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MASTER’S DEGREE IN ELECTROTECHNICS

OPTION: ELECTRICAL CONTROLS

RESEARCH TITLE

Study and simulation of a hybrid filter delivering on a non-linear load

Presented by

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Defended on September 30th, 2021, before a jury composed of:

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DEDICATION

I wholeheartedly dedicate this work to Almighty God who gave me strength, courage and protection, and who kept me healthy during the research process, for that, I'm sincerely and truly grateful.

To my beloved parents Gyenin JOHN and Gyenin CYNTHIA as you have been my pillars of strength and inspirational through your continuous moral and emotional support throughout the process.

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My special appreciation goes to the Department of Electrical Engineering for granting me the opportunity to do my research work in my native language English. This has always been my stronghold and I humbly appreciate the acceptance.

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ملخص

الهدف من هذه الأطروحة هو التركيز بشكل أساسي على تقليل التوافقيات الحالية للحمل وتحسين عامل القدرة باستخدام النهج الهجين وبالتالي تركيبة المرشح النشط والسلبي. يتم استخدام المرشح النشط للتخلص من التوافقيات ذات السعة العالية ذات الترتيب المنخفض على الرغم من أنها ليست حلاً اقتصاديًا. بقدر ما يتم قبول المرشحات السلبية كحل فعال من حيث التكلفة ، فهناك فرصة لحدوث الرنين في النظام. في هذه الحالة ، ساعدت مجموعة المرشحات في تحسين خصائص التصفية.

في الجزء الأول ، يتم تقديم "جودة الطاقة / الطاقة" ، والاضطرابات المختلفة التي يمكن أن تحدث في الشبكات الكهربائية ، ومعايير الصناعة القياسية الدولية وتصفية نظام الطاقة المختلفة ، وخاصة Shunt Active Power Filter ، وتكوينه. نتعمق في نظرية pq وأهميتها في المرشحات النشطة. في الجزء اللاحق ، كان التركيز على دراسة المرشحات الهجينة التي تقدم حملاً غير خطي.

تهدف أطروحة الماجستير هذه إلى دراسة ومحاكاة مرشح هجين تم تصميمه في برنامج MATLAB SIMULINK و SimPowerSystems Toolbox، مع مرشح نشط هجين للتعويض عن التيار التوافقي الذي يتم حقنه بواسطة الأحمال غير الخطية في الشبكة الكهربائية. يعتمد تقييم الأداء لكل تكوين تمت دراسته على سلوكهم في حالة ثابتة وديناميكية. توضح نتائج المحاكاة التي تم الحصول عليها فعالية مرشح الطاقة النشط الهجين المقترح ولضمان حصوله على النتائج أو الأداء المتوقع.

الكلمات الدالة

مرشح الطاقة النشط ، جودة الطاقة ، المرشح السلبي الخطية ، المرشح الهجين ، طاقة التيار المتردد ، التوافقيات ، الأحمال غير

Abstract

The objective of this thesis is to mainly concentrate on reduction of load current harmonics and power factor improvement using the hybrid approach thus active and passive filter combination. The active filter is used to eliminate low order high amplitude harmonics even though it is not an economic solution. Inasmuch as the passive filters are accepted as cost-effective solution, there is a chance for occurrence of resonance in the system. In this condition, the combination of filters helped to improve filtering characteristics.

In the first part, Power/Energy Quality is presented, the various disturbances that can occur in electrical networks, international industry standard norms and the different power system filtering particularly Shunt Active Power Filter, its configuration. We delve into the pq theory and its relevance in the active filters. In the subsequent part the focus was on the study of Hybrid filters delivering on a nonlinear load.

This Master's thesis is aimed at studying and simulating of a hybrid filter modelled in MATLAB SIMULINK software and SimPowerSystems Toolbox, with a hybrid active filter to compensate for the harmonic current injected by the nonlinear loads in electrical network. The performances evaluation of each configuration studied is based on their comportment in steady and dynamic state. The obtained simulation results demonstrate the effectiveness of the proposed hybrid active power filter and to ensure it has the expected results or performance.

Key Words:

Active Power Filter, Power Quality, Passive filter, hybrid filter, AC power, Harmonics, Nonlinear loads, THD, P-Q theory.

Resumé

L'objectif de cette thèse est de se concentrer principalement sur la réduction des harmoniques de courant de charge et l'amélioration du facteur de puissance en utilisant l'approche hybride donc la combinaison de filtres actifs et passifs. Le filtre actif est utilisé pour éliminer les harmoniques de faible ordre et de forte amplitude même s'il ne s'agit pas d'une solution économique. Dans la mesure où les filtres passifs sont acceptés comme une solution rentable, il existe un risque d'apparition de résonance dans le système. Dans cette condition, la combinaison de filtres a permis d'améliorer les caractéristiques de filtrage.

Dans la première partie, la Qualité Puissance/Energie est présentée, les différentes perturbations pouvant survenir dans les réseaux électriques, les normes internationales standards de l'industrie et les différents filtrages du système d'alimentation notamment Shunt Active Power Filter, sa configuration. Nous approfondissons la théorie pq et sa pertinence dans les filtres actifs. Dans la partie suivante, l'accent a été mis sur l'étude des filtres hybrides délivrant une charge non linéaire.

Ce mémoire de maîtrise vise à étudier et simuler un filtre hybride modélisé dans le logiciel MATLAB SIMULINK et SimPowerSystems Toolbox, avec un filtre actif hybride pour compenser le courant harmonique injecté par les charges non linéaires dans le réseau électrique. L'évaluation des performances de chaque configuration étudiée est basée sur leur comportement en régime permanent et dynamique. Les résultats de simulation obtenus démontrent l'efficacité du filtre de puissance active hybride proposé et garantissent qu'il a les résultats ou les performances attendus.

Mots Clé :

Filtre de puissance actif, Qualité de puissance, Filtre passif, Filtre hybride, Puissance en régime Alternatif, Harmonics, Charges Non Linéaire, THD, Théorie p-q

GLOSSARY

PCC	Power Control Center
APF	Active Power Filter
DTPF	Double Tuned Passive Filter
STPF	Single Tuned Passive Filter
SCR	Silicon Control Rectifier
PAF	Parallel Active Filter
AC	Alternative Current
DC	Direct Current
GTO	Gate Turned Off
UPQC	Unified Power Quality Conditioner
IGBT	Insulated-gate bipolar transistor
THD	Total Harmonic Distortion
PI	Proportional Integral
SAPF	Shunt Active Power Filter
LED	Light Emitting Diode
FFT	Fast Fourier Transform
DFT	Discrete Fourier Transform
PWM	Pulse Width Modulation
DSP	Digital Signal Processor

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General Introduction

Energy service is the factor of the development for most nations, the quality of energy we have in various countries play a major role in the country’s development. Electricity generation is one of the key factors in order to achieve the development of the Ghanaian national economy. However, to achieve this quality of energy lies in the hands of the producer and the consumer. Technological advancements have seen us moving away from the conventional linear loads in our various homes lately, it is very rare to see incandescent lamps now in our homes or communities. All have been replaced by fluorescent lamps and lately LED’s. Moreover, to switch to the industries, an induction motor that can be considered as a linear load in a steady state is now equipped with a rectifier and inverter for the purpose of achieving adjustable speed control.

The induction motor together with its drive are no longer considered as a linear load. However, to achieve this has not been something to acquire easily on a silver platter. To bring this to effect, there should be a constant ac power system with constant voltage and frequency. One may ask why these changes?For a very long time there have been issues concerning the relation between the average power actually delivered or consumed in a circuit and the apparent power at the same point (Power FactorCorrection). With this correction that was made, it was later realized that, Non-linear Loads draw in currents in abrupt short pulses. These pulses distort the current waveforms, which in turn generates harmonics that can lead to power problems affecting both the distribution system equipment and the loads connected to it. In view of this, a hybrid filter is created to isolate the harmonics. Furthermore, this my research work is centered on isolating or eliminating harmonic current created by nonlinear loads from the power network using a hybrid filter. This was realized by the help of the various simulations that were carried out.

Hybrid Filter which is a combination of an active power filter and a passive power filter were studied and simulations were carried out in each of these filters, active filter provided a better response even at a very low frequency but components are expensive, however in the case of a passive filter, it compensated for the reactive power by eliminating the harmonics. Both filters were put together by the help of MATLAB to create a hybrid active power filter, a simulation was run lastly and realized a better response. Finally, I realized a hybrid filter is a cost-effective option for power quality improvement, compensation of the poor power quality effects due to nonlinear loads.

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CHAPTER I

State of the Art

I.1 Introduction

Generally, the energy distributor delivers electrical energy in the form of a three-phase system of sinusoidal voltages. The characteristic parameters of this system are the frequency, amplitude, waveform, which must be sinusoidal to the symmetry of the three-phase system. But in recent years, with the technological evolution of components power electronics energy distributors encounter several problems related to the increase in the number of static converters connected to the distribution networks of energy. Indeed, these converters are polluting sources which absorb currents non-sinusoidal and consumed most of the reactive power. It generates harmonics and affects the power factor. However a lot of solutions are created to compensate all these disturbances.

I.2 Distortion in Power Networks[1].

There are different sources of distortion in power networks. They can be divided into three classes according to the power level of the equipment and frequency range.

1) sub-cycle distortion give rise to flicker and occur generally at the highest power level(S>10MVA), they are caused by dynamic loads, such as arc furnaces, mil1 drives, mine winders
2) high frequency distortion is caused by modem power electronic equipment, due to hi& rate of rise of current and voltage.(1KVA<S<10MVA)
3) intracycle distortion which covers a very wide range of power, and results from the power processing technique. (S<1KVA).

However, the distortions caused by these are called harmonics.

I.2.1 Harmonics

1.2.1.1 Sources of Harmonics and its Effects

Harmonic currents[2] are generated mainly due to the presence of:

1. nonlinear loads
2. harmonic voltages in the power system

The presence of harmonics in electrical systems means that current and voltage are distorted and deviate from sinusoidal waveforms. Some harmonic currents are caused by non-linear loads connected to the distribution system. The flow of harmonic currents through system impedances in turn creates voltage harmonics, which distort the supply voltage. Harmonics are deformation in the conventional electrical current wave shape. These are integral multiples of the central power frequency. For the analysis of complex signals Fourier Transform[3] is used. This can be “Fast Fourier Transform” (FFT) or “DiscreteFourier Transform” (DFT). These methods give results when the signal contains only the fundamentaland harmonic frequencies in a definite frequency range (known as Nyquist frequency, i.e., half of the sampling frequency). The harmonics which are not integer multiples of fundamental harmonicsare called inter harmonics. Inter harmonics which have frequency less compared to the fundamental frequency are known as sub harmonics.

I.2.1.2 Non-Linear Load

A load is said to be non-linear [4] when the current it draws does not have the same waveform as thesupply voltage. A nonlinear load offers varying impedance to the applied voltage so that the currentwaveform doesn’t vary according to the voltage waveform. This leads to a non-sinusoidal currentwaveform. Nonlinear loads provide large impedance at some part of voltage waveform. The impedance is sharply brought down as the voltage achieves the region of peak value. For the low impedance offered by the load current rises sharply and again with sudden rise in the impedance value, the current experiences a sudden drop. As the voltage and the current waveform are not more colligated, they are stated as nonlinear. Some illustrations of nonlinear loads are laser prints, uninterruptible power supply, drives with altering speeds, loads with diode-capacitor power supplies etc. These loads attract short pulse currents at time of crest of the line voltage. These non-sinusoidal current pulses insert unforeseen reflective currents back to the power distribution system resulting in functioning of current at frequencies apart from primal frequency

Harmonics can cause problems such as [5]:

- distortion of the mains supply voltage
- equipment overheating
- nuisance tripping of circuit breakers

- misfiring of variable speed drives

Types of Equipment Non-Immune to harmonic distortion are:

- The odd triplet harmonics in three phase wye circuits sum up with the neutral.
- Incorrect reading including induction disc, watt hour meters and averaging type current meters
- Due to different harmonics having different sequencing values in balanced systems there is possibility of forward torque, backward torque and no torque in case of motors, generators
- Failure of electronic equipment
- Protective devices comprising zero crossing sensing circuits can experience false tripping of relay and failure of a UPS to transfer the right way
- Due to un-insulated bearings of electric motors shaft currents can do bearing failure

I.2.1.3 Total Harmonic Distortion

The total harmonic distortion (THD or THDi) [6]. is a measurement of the harmonic distortion presentin a signal and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. Different criteria are defined to characterize this type of disturbance. The THD (the rate of Harmonic Distortion) and the power factor are the most used toquantify harmonic disturbances and reactive power consumption respectively.

$$THD = \sqrt{\sum_{h=2}^{\infty} \frac{X_h^2}{X_1^2}}.100\% \qquad \text{I.01}$$

With X1 the rms value of the fundamental current (voltage) and X h the rms values of the different harmonics of the current (voltage). In general, the harmonics taken into account in a electrical network are below 2500 Hz, which corresponds to the range of low disturbances frequencies in the sense of standardization. Higher frequency harmonics are strongly attenuated by the skin effect and by the presence of line inductors. In addition, the devices generating harmonics have, for the most part, an emission spectrum of less than 2500 Hz, this is the reason why the field of study of harmonics generally extends from 100 to 2500 Hz, that is, ranks 2 to 50.

The TDD represents the ratio of the effective value of the harmonics to the maximum value of the current drawn by the load. It is defined by the relation :

$$TDD = \sqrt{\sum_{h=2}^{\infty} \frac{I_h^2}{I_L^2}}.100\% \tag{I.02}$$

I.2.1.4 Harmonic Index

Form factor of a wave can be used for detection of harmonics.

$$Form\ factor = \frac{rms\ value}{average\ value} \tag{I.03}$$

the ratio of root mean square (RMS) value and average value for an alternate current waveform is called form factor [7]. Form factor for a sine wave is 1.11 approximately. If after examination of a certain sinusoidal waveform the form factor differs from 1.11 then it is contaminated with harmonics.

- Crest factor of a wave can be used for detection of harmonics. The ratio of peak value to the root mean square (RMS) value for a waveform is known as crest factor. A typical sinusoidal wave has a value of crest factor as 1.414. Crest factors other than 1.414 indicate a deformation in the waveform. Typically deformed current waveforms show crest factor greater than 1.414 and distorted voltage waveforms have crest factor lower than 1.414. Distorted waveforms with crest factor lower than 1.414 lower than 1.414 is known as Flat Top voltage waveforms.

- Due to fluctuations in loads distribution system can undergo frequency deviation. The change in frequency can be determined as deviation of instantaneous frequency from the nominal frequency.

We present the Harmonic Standard and Recommended Practices in annex 01.

I.2.1.5 Resonance

On networks, there are two types of resonance[8] (parallel resonance and series). The presence of resonances entails additional constraints on certain equipment, and in particular on capacitors which can then deteriorate rapidly. Certain precautions must therefore be taken when installing this equipment, so as not to amplify the harmonic currents and voltages present on the networks.

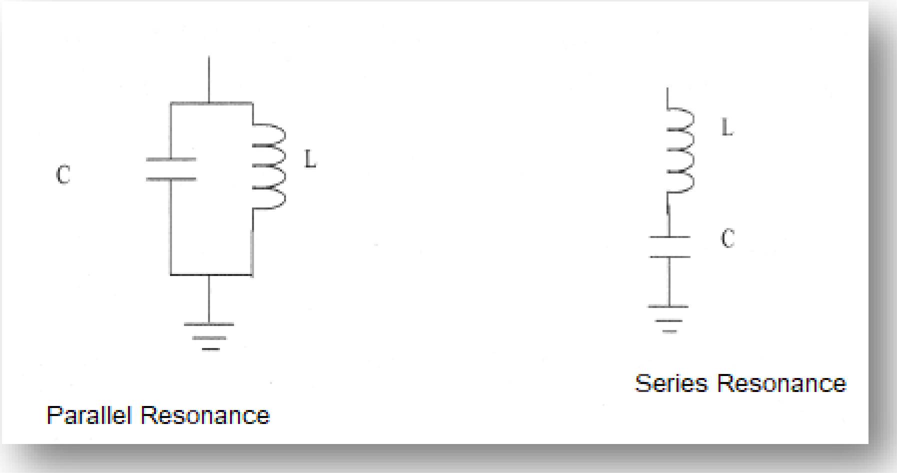


Figure I.01 : Example of Series and parallel Resonance

I.2.1.6 Power Factor

For a sinusoidal signal the power factor is given by the ratio between the active power **P** and the apparent power **S**. A low value of the power factor results in improper use of these equipment.

So the power factor [9] (PF) becomes :

$$PF = P / S \qquad \text{I.04}$$

In the presence of harmonics, the apparent power S is made up of three parts : Active P, reactive Q and distorting D.

