DESIGN OF SHUNT ACTIVE POWER FILTER TO MITIGATE THE HARMONICS CAUSED BY NONLINEAR LOADS

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ABSTRACT

Application of non-linear electrical devices has led to a distortion in the output sine waveforms of source current and voltage. It may lead equipment (connected to it) to overheat and sometimes cause damage. This paper concentrates on the design and application of three-phase shunt active power filter (SAPF) by using p-q theory to mitigate the harmonics which are created by nonlinear loads. To obtain result for this paper, the MATLAB / Simulink was used as a simulation tool. The achieved results are within the recommended IEEE-519 standard i.e. less than 5% and also the power factor (PF) of the system to almost unity.

ABSTRACT

Pemakaian alat-alat elektrik bukan linear telah membawa kepada penyelewengan dalam pengeluaran bentuk gelombang sinus sumber arus dan voltan. Ia boleh membawa peralatan (yang berkaitan dengannya) untuk terlalu panas dan kadang-kadang menyebabkan kerosakan. Kertas kerja ini memberi tumpuan kepada reka bentuk dan penggunaan tiga fasa pirau kuasa aktif penapis (SAPF) dengan menggunakan teori pq untuk mengurangkan harmonik yang dicipta oleh beban tak linear. Untuk mendapatkan hasil untuk kertas ini, MATLAB / Simulink telah digunakan sebagai alat simulasi. Keputusan yang dicapai adalah dalam disyorkan IEEE-519 standard iaitu kurang daripada 5% dan juga faktor kuasa (PF) sistem kepada hampir perpaduan.

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PQ	Power quality
PS	Power system
PPF	Passive power filter
HV	High voltage
AC	Alternating current
DC	Direct current
APF	Active power filter
PF	power factor
THD	Total harmonic distortion
HAPF	Hybrid active power filter
PFC	Power factor correction
IEEE	Institute of electrical and electronic engineers
H	Harmonic
$\mathrm{I_n}$	Total current
F	Frequency
HZ	Hertz
I_{SC}	maximum short –circuit at PCC
I_L	maximum demand load current at PCC
P	Real power
Q	Reactive power
S	Apparent power
Qc	Capacitor power bank
PF_{disp}	Displacement power factor
PF_{dist}	Distortion power factor
PF_T	Total power factor
Ls	Source inductor
C	Capacitor
R	Resistor
Q_C	capacitive reactive power
I_L	Load current
I_s	Source current
I_f	Filter current
VSI	Voltage source inverter
CSI	Current source inverter
Se APF	Series active power filter
Sh APF	Shunt active power filter
LPF	Low pass filter
HPF	High pass filter

BPF	Band pass filter
fc	cut off frequency
PCM	Power control mode
PI	Proportional- integral
PWM	Pulse width modulation
IGBT	Insulated Gate Bipolar Translator

CHAPTER 1

INTRODUCTION

1.1 Introduction

Power Quality (PQ) issues are becoming a major concern of today's power system (PS) engineers. Harmonics play significant role in deteriorating PQ, called harmonic distortion. Harmonic distortion in electric distribution system is increasingly growing due to the widespread use of nonlinear loads. Large considerations of these loads have the potential to raise harmonic voltage and currents in an electrical distribution system to unacceptable high levels that can adversely affect the system currents. IEEE standards have defined limits for harmonic voltages and harmonic [1].It has been lost in distribution system , current harmonics cause serious harmonic problems in distribution feeders for sensitive consumers .some technology solutions have been reported in order to solve PQ [1.2] .

Initially, passive power filters (PPF) (combinations of capacitors and inductors) were normally used to mitigate the PQ problems. These approaches were extensively used in high voltage DC transmission (HVDC) for filtering the harmonics on the AC and DC sides. However, this approach is unsuitable at the distribution level as PPF can only correct specific load conditions or a particular state of the power system. These filters are unable to follow the changing system conditions. Thus, the active power filter (APF) was introduced to compensate harmonics and reactive power[3].

There are three types of APF which are shunt APF, series APF and hybrid APF which is the combination of AP with PPF.

The purpose of APF power line conditioner is to compensate the utility line current waveform so that it approximates a sine wave in phase with the line voltage when a nonlinear load is connected to the system. Classically, shunt power line conditioner (shunt PPF) consists of tuned LC filters and/or high pass filters are used to suppress harmonics and power capacitors are employed to improve the power factor (PF) of the utility/mains. But these conventional methods have the limitations of fixed compensation, large size and can also excite resonance conditions [1, 4]. Hence APF is introduced as a viable alternative to compensate harmonics and improve PF.

This project is focusing on the application of APF in treating the harmonics distortion in distribution system by determining low Total Harmonics Distortion (THD) value and improving the system's power factor (PF).

1.2 Problem Statement

Harmonics play significant role in deteriorating PQ, called harmonic distortion. Harmonic distortion in electric distribution system is increasingly growing due to the widespread use of nonlinear loads.

The main problem that needs to be solved is to reduce the harmonics level in the line current. Non-linear loads create harmonic current and increase the deterioration of the PS voltage and current waveforms. These loads cause the sine wave of the current to deform [6]. Harmonics in the PS can be measured through the measurement of THD. As a result, APF is used to implement in the PS for harmonics compensation purpose.

1.3 Objectives of research

The objectives of this project can be summarized as follows:

- To design an shunt APF
- To investigate the (Shunt APF) under different nonlinear load conditions.
- To analyse the harmonic spectrum of the system and achieve low THD

1.4 Scope of project

- Represent the linear load R
- Represent the nonlinear load with RL load, and analysis as the distorted source current waveform drawn by the nonlinear load.
- Three-phase (shunt APF) will be simulated Using MATLAB Simulink.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will discuss about the literature review of the project. The sources of the information had been gathered from books, journals, research papers, newspapers, magazines, hand books and thesis.

