REVCON

ADM Engineering

Improve your grid with REVCON Power Quality Solutions

Marine

HVAC

Oil & Gas

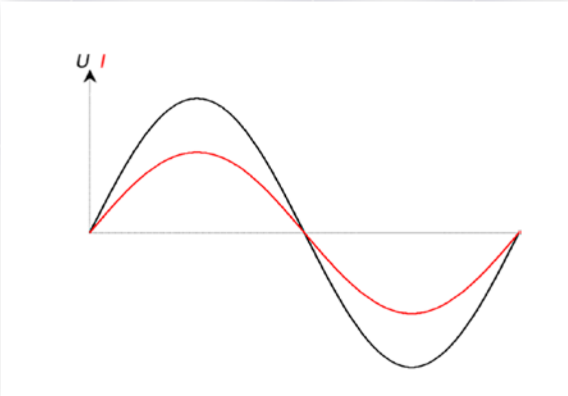
Water Treatment

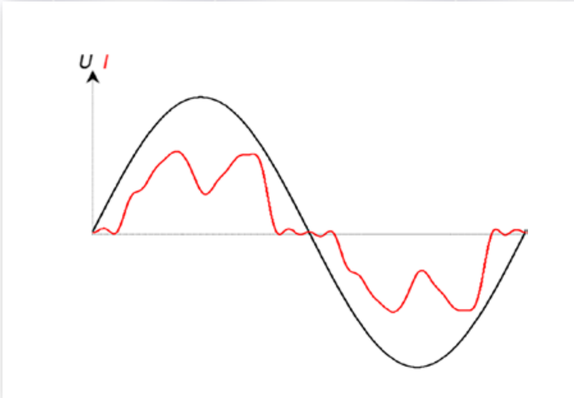
General Industry

HARMONIC DISTORTION, one of the biggest POWER QUALITY issues

“Alternating current is the form in which electric power is delivered to businesses and residences […]. The usual waveform of alternating current in most electric power circuits is a sine wave!” (Wikipedia)

Unfortunately, the Wikipedia statement above is incorrect, or at least simplified. The true waveform of our power supply is far away from an ideal sine wave. But how is this possible as most Generators produce a more or less pure sine wave output, who is the bad guy?





The red signal in the second picture is showing the input-current-shape of a standard drive with about 4% inductance and clearly, this is far away from sinus. Of course, the input-current-shape of any drive without inductance is significantly worse.

Linear and non-linear load

Electrical loads where the current is not proportional to the voltage are called non-linear loads. Linear loads are pure sinusoidal, and either resistive, inductive or capacitive.

Although there are many different sources of harmonic distortion, a very significant part is caused by variable frequency drives (VFD).

The voltage distortion caused by one 200kW drive, is about the same as 7,000 x 10W USB charger. REVCON harmonic solutions may be used in various applications, but are optimized for drive applications.

Evaluation of harmonic distortion.

The THD Total Harmonic Distortion is the most used evaluation for harmonic distortion, and is defined for voltage THDv and current THDi, both typically consider the harmonics up to the 40th or 50th.

$$\boldsymbol{THDi} = \frac{\sqrt{\sum_{n=2}^{n=40} I_n^2}}{I_1} \bullet 100\% = \frac{\sqrt{I_{h2}^2 + I_{h3}^2 + I_{h4}^2 + I_{h5}^2 + I_{h6}^2 + \cdots + I_{h40}^2}}{I_1} \bullet 100\%$$

Basically the THD is a good evaluation for Harmonic Distortion but it is not sufficient to give a full evaluation of the problems that may be caused by harmonics. Please visit www.revcon.de or read our “Harmonic Solution Guide” for more detailed information.

HARMONIC DISTORTION ISSUES

Non-linear loads are causing various different problems. The most obvious one is that equipment such as VFD´s are causing harmonic currents that will increase the input current of the system. A three-phase VFD without any inductance will cause a *THDi* of about 105%, which will increase the input current I_{RMS} by 43%. Typically these harmonics have reactive characteristics, but this higher input current will require significant higher sizing of wires, protective devices and will also cause significant higher power losses in the system.

