more turnover – while ecology calls for less: lower CO_2 emissions, less waste of energy, less over-exploitation of natural resources. Unreliable operation of production equipment due to poor power quality reduces production output due to machine breakdowns. Apart from this visible effect of harmonics, damage to the equipment due to high currents and subsequent thermal overloads is to be expected. In addition, the **consumption of reactive power** not only has a positive impact on the electricity bill: the reduction of – idle – reactive power helps to decrease emissions of the harmful greenhouse gas CO_2. The management of Huatai was convinced that **both targets can be combined,** and they are right. EPCOS power quality solutions can satisfy both demands.

Fig. 2: Paper-making today

3. The first project

Together with technical experts from Siemens, Huatai found a suitable way to realize both targets. **Systems for detuned power factor correction** are a proven way to achieve:

- stabilization of the power supply
- reduction of harmonics
- reduction of reactive power consumption
- increase of power quality
- maximum utilization of apparent power
- minimization of CO_2 emissions by reducing power losses.

The Huatai management thus decided to invest in **a first installation** of detuned PFC systems.

Initial conditions:

Type of load:	Drives, inverters, UPS, motors, resistor heating, lighting
kW installed:	40,000 kW
System voltage:	400 V and 690 V
Frequency:	50 Hz
Fault level:	75 kA

Transformer data:

Primary voltage:	10 kV
Secondary voltage:	400 V and 690 V
Short circuit voltage U_k:	6%
Power 1:	10 kV / 0.4 kV
Split into:	6 x 1600 kVA 8 x 2000 kVA
Power 2:	10 kV / 0.69 kV
Split into:	2 x 2000 kVA 4 x 3150 kVA

Thanks to their excellent reputation obtained over many years of successful application in power quality solutions, capacitors and key components from EPCOS were chosen for these tailor-made, detuned PFC systems.

The first installation has a total output of:
16 200 kvar
divided into 20 systems

Power-line voltage	400 V
Output	9800 kvar 7 x 600 kvar 7 x 800 kvar
Power-line voltage	690 V
Output	6400 kvar 4 x 1200 kvar 2 x 800 kvar

PQS components from EPCOS:

PFC capacitors of MKK type,
PhaseCap series **400 V power line:**

- MKK480-D-25-01(B25667B4347A375)
- MKK480-D-16.7-01 (B25667B5237A375)

PhaseCap series **690 V power line:**

- MKK800-D-25-11 (B25668A7127A375)
- MKK800-D-12.5-11 (B25668A7626A375)

EPCOS high-linearity anti-resonance harmonic filter reactors with a detuning factor of 7%:

- 400 V: 50 kvar – B44066D7050S400
- 690 V: 50 kvar – B44066D7050S690

PFC controller for up to 12-step standard PFC systems – B44066R6012S230

By choosing a detuned PFC system, the main target of the company – stabilizing the power supply and improving the power quality – was achieved by reducing the harmonics in the power network.

4. The second project

This first installation was realized in 2005 and was so successful that **Huatai decided to invest further** in power quality improvement and environmental protection. Key PFC components from EPCOS have now been installed in two of Huatai's three production sites. The second tailor-made PFC solution was installed in March 2007.

Initial conditions:

Type of load:	Drives, inverters, UPS, motors, resistor heating, lighting
kW installed:	20 000 kW
System voltage:	400 V and 690 V
Frequency:	50 Hz
Fault level:	75 kA

Transformer data:

Primary voltage:	10 kV
Secondary voltage:	400 V and 690 V
Short circuit voltage U_k:	6%
Power 1:	10 kV / 0.4 kV
Split into:	1 x 1000 kVA 3 x 1600 kVA 4 x 2000 kVA
Power 2:	10 kV/ 0.69 kV
Split into:	1 x 2000 kVA 2 x 2500 kVA

This second installation has a total output of:
8200 kvar
divided into 11 systems

Power-line voltage	400 V
Output	5400 kvar 1 x 400 kvar 3 x 600 kvar 4 x 800 kvar
Power-line voltage	690 V
Output	2800 kvar 1 x 800 kvar 2 x 1000 kvar

Due to the excellent prior experience, the same EPCOS components were used as for the first installation.

- PhaseCap PFC capacitors, PFC controllers and harmonic filter reactors with a 7% detuning factor.