Its expression is given by the following equation :

$$S=\sqrt{P^2+Q^2+D^2} \qquad \text{I.05}$$

The reactive power Q is associated with the fundamental current. The distorting power D is due to current harmonics with :

$$D = 3v\sqrt{Ic^2+Ic1^2} \qquad \text{I.06}$$

Where Ic is the rms value of the load current. For a sinusoidal signal the power factor PF is equal to the quotient of the Active power P by the apparent power S:

$$PF = \frac{P}{S} = \frac{P}{\sqrt{P^2+Q^2+D^2}} \qquad \text{I.07}$$

The power factor will always be less than 1, by setting :

$$P= 3v.Ic1.\cos\phi \qquad \text{I.08}$$

We would have :

$$PF = Ic1/Ic.\ \cos\phi = Fdis.\cos\phi \qquad \text{I.09}$$

Where Fdis is the distortion factor. It is 1 when the current is perfectly Sinusoidal and decreases when the deformation of the wave increases. Φ represents the phase shift between the fundamental current and the voltage.

In order to avoid the inconvenience caused by the presence of currents and voltages harmonics in the network, standards are imposed on users. [10]

Observation:

By definition, the power factor - in other words the Cosø of an electrical device - is equal to the ratio of the active power P (kw) to the apparent power S (kVA) and may vary from 0 to 1. It thus makes it possible to easily identify more or less consuming devices reactive energy.

- A power factor equals to 1 will not lead to any energy consumption reactive (resistance).
- A power factor of less than 1 will lead to energy consumption reactive all the more so as it approaches 0 (inductance).

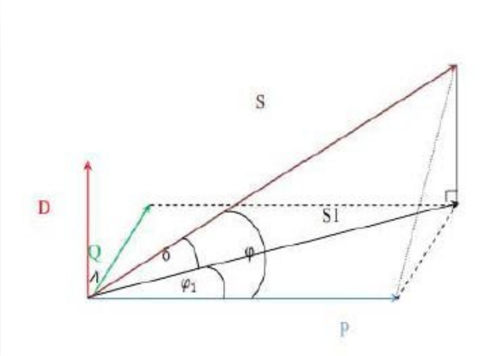


Figure I.02 : Fresnel Diagram of Power Factor

I.2.1.7 Interharmonics :

Interharmonics are frequency signals that are not integer multiple of the frequency fundamental (130Hz, 170Hz, 220Hz… ..) that is to say located between the harmonics.

Some are emitted by non-linear loads, others are intentionally injectedby distributors on their networks to remotely control relays and thus control changes in the pricing of domestic and professional meters. [11]

Comparison between Harmonics and interharmonics:

Harmonics are a superposition on the fundamental wave (50Hz) of sine waves but of multiple frequencies integer of the fundamental. The main source of the presence of harmonics in power grids is the heavy use of static converters.

The inter-harmonics are superimposed on the fundamental wave but are not multiples integers of the network frequency.

1.3 Voltage Dip

1.3.1 Source and effects of Voltage Dip [12]

Voltage Dip is defined as a decrease of voltage value below 90% of nominal voltage UN for durations from 10 ms up to 1 minute. A voltage dip is mainly caused by remote short-circuits, are generally considered to be the serious power quality problem. Their effect on the operation of sensitive equipment is the same like the effect of the short supply interruptions. A voltage dip is a momentary decrease in the rms voltage magnitude. Voltage dips are characterized by their magnitude (remaining voltage, i.e., the voltage during the fault) and duration. The voltage dips occur during faults in a wide part of the power system. Compared to interruptions, the voltage dips occur more frequent and affect a larger number of consumers. The knowledge about the occurrence of voltage dips in a network can be obtained through the use of power quality monitors or by means of prediction methods.

Table : Consequence of Voltage dip on some electrical equipment

Type of Device	Consequences
Lightning	Less Brightness, extinction and re-ignition
Power Electronics	Stoppage of Device
Protection Device	Openings of Contactors
Asynchronous Motors	Slowdowns, blockings, overcurrent on voltage returns.
Synchronous Motors	Loss of synchronism, stalling and stopping of the engine
Variable speed drives for a DC motor	• Invertor Mode=Destructions of Protection • Rectifier Mode= Slowing down of the machine
Variable speed drives for an asynchronous motor	Slowing down, blocking, overcurrent on voltage return, possible destruction of equipment at the converter

I.4 Power Quality

However, Power Quality [13] therefore is related to Energy quality. The difference between ‘Power Quality’ and ‘Energy Quality’ is that the power quality is mainly concerned with the quality of voltage and current waveforms while the energy quality is mainly concerned with the quality of power flows, power generation and power demand waveforms (or profiles). In other words, power quality and energy quality are not directly correlated. The two frameworks have different primary concerns/focuses, drivers and motivations. It should be pointed out that both frameworks could not cover everything by themselves, and both concepts are needed and useful to characterize the operations and performances of future renewable energy dominated power systems. The two frameworks will help each other and bring strength and prosperity of our power & energy system subjects.

I.4.1 Effects of Power Quality

- Mal Operation of remote controls.
- Overheating of cables, which is caused by the circulation of harmonic currents in the neutral of three-phase systems.
- Increased eddy losses in transformers.
- Incorrect operation of protective devices.
- Errors in energy metering.
- Greater poor losses in distribution network
- Interference problems in communication systems

I.4.2 Low Quality Energy

Low quality energy is any form of energy which is dispersed and disorderly, and has less potential or ability to be utilized for work. It is directly contrasted with high quality kinds of energy. Electricity for example is high quality and can be converted to heat, mechanical or electromagnetic energy with great efficiency and not muchloss. Heat from burning fuel is a low-quality energy, thus can only take care of tasks like water heating that are simple.

I.4.3 High Quality Energy

High quality type of energy can be transformed into several others without much loss. High quality energy for example, electricity,can easily be used to produce low quality energy, such as low temperature heat, whereas the opposite is much more difficult and, in some cases, impossible in practice. High quality energy is more valuable than low quality energy.

I.4.4 Energy Quality

Energy Quality[14] is mainly concerned with the quality of power flow waveform in power networks, output power waveforms of power generation sources as well as power demand waveforms (profiles) over time. Energy Quality, which is time dependent and locational related, can be measured at different locations in different time scales from seconds to long-term period. It characterizes time dependent locational power waveform (or profile) behaviors so as to value their behaviors and/or services in regarding to their time dependent and locational related characteristics and performances. And hence Energy Quality is very much related to the characterization of frequency and power variations/deviations and power balancing in terms of technical performances and market values.

I.4.5 Classification of Energy Quality

- Short-term power variations
- Mid-term power variations
- Long-term power variations
- Very Long-term power variation

Short-term power variations: This considers the power waveforms typically in the time scale of seconds (or even milliseconds), up to minutes. Hence this will look at transients of power waveforms.

Mid-term power variations: This considers the power waveforms in the time scale of minutes, up to hours. This is related to spinning reserve and non-spinning reserve time frame.

Long-term power variations: This considers the power waveforms in the time scale of half hour, up to days or a week, or a month, or up to a year.

Very long-term power variations: This considers the power waveforms in the time scale of from a year, up to 10–20 years. This time scale is particularly related to power system planning.

1.5 Electrical Surge

1.5.1 Definition of Overvoltage

The proper functioning of electrical devices is relative to voltage. Under voltage may cause the device to malfunction or even fail to operate, and overvoltage may damage it.

The overvoltage is a phenomenon which results when the voltage at the input of the terminals of a device is higher than the accepted threshold: it is an increase over a short period of the voltage[15].

1.5.2 Causes of Power Surge

- Internal Sources within homes
- Outdated Electrical Systems
- Lightning Strikes
- Fallen Tree Limbs, Car Accidents and Wildlife

I.5.3 Signs of Power Surge

- Electrical appliances and electronic devices with flashing clocks are a fairly obvious sign that an electrical surge to the power strip or wall outlet occurred.
- Since power surges can cause burning, you might catch a whiff. If you suspect a power surge, smell around the wall outlet or power strip to see if you can detect a burnt aroma.
- Some wall outlets and power strips have reset buttons. These buttons will move to the reset position if the outlet has experienced an electrical fluctuation. If you have to reset this button manually, there’s a good chance there was a power surge[16].

I.5.4 Effects of an electrical surge

Surges, internal or external, have direct effects on electrical equipment:

- Internal overvoltage causes a slow but continuous degradation of household appliances until the appliance is damaged, because the microprocessors of the appliances short-circuit each other.
- External surges directly damage the appliance or electrical equipment by “burning” it.

I.6 Compensation Solution

I.6.1 Passive Filter

Passive filter is another approach to filter out harmonic present in system and in this filter designing we are using passive elements. Passive elements R, L, C are being used to overcome the complexity of system. The combined of these three elements did not depend on external power supply and it is called passive filter. The capacitor passing high frequency signals and blocking low- frequency signals, and inductor do the just opposite of it. . Similar as active filter we are dealing with the attenuation when we analysis that the inductor is passing the signals whereas the capacitor will ground it, the filter providing a less attenuation for low frequency filter. This low frequency filter called low-pass filter. The reverse action of capacitor and inductor, called high pass filter. Here if the signal passes through a capacitor, or ground through an inductor, then the filter presents less attenuation and called high-pass filter. The resistors have no frequency selection assets but used for determining the time constants of both inductor & capacitor[18].

I.6.2 Active Filter

Active filter is electronic filter & using active component for the proper working like an amplifier[19].In filter amplifier used for improving performance of filter. The purpose of these active filters is to generate either currents or harmonic voltages so that the current or voltage becomes sinusoidalagain.

The most important advantages of active filters over passive filters are as follows :

- The physical volume of the filter is smaller,
- The filtering capacity is greater,

- The flexibility and adaptability are much higher.

However, they also have a few drawbacks:

- Their high cost (which limited their establishment),
- The losses are higher (power supplied for compensation).

I.6.3 Shunt Active Filter

A PAF connects in parallel with the network and injects the components in real time harmonics of the currents absorbed by the non-linear loads connected to the network. So, the distorted current supplied by the power source becomes sinusoidal. The objective of the parallel active filter[20] (P.A.F)consists in preventing disturbing currents (harmonics, reactive and unbalanced), produced by polluting loads, to circulate through the network impedance, located upstream of the active filter connection point.

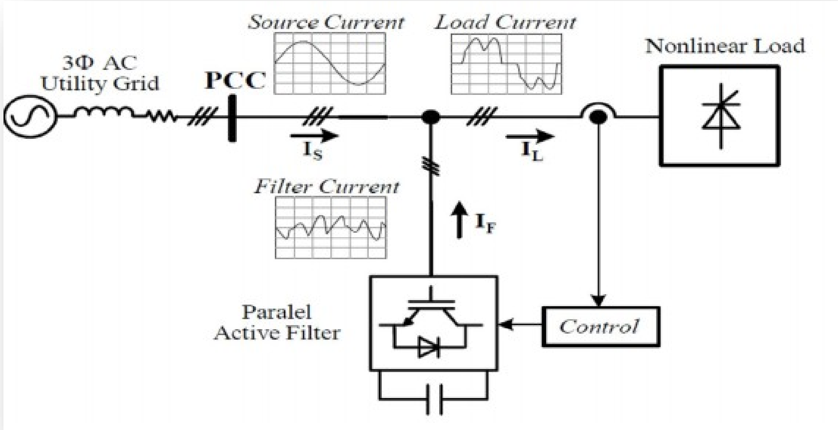


Figure I.03 Shunt Active Filter

Shunt active filters have more advantage over series active filters regarding their form and function. So, series active filters are basically suitable only for harmonic filtering. Shunt active filter circuit configuration: -

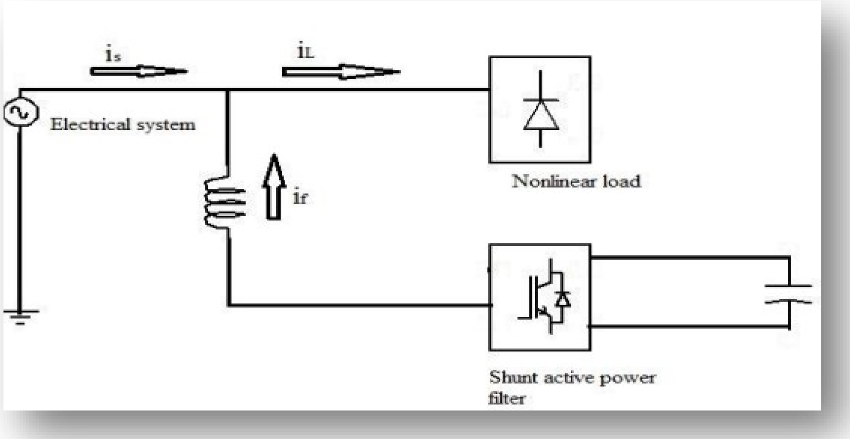


Figure1.04 Schematic diagram of a shunt active filter.

This is a very fundamental system design which can be modified further. The dc load can be treated as ac motor driven by a voltage source PWM (VS-PWM) inverter. This active filter has been connected in parallel with the harmonic generating load.

Feed forward method has been implemented to control the filter.

- The instantaneous load current is observed by the controller.
- From the detected load current harmonic current is pulled out with the help of DSP.
- To cancel out the harmonic current, active power filter draws compensating current from utility supply.

I.6.4 Series Active Filter

The most flexible modern solution that allows the decontamination of the electrical networks of voltage disturbances is the use of series active filters. This filter is connected in series with the distribution network as shown in Fig. I-3, it behaves like a voltage source which opposes disturbing voltages (harmonics, troughs, imbalance, etc.) coming from the source and also that caused by the circulation of disturbing currents through network impedance. Thus the voltage across the (sensitive) load to be protected is purely sinusoidal.

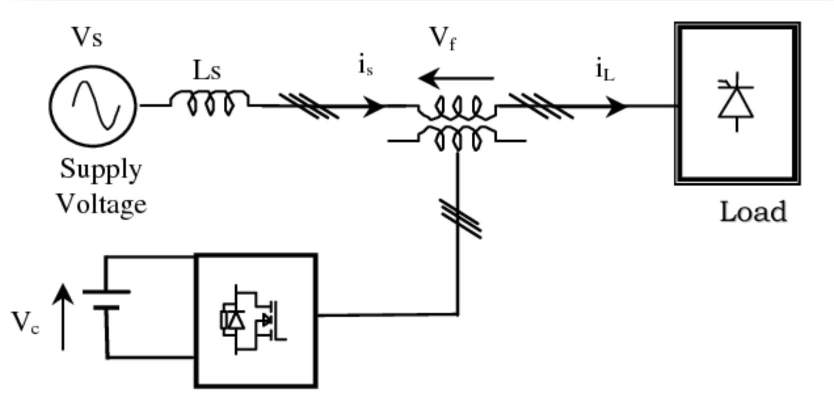


Figure 1.05 Series Active Power Filter

I.6.5 Hybrid Filter

Hybrid active filters for harmonic filtering

There are two types of hybrid active filters for harmonic filtering of nonlinear load. The proposal of the two hybrid filters has encouraged power electronics researchers/engineers to do further research on various hybrid active filters, concentrating on their practical use.

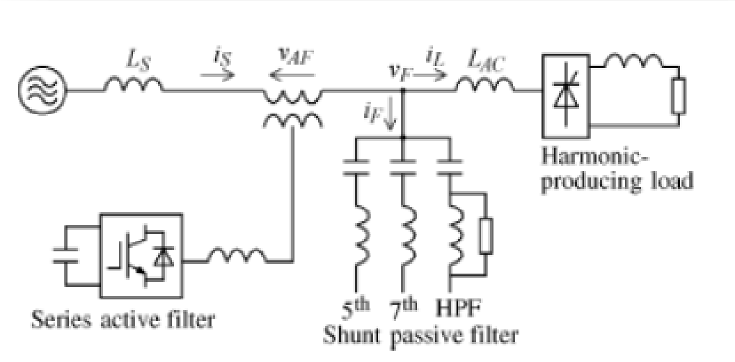


Figure1.06 Combination of a series active filter and a shunt passive filter

The two hybrid filters are based on combinations of an active filter, a three-phase transformer (or three single-phase transformers), and a passive filter consisting of two single tuned filters to the fifth- and seventh-harmonic frequencies and a second-order high-pass filter tuned around the 11th-harmonic frequency. Although these hybrid filters are slightly different in circuit configuration, they are almost the same in operating principle and filtering performance.

