T.C.
BAHÇEŞEHİR UNIVERSITY

"SHUNT ACTIVE POWER FILTERS BASED ON DIODE CLAMPED MULTILEVEL INVERTER AND HYSTERESIS BAND CURRENT CONTROLLER"

Master's Thesis

AKRAM QASHOU

İSTANBUL 2013

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ABSTRACT

"SHUNT ACTIVE POWER FILTERS BASED ON DIODE CLAMPED MULTILEVEL INVERTER AND HYSTERESIS BAND CURRENT CONTROLLER"

QASHOU, AKRAM

Electrical & Electronics Engineering

Supervisor: Prof. Dr. EMİN TACER

AUGUST, 2013, PAGES 88

In recent years the interest about semiconductors material and its applications was increased, because the power electronic devises are widely used in different applications and practical fields. In another point of view, the growth of power quality problems increased due to the increasing of power electronics equipment such as adjustable speed derive (ASD), programmable logic controller (PLC), electronic lightning and other nonlinear loads.

These loads cause to change the electrical nature of the load. This change will affect mainly the electrical equipment which is sensitive to the power quality problems; this leads to economic losses. The rapid development and growing of power electronics technologies reducing the power quality problems by found semiconductor devices with high speed response to eliminate ripple or having smoothing signals.

Most researchers studied shunt active power filters (APF) based on conventional two-level inverters with conventional controllers requiring a complex and a complicated mathematical model. In order to overcome this problem a hysteresis band controller based diode clamped multilevel inverter is used and extended to an 11- Step two inverters shunt active power filter.

This research will investigate and analyze, the design of hysteresis band controller biasing multi-level inverter to work as shunt active power filter (APF). Making use of the multilevel inverter advantage of less total harmonic distortion and reduced semiconductor ratings compared with conventional inverter.

A three phase 11- Step diode clamped Multi-Level two parallel inverter is to be used as a voltage source inverter (VSI). The Hysteresis band controller determines the optimum switching pattern needed for the inverter to compensate current harmonics and reactive power of the load. A study of its performance through simulation results will be investigated through MATLAB Simulink.

Keywords: Shunt Active power filter (SHAPF), diode clamped Multilevel Inverter (DCMLI), Hysteresis band controller.

ÖZET

“PARALEL BAĞLI AKTIF GÜÇ FILTRESI DAYALI DIYOT TAKILI ÇOK AMAÇLI INVERTÖR VE HISTEREZIS BANT AKIM KONTROLÖRÜ”

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Elektrik – Elektronik Mühendisliği

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Son yıllarda yarı-iletkenler ve uygulamalarına olan ilgi arttı zira güç elektroniği cihazları çeşitli uygulama ve mesleki alanlarda kullanılıyor. Bir başka bakış açısından ise güç kalite problemleri ayarlanabilir hız sürücüsü (AHS), programlanabilir lojik kontrolörü (PLK), elektronik ışıklandırma ile diğer doğrusal olmayan yükler gibi güç elektroniği ekipmanlarındaki artışa dayalı olarak artmıştır.

Söz konusu yükler, yükün elektriksel doğasında değişime yol açar. Bu değişim ise başta güç kalite problemlerine duyarlı olan elektrikli aletleri etkiler bu da ekonomik kayıplara yol açar. Ayrıca güç elektroniği teknolojilerindeki hızlı gelişme ve büyüme, dalgalanmayı önlemek veya süzgeçleme sinyallerine sahip olmak için yarı-iletken cihazların bulunmasıyla güç kalite problemlerini azaltmaktadır.

Çoğu araştırmacı karmaşık bir matematiksel model gerektiren geleneksel kontrolörlere sahip sıradan iki aşamalı invertörlere dayalı paralel bağlı Aktif Güç Filtrelerini (AGF) araştırmıştır. Bu problemin üstesinden gelmek için histerez bant kontrolörüne dayalı diyot sıkıştırılmış çok aşamalı invertör kullanılır ve bir 11-adımlı iki invertör paralel bağlı aktif güç filtresine uzatılır. Bu araştırma çok aşamalı invertörü saptırarak paralel bağlı Aktif Güç Filtresi (AGF) olarak çalışmasını sağlayan Histerez bant kontrolörünü inceleyecek ve analiz edecektir. Çok aşamalı invertörün kullanılması daha az toplam harmonik bozulma avantajını sağlar ve geleneksel invertörlere kıyasla yarı-iletken değerlerini azaltır.

Üç aşamalı 11-adımlı diyot takılı çok aşamalı iki paralel invertör gerilim kaynağı invertörü (GKI) olarak kullanılacaktır. Histerez bant kontrolörü invertörün akım harmonikleri ile yükün reaktif gücünü dengelemesi için gerekli olan en uygun anahtarlama düzenini belirler. Performansının simülasyon sonuçları yoluyla araştırılması MATLAB Simulink yoluyla incelenecektir.

Anahtar Kelimeler: Paralel Bağlı Aktif Güç Filtresi (PBAGF), diyot takılı çok amaçlı invertör (DTÇAI), histerez bant kontrolörü.

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LIST OF ABBREVIATION

A	**Ampere.**
AC	**Alternating Current.**
ANSI	**American National Standard Institute.**
APLC	**Active Power Line Conditioners.**
BW	**Bandwidth.**
DCMLI	**Diode Clamped Multi-Level Inverter.**
DC	**Direct Current.**
DPF	**Displacement Power Factor.**
FFT	**Fast Fourier Transformation.**
HCC	**Hysteresis current Controller.**
IEEE	**Institute Of Electrical And Electronic Engineering.**
kVA	**Kilo Volt Ampere.**
LPF	**Low Pass Filter.**
MLI	**Multilevel Inverter.**
PCC	**Point Of Common Coupling.**
PD-PWM	**Phase Disposition Pulse Width Modulation.**
PF	**Power Factor**
PQ	**Power Quality.**
PU	**Per Unit.**
PWM	**Pulse Width Modulation.**
RMS	**Root Mean Square.**
SHPWM	**Sub-Harmonic Pulse Width Modulation.**
SNPWM	**Sinusoidal Natural Pulse width modulation.**
SVC	**Static Var Compensator.**
TDD	**Total Demand Distortion.**
THD	**Total Harmonic Distortion.**
TPF	**True Power Factor.**
V	**Volt.**

VA	**Volt Ampere.**
VSC	**Voltage Source Converter.**
VSI	**Voltage Source Inverter.**
SDC	**Source direct current**
APF	**Active power filter**
SHAPF	**Shunt active power filter**

LIST OF SYMBOLS

F	**Frequency**
Hz	**Unit of frequency defined as the number of cycles per second**
V	**Symbol for the volt**
A	**Ampere symbol**
S	**Apparent power**
V_{rms}	**Root mean square of voltage**
I_{rms}	**Root mean square of current**
V_1	**The fundamental component of voltage**
I_1	**The fundamental component of current**
h	**Harmonic order**
µ	**Micro(e-6)**
h_{max}	**Maximum harmonic order**
V_h	**Amplitude of voltage at the harmonic component h**
I_h	**Amplitude of current at the harmonic component h**
P	**Active or Real power measured in Watt**
θ_1	**The phase angle between voltage and current at the fundamental frequency.**
Q	**Reactive or Imaginary power measured in Var**
V_{1rms}	**Root mean square of voltage at fundamental frequency**
I_{1rms}	**Root mean square of current at fundamental frequency**
D	**Distortion power measured in Volt-Ampere**
M_h	**RMS value of harmonic component h**
I_c	**Compensation current**
I_s	**Source current**
I_l	**Load current**
L_{load}	**Load inductance**
L_{sorce}	**Source inductance**

$L_{coupling}$	**Coupling or linking inductance**
V_{dc}	**Voltage across the inverter capacitor**
$\alpha,\ \beta$	**α, β transformation , Clark’s transformation**
I_a, I_b, I_c	**Phase A,B and C currents**
V_a, V_b, V_c	**Phase A,B and C voltages**
$p{-}q$	**Instantaneous Reactive Power Theory**
A	**α, β transformation matrix**
$I_\alpha , I_{,\beta}$	**Currents in α,β coordination**
V_α, V_β	**Voltages in α,β coordination**
$I_{\alpha p}, I_{\alpha q}$	**Where**$I_\alpha = I_{\alpha p} + I_{\alpha q}$**, currents in the α plane as function of instantaneous power.**
$I_{\beta p}, I_{\beta q}$	**Where** $I_{,\beta} = I_{\beta p} +, I_{\beta q}$**, currents in the β plane as function of instantaneous power**
$\overline{p}$	**DC component of the instantaneous power p**
$\widetilde{p}$	**AC component of the instantaneous power p**
$\overline{q}$	**DC component of the imaginary instantaneous power q**
$\widetilde{q}$	**AC component of the instantaneous imaginary power q**
${I_{c\alpha}}^*$	**α plane reference current required by the shunt active power filters to compensate**
${I_{c\beta}}^*$	**β plane reference current required by the shunt active power filters to compensate**
${I_{ca}}^*, {I_{cb}}^*, {I_{cc}}^*$	**Compensating currents a, b, c reference frame**
I_0	**Zero sequence current component**
L_r	**Synchronous Link Reactor**
C	**Inverter capacitor**
di/dt	**Current derivative with respect to time**
Van	**Voltage to neutral of phase A**
V_{cmax}	**Maximum voltage across the dc capacitor**
θ_1/w	**Starting time of capacitor charging**
θ_2/w	**Time of decreasing the voltage across the capacitor until** V_{dc}

i_c	**Compensation current by the shunt active power filter**
ΔV	**Voltage difference between V_{cmax} and V_{dc}**
w	**Angular frequency**
i_{sh}	**Harmonic current component flowing through the source**
i_{fh}	**Harmonic current component flowing through the passive filter**
i_h	**Harmonic current**
Z_s	**Source impedance**
Z_f	**Passive filter impedance**
f_r	**Resonant frequency of the passive filter**
Q	**Quality factor of the passive filter**
Y	**Admittance**
$S_{1,2,3,4}$	**Inverter bridge switches**
H1	**H bridge number one**
V_{a1}	**Voltage produced by the first H bridge**
S	**The number of H bridges used per phase**
$\alpha_1, \alpha_{2.}\alpha_s$	**Switching angles**
k_p	**Proportional gain of PI controller**
k_I	**Integral gain of PI controller**
R_s	**Source resistance**
L_s	**Source Inductance**
L_r	**Load inductance**
R_r	**Load Resistance**
C_r	**Load Capacitance**
D	**Distortion power**

1. INTRODUCTION

1.1 OBJECTIVE

(a)-Two inverter Shunt active power filter will be used in this thesis to decrease harmonics in current wave and compensate reactive power of non-linear loads. A control system based on hysteresis band controller with Shunt Active Power Filter (SAPF) is proposed to study the system results and performance.

(b)-Three phase 11- Step Diode Clamped Multi-Level Inverter (DCMLI) proposed as a voltage source inverter instead of other inverters because specification of this type of lowest Total Harmonic Distortion (THD) and 11-Step according to the cost condition. [Harmonics current generation will be used by Diode Clamped Multi-Level Inverter (DCMLI) with the same magnitude of the source current harmonic but in opposite phase]. The DCMLI output will be connected at the point of common coupling of the system in order to avoid or cancel the current source harmonics. Typically, conventional (two and three levels inverters) were used as voltage source inverter (VSI) in the APF. The advantage of DCMLI over the conventional inverter such as, more output voltage levels, less harmonic content, and less switching losses. Therefore, a studying of DCMLI performance through simulation results will be investigated with a non-linear load on this thesis.

(c)-Instantaneous reactive power theory based on proposed system, it will be employed to obtained the reference current of the DCMLI, the theory based on instantaneous values in three-phase power systems with or without neutral wire, and is valid for steady-state or transitory operations, in this theory instantaneous active current (i_p) and instantaneous reactive current (i_q) of three phase system are calculated based on Clark transformation which applied to the voltage and current vectors.

(d)-Hysteresis band controller will be used to optimize the switching pattern of diode clump inverter to compensate harmonic and reactive load currents.

(e)-Analyze the obtained results and compare it with other published results.

MATLAB/Simulink is suitable software used to investigate and integrate the system; the Active power filter system was simulated under Mat lab/Simulink application environment. Simulink is a simulation tool under the environment of Mat lab mathematical computing package in the time domain. Using Simulink detailed equations of the system could be modeled using a wide range of graphical building blocks including control system equations, control system notations, and state-space representations for various models such as control circuit and power-electronic devices. Since Mat lab/Simulink provides full capabilities required for accurate simulation of all test cases in the study.

1.2 BACK GROUND OF PROJECT:

This thesis focused to design and implementing the three phase shunt Active Power Filter (APF) to compensate a typical non-linear load, composed from uncontrolled bridge rectifier loaded with inductive load. The current drawn by the load significantly distorted and contain reactive component. Also the function of the APF is used to minimize the harmonics and improve the source side power factor by compensate the reactive power. Many conventional ways to filter the harmonic resonance as well as to suppress the existence of voltages and current harmonics appear at the customer-utility point of common coupling such as passive filters and active filters. However passive filters implementation could cause resonance effect if it reacts with the system impedance, thus contributing to amplification of harmonic distortion. Moreover, using active filter cause other disadvantages such as switching losses and disability to filter higher harmonic order.

The non-linear loads achieved rapid increase in usage and power electronics equipment usage continues rises. The non-linear loads are one of the main reasons of low power factor due to the harmonics and reactive currents generated in power applications and systems, its leads to low energy efficiency, harmful disturbance to other appliances, and low power capacity. In recent decades due to their flexibility and reliability, the shunt Active Power Filters (APFs) are one of the most common, versatile and efficient solutions in the compensation of the load power factor and reducing current harmonics.

The proposed system represent two inverter Shunt Active filters are connected in shunt with the distribution line and they compensate the harmonics by injecting compensating currents, equal in magnitude but opposite in phase to the disturbances in the system. This eliminates the harmonics in the transmission system and makes the source voltage and source current waveforms sinusoidal regarding to typical waveforms. Depending upon the objective of the SAPF, harmonic compensation can eliminate oscillations in the real power, it can improve power factor or eliminate current harmonics from the distribution system.

1.3 PROBLEM STATEMENT:

The operation of non-linear loads in power system and applications almost creates harmonics currents and harmonics voltages especially in industrial systems. Therefore, the harmonic current and voltage exist at the same frequency where inductive and capacitive of industrial power system are equal, this situation reflected to the harmonic current and voltages and raise it and become much greater.

Industrial system utilization of machinery equipment's involves the increase of inductive reactance which affects in power factor condition. To compensate the problems and founded suitable solution, the power factor capacitor installed by considering system impedance and existing capacitor bank that could lead the resonance effect. In fact, the harmonic resonance need to be controlled when harmonic distortion draw by the non-linear loads exist by the same frequency.

1.4 SCOPE OF PROJECT:

Basically, the scopes of project focus on harmonic resonant effect in an industrial power system. Also the utilization of machinery equipment in industrial power system produces harmonic distortion. On other hand, the installation of such filter is important to avoid permanent damage to the equipment's. To represent the harmonic producing load in industrial power system, a 6-pulse diode rectifier is utilized (to produce the harmonics) and the APF will cancel the harmonics.

The model of installation of active filter is in parallel to the load and in the vicinity of utility-consumer point of the common coupling.

1.5 THESIS ORGANIZATION:

The organization of this thesis consists of seven chapters arranged as follow:

Introduction gives present the background project, problem statement, objective, scope of project and thesis organization.

Power system Quality and harmonic problems (see page 5)

Literature review gives an introduction and short peep on the fundamental aspects of the project, such as: overview, project background, literature review.

Multi-level Inverter (MLI) As Voltage Source Inverter (VSI) (see page 30)

Power circuit topology gives an overview on two inverter Shunt Active Power Filters (SAPFs) ,Series Active Power Filter types in terms of principle of operation, configuration, power circuit topologies and reference current generation, Hysteresis band current control schemes required for correct operation of APFs and Control loop design (PI controller).

Simulation circuits and results gives the simulation results for the performance of SAPF, to reduce harmonics and compensate reactive power for typical non-linear load by using hysteresis current controller. The SAPF system response has been tested under steady state and transient conditions.

Conclusion and future work gives the conclusion of this thesis and planning future work.

2. POWER SYSTEM QUALITY AND HARMONIC PROBLEMS

2.1 INTRODUCTION

Depending on whether you supply or consume electricity, Power quality could be defined according to these two perspectives. Power quality at the generator side defines as the generator's ability to generate power at 50 Hz with little variation, while power quality at the transmission and distribution level refers to the voltage staying within plus or minus 5 percent. In Electric Power Quality defines power quality as "the measure, analysis, and improvement of bus voltage, usually a load bus voltage, to maintain that voltage to be a sinusoid at rated voltage and frequency." The type of equipment being used by the end user affects power quality at the end-user level (Kusko, Thompson, 2007), Electrical Power Systems Quality define a power quality problem as "any power problem manifested in voltage, current, or frequency deviations that results in failure or miss operation of utility or end user equipment(Dugan, McGranaghan, Santosa, Beaty, 2002),

" Nowadays, the power quality is not only defined by the continuity of electricity but also characterized by its main parameters. The frequency and magnitude of the supply voltage, current and voltage harmonics, voltage sags, voltage swells, flicker and phase imbalances are the main parameters of the power quality (IEEE Standards Board "Guide for Harmonic Control and Reactive Power Compensation of Static Power Converters", IEEE Std. 519-1981),

Electronic loads are very sensitive to harmonics, sags, swells and other disturbances. So, power quality has become as important as the continuity of the electricity. In this research the interest will be on the harmonic problems, and how to reduce its effect on the electrical systems.

2.2 WHAT IS POWER QUALITY:

There can be totally different definitions of power quality, depending on one's frame of reference. It is related to the delivery of a sufficiently high grade of electric energy to suit the needs of the equipment's (Dugan, McGranaghan, Santosa, Beaty, 2002),
Another simpler and briefer definition might state: "Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy" (Sankaran, 2002),
In general it involves maintaining a sinusoidal voltage and current at stipulated magnitude, frequency and continuity, and it's sometimes called Quality of Supply.

The power quality disturbance is the change in the power (voltage, current or frequency) that interferes with the normal operation of electrical equipment (Dugan, McGranaghan, Santosa, Beaty, 2002),

2.3 POWER QUALITY IMPORTANCE:

Since the discovery of electricity, the interest to produce and improve the supply was the main goal of electrical engineers. The power quality of electricity has become a strategic issue for electricity companies. The three level of electricity work - operating, maintenance and management personnel- of service sector and industrial sites, in additional to the equipment's manufacturers have been working together for the following main reasons:

(a)- The widespread use of small and sensitive electrical devices due to the proliferation of electronics (Dugan, McGranaghan, Santosa, Beaty, 2002),

(b)-The rapid demands increase in electricity created extensive power generation and distribution grids (Dugan, McGranaghan, Santosa, Beaty, 2002),

(c)-Industries demands become larger and need more shares of the generated power, which, along with the growing use of electricity in the residential sector.

(d)-Monitoring, recording, and continuous analyzing the electric power are available by customers, consultants, and utilities due to the availability of the means. This assists the distribution engineer to determine the nature of the problem and the responsibility for its solution (Dugan, McGranaghan, Santosa, Beaty, 2002),

(e)-The economic necessity for businesses to increase their competitiveness (FERRACCI, 2001),

(f)-The opening up of the electricity market (FERRACCI, 2001),

Therefore, electrical services are no longer independently concern of different electrical utilities; they are part of a huge complex grid formulated from large number of tied utilities network. The combination of these different factors has created complex electrical systems requiring power quality.

Power quality concerns are difficult to quantify because it is examines by the nature of the interaction between power quality and susceptible equipment.

"Good" power for one piece of equipment could be "bad" power for another one. Two identical devices or pieces of equipment from two different manufacturers might react differently to the same power quality parameters due to differences in component tolerance (Sankaran, 2002),

2.4 POWER QUALITY PROBLEMS CAUSES:

There are numbers of “outages” or “glitches’ happened in the power service that the end users may complain but the utility records may indicate no abnormal errors during feeding the customer

Recently, the utility records showed a case where the end-use equipment was knocked off line 30 times in 9 months. However, the utility substation breaker operates only five times. This will definitely proof that there are many events never show up in the utility statistics but resulting in end-user problems. One example is capacitor switching, it is a quite common operation and normal on the utility system, but due to the customer it can cause transient over-voltages that disrupt manufacturing machinery. Another example is briefly voltage sag at the customer side due to a momentary fault elsewhere in the system. This might because an adjustable-speed drive or a distributed generator to trip off, but the utility will have no indication that anything was amiss on the feeder unless it has a power quality monitor installed.” (Dugan, McGranaghan, Santosa, Beaty, 2002),

2.5 GENERAL CLASSES OF POWER QUALITY PROBLEMS:

There are several types of power disturbances that may affect electrical industry. The degree of impact of these types is varied, depending on the magnitude, frequency and duration of the event, as well as the sensitivity of the electrical equipment.