Ohm´s law teach us, $V = I \bullet Z$, which means that due to the impedance of the system, every harmonic current, will cause a distortion of the voltage. The impact of this voltage distortion *THDv* is diverse, and the most typical effect is overheat of transformer and PFC applications (Capacitor banks). An underestimated impact of harmonic distortion is the significantly reduced lifetime expectation of electrical and mechanical equipment.

Transformers and PFC. Significant increase of power loss on any inductances or capacity results in reduced rating, lower expected lifetime, lower efficiency or even damaged equipment.

Electronic equipment usually have a rectifier with capacitor input, whose lifetime is significantly affected by voltage distortion. This results in immediate damage or significant reduced lifetime.

Motors and Generators direct on line follow the connected frequency! Supply voltage with additional frequencies (harmonics) are lethal for both mechanical and electrical side.

System Efficiency is directly affected by the harmonics as nearly all equipment and wires produce more heat when voltage distortion rise.

RHF = REVCON Harmonic Filter overview

RHF 5P/8P

The passive range is designed for <5 % or <8% THDi. 1.1kW–280kW in compact enclosure design 315kW–800kW in space saving panel design.

RHF Hybrid

For symmetrical loads , this unique technology offers the best performance for Harmonic mitigation on the market still saving costs compared to pure active solutions .

RHF Active

SiC MOSFET Technology solutions ensures lowe power loss and enables a compact design. Harmonic mitigation, pf correction and unbalance compensation. For symmetrical (3P3W) or unsymmetrical (3P4W) loads.

REVCON Harmonic Filter

280kW typical motor power rating

IP20 degree of protection (IP00–IP54)

RHF-5P 280-400-50-20-C

5P: <5%THDi
8P: <8% THDi
Hybrid: ~1% THDi
Active: Scalable THDi

400V Nominal Voltage
Available from 200-690V

50Hz nominal frequency

C: Compact all in one design
S: Split design for Panel installation
E: Enclosed Panel

Application	RHF-8P <8% THDi	RHF-5P <5% THDi	RHF-Hybrid ~1% THDi	RHF-Active Scalable
Variable Frequency Drives - VFD	Yes	Yes	Yes	Yes
Water and wastewater treatment	Yes	Yes	Yes	Yes
HVAC	Yes	Yes	Yes	Yes
Pumps and Fans (VFD)	Yes	Yes	Yes	Yes
Industrial/ Factory Process (VFD)	Yes	Yes	Yes	Yes
DC charger	Yes*	Yes*	Yes	Yes
Buildings	Yes	Yes	Yes	Yes
Data Center (power supply)	No	No	Yes	Yes
IEEE 519-2022 requirement	Yes*	Yes	Yes	Yes
IEEE 519-2022 specified application	Yes	Yes	Yes	Yes
Electronically comutated / EC Motor	No	No	No	Yes
Non symmetrical Load	No	No	No	Yes
symmetrical load multiple VFD	Yes	Yes	Yes	Yes
symmetrical load multiple	No	No	No	Yes
equimpment Displacement factor	No	No	No	Yes
Unbalance compensation	No	No	No	Yes

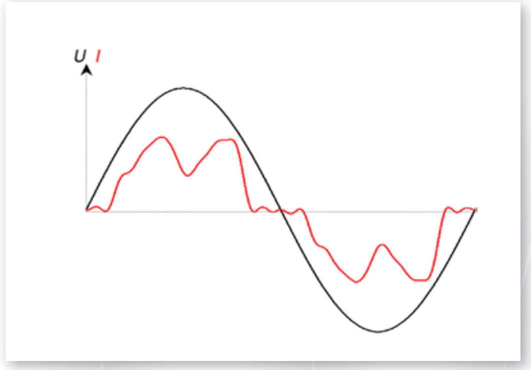
REVCON Harmonic Filter *1.1kW – 800kW*

RHF-8P and RHF-5P are high efficient double-stage passive Harmonic Filter used to avoid mains distortion caused by non-linear loads such as variable frequency drives VFDs.

