SIMULATION OF ACTIVE POWER FILTER USING MATLAB/SIMULINK

NUR IZZATI NADIAH BINTI ISHAK

Bachelor of Electrical Engineering(Industrial Power)

May 2010

" I hereby declared that I have read through this report and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

Signature :

Supervisor's Name : EN. AZHAR BIN AHMAD

Date :

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This report is submitted in partial fulfillment of requirement for degree of Bachelor in Electrical Engineering (Industrial Power)

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Universiti Teknikal Malaysia Melaka

April 2010

" I hereby declared that this report is a result of my own work except as cited clearly in the references "

Signature **:**

Name **: NUR IZZATI NADIAH BINTI ISHAK**

Date **:** 22 APRIL 2010

ACKNOWLEDGEMENT

First and foremost, I thank Allah the Almighty for blessing me to complete my Final Year Project 1. I would like to enlarge my appreciation to En. Azhar bin Ahmad because of the kindness heart to accept me as one of the student under his supervision. Special thanks also dedicated to her for all comments, idea and guideline begin from the first day I start this project.

This appreciation also goes to my friends that always give me support, opinion, sharing ideas and advices for me to complete this project.

To my beloved family, I would like to forward my obliged to them for their continuous support during my study period, their patience and benevolence. Lastly, I would like to thank everyone who has contributed during my Final year Project 1. Your kindness and cooperation in completion of my paper work is much appreciated.

Thank You

ABSTRACT

This project was about the simulation of active power filter using Matlab software. The aim of this project is to review an active power filter that commonly used to mitigate harmonics. Harmonics are AC voltage or currents whose frequency is some integral multiple of the fundamental frequency. Harmonics degrade the level of power quality and efficiency in a industrial and commercial facility. Thus, to solve this harmonics problems, there are new class of harmonic mitigation devices injects a mirror image waveform of the harmonic portion of the distorted waveform which is active power filter. Active power filters are relatively new and rather costly but have important advantages that should be watched carefully which are inherently current limiting, have no resonance problems, intelligent and adaptable, can be configured to either correct the full spectrum of harmonics or to target specific harmonics and being able to compensate for harmonics without fundamental frequency reactive power concerns. The system is verified by simulation using Matlab/Simulink simulation package. The paper starts with a brief overview of harmonic distortion problems and their impacts on electric power quality, how the active power filter solved this problems and the verifying using Matlab software. As the result the harmonics problems can be solved using active power filter.

ABSTRAK

Projek ini adalah berkaitan dengan simulai penapis kuasa aktif yang menggunakan perisian Matlab. Projek ini bertujuan untuk mengkaji tentang penapis kuasa aktif yang sering digunakan untuk mengurangkan kesan harmonik. Harmonik adalah voltan atau arus ulang-alik di mana frekuensinya terdiri daripada gandaan frekuensi asas.Harmonik merendahkan tahap kualiti kuasa dan kecekapan dalam kemudahan industri dan komersial. Jadi, untuk menyelesaikan masalah harmonik, terdapat alat baru untuk mengurangkan kesan harmonic di mana ia berfungsi dengan menyuntik gelombang imej cermin ke gelombang herot yang terkena kesan harmonic iaitu penapis kuasa aktif. Penapis kuasa aktif masih baru dan agak mahal tetapi mempunyai beberapa kelebihan penting yang patut dinilai iaitu secara semula jadinya ia menghadkan arus, tiada masalah resonans(gema), bijak dan boleh diubah-suai, boleh ditatarajah samada pada semua spectrum atau pada kawasan sasaran tertentu harmonik dan juga ia boleh mengganti untuk harmonic tanpa frekuensi kuasa reaktif yang asas.Sistem ini disahkan dengan simulasi menggunakan perisian simulasi Matlab/Simulink. Laporan ini bermula dengan ulasan kajian tentang masalah gangguan harmonik dan kesannya pada kualiti kuasa elektrik, bagaimana penapis kuasa aktif menyelesaikan masalah ini dan pengesahan projek ini menggunakan perisian simulasi Matlab. Hasilnya, masalah harmonik dapat diselesaikan dengan menggunakan penapis kuasa aktif.

