How can power factor correction and harmonic filtering be part of your energy efficiency program?

Consult the power quality solution experts.

SQUARE D

by Schneider Electric

Make the most of your energy℠

Schneider Electric

Energy efficiency has significant impact on energy savings.

Technologies designed to lower energy costs, could cause unexpected power quality effects.

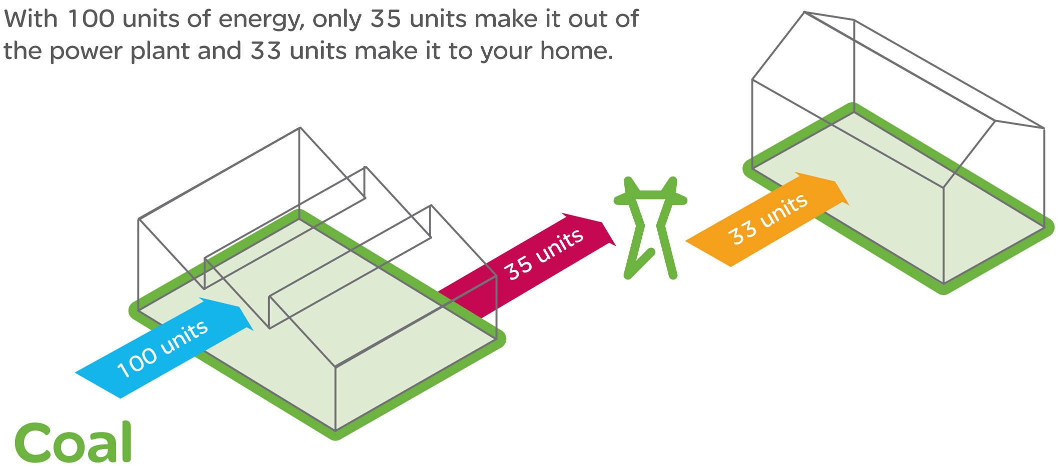
Schneider Electric can provide a full range of **ReactiVar®** and **AccuSine®** power quality solutions to help you improve energy efficiency – without unwanted side effects.

Energy demand is anticipated to be double by 2030. CO_2 emissions should be halved to avoid global warming acceleration. Both issues place a major challenge on the generating capacity of all utilities, and on us as electricity end users.

Energy efficiency becomes more than a cost issue today. It becomes part of the journey to ensure energy availability and preserve the environment in the future. Many organizations put energy efficiency at the top of their agenda as part of a green initiative and sustainable development strategic plan. Increasing efficiency has significant impact on energy savings.

Do you know a small saving at home is a big saving at the power plant?

With 100 units of energy, only 35 units make it out of the power plant and 33 units make it to your home.



If you save **100 units** at home → You are really saving **300 units** at the power plant