The most common categories of disturbances are:

2.5.1 Impulsive Transient:

An impulsive transient a sudden, no frequency change in the steady-state condition of voltage, current, or both that is unidirectional in polarity. Impulsive transients are normally characterized according to their rise time and its decay time, which can also be shown by their spectral content. As an example, a 1.2 ×50 μs 1000 volt (V) impulsive transient nominally rises from zero to its peak value of 1000 V in 1.2 μs and then decays to half its peak value in 50 μs in case of lightning strike (Dugan, McGranaghan, Santosa, Beaty, 2002), Lightning is considered the most common cause of impulsive transients. [Fuchs, Masoum, 2008],

2.5.2 Oscillatory Transient

An oscillatory transient is a sudden, non–power frequency change in the steady-state condition of voltage, current, or both, that includes both positive and negative polarity values. In oscillatory transient the instantaneous value of a voltage or current changes polarity rapidly. It is described by its spectral content, duration, and magnitude. Back-to-Back capacitor energized and the results in oscillatory transient currents in the tens of kilohertz as illustrated in Fig. 2.1.(Kusko, Thompson, Hill,2006),

As an example for voltage transients Cable switching which results transients in the same frequency range. Medium-frequency transients can also be the result of a system response to an impulsive transient. Distribution system could have oscillatory transients with principal frequencies less than 300 Hz. These are generally associated with zero resonance and transformer energized (Dugan, McGranaghan, Santosa, Beaty, 2002),

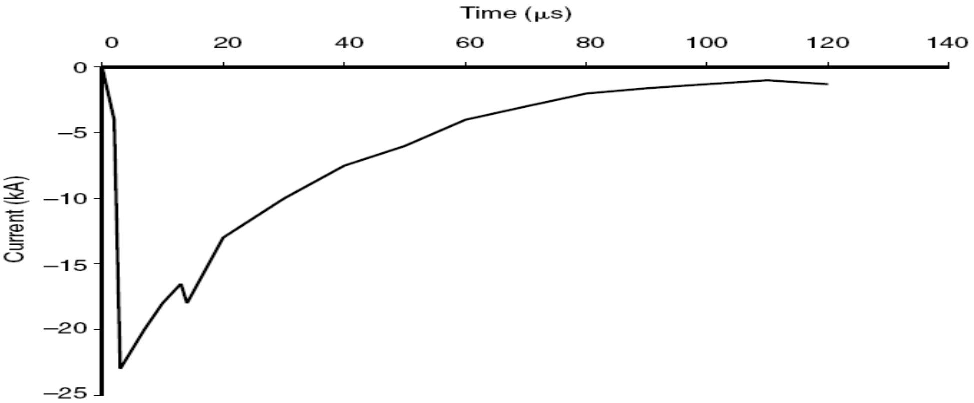


Figure 2.1: Current impulsive transient while lightning stroke [Kusko, Thompson, Hill, 2006],

2.5.3 Short Duration Voltage Variations:

2.5.3.1 Voltage sags (dips):

Voltage Sags can be occurred when RMS value of voltage or current at the power frequency drop in the range 0.1 and 0.9 pu for duration from 0.5 cycles to 1 min. This phenomenon which causes the dropouts of sensitive customer equipment results from local and remote faults figure 2.2 (Dugan, McGranaghan, Santosa, Beaty, 2002),

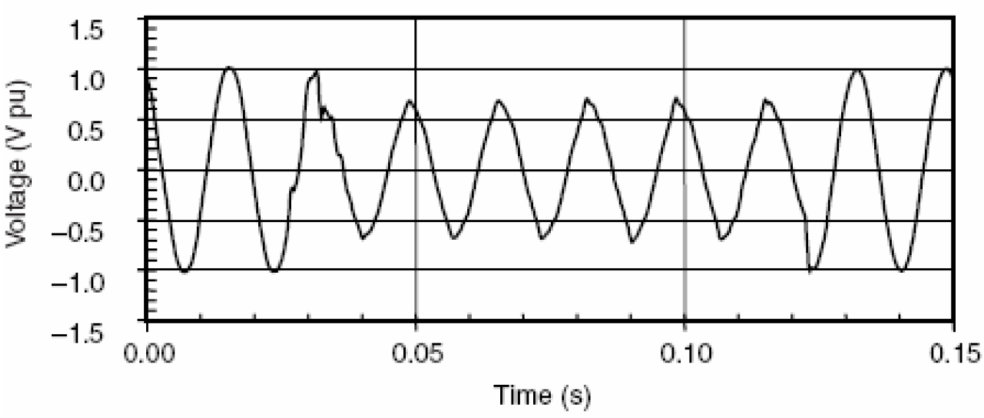


Figure 2.2: Voltage Sag waveform [Dugan, McGranaghan, Santosa, Beaty, 2002],

2.5.3.2 Voltage swells (surges):

Surges are the increase in the RMS values of voltage or current. Technically, Swell is an increase in RMS voltage or current in the range of 1.1 and 1.8 Pu at the power frequency for durations from 0.5 cycles to 1 min. The main cause of this phenomenon, which results in equipment overvoltage and failure, is the single-line-to-ground faults figure 2.3 (Dugan, McGranaghan, Santosa, Beaty, 2002),

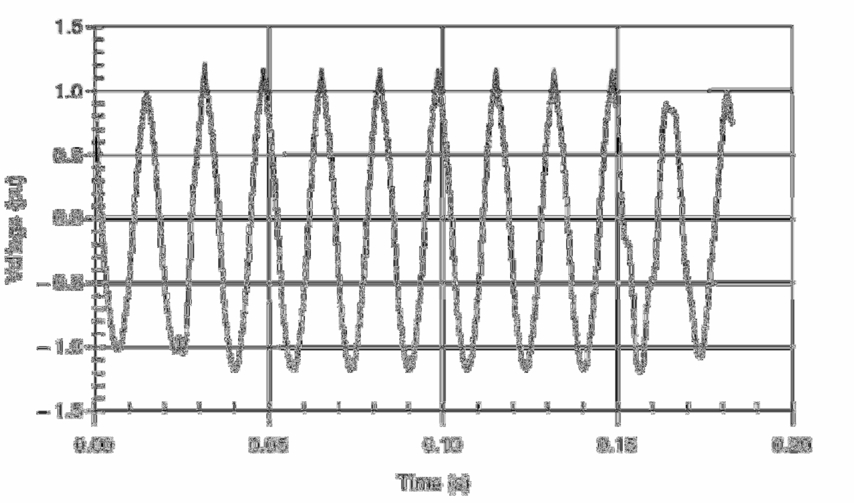


Figure 2.3: Voltage Swell waveform [Dugan, McGranaghan, Santosa, Beaty, 2002],

2.5.4. Long Duration Voltage Variation

The main types of this phenomenon are:

2.5.4.1 Overvoltage:

It is any increase greater than 110 percent in the RMS value of AC voltage at the same power frequency longer than 1 min. Load switching used to be the cause of over voltages (e.g., switching off a large load or energizing a capacitor bank). Incorrect tap settings on transformers can result in system over voltages. Weakness of Power system such it can't achieve the desired voltage regulation and the unsuitable voltage control system are also two causes of the over voltages. (Dugan, McGranaghan, Santosa, Beaty, 2002),

2.5.4.2 Under voltage:

Due to the use of voltage regulation equipment in the power system utilities, the voltage must kept in desired level. But under voltage occurs when the RMS value of the AC voltage at the same power frequency decrease to less than 90 percent longer than 1 min. Switching events that are the opposite of the events that cause over voltages is also causes under voltages. For example switching a load on or switching off a capacitor bank can cause an under voltage until voltage regulation equipment on the system can bring the voltage back to within tolerances. Overloaded circuits can result in under voltages also.

The term brownout is often used to describe sustained periods of under voltage initiated as a specific utility dispatch strategy to reduce power demand. Because there is no formal definition for brownout and it is not as clear as the term under voltage when trying to characterize a disturbance, the term brownout should be avoided (Dugan, McGranaghan, Santosa, Beaty, 2002),

2.5.5. Interruptions:

Interruptions are a special case of voltage drop to a few percentage of Vref (typically within the range 1-10 %). Interruptions characterized by only one parameter: the duration. Short and long interruptions are two types depend on their duration. Short interruption duration is less than one minute (extended to three minutes depending on network operating conditions). Short interruption usually occurs from tripping and automatic enclosure of a circuit breaker designed to avoid long interruptions which have longer duration. Long and Short interruptions types differ in firstly: their origins and secondly: the solutions required preventing or reducing their occurrence figure 2.4 (Undeland, 2006),

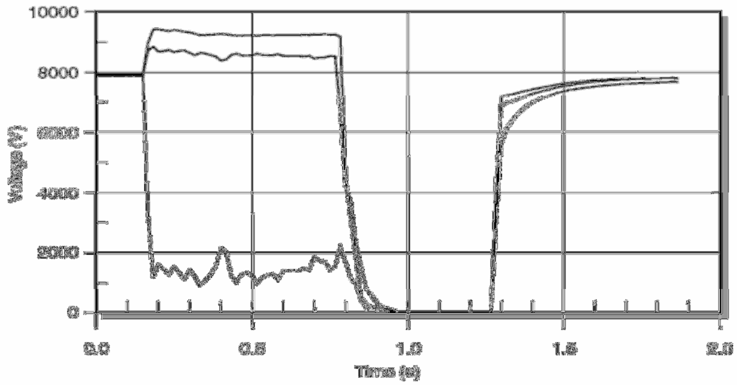


Figure 2.4: 3-Ø RMS voltages for short interruption due to a fault and recovery operation [Undeland, 2006],

2.5.6 - DC Offset:

This term refers that the AC power system has a DC voltage or current. This can occur as the result of a geomagnetic disturbance or asymmetry of electronic power converters. For example, diodes exist in the Incandescent light bulb life extenders that work as half-wave rectification to reduce the RMS voltage supplied to the light bulb. Direct current in ac power system can have a harmful effect to the transformer cores so they saturate in normal operation. This causes additional heating and loss of transformer life. Electrolytic erosion of grounding electrodes and other connectors is another result of direct current (Dugan, McGranaghan, Santosa, Beaty, 2002),

2.5.7 – Notching:

Notching is defined as a continuous and cyclic disturbance in voltage caused when current is commutated from one phase to another during the normal operation of power electronic devices. Notching features are continuous and occurs periodically, so it can be characterized through the harmonic spectrum of the affected voltage. The frequency components associated with notching can be quite high and may not be readily characterized with measurement equipment normally used for harmonic analysis. Three-phase converter produces a continuous dc current is one example of voltage notching, See figure 2.5 (Baggini , West Sussex PO19 8SQ),

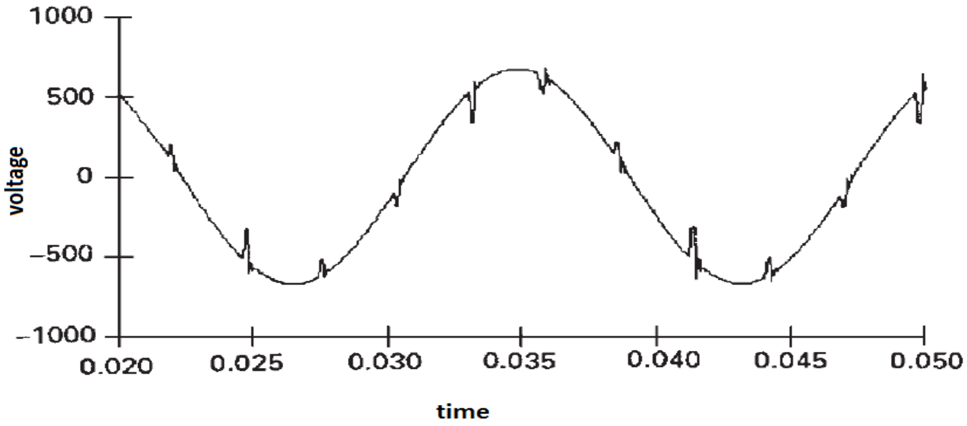


Figure 2.5: Three-phase converter create voltage notching [Baggini , West Sussex PO19 8SQ]

2.5.8 Voltage Fluctuation (Flicker):

Voltage fluctuations are the continuous random change and the periodic or random variation in voltage frequency and magnitude. Welding machines, arc furnaces and rolling mills are example of voltage fluctuations sources due to rapidly varying industrial loads (FERRACCI, 2001).

Human eye perceived the flicker on lamps as impact of the voltage fluctuation. This is due to continuous, rapid variations in the load current, specially the reactive component. This phenomenon, which leads to lighting flicker and disoperation of sensitive loads, results from the arc furnaces and the intermittent loads figure 2.6 (Dugan, McGranaghan, Santosa, Beaty, 2002),

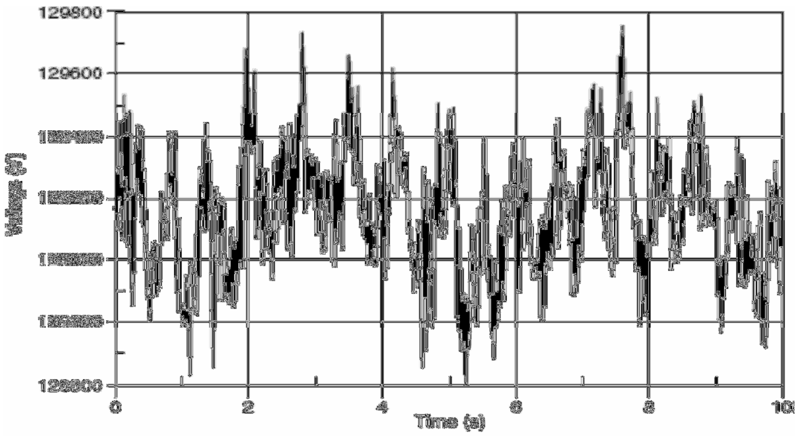


Figure 2.6: Voltage fluctuations- rapid and random change – as result of arc furnace [Dugan, McGranaghan, Santosa, Beaty, 2002]

2.5.9 Unbalance:

If the RMS values of the phase voltages or the phase angles between consecutive phases are not equal then a three phase system is unbalanced. The unbalance degree of the three phase system is defined using the Fortes cue components, comparing the negative sequence component (V2A) (or zero sequence component (V0A)) of the fundamental to the positive sequence component (V1A) of the fundamental.

$$\Delta \text{ V2} = \frac{V2}{V1} \times 100\% \tag{2.1}$$

$$\Delta \text{ V0} = \frac{V0}{V1} \times 100\% \tag{2.2}$$

Due to the voltage drops along the power system network impedances, the negative sequence -or zero sequence- voltage is produced due to negative sequence (or zero sequence) currents created by unbalanced loads which in turn lead to non-identical currents on the three phases (Line to neutral LV loads, or single or two-phase MV loads i.e. induction furnaces and welding machines). Unsymmetrical faults (two phase and single phase faults) produce turbulence and unbalance till the protective devices work and trip off (Dugan, McGranaghan, Santosa, Beaty, 2002),

2.5.10 Harmonics:

Harmonics of a wave is a component frequency of the origin signal - sinusoidal voltages or currents- that is an integer multiple (where n is the order of harmonic) of the fundamental frequency which the supply system is designed to operate (usually 50 or 60 Hz). Periodically distorted waveforms can be decomposed into a sum of the fundamental frequency and the harmonics.

The nonlinear characteristics on the power system loads and devices are results of the Harmonic distortion. Harmonic distortion levels are described by the complete harmonic spectrum with magnitudes and phase angles of each individual harmonic component. A single quantity is the common to use, where the total harmonic distortion (THD), measure the effective value of harmonic distortion. (Dugan, McGranaghan, Santosa, Beaty, 2002).

Harmonics is an integer multiple, so the first harmonic is the fundamental frequency (50 or 60 Hz). The second harmonic is the part has a frequency two times the fundamental (100 or 120 Hz) and so on, see Fig.2.7 (Baggini, Wiley, Ltd. The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ). According to the definition the harmonic distortion is a sort of pollution of the electric system. If theses harmonics accumulate to exceed a certain limits, serious problems could be occurring. The utilization of electrical power mainly depends upon supply of power at nominally constant levels. So to convert nominal frequency to variable frequency power electronics circuitry (non-linear loads) is needed, which distorts the voltage and current waveforms. Consequently, the nonlinear loads exists in the power system is the main source of harmonics figure 2.7 (Baggini, Wiley, Ltd. The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ),

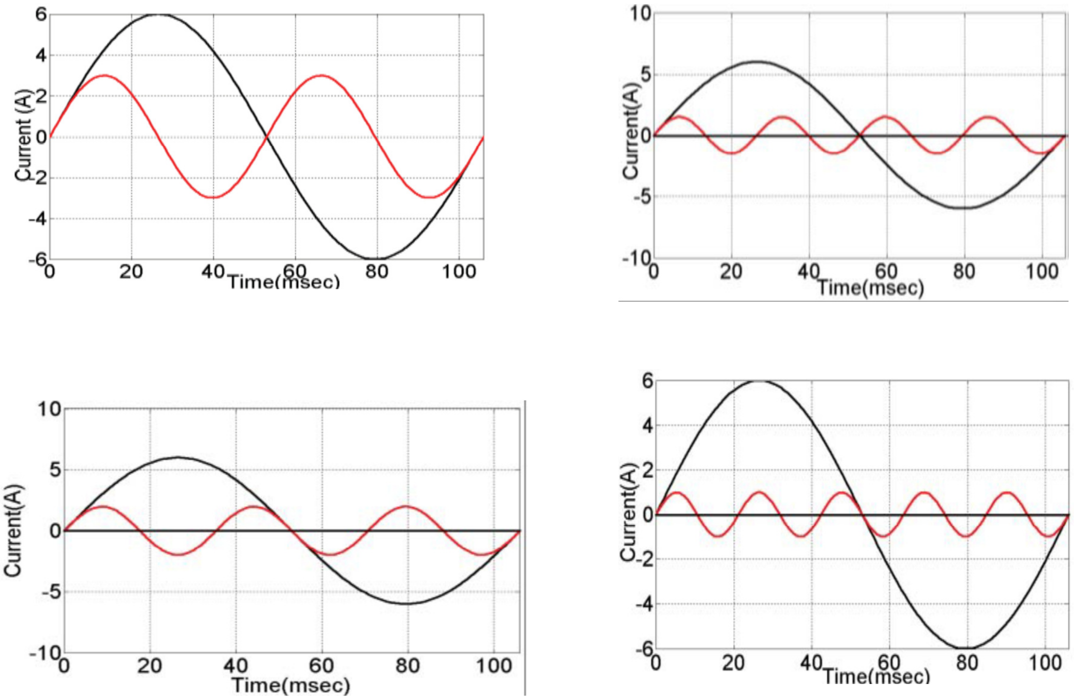


Figure 2.7: Harmonics of a sinusoidal waveform having fundamental frequency of 50 Hz: (a) second (100 Hz); (b) third (150 Hz); (c) fourth (200 Hz); (d) fifth (250 Hz)

2.6 HARMONICS AS A POWER QUALITY PROBLEM:

Harmonic in the electrical system is one of the challenging problems in power quality aspects. Harmonics are qualitatively term which are sinusoidal waveforms having frequencies that are numeral multiples of the power frequency. Harmonics is a term describes the distortion for voltage or current waveforms generally; harmonics divided into two types:

1) Voltage harmonics.

2) Current harmonics.

Usually the type of the loads such as resistive load, inductive load and capacitive load determine the harmonics which generated in voltage supply. Both types of harmonics can be generated by either the source or the load side. The source harmonics are mainly created by non-sinusoidal voltage waveform power supply. On the other hand, load harmonics are result of nonlinear operation of devices, arc-furnaces, power converters, and gas discharge of the lighting devices, etc. Overheating the iron cores of the motors and transformers is an impact of the load harmonics.

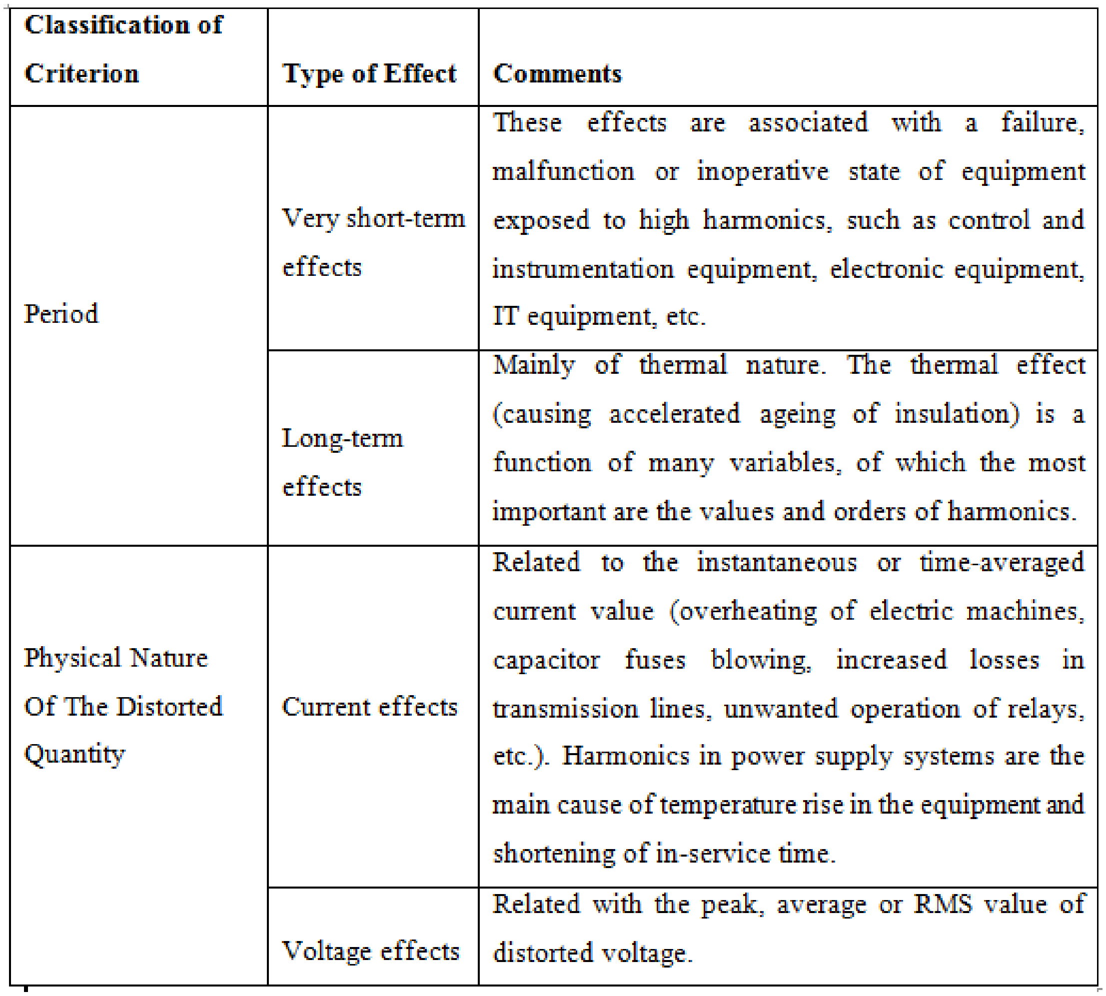
Power losses, Electromagnetic Interference (EMI) and exciting torque in AC motor drives are caused by Voltage and current source harmonics. Harmonic distortion can have detrimental effects on electrical distribution systems. It can waste energy and lower the capacity of an electrical system. However understanding the problems related with sources and effects of harmonics as well as the methods to reduce the harmonic will increase the overall efficiency of the distribution system.

Due to the importance of the harmonics quantity, several methods to indicate of the quantity of harmonics contents are used. In North America, The most widely used method is the total harmonics distortion (THD)(Johan, Frederik S, IEEE Transactions on Power Electronics, Vol.3, July, 1988, pp.297-302),

Sensitivity of loads – also for power sources- determined the voltage or current distortion limits, which are influenced by the distorted quantities. Heating the equipment of any kind is the least sensitive affect. The electronic devices which designed assuming ideal sinusoidal fundamental frequency voltage or current waveforms are the most sensitive kind. The most popular loads are the electric motors which are situated between these two categories (Ranjan Prusty, 2011),

As an example the effects classification of the high harmonics is given in Table (2.1) (Ranjan Prusty, 2011),

Table 2.1: Effects of current and Voltage Harmonics



Classification of Criterion	Type of Effect	Comments
Period	Very short-term effects	These effects are associated with a failure, malfunction or inoperative state of equipment exposed to high harmonics, such as control and instrumentation equipment, electronic equipment, IT equipment, etc.
	Long-term effects	Mainly of thermal nature. The thermal effect (causing accelerated ageing of insulation) is a function of many variables, of which the most important are the values and orders of harmonics.
Physical Nature Of The Distorted Quantity	Current effects	Related to the instantaneous or time-averaged current value (overheating of electric machines, capacitor fuses blowing, increased losses in transmission lines, unwanted operation of relays, etc.). Harmonics in power supply systems are the main cause of temperature rise in the equipment and shortening of in-service time.
	Voltage effects	Related with the peak, average or RMS value of distorted voltage.

2.7 SOURSEC OF HARMONICE:

There are many sources of voltage and current harmonics. These sources are surely different and come from many objects and devices, but we must mention that during the generation of the voltage waveform, it contains a small amount of harmonic distortion. The main reasons of the distortion in the generation period are the excitation magnetic field is not uniformly distributed. The second reason is the discrete spatial distribution of coils around the generator stator slots. However, this type of harmonic distortion source is usually very small, we will mention here some of these causes (Dugan, McGranaghan, Santosa, 2002), (Rosa, Francisco C, 2006), Firstly the current harmonics causes are:

1-Solid state phase converters

2-Adjustable speed drives.