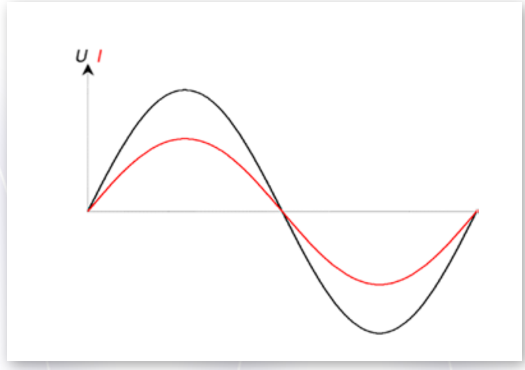
REVCON HARMONIC FILTER

The REVCON Harmonic Filter reduces the THDi of nonlinear loads and sources to significantly below 5% (optional <10%) even under realistic circumstances including imbalance and pre-distortion. This is necessary to reach various standards and recommendations, such as IEEE 519-2022. Typically, the filter reduces the THDi from 35% to ~3%, with a smooth damping across the full spectrum.

Typical single stage passive harmonic filters are tuned to 250Hz and therefore focus mainly on the 5th harmonic. The two stage harmonic filter RHF works like a bandwidth filter due to its unique circuit and reduces all harmonics up to ~60. As a bonus, this patented filter circuit do not cause any DC-voltage drop inside the drive. It reaches an efficiency of up to 99.5% and therefore the produced power losses are up to 75% less than those produced by comparable solutions. All our filters are available for all low voltage 3-phase supplies and cover power from 1.1kW up to 800kW, with an open end in parallel setup!



NON-LINEAR LOAD
This Picture is showing a typical rectifier input bridge of a B6 diode bridge and a DC choke of ~4%. The current (red) is almost in phase with the voltage (black) but the current waveform is very different from sinusoidal.



LINEAR LOAD
This picture is showing a pure resistive load. The current (red) is in phase with the voltage (black). Except for the difference in amplitude, the signal of voltage and current are equal.

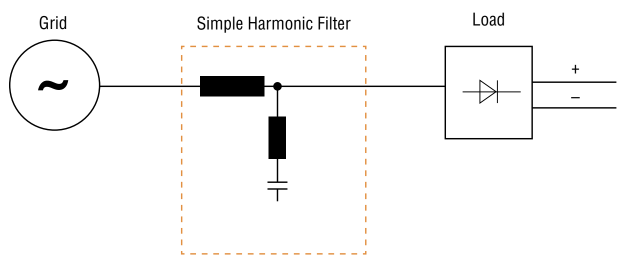
The REVCON Passive Harmonic Filter circuit

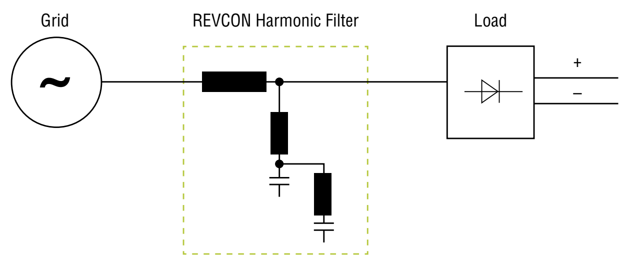
The following pictures describes the RHF-5P and 8P hardware configuration. Instead of using a simple drain circuit for the 5th Harmonic, both RHF-5P and 8P are using a double stage filter and specifies the performance by changing the main inductance value. The 3 main advantages of this REVCON patented filter circuit are:

1. Performance: The RHF is designed to reach its stated performance in the field and not defined for unique simulated conditions. The double stage filter offers a smooth damping of all Harmonics, instead of focusing on the 5th Harmonic.

2. Full Drive Power: The RHF allows for 100% DC-Bus voltage at 100% drive load. This avoid further calculations and de-rating of the drive. (Drives connected to Simple Harmonic Filter may have up to 7% less power ratings)!

3. Efficiency: Simple Harmonic Filter may add RC circuits in order to reach specified 5% THDi which leads to a significant lower efficiency. The RHF-5P double stage harmonic filter cause up to 70% less power loss than comparable <5% THDi solutions.