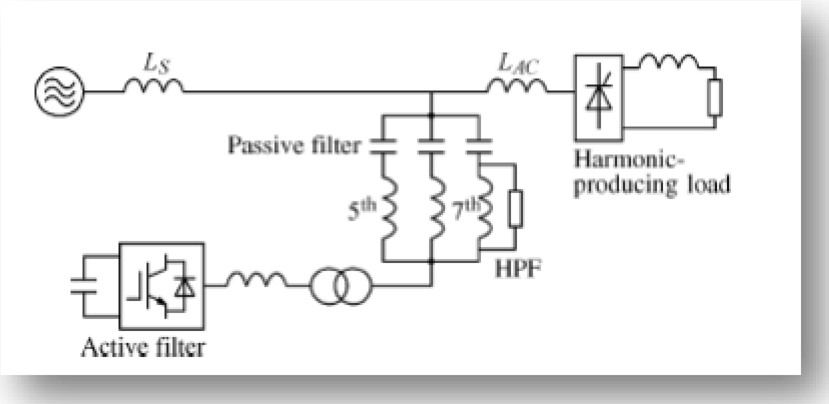


Figure I.07 Series connection of an active filter and a passive filter

Such a combination with the passive filter makes it possible to significantly reduce the rating of the active filter. The task of the active filter is not to compensate for harmonic currents produced by the thyristor rectifier, but to achieve ―harmonic isolation between the supply and the load. As a result, no harmonic resonance occurs, and no harmonic current flows in the supply.

I.6.6 Active Parallel-Series Combination

The active parallel-serial combination, also called Unified Power Quality Conditioner (UPQC), following the association of the two parallel and series active filters, as shown in Fig. I.12. Taking advantage of the advantages of the two active filters, the UPQC ensure sinusoidal current and voltage of the electrical network from a current and voltage disturbances thereof [21].

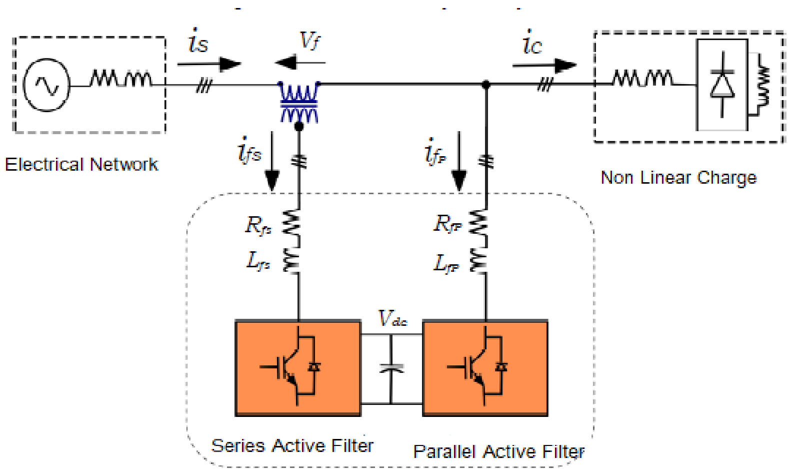


Figure. I.08 Active parallel-serial combination

This configuration is considered to be an ideal active filter which makes the voltage and current harmonics. It is able to deliver power clean under fairly high harmonic pollution, to compensate for the imbalance voltage and current. Its cost is quite high and its order is complex because there are a lot of semiconductors involved.

Active and passive hybrid combination

In order to reduce the sizing and consequently the price of filters active, the association of low power active filters with passive filters can be a solution. In this case, the role of the passive filters is to eliminate preponderant harmonics to reduce filter sizing assets that only compensate for the rest of the disturbances.

On the other hand, hybrid filters can be classified according to the number of elements implemented in the topology studied (active filters and passive filters), the treated system (single-phase, three-phase three-wire and three-phase four-wire) and the type inverter used (voltage or current structure).

Several topologies have been discovered in the literature, the most studied being :

- The series active filter with parallel passive filters
- The series active filter connected in series with parallel passive filters
- The parallel active filter with a parallel passive filter

I.7 Conclusion

In this chapter, we have presented harmonic distortion and the different sources of disturbance affecting the waveform of network voltages electrical equipment as well as their harmful effects on the electrical equipment therein connected. These effects are the cause of heating and degradation of the operation of this equipment. The standards imposed were also present. They set the limits for the generation of harmonics. Several traditional and modern pollution control solutions have been present. We have shown that the classic solution based on passive filters is often penalized in terms of bulk and resonance. In addition, the filter liabilities cannot adapt to changes in the network and to polluting loads.

CHAPTER II

Shunt Active Filter

II.1 Introduction

The intensive use of powers converters and other nonlinear loads in industry, and by consumers in general, has increased the deterioration of the power systems voltages and currents waveforms. The harmonics presence in the power lines results in varied problems, like: low system efficiency and poor power factor. These problems result in high costs industry and commercial activities, since they can lead to a decreasing in productivity and to a reduction of quality in the products or services. However, active power filter with a control system based on the p-q theory and studies, the performance through MATLAB simulation we obtained results through the p-q theory and its application in the control of an active power filter. The simulations were carried out on a non-linear. The active power filter allows compensating harmonic currents, reactive power, unbalanced loads, presenting a good dynamic and steady-state performance, as it can be observed in the simulation results. The reference signal is utilized to generate signals with the help of pulse width modulation technique/Hysteresis loop control. In the end, a shunt active filter can compensate only for the harmonic current of a selected nonlinear load and can continuously track changes in its harmonic content.

General advantages and disadvantage of a shunt active power filter [22]

- **Advantages of a shunt active power filter**
  - Reactive Power Compensation
  - Regulating Terminal Voltage
  - Compensating the Voltage flickering
  - It has faster response,
  - Good filtering action for a large range of frequency
  - Independent of the distribution system to which it is connected
- **Disadvantage of a shunt active power filter**
  - Higher Initial Installation Cost
  - It provides a complex control system.

- It cannot handle a large amount of power.
- It requires DC power supply for their operation.
- This filter is limited in their frequency range.

II.2 General structure of a shunt active power filter

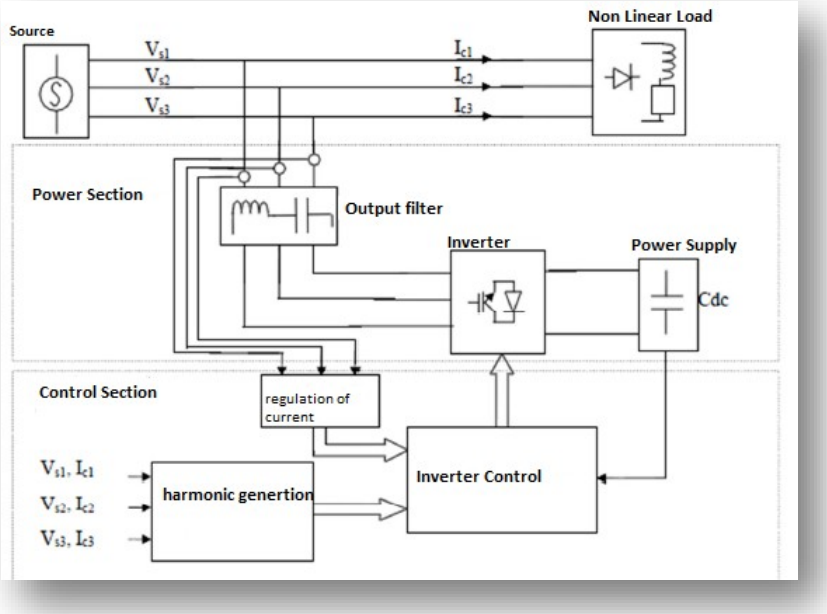


Figure II.01 : General Structure of A Shunt Active Filter

The general structure of the parallel active filter (II.01) under the form of two blocks: the power part and the control-command part

II.2.1 Study of the power section

The power Section: consists of:

- ➢ An inverter based on power switches, controllable on starting and blocking (GTO, IGBT, etc.…) with antiparallel diodes.
- ➢ Energy storage circuit :

The energy storage can be by a direct voltage source Vdc, or by a Cdc capacitor which plays the role of a DC voltage source Vdc, the choice of parameters (Vdc and Cdc) affects the dynamics and the quality of compensation of the parallel active filter.

II.2.2 Voltage Inverter

The IGBT-based two-level three-phase voltage inverter as shown in Figure II.02 consists of six bidirectional current switches (triggered and blocked) conducting current in both directions through diodes. in antiparallel. The energy storage on the DC side is done through a voltage capacitor.

For the pure parallel active filter, the inverter is connected to the grid via a first order filter called an output filter or coupling filter consisting of an inductor. For the configuration of the hybrid filter the inverter we used is directly linked to a resonant passive filter L_f C_f tuned to the fifth harmonic. For this structure of the parallel active filter, the following constraints must be respected:

- At any given moment, only one switch of the same arm must be driving in order to avoid short-circuiting the voltage source.
- Line current must always find a possible path, hence the need to use anti-parallel diodes at each switch.

In practice, the two semiconductors of the same arm are controlled in a complementary manner: the conduction of one causes the blocking of the other. The mode or the semiconductors of the same arm are both closed, actually only exists during switching.

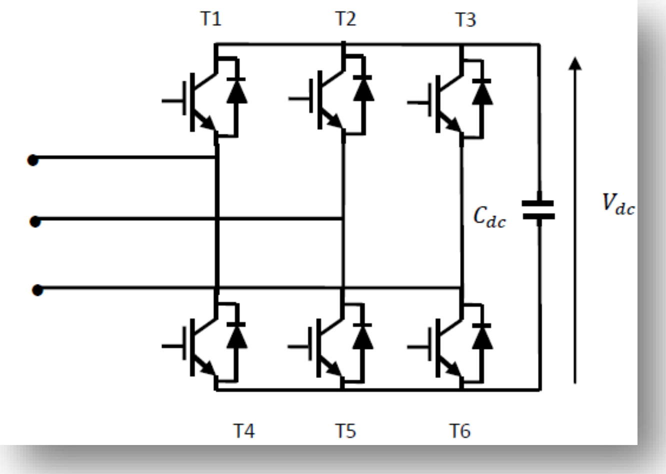


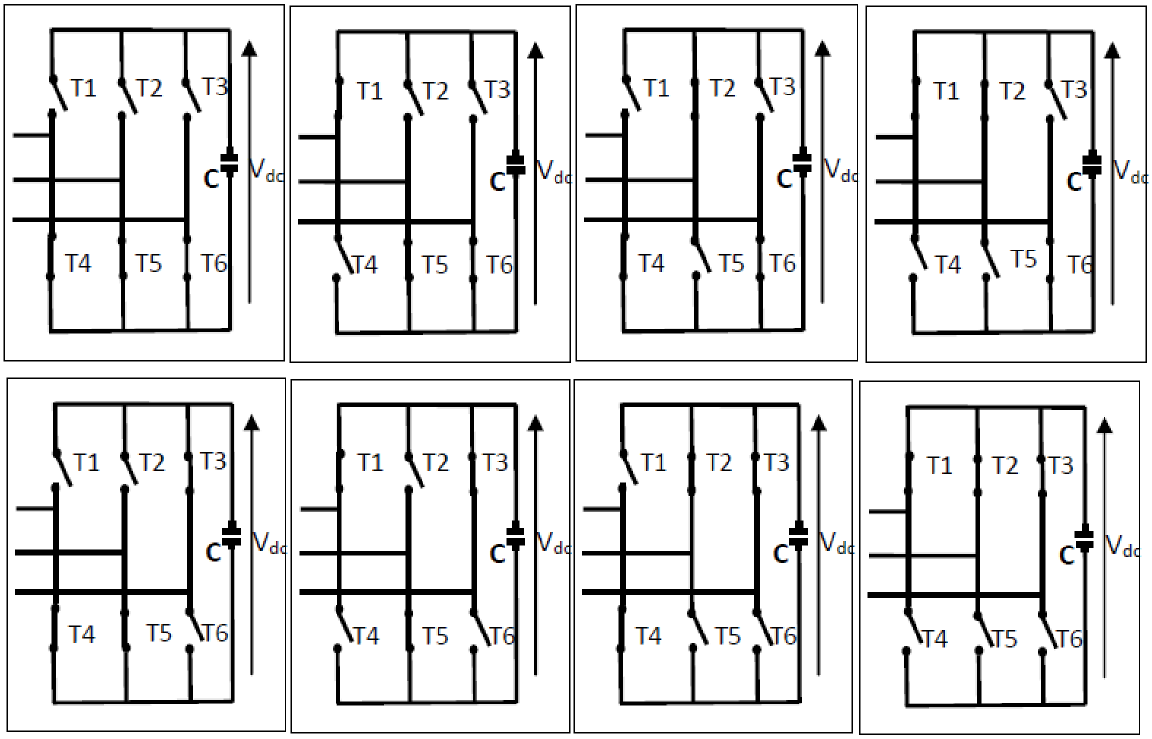
Figure II.02 Three-phase voltage inverter with voltage structure

In order to avoid a short-circuit because of the switch blocking delay, it is necessary to insert on the same arm, a waiting time, also called dead time, between the blocking command of a switch and the control of priming of the other [23].

With this assumption, the opening and closing of the inverter switches in Figure. II.04 depend on the state of the three control signals (S1, S2, S3) defined below :

S1= 1 if T1 is closed and T4 opened
0 if T1 is opened and T4 is closed
S2= 1 if T2 is closed and T5 opened
0 if T2 is opened and T5 is opened
S3= 1 if T3 is closed and T6 opened
0 if T3 is opened et T6 is closed

Thus, from the states of the switches presented by the variables S1, S2 and S3, we can examine eight possible configurations of the inverter as summarized in Figure II.03. Each configuration is determined by the state of the switches of the top switch, and those of the bottom switch being in the opposite state by principle of complementarity [24].



-5- -6- -7- -8-

Figure II.03 configuration of state of the switches by the principle of complementarity

Output filter:

The main role of the output filter is to allow the connection of the voltage converter to the electrical network which is very often considered as a source of current which generates harmonic currents from the difference in voltages between the output of the converter and the network. This filter has a dual role, it limits the dynamics of the current and reduces also the propagation on the electrical network of the components due to the commutations. In the case of the PAF, this filter is composed of an inductance Lf with an internal resistance Rf. Note however, third order decoupling filters, type L-C-L, could also be used.

The control-command

It is the main functions of control circuitry are voltage control, current control and current reference generation. Voltage control can be achieved with the help of PI and sliding mode control techniques. Current control is maintained with the help of artificial neural network, fuzzy logic and sliding mode controllers. Current reference is generated with the mean of PQ Theory, synchronous reference frame method, Fourier Transform and by applying various soft computing approaches by Firing Angle Generator, Voltage Source Inverter.

The voltage inverter control:

The purpose of controlling the inverter is to control the currents at the output of the filter so that they follow their referrals. The principle is based on the comparison between filter output currents and their references identified from the different methods identification. For regulating the current of the inverter: the two presiding methods are used by hysteresis and sinus-triangular PWM.

Voltages generated by the inverter

The three-phase output voltages with respect to the reference of the DC source "o" can be expressed by:

$$\begin{bmatrix} V_{ao} \\ V_{bo} \\ V_{co} \end{bmatrix} = \begin{bmatrix} S_{a1} \\ S_{b1} \\ S_{c1} \end{bmatrix} . V_{dc} \qquad \text{II.1}$$

The phase-to-phase voltages are given by :

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = 3 \begin{bmatrix} V_{ao} - V_{bo} \\ V_{bo} - V_{co} \\ V_{co} - V_{ao} \end{bmatrix} = \begin{bmatrix} S_{a1} - S_{b1} \\ S_{b1} - S_{c1} \\ S_{c1} - S_{a1} \end{bmatrix} . V_{dc} \qquad \text{II.2}$$

Thus, we can easily express the voltages Va, Vb, Vc as a function of the switching functions S1, S2, S3 of the three phases a, b, c as follows :

$$\begin{bmatrix} V_{a} \\ V_{b} \\ V_{c} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} V_{ab} - V_{ca} \\ V_{bc} - V_{ab} \\ V_{ca} - V_{bc} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2S_{a1} - S_{b1} - S_{c1} \\ -S_{a1} + 2S_{b1} - S_{c1} \\ -S_{a1} - S_{b1} + 2S_{a1} \end{bmatrix} . V_{dc} \qquad \text{II.3}$$

Since the variables S1, S2 and S3 for the three phases a, b, c each take two values, eight control combinations result, which are shown in Table II.01. [25].