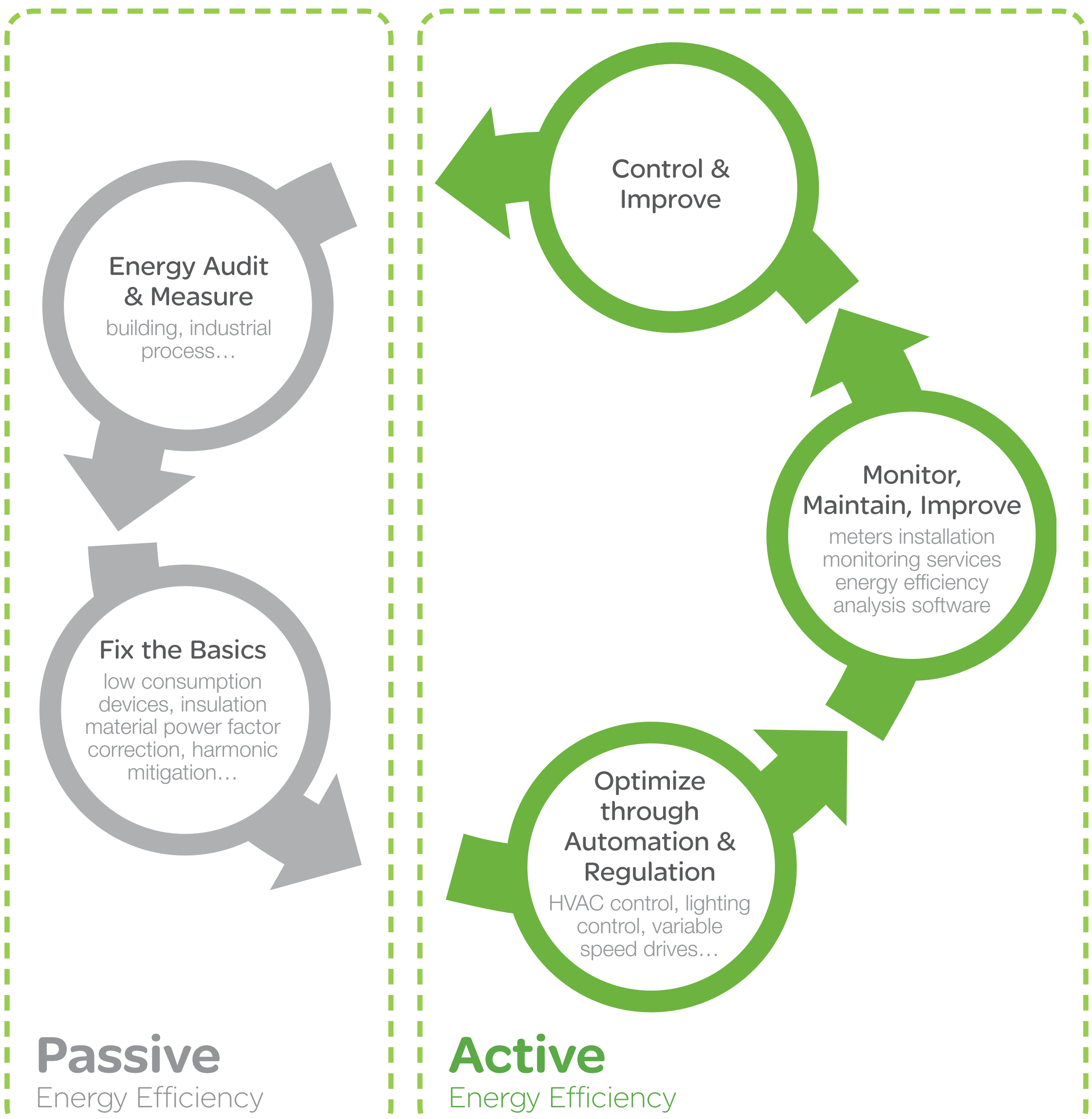
As you can see, we can make a big difference in conserving energy by increasing efficiency in end user environments – our electrical distribution network and loads.

83%

Electricity generation consumes 40% of U.S. primary energy and is responsible for 40% of carbon dioxide emissions. In the electric power sector, coal accounts for 83% of the emissions.

How can power factor correction and harmonic filtering be part of your energy efficiency program?

Schneider Electric has developed a life cycle solution to illustrate the process.



Schneider Electric power quality correction products are part of the solution.

A capital investment in power factor correction and harmonic filtering equipment can result in a healthy return of investment – depending on the utility's demand rate structure, production quality cost due to harmonics and voltage fluctuations in the distribution system.

Most utilities charge for peak electrical demand on each month's electrical bill. The demand charge is to allow the utilities to recoup part of their capital investment in the distribution network they operate. Each customer pays a demand charge for its peak operating load. Often inherent in the structure of these demand charges is an allowance for some inefficiency but most utilities will offer an incentive to their customers to keep electrical efficiency (measured by power factor) high. Power factor correction devices improve overall electrical efficiency upstream of their point of connection in the electrical network and can be used to minimize utility kVA demand charges.

Power electronic devices that have rapid and frequent load variations have become abundant today due to their many process control related and energy saving benefits. However, they also bring a few major drawbacks to electrical distribution systems such as harmonics and rapid change of reactive power requirements.

