

HARMONIC FILTERS FOR INDUSTRIAL APPLICATIONS. TECHNOLOGY PROCUREMENT REPORT FROM THE SWEDISH NATIONAL ENERGY ADMINISTRATION.

N. Gothelf

Harmonizer Power Quality Consulting AB, Sweden

A. Lewald

Swedish National Energy Administration

SUMMARY

The Harmonic Filter Project was started in June 1998 and conducted as technology procurement directed and financed by the Swedish National Energy Administration. The project was supported by a purchase group consisting of the following companies: Fagersta Stainless, LKAB, AB Sandvik Steel, Fundia Special Bar, SSAB, Vasakronan, Scania Partner, MoDo Paper, Stora Paperboard AB and Korsnäs. The purpose of the project was to select a system capable to meet Industries' needs of harmonic filtering and reactive power compensation. The purchase group formulated the requirements and specifications for the product which became the basis for a "competition" among manufacturers throughout the world.

The Specification of User's Requirements called for a system suitable to serve dual purposes: reactive power regulation and harmonic filtering, located centrally on the low voltage side of distribution transformers. The reactive power compensation should be dynamic, regulated continuously or in steps, and extendible. The harmonic filter should be of active type or a combination of active and passive filters. As a part of the Framework Agreement with the winner, two pilot series filters were installed and tested - the first one at AB Sandvik Steel and the second one at Stora Enso, Gruvön. Both installations have been subjected to extensive verification tests. The results of the tests proved that the new filter technology has the potential to solve most of the harmonic related problems in industrial low voltage networks.

BACKGROUND

Electrical engineers responsible for design and maintenance of industrial networks are facing increased problems caused by harmonic pollution. Due to the recent developments in the power electronics field, a range of new energy effective devices such as DC rectifiers, frequency converters, soft starters, etc. have been introduced on the market. By means of these devices the manufacturing and processes can be run more efficiently and more economically. However, power electronics devices are by their nature not compatible with AC power systems. Rectifiers and converters constitute non-linear loads that draw non-sinusoidal currents. Consequently, a certain portion of energy is being injected to the network as harmonic currents causing thermal overloading and interference

with network components and equipment. Common solutions to p.f. improvement and harmonic filtering are passive filters built up of capacitors and reactors tuned to a certain frequency. The users have generally found that, although the passive harmonic filters presently available on the market have demonstrated their filtering and power factor improvement potential, they have not fully satisfied the users' expectations. The main disadvantages of passive filters are: sensitivity to changes of the network's impedance and sensitivity to changes of harmonic generation. Since many installations have suffered high failure rate and severe equipment damages, industries tend to avoid compensation on the low voltage side and are even restrictive in using frequency converters.

HARMONIC FILTER PROJECT

Discussions with representatives of the Swedish industry have indicated, that availability of reliable p.f. correction and harmonic filter devices would remove some of the obstacles to invest in energy effective equipment. Since one of the main tasks of the Swedish National Energy Administration is promotion of energy efficiency, it became obvious, that finding a solution to this problem is of great importance. It has therefore been decided to conduct a Harmonic Filter Project. The purpose of the project was to select a system capable of meeting Industries' needs of harmonic filtering and reactive power compensation.

The project has been performed in the following steps:

- Development of Specification of user's requirements.
- Announcement of the procurement.
- Evaluation of proposals.
- Framework Agreement with the successful Bidder
- Purchasing and installation of pilot series filters.
- Tests and evaluation of the pilot series filters.
- Main series procurement

The technology procurement has been conducted by the Swedish National Energy Administration together with a purchaser group that formulated the requirements and specifications for the product. The specification then became the basis for a "competition" among manufacturers throughout the world. The competition was announced in the Official Journal of the European Communities and thus open to all manufacturers of the product.

SPECIFICATION OF USERS' REQUIREMENTS

The general policy behind the preparation of the Specification has basically been:

- To provide the prospective manufacturer with the available information on the user's operating and maintenance environment and hence enable the manufacturer to optimise his design and choice of components.
- To express requirements in user terms, not in design terms. The Specification defines the required function and performance of the filter without limiting the manufacturer's choice of system design or components;

The Specification of User's Requirements called for a modular system located on the low voltage side of distribution transformer supposed to serve dual purposes: reactive power regulation and harmonic filtering. The reactive power compensation should be dynamic, regulated continuously or in steps, and extendible. The harmonic filter should be of active type or a combination of active and passive filters. The regulation of reactive power and harmonic filtering should be completely independent from each other, which means that maximum filtering capability should be possible to achieve without reactive power generation. The system should be capable of meeting the following requirements:

Systems Requirements

- System voltages : 400V, 525V and 690V.
- Transformer ratings: 1000 kVA , 2000 kVA and 3150 kVA
- Esc: <10 %
- Grounded or ungrounded neutral.