5. Principle of detuned filtering

The increasing use of modern power electronics such as converters, variable speed drives, uninterruptible power supplies and power semiconductors increasingly loads the power line with non-sinusoidal currents and voltages. These deviations from the **perfect sinusoidal shape** can be described as currents/voltages at multiples of the basic line frequency of 50/60 Hz, e.g. the 5th harmonic at 250/300 Hz or the 7th harmonic at 350/420 Hz. This frequency description is obtained by performing a **Fourier transformation** of the current–over-time spectrum to the current-over-frequency spectrum. As a rule, only the odd multiples of the base frequency are present and the 3rd harmonic and its multiples only appear in systems with a neutral conductor. In addition, the harmonic spectrum of quite unique for individual types of devices. For example, 6-pulse converters are known to produce 5th and 7th harmonics of about 30% and 10% of the base 50 Hz current.

In a power distribution system with such nonlinear loads, the fundamental current will flow from the generator/transformer to all loads. But the harmonic currents produced at the nonlinear loads will flow from these to the whole system. These additional currents can harm the installations in many ways. They act as additional currents that cause extra losses without contributing to useful work and may cause meters, breakers or switches to fail. Due to the **skin effect**, high-frequency currents flow preferentially across the surface of conductors. So harmonics lead to even higher losses and often cause conductors, transformers and rotating equipment to overheat.

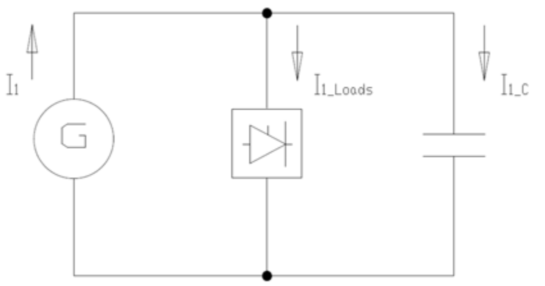


Fig. 3: Base frequency current flowing to the loads

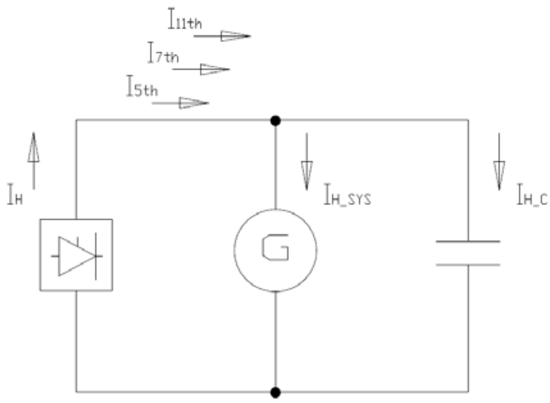


Fig. 4: Harmonic currents caused by nonlinear loads

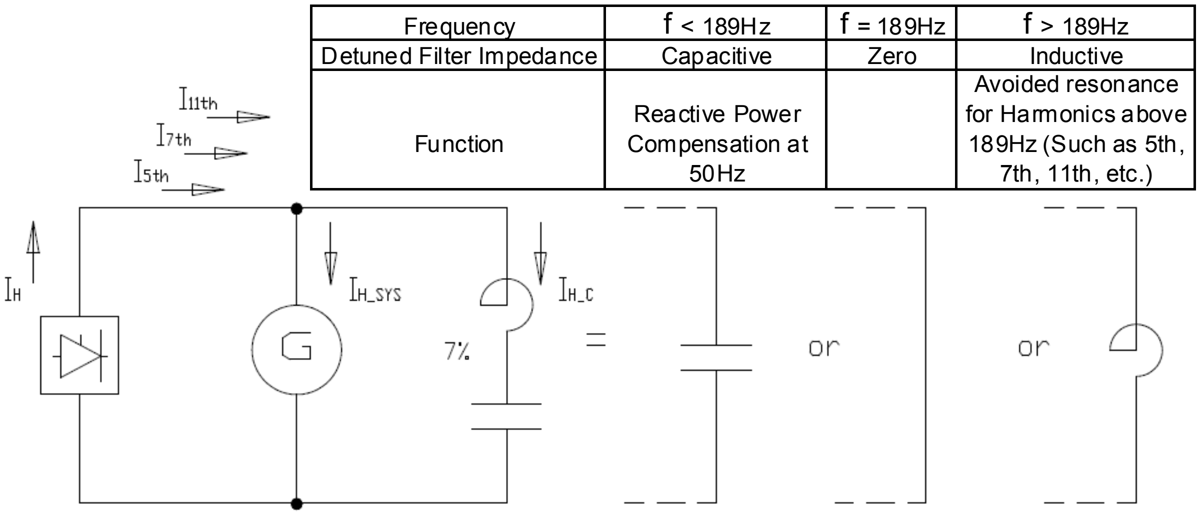
If standard PFC is applied and filter reactors are not used, the capacitance of the power capacitor forms a resonant circuit in conjunction with the inductance of the feeding generator/ transformer. Experience shows that the self-resonant frequency of such a circuit is typically between 250 and 500 Hz and thus in the region of the 5th and 7th harmonics.