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CHAPTER 1

INTRODUCTION

1.1 Introduction of the project

The past several years have seen a rapid increase of power electronics-based loads connected to the distribution system. These types of loads draw nonsinusoidal current from the mains, degrading the power quality by causing harmonic distortion. These nonlinear loads appear to be prime sources of harmonic distortion in a power distribution system. In addition, the harmonic currents produced by nonlinear loads can interact adversely with a wide range of power system equipment, most notably capacitors, transformers, and motors, causing additional losses, overheating, and overloading and interferences.

Harmonic distortion in power distribution systems can be suppressed using two approaches namely, passive and active powering. Passive filters are known to cause resonance, thus affecting the stability of the power distribution systems. The basic principle of active power filter is to utilize power electronics technologies to produce specific currents components that cancel the harmonic currents components caused by the nonlinear load. Active power filter have a number of advantages over the passive filters. First of all, they can suppress not only the supply current harmonics, but also the reactive currents. Moreover, unlike passive filters, they do not cause harmful resonances with the power distribution systems. The active filter uses power electronic switching to generate harmonic currents that cancel the harmonic currents from a nonlinear load.

The result is verify using Matlab/Simulink simulation package which the expected result achieved when the harmonics problem that produced by non linear load solved using an active power filter.

1.2 Problem statement

- Harmonics has become the common problem nowadays.

  Nowadays there are many modern electronic equipment such as personal or notebook computers, laser printers, fax machines, telephone systems, stereos, radios, TVs, adjustable speed drives, and any other equipment powered by switched-mode power supply (SMPS) equipment. This switch mode power supply equipment is also referred to as non-linear loads. This type of non-linear loads or SMPS equipment generates the harmonics they're sensitive to and that originate right within your building or facility. SMPS equipment generates electrical non-linear load in most electrical distribution systems. There are two types of non-linear loads: single-phase and three-phase.

- Harmonics is not mitigating properly and need an effective solution.

  Not all harmonic mitigation solution is ideal for every application. There has many ways to mitigate harmonics depend on the cost and load.Active power filter is one of the best solution to mitigate harmonics and suitable for all application.

- Simulation of an active power filter is still an open problem.

  Although there were many research and simulation based on active power filter, there still have no absolute method in order to mitigate harmonics effectively.

1.3 Project Objectives

- Able to study about active power filter.
- Able to design circuit of the active power filter.

- Able to mitigate harmonics effectively.
- Simulation of active power filters to verify its effect in mitigating harmonics.

1.4 Scope of the project

- Simulate single-phase active power filter to eliminate harmonic distortion.
- The circuit of single-phase active power filter will be simulating using Matlab Simulation package.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will discuss about the literature review of the project. The sources of the information had been gathered from books, journal, research papers, encyclopedias, newspapers, magazines, handbooks, thesis, bibliographies and World Wide Web (WWW).Fact and finding is the formal process to collect and capture the entire information about system, system requirements and system preferences. Fact and finding is most crucial to the system planning and system analysis phase. It helps to learn about the vocabulary, problems, opportunities, constraints, requirements and priorities of a business and a system.

The literature review starts with the theory of power quality problems, continue with the harmonics which one of the main factor that degrading the power quality level. Then, there are explanation about several ways to mitigate harmonics then continue with the theory about an active power filter that use to mitigate harmonics and the circuit connection of an active power filter that been chosen for the project. Finally, there are brief explanation about the software that been used in this project to verify the result which is Matlab software.

2.2 Power Quality

Power quality is simply the interaction of electrical power with electrical equipment. If electrical equipment operates correctly and reliably without being damaged or stressed, we would say that the electrical power is of good quality.(Heydt, G.T. (1991) .On the other hand, if the electrical equipment malfunctions, is unreliable, or is damaged during normal usage, we would suspect that the power quality is poor. As a general statement, any deviation from normal of a voltage source (either DC or AC) can be classified as a power quality issue. Power quality issues can be very high-speed events such as voltage impulses / transients, high frequency noise, wave shape faults, voltage swells and sags and total power loss. The power quality (PQ) problems in power utility distribution systems are not new, but only recently their effects have gained public awareness. Power quality means to maintain purely sinusoidal current waveform in phase with purely sinusoidal voltage waveform(Bollen, Math H.J. (2000)).In its broadest sense, **power quality** is a set of boundaries that allows electrical system to function in their intended manner without significant loss of performance or life (Dugan, Roger C)