Harmonic Spectrum

The equipment should be designed for operation in networks with the maximum harmonic current generation as follows:

n	In(%)	n	In(%)
2	1	13	9
3	5	17	4
4	1	19	4
5	25	23	2
6	2	25	2
7	15		
9	3	25-40	1
11	9		

where

In (%) = harmonic current in percent of the transformer's nominal current.

Distortion Limits

The filter should be capable of reducing the voltage distortion on the busbar to values below the compatibility levels for industrial plants of class 1 according to IEC 1000-2-4 as follows:

n	Un (%)	n	Un (%)
2	2	13	3
3	3	17	2
4	1	19	1,5
5	3	23	1,5
6	0,5	25	1,5
7	3	>25 odd	0,2+12,5/n
9	1,5	>25 even	0,2
11	3	interharm	0,2
		THD	< 5

Reactive Power Generation

The reactive power regulation should be either continuous or in steps and extendible up to 1500 kvar. Suitable compensator type should be selected for each load category in order to obtain optimum solution from both the technical and economical point of view. The following load categories should be considered:

Category	Duration	Step
Quasi stationery	> 15 min	100 kvar
Fluctuating	> 2 min.	100kvar
Rapidly changing	> 0,1 sec.	100 kvar

Losses and Power Consumption

The total active power consumption of the filter (including losses) should not exceed the harmonic losses in the system prior to the installation of the filter.

Other Requirements

- The equipment should be compatible with other electrical equipment and other filters and capacitors in the system.
- The equipment shall not create any power quality problems such as resonance, over voltages, transients or voltage sags.
- The equipment shall be easily extendible both with respect to filtering and to reactive power compensation.
- The equipment shall not become overloaded when subjected to higher harmonic levels than specified above.

MAIN CHARACTERISTICS OF THE WINNING CONCEPT.

After an examination of the received proposals, the evaluation committee came to the conclusion that the solution proposed by ABB best satisfied the Specification requirements. ABB has therefore been nominated as a winner of the contest. The system proposed by ABB is a modular system consisting of active filters and dynamic compensators. The controller of the system is monitoring the operating conditions of the network and reduces the harmonic distortion and reactive power consumption to pre-programmed levels. The filter is capable of filtering up to 20 harmonics simultaneously up to the 50-th harmonic. The desired reactive power is generated by the active filter or by means of thyristor- or contactor switched capacitors.

PILOT SERIES FILTERS

As a part of the Framework Agreement, two pilot series filters were installed and tested - the first one at AB Sandvik Steel and the second one at Stora Enso, Gruvön. Both locations have been found especially suitable as test objects for the new technique. The load at Sandvik Steel consists of an electrolysis plant fed by an AC/DC rectifier with a low power factor and high harmonic distortion. The solution used in this case is an active harmonic filter rated 170 A and a passive detuned filter generating 3 x 200 kvar reactive power. The intention with this installation was to test both the performances of the active filter and the compatibility between active- and passive filters.

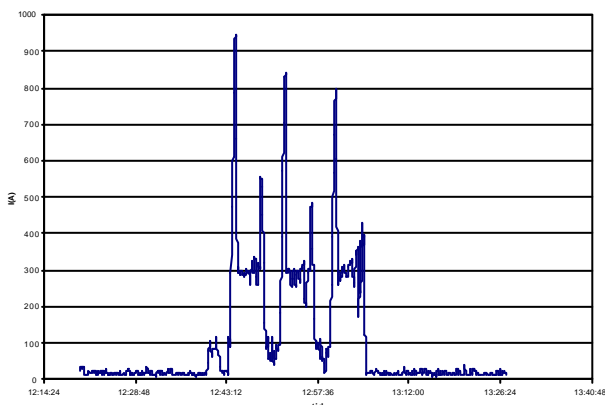


Figure 1 Stora Enso, Gruvön. Load cycle

The load at Stora Enso Gruvön consists of three frequency converters feeding a rewinding machine. A typical load cycle is shown on Figure 1. It consists of

three phases: acceleration, steady state operation and retardation. The special features of this load are: very fast load variations, high harmonic distortion during acceleration and retardation and low reactive power consumption. The Pilot installation consists in this case of an active filter rated 430 A. The purpose of this installation was to test the dynamic behaviour of the active filter.