Harmonics may disrupt normal operation of other devices and increase operating costs. Symptoms of problematic harmonic levels include overheating of transformers, motors and cables, thermal tripping of protective devices, logic faults of digital devices and drives. Harmonics can cause vibrations and noise in electrical machines (motors, transformers, reactors). The life span of many devices can be reduced by elevated operating temperature.

Plus, rapid reactive power changes demand timely reactive power (VAR) compensation. Lack of timely and adequate VAR compensation can lead to voltage fluctuations in the electrical distribution system, impacting equipment operation, as well as product quality.

An active harmonic filter (AHF) provides an effective means to mitigate harmonics, reduce process-related voltage fluctuations and improve equipment operating life and system capacity. It can be part of a power factor correction and harmonic filtering system.

Other benefits include:

- **Transformer and distribution network offloading.** Improving power factor reduces kVA loading of the distribution network such that additional process equipment may be added without the need for incremental investment in transformers and distribution equipment.
- **Ensuring compliance with harmonic standards.** Standards limiting a customer's harmonic pollution of the utility grid exist and can be enforced by the utility.
- **Improving reliability of the distribution network and process equipment.** Harmonics generated by non-linear loads can cause problems, such as logic faults of digital devices with sensitive process equipment leading to downtime and scrap.
- **Reducing overheating** of transformers, motors and cables to prolong the life span of these components.

Applications

Many industrial facilities place poor power quality at the top of the list of inefficiency factors responsible for losses due to reduced productivity and lower quality of products. Optimal electrical power utilization becomes a challenge, as well as a necessity to keep up with ever-increasing energy demand without drastic increases in energy costs.

Large industrial, commercial and institutional power users can benefit from centralized medium voltage reactive power compensation systems. Medium voltage solutions typically require lower initial capital expenditures ($/kVAR) than low voltage solutions while addressing most common power quality problems. Medium voltage metal-enclosed compensation systems provide centralized solution approach with attractive installation options supporting the scale and scope of large electrical services.

Typical installations can be found at automotive, pulp/paper, steel, petrochemical, mining/mineral and other large industrial facilities. Many large commercial and institutional customers with medium voltage distribution network can also take advantage of medium voltage reactive compensation systems.

Low voltage capacitor compensation systems can provide similar benefit of centralized solution at attractive costs for most mid and small industrial, commercial and institutional users. It offers very flexible, yet effective power factor compensation system in the low voltage network.

An AHF can be used alone or in conjunction with other power quality correction equipment such as tuned harmonic filters, capacitor banks, etc. It can be placed in various locations within the electrical distribution network. Multiple units can be connected in parallel to provide higher compensation current to meet the TDD levels defined in IEEE519-1992 standard or levels defined in the plant operating requirements (5%-8%).

Introduction of basic terminologies

Power factor basics

AC Power flow has three components:

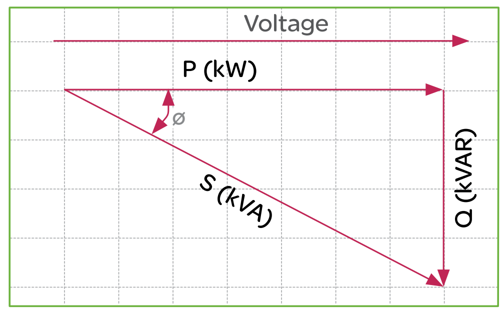
- **Active Power (P)** is the power needed for useful work such as turning a lathe, providing light or pumping water. It is expressed in Watt or KiloWatt (kW).
- **Reactive Power (Q)** is a measure of the stored energy reflected to the source. It is expressed in var or Kilovar (kVAR).
- **Apparent Power (S)** is the vector sum of both the active and the reactive components. It is expressed in Volt Amperes or in KiloVolt Amperes (kVA).

Power triangle

The relations between the various power components are illustrated in the power triangle shown in f.1.

From f.1, it is apparent that the active power component is in phase with the applied voltage while the reactive component occurs 90° out of phase with the voltage.