Table II.01 The eight voltage inverter configurations

No of Case	**S3**	**S2**	**S1**	**Vf3**	**Vf2**	**Vf1**
1	0	0	0	0	0	0
2	0	0	1	$\frac{-Vdc}{3}$	$\frac{-Vdc}{3}$	$\frac{2Vdc}{3}$
3	0	1	0	$\frac{-Vdc}{3}$	$\frac{2Vdc}{3}$	$\frac{-Vdc}{3}$
4	0	1	1	$\frac{-2Vdc}{3}$	$\frac{Vdc}{3}$	$\frac{Vdc}{3}$
5	1	0	0	$\frac{2Vdc}{3}$	$\frac{-Vdc}{3}$	$\frac{-Vdc}{3}$
6	1	0	1	$\frac{Vdc}{3}$	$\frac{-2Vdc}{3}$	$\frac{Vdc}{3}$
7	1	1	0	$\frac{Vdc}{3}$	$\frac{Vdc}{3}$	$\frac{2Vdc}{3}$
8	1	1	1	0	0	0

The three phase voltage inverter is the key element of the active power filter. Using stored energy in the energy storage system, it delivers a voltage will generate a current like its reference signal which will be determined from the reference signal of the active filter and of the current generated by the filter

II.2.3 Energy storage system

The use of capacitor banks is effective in small and medium-sized powers. In the case of high powers, superconducting coils [26] are used. The choice of the voltage Vdc and the capacitance of the capacitor Cdc affects the dynamics and the compensation quality of the parallel active filter. Indeed, a high voltage Vdc improves the dynamic range of the active filter. In addition, the ripples of the direct voltage Vdc caused by currents generated by the active filter and limited by the choice of Cdc, can degrade the quality parallel active filter compensation [27-28]. These fluctuations are all the more important that the magnitude of the filter current is large and its frequency is low.

II.3. Control of Shunt active power filters

II 3.1 Hysteresis

Hysteresis loops produced by homogenous cores reveal visual parameters that allow reproduction of the flux and magnetizing current in time domain. Hysteresis loops are generally modeled using piecewise linear segments for the non-linear magnetizing inductance and a power measurement to estimate the core losses. Typically, by joining flux-current data pairs to represent the nonlinear inductance, straight line segments are created to represent the different sections of the curve. Although results are acceptable, this poses at least four issues for the modeling method; the choice of the number of straight-line segments, the choice of a correct slope in the saturated region, table adaptation time when the extracted data-points are not continuously increasing and the repetition of the process every time of a different core needs to be modeled.

Determination of the parameters of the PI Regulator

PI Controller

Proportional-Integral "PI" regulators are widely used in industry because of their performance and computational speed. Their principle of operation is to compare the actual measured values with the values of reference and stabilize the system to be regulated. The variation of the voltage Vdc at the terminals of the storage capacitor depends mainly on the value of the capacitor Cdc. The direct voltage Vdc across the storage capacitor must be kept constant. The cause of this voltage variation is the exchange of active power with the network The main purpose of voltage regulation is to limit voltage variations by inserting a low value capacitor. For this, a proportional regulator (PI) is necessary, to regulate the capacitor voltage to its setpoint V^2dc:

The general expression of the PI regulator used in our studies is given as:

$$K(s) = \frac{K_c}{1 + \tau_c s} \qquad \text{II.4}$$

With Kc= Gain regulator : Fixed time of the first order

The relationship between the active power absorbed by the active filter and the voltage across the capacitor can be written as follows:

$$p_c = \frac{d}{dt}\left(\frac{1}{2}C_{dc}.V_{dc}^2\right) \tag{II.5}$$

After Laplace Transformation:

$$V_{dc}^2 = \frac{2p_c(s)}{C_{dc}s} \tag{II.6}$$

From the equation (II.4) and (II.6) the DC voltage regulation loop can be represented by the diagram .

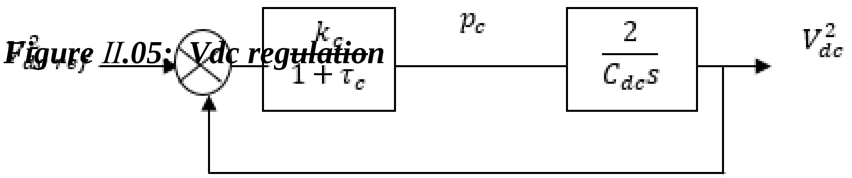


Figure II.05: Vdc regulation

The closed loop transfer function can then be written:

$$F(s) = \frac{\omega_c^2}{s^2 + 2\xi\omega_c s + \omega_c^2} \tag{II.7}$$

With:

$$\omega_c = \sqrt{\frac{2k_c}{C_{dc}\tau_c}} \quad \text{et } \xi = \frac{1}{2\sqrt{2}}\sqrt{\frac{C_{dc}}{k_c\tau_c}} \quad (\xi \text{ **lies between** } 0.5 \text{ et } 0.707) \tag{II.8}$$

II.4 Methods of identifying harmonic currents

The different methods of identifying interference current can be grouped into two approach families.

The first uses the fast *Fourier transform* in the frequency domain, to extract the harmonics from the current. This method is well suited to loads where the content harmonic varies slowly. It also gives the advantage of selecting the harmonics individually and to choose to compensate only the most preponderant. It is to highlight that this method requires a great deal of computing power in order to carry out, in real time, all the transformations necessary to extract the harmonics.

The second family is based on the *calculation of instantaneous powers* in the field temporal. Some of these methods are based on the calculation of the harmonic powers of the non-linear load. Others can be used to compensate for both currents harmonics and reactive power, based on thesubtraction of the fundamental part active of the total current.

Current method

The principle of this method is to identify the harmonic currents from the total current. And forced the inverter to inject reverse harmonic currents into the network, This eliminates these harmonics. The polluting load current is captured, this current is filtered by a band pass filter of the second order, which eliminates the harmonic component and allows only the fundamental component. The total current minus the fundamental component. Gives us the harmonic current. The current injected from the inverter is set around this reference harmonic current. The two regulation techniques: sinus-triangular PWM and hysteresis are used. The output filter is used to connect the inverter to the grid and to prevent switching components to propagate over the network.

Algorithm of the current method

The current absorbed by the load is made up of the fundamental component and harmonic components at multiple frequencies of the fundamental frequency.

$$\mathrm{iL}=\mathrm{iL1}+\sum_{h=}^{\infty} iiL \qquad \text{II.9}$$

with

iL = total current of the load

iL1 = fundamental current absorbed by the load

ih = harmonic current absorbed by the load

The second order band pass filter aims to extract the component fundamental of the current The central frequency is chosen equal to the fundamental frequency (fc = 50Hz). This method is characterized by simplicity.

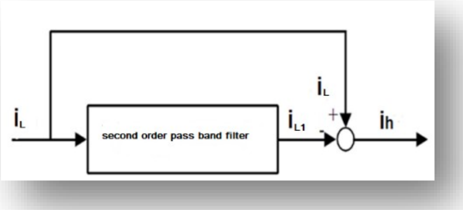


Figure II.04 Algorithm of the Current Method

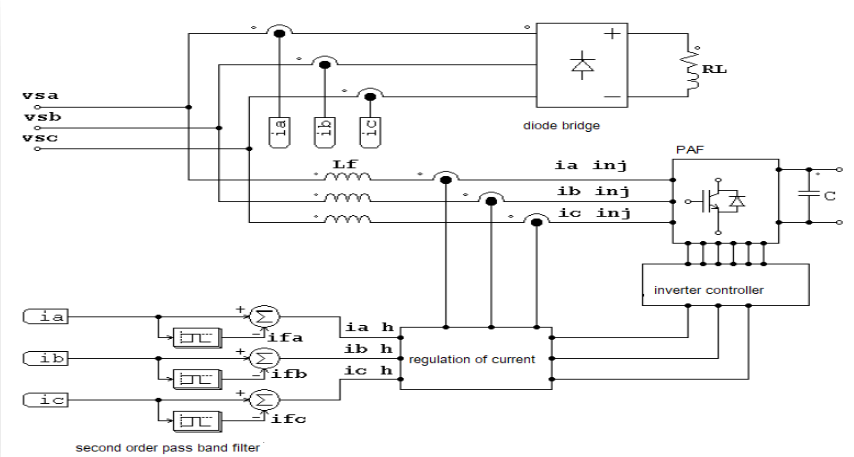


Figure II.05 Current method algorithm associated with the parallel active filter

II.4.1 The instantaneous power theory

II.4.1.1 Introduction

The instantaneous power method was introduced by H. Akagi. Its principle is based on the transition from three-phase systems consisting of phase-to-neutral voltages and line currents, to a two-phase system (α-β) using the Concordia transformation, in order to calculate the real and imaginary instantaneous powers. Then, to determine the harmonic currents of the load, the fundamental component is transformed into a continuous component and the components harmonics in AC components. In the classical instantaneous power method one generally uses either a high pass filter or a low pass filter in order to keep only the harmonic component of the signal. The block diagram relating to this method is shown in FigII.06.

II.4.1.2 Instantaneous active and reactive power identification method

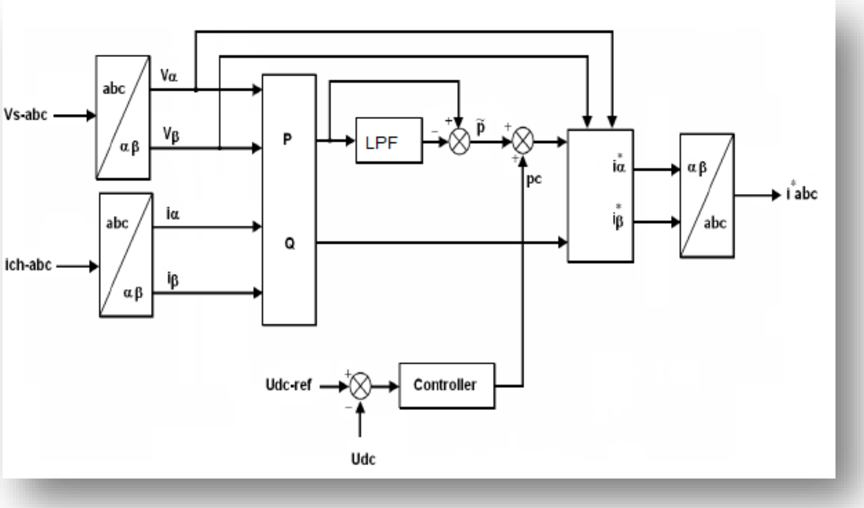


Figure II.06 Instantaneous active and reactive power identification method

Let us note, respectively, the phase-to-neutral supply voltages and the charging currents of a three-phase system balanced by (vsa, vsb, vsc) and (icha, ichb, ichc). The transformation of Concordia makes it possible to reduce this balanced three-phase system to a two-phase system whose axes are in quadrature. This transformation applied to network voltages and line currents leads to following expressions :

$$\begin{bmatrix} v_{s\alpha} \\ v_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} \qquad \text{II.10}$$

$$\begin{bmatrix} i_{ch\alpha} \\ i_{ch\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} i_{cha} \\ i_{chb} \\ i_{chc} \end{bmatrix} \qquad \text{II.11}$$

Instantaneous active power p and instantaneous reactive power q are defined by :

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_{\alpha} & v_{\beta} \\ -v_{\beta} & v_{\alpha} \end{bmatrix} . \begin{bmatrix} i_{ch\alpha} \\ i_{ch\beta} \end{bmatrix} \qquad \text{II.12}$$

Instantaneous active and reactive powers can be written as the sum of a component continuous and a harmonic component :

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} \overline{p} & + & \tilde{p} \\ \overline{q} & + & \tilde{q} \end{bmatrix} \qquad \text{II.13}$$

With $\bar{p}$ and $\bar{q}$ the continuous components of p and q, and $\tilde{p}$ and $\tilde{q}$ the harmonic components of p and from equation (4), we can deduce the expressions for the components of the current of load along the axes αβ

$$\begin{bmatrix} i_{ch\alpha} \\ i_{ch\beta} \end{bmatrix} = \begin{bmatrix} v_{\alpha} & v_{\beta} \\ -v_{\beta} & v_{\alpha} \end{bmatrix}^{-1} \begin{bmatrix} p \\ q \end{bmatrix} = \frac{1}{v_{\alpha}^{2} + v_{\beta}^{2}} \begin{bmatrix} v_{\alpha} & -v_{\beta} \\ v_{\beta} & v_{\alpha} \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \qquad \text{II.14}$$

The replacement of (II.13) in (II.14) gives the expressions of the currents iα and iβ according to the axes By

$$\begin{bmatrix} i_{ch\alpha} \\ i_{ch\beta} \end{bmatrix} = \frac{1}{v_{\alpha}^{2} + v_{\beta}^{2}} \begin{bmatrix} v_{\alpha} & -v_{\beta} \\ v_{\beta} & v_{\alpha} \end{bmatrix} \begin{bmatrix} \overline{p} \\ \overline{q} \end{bmatrix} + \frac{1}{v_{\alpha}^{2} + v_{\beta}^{2}} \begin{bmatrix} v_{\alpha} & -v_{\beta} \\ v_{\beta} & v_{\alpha} \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \qquad \text{II.15}$$

Since we are interested in the simultaneous compensation of current and energy harmonics reactive, in this case we then eliminate the DC component of p using a simple FPB and the active power pc necessary for the regulation of the direct voltage Udc is added to the harmonic component of the instantaneous active power. Reference disturbance currents, denoted iα-ref and iβ-ref, are expressed along the axes αβ par :

$$\begin{bmatrix} i_{\alpha-ref} \\ i_{\beta-ref} \end{bmatrix} = \frac{1}{v_{\alpha}^{2}+v_{\beta}^{2}} \begin{bmatrix} v_{\alpha} & -v_{\beta} \\ v_{\beta} & v_{\alpha} \end{bmatrix} \begin{bmatrix} \tilde{p}+pc \\ \tilde{q} \end{bmatrix} \qquad \text{II.16}$$

The reference interference currents along the axes (abc) can be determined using the reverse transformation of Concordia :

$$\begin{bmatrix} i_{a-ref} \\ i_{b-ref} \\ i_{c-ref} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} i_{\alpha-ref} \\ i_{\beta-ref} \end{bmatrix} \qquad \text{II.17}$$

Table 02: Instantaneous power control compensation modes

	Compensation of Harmonic Current	Compensation of Reactive Energy	Compensation of Harmonic Current and Reactive Energy
Parameters of the Control	$p_f = \tilde{p}$ and $q_f = \tilde{q}$	$p_f = 0$ and $q_f = \bar{q}$	$p_f = \tilde{p}$ and $q_f = q$

Separation of disturbing powers

The powers defined above contain a constant term relating to the fundamental as well as an alternative term corresponding to the harmonics, in order not to keep as the part relating to harmonics, the DC component of the power must be filtered. This separation can be achieved by using one of two filtering devices, a filter high pass or low pass filter.

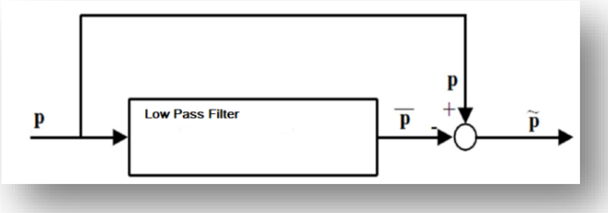


Figure II.07 Diagram representing the principle of separation of powers.

Identification strategy:

The control strategy is based on the detection of interfering currents in the time domain. There are three possibilities for identifying interference currents:

- identification based on the detection of the polluting load current.
- identification from the detection of the source current.
- identification from the detection of the source voltage.

The first method is the most used for the parallel active filter to compensate for disturbance currents caused by polluting loads. This detection method will be used in this study.