3-Large power supplies.

4-Computer and data-processing loads.

5-Electronic analyzers.

6-Electronic lighting.

7-Magnetic core equipment.

8-Arc furnaces, Arc welders.

9-High-pressure discharge lamps.

10-Switched Mode Power Supplies.

In general all non-linear loads cause harmonic distortion, the voltage harmonics causes are due to:

1. Impedance voltages associated with the various power distribution equipment's, such as transmission and distribution lines, transformers, cables, buses, and so on.
2. Uninterruptible Power Supply (UPS) systems.

2.8 HARMONIC INDICES:

The Total Harmonic Distortion (THD) and the Total Demand Distortion (TDD) are the most two used indices to measure the harmonic content of a waveform. THD and TDD measure the effective value of a waveform and could be used to either voltage or current.

2.8.1 Total Harmonic Distortion (THD):

It is a complex term and cause huge confusing to grasp. TDH is defined as the summation of all harmonics in a system. However, it becomes much easier to understand returning back to the basic definitions of harmonics and distortion, Harmonics characterized as integer multiples of the waveform's fundamental frequency (Lundquist, Johan, 2001),

An example of a waveform with fundamental frequency of 50Hz, have the 2nd, 3rd, 4th and 5th harmonic components. These components frequencies will be 100Hz, 150Hz, 200Hz and 250Hz respectively. Therefore, these harmonic elements collate to deviates the waveform from its pure sinusoidal values to determine the level of the harmonic distortion. Zero harmonics only exist in the ideal sine wave. In that case, perfect wave can't be distorted.

$$\textbf{THD V} = \frac{\sqrt{\sum_{n=2}^{\infty}(V(n)^2)}}{V(1)} \times 100\ \% \tag{2.3}$$

$$\textbf{THD I} = \frac{\sqrt{\sum_{n=2}^{\infty}(I(n)^2)}}{I(1)} \times 100\ \% \tag{2.4}$$

From the above two equations the percentage total harmonic distortion is calculated, and the resulted values denotes to the harmonic component of the signal fundamental component. The more of harmonic contents in the main signal is the higher percentage (Lundquist, Johan, 2001),

2.8.2 Total Demand Distortion:

As has been described, total harmonic distortion (THD) characterized the current distortion levels, but this can often be misleading. High THD exists in a small current wave may not act as significant threat to the system. One example is high THD values for the input current when operating many types of adjustable-speed drives at very light loads. In this case, the magnitude of harmonic current is low so it is not necessarily a significant concern, even though it's high relative current distortion. By referring THD to the fundamental of the peak demand load current rather than the fundamental of the present sample is a try by some analysts to avoid this difficulty and known as total demand distortion (TDD) . TDD considers the IEEE Standard 519-1992 basis guidelines, Harmonic Control in Electrical Power Systems Recommendation Practices and Requirements. It is defined as follows:

$$TDD = \frac{\sqrt{\sum_{h=2}^{h_{max}} I_h{}^2}}{I_l} \tag{2.5}$$

$I_l$is the maximum load current at the fundamental frequency measured at the point of common coupling (PCC).

2.9 POWER FREQUENCY VARIATIONS:

This occurs when the power system fundamental frequency deviates from its specified rated value (e.g., 50 or 60 Hz). The main causes of this phenomenon are: bulk power system faults, poor speed regulations of generation unit, disconnecting a large block of load, and source of generation being disconnected which leads to equipment failure (Dugan, McGranaghan, Santosa, Beaty, 2002),

2.10 POWER FACTOR CORRECTION:

2.10.1 Need For Power Factor Correction And Solutions:

With most electronic equipment being connected to the electricity distribution network, the non-sinusoidal input line current drawn by this equipment due to input line rectification generates current harmonics that causes severe problems. And due to the unbalance loading overheating of transformers and induction motors is a result of the increased magnitudes of neutral currents in three-phase systems. This creates the need for some kind of power Conditioning Thus, the need to vanish the harmonic content of line currents drawn by electronic equipment connected to the electricity distribution networks, results in the need for Power Factor Correction – PFC.

2.10.2 Definitions:

Ratio of the average real power -P (Watt) - to the apparent power -S (VA) - to feed a load from an AC source is the definition of Power factor. For an ideal periodic (sinusoidal) input voltage source, the power factor may be calculated as the product of the distortion power factor and the displacement power factor, equation (2.6). The distortion power factor K_d as shown in equation (2.7) is the ratio of the fundamental RMS current (I_{rms} (1)) to the total RMS current (I_{rms}). The displacement power factor K_θ as shown in equation (2.8) is the cosine of the displacement angle (phase angle) between the fundamental input voltage and the input current (Lundquist, Johan, 2001),

$$PF = KdK\theta \tag{2.6}$$

$$Kd = \frac{Irms(1)}{Irms} \tag{2.7}$$

$$K\theta = \cos\theta \tag{2.8}$$

Where:

Kd: distortion power factor

Kθ : displacement power factor

It is a difficult operation to make the distortion power factor Kd unity. However, by adding a capacitors or inductors to the network the displacement power factor Kθ can be made unity.

A non-unity power factor converter means that the apparent power that converter absorbed is higher than the real power it consumes. Consequently, the apparent power VA rating of the source higher than what the load needs. Furthermore, the power quality of the source deteriorates by the harmonics in current waveform which generated by the converter and eventually affects other equipment. (Lundquist, Johan, 2001),

There is no solid or direct relation between having excellent power factor value and low harmonics. The total harmonic distortion (THD) and power factor is related together according to the following equations.

$$\textbf{THD}\ (\%) = \sqrt{\frac{1}{Kd^2} - 1} \times 100\% \qquad \textbf{(2.9)}$$

$$\textbf{Kd} = \frac{1}{\sqrt{(\frac{THD(\%)}{100})^2 + 1}} \qquad \textbf{(2.10)}$$

Kd : distortion power factor

Hence, when the fundamental input voltage and fundamental input current are in phase, Kθ = 1. The equation would be,

$$\textbf{PF = Kd K}\theta\ \textbf{= Kd} \qquad \textbf{(2.11)}$$

Substituting (2.10) in (2.11), we have

$$\textbf{PF} = \frac{1}{\sqrt{(\frac{THD(\%)}{100})^2 + 1}} \qquad \textbf{(2.12)}$$

Moreover, a perfectly sinusoidal current could also have a poor power factor if its phase was not in line with the voltage. The specifying limits for each of the harmonics will help in the control of input current "pollution" better, both from the standpoint of minimizing the circulating currents and reducing the interference with other equipment.

So, while the process of shaping this input current is commonly called "power factor correction," the measure of its effectiveness towards complying with international regulations is the amount of reduction in input current harmonics (Undeland, Basu,2006),

2.10.3 Capacitor Bank:

Loads require actual power (kW) as well as magnetizing current characterized as Reactive power (kVAR) is needed to operate the majority of inductive loads i.e. transformers, Induction motors, and many other electrical. Representing these power components on a right power triangle, the right triangle rule give the apparent power (KVA) equation as:

$$KVA^2 = KW^2 + KVAR^2 \tag{2.13}$$

Shorten the line that represents the kVAR, technically performed by adding capacitor banks; will reduce the kVA needed for the load.

The capacitors help the utility relieve the burden of loading the extra kVAR when supplying right amount of kVAR to the load. As a result, the transmission/distribution system of the utility will reduce the cost of the utility and the customers and so the utility work efficiently, (Undeland, Basu, 2006).

2.11 POWER SYSTEM QUANTITIES UNDER NON-SINUSOIDAL CONDITIONS:

Reactive power, active power and apparent power are the traditional power quantities i.e. RMS power. In additional to power factor, all these quantities are defined for the fundamental frequency context in a pure sinusoidal condition. In case of harmonic distortion exist; the sinusoidal condition operation case does no longer exist. In this situation, unfortunately, many of the power engineer's simplifications, equations and assumptions used for the pure wave with fundamental frequency do not apply.

2.11.1 Apparent Power:

The product of the RMS current and RMS voltage is the definition of apparent power S [Volt-Ampere (VA)]. The apparent power (VA) applies to sinusoidal and non-sinusoidal wave conditions. The apparent power equation is given as follows:

$$S=V_{rms} \times I_{rms} \tag{2.14}$$

Where

I_{rms} : The RMS value of the current.

V_{rms} : The RMS value of the voltage.

The current or voltage waveforms contain only the fundamental frequency component is the sinusoidal condition; hence, the RMS values would be written as follows:

$$\boldsymbol{V_{rms}} = \frac{1}{\sqrt{2}} \times \boldsymbol{V_1} \qquad \textbf{(2.15)} \qquad \textbf{and} \qquad \boldsymbol{I_{rms}} = \frac{1}{\sqrt{2}} \times \boldsymbol{I_1} \qquad \textbf{(2.16)}$$

Where:

$\boldsymbol{I_1}$: The amplitude of current waveform.

$\boldsymbol{V_1}$: The amplitude of voltage waveform.

Quantities in the fundamental frequency are declared by the subscript “1”. In a non-sinusoidal condition a harmonically distorted waveform is made up of sinusoids of harmonic frequencies with different amplitudes .The RMS values of the waveforms are computed as the square root of the sum of RMS squares of all individual components.

$$\boldsymbol{V_{rms}} = \sqrt{\sum_{h=1}^{h_{max}} \left(\frac{1}{\sqrt{2}} \boldsymbol{V_h}\right)^2} = \frac{1}{\sqrt{2}} \sqrt{\boldsymbol{V_1}^2 + \boldsymbol{V_2}^2 + \boldsymbol{V_3}^2 + \cdots + \boldsymbol{V_{h_{max}}}^2} \qquad \textbf{(2.17)}$$

$$\boldsymbol{I_{rms}} = \sqrt{\sum_{h=1}^{h_{max}} \left(\frac{1}{\sqrt{2}} \boldsymbol{I_h}\right)^2} = \frac{1}{\sqrt{2}} \sqrt{\boldsymbol{I_1}^2 + \boldsymbol{I_2}^2 + \boldsymbol{I_3}^2 + \cdots + \boldsymbol{I_{h_{max}}}^2} \qquad \textbf{(2.18)}$$

Where $\boldsymbol{V_h}$and $\boldsymbol{I_h}$are the amplitude of a waveform at the harmonic component h. In the sinusoidal condition, harmonic components of $\boldsymbol{V_h}$and $\boldsymbol{I_h}$are all zero, and only $\boldsymbol{V_1}$ and $\boldsymbol{I_1}$ remain.

2.11.2 Active Power:

The active power P is also commonly referred to as the average power, real power, or true power. It represents useful power expended by loads to perform real work, i.e., to convert electric energy to other forms of energy. Real work performed by an incandescent light bulb is to convert electric energy into light and heat. Real work is performed for the portion of the current that is in phase with the voltage. No real work will result from the portion where the current is not in phase with the voltage. Active power measured in watts and can be computed by averaging the product of the instantaneous voltage and current (Lundquist, Johan, 2001),

$$\boldsymbol{P} = \frac{1}{T}\int_0^T \boldsymbol{v(t)i(t)dt} \qquad \textbf{(2.19)}$$

Equation (2.19) is valid for both sinusoidal and non-sinusoidal conditions. For the sinusoidal condition, P resolves to the familiar form:

$$P = \frac{V_1 I_1}{2} \cos\theta_1 = V_{1rms} I_{1rms} \cos\theta_1 = S \cos\theta_1 \tag{2.20}$$

Where $\theta_1$the phase angle between voltage and current at the fundamental frequency is in the non-sinusoidal case, the computation of the active power must include contributions from all harmonic components; thus it is the sum of active power at each harmonic. Furthermore, because the voltage distortion is generally very low on power systems (less than 5 percent), Eq. (2.20) is a good approximation regardless of how distorted the current is.

2.11.3 Reactive Power:

The reactive power is a type of power that does no real work and is generally associated with reactive elements (inductors and capacitors). Appearing Power across the inductance moves back and forth between the inductance itself and the power system source, producing no net or effective work. For this reason it is called imaginary or reactive power since no power is dissipated or expended. It is expressed in units of vars. In the sinusoidal case, the reactive power is simply defined as:

$$Q = S \sin\theta_1 = \frac{V_1 I_1}{2} \sin\theta_1 = V_{1rms} I_{1rms} \sin\theta_1 \tag{2.21}$$

Which it is the portion of power in quadrature with the active power shown in Eq. (2.21) there is some disagreement among harmonics analysts on how to define Q in the presence of harmonic distortion. The reactive components actually sum in quadrature (square root of the sum of the squares). This has prompted some analysts to propose that Q be used to denote the reactive components that are conserved and introduce a new quantity for the components that are not conserved. Many call this quantity D, for distortion power or, simply, distortion volt-amperes. It has units of volt-amperes, but it may not be strictly appropriate to refer to this quantity as power, because it does not flow through the system as power is assumed to do. In this concept, Q consists of the sum of the traditional reactive power values at each frequency. D represents all cross products of voltage and current at different frequencies (Lundquist, Johan, 2001),

$$Q = \sum_k V_k I_k \sin\theta_k \tag{2.22}$$

$$D = \sqrt{S^2 - P^2 - Q^2} \tag{2.23}$$

3. LITERATURE REVIEW

3.1 LITERATURE REVIEW:

The power quality problem was as old as electrical system, but the interest in these problems starts from thirty years only. However, the use of active power filters has started only in the last twenty years. There are some of researches in this field in the last two decades are summarized as follows:

A distributed active filter system (DAFS) was discussed by (Po-Tai Cheng and Zhung-Lin Lee.2004), to alleviate power systems harmonic distribution. Multiple active filter units of the DAFS are proposed to install on the same location or different locations within the power system. In order to reduce the power lines voltage harmonic distortion, the active filter units of the proposed DAFS cooperate without any communication among them. They reduce voltage harmonics by work like a harmonic conductance. A controller of each unit is programmed by droop relationship between the volt-ampere of the active filter unit and the harmonic conductance so multiple active filter units can share the workload of harmonic filtering. The volt-ampere rating of the active filter unit decides the slope of the relation in order to evenly distribute the workload according to the each unit rated capacity. The distributed deployment of active filter units also shows that they can effectively improve the power lines voltage THDs more than installing active filter in the radial system terminals.

The converter absorbed a current rich in harmonics. This would disrupt the network and the consumers joined at the same node will influences. Several techniques used including active filtering and/or passive, to minimize the harmonics of side network. (M. T. Benchouia, M.E.H. Benbouzid, A.Golea, S.E.Zouzou, 2007), have discussed these techniques. Adaptive controller Referenced by The Fuzzy Model is used to minimize the converter harmonics of the side network, including the DC-link voltage and power factor control. The result shows the line current wave is approximately sinusoidal. They found that, the system has adequate dynamic response to load variation according to the rapid change of the line current results. Also they found that any external disturbance has not affected the reactive power. Also the study ends with the result that the increasing or decreasing of step load torque determines the sign of the Input real power peaks.

(Y.Qu, W.Tan, Y.Dong and Y.Yang, 2007), discussed that the accurate current reference is needed to successful control of active filter. However the conventional detecting method for harmonic currents has various limitations. They found that, the conventional adaptive filter for APF has some shortcoming.

(Tain-SyhLuor, 2000), discussed characteristics of harmonic voltage source and harmonic current source are investigated by experimental simulation. a laboratory 110KVA six-pulse rectifier loads, one 50KVA active filter, and six-step 54KVAR passive filter has been constructed. The diode rectifier with DC link inductor behaves as a source of harmonic current because the system condition has no effect on current harmonic. The DC link capacitor of the rectifier behaves as source of harmonics in voltage because the system conditions have great influence on current harmonics and the system impedance has weak relation on the rectifier voltage.

Harmonic current-source load generates the harmonics and by using both of the shunt passive filter and shunt active filter this harmonics can be compensated. Passive filter is not recommended to use because the system impedance strongly determined the performance of passive filter and it may cause resonance problem, and so, the active filter is more attractive**.**

If the harmonic of the voltage source load compensated by using shunt passive filters or shunt active filters, an over current problems may occurs due to the amplification of the load current. The active filter capacity may be the same or larger than that of the load**.** Hence**,** it is neither practical nor economical to use shunt active filter to compensate harmonic voltage source**.** The power factor improvement is the determinant of the capacity of passive filter; it may be overloaded in the harmonic voltage source application. When applying active filter with harmonic voltage source load, a series reactor must be placed on the load side.

Another research discuss the design and simulation of Harmonic and power factor compensation of multiple non-linear loads of a single phase shunt active power filter by (Z.F. Hussien, N. Atan, I.Z Abidin,2003). Whereas the active filter is based on a full bridge single phase inverter. The system was modeled in Mat lab Simulink to consist of an AC controller as nonlinear loads connected to active filter to enhance the harmonic of the current injected by the load, and an uncontrolled rectifier.

An interleaved active power filter concept with reduced size of passive components was discussed by (L. Asiminoaei, E. Aeloiza, P.N. Enjeti, F. Blaabjerg, 2008), the topology is composed of two interleaved voltage source inverters with pulse-width modulation, both connected together to the AC line and have the same capacitor of the dc-link. The result of their research was as follows:

1-Linkage inductors' size is significantly reduced by decrease the ripple in the line-current due to the interleaving.
2-High-power applications need more accurate compensation; due to the power sharing permits one to use a higher switching frequency in each inverter.
3-Switching stress in the capacitor of the dc-link is reduced, because of the shared connection.
Using common-mode coils to the design of the passive components gives a low-cost and practical solution for the minimization of the inverters circulation currents. This makes the topology very attractive for high-power industrial APFs. Also they conclude that, to gain lower costs and allow a faster response in tracking the harmonic-current reference it must use of replacement of the isolation transformer with common mode coils and use smaller line inductors.

Random-Band Hysteresis voltage Control technique with bipolar Modulations for voltage sag/swell correction is discussed by (H. Ezoji, M. Fazlali, A. Ghatresamani, M. Nopour, 2009). The switching signals of the dynamic voltage restorer (DVR) are determined by the hysteresis voltage controller. Also, evaluate the quality of the load voltage during the operation of DVR by using Total Harmonic Distortion (THD) are investigated. Performance of the proposed control algorithm showed by the Simulation results using MATLAB/Simulink, they found the quite satisfaction to eliminate voltage sag and swell. The study concludes that the hysteresis bandwidth (HB) with the objective of constant device switching frequency is dynamically adjusted by the adaptive hysteresis band calculator. In order to optimize the PWM performance, the bandwidth can be programmed as a function of system parameters. MATLAB/Simulink simulation model results approved the validity of proposed method. The simulation results of new DVR control technique discussed in this study found that protect of sensitive load is quite satisfactory.

(X. Dianguo, G. Jianjun, L. Hankui, and G.Maozhong, 2002), improve a hysteresis current control technique. The improved control technique utilizes the advantages of the reduced number of the switching devices of the SVM scheme and the fast dynamic response of the conventional hysteresis current control. The performance of current tracking control for active power filter while reduce the number of switching is enhanced by using hysteresis current control. The errors in the current wave go beyond the outer hysteresis band, and obtain fast current response by selecting a suitable space voltage vector, which corresponding the current error differential vector is of the largest partial vector in reverse direction of error vector of the current. Or else, track the reference current and limit the current error within the specified hysteresis band by selecting the low harmonic current control of space vector modulation (SVM). The conclusion of result implies that, an improved hysteresis current control technique utilizes the advantages of the fast dynamic response of the conventional hysteresis current control and the reduced switching number of the SVM scheme. To obtain fast current response, a suitable space voltage vector is selected, while the current errors go beyond the outer hysteresis band. Else, to limit the current error within the specified band and track the reference current, they select the low harmonic current control as SVM. Asset of vectors of space voltage containing the zero vectors to decrease the switching number is decided from the middle current error band information. Furthermore, according to the inner current error band, a proper space voltage vector selected for better current shape. The proposed hysteresis control is confirmed and validated according to the experimental tests on a prototype.

The multilevel voltage source converter discussed by (P. Boonchiam and N. Mithulananthan) . This converter based on medium voltage dynamic voltage restorer. They compare between diode-clamped, flying capacitor and cascaded H-bridge converters. These converters are belonging to the three multilevel voltage source converters and are well suitable for high-voltage level, low harmonic and high power. Additionally, with only one DC-link energy storage these converters can feed power into distribution system. In this study, they investigate the power semiconductors development, control the dynamic voltage restorer methodology, and scheme of the modulation.

(K. DerradjiBelloum, and A. Moussi, 2008), they work to control the PWM AC chopper by deploying the same controller. The controller while maintaining acceptable losses in the AC chopper aims for harmonic content optimization at both output and input sides, also to control the fundamental output voltage in wide range. In this research, for a single-phase AC chopper a fixed band controller has been analyzed and simulated and extend the study to three-phase systems easily. The modulation method simulation that deployed to the AC chopper shows an excellent behavior and confirms the advantages. By using this controller and according to the digital simulation and the obtained spectral analysis of the waveforms, the load current and the tension harmonics are sharply attenuated, which leads finally to improve the distortion factor. Also, regulate the charging current amplitude with a distortion factor around the unit could be achieved using the algorithm of the order. Moreover, the study proofs that this controller results in a lower harmonic content and reduced ripple with a reasonable hysteresis width. However, with the fast switching devices availability that low higher switching frequencies this should not be major concern. Hence, in DSP based controllers the control strategy can easily be implemented and could be expand in three phase controllers.

(Keith A. Corzine, 2000), in his research a new type of converters control discussed. This type proposed to be multi-level control that includes extending regulation of hysteresis current to the *n*-level converter. The control has conceptual simplicity advantage; despite it is installed based on analog circuitry method (as compared to the digitally implemented SVM method. The last advantage is particularly crucial for high number of voltage vectors converters. Experimentally, and by using an induction machine drive system of four-level converter, the control was verified and examine as good to the SVM technique. The results show that, the hysteresis control -for the same level of current THD - had a slightly higher THD of voltage wave, but the SVM control has a higher switching frequency. The system shows also for a step change in current command it has a fast dynamic response which is advantage of the controllers of two-level hysteresis current.

(XuDianguo, GuJianjun, Liu Hankui, and Gong Maozhong, 2003), try to improve the behavior of current tracking control and minimize the switching number for the filter of active power by studying an improved control of hysteresis current. The reduced switching number of the SVM scheme and the conventional hysteresis current control fast dynamic response are advantages that the Control technique utilized. A suitable selection of space voltage vector in instant of the current errors exceeds the outer band of hysteresis, will gain fast response of the current. This means the current error vector has a direction in opposite to direction of current error differential vector that is the largest partial vector. Otherwise, select the S\Mis control of low harmonic current in order to limit the error of current within the specified band of hysteresis and follow the reference current. From the middle current error information, a set of space vectors involving the zero vectors determined to reduce the switching number.