The equation that defines this relationship is:
$(kW)^2 + (kVAR)^2 = (kVA^2)$



f. 1

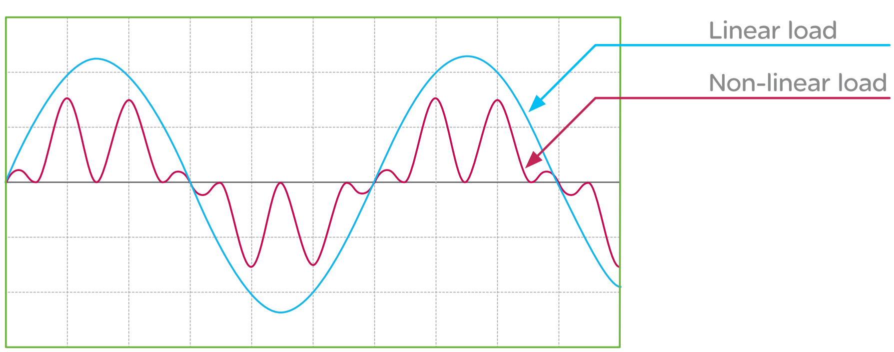
Power factor (PF) is, in fact, a measure of efficiency. When the PF reaches unity (as measured at the utility power meter), it can be said that the electrical system in the plant is operating at maximum efficiency. Depending on the local utility rate structure, a PF below target PF may result in higher utility power bills than are necessary.

There are two commonly used definitions of power factor:

- **PF** = Cosine of phase displacement between current and voltage.
- **PF** = Cosine of angle between active power and apparent power.

Basic concepts

Harmonics are multiples of the fundamental frequency (60Hz in North America) of currents and voltages, which are caused by non-linear loads in response to the manner in which they draw current (see f.2). As more non-linear loads are added to the electrical distribution system, they cause the amount of harmonic current increase in the system.



f. 2

Terms and definitions

a. **Harmonic component:** Any one of the sinusoidal components in which frequency is an integer multiple of the fundamental component.

b. **Harmonic order:** The harmonic order is the ratio of the frequency of the harmonic component to that of the frequency of fundamental. By definition, the harmonic order of the fundamental is equal to one. Note that the harmonic of order n is often referred to simply as the n^{th} harmonic.

$$n = \frac{f_n}{f_1}$$

c. **Spectrum:** The spectrum is the distribution of the amplitudes of the various harmonics as a function of their harmonic order, often illustrated in the form of a histogram.

d. **Expression of distorted wave:** the Fourier series expression of distorted wave is as follows:

$$y(t) = y_0 + \sum_{n=1}^{n=\infty} y_n \sqrt{2} \sin(n\omega t - \varphi_n)$$

where;

y_0 = the amplitude of the DC component, which is generally zero in AC distribution systems

y_n = the RMS value of the nth harmonic component

ω = fundamental frequency

φ_n = phase angle of the nth harmonic component when t = 0

e. **RMS value of a distorted wave:** Harmonic quantities are generally expressed in terms of their RMS value since the heating effect depends on this value of the distorted waveform.

For distorted quantity, under steady-state conditions, the energy dissipated by the Joule effect is the sum of the energies dissipated by each of the harmonic components:

$$RI^2t = RI_1^2t + RI_2^2t + \ldots\ldots + RI_n^2t$$

where; $I = \sqrt{\sum_{n=1}^{n=\infty} I_n^2}$ if the resistance can be considered as constant.

f. **Individual harmonic ratio and total harmonic distortion (THD):** The individual harmonic ratio and total harmonic distortion ratio quantify the harmonic disturbances present in the distribution network. The individual harmonic ratio expresses the magnitude of each harmonic with respect to the fundamental.