Advantages of using p-q theory [29]

- Simplicity of its Calculations
- Possible to use when power system deals with Non-Linear Load
- Used for designing of power electronic devises, especially when it is used as power compensator
- Possible to exploit the symmetries of the instantaneous power waveform for each specific power system

II.5 Simulation and Results

Simulation Model

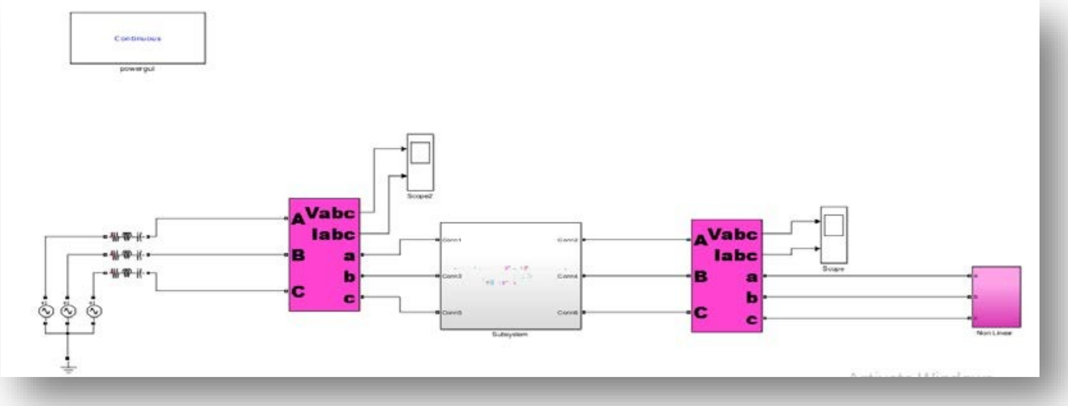


Figure II.08: Active Power Filter

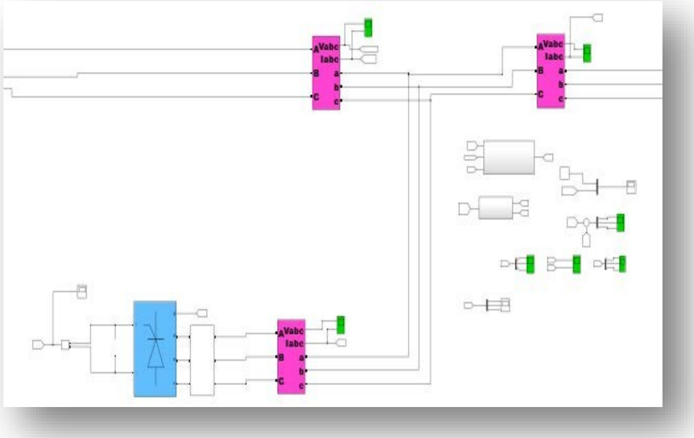


Figure II.09 :Block Diagram of the Subsystem in Figure.08

Simulation parameters:

SOURCE	LOAD
Us_{effs} = 230 (v);	R_l = 0.79 (Ω)
fs = 50 (Hz);	L_l = 2.6 10-6 (H);
$R_S = 10^{-3}$ (Ω)	
$L_S = 10^{-8}$ (H);	

Results of the Simulation

We will present the simulation results concerning the study carried out on this active power filter that we have just developed by using the method of instantaneous active and reactive theory, thus the p-q command. On the other hand, the simulation work concerning this p-q command are carried out by taking the same aforementioned parameters summarized above. The compensator can simultaneously compensate the harmonic currents due to the non- linear (rectifier). Reactive energy with parallel active filter with hysteresis control, and the proportional regulator to regulate the DC voltage across the capacitor.

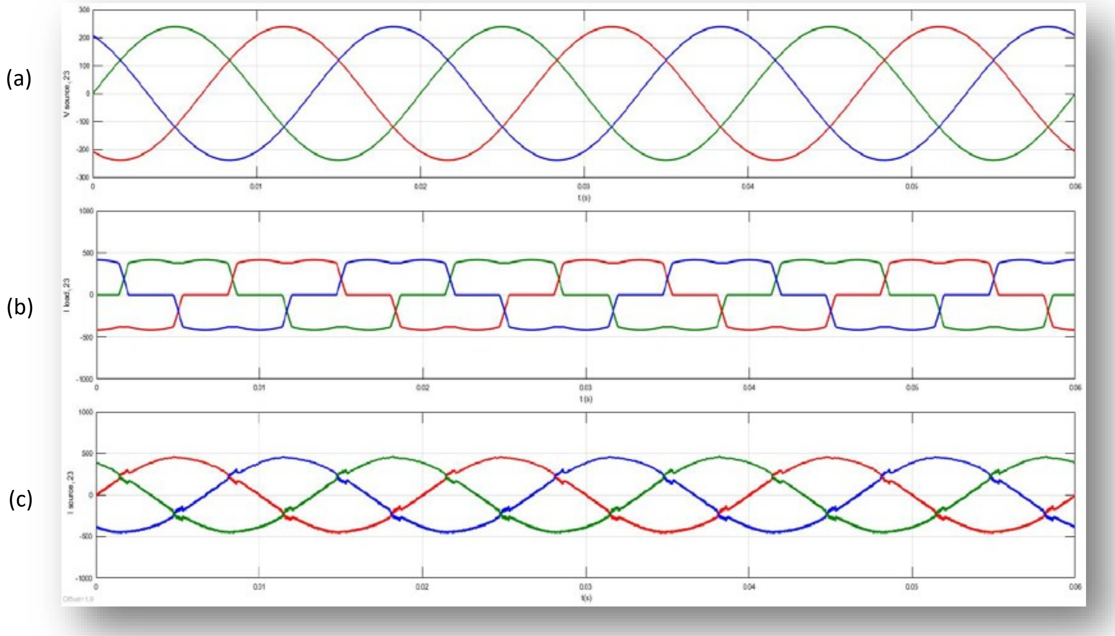


Figure II.10: three phase signals of :
(a) : Voltages of the Source, (b): Currents of the load, (c): Currents of the source.

(a) Voltage of the source

Since the voltage and current sources in the active power filter are AC sources with the same frequency, we realized a sinusoidal wave.

(b) : Currents of the load

It represents the shape of the load of the current, which has a lot of disturbances and distortion in the signal

(c) : Currents of the source.

It represents the signal of the source currents . We can see that the shape is sinusoidal which minimizes harmonics.

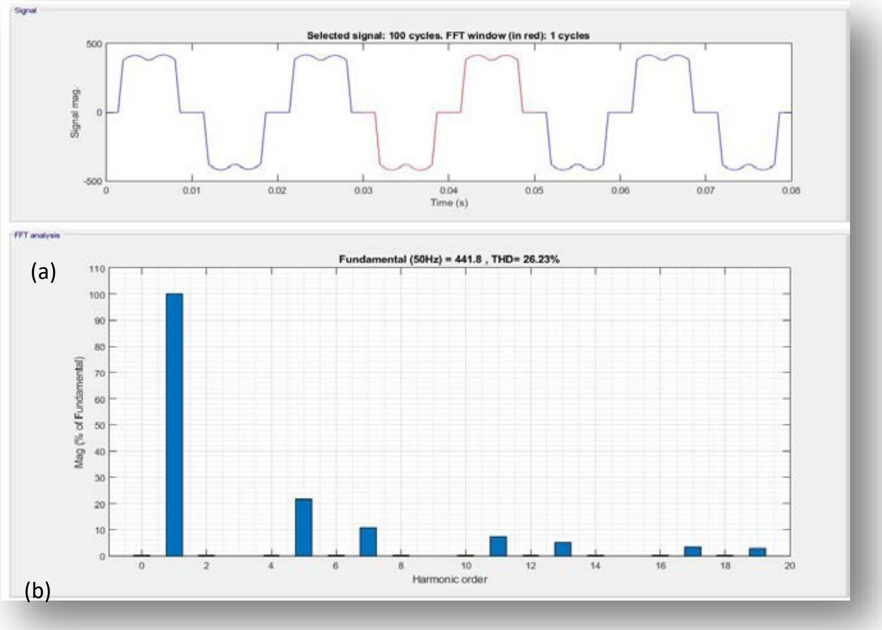


***Figure II.**11 Waveform and THD of the Load of the Current (Before Filtering)*

Figure II.11 (a) represents the waveform of the current supply which contains harmonics with the value of the THD 28.23% as shown in figure II.11 (b).

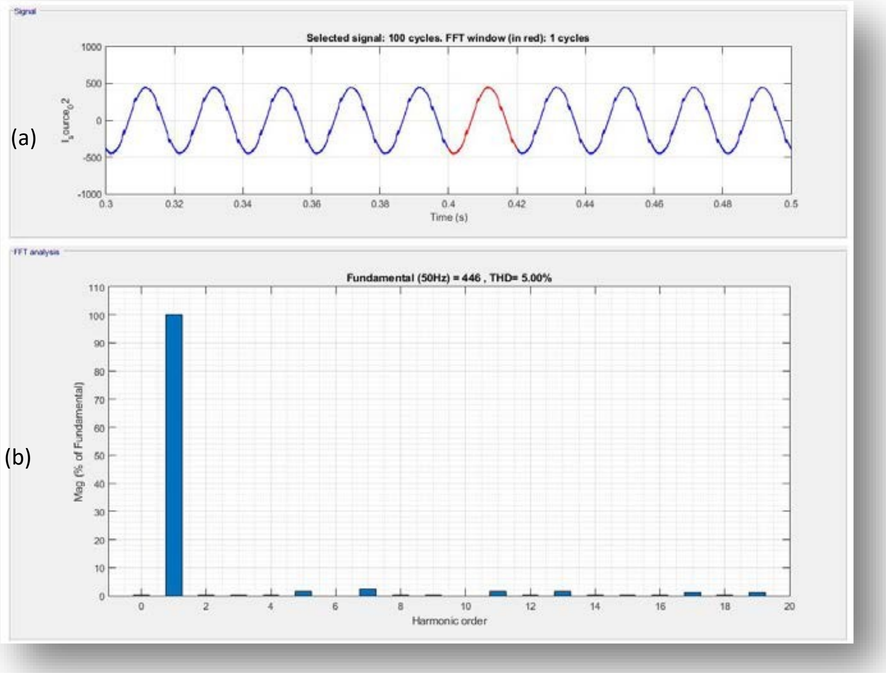


***Figure II.**12 Waveform and THD of the source of the Current (After Filtering)*

Figure II.12 (a) represents the waveform of phase 1 of the current supply which contains harmonics with the value of the THD 5,00 % as shown in figure II.12 (b).

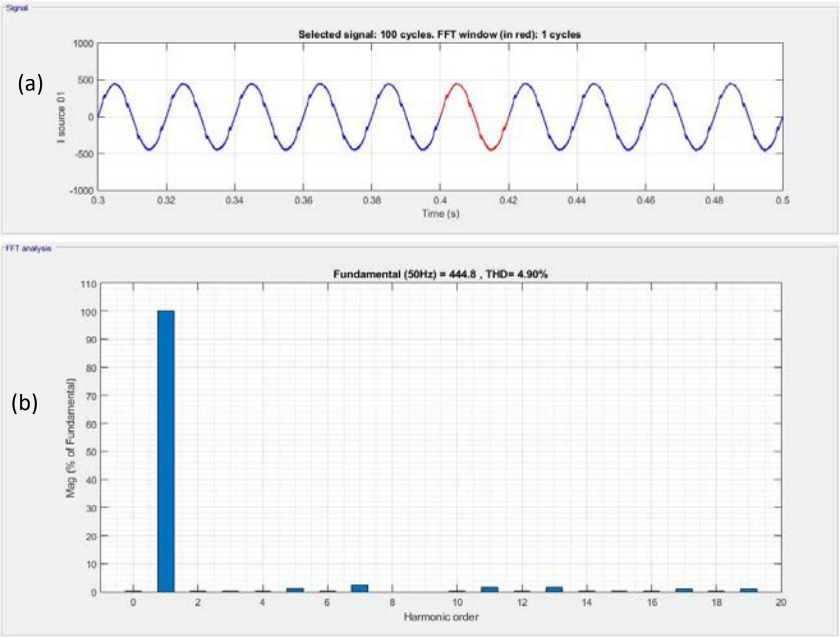


***Figure II.**13 Waveform and THD of the source of the Current (After Filtering)*

Figure II.13 (a) represents the waveform of phase 2 of the current supply which contains harmonics with the value of the THD 4,90 % as shown in figure II.13 (b).

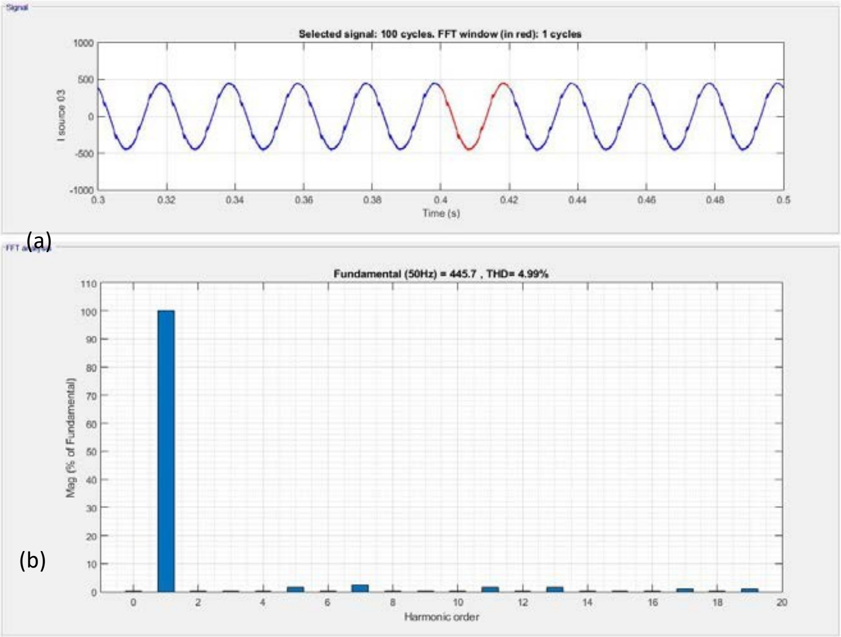


***Figure II.**14 Waveform and THD of the source of the Current (After Filtering)*

Figure II.14 (a) represents the waveform of phase 3 of the current supply which contains harmonics with the value of the THD 4,99 % as shown in figure II.14 (b).

In summary of our results, we obtained :

Table II.03 : THD of Current Source

	THD Before filtering	**THD after filtering**
Phase 1	26.23	5.00
Phase 2	26.23	4.90
Phase 3	26.23	4.99

The figure II.6. Represents the waveform of the supply currents, after filtering of harmonic we noticed that the distortions of the currents are more attenuated or reduced more than in the case of the currents presented in figure II.5.

In Figure (II.11): The current THD of the filtering network is high as 26.23%.

In Figures (II.12), (II.13), (II.14), our THDs were conformed to standards harmonics norms : 5,00 % , 04,90 % , 04,99 %.

II.6 Conclusion

The active power filter based on the p-q theory was tested for three-phase power system with a non-linear load. It was shown through computation simulations using MATLAB that the p-q theory can be used with success in the implementation of active power filters. The THD which isa concept widely used to define the importance of the harmonic content of a signal was used in theMATLAB, we realized when the rate is high, the harmonic disturbance is too high and to reduce the THD a filter must be added in order to obtain good energy quality or results. So, we can state emphatically. The obtained results show good steady-state and transitory performances.

CHAPTER III

Hybrid Filter

III.1Introduction

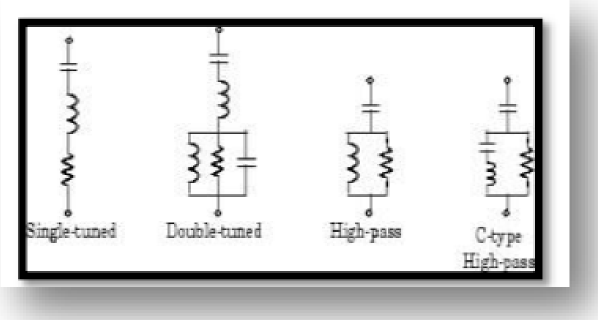
The hybrid active filter results from the association of an active filter and a passive filter, this structure makes it possible to reduce the cost of an active filter by reducing its size, and to optimize its performance thanks to the passive elements which reduce considerably the power of the converter of the active filter. In fact, the passive and active filters share the tasks: the passive filter takes care of the compensation of a large part of the harmonics while the active filter takes care of maintaining the performance of the filtering according to the evolution of the load. and the network.

Passive filter is another approach to filter out harmonic present in system and in this filter designing we are using passive elements. Passive elements R, L, C are being used to overcome the complexity of system. The combined of these three elements did not depend on external power supply and called passive filter. The capacitor passing high frequency signals and blocking low-frequency signals, & inductor do the just opposite of it. Similar as active filter we are dealing with the attenuation when we analysis that the inductor is passing the signals whereas the capacitor will ground it, the filter providing a less attenuation for low frequency filter. This low frequency filter called low-pass filter. The reverse action of capacitor and inductor, called high pass filter. Here if the signal passes through a capacitor, or ground through an inductor, then the filter presents less attenuation and called high-pass filter. The resistors have no frequency selection assets but used for determining the time constants of both inductor & capacitor. Inductors and capacitors are the reactive elements of filter and the number of elements used in circuit determines the order of the filter. Passive filter is most commonly used filtering techniques for mitigation of harmonics, it offers low impedance path to divert harmonic current caused by non-linear load. Passive filter has two types, series passive filter and shunt passive filter as connection based, a series filter should carry full load current while shunt type filter takes only a part of full load current. The shunt passive filter can able to deliver reactive power at fundamental line frequency and due to lower cost, it is best suited to practical use for harmonic filters. The shunt passive filters are of simple series/ parallel arrangement of resistors, inductors and condensers (capacitor). Figure. III.01 shows the different arrangements of shunt passive filters.