Advances in semiconductor device technology have fuelled a revolution in power electronics over the past decade, and there are indications that this trend will continue .However the power electronics based equipments which include adjustable-speed motor drives, electronic power supplies, DC motor drives, battery chargers, electronic ballasts are responsible for the rise in PQ related problems. These nonlinear loads appear to be prime sources of harmonic distortion in a power distribution system. Harmonic currents produced by nonlinear loads are injected back into power distribution systems through the point of common coupling (PCC). As the harmonic currents pass through the line impedance of the system, harmonic voltages appear, causing distortion at the PCC. Ideally, voltage is supplied by a utility as sinusoidal having an amplitude and frequency given by national standards or system specifications with an impedance of zero ohms at all frequencies. No real-life power source is ideal and generally can deviate in at least the following ways; this is several of power quality problems which are:

- Variations in the peak or RMS voltage are both important to different types of equipment. When the RMS voltage exceeds the nominal voltage by 10 to 80% for 0.5 cycles to 1 minute, the event is called a "swell".

- A "dip" (in British English) or"sag" (in American English - the two terms are equivalent) is the opposite situation: the RMS voltage is below the nominal voltage by 10 to 90% for 0.5 cycles to 1 minute.
- Random or repetitive variations in the RMS voltage between 90 and 110% of nominal can produce a phenomenon known as "flicker" in lighting equipment. Flicker (light flicker) is the impression of unsteadiness of visual sensation induced by a light stimulus on the human eye. A precise definition of the voltage fluctuations (voltage flicker) that produce light flicker that annoys humans, has been subject to ongoing debate in more than one scientific community for many years.
- Abrupt, very brief increases in voltage, called "spikes", "impulses", or "surges", generally caused by large inductive loads being turned off, or more severely by lightning.
- "Undervoltage" occurs when the nominal voltage drops below 90% for more than 1 minute. The term "brownout" is an apt description for voltage drops somewhere between full power (bright lights) and a blackout (no power - no light). It comes from the noticeable to significant dimming of regular incandescent lights, during system faults or overloading etc., when insufficient power is available to achieve full brightness in (usually) domestic lighting. This term is in common usage has no formal definition but is commonly used to describe a reduction in system voltage by the utility or system operator to decrease demand or to increase system operating margins.
- "Overvoltage" occurs when the nominal voltage rises above 110% for more than 1 minute.
- Variations in the frequency
- Variations in the wave shape - usually described as harmonics
- Nonzero low-frequency impedance (when a load draws more power, the voltage drops)
- Nonzero high-frequency impedance (when a load demands a large amount of current, then stops demanding it suddenly, there will be a dip or spike in the voltage due to the inductances in the power supply line) .

Each of these power quality problems has a different cause. Some problems are a result of the shared infrastructure. For example, a fault on the network may cause a dip that will affect some customers and the higher the level of the fault, the greater the number affected, or a problem on one customer's site may cause a transient that affects all other customers on the same subsystem.(Dugan, Roger C et al (2003).

In this project, we will discuss mainly about the power quality that causes by the harmonics. For harmonic problems, arise within the customer's own installation and may or may not propagate onto the network and so affect other customers. Harmonic problems can be dealt with by a combination of good design practice and well proven reduction equipment

2.3 Harmonics

Harmonics are currents or voltages with frequencies that are integer multiples of the fundamental power frequency being 50 or 60Hz (50Hz for European power and 60Hz for American power). For example, if the fundamental power frequency is 60 Hz, then the 2^{nd} harmonic is 120 Hz, the 3^{rd} is 180 Hz, etc. In modern test equipment today harmonics can be measured up to the 63^{rd} harmonic. When harmonic frequencies are prevalent, electrical power panels and transformers become mechanically resonant to the magnetic fields generated by higher frequency harmonics. When this happens, the power panel or transformer vibrates and emits a buzzing sound for the different harmonic frequencies. Harmonic frequencies from the 3^{rd} to the 25^{th} are the most common range of frequencies measured in electrical distribution systems. Harmonics are electric voltages and currents that appear on the electric power system as a result of certain kinds of electric loads. Harmonic frequencies in the power grid are a frequent cause of power quality problems. (Sankaran, C. (1995-10-01). "Effects of harmonics on power systems").A harmonic is the term used for unwanted and possibly destructive current flow on your facilities conductors (wiring). They are most prevalent on your neutral conductors. (Dan Maxcy (2001)."Harmonics".)