The literature review starts with the theory of PQ problems, continue with the harmonics, PF and APF. Finally, there are explanation about several ways to mitigate the effect of (PFC) .

2.2 Power quality problems

Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines PQ as “the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment.” As appropriate as this description might seem, the limitation of PQ to “sensitive electronic equipment” might be subject to disagreement. Electrical equipment susceptible to power quality or more appropriately to lack of PQ would fall within a seemingly boundless domain [5].

All electrical devices are prone to failure or malfunction when exposed to one or more PQ problems [4.]. The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment, or a household appliance. All of these devices react adversely to PQ issues, depending on the severity of problems [5.6]. PQ can be roughly broken into categories as follows:

1. Steady-state voltage magnitude and frequency
2. Voltage sags
3. Grounding
4. Harmonics
5. Voltage fluctuations and flicker
6. Transients, and
7. Monitoring and measurement

2.3 Harmonic (H)

The harmonic problem is not a new phenomenon in PS. It was detected as early as the 1920s and 30s [6-8]. At that time, the primary sources of harmonies were the transformers and the main problem was the inductive interference with open-wire telephone systems. Some early work on harmonic filtering in distribution feeders was performed around that time.

In the recent time we have been notifying a big change in the use of non-linear loads. Due to this the value of harmonic non-sinusoidal currents and voltages has also increased up to a great extent in the system. These harmonic elements affect the overall PS as well as the client's equipment's also .So today the issue of maintaining the PQ is a big issue.

Harmonics are defined sinusoidal voltages or currents having frequencies that are whole multiples of the frequency at which the supply system is designed to operate (50 Hz or 60 Hz). Figures (2.1) and (2.2) show that any periodic distorted waveform can be expressed as a sum of pure sinusoids. The harmonic number (h) usually specifies a harmonic component, which is the ratio of its frequency to the fundamental frequency [9.10].

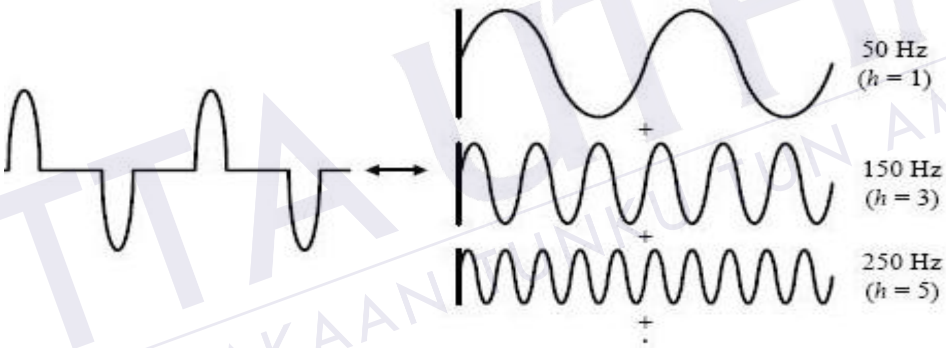

Figure (2.1) shows periodic distorted waveform

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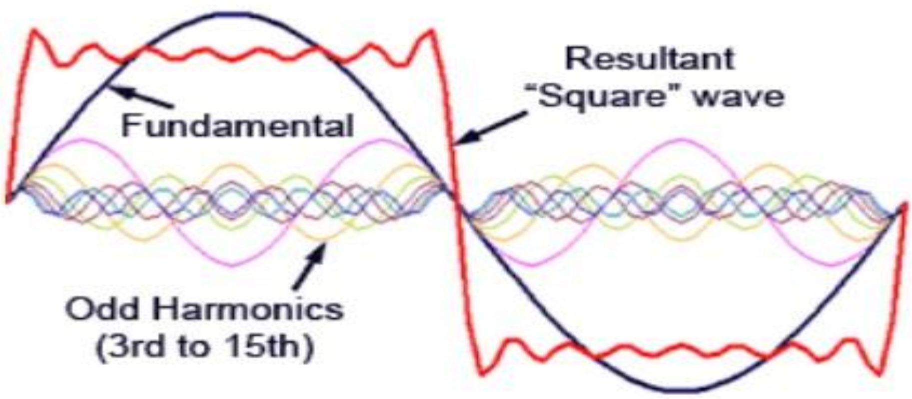


Figure (2.2) shows periodic distorted waveform

Harmonics have frequencies that are integer multiples of the waveform fundamental frequency. For example, given a 60 Hz fundamental waveform, the 2^{nd} , 3^{rd} , 4^{th} , 5^{th} harmonic components will be at 120 Hz, 180 Hz, 240 Hz and 300 Hz respectively Thus, harmonic distortion is the degree to which a waveform deviates from its pure sinusoidal values as a result of the summation of all these harmonic elements. The ideal sine wave has zero harmonic components. In that case, there is nothing to distort this perfect wave[11.12].