The NEW RHF-Hybrid

HVAC

Oil & Gas

Water Treatment

General Industry

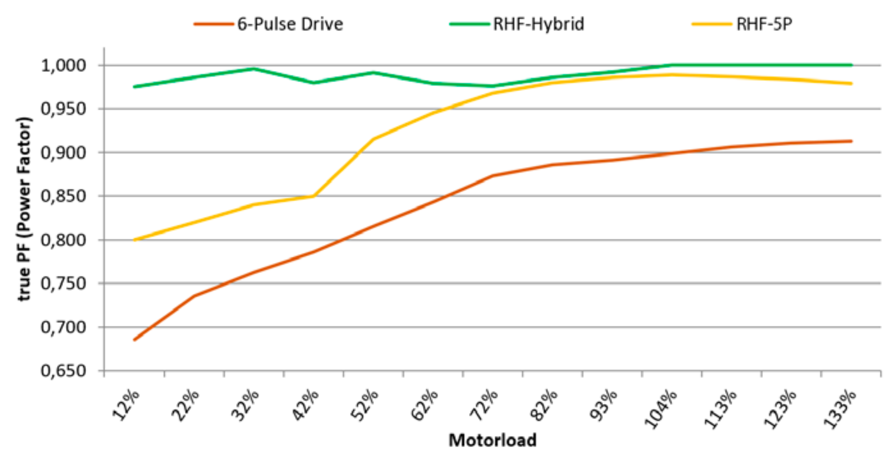
Marine

+ Efficiency **+ Reliability** **+ Performance**

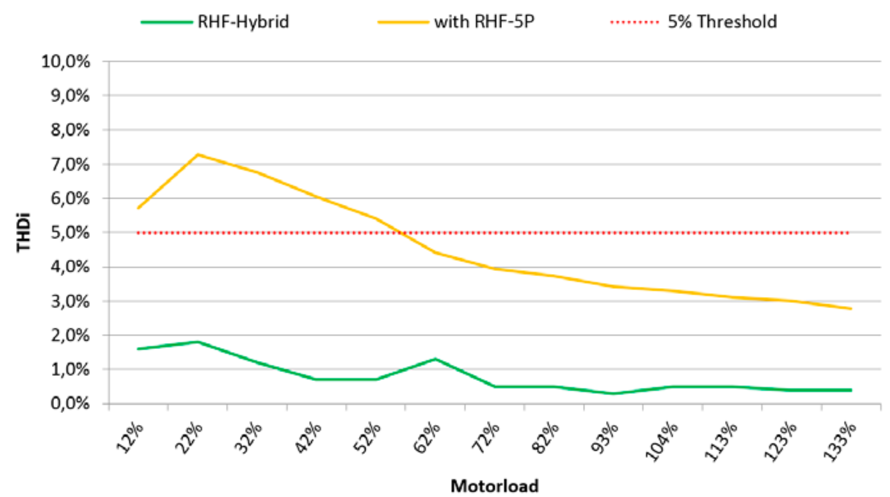
RHF-Hybrid

The new RHF-Hybrid range combines the benefits of the passive and active technologies and at the same time eliminates their disadvantages. A circuit similar to the RHF-8P is eliminating the major part of the Harmonics while the active filter takes care of the fine-tuning in harmonic performance. In part load, any passive harmo-nic filter will cause a reactive current. As the harmonic current is low in part load, the RHF-Hybrid use the re-sources of the active filter component and eliminates the reactive power.

In addition the active filter component control the swit-ching of the two passive filter circuits, which allows to size the active component to about 10% of the RHF-Hy-brid rating, which makes the Hybrid not only superior in performance, but also com-petitive in price.



This diagram show the smooth true power factor of the RHF-Hybrid. Close to 1 at any operating point.



The harmonic performance of the RHF-Hybrid is unique, even for strong distorted networks.

At last but not least: The RHF-Hybrid can be used with any standard 6-pulse drive and the system creates, de-spite the higher performance, about 30% less power losses compared to AFE technology.

Active REVCON Harmonic Filter

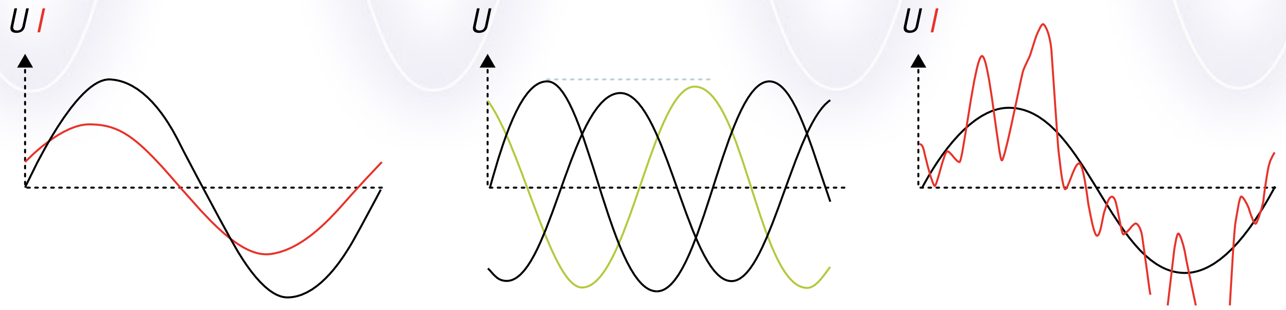
RHF-Active is a high efficient design used to avoid mains distortion caused by any non-linear load