Additionally, harmonics are caused by and are the by-product of modern electronic equipment such as personal or notebook computers, laser printers, fax machines, telephone systems, stereos, radios, TVs, adjustable speed drives and variable frequency drives, battery chargers, UPS, and any other equipment powered by switched-mode power supply (SMPS) equipment. The above-mentioned electronic SMPS equipment is also referred to as non-linear loads. This type of non-linear loads or SMPS equipment generates the very harmonics they're sensitive to and that originate right within your building or facility. SMPS equipment typically forms a large portion of the electrical non-linear load in most electrical distribution systems.

There are basically two types of non-linear loads: single-phase and three-phase. Single-phase non-linear loads are prevalent in modern office buildings while three-phase non-linear loads are widespread in factories and industrial plants.

In an electrical distribution system harmonics create:

1. Large load currents in the neutral wires of a 3 phase system. Theoretically the neutral current can be up to the sum of all 3 phases therefore causing overheating of the neutral wires. Since only the phase wires are protected by circuit breakers of fuses, this can result in a potential fire hazard.
2. Overheating of standard electrical supply transformers which shortens the life of a transformer and will eventually destroy it. When a transformer fails, the cost of lost productivity during the emergency repair far exceeds the replacement cost of the transformer itself.
3. High voltage distortion exceeding IEEE Standard 1100-1992 "Recommended Practice for Powering and Grounding Sensitive Electronic Equipment" and manufacturer's equipment specifications.
4. High current distortion and excessive current draw on branch circuits exceeding IEEE Standard 1100-1992 "Recommended Practice for Powering and Grounding Sensitive Electronic Equipment" and manufacturer's equipment specifications.
5. High neutral-to-ground voltage often greater than 2 volts exceeding IEEE Standard 1100-1992 "Recommended Practice for Powering and Grounding Sensitive Electronic Equipment."
6. High voltage and curent distortions exceeding IEEE Std. 519-1992 "Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems."
7. Poor power factor conditions that result in monthly utility penalty fees for major users (factories, manufacturing, and industrial) with a power factor less than 0.9.

8. Resonance that produces over-current surges. In comparison, this is equivalent to continuous audio feedback through a PA system. This results in destroyed capacitors and their fuses and damaged surge suppressors which will cause an electrical system shutdown.
9. False tripping of branch circuit breakers.
10. Malfunctioning of microprocessor-based equipment.
11. Overheating in neutral conductors. transformers, or induction motors.
12. Deterioration or failure of power factor correction capacitors.
13. Erratic operation of breakers and relays.
14. Pronounced magnetic fields near transformers and switchgear.

There are several solutions to compensate for and reduce harmonics, which are:

1. Oversize the neutral wiring.

In modern facilities, the neutral wiring should always be specified to be the same capacity as the power wiring, or larger—even though electrical codes may permit under-sizing the neutral wire. An appropriate design to support a load of many personal computers, such as a call center, would specify the neutral wiring to exceed the phase wire capacity by about 200 percent. Particular attention should be paid to wiring in office cubicles. Note that this approach protects the building wiring, but it does not help protect the transformers.

2. Use separate neutral conductors.

On three-phase branch circuits, instead of installing a multi-wire branch circuit sharing a neutral conductor, run separate neutral conductors for each phase conductor. This increases the capacity and ability of the branch circuits to handle harmonic loads. This approach successfully eliminates the addition of the harmonic currents on the branch circuit neutrals, but the panel board neutral bus and feeder neutral conductor must still be considered.

3. Use DC power supplies, which are not affected by harmonics.

In the typical data center, the power distribution system converts 480-volt AC utility power through a transformer that steps it down to 208-volt AC power that feeds racks of servers. One or more power supplies within each server convert this AC input into DC voltage appropriate for the unit's internal components. These internal power supplies are not energy efficient, and they generate substantial heat, which puts a costly burden on the room's air conditioning system. Heat dissipation also limits the number of servers that can be housed in a data center. According to a recent article in *Energy and Power Management* magazine, "Computers and servers equipped with DC power supplies instead of AC power supplies produce 20 to 40percent less heat, reduce power consumption by up to 30 percent, increase server reliability ,offer flexibility to installations, and experience decreased maintenance requirements."That sounds good, but when cost, compatibility, reliability and efficiency are considered together, the move from AC to DC power is not justified for most data centers. AC power—even though it is slightly less efficient is universally acceptable to existing equipment.