2.3.1 Total harmonic distortion (THD)

THD of a signal is a measurement of the harmonic distortion present in current or voltage. It is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency [7-9].

$$\mathrm{THD_i} = \sqrt{\frac{\sum \mathrm{I_n^2}}{\mathrm{I_1}}} \times 100\% \quad (n = 2,3,4,5\ldots..\infty) \qquad (2.1)$$

Where

I_1 is the fundamental component of the current

I_n is the total current

Harmonic distortion can have detrimental effects on electrical distribution systems, It can waste energy and lower the capacity of an electrical system; it can harm both the electrical distribution system and devices operating on the system. Understanding the problems associated with harmonic distortion, it causes and effects, as well as the rnethods of dealing with it, is of great importance in minimizing those effects and increasing the overall efficiency of the distribution system [13. 14]

2.3.2 IEEE standard for harmonic

IEEE 519-1981, “IEEE Guide for harmonic control and reactive compensation of static power converters”, originally established levels of voltage distortion AC- capable to the distribution system for individual non-linear loads. With the rising increase usage of industrial non-linear loads, such as variable frequency (F) drives, it became necessary to revise the standard [12.15].

The IEEE working groups of the power engineering society and the industrial applications society prepared recommended guidelines for PQ that the utility must supply and the industrial user can inject back onto the power distribution system. The revised standard was issued on April 12, 1993 and titled“IEEE recommended practices and requirements for harmonic control in electrical power systems [15] .

The IEEE 519 standard clearly states that harmonic current should be reduced to voltage distortion, table (2.1) show that limits of current.

Table (2.1) current distortion limits for distribution system
(120 through 69,000 v)

I_{SC}/I_L	<11	11≤h<17	17≤h<23	23≤h<35	35≥h	TDD
< 20	4	2	1.5	0.6	0.3	5
20 - 50	7	3.5	2.5	1	0.5	8
50 - 100	10	4.5	4	1.5	0.7	12
100 - 1000	12	5.5	5	2	1	15
> 1000	15	7	6	2.5	1.4	20

Where;

I_{SC} = maximum short –circuit at PCC

I_L = maximum demand load current at PCC

2.4 Power Factor (PF)

In PS, wasted energy capacity, also known as poor PF, is often overlooked. It can result in poor reliability, safety problems and higher energy costs. The lower PF, the less economically your system operates.

PF is the ratio of the active power measured in kilowatts (kW), to the total apparent power measured in kilovolt amperes (kVA), and is calculated as

$$PF = \frac{P}{S} \quad (2.2)$$

$$PF = {}^{KW}/_{KVA} \quad (2.3)$$

Where;

P is active power

S is apperant power

PF is commonly referred to in percent, with 100% being a perfect PF, also called unity. At unity PF, the kVA

= kW, therefor the utility company does not supply any reactive power [12].

2.4.1 Power factor with linear loads

When the loads connected to the system are linear and the voltage is sinusoidal, the PF is calculated with the following equation:

$$PF = \cos(\phi) \quad (2.4)$$

Unfortunately, this formula has led to a misunderstanding of the PF concept. PF is the proportional relation of the active power (or working power) to the S (total power delivered by the utility or consumed by the load) [16]. Using this definition, the PF must be calculated as:

Where;

$$P = VI\cos(\phi) \quad (2.5)$$

$$S = VI \quad (2.6)$$

A low PF means a that a low amount of the total power delivered or consumed (S) is used as (P) and a considerable amount is reactive power (Q). the purpose of PFC is to reduce the reactive component of the total power.

This achieves a more efficient use of the energy because when the PF is improved the working power is equal (or nearly equal) to the total power, and reactive power is zero or negligible .The most common way to correct PF is by adding a capacitor bank connected in parallel with the PS , to calculate the capacitor banks to be installed, use the following method:

- Select the month in which the bill is highest (kVArh to be billed)
- Assess the number of hours the installation operates each month
- Calculate the capacitor power Qc to be installed

$$Q_c = \frac{KVArh\ to\ be\ billed\ (monthly\ )}{NO\ ,of\ hours'operation\ (monthly\ \ )} \quad (2.7)$$

The capacitor bank supplies most of the reactive power needed by the load and a small amount is supplied by the utility (*Q*2).The original angle *(ϕ1)* between the *P* and *S* is reduced to a smaller value *(ϕ2)* and the PF is improved because *cos (ϕ 2) > cos(ϕ1)* .

It is very important to note that the reduction in the angle obtained by the PF improvement is a result of the vector relationship between the active, reactive and S, but what we are really doing is reducing the Q, consequently the S is also reduced and the PF is increased [17,18]

2.4.2 Power factor with non–linear loads

A non-linear load on a PS is typically a rectifier or device such as (a fluorescent lamp, electric welding machine, or arc furnace). Because current in these systems is interrupted by a switching action, the current contains frequency components that are multiples of the PSF. Distortion PF is a measure of how much the harmonic distortion of a load current decreases the average power transferred to the load[19].

When the loads are non–linear but the voltage is sinusoidal, the current has harmonics and the *P*, *Q* and *S* should not be calculated using the traditional methods as demonstrated by equations (2.4), (2.5) .This means that the equation (2, 3) cannot be used to calculate the PF when non–linear loads are concerned.

The active power is the mean (or average) value of the instantaneous power, so it can be calculated

$$P = VI\cos(\emptyset_1) \quad (2.8)$$

The rms value of current is a function of the $\boldsymbol{THD_i}$ and the rms value of the fundamental component of current can be calculated by:

$$I = I_1\sqrt{1 + THD_i^2} \quad (2.9)$$

The PF for non–linear loads, can be calculated using equations (2.6), (2.8) and (2.9).

$$Pf = \cos(\emptyset_1) * 1/\sqrt{1 + THD_i^2} \quad (2.10)$$

Where:

cos $(\boldsymbol{\emptyset_1})$ is called displacement power factor (PF_{disp}) because it depends on the phase angle between the voltage and the fundamental component of the current, and it is similar to the *PF* calculated with linear loads and sinusoidal voltage .

$\boldsymbol{1/\sqrt{1 + THD_i^2}}$ is called distortion power factor (PF_{dist}) because it depends on the current harmonic distortion .