III.1.2 Principle of passive filter

Passive filter circuitry consists passive elements inductor, capacitor, resistor & in other way we can say as a tuned filter & high pass filter also. Passive filters are parallel connected with non-linear load. The load we analysis is the electronics elements like diode, SCR, rectifier circuit and many other. The principle of a passive filter is to locally modify the network impedance, so as to “derive” the harmonic currents and eliminate the related harmonic voltages. The capacitive and inductive elements are in fact associated in order to obtain a series resonance tuned to a selected frequency. A precise knowledge of the harmonic ranks to be filtered and of the attenuations required is necessary for the realization of a filter. Such a study is usually carried out using simulation software (MATLAB). Depending on the desired harmonic attenuation, different types of passive filters are used. They can be classified according to their location, how they are connected to the main circuit, their degree of damping as well as the frequencies of their resonances. We distinguish usually a shunt filter and a series filter. In addition, the shunt filter is used exclusively on the alternating current (AC) side for the following reasons: - The series filter can carry the entire current from the main circuit and must be isolated from the ground or earth. The shunt filter, on the other hand, carries only the harmonic current and can be linked to earth at one end.

- At the fundamental frequency, a shunt filter (AC) has the advantage of providing reactive power while a series filter consumes reactive power.
- For equal performance, a shunt filter is much cheaper than a series filter.



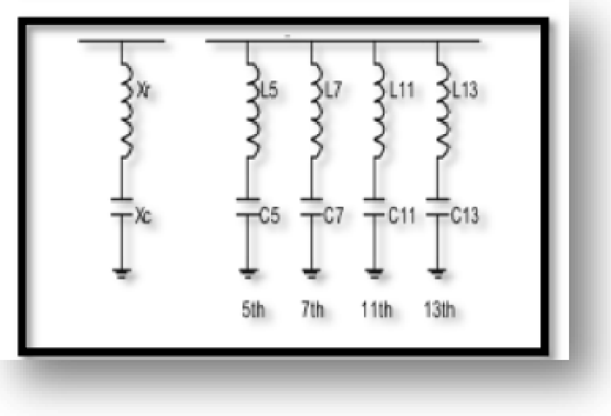


Figure III.01: Filter & Product of Harmonic filter

This filter is tuned to suppress a single frequency and is designed based on three quantities: The harmonic current order that requires blocking, the capacitive reactive power that it is going to provide, and its quality factor. The voltage level and the fundamental frequency, which are given by the system, must also be considered during the design process. In h = Tuning point of filter [harmonic order] QC = Reactive power of the filter [MVAr]

III.1.2.1Advantages and disadvantages of a passive filter

Passive filtering has already proven its worth in the industrial sector thanks to its low cost, its efficiency and its suitability for high power networks. However, it presents the following disadvantages:

- The presence on the same network of two passive filters granted on a theoretically rank equal, but in practice slightly different, causes currents to flow between them very important harmonics which quickly causes their destruction. This case occurs easily due to the fact that the tuning frequency varies slowly with the aging of the filter elements. It is absolutely necessary to avoid connecting harmonic filters of the same rank on the same network.
- The parallel setting of an anti-harmonic filter and a capacitor bank causes a constraint that can lead to the destruction of the capacitors.
- When there are several harmonic ranks to filter, it is necessary to put as many filters this with a lower attenuation factor
granted on the corresponding ranks. This problem can be solved by adopting a wide filter
band which attenuates several harmonic ranks.

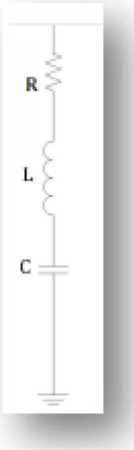
- The installation of passive filters on a network requires a thorough and precise study. Besides, it is not always possible to know all the network parameters necessary for the study, when it is large.

- Finally, resonance damping in power systems by filters passive can introduce unwanted additional resonances which can lead to destruction of these filters. Damping using control and power electronics is presented as a solution to effectively improve the operating mode of the network.

III 1.2.2 Design Of Passive Filters

III 1.2.3 Single Tuned Passive Filter Design

The STPF is most frequently used as shunt passive filter which may be high-cut filter or pass-band filter. The designing of this kind of filter is simple and lower cost to employ. The essential criterion for the filter design is by choosing an appropriate capacity of condensers, inductors and resistors that gives an acceptable power factor at line frequency [30]



FigureIII.02 Single Tuned Filter

The capacitive reactance is related to reactive power as [31],

$$X_c = \frac{{V_{rc}}^2}{Q_c}$$

Where, Vrc is the nominal voltage of condenser and Qc is reactive power supplied by condenser. The filter capacitance value is then obtained through,

$$C_{STF} = \frac{1}{2\pi f_s X_c}$$

Where, is is the frequency of supply mains. The inductance value of the filter is then calculated by

$$L_{STF} = \frac{1}{(2\pi f_s)^2 {h_o}^2 C_{STF}}$$

Where, ho is order of harmonic to which filter is designed to tune. The value of filter resistor R is related to quality factor (Qfactor), which shows the sharpness of the resonance. Then the Q-factor is described as,

$$Q = \frac{X_n}{R} = \frac{\sqrt{L_{STF}/C_{STF}}}{R}$$

Where, Xn is the characteristic reactance. This resistance value can be decided by choosing a suitable value of quality factor ranging from 30 to 100 .

III 1.2.4 Double Tuned Passive Filter

Design The DTPF is design to eliminate two harmonic components simultaneously. [t has many advantages when compared with STPF, such as it requires just a single inductor subjected to full line voltage, smaller in size and only one switchgear required, etc. [32]. Figure III.03 shows a basic configuration of DTPF, which is a combination of series resonance circuit having parameters Ldl and Cd1 and parallel resonance circuit having parameters Ld2 and Cd2

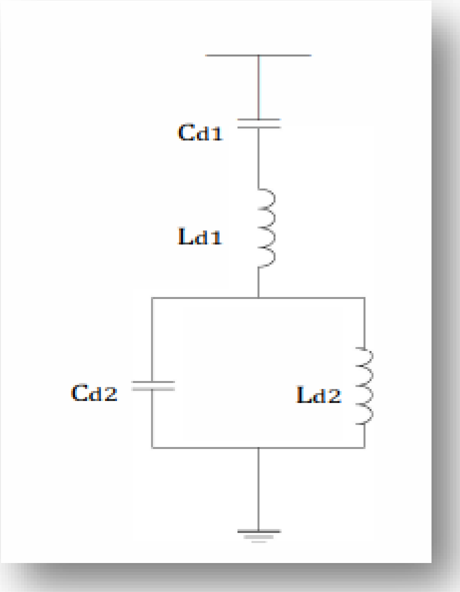


Figure III.03: Double tuned passive filter configuration

In design of a DTPF, the known tuned frequencies COl and CO2, series resonant frequency Ws and parallel resonant frequency wp are related as [32],

$$\omega_1 \omega_2 = \omega_s \omega_p$$

Under the condition of neglecting the reactors resistance and capacitors dielectric losses, the parameters of DTPF can be formulated by considering with two single tuned filters. Cdl is given by

$$C_{d1} = C_1 + C_2$$

Where, C1 and C2 are the capacitances of two single tuned passive filters. The Ldl value can be obtained from,

$$L_{d1} = \frac{1}{C_1 {\omega_1}^2 + C_2 {\omega_2}^2}$$

The series resonant frequency Ws is calculated by

$$\omega_s = \frac{1}{\sqrt{L_{d1} C_{d1}}}$$

The parallel resonant frequency is obtained from (5) and LdZ is given by,

$$L_{d2} = \frac{\left(1 - \frac{{\omega_1}^2}{{\omega_s}^2}\right)\left(1 - \frac{{\omega_1}^2}{{\omega_p}^2}\right)}{C_{d1} {\omega_1}^2}$$

The value of capacitance Cd2 is then given by

$$C_{d2} = \frac{1}{L_{d2} {\omega_p}^2}$$

Among the most conserved passive filtering devices, we distinguish the resonant passive filter and the damped or high-pass passive filter.

III 1.2.5 High Pass Filter

Figure III.03 shows the circuit schematic and a typical impedance characteristic for a high-pass filter.

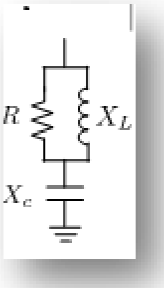


Figure III.04 High Pass Filter

This filter is designed to have an impedance characteristic that is flat for high frequencies. Looking at the equation that represents the variation of the impedance with the frequency,

$$Z(W) = \left(\frac{1}{R} + \frac{1}{jWL}\right)^{-1} + \frac{1}{jWC_1}$$

It can be shown that low resistance values will increase the losses, due to that parallel connection with the inductor, and having higher inductance is easier to achieve when designing the filter to work at high frequencies. Thus, this type of filter is applied to suppress 5th harmonic order currents or higher. The resistance also establishes an asymptotic behaviour in the impedance, limiting the maximum value at high frequencies. This means wide bandwidth that can be measured by the quality factor, which is the inverse of that for the series filter, and it is designed to have values between 0.5 and 2.

$$Q = \frac{R}{\sqrt{\frac{L}{C}}} = \frac{R}{X_{LN}} = \frac{R}{X_{CN}}$$

Where $X_{LN} = X_{CN}$ are reactances at the tuned frequency.

III 1.2.6 C-Type Filter

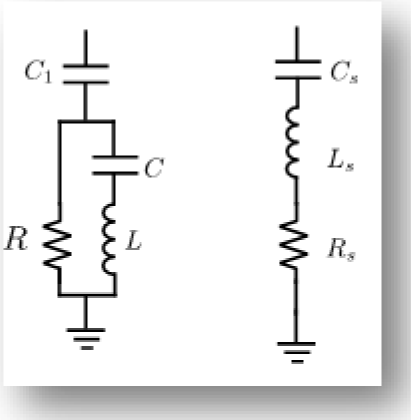


Figure III.05: Equivalent Series Filter for the C-Type Filter

C-type filters are second-order filters that have the capacity of suppressing harmonic currents with lower losses than the series filter or the band-pass filter. The reason for this capability is the L and C elements, which are parallel with the resistor, resonate at the fundamental frequency. Thus, the fundamental current that circulates through the damping resistor is reduced to a minimum. Another advantage is that c-type filters perform well in suppressing high frequency harmonics, due to their inherently flat impedance characteristic above the tuned frequency,

The design input parameters for the C-type filter are the same as they are for the series filter, and its impedance can be expressed on the basis of R, L, C, C_1:

$$Z(W) = \left(\frac{1}{R} + \frac{1}{jWL - j(WC)^{-1}}\right)^{-1} + \frac{1}{jWC_1}$$

$$Z(W) = \frac{R\times\left(W^2LC-1\right)^2 + jR^2WC\times(W^2LC-1)}{(RWC)^2+(W^2LC-1)^2} - j\frac{1}{W\times C_1}$$

III 1.2.7 Resonant passive filter

It is a selected filter consisting of a resistor, a capacitor and a coil in series, as described in Figure III.03, its equivalent impedance is:

$$Z_{equ}(\omega) = \frac{1-LC\omega^3+jRC\omega}{Jc\omega}$$

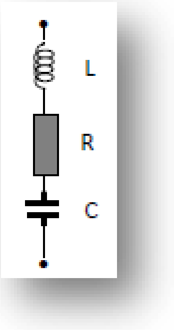


Figure III.06: Resonant Passive Filter

Main Characteristics Of a Resonant Passive Filter

They depend on the rank of agreement of the filter With nr=$\frac{ffr}{ff1}$ with fr tuning frequency given by

the following formula:

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

F1= fundamental frequency (or industrial, 50Hz for example)

These characteristics are:

- The reactive compensation power QVAR

The resonant filter, capacitive below its tuning, compensates for reactive energy at industrial frequency.

The reactive compensation power of the resonant filter under the operating voltage U1 at the connection busbar is given by the formula:

$$Q_{VAR} = \frac{n_r^3}{n_r^3-1} U_1^2 C2\pi f_1$$

Index 1 is relative to the fundamental

C being the phase-neutral capacity of one of the three branches of the battery seen as a star.

- The characteristic impedance

The characteristic impedance is given by the following formula:

$$X_0 = \sqrt{\frac{L}{C}}$$

The quality factor

The quality factor is given by the following formula:

$$q=\frac{XXo}{r}$$

An effective filter must have an inductance with a large factor therefore r<<X0 at the frequency

III.2 Simulation and Results

III.2.1 Simulation Model

A hybrid active power filter is simulated in order to compensate for the harmonics.Firstly, an active power filter was introduced together with our single tuned harmonics from the the passive filter to create a hybrid filter. Simulations were run on all the filters to compare and evalutate the results.

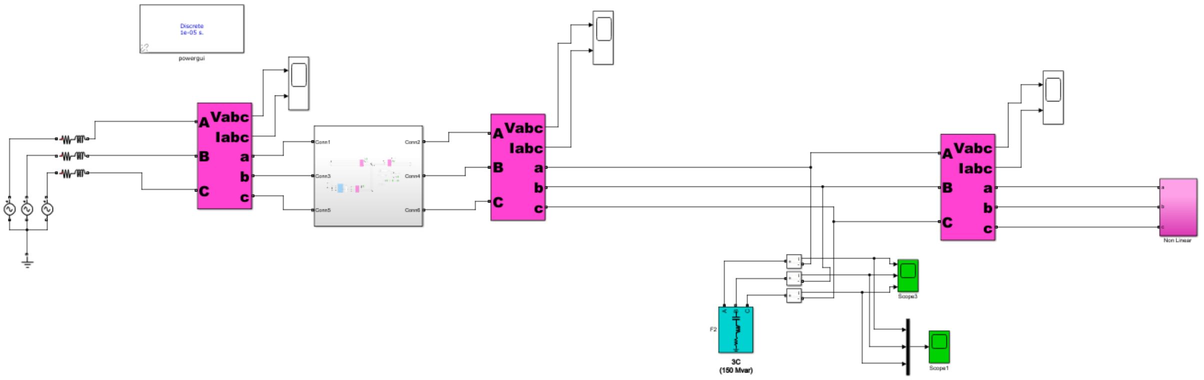
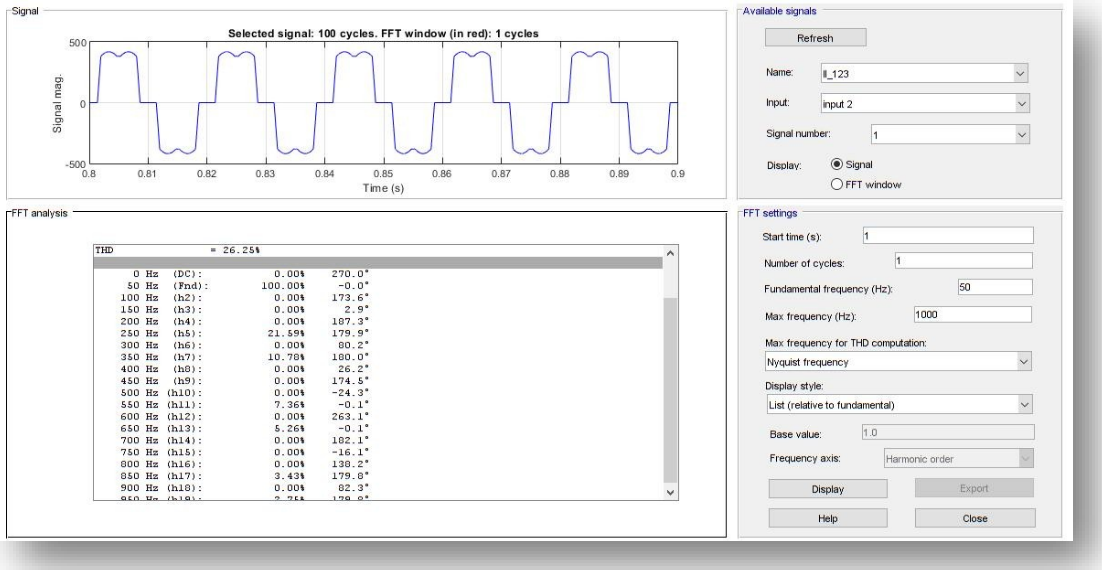