(Siriroj Sirisukprasert, 1999), investigates the modulation topologies, and concept of multilevel voltage source inverters. He presents for a multilevel inverter, the Optimized Harmonic Stepped-Waveform (OHSW) concept technique. The result implies that the output voltage THD can be improved by applying this concept technique; also it can eliminate a specific harmonics. In the research, the author proposed a procedure aims to gain right switching angles of the OHSW. To verify the concept, experimental results are presented. Based on inverter of the multilevel and using cascaded-inverter of separated dc sources the proposed OHSW techniques implemented. The research Compare the OHSW and the Selective Harmonic Eliminated PWM.1999, Blacksburg, Virginia.

(Adnan TAN, 2011), modeling and analyses of power quality compensation system for current source inverter based induction furnace, research discussed In this thesis, the CSI-IF is modeled in PSCAD/EMTDC simulation program in order to investigate the time varying harmonics and interharmonics of CSI-IF and find solutions to these PQ problems. For the solution of PQ problems of CSI-IF, passive filtering and active filtering methods are investigated. In active filtering methods, hybrid active power filters (HAPF) which use APF in series with shunt passive filters topology are designed for the PQ problems of CSI-IF. Adana, 2011

Ibrahim A. Altawil, 2011) works on shunt Active Power Filter (APF). The author investigates the design and analysis of ABF based in the theory of p-q instantaneous and using the band of hysteresis current. The research aims to get the signals of gating 9- Step Diode Clamped Multilevel Inverter (DCMLI). To compensate the reactive power, enhance the power factor and reduce the non- linear load current (THD), the proposed active power filter (APF) is installed. The Proportional Integral (PI) controller is deployed to minimize the dc capacitor voltage ripple of the diode clamped inverter. 2012, Jordan.

4. MULTILEVEL INVERTER (MLI) AS VOLTAGE SOURCE INVERTER (VSI) AND RECTIFIER LOAD BRIDGE

4.1 INTRODUCTION:

Due to the extensive utilize of modern electronic apparatus and the natural limitation to the appliance of active filters at high power levels, it is complicated to recognize high power rated filters with the required bandwidth for compensating the typical harmonic currents through the conventional inverter (two level inverter), so that the application of using multilevel inverters instead of conventional one has been improved recently.

4.2 INVERTERS:

4.2.1 Two-Level and Three-Level Conventional Voltage Source Inverter:

In AC power supplies, and electrical application especially the AC motor drives system, DC/AC Switch-mode inverters used. Produce a controlled sinusoidal AC output is the main objective of these inverters, the AC output frequency and magnitude can both be adjusted according to the controller. Practically, both single-phase and three phase AC systems may use inverters. There are many topologies of the inverters differentiate in the objectives and output quality. So, to produce an output of two level of waveform with square shape, a half-bridge is used and it is the simplest topology. A voltage source supply of center-tapped is important in such a topology. A three-level square-wave output waveform is synthesized by using the full-bridge topology. Figure 4.1 illustrates the single-phase, half-bridge voltage source inverter and fig 4.2 shows the full-bridge configurations. (Sirisukprasert, 1999)

Only two switches are needed in a single-phase half-bridge inverter. Both switches are never turned on simultaneously but reciprocally to avoid shoot-through fault. Initially, turned on S1 and S2 is turned off, so the load voltage is V_{AO} shown in Fig. 4.1, of + V s/ 2. The cycle will completed by turning S1 off and S2 is turned on, so the load voltage, V_{AO}, of -V s / 2. Four switches are needed for full bridge configuration, the first stage of the cycle starts with turning both S1 and S4 on and turning off S2 and S3, Fig 4.2 illustrates that, +VS voltage appears between point A and B (V_{AB}). However, when turning (S1 and S4) off and (S2 and S3) turning on, this gives a voltage of -Vs.

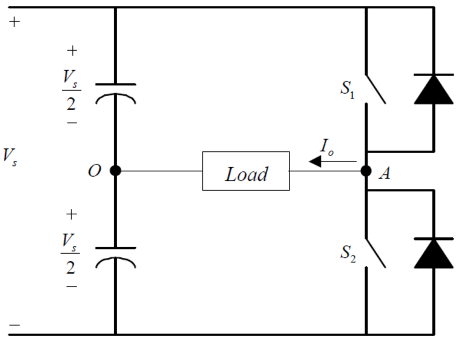


Figure 4.1: Half-bridge configurations (Sirisukprasert, 1999),

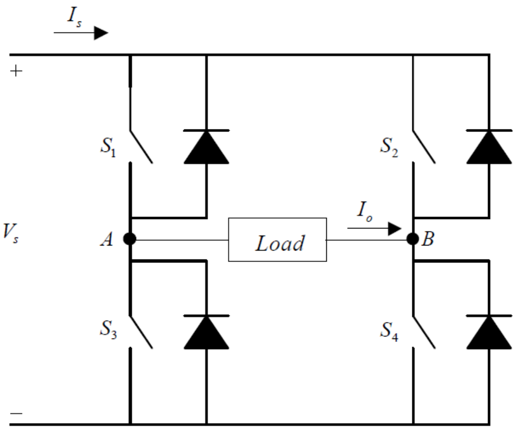


Figure 4.2: Full-bridge configurations (Sirisukprasert, 1999),

Zero level voltage in a full-bridge inverter can be achieved by turning the switches in the following scenario, the combination is turning S1 and S2 on where S3 and S4 off or vice versa. Table 4.1 presents, referring to above discussion the three possible levels.

Table 4.1: Load voltages with corresponding conducting switches (Sirisukprasert, 1999),

Conducting Switches	**Load Voltage V_{AB}**
S1, S4	**+Vs**
S2, S3	**-V s**
S1, S2 or S3, S4	**0**

Note that S1 and S3 should not be closed at the same time, nor should S2 and S4 Otherwise, a short circuit would exist across the DC source. The output waveform of half bridge and full-bridge of single-phase voltage source inverter are shown in Fig. 4.3 and 4.4, respectively. (Sirisukprasert, 1999),

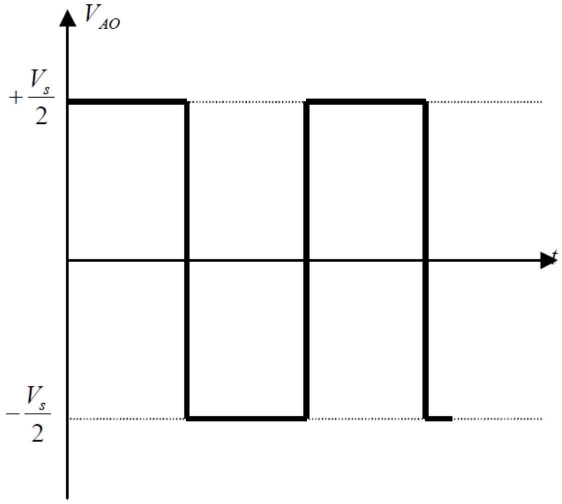


Figure 4.3: Output waveform of half-bridge configuration (Sirisukprasert, 1999),

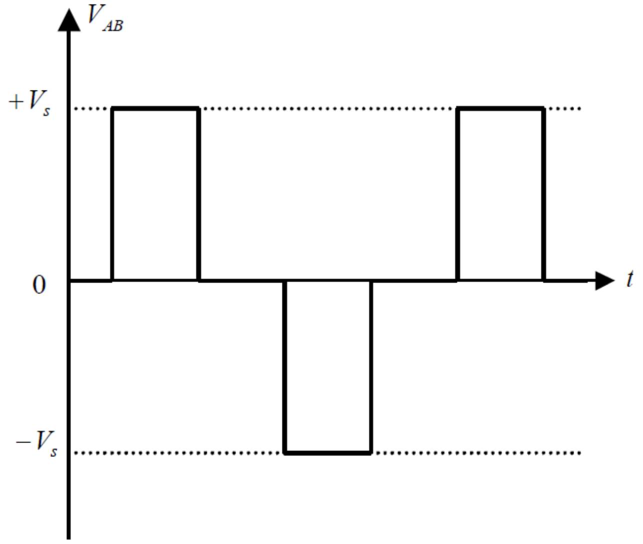


Figure 4.4: Output waveform of full-bridge configuration (Sirisukprasert, 1999),

4.2.2 Structures of Multilevel Power Inverters

There are some types of multilevel inverter. The three main types of multilevel converters are: (Sirisukprasert, 1999),

1. Cascaded H-bridges multilevel inverters
2. diode-clamped multilevel inverters
3. flying-capacitor (also referred to as capacitor-clamped) multilevel inverters

I would only be using diode-clamped multilevel inverters in my thesis and the other two would only be for definition purposes.

4.2.2.1 Cascaded H-bridges

Figure 4.5 illustrates the structure of an m-level single-phase cascaded inverter (Sirisukprasert, 1999), as shown, a single-phase full-bridge or H-bridge, inverter is connected to each separate DC source (SDCS). Three different voltage outputs, $+V_{dc}$, 0, and $–V_{dc}$ can be generated from each inverter level by build a connection between the DC source and the AC output and by another switching scenario of the four switches, S_1, S_2, S_3, and S_4. By switching S_1 and S_4 on, $+V_{dc}$ is the output voltage, whereas switching S_2 and S_3 on, $(–V_{dc})$ obtained as output voltage. Zero output voltage obtained by turning all switches (S_1, S2, S3, and S_4) on. The output voltage waveform is the sum of the inverter outputs, and formed by synthesizing the AC outputs of each of the different full-bridge inverter levels which connected in series. Output phase voltage levels m in a cascade inverter is given by m = 2s+1, where s is separate DC sources number. For example, Figure 4.6 presents the phase voltage waveform of an 11-Step cascaded H-bridge inverter with 5 full bridges and 5 SDCSs. Figure 4.5 (Sirisukprasert, 1999), the phase voltage $v_{an} = v_{a1} + v_{a2} + v_{a3} + v_{a4} + v_{a5}$.

Figure 4.6, depicted a stepped waveform with s steps (Sirisukprasert, 1999), the Fourier Transform for this waveform follows (Benchouia, Benbouzid, Golea, Zouzou, 2007) (taicheng, 2004)

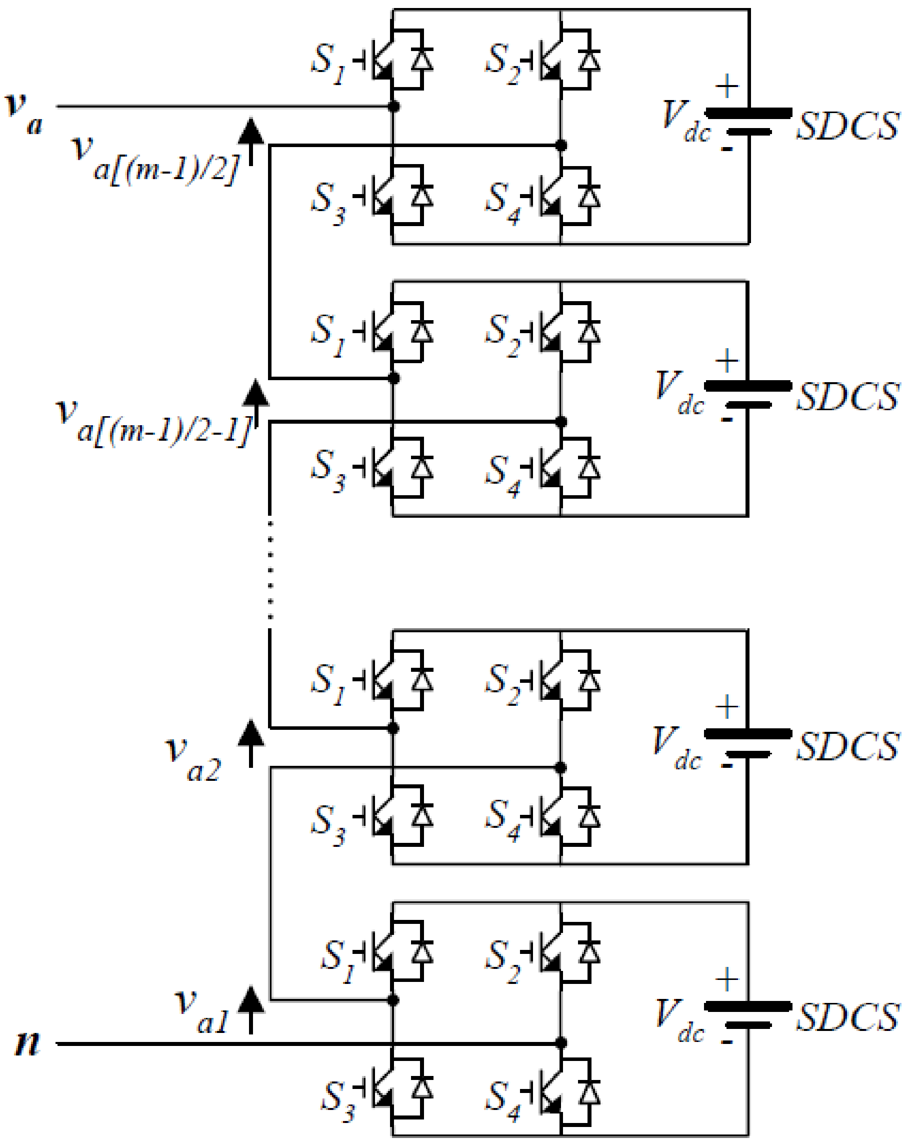


Figure 4.5: Structure of Multilevel cascaded Single-phase H-bridges inverter [Sirisukprasert, 1999],

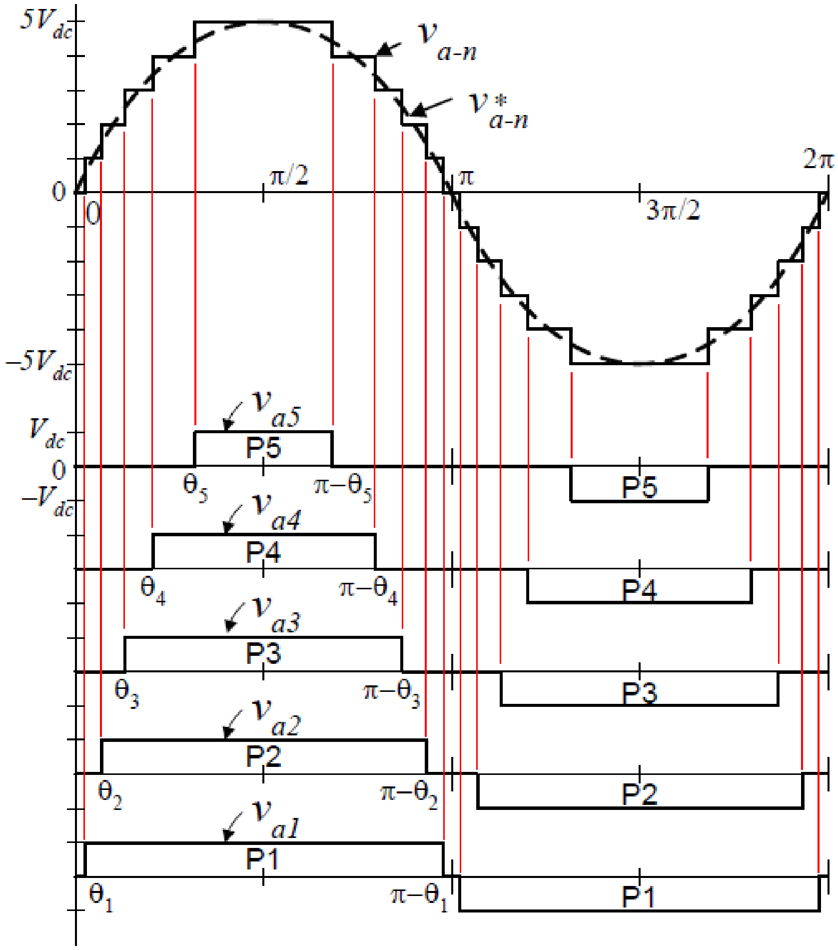


Figure 4.6: Output Waveform of an 11-Step cascade phase voltage inverter with 5 separate DC sources. [Sirisukprasert, 1999],

For applications such as static VAR (volt-ampere reactive) generation, battery-based applications, and interfacing with sources of renewable energy, multilevel cascaded inverters have been proposed. Figure 4.5 shows the wye connection of Three-phase cascaded inverters, (Sirisukprasert, 1999), also it may connect in delta. A prototype of multilevel cascaded static VAR generator has been demonstrated by Peng. In his work, the electrical system that may feed or draw reactive power- reactive current- from an electrical system is connected to the VAR generator in parallel (L.Asiminoaei, E.Aeloiza, P.N.Enjeti, F.Blaabjerg,2008) (P. Boonchiam and N. Mithulananthan, "Diode-Clamped Multilevel Voltage Source Converter for Medium Voltage Dynamic Voltage Restorer) . The controller may control the inverter to either working with regulated source current power factor or regulate the bus voltage where the inverter was connected in the electrical system. A cascade inverter has been investigated by Peng

(Dianguo, G. Jianjun, L. Hankui, and G.Maozhong, 2002), and Joos (XuDianguo, GuJianjun, Liu Hankui, 2003), they deduce that for static VAR compensation, the cascade inverter could be serially connected with the electrical system. Renewable energy sources connection with an ac grid is an application where using cascaded inverter in the connection is ideal choice, due to the need of separate dc sources, i.e. fuel cells or photovoltaic cells.

The converters of multilevel cascaded H-bridge have primary advantages and other disadvantages (F. Z. Peng, J-S Lai, 1996)(Z. Salam, T. P. Cheng, and A. Jusoh,2006).

(a)-Advantages:

(i)-The number of DC sources determine the number of possible output voltage levels, so the latest is more than twice the dc sources number and given by ($m = 2s + 1$).

(ii)-Modularized layout and packaging is a result of the series H-bridges. So, manufacturing process of the series H-bridge would be completed more quickly and cheaply.

(b)-Disadvantages:

(i)- The limitation of the productivity in case of has multiple SDCSs readily available, due the fact that each of the H-bridges need separate dc sources.

4.2.2.2 Diode-clamped multilevel inverter

Nabae, Takahashi, and Akagi proposed a converter of neutral point in 1981. The proposed converter essentially was an inverter of three-level diode-clamped (FERRACCI, 2001). Many published researches in 1990s concentrated on 7, 9, and 11-step diode-clamped converters, the authors reported experimental results to use converters as static VAR compensator, interconnections between high-voltage systems, and drives of variable speed motor (Z. F. Hussien. N. Atan, I. Z. Abidin, 2003) (F. Z. Peng, J-S Lai, 1996). Figure 4.7 depicted an inverter of three-phase 11-step diode-clamped (Sirisukprasert, 1999), as shown; a common dc bus is shared by each of the inverter's three phases. The inverter's capacitors –figure 4.7 - have been subdivided by five capacitors into 11- steps. The capacitor voltage is V_{dc}, where the voltage potential between each switching device terminals is limited through the clamping diodes to V_{dc}. Taking reference the negative rail voltage of DC $V_{0,}$ the output voltage levels shown in Table 4.2 are the possible voltages for one phase of the inverter. As listed in the table, the on state of the switch is presented by the state condition 1, and 0 means the switch is off. Five extra switch pairs contained in each phase, such that the turning on of one switches of the pair is reciprocal in operation with the other complementary switch. (S_{a1}, $S_{a'1}$), (S_{a2}, $S_{a'2}$), (S_{a3}, $S_{a'3}$), (S_{a4}, $S_{a'4}$), and (S_{a5}, $S_{a'5}$) are the pairs of the complementary switch for phase leg a. Table 4.2 also illustrates that the turned on switches in a diode-clamped inverter are always adjacent and in series for a particular phase leg. For example, the inverter of 11-Step has five on switches at any given operation state.

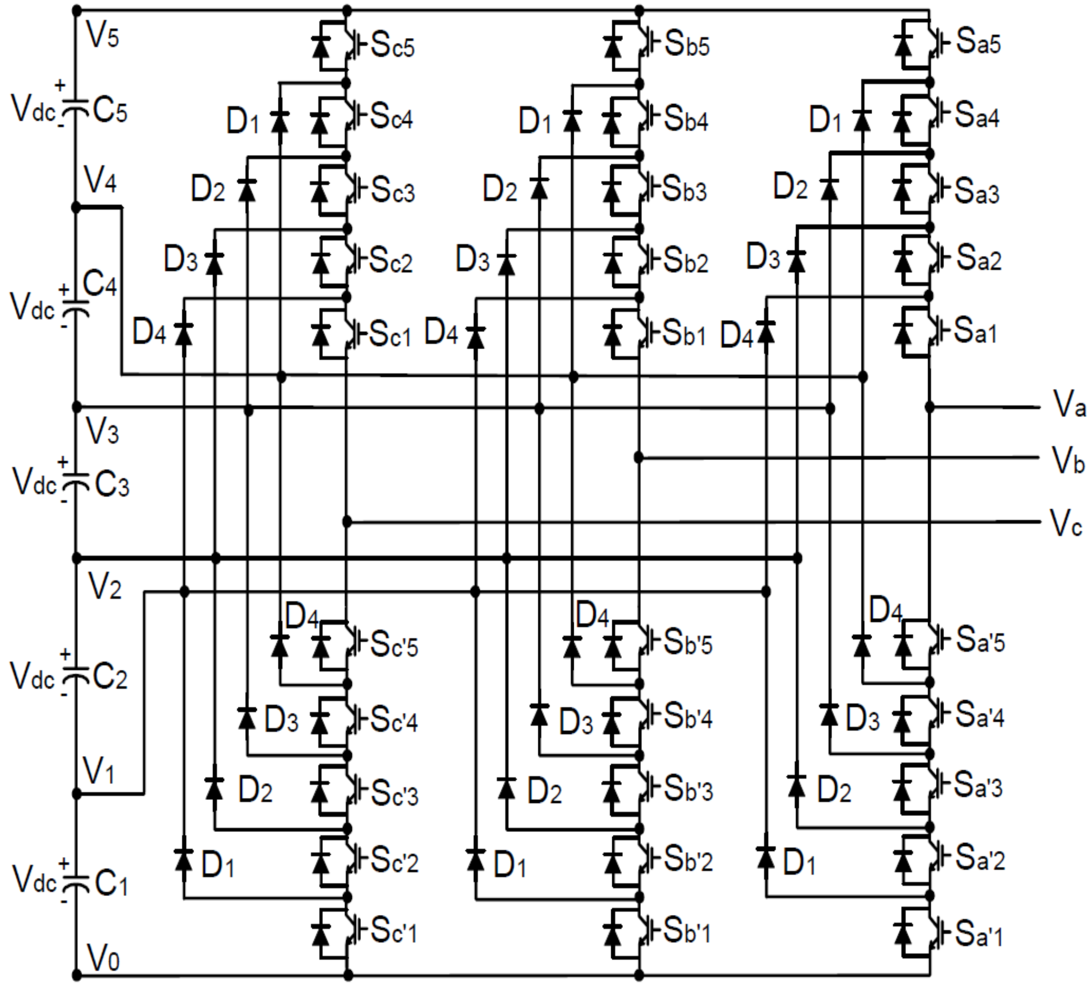


Figure 4.7: Structure of three-phase, 11-Step of a diode-clamped inverter [Sirisukprasert, 1999],

Now we have these figure the block diagram of 11-Step (DCMLI), the main aim of this inverter is to produce compensation current to cancel the harmonic current, now we transfer the dc voltage from a battery to produce ac, we have five capacitors that will divide the dc voltage, we have in each phase 10-swiches as we see in the next figure 4.9 (Sirisukprasert,1999), for of them the positive side and the other for the negative side as we see in the next table 4.2 if the positive 5-swiches is(Sa1,Sa2,Sa3,Sa4,Sa5),are (1) the voltage will be maximum (V5=5Vdc) , if the switching state Sa4,Sa3,Sa2,Sa1,Sa′1,are (1) the voltage will(V4=4Vdc) ,and if the switching state Sa3,Sa2,Sa1,Sa′5,Sa′4 , are (1) the voltage will (V3=3Vdc) , and if the switching state Sa2,Sa1,Sa′5,Sa′4,Sa′3, are (1) the voltage will (V2=2Vdc), and if the switching state Sa1,Sa′5,Sa′4,Sa′3,Sa′2,are (1) the voltage will

(V1=Vdc), and if the switching state Sa′5,Sa′4,Sa′3,Sa′2,Sa′1, are (1) the voltage will (V0=0), all the these switching state will gave as the output voltage of the diode clamped multilevel inverter which is 11-Step.