Thus, The total power factor(PF_T) calculated as the product of the PF_{disp} and the PF_{dist} is known *as* (PF_T)

$$PF_T = PF_{disp} * PF_{dist} \quad (2.11)$$

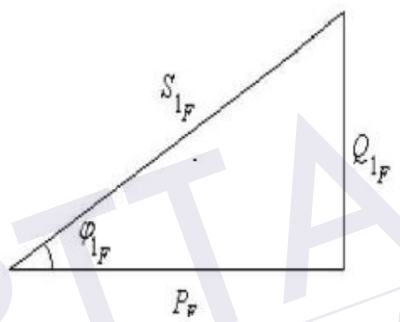
If the Q of the loads increases, the displacement angle between the voltage and the fundamental component of the current also increases and the total *PF* decreases. Likewise, if the THD of current increases, the PF_T decreases. It is clear by equation (2.9) that PF_T will always be lower than PF_{disp} the whenever harmonic distortion is present. PF_T can only be achieved when both PF_{disp} and PF_{dist} are corrected. This requires a two steps process:

- Reduce the displacement angle between voltage and current
- Reduce the total harmonic current distortion

If either of these steps is taken without the other the PF_T will be increased but it may not be high enough to reach the minimum value required by the utility. Additionally, if one step is taken without the other, the PF_T and the corresponding efficiencies will not be achieved.

Now, vector relationship, as shown in figure(2. 3A), can be obtained from the P, the fundamental (Q_{1f}) and the fundamental **(** S_{1f}**)** prior to displacement power factor improvement. This relationship allows us to visualize the effect that a capacitor bank (QCF) has on correcting the displacement power factor figure(2.3.B).

Whenever capacitors are used, care should be taken to avoid a resonant condition between the capacitor bank and the main transformer.



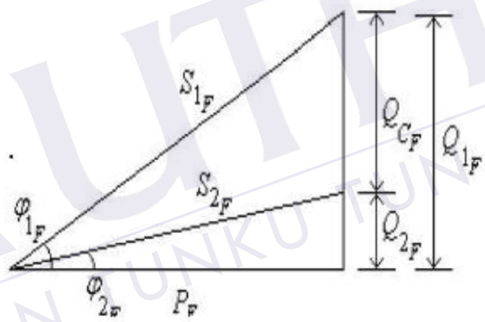


Figure (2.3.A)   figure (2.3.B)

The PF_T can be improved by decreasing the harmonic current distortion, which is accomplished by using a filter instead of a capacitor bank. The capacitive part of the filter improves the PF_{disp} , while the combination of the reactor and the capacitor bank decrease the THD of the current. A twofold result is achieved, that is improvement of the PF_{dist} and improvement of thePF_{disp}. If a capacitor bank were used instead of a filter, the PF_{dist} would have been improved. If there is no resonance, the distortion power factor does not change and the PF_T increases only because the PF_{disp} also increases, but the PF_T may not be high enough to reach the minimum value required by the utility. Of a resonant condition is created between the capacitor bank and the main transformer, the THD of current increases so the PF_{dist} degrades and the final result is a lowPF_T even with a capacitor bank and a high PF_{disp}.

The figure (2.4) shows the behaviour of the PF_T for different values of PF_{disp} and THD of current.

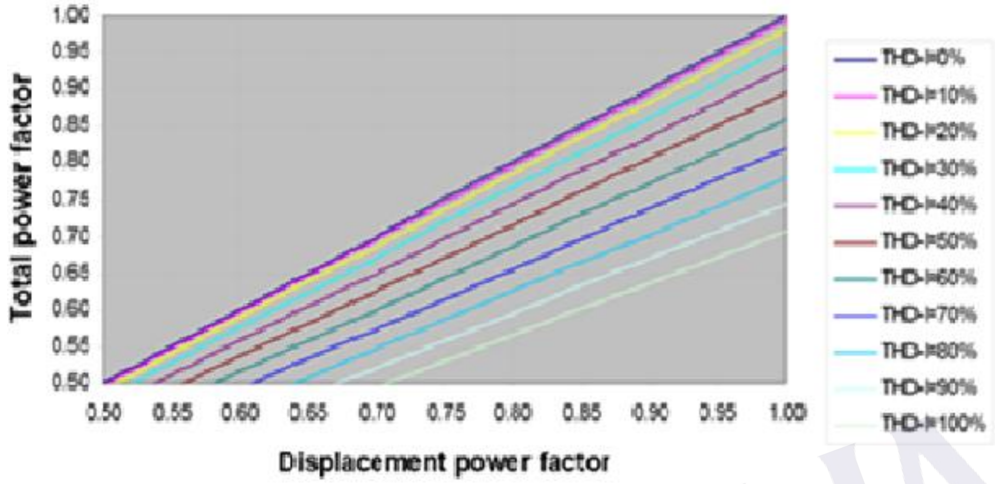


Figure (2.4) show the behaviour (PF_T) and THD

2.5 Effect of Harmonics

Harmonics are a major cause of power supply pollution lowering the power factor and increasing electrical losses. The effect of harmonic results in premature equipment failure and also cause of requirement of equipment of high rating The voltage distortion produced in the system is the major issue with the harmonics distribution. The electronics equipment used in the system usually generate harmonics more than one. In all type of harmonics the tripled harmonics are more severe example of triplet harmonics are 3rd 9th 15th [20.21].