THD quantifies the thermal effect of all the harmonics. It is the ratio of the RMS value of all the harmonics to that of the fundamental. IEEE 519-1992 has defined THD in mathematic formula below:

$$THD = \sqrt{\frac{\sum_{n=2}^{n=\infty} y_n^n}{y_1^2}} \times 100\%$$

where; y_1 is fundamental component

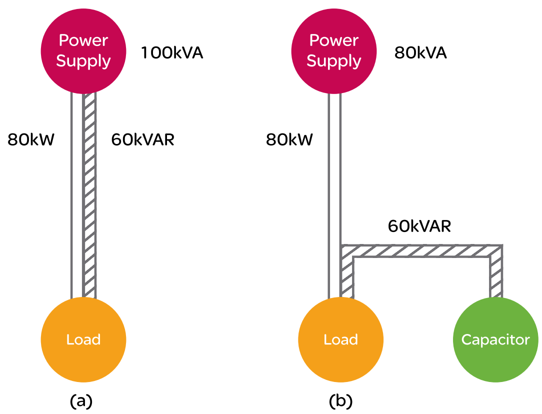
g. **Total demand distortion (TDD):** TDD is defined in IEEE519-1992 as:

$$TDD = \frac{\sqrt{\sum_{n=2}^{n=\infty} y_n^2}}{y_1} \times 100\%$$

where; y_1 is the maximum demand load current of the facility within 15 or 30 minute demand window.

Power factor correction

Power factor can be improved by either increasing the active power component or reducing the reactive component. Of course, increasing the active power component for the sole purpose of power factor correction would not be economically feasible. Thus, the only practical means for improving the system's power factor is to reduce the reactive power component. One method of reducing this component is to provide reactive power locally close to the load. This method will improve the power factor from the point where the reactive power source is connected. As an example, consider the load in f.3a.



f. 3

The total power required is 100kVA of which 80kW is active power and 60kVAR is reactive power. If the reactive power is furnished locally (f.3b), the power system only has to carry 80kVA (80kW). Thus, the power factor (from the point where the reactive power is locally supplied back to the source) is improved to unity.

It is not that simple

Applying power factor capacitors used to be straightforward. Today, with the proliferation of harmonic generating loads such as variable frequency drives, soft starters and welders, very careful attention must be paid to the proper application of power factor correction and harmonic filtering equipment to avoid application.

The problem

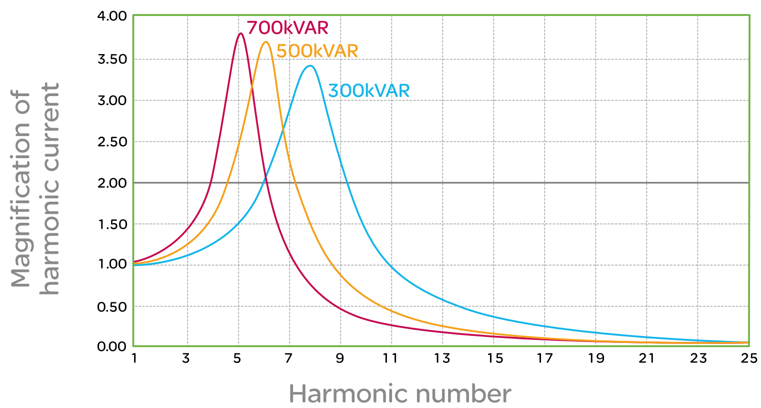
When applying power factor correction capacitors in the presence of harmonics, a couple of issues come to surface.

First, capacitors are a natural low impedance path for harmonic currents and will, therefore, absorb these energies. This increase in capacitor current results in higher element temperature which reduces the life of the capacitor. Also, because capacitors reduce the network impedance, capacitors can actually increase the level of harmonic current on the network. It is important to remember that while capacitors do not produce harmonic currents, they can magnify their effects. Furthermore, harmonic voltages present on the network create voltage stresses on the capacitor.