The reason why I choose 11-Step in my system is if the level increases then the total harmonic distortion (THD) decreases because of that 11-Step is better than 9-Step or lower.

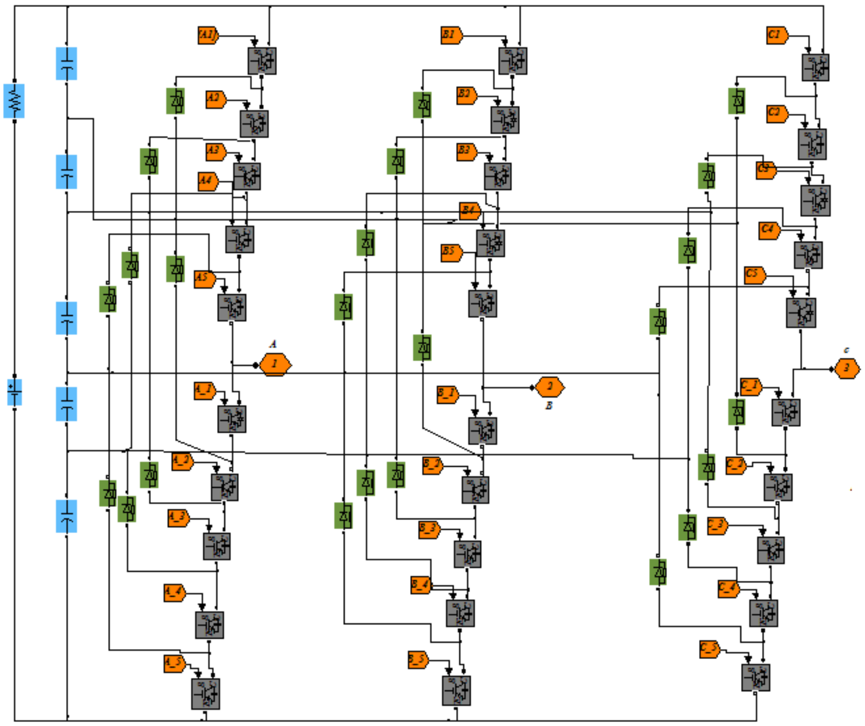


Figure 4.8: Simulation model of 11-Step diode-clamped three phase inverter [Sirisukprasert, 1999],

Table 4.2: Diode-clamped 11-Step inverter voltage levels and corresponding switch states [Sirisukprasert, 1999],

Voltage V_{a0}	Switch State									
	S_{a5}	S_{a4}	S_{a3}	S_{a2}	S_{a1}	$S_{a'5}$	$S_{a'4}$	$S_{a'3}$	$S_{a'2}$	$S_{a'1}$
$V_5 = 5Vdc$	1	1	1	1	1	0	0	0	0	0
$V_4 = 4Vdc$	0	1	1	1	1	1	0	0	0	0
$V_3 = 3Vdc$	0	0	1	1	1	1	1	0	0	0
$V_2 = 2Vdc$	0	0	0	1	1	1	1	1	0	0
$V_1 = Vdc$	0	0	0	0	1	1	1	1	1	0
$V_0 = 0$	0	0	0	0	0	1	1	1	1	1

11-Step inverter, line to line voltage wave form is illustrated in Figure 4.9. The line voltage V_{ab} is the voltage between the line phase (a) and the line phase (b). The shown output line voltage has a staircase waveform of an 11-Step. It can be deduced that a (2m-1)-Step output line voltage and a m-Step output phase voltage can be generated from an m-Step diode-clamped inverter.

Blocking only a voltage level of V_{dc} can be achieved by using only one active switching device. However, for reverse voltage blocking the clamping diodes require different ratings. According to the considered inverter example and phase a of figure 4.7 (Sirisukprasert,1999), in the instant of turned on switches $S_{a'1}$ through $S_{a'5}$ -the lower switches, four voltage levels had to be blocked by D_4, or $4V_{dc}$. Typically, $3V_{dc}$ had to be blocked by D_3 , $2V_{dc}$ had to be blocked by D_2, and D_1 must block V_{dc}. n diodes in series is required by D_n , in case of the designed inverter built such that voltage rating of each blocking diode are the same as the active switches; it can be stated that, (m-1) × (m-2) is the diodes number needed for each phase. Consequently, the blocking diodes number is quadratic ally related to the levels number in a diode-clamped converter figure 4.7(Sirisukprasert, 1999), The high-voltage DC transmission line interface with AC transmission line is one of the applications of the multilevel diode-clamped inverter figure 4.7(Sirisukprasert, 1999), Another application is a high-power medium-voltage (2.4 kV to 13.8 kV) motors variable speed drive system which are proposed in (Basu, 2006), (quist, 2001) (XuDianguo, GuJianjun, Liu Hankui,2003) (Peng,1996], Several authors have proposed Static VAR compensation as an additional function for the diode-clamped converter. The multilevel diode-clamped converters advantages and disadvantages would be as follow

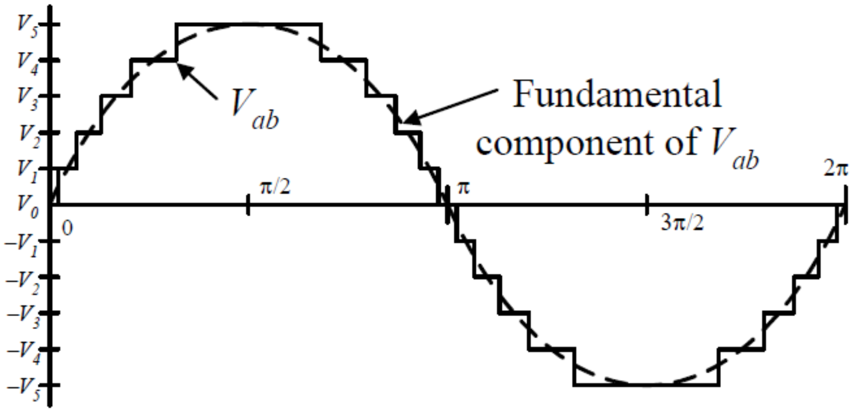


Figure 4.9: 11-Step diode-clamped inverter's Line voltage waveform [Sirisukprasert, 1999]

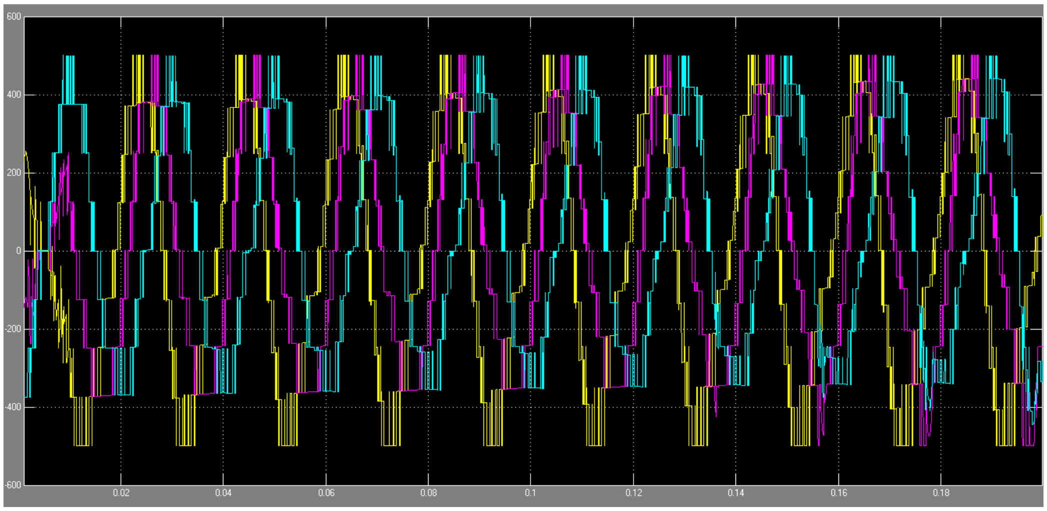


Figure 4.10: The output simulation of three phase 11-Step diode clamped

(a)-Advantages:

(i)-A common DC buses are shared by all of the phases, which reduces the converter capacitance requirements. For this reason, possibly and practically, a back-to-back topology is used as back-to-back inter-connection of a high-voltage or a controlled speed drive.

(ii)-Pre-charged the capacitors as a group is possible.

(iii)The high efficiency of fundamental frequency switching.

4.2.2.3 Multilevel inverter with flying capacitor

An inverter based on a flying-capacitor is introduced in 1992 by Meynard and Foch (Salam, Cheng, Jusoh, 2006). The introduced inverter structure is a kin to the inverter of the diode-clamped structure except that the inverter utilizes capacitors instead of clamping diodes in their place. Figure 4.11 depicted the flying capacitor multilevel inverter circuit topology (Sirisukprasert, 1999). According to this topology, the DC side capacitors have a ladder structure, where each capacitor has a voltage differs from the next capacitor voltage. The voltage steps size in the output waveform are determined by the increment in voltage between two adjacent capacitor legs.

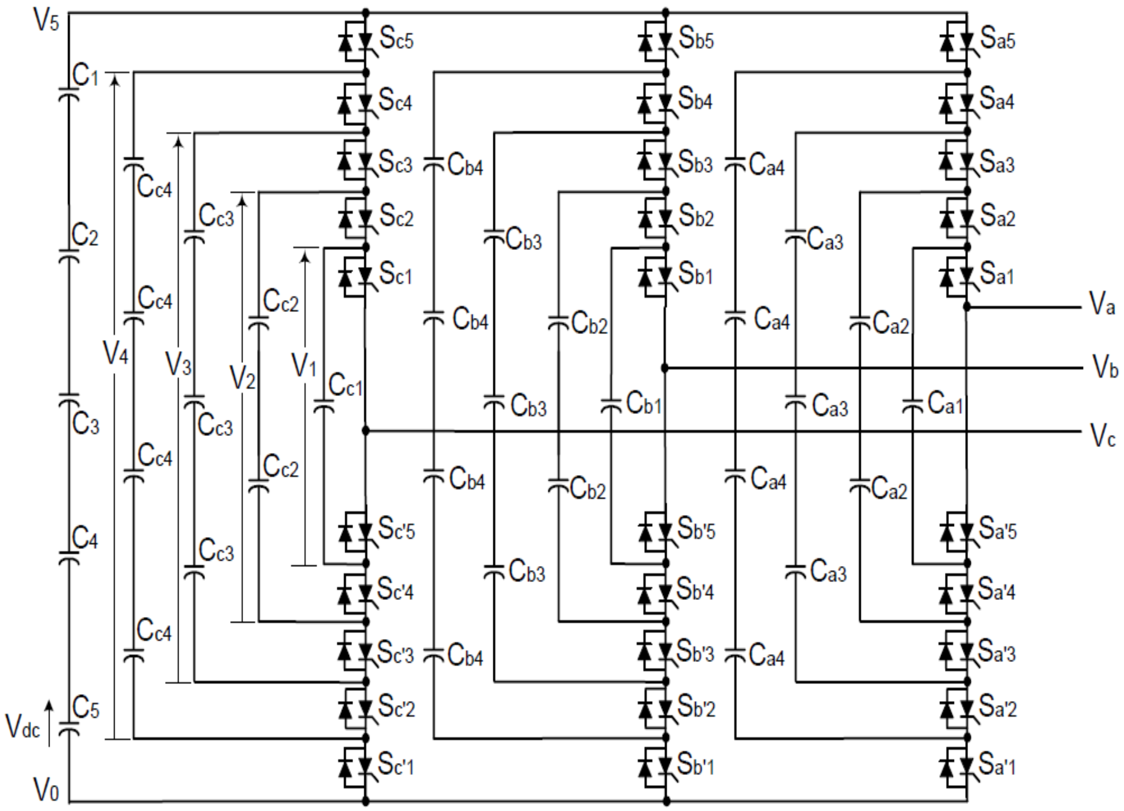


Figure 4.11: A flying capacitor inverter structure of three-phase 11-Step, [Sirisukprasert, 1999].

Redundancies for inner voltage levels are one advantage of the flying-capacitor-based inverter; this means that, an output voltage can be synthesized by combinations of two or more valid switch. Phase voltage levels combinations list shown in Table 4.2 are possible for the 11-Step circuit shown in Figure 4.11.(Sirisukprasert, 1999), the inverter of flying-capacitor and Unlike the inverter of diode-clamped, does not need all the conducting switches (on switches) be in a consecutive series. Additionally, the inverter of flying-capacitor has phase redundancies, On the other hand, only line-line redundancies are characteristic of the diode-clamped inverter (Dugan,2002), (Basu,2006), and (Akagi, Instantaneous power theory and applications to power conditioning) . Choose of charging/discharging specific capacitors is based on these redundancies and may use to balance the voltages across the various levels in the control system.

If the capacitors and the main switches have the same voltage rating, (m-1) × (m-2)/2 auxiliary capacitors per phase are required to the multilevel inverter of m-level flying-capacitor, In addition to the (m-1) DC link capacitors. In the literature, Static VAR generation is a proposed application for the multilevel flying capacitor (Dugan, 2002), (Sankaran, 2002), the converters of the multilevel flying capacitor advantages and disadvantages are as follows (Dugan, 2002), (Sankaran, 2002),

(a)-Advantages:

Balance the capacitors voltage levels achieved by Phase redundancies.

Controlling the flow of power (Real and reactive power).

Deep voltage sags, and short outage duration could be healed by the large number of inverter capacitors.

(b)-Disadvantages:

(i).The complexity in control for tracking all of the capacitors voltage levels. In additional to the complexity due to startup the capacitor after recharging all the capacitors to the same voltage level.

(ii).In transmission of real power, the efficiency and switching utilization are poor.

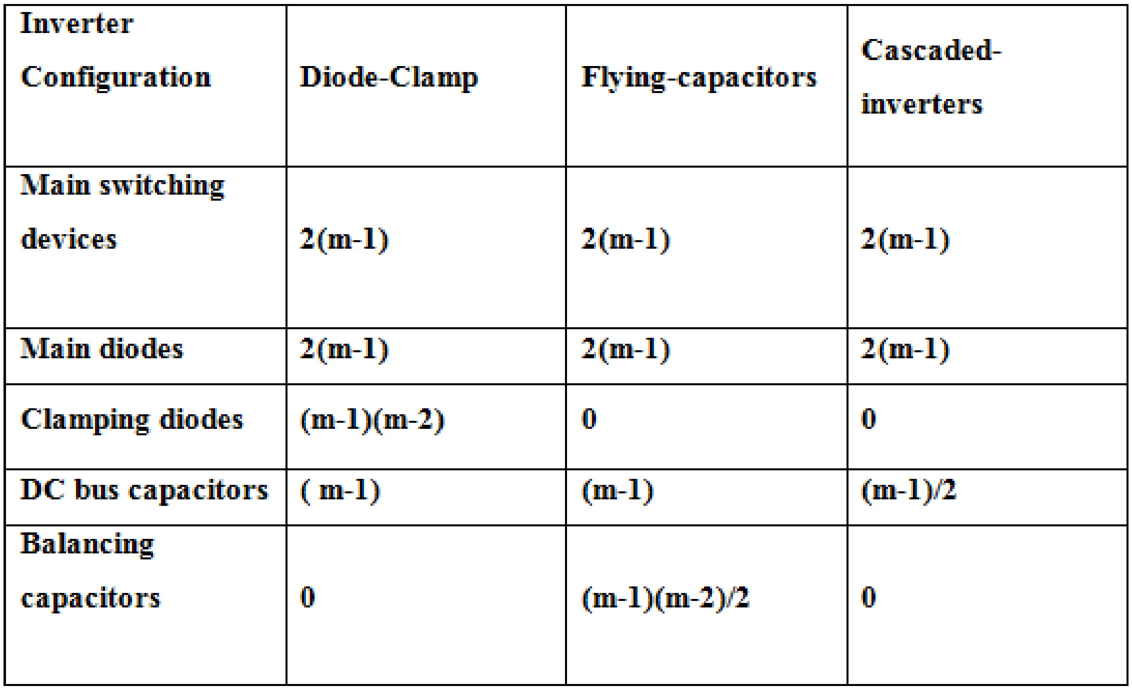
(iii)-More expensive and bulky due to the big capacitors numbers than clamping diodes in the converter of multilevel diode-clamped. Inverters with a large levels number are also more difficult for Packaging.

4.2.3 Application Aspects Comparison Among Inverters of Three Multilevel

Practically, the exits system that uses traditional inverter of multi-pulse in power system can be perfectly replaced by the inverters of multilevel without the need for transformers. So, without having the voltage unbalance problem during reactive power compensation, all the inverters of the three multilevel can be used.

The table below holds a comparison between the three kinds of the inverters of the multilevel voltage source remarked before and per phase power components requirements. Table 4.3 stated that to achieve the same number of voltage levels, the inverter must have a number of main diodes equals the number of main switches. In configuration of cascaded inverter and flying capacitor, the clamping diodes do not needed, while in cascaded inverter and diode clamp configuration, balancing capacitors do not needed. Table 4.3 (Sirisukprasert, 1999),

Table 4.3: Application Aspects Comparison between Three Multilevel Inverters. [Sirisukprasert, 1999],



Inverter Configuration	**Diode-Clamp**	**Flying-capacitors**	**Cascaded-inverters**
Main switching devices	**2(m-1)**	**2(m-1)**	**2(m-1)**
Main diodes	**2(m-1)**	**2(m-1)**	**2(m-1)**
Clamping diodes	**(m-1)(m-2)**	**0**	**0**
DC bus capacitors	**(m-1)**	**(m-1)**	**(m-1)/2**
Balancing capacitors	**0**	**(m-1)(m-2)/2**	**0**

4.2.4 Modulation Topologies for Multilevel Inverter:

In general the performance of the inverter is accepted, with any switching strategies, can be related to the harmonic contents of its output voltage. Decreases harmonics in waveform have constantly studied through many novel control techniques by power electronics researchers. Many techniques have applied and tested to the inverter topologies ill the present time. Several modulation topologies in multilevel technology found, there are as follows:

1 -Sinusoidal or “Sub harmonic” Natural Pulse Width Modulation (SPWM).

2- Selective Harmonic Eliminated Pulse Width Modulation (SHE PWM) or Programmed-Waveform Pulse Width Modulation (PWPWM)

3- Optimized Harmonic Stepped-Waveform Technique (OHSW)

These three techniques have advantages and disadvantages. Pulse width modulation technique will be briefly presented in the following sections of this thesis.

4.3 RECTIFIRE LOAD BRIDGE:

4.3.1 Single Phase Full Wave Rectifiers:

A rectifier is an electrical device aims to converts electrical current from alternating current (AC) - has periodically reverses direction- to direct current (DC), which has only one direction. Physically, the rectifiers is a circuit that may synthesized of number of forms, including mercury-arc valves, vacuum tube diodes, solid-state diodes, mercury-arc valves, and in the latest decade rectifiers consist of silicon-controlled rectifiers and other silicon-based semiconductor switches. In the initial ages of rectifiers, they were used motors and synchronous electromechanical switches.

Figure 4.12. (Lander, Cyril W, 1993), shows this type of rectifier. This rectifier has four diode connected as bridge

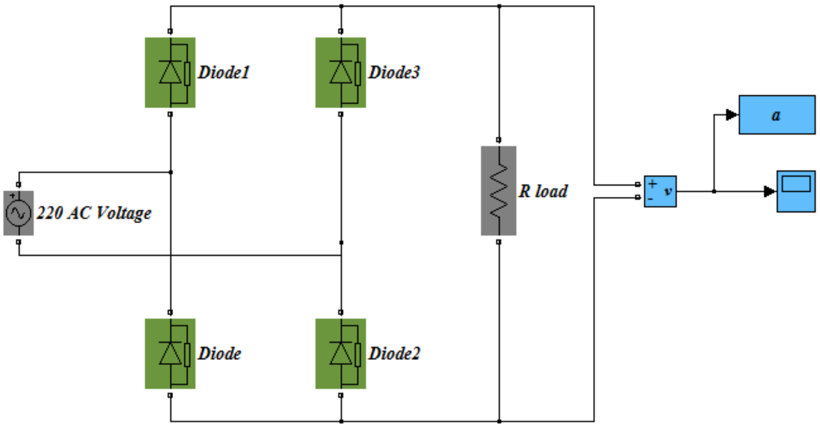


Fig 4.12: Circuit of Single phase full wave rectifier [Lander, Cyril W, 1993],

The rectifier work scenario based on that the two diodes at the same arm will not be in the conducting state simultaneously. The rectifier starts work though the input voltage positive half cycle, during this period D1 and D2 will be in the conducting state and the power is fed to the load. While D3 and D4 will work during the negative half cycle, and the power is supplied to the load. Figure4.13 illustrates the output voltage of this bridge [Lander, Cyril W, 1993].

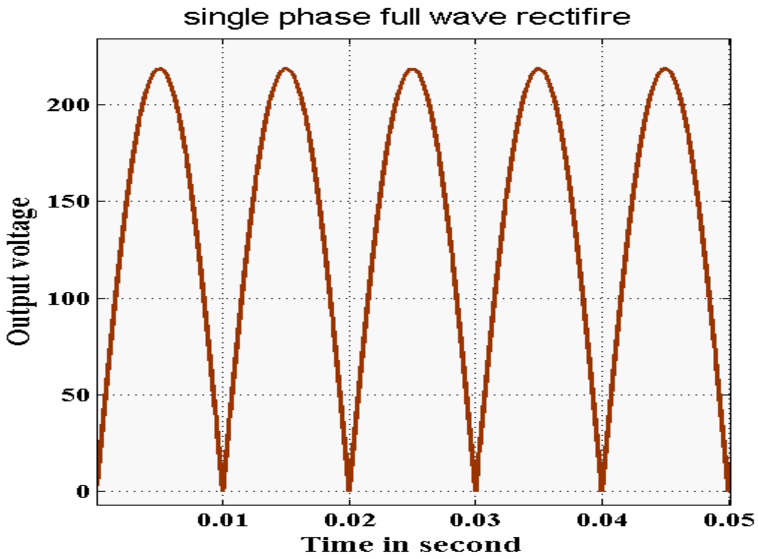


Fig 4.13: Output voltage waveform.