So in a system where harmonics are present there is a danger that a resonance state and the respective extreme currents may occur and cause severe damage.

Resonance can lead to the following undesirable effects:

- overloading of capacitors
- overloading of transformers and transmission equipment
- overloading of production equipment
- interference with metering and control systems, computers and electrical gear
- severe resonance elevation, i.e. amplification of harmonics
- severe voltage distortion and subsequent effects

These resonance phenomena can be avoided by connecting capacitors in series with filter reactors, thus producing a special series resonant circuit. The capacitor and reactor are dimensioned to match the requirement for reactive power compensation. In addition, the series resonant frequency of the resonant circuit is suitably modified by the reactor to achieve the situation described in the graph below. In this project, the resonance frequency is fixed at 189 Hz (detuning factor is 7%).



Frequency	f < 189Hz	f = 189Hz	f > 189Hz
Detuned Filter Impedance	Capacitive	Zero	Inductive
Function	Reactive Power Compensation at 50Hz		Avoided resonance for Harmonics above 189Hz (Such as 5th, 7th, 11th, etc.)

Fig. 5: Properties of a detuned PFC installation depending on the frequency

As a rule, the resonant frequency is selected to be below the lowest harmonic frequency (in this example, the 5th). Below this frequency, the system will act in a capacitive way and compensate the reactive power at 50 Hz. Above this frequency, however, the detuned PFC system acts in a purely inductive way and resonance in the complete installation is avoided. Depending on the detuning ratio, the impedance above the filter frequency is set to withdraw the harmonics from the installation to a certain extent (e.g. 5.7% or 7%). In case of extreme harmonic contents (e.g. THD-V above 10%), this method of withdrawing the harmonics through the PFC system is no longer possible as the capacitors would be overloaded. In this case, a 14% detuning will set the impedance to avoid resonance and allow PFC because all harmonic currents are blocked by the PFC setup.

Customer benefits of detuned PFC

- Elimination of reactive power drawn from power utilities, reduced electricity costs
- Reduction of harmonic voltage and current distortion
- Avoidance of resonance
- Lower investment for new equipment due to cutting off kVA loads
- Stabilizing line voltage, power supply
- Overall improvement of power quality
- Longer service life of equipment
- Reduced maintenance cost
- Lower failure risk for production equipment

6. Harmonics measurement and analysis example

The Huatai paper mill is split into **several segments** according to the individual papermaking processes. Transformer line 3-TD06 was chosen for sampling because it contains the largest number of nonlinear loads in the factory.

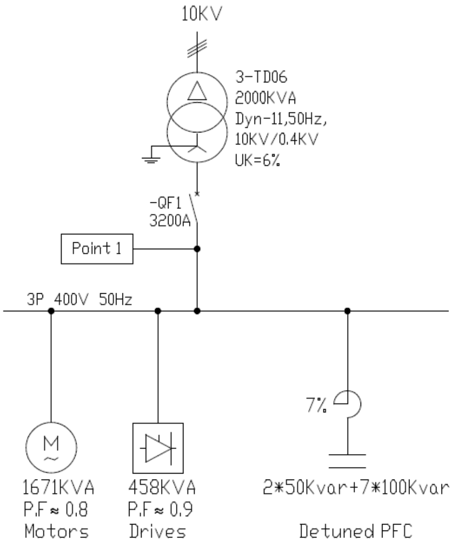


Fig. 6: Single line diagram for transformer line 3-TD06 including the detuned PFC system

At standard operating conditions, the total power of the loads is approximately 600 kW. Measurements to determine the harmonic load in the system were taken at point 1 (output/secondary side of the transformer).