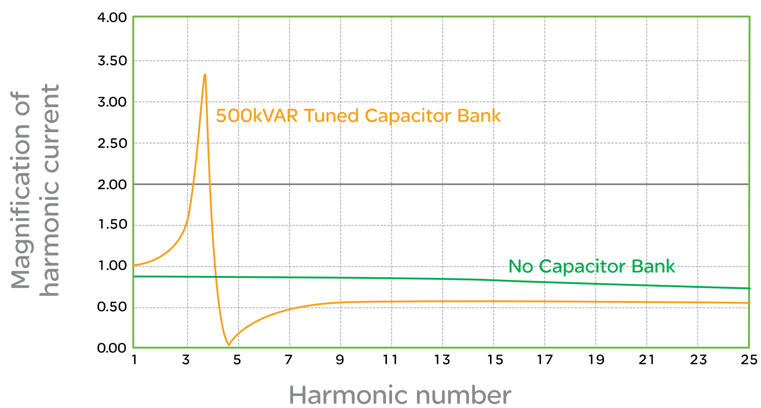
The second and potentially more serious concern, is network resonance. When capacitors are added to the network, they set up a parallel resonance circuit between the capacitors and the network inductance. Harmonic current components that are close to the parallel resonance point are magnified (see f.4). The magnified current can cause serious problems such as excessive voltage distortion, nuisance fuse and breaker operation, overvoltage tripping of drives and insulation breakdown within motors, transformers and conductors.

Both risks increase with the size of the capacitor bank. The larger the size of the capbank, the higher the risks.

To address this issue, a tuned capacitor bank is one of the solutions that can be used to suppress a given harmonic order (see f.5) to prevent network resonance.



f. 4



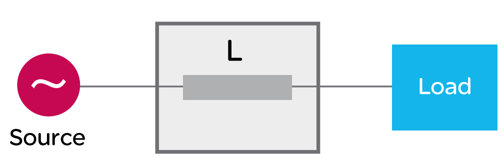
f. 5

Harmonic mitigation

There are various harmonic mitigation methods that we can use to address harmonics in the distribution system. They are valid solutions depending on circumstances, and have their pros and cons.

Line reactors (LR)/DC bus chokes/isolation transformers

This is the simplest form to reduce harmonic current caused by non-linear load, typically converter-based devices. Inductors or isolation transformers, installed ahead of the load, can reduce the harmonic current content up to 50% and reach TDD levels of 30-40%. Typically, LRs are less expensive than transformers.



f. 6

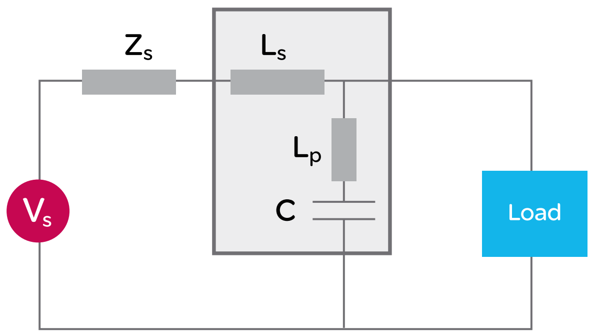
Power factor correction

Harmonic mitigation (cont.)

Tuned harmonic filters

A tuned harmonic filter is a type of passive filter. We call it passive as it consists of a passive elements such as an inductor and capacitor.

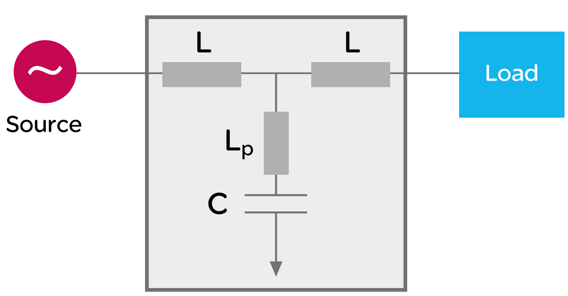
F.7 is a typical tuned harmonic filter circuit. Inductor (L_p) and capacitor (C) provides low impedance path for a single (tuned) frequency. An inductor (L_s) is required to detune the filter from the electrical system and other filters' resonance point. This type of filter is very application specific. It can only mitigate a single frequency, and it injects leading reactive current (kVAR) at all times. But it is economical if you only need to deal with a dominant harmonic in the facility. It normally can reach TDD target of 20%.



f. 7

Broadband filters

As its name indicated, a broadband filter is designed to mitigate multiple orders of harmonic frequencies. You will notice the similarity and the difference of its circuit from the tune filter (f.8). Both inductors (L) could have an impedance > 8%, which means you could see a 16% voltage drop across the filter. Its physical dimension is normally very large, and it generates quite high heat losses (> 4%). A well-designed broadband filter can meet TDD target in the 10% range. However, broadband filters have their limitation and are not suitable for certain harmonic load applications.