These harmonics creates a big challenge for engineers because they pose more distortion in voltage. The effect of triplex harmonics come with overheating in wires, overheating in transformer units and also may become the cause of end user equipment failure. Triplex harmonics overheat the neutral conductor of 4 wire system. the neutral have generally no fundamental frequency or even harmonics but there may be existence of odd harmonics in system neutral conductor and when there is system consist of triplex harmonics it is become additive. These triplex frequency impact on the system can be understand by this way that even under balanced load condition on the account of triplex frequency neutral current magnitude reaches up to 1.75 times of average phase current [20]. Under above discussed case if the load of system increase may become cause of failure of insulation of neutral conductor which further result in the breakdown of transformers winding. The important and major effect of Harmonics is further discussed as:

2.5.1 Effect on Transformer

Harmonics effect transformer losses and eddy current loss density [23]. Actually, the harmonic effects on transformer will not be notice until actual failure occurs. It will occurs when there has been changes that been made to the system like additional or replacement of new loads. Overheating of transformer is always been related with harmonics effects.

Harmonics produce addition losses in the transformer core as the higher frequency harmonic voltages set up hysteresis loops, which superimpose on the fundamental loop. Each loop represents higher magnetization power requirement and higher core losses.

Because of harmonics, the losses in conductor will increase. The resultant current will increase the distortion and is given by equation (2.1). Overheating also can occur when there is resistive skin effect and winding proximity effect [13]

2 .5.2 Effect on Capacitor bank

In industrial load where a lot of motors are used, we need to improve power factor. For this purpose we are connected capacitor banks near to the loads to improve it. Since harmonics create reactance as for capacitor reactance will increase as the frequency decrease. Therefore, the linear loads served from a common feeder, which also serves nonlinear loads of some other consumers, may become susceptible to harmonic distortion. Moreover, a consumer's system which does not have harmonics can be subjected to harmonic pollution due to of other consumers in the system. The capacitors can be severely overloaded due to harmonics and can be damaged [23 .24]

2.5.3 Neutral conductor over loading

In single phase PS neutral play a very important role as they carry the return current and complete the circuit. But in case of harmonics it also becomes the return path for the harmonic current to transformer through neutral connection. For an unbalanced system the unbalanced currents are passed through the neutral and for this purpose we need to balance the system the size of neutral cable is almost taken equal to its phase cable. Under environment of harmonics the unbalanced current which is passed through the neutral produces a heat loss in the system which again affects the power quality of distribution system [25]

2.5.4 Effect on lines and cables

Harmonic distortion in a distribution system affects the system current and significantly. These increased rms currents produce additional heat losses in the system lines and cables Harmonic distortion in cables affect by increasing the dielectric stress in the cables. This stress is proportional to the voltage crest factor which represents the crest value of voltage waveform to rms value of waveform. The effect of this increased stress is such that, the cable useful life is shortened, causing faults, which ultimately increases the system capital and maintenance cost [26].

2.5.5 Thermal effect on rotating machine

Rotating machine are also affected by harmonics same as transformer. Resistance of rotating machine will go high if the frequency of system is high. For this if there is harmonic present in the system have a very rich current value which tends to produce a heat loss in the rotating machine . This overall heat loss will again affect its life and thus increase maintenance problems [27.28].

2.5.6 Undesired operation of fuse

In the environment of harmonic the RMS value of voltage and current may increase. This tendency will lead the problem of unexpected operation of fuse in capacitor banks or other arrangements which are used in the system to make operation of nonlinear load. If the fuse of one connected phase blown off then the other remaining fuse is in operation under a stress. In this condition the system become unbalanced and it will tends to produce the overvoltage in the system. To summarize above discussion it is concluded that, the following problems arise due to harmonics [29].

- Equipment overheating
- Equipment malfunction or operation failure of equipment
- Equipment failure
- Communications interference
- Fuse and breaker operation failure
- Maintenance problem

To overcome such issues, there are various harmonic mitigation methods that we can use to address harmonics in the distribution system. They are valid solutions depending on circumstances, and have their pros and cons. One of the way out to resolve them using filters [30] . The filters are widely used for reduction of PQ problems with the increase of nonlinear loads in the PS more and more filters are required

.

2.6 Types of power filter

Filter is method to reduce harmonics in an industrial plant when the harmonic distortion has been gradually increased or as a total solution in a new plant. Broadly there are two basic methods: PPF and APF.

2.6.1 Passive power filter (PPF)

It calls passive as it consists of a passive elements such as an inductor and capacitor. Is a typical tuned harmonic filter circuit. Inductor (Lp) and capacitor (C) provides low impedance path for a single (tuned) frequency. An inductor (Ls) is required to detune the filter from the electrical system and other filters' resonance point. This type of filter is very application specific. It can only mitigate a single frequency, and it injects leading reactive current (kVAr) at all times. But it is economical if you only need to deal with a dominant harmonic in the facility. It normally can reach THD target of 20% [31].

2.6.2 Active power filter (APF)

APF have been proven to be an important and flexible alternative to compensate for current and voltage disturbances in power distribution systems (at PCC). The idea of active filters is relatively old, but their practical development was made possible with the new improvements in power electronics and microcomputer control strategies as well as with cost reduction in electronic components. APFs are becoming a viable alternative to PPF and are gaining market share speedily as their cost becomes competitive with the passive variety. Through power electronics, the active filter introduces current or voltage components, which cancel the harmonic components of the nonlinear loads or supply lines, respectively. Different APF topologies have been introduced and many of them are already available in the market [32, 33].

The concept of an APF is to produce harmonic components, which cancel the harmonic components from the non-linear loads. Figure (2.6) illustrates how the harmonic current generated by APF is injecting into the system to cancel harmonic from a VFD load. AHF is a highly-effective device that cancels multiple order harmonics in the distribution system. It is installed as a parallel device and scaled via paralleling multiple units. It can handle different type of loads, linear or non-linear. It addresses harmonics from a system point of view and can save significant cost/space in many applications. Its performance level can meet THD 5% target.