Fig. 7: The PFC system

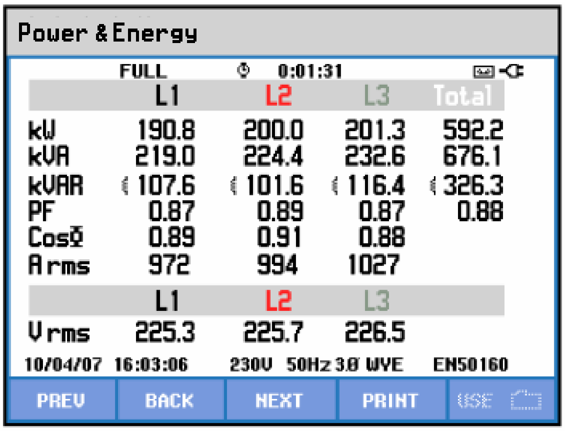
PFC system details

For this section of the paper mill, a PFC system with a total capacity of 800 kvar was installed in two cabinets. It was overdimensioned in view of possible future expansion of the factory. Also, relatively high compensation steps were designed-in as the loads in this production part are usually at a high level. To follow the reactive power load appropriately, two steps of 50 kvar and seven steps of 100 kvar were implemented. A 100 kvar step was realized by connecting two 50 kvar steps to the same output of the PFC controller. So the system is composed of 16 identical capacitor/reactor combinations. As already noted, the detuning factor is 7%, corresponding to a filter frequency of 189 Hz. The accuracy of the PFC system was improved further by utilizing the integrated intelligent switching sequence built into the EPCOS PFC controller.

7. Measurement with and without the EPCOS 7% detuned PFC-system

To investigate the efficiency of the setup, measurements to determine the basic power-line parameters and the harmonics were performed with and without the PFC system. The 3-phase power quality analyzer FLUKE 434 was used for the measurement and was connected to determine the parameters of interest at point 1 in the single-line diagram.

A) Basic power-line parameters



Power & Energy

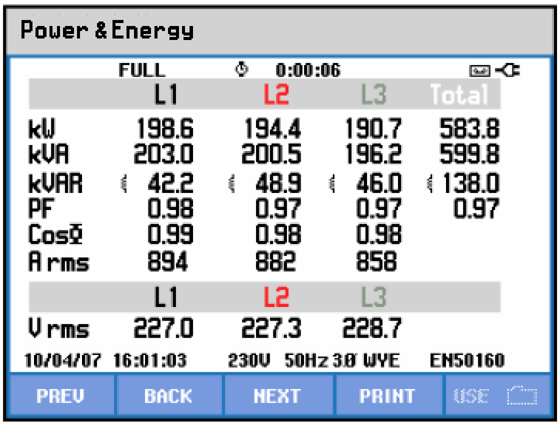
FULL 0:01:31

	L1	L2	L3	Total
kW	190.8	200.0	201.3	592.2
kVA	219.0	224.4	232.6	676.1
kVAR	107.6	101.6	116.4	326.3
PF	0.87	0.89	0.87	0.88
CosΦ	0.89	0.91	0.88	
Arms	972	994	1027	

	L1	L2	L3
Vrms	225.3	225.7	226.5

10/04/07 16:03:06 230V 50Hz 3Ø WYE EN50160

Fig. 8: Screenshot of the basic power-line parameters without PFC



Power & Energy

FULL 0:00:06

	L1	L2	L3	Total
kW	198.6	194.4	190.7	583.8
kVA	203.0	200.5	196.2	599.8
kVAR	42.2	48.9	46.0	138.0
PF	0.98	0.97	0.97	0.97
CosΦ	0.99	0.98	0.98	
Arms	894	882	858	