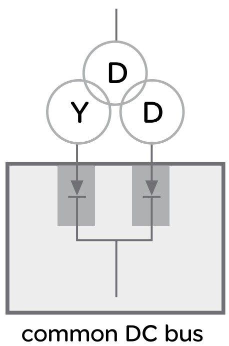


f. 8

Multi-pulse transformers/converters

The 12 or 18 pulses variable freqency drive (VFD) has been developed to address the harmonic issue caused by common 6 pulse VFD. F.9 is a typical concept of 12 pulse VFD. The input is connected to the transformer's primary winding, then the outputs are connected with two separated phase-shifted secondary winding to two sets of rectifiers. This configuration reduces the current harmonic distortion to a 10% range (12 pulse). For the 18 pulse VFD, an additional secondary winding and a set of rectifiers are added in to the scheme. It can achieve 5% TDD.

The 18 pulse VFD is replacing the 12 pulse as the prevailing choice in multi-pulse solutions. It can reach 5% TDD at device level. However, it is normally very bulky, has larger heat loss and a higher operating cost when comparing to other solutions.

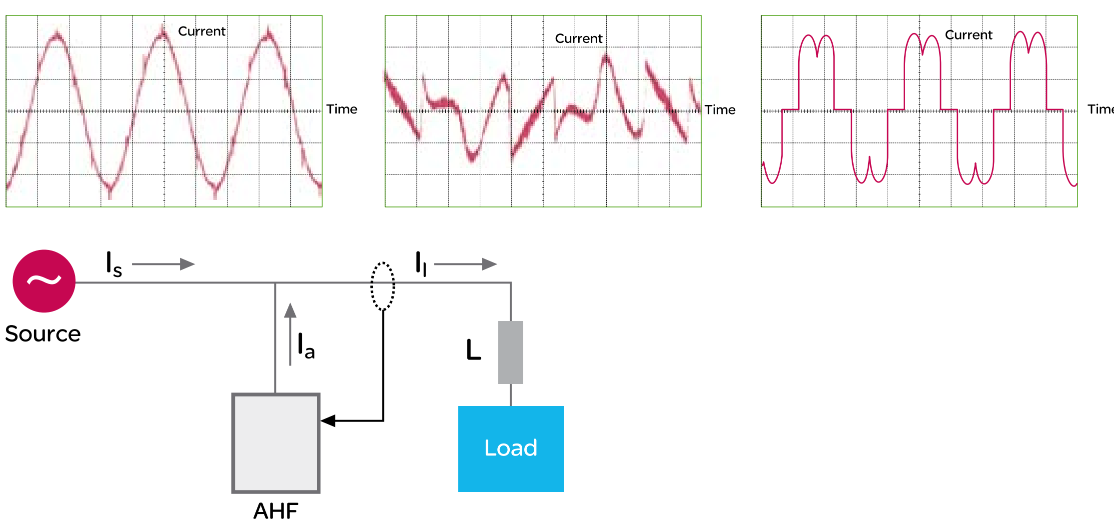


f. 9

Active harmonic filter (AHF)

The concept of an active filter is to produce harmonic components, which cancel the harmonic components from the non-linear loads. F.10 illustrates how the harmonic current generated by AHF is injecting into the system to cancel harmonic from a VFD load.

An AHF is a highly-effective device that cancels multiple order harmonics in the distribution system. It is installed as a parallel device and scaled via parallelling multiple units. It can handle different type of loads, linear or non-linear. It addresses harmonics from a system point of view and can save significant cost/space in many applications. Its performance level can meet TDD 5% target.



f. 10

Schneider Electric provides a comprehensive product portfolio for various application needs.

Power factor correction fixed capacitors (PFCD)

PFCD fixed capacitor is ideally suited for power factor correction in applications where the load does not change or where the capacitor is switched with the load, such as the load side of a motor starter. ReactiVar capacitors are available up to 200kVAR as individual units at 480/600V. Assemblies are available unfused or fused with three fuses and three blown-fuse indicators. Enclosures are available as indoor NEMA 1, outdoor N3R and are suitable for floor or wall mounting.