4.6.2 Three Phase Rectifiers:

Rectification is the process of conversion of alternating input voltage to direct output voltage. In diode rectifiers, the output voltage cannot be controlled. AC to DC converter (Rectifiers) can be classified as:

- Full wave rectifier FWR these can further be classified depending upon the rectifying element being used. If using diode, are called uncontrolled rectifiers. Whereas if using thermistors (controlled diode), are called controlled rectifiers. The application of these converts may include the following:

(i)-DC drives of Variable speed

(ii)-Battery chargers

(iii)-DC power supplies and a specific application Power supply like laser sources, electronic sets.

Three-phase bridge rectifiers have the highest possible transformer utilization factor for a three-phase system. Consequently, these rectifiers are commonly used for high power applications.

The conduction sequence for diodes is D1-D2, D3-D2, D3-D4, D5-D4, D5-D6 and D1-D6. Each diode conducts for 120º. During work, instantaneously, there is pair of diode face the highest amount of instantaneously line voltages, these pair is the conducting pair in that instant.

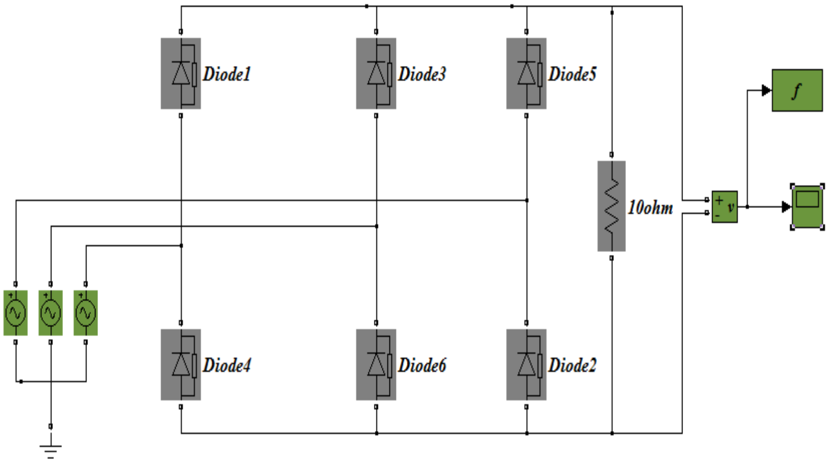


Fig 4.14: Three phase full wave rectifier circuit [44],

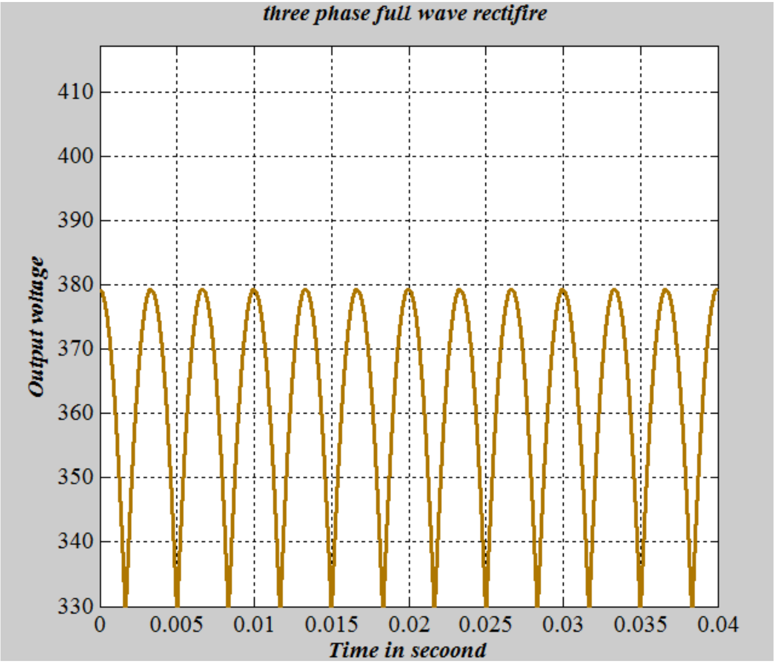


Fig 4.15: Output voltage waveform.

5. POWER CIRCUIT TOPOLOGY

5.1 INTRODUCTION:

Many non-linear loads are the cause of non-sinusoidal current drawn from electrical power supply. This current will produce voltage harmonics when passing through different kind of power system impedances. The connected sensitive equipment which attached to the same power system will affected by these harmonics, (Hussien, Atan, Abidin,2003). To reduce these harmonics, regularly, passive filters (LC filters) used, but other unnecessary effects may occur it may result in parallel resonances with the network impedance. Active power filters is proposed to use instead of the passive filter due to the harmful of resonance. Improve the power quality without the disadvanteges of passive filters is the main objective to use shunt active power filters.

The Power Circuit Topology will be explained by the headings below.

1- Active power filters.
2- Two Inverter Shunt Active Filters (SAFS).
3- Hysteresis PWM current controller.
4- Reference current generation.

5.2 ACTIVE POWER FILTERS:

Active filter itself is a harmonic source. It is a power electronic device which detects the harmonics in the system and produces a set of equal amplitude and phase contrast harmonic vectors; this can offset the harmonics, making it a sine wave. In addition to filtering harmonic active filter, but also can dynamically compensate for reactive power. The advantage is reflected in the rapid movement, harmonic filter can reach 95% or more, reactive power compensation and detailed. (Hussien, Atan, Abidin,2003) (Zeng, Tan, Wang,2008) in other way the passive filter solution Generally the passive filter inductance and capacitance matching of a harmonic to a certain harmonic currents to low resistance path to cancel the harmonic. This harmonic current cannot flow into the system. The advantages of passive filter low-cost, stable relatively mature technology and large capacity. Disadvantages for harmonic filtering rate are normally only 80% of the fundamental reactive power compensation is also certain. Current capacity and demand compensation for detailed areas is generally the use of active power filter, that is, active fine-tuning.

The shunt active power filter works to inject current harmonics into the AC source by working as a controlled current source attached shuntly with the non-linear loads. A shunt active power filter is an inverter driven by pulse width modulation technique (PWM) and placed in parallel with a load. The shunt active filter injects a harmonic current with the same amplitude of those of the load into the ac system but with opposite phase displacement. Then the load current harmonic components are cancelled due to using a shunt active filter. (Zeng, Tan, Wang, 2008), so the harmonic control is possible by using voltage source inverter in the active filter. The used inverter is able to switch at high frequency generating signal that cancel the non-linear loads harmonics, also it use dc capacitors as the supply. Cancelling the load harmonic currents by providing the real power is not the objective of the active filter. (David Irwin, Power electronics handbook, Auburn University, Series editor),

5.2.1 Two Inverter Shunt Active Filters (SAFS)

SAFs are attached to the distribution line shunt, and they compensate the harmonics by injecting compensating currents. The injected currents magnitude is equals to the disturbances in the system magnitude but opposite in phase. This eliminates the harmonics in the transmission system to restore the waveforms of source voltage and source current sinusoidal again. Depending upon the objective of the SAF, harmonic compensation yields real power oscillations elimination; power factor correction or reduction of current harmonics from the distribution system. Constant real power compensation can be provided by SAPF by compensating the oscillating active power (P) and reactive power (Q) of the load. Fig.5.2 (TAN, 2011) describes the basic concept of a shunt active filter (SAF) in this configuration; the source draws a current I_L due to the nonlinear load. The load harmonics generated by this load is compensated by the SAF by generating the correction current that should be injected in to the power system. SAF consists of AF controller and VSC with a PWM controller.

The AF controller generates the reference instantaneous compensating current signal in real time. PWM current modulation controller processing the signal and generate the VSC switching signals. The VSC switching and conduction losses are provided by the capacitor connected to the VSC.

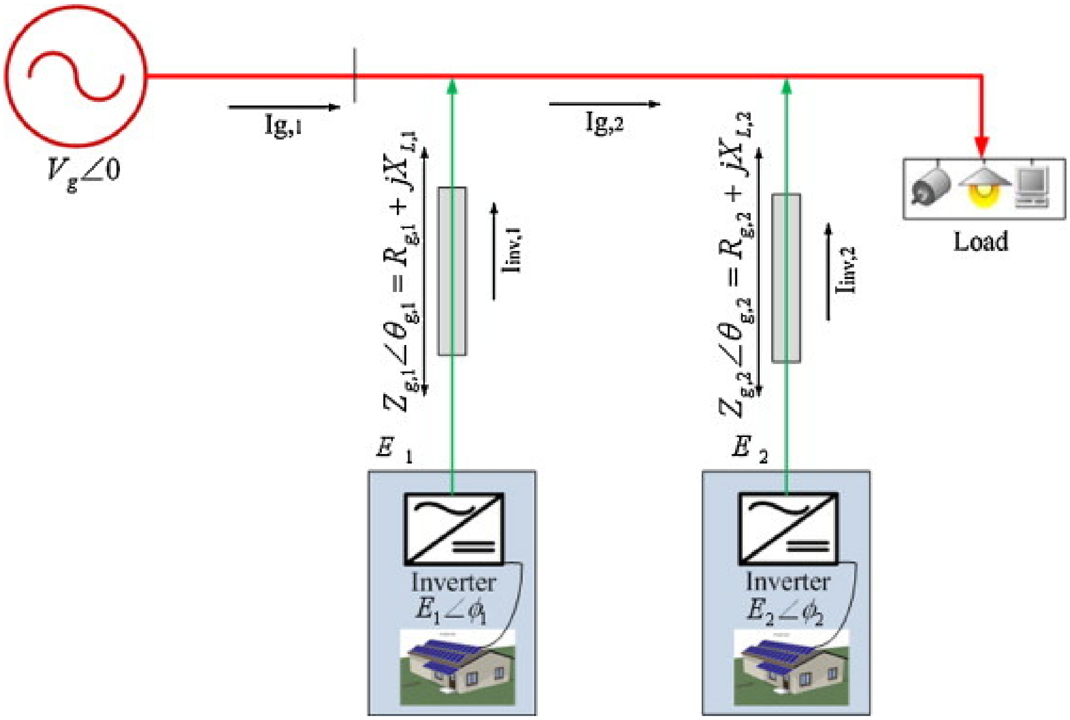


Figure 5.2: Two parallel inverters Shunt Active Filters [TAN, 2011],

In this power circuit topology two inverters shunt active filter (SAF) has been used the same inverter topology used by the literature review figure 5.2 (TAN, 2011), but the different my circuit from the studied in the literature. In this thesis, the current source inverter based induction furnace (CSI-IF) is modeled in PSCAD/EMTDC simulation program in order to investigate the time varying harmonics and interharmonics of CSI-IF and find solutions to the power quality (PQ) problems. For the solution of power quality (PQ) problems of current source inverter based induction furnace(CSI-IF) in active filtering methods, hybrid active power filters (HAPF) which use active power filter(APF) connected serially with shunt passive filters topology are designed for the power quality(PQ) problems of current source inverter based induction furnace (CSI-IF). In proposed shunt hybrid active power filter (SHAPF) system, two identical shunt hybrid active power filter (SHAPF) modules are used because the passive filter ratings cause high active power filter (APF) currents in order to obtain the reactive power requirements of current source inverter based induction furnace (CSI-IF).

In my thesis deal with implementing and design of three phase two inverters shunt Active Power Filter (APF). In distribution system 11 Kv to enhance the reactive power and so eliminate harmonics from a typical non-linear load, composed from (uncontrolled bridge rectifier with inductive load and DC motor). The current fed due to the load significantly distorted and contain reactive component. The function of the (APF) is to reduce the harmonics and enhance the passive power (Q) to correct the power factor at the source side.

Two inverter Shunt active filters are connected in shunt with the distribution line and they compensate the harmonics by injecting compensating currents, equal in magnitude but opposite in phase to the disturbances in the system. This eliminates the harmonics in the transmission system to make the source voltage and source current waveforms sinusoidal.

5.3 CURRENT CONTROLLER of HYSTERESIS PWM:

The current controller of the hysteresis band for shunt active power filter can be approved for inverter switching pattern generation. The proposed current control methods has an assortment for the configurations of such active power filter, but in terms of immediate current controllability and straight forward the control method of hysteresis current has the biggest rate of implementation than other current control methods. Hysteresis band current controller has properties like sturdiness, fastest control, and tremendous dynamics with minimum hardware. The hysteresis current controller of 11-step PWM- voltage source inverter systems are utilized for each phase independently. The three phases switching signal are directly generated by each current controller. Figure. 5.3 describes the positive input current case of the voltage control scheme of conventional hysteresis band (Sirisukprasert, 1999) (Kale, Ozdemir, 2003), the reference voltage V_{ref} is the desired response, but for other bands under or above the reference voltage the system will behaves according to the following; forcing to increase (decrease) the injected voltage V_{inj} when the lower (upper) limits reached by the error; as shown in Figure.5.3. (Kale, Ozdemir, 2003),

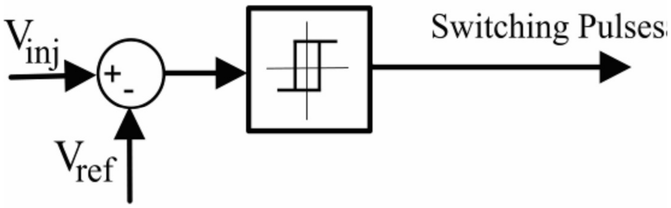


Fig 5.3: Hysteresis band current controllers [Kale, Ozdemir, 2003],

The following cases describe the switching logic algorithm and rules:

- Where $V_{inj} < (V_{ref} - HB)$, for leg “a” (S1, S3=1) the lower switch is ON and upper switch is OFF.
- Where $V_{inj} > (V_{ref} + HB)$, for leg "a" (S2, S4 = 0) the lower switch is OFF and upper switch is ON.

Figure 5.4. (Kale, Ozdemir, 2003), shows a single phase full bridge inverter operation principle of hysteresis modulation that is connected in series to a sensitive load.

Similarly using corresponding reference and measured hysteresis band width (HB) of voltage, the phases switching signals are determined.

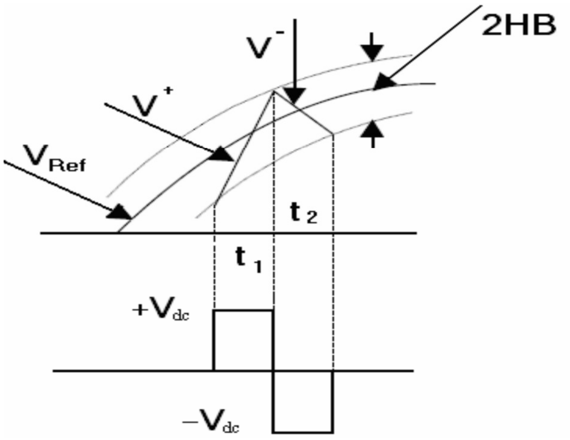


Fig 5.4: Operation principle of hysteresis modulation [Kale, Ozdemir, 2003],

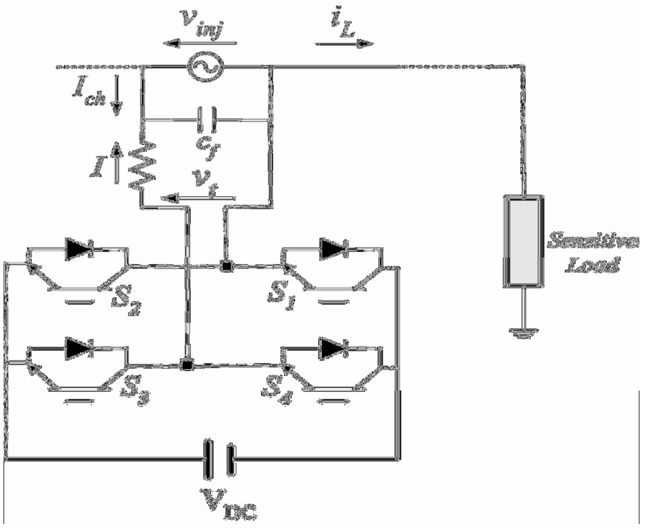


Fig 5.5: Inverter of single phase full bridge [Kale, Ozdemir, 2003],

The inverter switching frequency is determined by the hysteresis band width. The switching frequency increases if the band width is narrow. The inverter switching capability determines the suitable bandwidth.

There are advantages and disadvantages to Hysteresis PWM:-

1-Advantages of Hysteresis PWM: [Kale, Ozdemir, 2003]

(i)- Excellent dynamic response.

(ii) Low cost and easy implementation.

2-Disadvantages of Hysteresis PWM: [Kale, Ozdemir, 2003]

(i) Steady-state high current ripple.

(ii) Variation of switching frequency.

(iii) The modulation process generates sub-harmonic components.

5.4 GENERATION OF REFERENCE CURRENT:

For this kind of applications this concept is very useful and popular. Basically it formed of the a, b and c variable transformation, instantaneous power reference frame, current, and voltage signals to the α, β reference frame. The phase diagram shown in Fig. 5.6 could be used to derive the transformation equations from the a, b, and c reference frame to the α, β coordinates (FERRACCI, 2001).

The three phase instantaneous reactive current (Iq) and instantaneous active current (Ip) are calculated by this theory based on instantaneous reactive power theory. The current and voltage vector is calculated according to the Clark transformation. The following equations illustrates the method to obtain the instantaneous values of currents and voltages in the α, β coordinates figure 5.6 (FERRACCI, 2001).

$$\begin{bmatrix} \boldsymbol{V_\alpha} \\ \boldsymbol{V_\beta} \end{bmatrix} = [\boldsymbol{A}].\begin{bmatrix} \boldsymbol{V_a} \\ \boldsymbol{V_b} \\ \boldsymbol{V_c} \end{bmatrix} \qquad ,\begin{bmatrix} \boldsymbol{I_\alpha} \\ \boldsymbol{I_\beta} \end{bmatrix} = [\boldsymbol{A}].\begin{bmatrix} \boldsymbol{I_a} \\ \boldsymbol{I_b} \\ \boldsymbol{I_c} \end{bmatrix} \tag{5.1}$$

Where:

A: transformation matrix and obtained of Fig. 5.6. (FERRACCI, 2001) .And given as:

$$\boldsymbol{A} = \sqrt{\frac{2}{3}}\begin{bmatrix} \mathbf{1} & -\frac{1}{2} & -\frac{1}{2} \\ \mathbf{0} & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \tag{5.2}$$

The transformation can be used in case of that the voltages are balanced and sinusoidal, as a summary if

$$\boldsymbol{V_a(t)}+\boldsymbol{V_b(t)}+\boldsymbol{V_c(t)}=0 \tag{5.3}$$

The instantaneous reactive and active power in the coordinates of α, β are given according to the coming formula: figure 5.6 (FERRACCI, 2001),

$$\boldsymbol{p(t)} = \boldsymbol{V_a(t)} \cdot \boldsymbol{I_\alpha(t)} + \boldsymbol{V_\beta(t)} \cdot \boldsymbol{I_\beta(t)} \tag{5.4}$$

$$q(t) = -V_{a}(t) \cdot I_{\beta}(t) + V_{\beta}(t) \cdot I_{\alpha}(t) \tag{5.5}$$

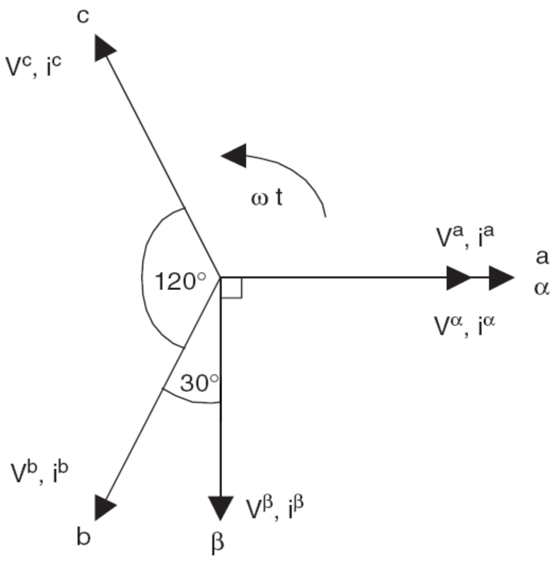


Figure 5.6: Diagram of transformation from the a, b, c reference frame to the α, β coordinates [FERRACCI, 2001],

According to the α–β plane, the equation of the currents as a function of the instantaneous power is addressed in the following expression:

$$\begin{bmatrix} I_{\alpha} \\ I_{\beta} \end{bmatrix} = \frac{1}{V_{\alpha}^{2}+V_{\beta}^{2}} \cdot \left(\begin{bmatrix} V_{\alpha} & V_{\beta} \\ V_{\beta} & -V_{\alpha} \end{bmatrix} \cdot \begin{bmatrix} p \\ 0 \end{bmatrix} + \begin{bmatrix} V_{\alpha} & V_{\beta} \\ V_{\beta} & -V_{\alpha} \end{bmatrix} \cdot \begin{bmatrix} 0 \\ q \end{bmatrix} \right) = \begin{bmatrix} I_{\alpha p} \\ I_{\beta p} \end{bmatrix} + \begin{bmatrix} I_{\alpha q} \\ I_{\beta q} \end{bmatrix} \tag{5.6}$$

This yields that:

$$I_{\alpha p} = \frac{V_{\alpha}\, p}{V_{\alpha}^{2}+V_{\beta}^{2}} \tag{5.7}$$

$$I_{\alpha q} = \frac{V_{\beta}\, q}{V_{\alpha}^{2}+V_{\beta}^{2}} \tag{5.8}$$

$$I_{\beta p} = \frac{V_{\beta}\, p}{V_{\alpha}^{2}+V_{\beta}^{2}} \tag{5.9}$$

$$I_{\beta q} = \frac{-V_{\alpha}\, p}{V_{\alpha}^{2}+V_{\beta}^{2}} \tag{5.10}$$

Equations (5.4) and (5.5), expressed in terms of the AC components in addition to the DC components the values of p and q, which is:

$$p = \overline{p} + \widetilde{p} \tag{5.11}$$

$$q = \overline{q} + \widetilde{q} \tag{5.12}$$

This means the AC and DC component of the signal (the DC signal is very small so in this theory there is no such equation for DC component and to make sure the DC component does not exist I use low pass filter which is clear in the figure 5.7 .(TAN,2011),

Where: $\overline{\boldsymbol{p}}$ the instantaneous power (p) DC component, and belongs to the conventional fundamental active current.

$\widetilde{\boldsymbol{p}}$ Is the instantaneous power (p) AC component and belongs to the harmonic currents caused by the instantaneous real power AC component.

$\overline{\boldsymbol{q}}$ Is the imaginary instantaneous power (q) DC component, and belongs to the reactive power generated by the voltages and currents fundamental components.

$\widetilde{\boldsymbol{q}}$ Is the instantaneous imaginary power (q) AC component, and belongs to the harmonic currents caused by the instantaneous reactive power ac component.