4. Use K-rated transformers in power distribution components.

A standard transformer is not designed for high harmonic currents produced by non-linear loads. It will overheat and fail prematurely when connected to these loads. When harmonics were introduced into electrical systems at levels that showed detrimental effects (circa 1980), the industry responded by developing the *K-rated transformer*. K-rated transformers are not used to handle harmonics, but they can handle the heat generated by harmonic currents and are very efficient when used under their K-factor value. K-factor ratings range between 1 and 50. A standard transformer designed for linear loads is said to have a K-factor of 1. The higher the K-factor, the more heat from harmonic currents the transformer is able to handle. Making the right selection of K-factor is very important, because it affects cost and safety. The table shows appropriate K-factor ratings to use for different percentages of non-linear current in the electrical system.

5. Passive filters

Passive filters (also called traps) include devices that provide low-impedance paths to divert harmonics to ground and devices that create a higher-impedance path to discourage the flow of harmonics. Both of these devices, by necessity, change the impedance characteristics of the circuits into which they are inserted. Another weakness of passive harmonic technologies is that, as their name implies, they cannot adapt to changes in the electrical systems in which they operate. This means that changes to the electrical system (for example, the addition or removal of power factor–correction capacitors or the addition of more nonlinear loads) could cause them to be overloaded or to create “resonances” that could actually amplify, rather than diminish, harmonics.

Although simple and least expensive, the passive filter inherits several shortcomings. The filter components are very bulky because the harmonics that need to be suppressed are usually of the low order. Furthermore the compensation characteristics of these filters are influenced by the source impedance. As such, the filter design is heavily dependent on the power system in which it is connected to. Passive filters are known to cause resonance, thus affecting the stability of the power distribution systems. Frequency variation of the power distribution system and tolerances in components values affect the filtering characteristics. The size of the components become impractical if the frequency variation is large. As the regulatory requirements become more stringent, the passive filters might not be able to meet future revisions of a particular Standard. This may required a retrofit of new filters.

6. Active power filters

This is the most versatile and flexible solution compared to others. Like an automatic transmission in a car, active filters are designed to accommodate a full range of expected operating conditions upon installation, without requiring further adjustments by the operator. Active harmonic filters are relatively new and rather costly, but offer several advantages. They are inherently current limiting, have no resonance problems, are "intelligent" and adaptable, and can be configured to either correct the full spectrum of harmonics or to target specific harmonics. Although this technology is new, it has important advantages and should be watched carefully. It is worth stressing that the particular solution for your facility must be the result of careful analysis and isolation of the problem.

From above options of solution to mitigate harmonics, using active power filter is chosen based on the advantages and the effect to the electrical system.(Anynomous,1992).

2.3 Active power filters

Active power filter applicable to compensate current-based distortions such as current harmonics, reactive power and neutral current. It is also used for voltage-based distortions such as voltage harmonics, voltage flickers, and voltage sag and swell and voltage imbalances. Active filters have the advantage of being able to compensate for harmonics without fundamental frequency reactive power concerns. This means that the rating of the active power can be less than a comparable passive filter for the same non-linear load and the active filter will not introduce system resonances that can move a harmonic problem from one frequency to another.

Remarkable progress in power electronics had spurred interest in APF for harmonic distortion mitigation. The basic principle of APF is to utilize power electronics technologies to produce specific currents components that cancel the harmonic currents components caused by the nonlinear load.