	L1	L2	L3
Vrms	227.0	227.3	228.7

10/04/07 16:01:03 230V 50Hz 3Ø WYE EN50160

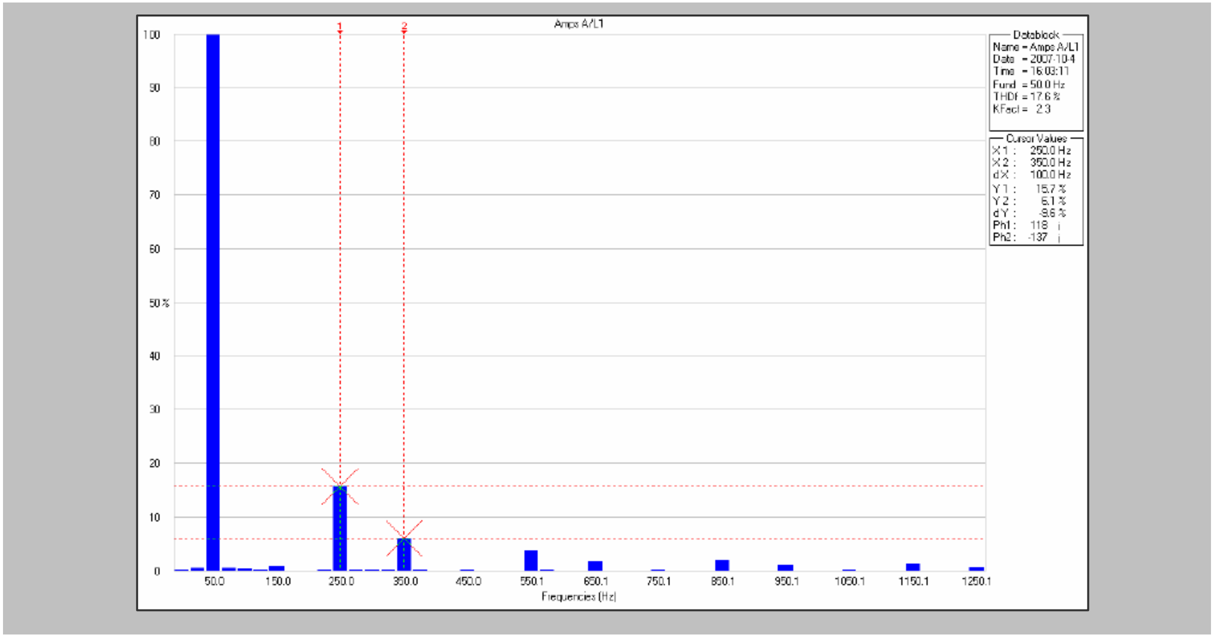
Fig. 9: Screenshot of the basic power-line parameters with PFC

Considering a target value for the cos-φ of 0.98 and using the values measured without PFC, the necessary compensation power for this factory segment can be calculated by the following formula:

$$Q = P \times \left(\tan\left(\arccos\varphi_1\right) - \tan\left(\arccos\varphi_2\right)\right)$$
$$= 592kW \times (0.5397 - 0.2031) = 199k\,\mathrm{var}$$

The measurement in Fig. 9 is taken at the target cos-φ of 0.98, and two 100 kvar steps are switched-in by the controller during the second measurement.

B) Harmonics



Datablock
Name = Amps A/L1
Date = 2007-10-4
Time = 16:03:11
Fund = 50.0 Hz
THDf = 17.6 %
KFact = 2.3

Cursor Values
X1 : 250.0 Hz
X2 : 350.0 Hz
dX : 100.0 Hz
Y1 : 15.7 %
Y2 : 6.1 %
dY : -9.6 %
Ph1 : 118 °
Ph2 : -137 °

Fig. 10: Without PFC, the 5th and 7th harmonics dominate in the factory segment. The THD-V (total harmonic voltage distortion) is 4.4%, the THD-I (total harmonic current distortion) 17.6%.