De-tuned automatic capacitor banks

The AV6000 anti-resonant power factor correction systems are designed to provide power factor correction in today's distribution networks with certain level of specific harmonic contents. The AV6000 assemblies include custom-designed iron-core reactors in series with three-phase heavy duty capacitor modules. The series capacitor/reactor combination is tuned well below the first dominant harmonic (usually the 5^{th}) thus preventing resonance and harmonic magnification. In addition to providing power factor correction without the risk of resonance, the AV6000 may absorb up to 50% of the 5^{th} harmonic (depending upon network characteristics).

The AV7000 filtered systems are specifically designed for harmonic filtering with power factor correction as a secondary benefit. The series capacitor/reactor combination is tuned close to the fifth harmonic (4.7 x 60Hz). Such close tuning to the target harmonic increases the effectiveness of harmonic energy absorption of the capacitor/reactor stage. Due to the specific nature of the AV7000 filtered systems, application issues must be examined prior to system installation.

Standard automatic capacitor banks

The AV5000 standard automatic power factor correction banks are designed for centralized power factor correction to supply varying amounts of reactive power required to compensate for changing load conditions. The AV5000 banks are ideally suited for facility electrical distribution systems with TDD < 5% and THD(V) < 3%. An advanced microprocessor-based reactive power controller measures plant power factor via a single remote CT. Plus, it switches capacitor modules in and out of service to maintain a user-selected target power factor.

Transient-free reactive compensation (TFRC) systems

The AT6000 TFRC systems are suitable for nearly all electrical networks and are ideal to correct poor power factor in electrical networks with a high concentration of electronic loads. Traditional electromechanical contactor switching of capacitors generates voltage transients that can impair the operation of sensitive process equipment. TFRC systems feature an advanced controller to precisely activate electronic switching elements to connect capacitor stages and avoid the creation of transients. Transient-free switching also reduces wear on capacitors due to switching and will result in longer life for the overall capacitor system. With a response time of less than five seconds to load changes, TFRC systems reduce the kVA demand on the transformer and will eliminate utility imposed penalties for low power factor.

Depending on the level of harmonic producing (non-linear) devices on the network, two TFRC systems are available. The AT6000 anti-resonant (de-tuned) system is designed to provide power factor correction and will reduce the normally dominant fifth harmonic by up to 50%. If harmonic conditions are severe, an AT7000 filtered system may be beneficial to further reduce the levels of fifth harmonic energy. Please contact Schneider Electric expert for application assistance.

AccuSine® PCS active harmonic filters

AccuSine PCS active harmonic filter (AHF) injects harmonic and reactive current to limit harmonic distortion and improve displacement power factor for the electrical distribution system. As a full spectrum product, AccuSine PCS measures the entire load current, removes the fundamental frequency component and injects the inverse of the remaining wave form for nearly complete cancellation of harmonic current. AccuSine PCS's full spectrum circuitry is not focused on specific frequencies; rather it creates a waveform "on the fly" based upon the input of its sensing circuitry, regardless of the particular frequencies that the nonlinear load current contains.

The AccuSine PCS AHF provides very simple and effective means to mitigate harmonics, reduce process-related voltage fluctuations and improve equipment operating life and system capacity.

Power Quality Correction Group

The Power Quality Correction Group in the Schneider Electric North American Operating Division is a team of experts who specialize in power factor correction and harmonic related power quality problems. Our focus is on application engineering with the goal of providing the correct solution for your specific application needs.

- Energy efficiency and power quality are linked together and a holistic approach is required to optimize solutions.
- Schneider Electric is your energy efficiency and power quality expert.
- We offer a variety of solutions and products to save energy and help identify and correct power quality problems.

To find out how our power quality solutions can smooth the way to greater energy efficiency, contact our experts through your local Schneider Electric field office to assess your situation and make recommendations to ensure that the most technically and cost effective solution is implemented.

Schneider Electric - North American Operating Division

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