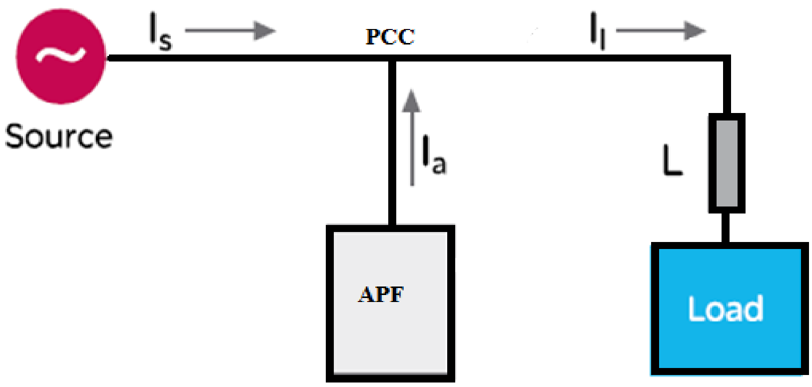


Figure (2.6) shows the connection of APF

The APF present many other advantages over the traditional methods for harmonic compensation such as [34]:

- Adaptation with the variation of the loads
- Possibility of selective harmonics compensation.
- Limitations in the compensation power.
- Possibility of reactive power compensation.

Table (2.2) show Comparison of PPF and APF

Influences of parameters	**passive power filter**	**Active power filter**
Influences of increase in current	Risk of over load damage	No risk of over load damage
Added equipment	Requires modification to the filter	No problems if harmonic current is greater than load current
Harmonic control by filter order	Very difficult	Possible via parameters
Harmonic current control	Requires filter for each frequency	Simultaneously monitors many frequencies
Influence of frequency variation	Reduced effectiveness	No effect
Influence of modification in the impedance	Risk of resonance	No effect
Modification in fundamental frequency	Cannot be modified	Possible via reconfiguration
Dimensions	Large	Small
Weight	High	Low

2.6.2.1 Configuration of (APF)

APF's can be classified based on converter type, topology, and the number of phases [34. 35]. The converter type is mainly two types:

- voltage source inverter (VSI)
- Current source inverter (CSI).

The topology of APF is classified in to three types.

- Series active power filters (Se APF).
- Shunt active power filters (Sh APF).
- Hybrid active power filters (HAPF) .

Finally based on the phases the APF mainly two types:

- Two-wire (single phase) system.
- Three or four wire three phase system.

2.6.2.1.1 Series Active Power Filter (series APF)

The aim of the series APF is to locally modify the impedance of the grid. It is considered as harmonic voltage source which cancel the voltage perturbations which come from the grid or these created by the circulation of the harmonic currents into the grid impedance. However, series APFs cannot compensate the harmonic currents produced by the loads [36.37] figure (2.7) shows Series APF connected to the network.

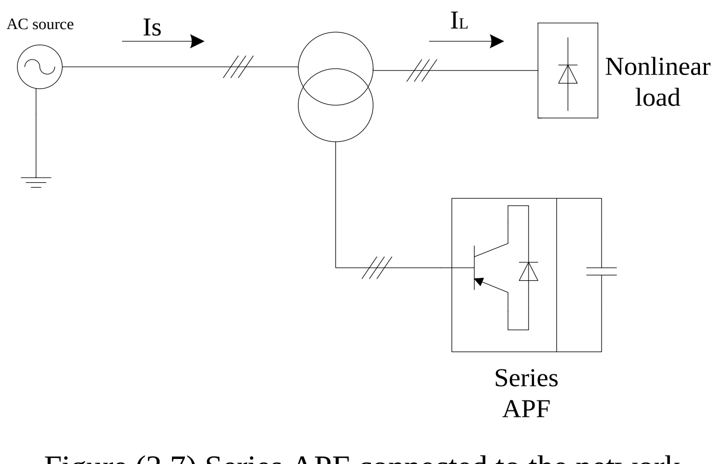


Figure (2.7) Series APF connected to the network

2.6.2.1.2 Shunt Active Power Filter (shunt APF)

The shunt APFs are connected in parallel with the harmonic producing loads. They are expected to inject in real time the harmonic currents absorbed by the pollutant loads. Thus, the grid current will become sinusoidal [36,38. 39].

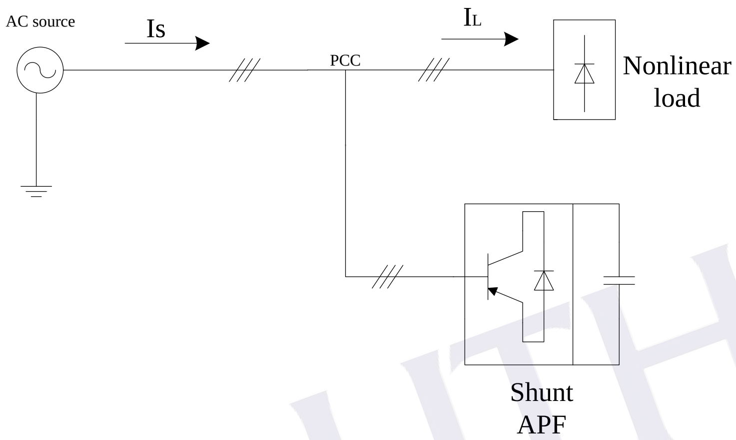


Figure (2.8) Shunt APF connected to the network

2.6.2.1.3 Hybrid Active Power Filter (HAPF)

To reduce the cost of the static compensation, combination of static and PF is called as hybrid APF. The PPF are used to cancel the most relevant harmonics of the load, and the active filter is dedicated to improving the performance of PPF or to cancel other harmonics components. As a result, the total cost decreases without reduction of efficiency. Figure (2.9) and (2.10) shows the usual hybrid topology [40,41].