VERIFICATION TESTS ON PILOT INSTALLATIONS

The pilot series filters have been subjected to an extensive test program where the following values have been monitored:

- Fundamental- and harmonic currents
- Harmonic voltages
- Power factor
- Active Power

The results can be summarised as follows:

Sandvik Steel

The verification measurements at Sandvik Steel have been conducted in a course of 14 days. The results are presented in figures 2-5. In order to simplify the evaluation of the results, the measured values with- and without filter are presented in one diagram as functions of active power.

The measurements' results demonstrate that the performance of the filter installation at Sandvik Steel is very satisfactory:

- The Total Harmonic Voltage Distortion VTHD has been reduced from 11,8% to 5,3%.
- The r.m.s. value of the current at maximum rectifier load has been reduced from 1420 A to 1050 A.
- The power factor at maximum rectifier load has been improved from 0,78 to 0,96.
- The total power consumption has decreased thanks to the higher Power Factor.

Stora Enso Gruvön

The results of the measurements are presented in figures 6-10. It can be concluded that the filter installation in Gruvön is performing very well.

- The 5-th harmonic current has been reduced from 425 A to 140 A during acceleration and from 150 A to 40 A during steady-state operation.
- The 7-th harmonic current has been reduced from 210 A to 140 A during acceleration and from 120A to 40 A during steady-state operation.
- The Total Harmonic Distortion VTHD has been reduced from 7% to 4% during acceleration and from 3,5% to less than 2% during steady-state operation.

- The Individual Voltage Distortion requirements have been fulfilled for frequencies up to 1250 Hz. The magnitudes of higher frequencies exceed however the specified levels.
- The filter losses are lower than the harmonics loss reduction obtained by harmonic filtering and reactive power compensation provided by the filter.

At two occasions of abnormal retardation of the motors, the magnitude of the generated harmonic currents exceeded the capacity of the filter. It could be concluded that such excessive harmonic generation didn't cause overload of the filter but resulted in temporary increased distortion level.

DISCUSSION

Some aspects of the project and the test results deserve special comments, which can be of interest for future applications:

Profitability

The active filters are sophisticated, semiconductor based products that offer a range of new filtering options. Some of the main advantages of active filters are:

- The filter does not affect the impedance of the network, i.e. does not create any resonance.
- The performance of the filter is not affected by changes of load or of network impedance.
- The filter enables selective choice of filtering with respect to harmonic frequencies and extent of filtering.
- Filtering of harmonics can be obtained independently from reactive power generation.
- Compact design.

Since there is a big difference between the performances of active- and passive filters it should be wrong to make a general cost comparison between these two products. Instead, a technical and economical evaluation must be made for each project. According to the experience of the project group, the active filter solution will give best profitability in applications where the above mentioned advantages can be utilised and thus result in technically and economically optimal solutions. As examples of such applications the following can be mentioned:

- Filtering of harmonics from 12-pulse drives (or drives with higher pulse order).
Comment: A solution with passive filters results in expensive and space demanding filters tuned to 5-th, 7-th, 11-th, ... harmonics.
- Filtering of harmonics generated by frequency converters with high harmonic distortion and high power factor, which requires harmonic filtering without reactive power compensation.
Comment: Such requirement is basically impossible to fulfil with passive filters where the main component is a capacitor.

- Application where the harmonic spectrum consists of both characteristic (5-th, 7-th, 11-th, 13-th,...) and non-characteristic harmonics (2-nd, 4-th, ...).
Comment: Passive filters can amplify the non-characteristic harmonics.
- Space limitation.
Comment: Active filter solutions are often more compact than solutions with passive filters.

In cases, where the advantages of active filters can not be utilised, for example when the harmonic spectrum is dominated by the fifth harmonic and generation of reactive power is desired, a combination of active and passive filters or passive filters only can still be an attractive solution.

High frequency disturbances.

In order to get some idea about the effects of active filters on high frequency disturbances, additional measurements in frequency range 3 – 100 kHz have been performed at Stora Enso, Gruvön. It could be concluded that high frequency disturbances with a magnitude of up to 2 V (< 0,5%) are present in the frequency range 3-50 kHz both when the filter is switched ON and OFF. The disturbances generated by the frequency converter are however better damped for frequencies higher than 10 kHz than the disturbances generated by the filter.

The design of both active filters and frequency converters is based on IGBT technology and thus both components generate high frequency disturbances at frequencies which are multiples of the switching frequency of the IGBT. The difference is that the load of a frequency converter consists of an AC motor while the output of an active filter is connected directly to the supplying network. Consequently, the effects of active filters on the system appear more evident than the effects of frequency converters.