The active power filter reference signal must have the values of $\widetilde{\mathbf{p}}$,$\overline{\mathbf{q}}$ and $\widetilde{\mathbf{q}}$ for compensation of the reactive power (displacement power factor) and non-linear loads current harmonics. The following equations calculate the reference currents needed by the active power filters:

$$\begin{bmatrix} \mathbf{I_{c\alpha}}^{*} \\ \mathbf{I_{c\beta}}^{*} \end{bmatrix} = \frac{\mathbf{1}}{\mathbf{V_{\alpha}}^{\mathbf{2}} + \mathbf{V_{\beta}}^{\mathbf{2}}} \cdot \left(\begin{bmatrix} \mathbf{V_{\alpha}} & \mathbf{V_{\beta}} \\ \mathbf{V_{\beta}} & -\mathbf{V_{\alpha}} \end{bmatrix} \cdot \begin{bmatrix} \widetilde{\mathbf{p}} \\ \overline{\mathbf{q}} + \widetilde{\mathbf{q}} \end{bmatrix} \right) \tag{5.13}$$

The following matrix equation 5.14 presents the final compensating currents gathered with a, b, c reference frames zero sequence components:

$$\begin{bmatrix} \mathbf{I_{ca}}^{*} \\ \mathbf{I_{cb}}^{*} \\ \mathbf{I_{cc}}^{*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \mathbf{1/\sqrt{2}} & \mathbf{1} & \mathbf{0} \\ \mathbf{1/\sqrt{2}} & \mathbf{-1/2} & \mathbf{\sqrt{3}/2} \\ \mathbf{1/\sqrt{2}} & \mathbf{-1/2} & \mathbf{-\sqrt{3}/2} \end{bmatrix} \begin{bmatrix} -\mathbf{I_{0}} \\ \mathbf{I_{c\alpha}}^{*} \\ \mathbf{I_{c\beta}}^{*} \end{bmatrix} \tag{5.14}$$

Where the zero sequence current components

$$\mathbf{I_0}=\mathbf{1/\sqrt{3}}(\mathbf{I_a}+\mathbf{I_b}+\mathbf{I_c}). \tag{5.15}$$

The proposed instantaneous power theory is simulated on MATLAB/ Simulink as represented in the Fig. 5.7.

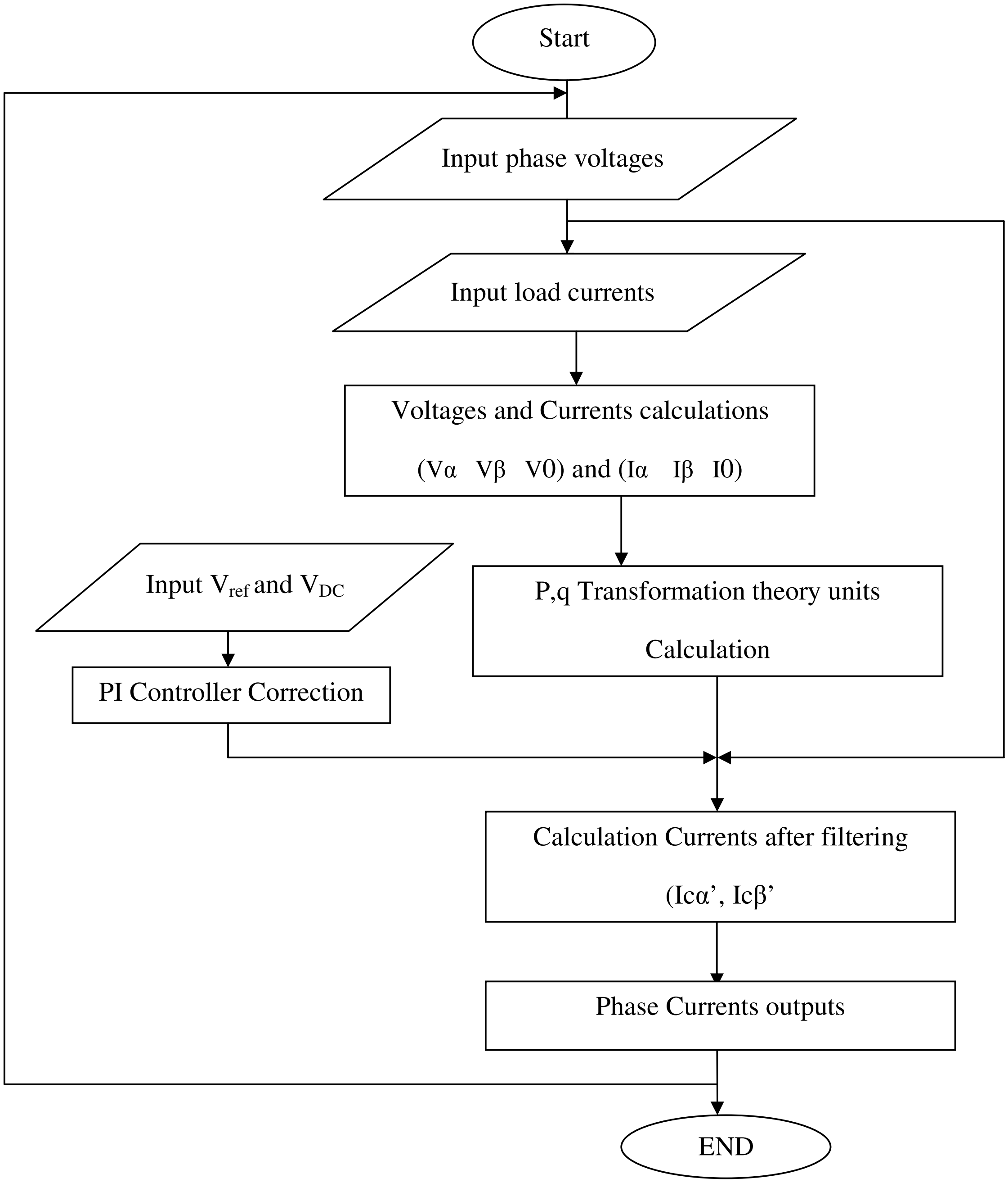


Figure 5.7: Generation of Reference current using p-q theories.

Adjusting the small power flowing in to inverter circuitry leads to voltage control of the DC bus, this finally aims to compensate conduction and switching loss. Therefore, to eliminate the steady state error and reduce the DC capacitor voltage ripples, a proportional integral (PI) controller is used and its constants are set using trial and error.

This block diagram (fig7.5): chooses the instantaneous reactive power theory which we used to generate the reference current and measure the power and reactive power and power factor. First of all we transfer the phase voltage and load current from (a, b, c) reference frame to (0, α, β) reference frame, then we find the power and reactive power and power factor. If there is a zero sequence in the power we cancel it by low pass filter another things if there is dc component in the power we cancel it by another loss pass filter. Now then we calculate the reference current in α, β reference frame then we transfer (Iα, Iβ, I0) to (Ia, Ib, Ic) then this current will be used as reference current in the hysteresis band current control .

6-SIMULATION AND RESULTS

6.1 INTRODUCTION:

In the latest decades, consultants and engineers have focused on study harmonic analysis due to the fact that it is a common important problem in every industrial project, basically in industrial plants, thermistor –the controlled devices is used in wide range. The main Power Quality's challenge is Harmonic. Harmonics mainly pollute the electrical power system, also the electrical equipment facing negative effects caused by harmonics. Decreasing Power factor is a result of current harmonics, as well as reactive current cause. Degradation of the power factor results is equipment of distribution system needs higher ratings and losses during power transmission are increased. Therefore, currents harmonic reduction is a necessary due to the same reasons for reactive current, also to minimize the other negative effects. So in this chapter 11KV distribution system will investigate and reduced the harmonics by using two parallel inverters with 11-Step diode clamped multi-level inverter the circuit is simulated by using MATLAB/ Simulaink, this simulink browser contains a large number of tools which are very usefull to simulate the parameters of the circuit. Also the mathematical equation of the system can be studied by this parameters tool.

6.2 OVERALL CIRCUIT DIAGRAM (SIMULATION MODEL): Fig 6.1(a)

The overall diagram of the simulation circuit contains in the table 6.1:

Table 6.1: system parameters

Parameter	Value
Source Voltage $\boldsymbol{V_s}$	11KV$_{p\text{-}p}$
Source frequency f	50 Hz
Voltage phase angle	$\mathbf{0^o}$
Source resistance $\boldsymbol{R_s}$	0.1 Ω
Source Inductance $\boldsymbol{L_s}$	10 mH
Load inductance $\boldsymbol{L_r}$	1.5 mH
Load Resistance $\boldsymbol{R_r}$	20 Ω
Armature Dc Motor Load inductance $\boldsymbol{L_r}$	**3 H**
Armature Dc Motor Load Resistance $\boldsymbol{R_r}$	**2 Ω**
Field Dc Motor Load inductance $\boldsymbol{L_r}$	13 **H**
Field Dc Motor Load Resistance $\boldsymbol{R_r}$	84Ω
Field of Dc Motor	**400 V**

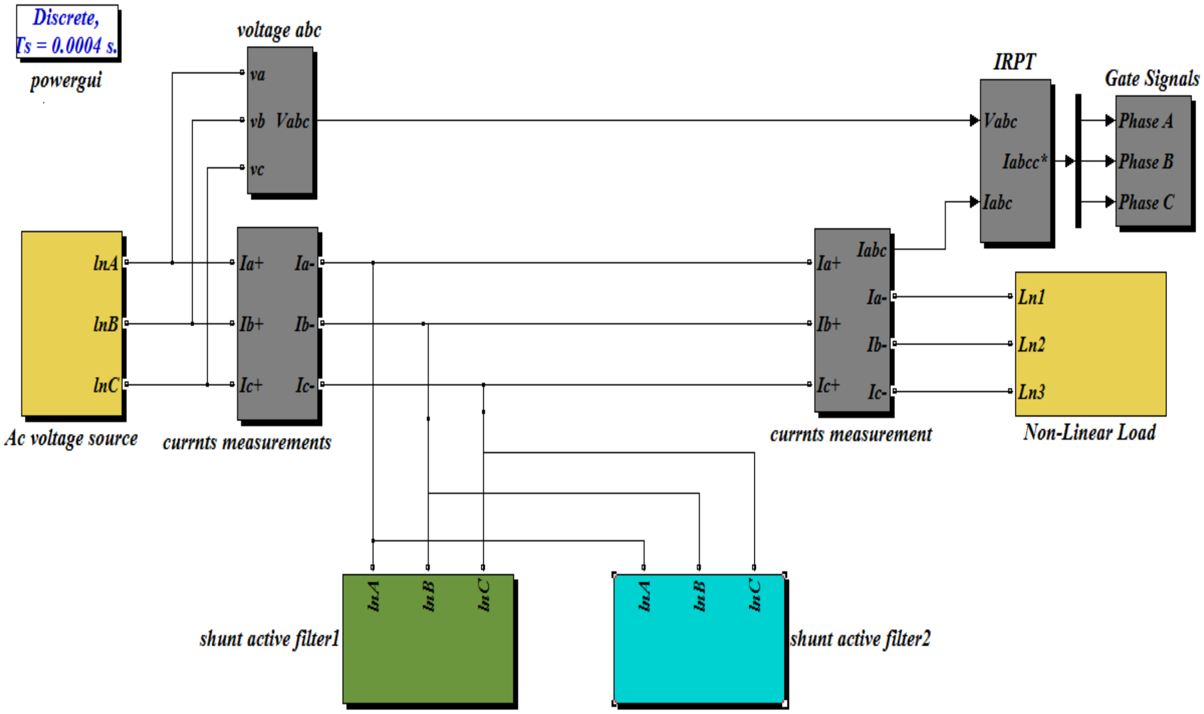


Fig 6.1 (a): Overall circuit diagram.

This figure is show overall system which mainly consists of:

1-AC voltage source.

2- Nonlinear load.

3-Two inverter Shunt active power filters (SAPF).

4- Instantaneous reactive power model (IRPT).

5- Gate signal (hysteresis band current control).

6 – Discrete time.

P-Q theory is used to generate the load current and line voltages and the reference current Figure 6.2(b) represents the simulation of this process.

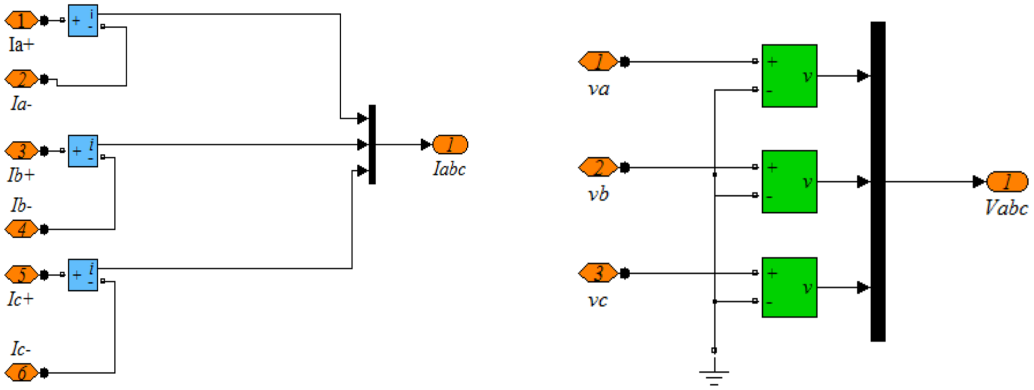


Fig 6.1 (b): Current and voltage measurement.

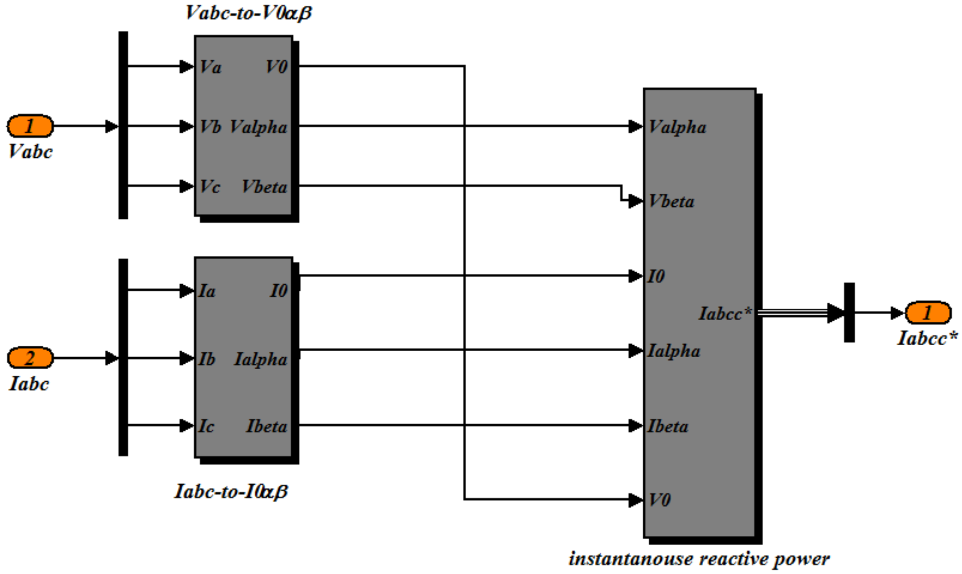


Fig 6.2: Inside IRPT block.

Fig 6.2 represents the current and voltages which is converted from ABC axis to 0αβ axis using equations mentioned in chapter five. The main objective this transformation is to cancel the zero sequence voltage and current. Figure 6.3 represent the transformations from ABC to 0αβ by using Clark matrix.

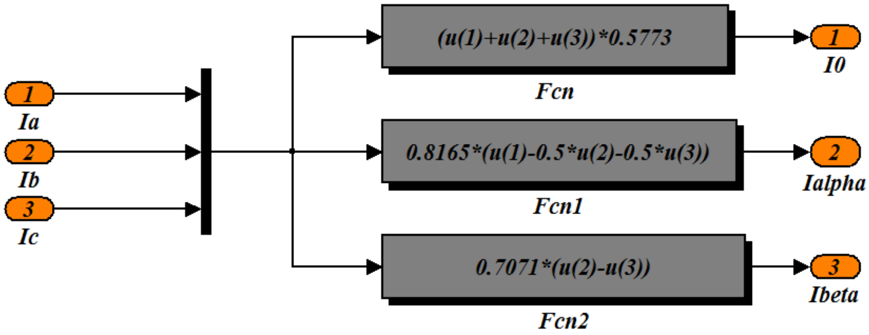


Fig 6.3 (a): Current transformation.

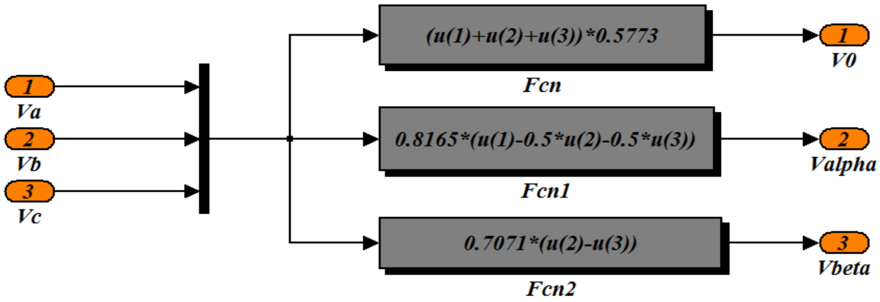


Fig 6.3 (b): Voltage transformation.

Instantaneous reactive power theory is used in simulation to generate the reference of main system elements of current, power, reactive power and power factor which it is used in the current control of hysteresis band. The current control signals compared with actual current to produce the gating signal, figure 6.4 represent the instantaneous reactive power simulation.

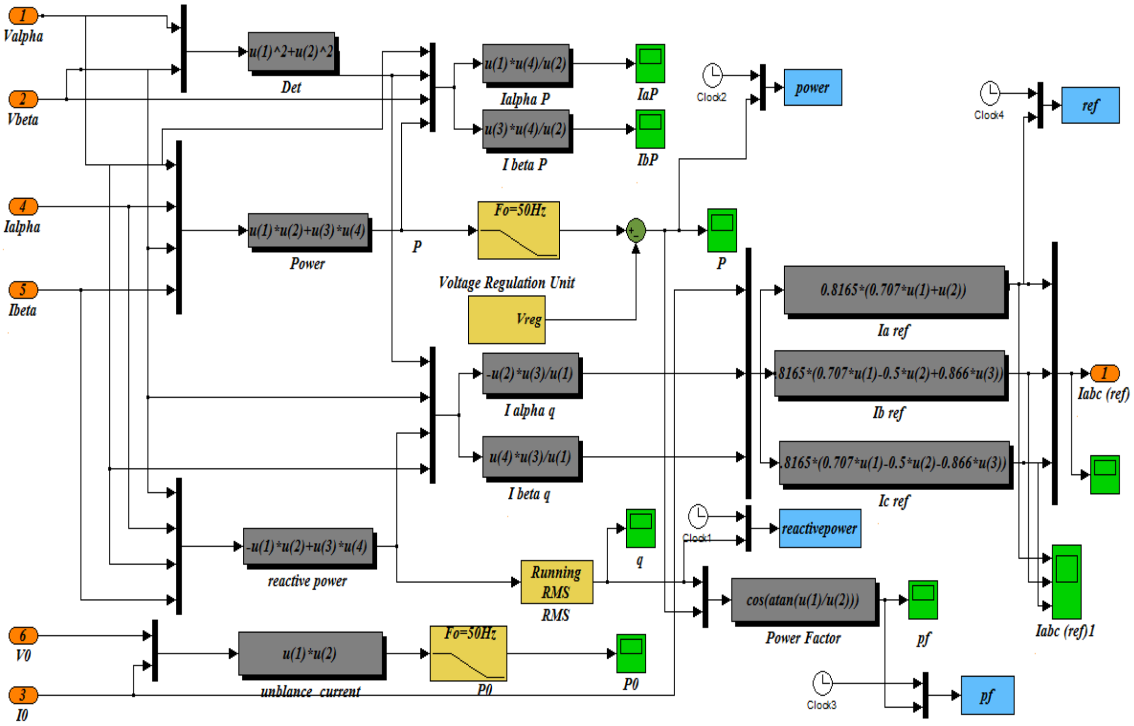


Fig 6.4: Inside instantaneous reactive power.

Fast Fourier Transform (FFT) is suitable algorithms to discrete time sinusoidal signals founded in modern software such as Mat lab. FFT algorithm required in discrete Fourier transforms (DFT) computation as well as FFT inverse. FFT algorithms have varied type's mentions as involving, number theory, group theory and also the arithmetic of simple complex-number.

In MATLAB/Simulink, FFT algorithms used to explore the compensated source current. This tool is very simple and easy to use. The main reason of used FFT is to order of harmonics by analyses the source current in the system. Otherwise, FFT gives the proportion of harmonics magnitude with respect to fundamental magnitude. Many features can found in this tool it can compute the signal and make many operations such as Total Harmonic Distortion (THD). Figure 6.13 (a), 6.13 (b) and 6.13 (c) represents the current source fast Fourier transform (FFT) analysis without SHAPF (THD = 20.18%) which is connected with one inverter SHAPF (THD = 4.35%). also with connected two inverters SHAPF (THD = 2.05%) which shows further decries in THD when using two inverter SHAPF for medium distribution system 11Kv is less than 5% the harmonic limit imposed by IEEE-519 standard.

The hysteresis current control objective is to generate pulses for switching operation of the diode clamped multi-level inverter. Also accomplished by comparing tow signals and the output of it will be pulses as zero and one to the Insulated Gate Bipolar Transistors (IGBT's) of the DCMLI. Figure6.5 represents the control process for three phases.

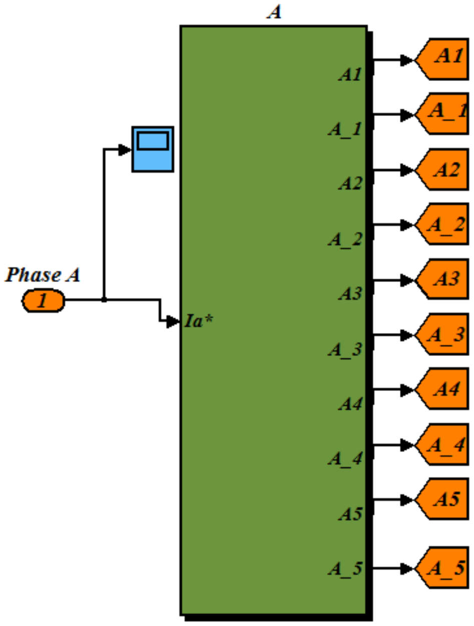


Fig 6.5: Phase (A) control block.

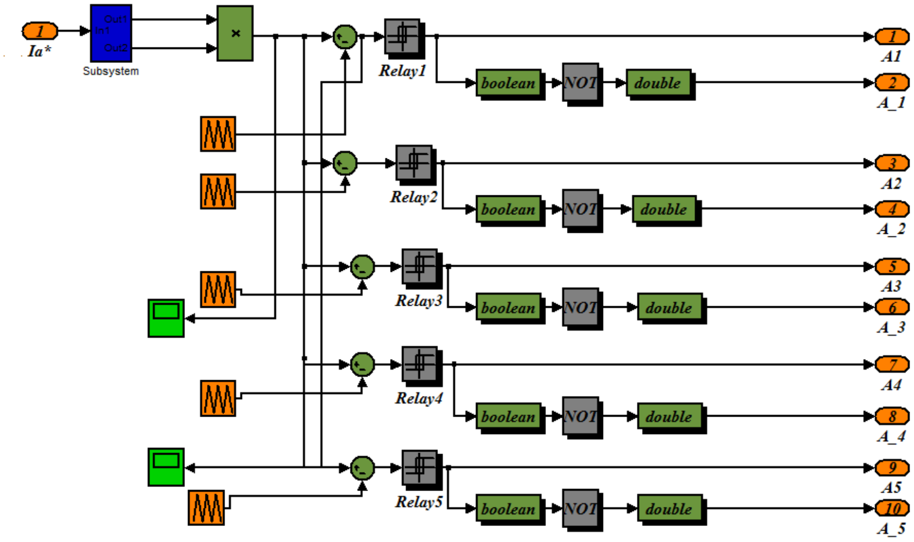


Fig 6.6: Current control of the hysteresis band

By using the initial elements and parameter represented on figure 6.1, and the diode rectifier of three phase with impedance R =20 Ω, L= 1.5 mH as a load, the system simulated from t=0 s to t=0.4s. Figure 6.7 illustrated to only balanced three phase load is considered, the three phase load current is very high distorted. Otherwise, figure 6.8 represents the pre-compensation current source.