Figure III.07: Hybrid Active Power Filter

III.2. 1.1 Load side

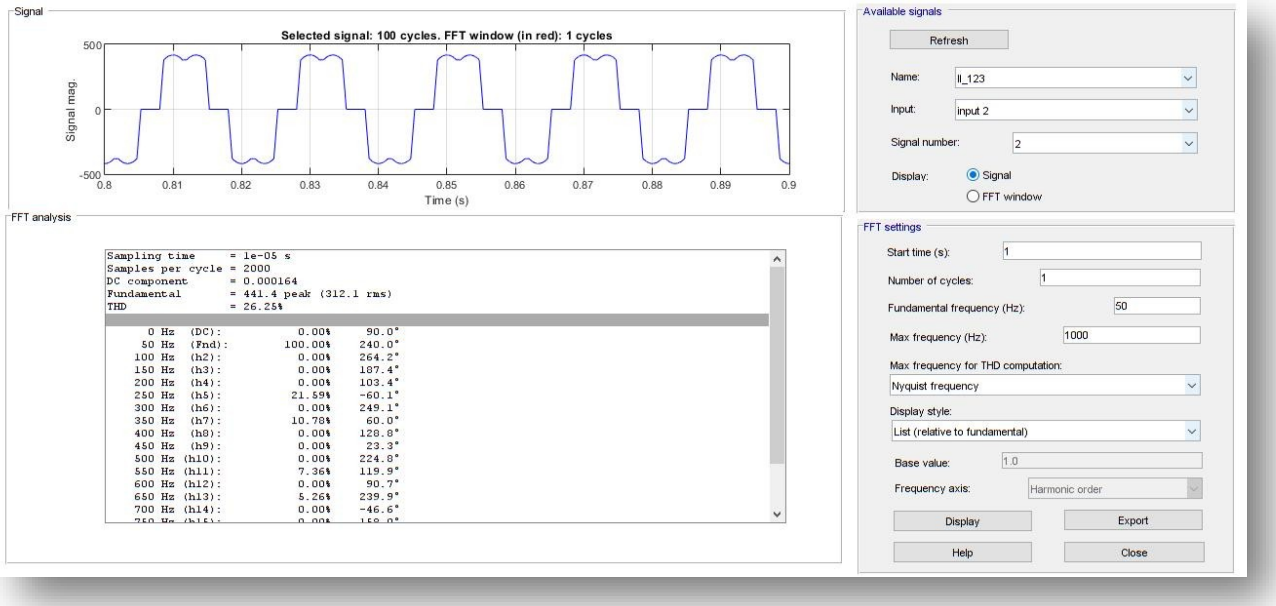


```
THD                 = 26.25%

      0 Hz   (DC):          0.00%    270.0°
     50 Hz  (Fnd):        100.00%     -0.0°
    100 Hz   (h2):          0.00%    173.6°
    150 Hz   (h3):          0.00%      2.9°
    200 Hz   (h4):          0.00%    187.3°
    250 Hz   (h5):         21.59%    179.9°
    300 Hz   (h6):          0.00%     80.2°
    350 Hz   (h7):         10.78%    180.0°
    400 Hz   (h8):          0.00%     26.2°
    450 Hz   (h9):          0.00%    174.5°
    500 Hz  (h10):          0.00%    -24.3°
    550 Hz  (h11):          7.36%     -0.1°
    600 Hz  (h12):          0.00%    263.1°
    650 Hz  (h13):          5.26%     -0.1°
    700 Hz  (h14):          0.00%    182.1°
    750 Hz  (h15):          0.00%    -16.1°
    800 Hz  (h16):          0.00%    138.2°
    850 Hz  (h17):          3.43%    179.8°
    900 Hz  (h18):          0.00%     82.3°
```

Name: Il_123
Input: input 2
Signal number: 1
Display: ● Signal ○ FFT window
Start time (s): 1
Number of cycles: 1
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: List (relative to fundamental)
Base value: 1.0
Frequency axis: Harmonic order

Figure III.08 : Current Load and THD of phase 1

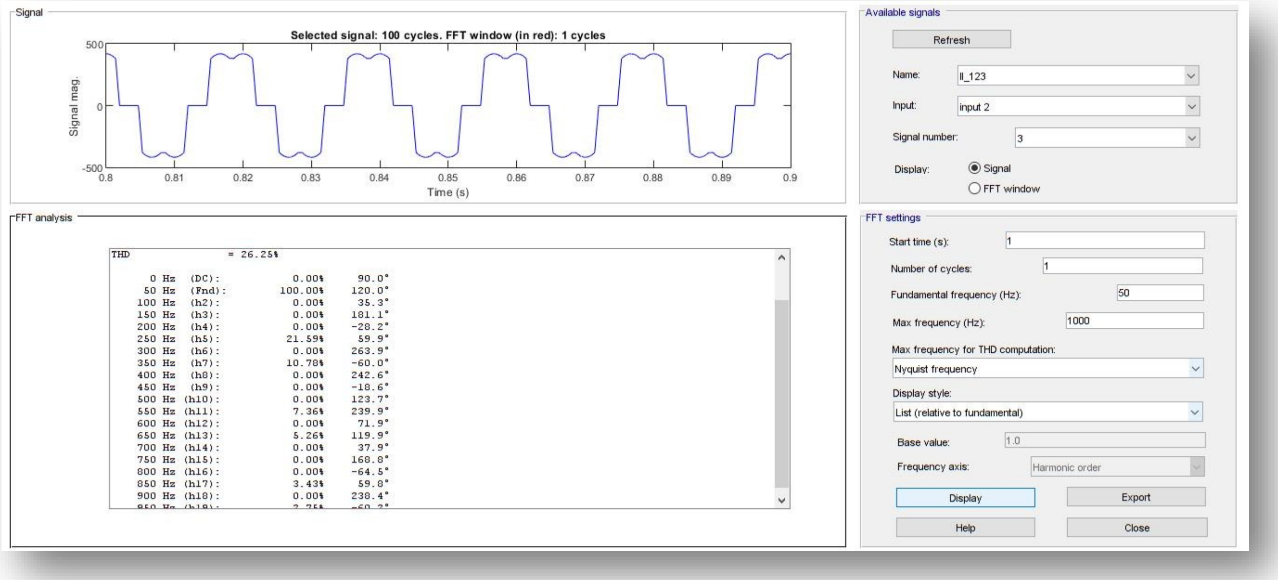


```
Sampling time       = 1e-05 s
Samples per cycle   = 2000
DC component        = 0.000164
Fundamental         = 441.4 peak (312.1 rms)
THD                 = 26.25%

      0 Hz   (DC):          0.00%     90.0°
     50 Hz  (Fnd):        100.00%    240.0°
    100 Hz   (h2):          0.00%    264.2°
    150 Hz   (h3):          0.00%    187.4°
    200 Hz   (h4):          0.00%    103.4°
    250 Hz   (h5):         21.59%    -60.1°
    300 Hz   (h6):          0.00%    249.1°
    350 Hz   (h7):         10.78%     60.0°
    400 Hz   (h8):          0.00%    128.8°
    450 Hz   (h9):          0.00%     23.3°
    500 Hz  (h10):          0.00%    224.8°
    550 Hz  (h11):          7.36%    119.9°
    600 Hz  (h12):          0.00%     90.7°
    650 Hz  (h13):          5.26%    239.9°
    700 Hz  (h14):          0.00%    -46.6°
```

Name: Il_123
Input: input 2
Signal number: 2
Display: ● Signal ○ FFT window
Start time (s): 1
Number of cycles: 1
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: List (relative to fundamental)
Base value: 1.0
Frequency axis: Harmonic order

Figure III.09 : Current Load and THD of phase 2



```
THD                  = 26.25%

  0 Hz   (DC):          0.00%     90.0°
 50 Hz  (Fnd):        100.00%    120.0°
100 Hz   (h2):          0.00%     35.3°
150 Hz   (h3):          0.00%    181.1°
200 Hz   (h4):          0.00%    -28.2°
250 Hz   (h5):         21.59%     59.9°
300 Hz   (h6):          0.00%    263.9°
350 Hz   (h7):         10.78%    -60.0°
400 Hz   (h8):          0.00%    242.6°
450 Hz   (h9):          0.00%    -18.6°
500 Hz  (h10):          0.00%    123.7°
550 Hz  (h11):          7.36%    239.9°
600 Hz  (h12):          0.00%     71.9°
650 Hz  (h13):          5.26%    119.9°
700 Hz  (h14):          0.00%     37.9°
750 Hz  (h15):          0.00%    168.8°
800 Hz  (h16):          0.00%    -64.5°
850 Hz  (h17):          3.43%     59.8°
900 Hz  (h18):          0.00%    238.4°
```

Name: Il_123
Input: input 2
Signal number: 3
Display: ● Signal ○ FFT window

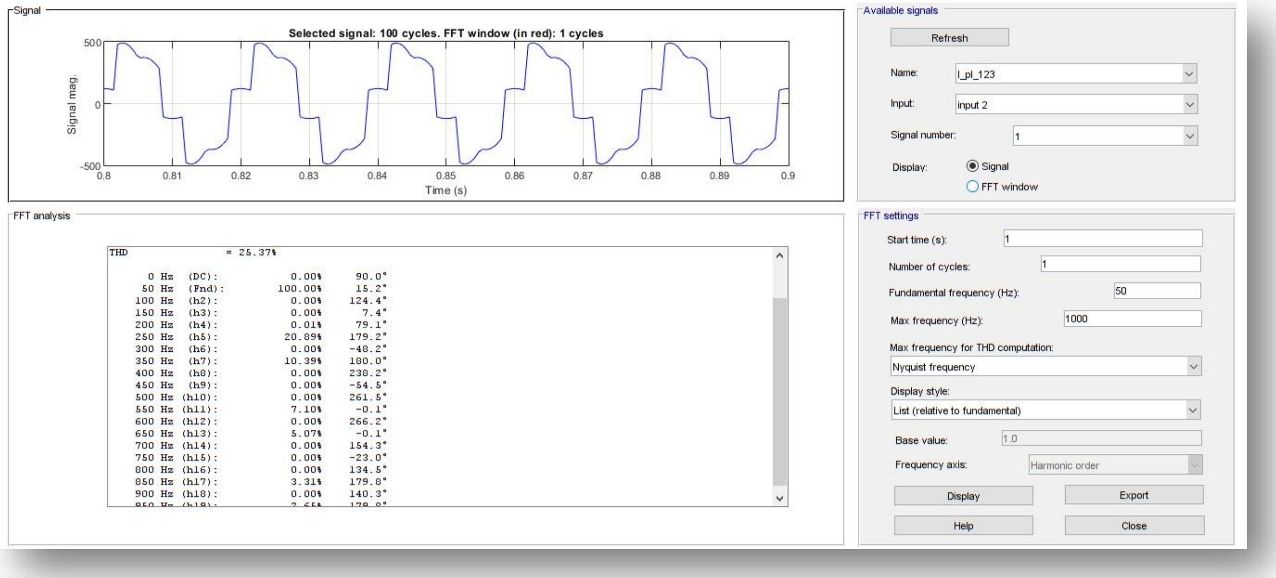
Start time (s): 1
Number of cycles: 1
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: List (relative to fundamental)
Base value: 1.0
Frequency axis: Harmonic order

Figure III.10 : Current Load and THD of phase 3

Simulations were run on the current load, we realised the disturbance or the distortion of harmonics present in the signal, however a steady and same THD was achieved after 3 trials which is 25.26 %.

III.2. 1.2 With Passive filter

Passive filter is introduced also to compensate for the harmonics, however after throughout the 3 phases diffenent THD was acquired with the same input signals from the single tuned harmonic filter.



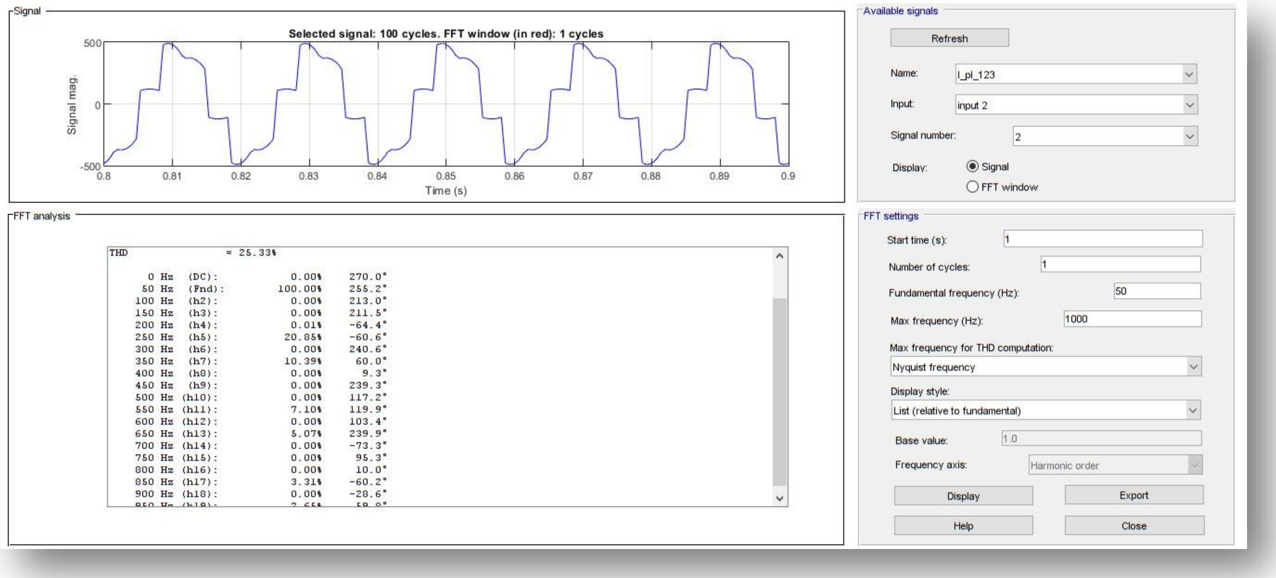
Name: I_pl_123
Input: input 2
Signal number: 1
Display: ● Signal ○ FFT window

Start time (s): 1
Number of cycles: 1
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: List (relative to fundamental)
Base value: 1.0
Frequency axis: Harmonic order

```
THD                  = 25.37%

     0 Hz   (DC):             0.00%      90.0°
    50 Hz  (Fnd):           100.00%      15.2°
   100 Hz   (h2):             0.00%     124.4°
   150 Hz   (h3):             0.00%       7.4°
   200 Hz   (h4):             0.01%      79.1°
   250 Hz   (h5):            20.89%     179.2°
   300 Hz   (h6):             0.00%     -48.2°
   350 Hz   (h7):            10.39%     180.0°
   400 Hz   (h8):             0.00%     238.2°
   450 Hz   (h9):             0.00%     -54.5°
   500 Hz  (h10):             0.00%     261.5°
   550 Hz  (h11):             7.10%      -0.1°
   600 Hz  (h12):             0.00%     266.2°
   650 Hz  (h13):             5.07%      -0.1°
   700 Hz  (h14):             0.00%     154.3°
   750 Hz  (h15):             0.00%     -23.0°
   800 Hz  (h16):             0.00%     134.5°
   850 Hz  (h17):             3.31%     179.8°
   900 Hz  (h18):             0.00%     140.3°
```

Figure III.11 :



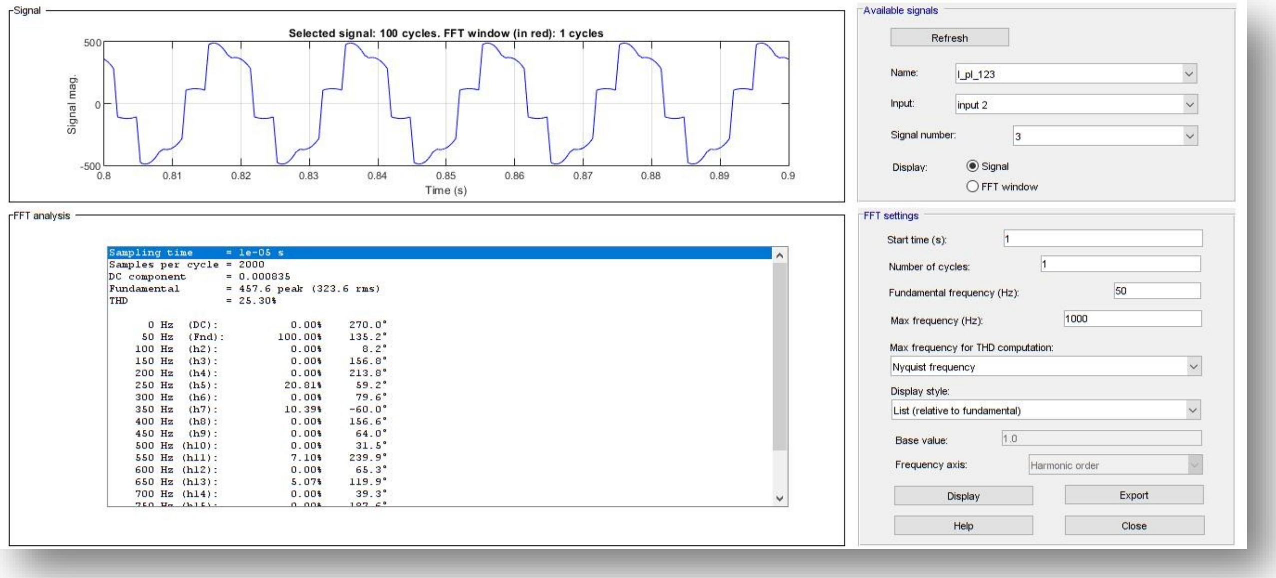
Name: I_pl_123
Input: input 2
Signal number: 2
Display: ● Signal ○ FFT window