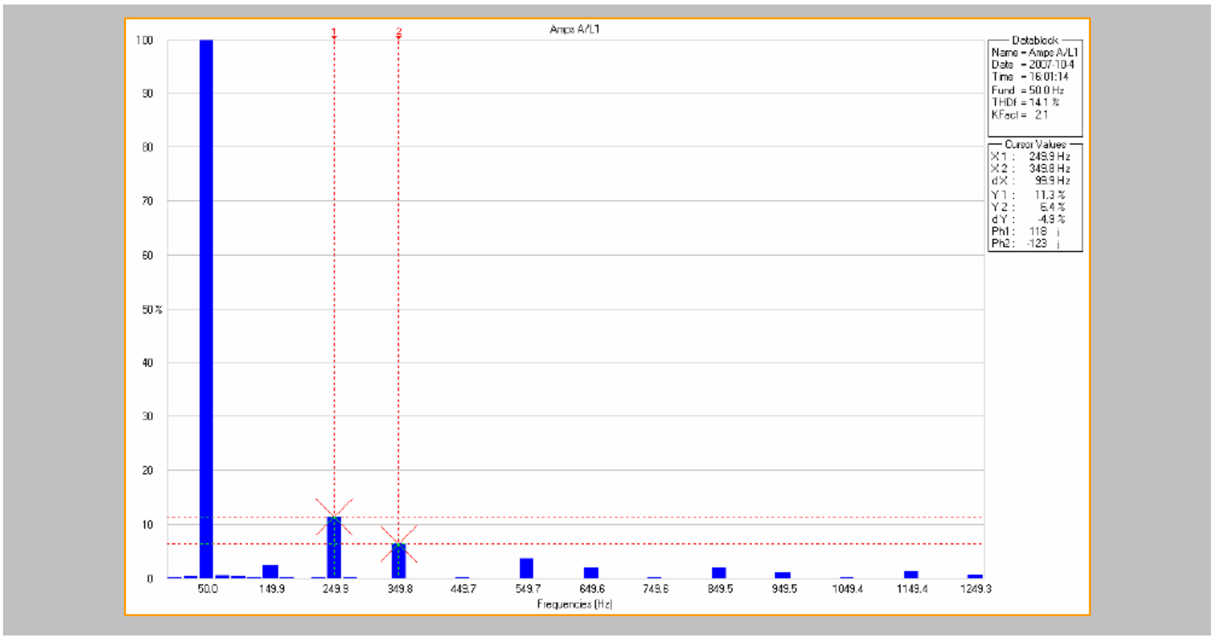


Fig. 11: With detuned PFC, the 5th and 7th harmonics still dominate. Compared with the situation without PFC, however, they have greatly decreased. The current of the 5th harmonic declined by 32.2%. Overall, the THD-V is now 3.7% and the total THD-I is 14.1%.

8. Conclusions

A detailed comparison of the measured values is given in the table below. The following overall summary/conclusions can be drawn:

- By operating a detuned PFC system, the target cos-φ value 0.98 was reached.
- The dominant 5th harmonic was reduced by 32% from 146 A to 98.8 A.
- The harmonic voltage distortion was reduced by 15% from 4.4% to 3.7%. The remaining distortion is within the limits of the international standards and should not lead to problems.
- The apparent power was reduced by 11% from 676 kVA to 599.8 kVA. The input transformer and distribution equipment can consequently be used more effectively for active power distribution.

The overall conclusion is very simple: all **targets achieved**! Installing a detuned PFC system has improved the power quality and optimized utilization of the installed equipment. In combination with the successful avoidance of power factor penalties, this leads to higher profits and reduced CO_2 emissions. The two targets that seemed so incompatible at first glance have been successfully reached in harmony with each other.

9. Standards

The recommendations and proposals stated in this Application Note are based (amongst others) on several international standards for PFC capacitors, LV switchgear design and electrical systems:

- IEC60831: LV-PFC Capacitor Standard
- IEC61921: Power Capacitors LV PFC banks
- DIN EN61921: Leistungskondensatoren Kondensatorbatterien zur Korrektur des Niederspannungsleistungsfaktors
- EN 50160: Voltage Characteristics of Electricity Supplied by Public Distribution Systems
- Engineering Recommendation G5/4: Planning levels for harmonic voltage distortion and the connection of non-linear equipment to transmission systems and distribution networks in the United Kingdom
- IEEE Standard 519-1992: IEEE Recommended practices and requirements for harmonic control in electrical power systems
- IEC60439-1/2/3: Low-voltage switchgear and control gear assemblies

The specifications in the standards and manufacturers’ data sheets should always be observed.

Published by

EPCOS AG

Product Marketing PFC

P.O. Box 80 17 09

D-81617 Munich/Germany