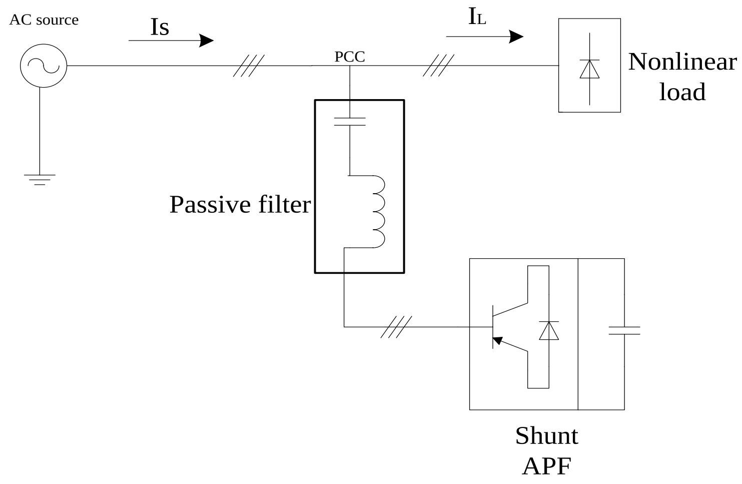


Figure (2.9) Parallel of SAPF and PPF

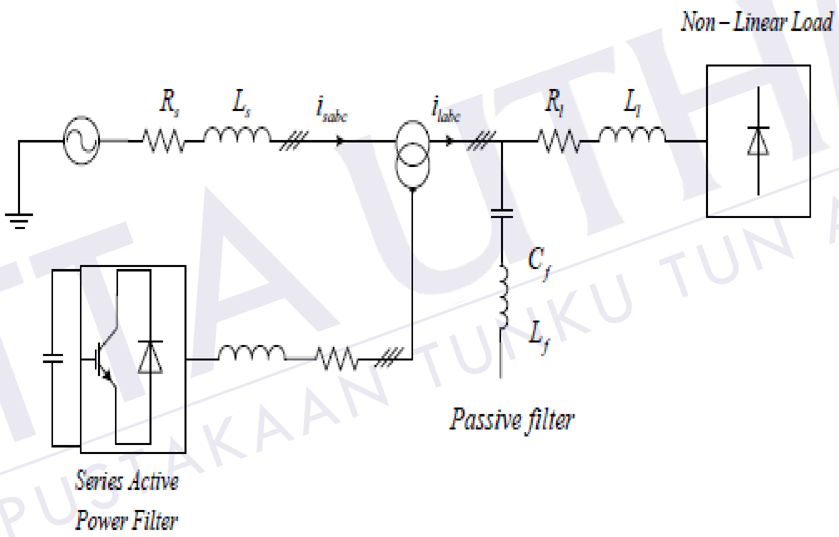


Figure (2.10) Series APF with PPF

2.6.2. Types of Active power Filter

There are three most common types of APF based on cut-off frequency show the compare between them in table (2.3)

- Low pass filter (LPF)
- High pass filter (HPF)
- Band pass filter (BPF)