Start time (s): 1
Number of cycles: 1
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: List (relative to fundamental)
Base value: 1.0
Frequency axis: Harmonic order

```
THD                  = 25.33%

     0 Hz   (DC):             0.00%     270.0°
    50 Hz  (Fnd):           100.00%     255.2°
   100 Hz   (h2):             0.00%     213.0°
   150 Hz   (h3):             0.00%     211.5°
   200 Hz   (h4):             0.01%     -64.4°
   250 Hz   (h5):            20.85%     -60.6°
   300 Hz   (h6):             0.00%     240.6°
   350 Hz   (h7):            10.39%      60.0°
   400 Hz   (h8):             0.00%       9.3°
   450 Hz   (h9):             0.00%     239.3°
   500 Hz  (h10):             0.00%     117.2°
   550 Hz  (h11):             7.10%     119.9°
   600 Hz  (h12):             0.00%     103.4°
   650 Hz  (h13):             5.07%     239.9°
   700 Hz  (h14):             0.00%     -73.3°
   750 Hz  (h15):             0.00%      95.3°
   800 Hz  (h16):             0.00%      10.0°
   850 Hz  (h17):             3.31%     -60.2°
   900 Hz  (h18):             0.00%     -28.6°
```

Figure III.12 :



Name: I_pl_123
Input: input 2
Signal number: 3
Display: ● Signal ○ FFT window
Start time (s): 1
Number of cycles: 1
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: List (relative to fundamental)
Base value: 1.0
Frequency axis: Harmonic order

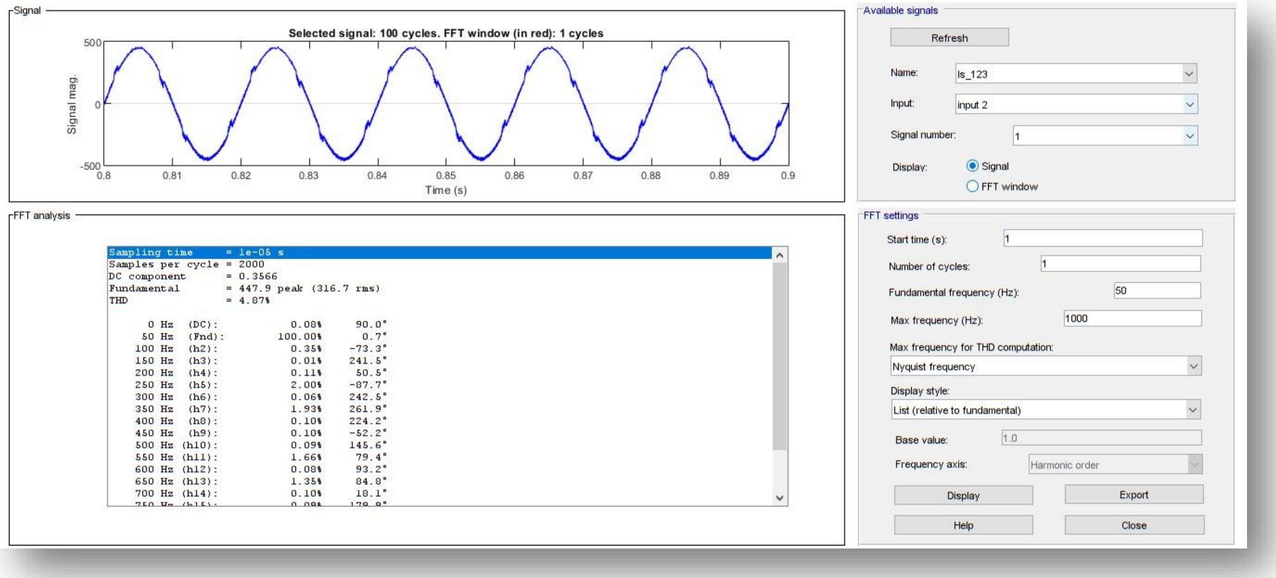
```
Sampling time      = 1e-05 s
Samples per cycle = 2000
DC component       = 0.000835
Fundamental        = 457.6 peak (323.6 rms)
THD                = 25.30%

     0 Hz  (DC):          0.00%    270.0°
    50 Hz  (Fnd):       100.00%    135.2°
   100 Hz  (h2):          0.00%      8.2°
   150 Hz  (h3):          0.00%    156.8°
   200 Hz  (h4):          0.00%    213.8°
   250 Hz  (h5):         20.81%     59.2°
   300 Hz  (h6):          0.00%     79.6°
   350 Hz  (h7):         10.39%    -60.0°
   400 Hz  (h8):          0.00%    156.6°
   450 Hz  (h9):          0.00%     64.0°
   500 Hz (h10):          0.00%     31.5°
   550 Hz (h11):          7.10%    239.9°
   600 Hz (h12):          0.00%     65.3°
   650 Hz (h13):          5.07%    119.9°
   700 Hz (h14):          0.00%     39.3°
```

Figure III.13 :

III.2. 1.3 Hybrid model

A hybrid configuation was achieved and simulated. A sinuisoidal wave was achieved with the hybrid model achieving the least of the harmonics and validating our theoretical studies and the norms

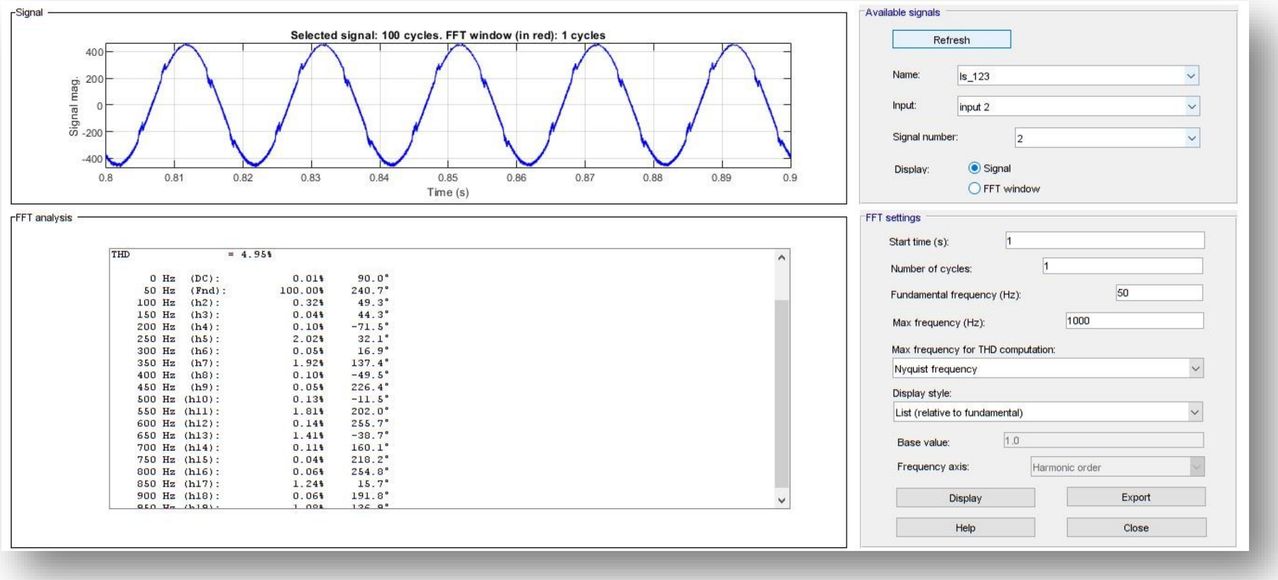


Name: Is_123
Input: input 2
Signal number: 1
Display: ● Signal ○ FFT window
Start time (s): 1
Number of cycles: 1
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: List (relative to fundamental)
Base value: 1.0
Frequency axis: Harmonic order

```
Sampling time      = 1e-05 s
Samples per cycle = 2000
DC component       = 0.3566
Fundamental        = 447.9 peak (316.7 rms)
THD                = 4.87%

     0 Hz  (DC):          0.08%     90.0°
    50 Hz  (Fnd):       100.00%      0.7°
   100 Hz  (h2):          0.35%    -73.3°
   150 Hz  (h3):          0.01%    241.5°
   200 Hz  (h4):          0.11%     50.5°
   250 Hz  (h5):          2.00%    -87.7°
   300 Hz  (h6):          0.06%    242.5°
   350 Hz  (h7):          1.93%    261.9°
   400 Hz  (h8):          0.10%    224.2°
   450 Hz  (h9):          0.10%    -52.2°
   500 Hz (h10):          0.09%    145.6°
   550 Hz (h11):          1.66%     79.4°
   600 Hz (h12):          0.08%     93.2°
   650 Hz (h13):          1.35%     84.8°
   700 Hz (h14):          0.10%     18.1°
```

Figure III.14 :



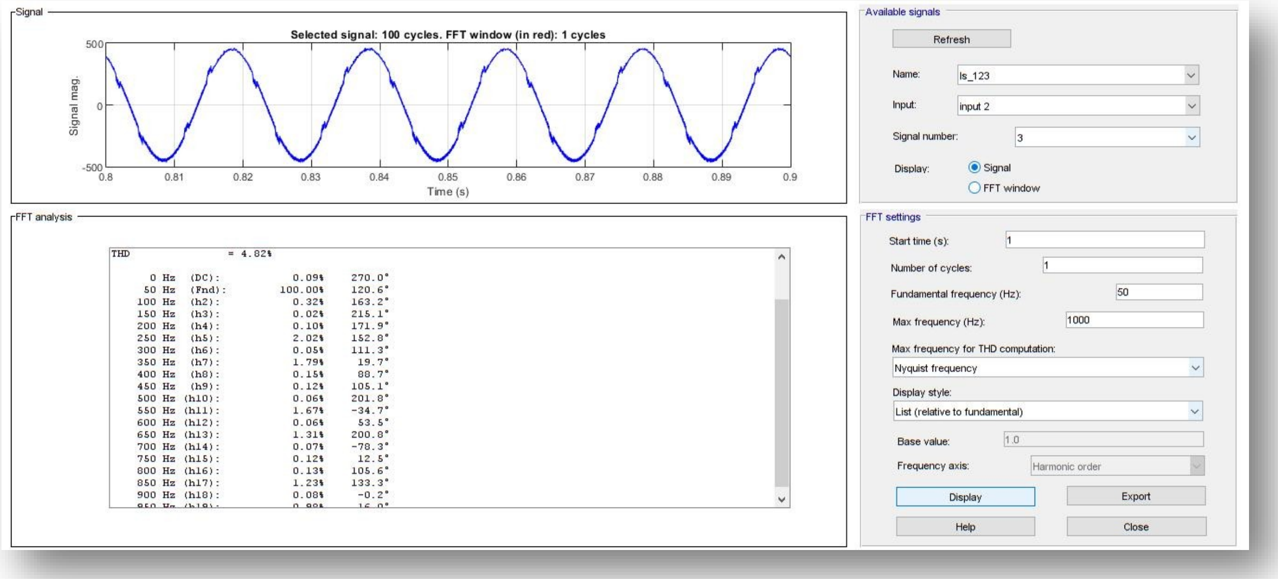
Name: Is_123
Input: input 2
Signal number: 2
Display: ● Signal ○ FFT window

Start time (s): 1
Number of cycles: 1
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: List (relative to fundamental)
Base value: 1.0
Frequency axis: Harmonic order

```
THD             = 4.95%

   0 Hz  (DC):           0.01%     90.0°
  50 Hz  (Fnd):        100.00%    240.7°
 100 Hz  (h2):           0.32%     49.3°
 150 Hz  (h3):           0.04%     44.3°
 200 Hz  (h4):           0.10%    -71.5°
 250 Hz  (h5):           2.02%     32.1°
 300 Hz  (h6):           0.05%     16.9°
 350 Hz  (h7):           1.92%    137.4°
 400 Hz  (h8):           0.10%    -49.5°
 450 Hz  (h9):           0.05%    226.4°
 500 Hz (h10):           0.13%    -11.5°
 550 Hz (h11):           1.81%    202.0°
 600 Hz (h12):           0.14%    255.7°
 650 Hz (h13):           1.41%    -38.7°
 700 Hz (h14):           0.11%    160.1°
 750 Hz (h15):           0.04%    218.2°
 800 Hz (h16):           0.06%    254.8°
 850 Hz (h17):           1.24%     15.7°
 900 Hz (h18):           0.06%    191.8°
```

Figure III.15 :



Name: Is_123
Input: input 2
Signal number: 3
Display: ● Signal ○ FFT window

Start time (s): 1
Number of cycles: 1
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: List (relative to fundamental)
Base value: 1.0
Frequency axis: Harmonic order

```
THD             = 4.82%

   0 Hz  (DC):           0.09%    270.0°
  50 Hz  (Fnd):        100.00%    120.6°
 100 Hz  (h2):           0.32%    163.2°
 150 Hz  (h3):           0.02%    215.1°
 200 Hz  (h4):           0.10%    171.9°
 250 Hz  (h5):           2.02%    152.8°
 300 Hz  (h6):           0.05%    111.3°
 350 Hz  (h7):           1.79%     19.7°
 400 Hz  (h8):           0.15%     88.7°
 450 Hz  (h9):           0.12%    105.1°
 500 Hz (h10):           0.06%    201.8°
 550 Hz (h11):           1.67%    -34.7°
 600 Hz (h12):           0.06%     53.5°
 650 Hz (h13):           1.31%    200.8°
 700 Hz (h14):           0.07%    -78.3°
 750 Hz (h15):           0.12%     12.5°
 800 Hz (h16):           0.13%    105.6°
 850 Hz (h17):           1.23%    133.3°
 900 Hz (h18):           0.08%     -0.2°
```

Figure III.16 :

THD of the Power System

III.3 Comparative study:

Table Comparative THDs

THD	Load	Load + Passive Filter	Load + Hybrid Filter
Phase 01	26.25	25.37	4.87
Phase 02	26.25	25.33	4.95
Phase 03	26.25	25.30	4.82

We saw that the results of the hybrid filter was far better than the results with the passive filter alone, as shown in the table above.

III.4 Conclusion:

In this chapter, the hybrid filter was modelled and simulated by using a single tuned passive harmonic filter, which is implemented to an active power filter to improve the steady state performance of the hybrid power filter.

Our Simulation results show that, the presented hybrid active power filter reduces THD percentage around 80% thus the THD of the source current is reduced from 26.25% to 4.87% approximately, as per IEEE-519 standard which is ideal for power network and also has an appropriate response to load variations.

Furthermore, the portion of reactive power which passive filter have been set to compensate is not big, comparatively from our THD a very minute portion was compensated from (26.25 to 25.30).

Harmonic Standard and Recommended Practices

There are now two criteria that are used to evaluate harmonic distortion. The first is a limitation in the harmonic current that a user can transmit into the utility system. The second criteria is the quality of the voltage that the utility must furnish the user. The interrelationship of these criteria shows that the harmonic problem is a system problem and not tied just to the individual load that requires the harmonic current [33].

Table 1.1 LEEE-519 Maximum odd-harmonic current distortion. % Limits of Harmonic Currents (Bus voltage @ PCC<69 KV)

I_{sc}/I_1	**h<11**	**11<h<17**	**17<h<23**	**23<h35**	**35<h**	**THD**
<20	**4.0**	**2.0**	**1.5**	**0.3**	**0.3**	**5.0**
20-50	**7.0**	**3.5**	**2.5**	**1.0**	**0.5**	**8.0**
50-100	**10.0**	**4.5**	**4.0**	**1.5**	**0.7**	**12.0**
100-1000	**12.0**	**5.5**	**5.0**	**2.0**	**1.0**	**15.0**
>1000	**15.0**	**7.0**	**6.0**	**25**	**1.4**	**20.0**

Table 1 lists the harmonic current limits based on the size of the user with respect to the size of the power system to which he is connected. The ratio of Isc/IL is the short circuit current available at the point of common coupling (PCC), to the nominal fundamental load current. Thus, as the size of the user load decreases with respect to the size of the system, the larger is the percentage of harmonic current ‘the user is allowed to inject into the utility system. This protects other users on the same feeder as well as the utility which is required to furnish a certain quality of power to its customers.

Table 2 - Harmonic Voltage Limits for Power Producers (Public Utilities or CO-generators)

Bus Voltage @PCC	HDv(%)	THDv(%)
69 KV and below	3.0	5.0

The second limitation specifies the quality of the voltage that the utility must furnish the user. Table 2 lists the amount of voltage distortion that is acceptable from a utility to a user.

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