All RHF-Active are available as using a unique Silicon Carbide (SiC) MOSFET topology. This technology offers significant benefits in size, performance and efficiency.

The efficiency of a RHF-Active SiC harmonic filter ~98.4% and therefore produce about 57% less heat than comparable solutions based on IGBT technology. Looking at the RHF-Active as a Harmonic solution for drives, the system efficiency is >99.5%. This is the most efficient harmonic solution available in the market.

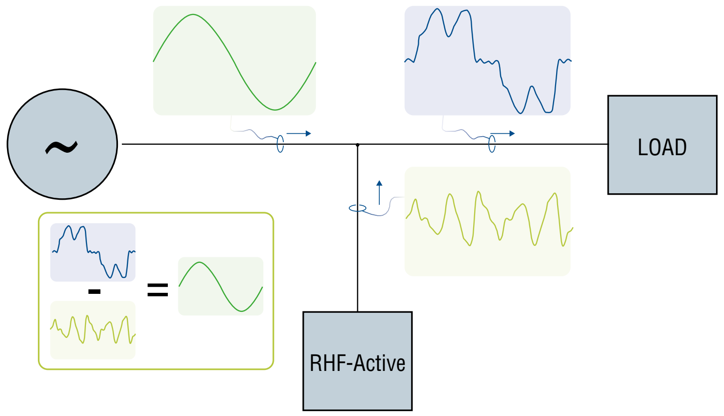
The SiC based active filter are available for every application, starting from 3.5A up to 150A as an individual module. Ratings up to 1500A are realized by parallel Master-Master configurations which ensures a higher reliability of the application.

Due to the high switching frequency of >50kHz, not only the performance of the RHF-Active is unique. In addition harmonics of higher order as created from IGBT based solutions are avoided.



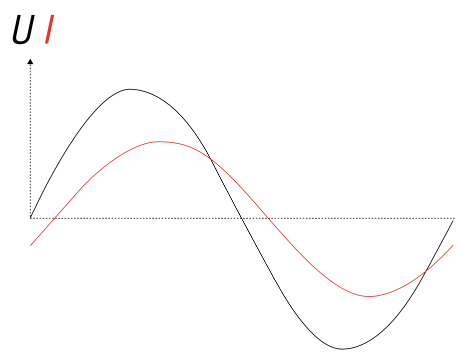
The RHF-Active may be used for pf correction, unbalance compensation, harmonic mitigation or altogether. It reduces the harmonic current distortion of non-linear loads and sources to any required THDi. This is necessary to reach various standards and recommendations, such as IEEE 519-2022.

A high switching frequency allows for efficient and accurate compensation of high order harmonics up to 61st. Due to its unique circuit, the RHF-Active is extremely efficient which allows for a very compact design. All RHF-Active can be used as 3P4W or 3P3W for 380-415V systems (further voltage levels coming soon!). Unlimited current possibilities due to open end in parallel setup!



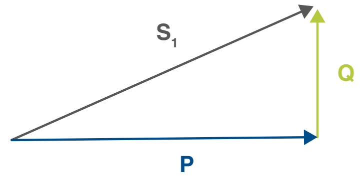
The working principle of an active REVCON Harmonic Filter RHF-Active is completely different from any other harmonic solution. Instead of working as a line filter with tuned passive filter circuits, the active solution is connected in parallel and injects harmonics. These injected harmonics are of inversed polarity and therefore eliminate the harmonics taken from the supply.

Power Factor, a major impact on your power quality



In a most common sense, when speaking about reactive power and power factor this is referring to fundamental sinewave signals where current and voltage are at a different angle.

$$\cos \varphi = \frac{P}{S} \text{ and } S_1 = \sqrt{P^2 + Q^2}$$



Typically the reactive power is calculated by the cos φ (also referred to as power factor, pf).