Table (2.3) shows Comparison of LPS ,HPF and BPF active power filter

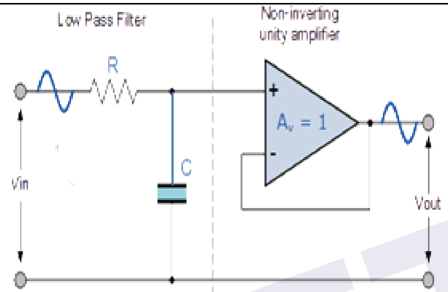
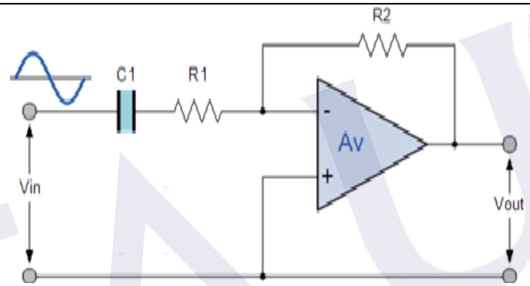
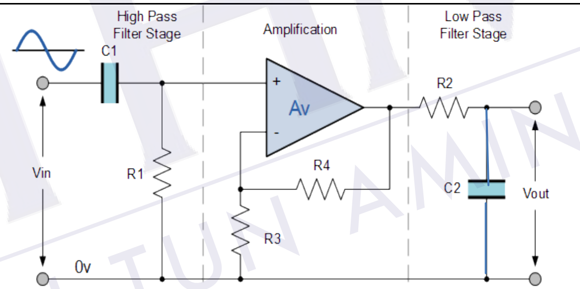
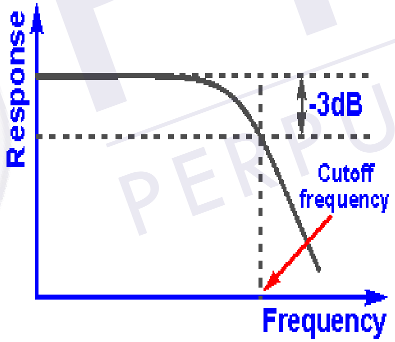
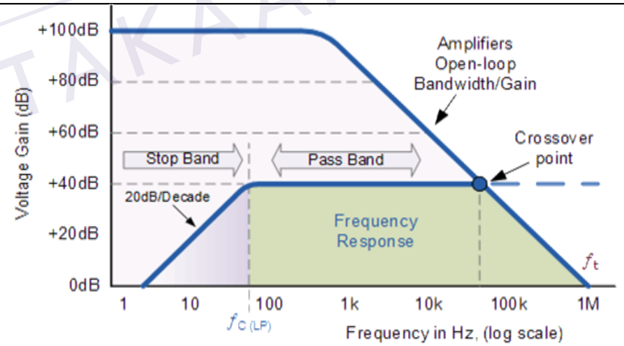
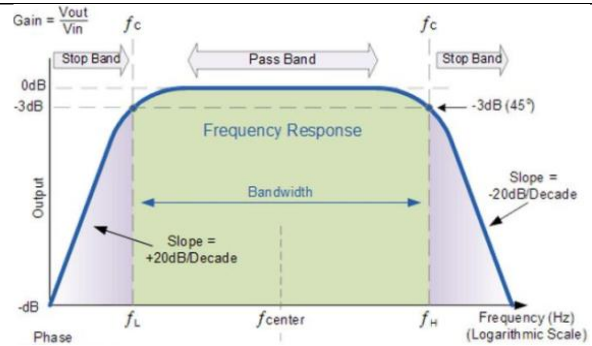
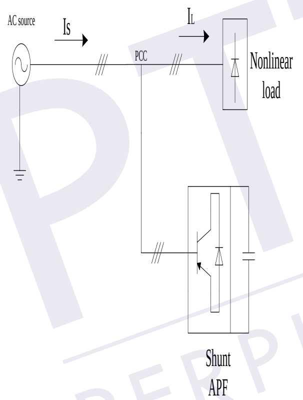
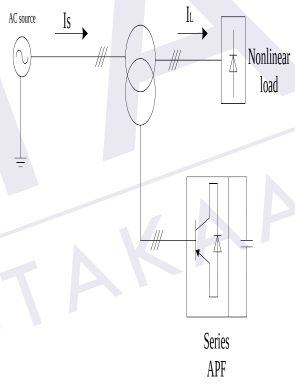
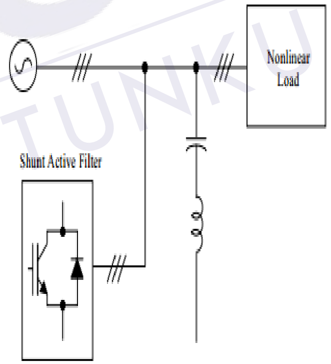
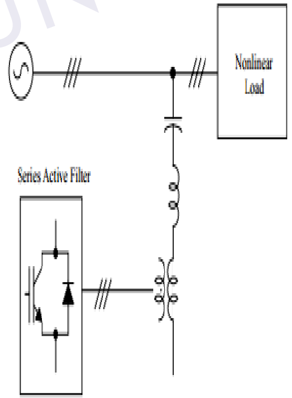
Type	Low pass APF	High pass APF	Band pass APF
Principle	Pass the lower frequencies and reject the high frequencies	the performance of a "high pass filter" at high frequencies is limited by this unity gain crossover frequency which determines the overall bandwidth of the open-loop amplifier. From around 100kHz up to about 1GHz.	This band or range of frequencies is set between two cut-off or corner frequency points labelled the "lower frequency" (f_L) and the "higher frequency"(f_H) while attenuating any signals outside of these two points .
Example Circuit			
Cut-off frequency	$f_c = {}^{1}/_{2\pi RC}$	$f_c = {}^{1}/_{2\pi R_1 C}$	$f_{c1} = {}^{1}/_{2\pi R_1 C}$ / $f_{c2} = {}^{1}/_{2\pi R_2 C_2}$
Gain	$Gain = (1 + \frac{R_2}{R_1})$	$Gain = -{}^{R_2}/_{R_1}$	$Gain = -{}^{R_2}/_{R_1}$
Shape of curve			

Table (2.4) shows compare between the topology of APF

Type of filter	**Shunt APF**	**Series APF**	**Parallel combination of shunt-APF and shunt PF**	**Series combination of series-APF and shunt PF**
Advantage/ disadvantage	• Eliminate current harmonics • Reactive power compensation • Balancing unbalanced current	• Eliminate voltage harmonics • Regulate and balance the terminal voltage • Damp out harmonic propagation	• Harmonic cancellation • Q control • Optimal sharing is needed • Commercialized	• Harmonic cancellation and damping • Series-APF enhanced existing PF • Easy protection is possible • Current Transformer is minimized • No Q control • Under developed
Circuit				

2.7 Previous Research

The table (2.1) below shows the summary from the previous research.

N0	year	Author	Title	Duplication				outcomes	Methodology		Remarks
				journal	VOL	No	PP		Tools	Technique	
1	2014	Priya- et al	Simulation results of a shunt APF using p-q theory power components calculation	IJARC SMS	2	2321-7782	247-254	Shunt APF is reduced THD in surce current at level well below the defined standards (from 30.28% to 0.11%) ,and also mitigate the effect of PFC	Matlab	p-q theory with HCC , PI controlle rs	To consider the effect of zero sequence in the supply voltage
2	2013	Bhakti et-al	Reduction in harmonic distortion of the system using active power filter in Matlab	IJACS MS	3	6	60-64	Explanation about APF to minimizes THD within an acceptable range (from 30.42% to 3.62)	Matlab	modify APF	Need to discuss about reactive power. To provide more cases for PQ Need to obtain reactive power results

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