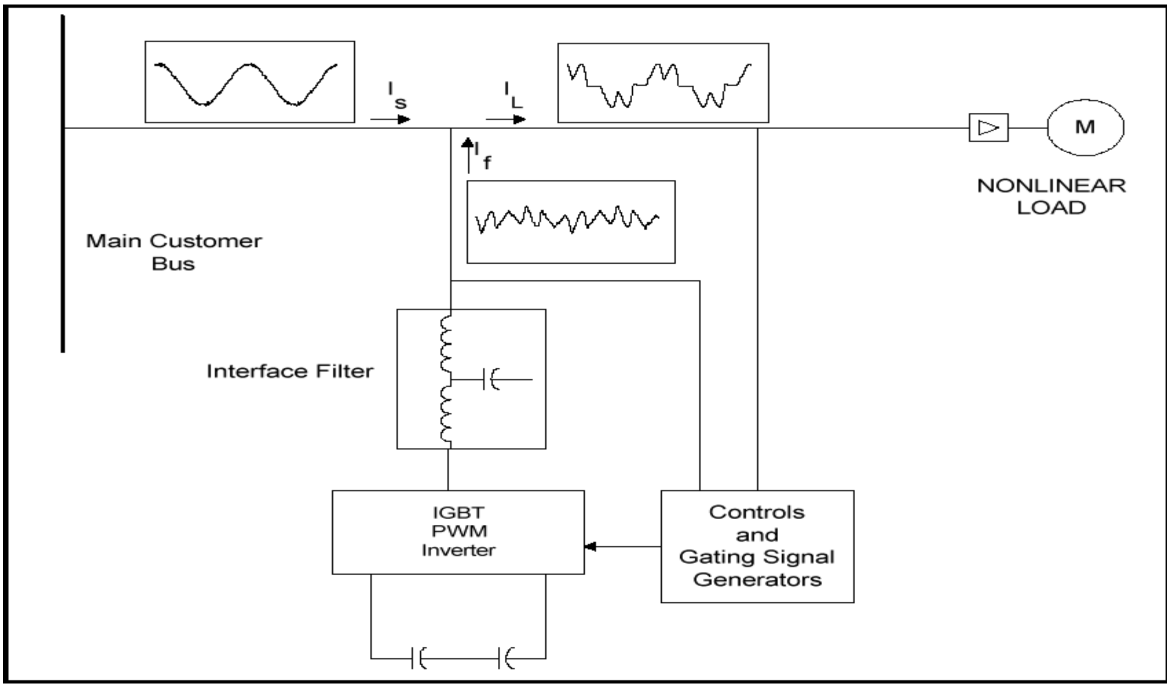
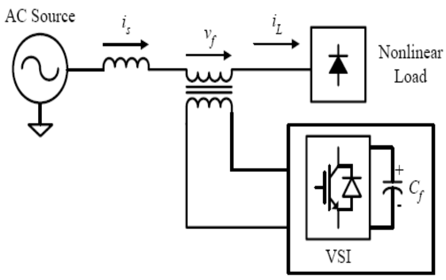


Figure 2.1: Components of a typical APF system

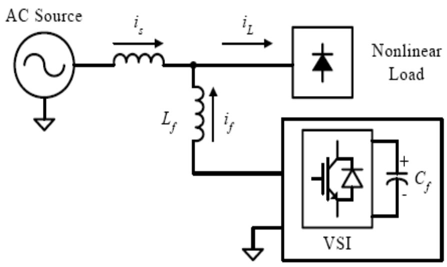
Figure 2.2 shows the components of a typical APF system and their connections. The information regarding the harmonic currents and other system variables are passed to the compensation current/voltage reference signal estimator. The compensation reference signal from the estimator drives the overall system controller. This in turn provides the control for the gating signal generator. The output of the gating signal generator controls the power circuit via a suitable interface. Finally, the power circuit in the generalized block diagram can be connected in parallel, series or parallel/series configurations depending on the interfacing inductor/transformer use.

APFs have a number of advantages over the passive filters. First of all, they can suppress not only the supply current harmonics, but also the reactive currents .Moreover, unlike passive filters; they do not cause harmful resonances with the power distribution systems. Consequently, the APFs performances are independent on the power distribution system properties. On the other hand, APFs have some drawbacks. Active filtering is a relatively new technology, practically less than four decades old. There is still a need for further research and development to make this technology well established.

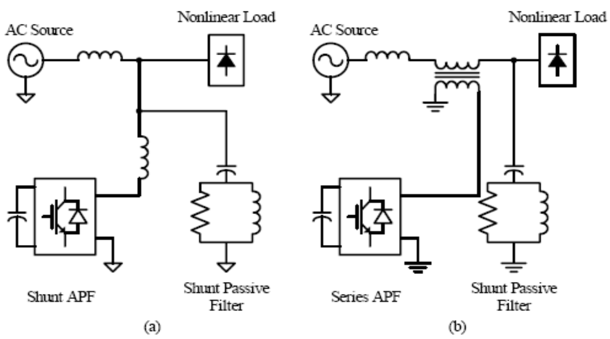
Active power filter can be connected in several power circuit configurations as illustrated in the block diagram shown in Figure 2.2. In general, they are divided into three main categories, namely shunt APF, series APF and hybrid APF.



Series connection of active power filter



Parallel connection of an active power filter



Hybrid connection of an active power filter

Figure 2.2: Connection of an active power filter; series, parallel and hybrid