When it comes to reactive power, the following illustration has become very famous.

The Beer is indicating what you actually wants, while the foam is representing the reactive power. This illustration is giving a simplified picture of the reactive power only taking into account the sinewave signals. This can be used for most typical inductive loads such as motors connected direct on line (without Variable Speed Drive).

4 Reasons why to take care of fundamental reactive power

Power Factor:

In many regions, utilities charge customer based on power factor. Due to inefficient use, a low power factor usually lead to higher charges.

Infrastructure efficiency:

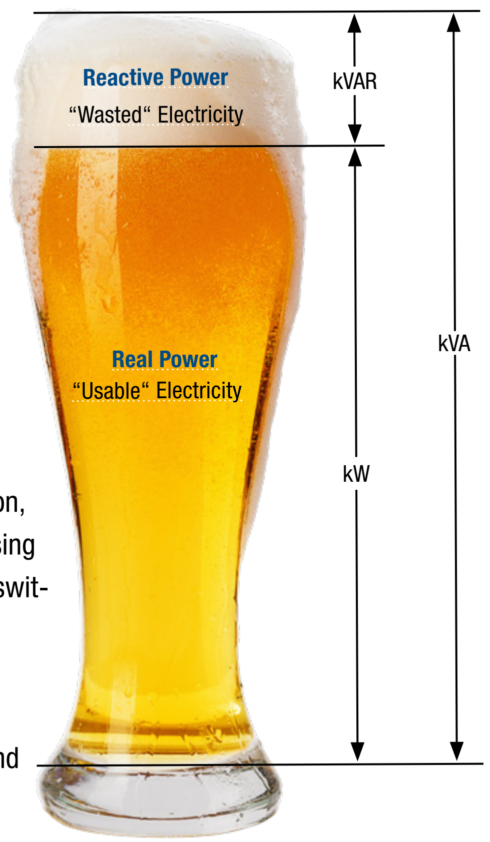
Reactive power needs to be generated, transferred and distributed. At all times, this will cause losses in the system.

Infrastructure costs:

While reactive power does not create any real work in the final application, reactive power still increase the current in the whole system. This is causing high costs due to necessary oversizing of equipment such as transformer, switches and wire.

Voltage stability:

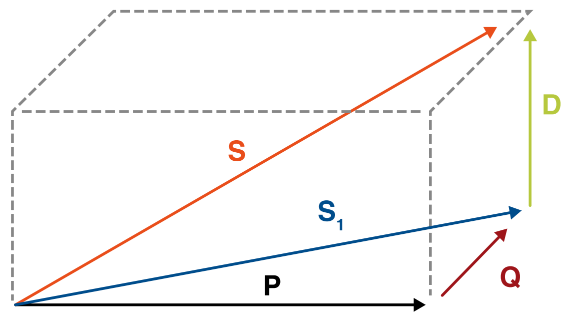
Avoiding reactive power and ensuring a stable pf stabilizes the voltage and helps avoiding fluctuations in the voltage.



With more complex loads, such as a mixture of VFD and inductive loads, the beer allegory is not sufficient. In order to evaluate the true reactive power, the distortion power caused by harmonics must be considered.

Looking at the true power factor this is affected by both THDi and cos(φ):

$$pf = \frac{\cos \varphi}{\sqrt{1 + THDi^2}}$$



Therefore when improving power factor both harmonics and fundamental reactive power should be treated, rather than dealing with these two issues individually. This leads to some advantages in the solution itself due to the calculation of the RMS current:

$$I_{RMS} = \sqrt{I_{h1}^2 + I_{h2}^2 + I_{h3}^2 + I_{h4}^2 + I_{h5}^2 + I_{h6}^2 + \ldots + I_{h40}^2}$$

Using the equation above, fundamental current and harmonic currents are added as square sum. In a system with 100A of harmonic currents and 150A of reactive current, they would typically require two individual solutions with 100A and 150A. This leads to 250A compensation current in total.

$$100\,A + 150\,A = 250\,A$$

With the use of REVCON active compensation by RPC-eSVG or RHF-Active, significant savings can be achieved.

$$I_{RMS} = \sqrt{I_{Reactive\,1}^2 + I_{Harmonics}^2} = \sqrt{100\,A + 150\,A} = 180\,A$$

The required compensation current in this example is reduced by 28% by a smarter connection.