At present, there are no requirements for limiting disturbances within the frequency range 2 -150 kHz. The active filters are therefore not equipped with special filters for these frequencies. In case it should be found that there are reasons for limiting emission of signals within the actual frequency range, the criteria for such limitation should be specified in coming procurements.

CONCLUSIONS

The project has demonstrated that the new filter technology has the potential to solve most of the harmonic related problems in industrial low voltage networks. The filter system fulfils the specified demands regarding voltage, reactive power, harmonic distortion, dynamics and user interface:

- The system is modular and can cover the specified voltage –and power range.

- The system has the capacity to fulfil filtering requirements with respect to the individual- and total harmonic distortion
- The system has the capacity to fulfil the compensation requirements for the specified load categories.

- The system fulfils the requirements of user friendly interface and monitoring of network- and filter status.

As a result of the positive experience with the pilot series filters, a number of Main series installations are being planned by the purchase group.

■ - Measurements with filter ◆ - Measurements without filter

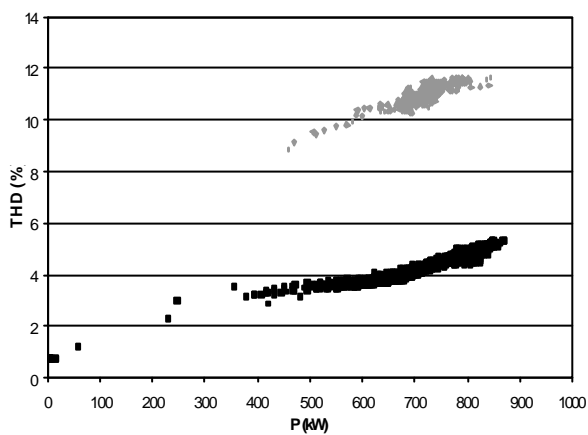


Fig. 2 Sandvik Steel. VTHD vs. active power

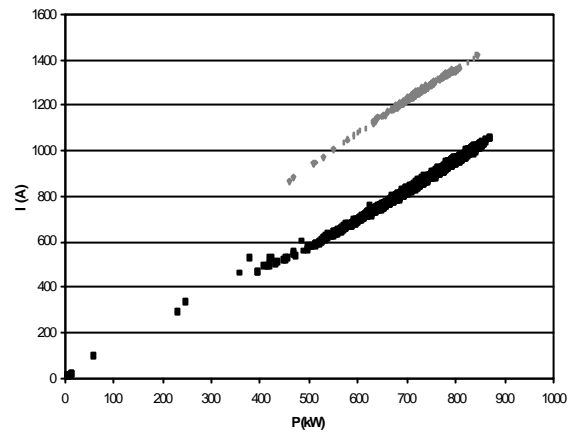


Fig. 3 Sandvik Steel. R.m.s current vs. active power

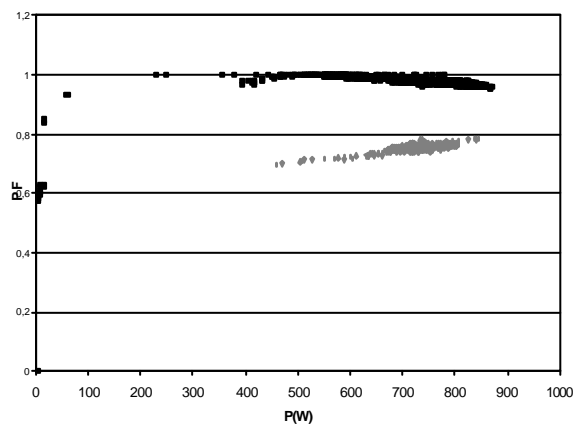


Fig. 4 Sandvik Steel. Power factor vs. active power

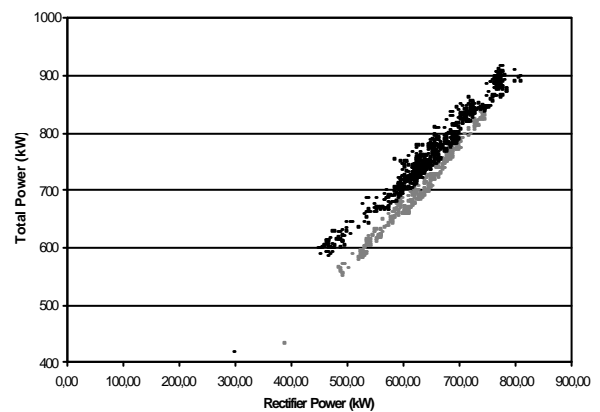


Fig. 5 Sandvik Steel. Total active power vs. active power of the rectifier

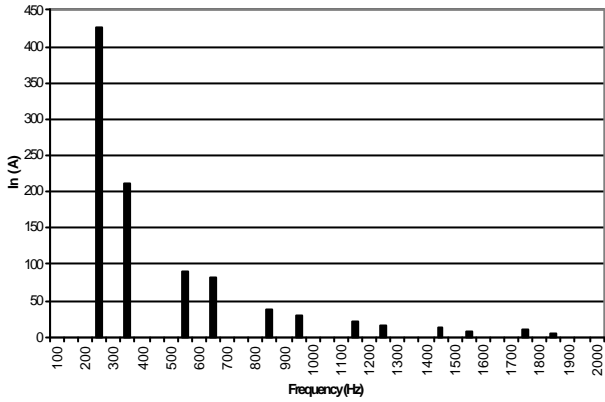


Fig. 6 Stora Enso, Gruvön. Max. harmonic currents without filter

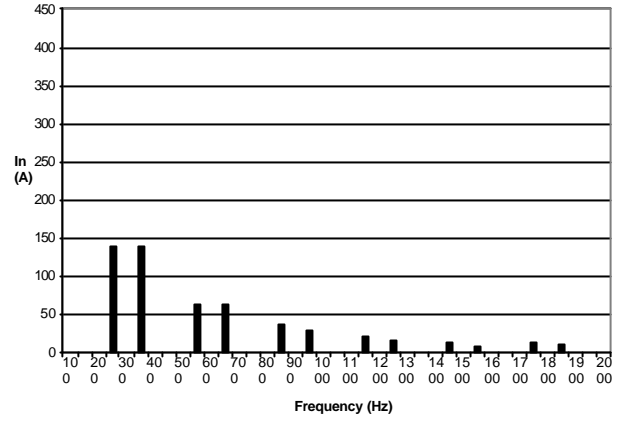


Fig. 7 Stora Enso, Gruvön. Max. harmonic currents with filter

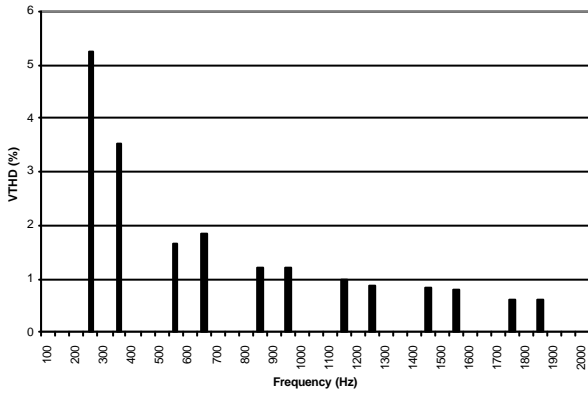


Fig. 8 Stora Enso, Gruvön. Max. voltage distortion without filter.

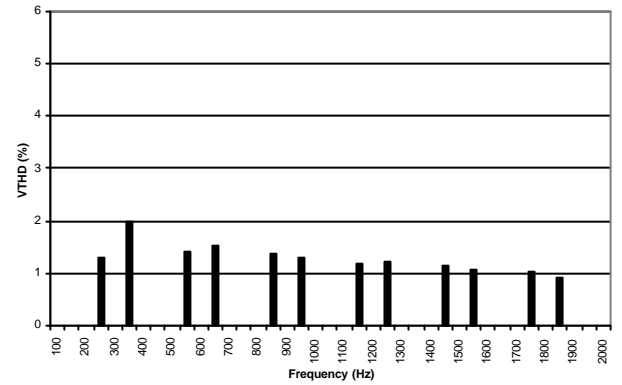


Fig. 9 Stora Enso, Gruvön. Max. voltage distortion with filter

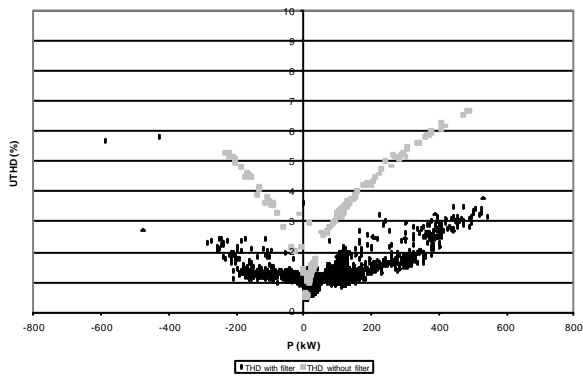


Fig. 10 Stora Enso, Gruvön. VTHD vs. active power