REVCON Power Factor Correction

REVCON offers a wide range of compensation modules for power factor correction, REVCON Powerfactor Correction (RPC). All active modules, are based on SiC Technology, which offers a significant advantage in efficiency.

RPC-eSVG

RPC – efficient Static VAR Generator.

This product is a SiC based active compensation module, and available from 70kVA to 480kVA in one panel, but can be parallel up to reach higher capacity if required. Unit may at the same time compensate harmonics (5-13th order), up to a maximum of 30% of the nominal capacity. The Harmonic compensation capability can be improved by combining with RHF-Active range. The efficiency of this solution >98.4%, this corresponds to 30% less losses than comparable systems using IGBT Technology.

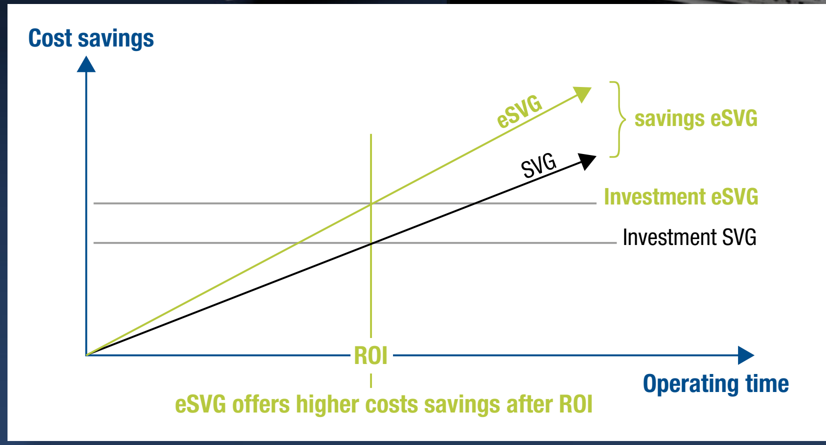
RPC-eSVG			
Typ	Harmonics compensation [A]	kVAR (400V)	kVAR (480V)
RPC-eSVG 85-480-50/60-20-A	33	70	85
RPC-eSVG 125-480-50/60-20-A	50	100	125
RPC-eSVG 170-480-50/60-20-A	66	140	170
RPC-eSVG 210-480-50/60-20-A	83	170	210
RPC-eSVG 250-480-50/60-20-A	100	200	250
RPC-eSVG 295-480-50/60-20-A	115	240	295
RPC-eSVG 335-480-50/60-20-A	133	270	335
RPC-eSVG 375-480-50/60-20-A	150	300	375
RPC-eSVG 420-480-50/60-20-A	167	340	420
RPC-eSVG 460-480-50/60-20-A	183	370	460
RPC-eSVG 500-480-50/60-20-A	200	400	500

RPC-Hybrid

The most efficient way to eliminate fundamental reactive power, is a simple detuned capacitor, which on its own has some disadvantages. The RPC-Hybrid is combining this well approved and conventional technology, with active compensation, which results in an extremely efficient solution at lower costs than an active module. At the same time this combination offers most of the advantages from an active solution such as stepless control and low response time.

RPC-Hybrid			
Typ	Harmonics compensation [A]	kVAR (400V)	kVAR (480V)
RPC-Hybrid 240/85-480-50/60-20-A	33	200	240
RPC-Hybrid 340/125-480-50/60-20-A	50	283	340
RPC-Hybrid 480/170-480-50/60-20-A	66	400	480
RPC-Hybrid 580/210-480-50/60-20-A	83	483	580
RPC-Hybrid 680/250-480-50/60-20-A	100	567	680

All products are available as IP20 up to IP55. For our Outdoor solutions please contact our sales team - sales@revcon.de



ADM Engineering

Exclusive Partner for North America

Phone: +1 877 236 8337
Email: info@admeng.com
Web: www.admeng.com
Address: 9990 SW 77th Ave Suite 200, Miami, FL 33156, USA

Center of Competence for Power Quality

REVCON

ELTROPLAN-REVCON, Elektrotechnische Anlagen GmbH - Edisonstraße 3 - DE-59199 Bönen