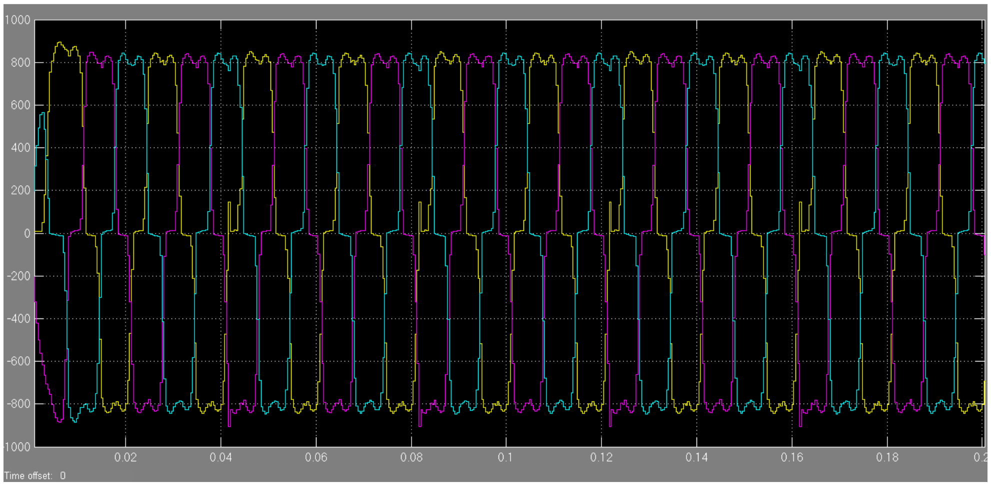


Figure 6.7: 3-phase load current

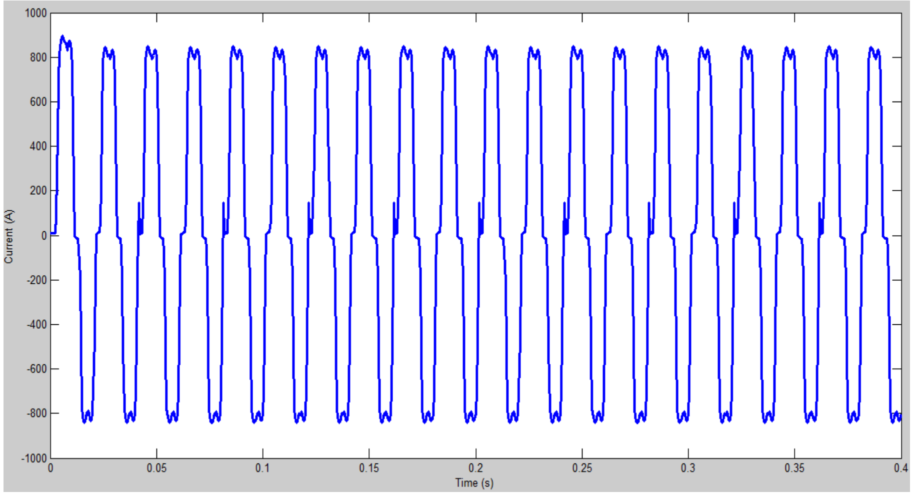


Fig 6.8 (a): unfiltering Load current.

Figure 6.8 shows the highly distorted load current in the simulation.

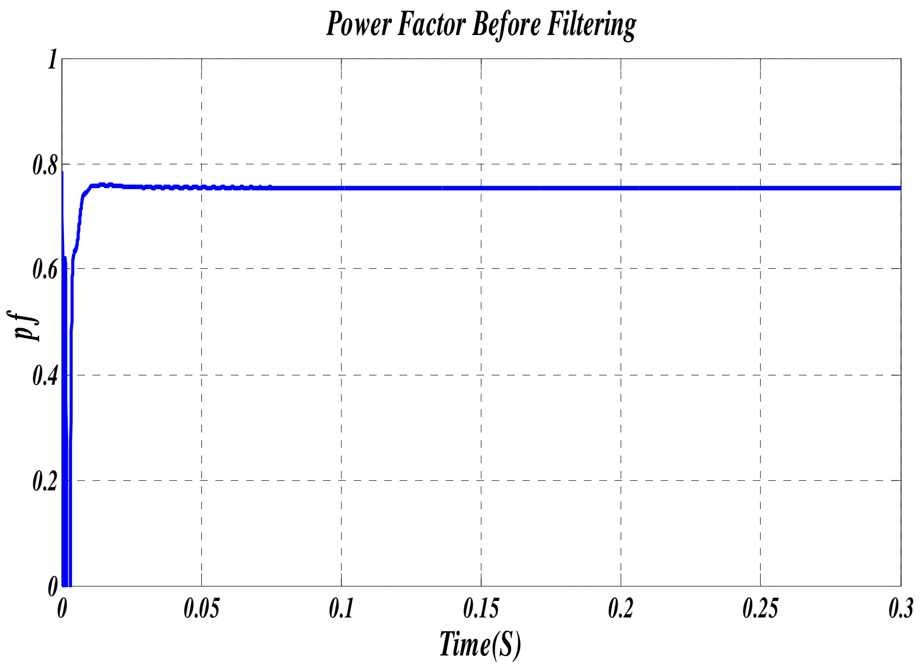


Fig 6.8 (b): (APF) unless power factor (PF =0.77%).

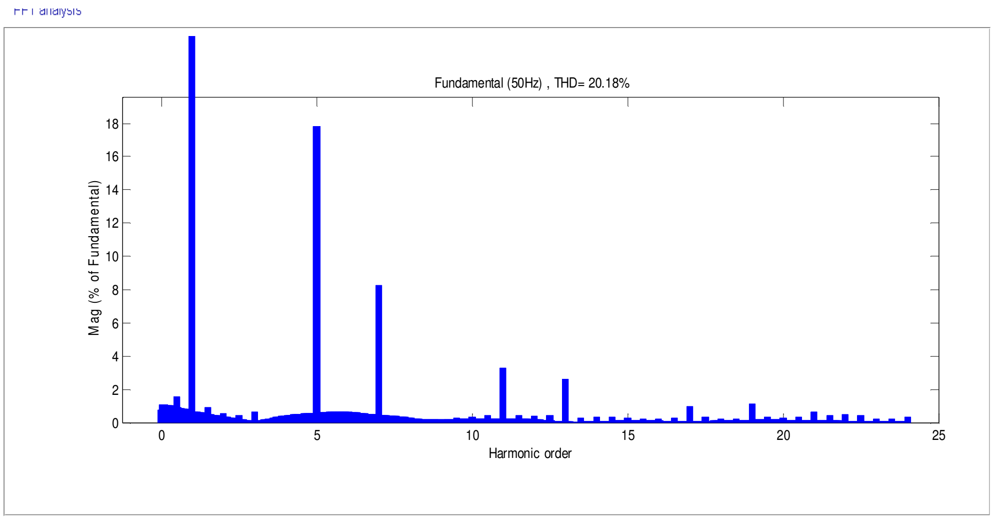


Fig6.9: (FFT) unless APF for source current.

(THD =20.18%).

Figure 6.9 deepened on choose of the harmonic in the source current unless active power filter. The figure represents a high destroyed as we see. Furthermore, the total harmonic distortion is very high (20.18%) and the most appearance harmonic is in the fifth.

Typically, by studying the steady state conditions, a small comparison must represented on thesis about the waveforms before and after load also between source currents with two and one inverters APF and study the effects on the harmonics

In the transient state conditions, it was observed that when the load current before and after filtering is increased and becomes more sinusoidal from 0.1 to 0.2, resulting that the harmonics is decreased. But the harmonics are not the same in Steady state and Transient state.

6.3 CASE1: STEADY STATE CONDITION:

Two parallel inverters Shunt Active Power Filter (SHAPF) model is considered to a study state condition. Study state test is made to evaluate the response of the two parallel SHAPF inverters. on this thesis focused to design a simulation to study the behavior of distribution power system with one inverter shunt active power filter (SHAPF), and with two parallel inverter together without shunt active power filter (SHAPF) to ensure that the SHAPF is able to compensate the current harmonic which produced by non-linear load and compare the best way to choose solution.

Figure 6.10a represents the post-compensation current source with single inverter for particular phase A. This shows the current have a sinusoidal form. Otherwise, the three phase's current is shown in Figure 6.10b.and the Total Harmonic Distortion (THD) by using one SHAPF inverter is illustrated in figure 6.10.c

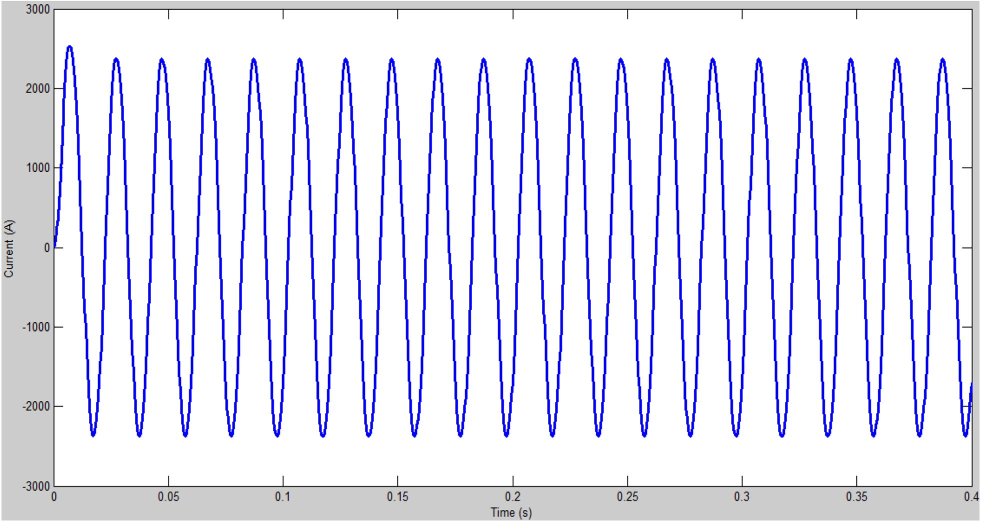


Fig 6.10 (a): Source current with filtering and single inverter.

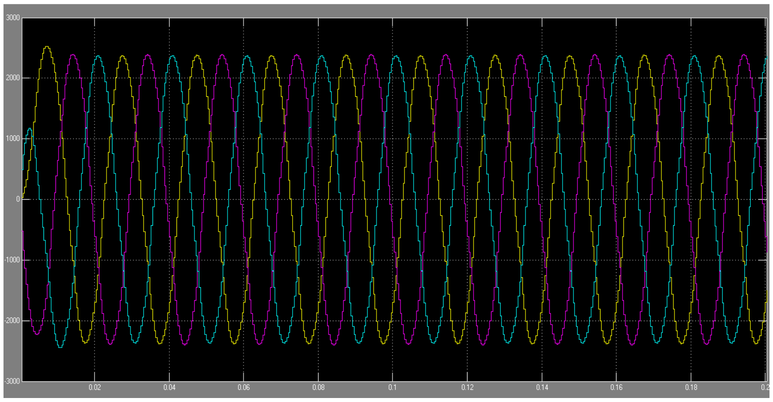


Figure 6.10 (b): 3-phase source current by using single inverter.

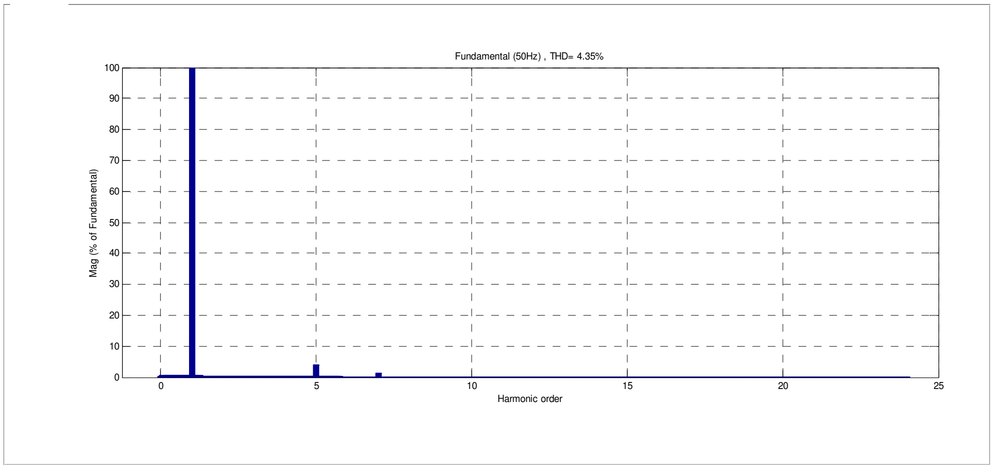


Fig 6.10 (c): (FFT) for source current with single inverter (THD =4.35%).

Figure 6.10 deepened on the parameters of the harmonic from the source current after using single inverter active power filter which is become small. The total harmonic distortion around (4.35%) which is a small and the most appearance harmonic is around fifth.

The particular phase current source after compensation with two inverters Shunt Active Power Filter (SHAPF) presented in Figure 6.11a to indicate that the current become more sinusoidal. Figure 6.11b represents the three phase's current and the THD by using two inverters Shunt Active Power Filter (SHAPF) is shown in figure 6.11.c.

The results shows that when using two inverters is much better

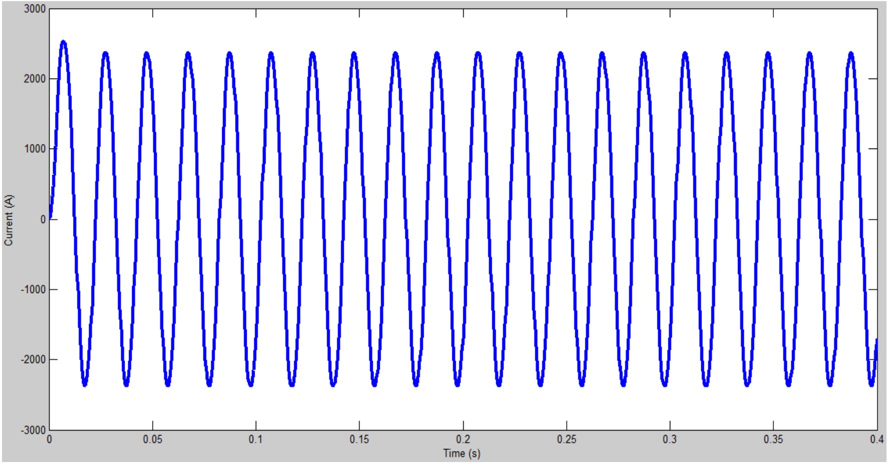


Fig 6.11 (a): Source current with filtering and two inverters.

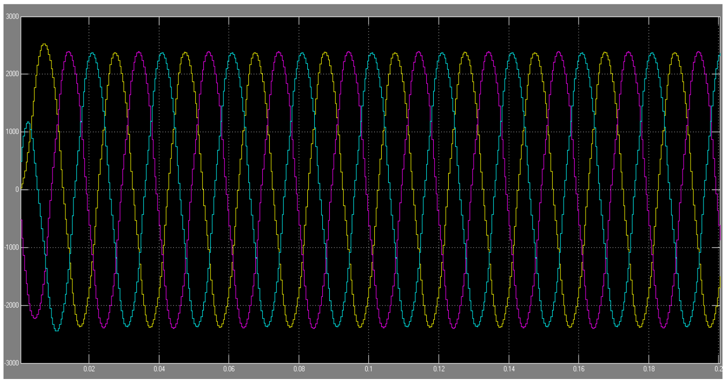


Figure 6.11 (b): 3-phase source current with two Inverters.

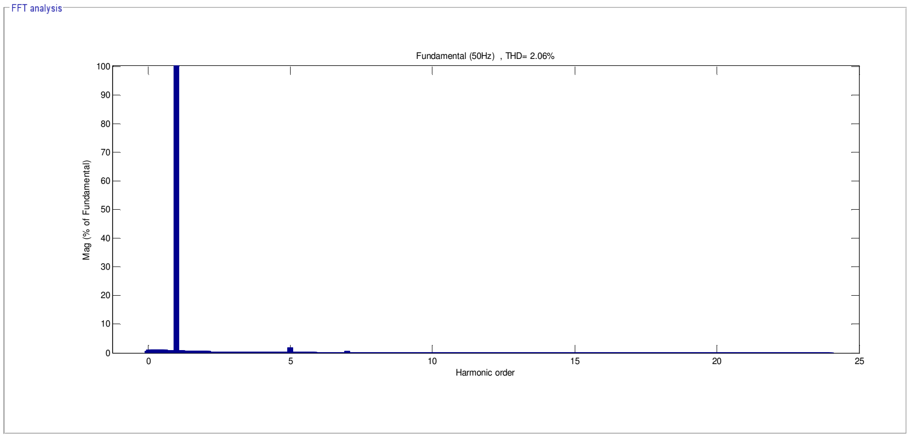


Fig 6.11 (c): FFT for source current and two inverter (THD =2.05 %).

Figure 6.11 consider to choose the harmonic of the source current after using two inverter active power filter which is become very small and the total harmonic distortion around (2.05%) and the most appearance harmonic is the are the fifth. Figure 6.12.a represents that that the power factor correction was achieved.

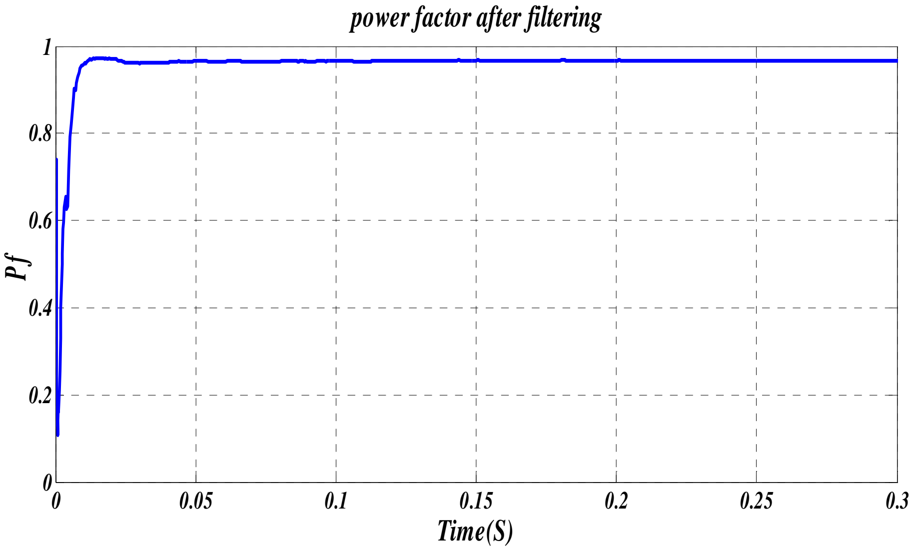


Fig 6.12 (a): Total PF with APF.

Each figures 6.12 (b) and 6.12 (c) represents the steady state conations with and without APF, the active and reactive power at the diode rectifier load.

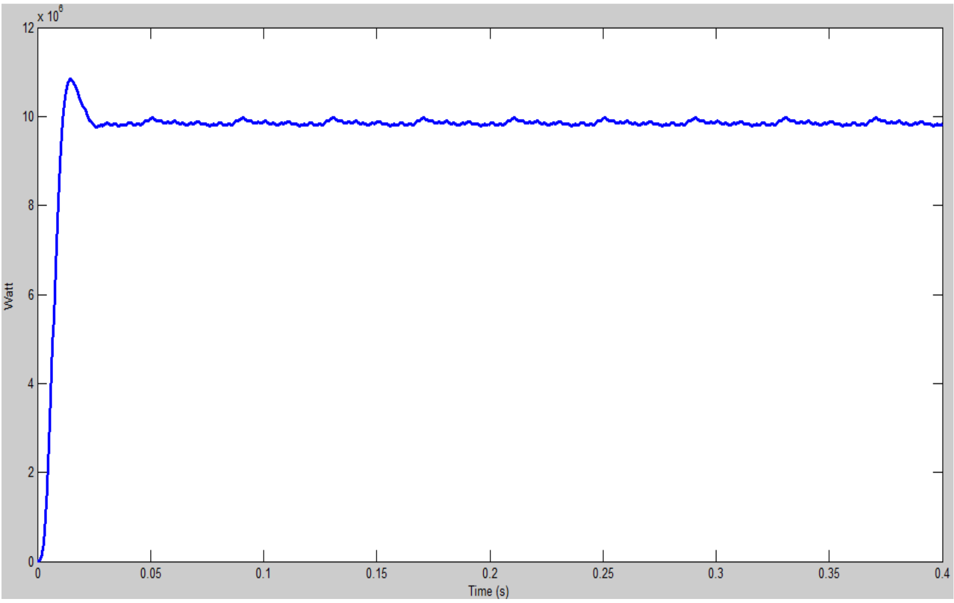


Fig 6.12 (b): Active power of the load.

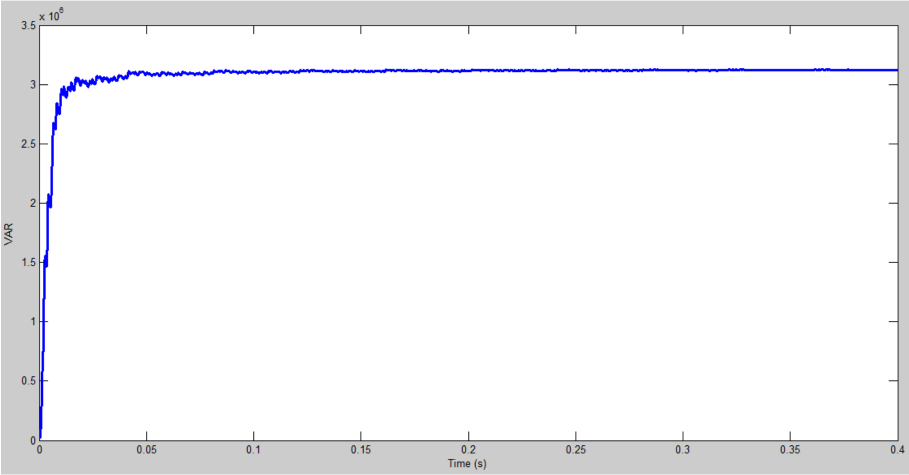


Fig 6.12 (c): Reactive power of the load.

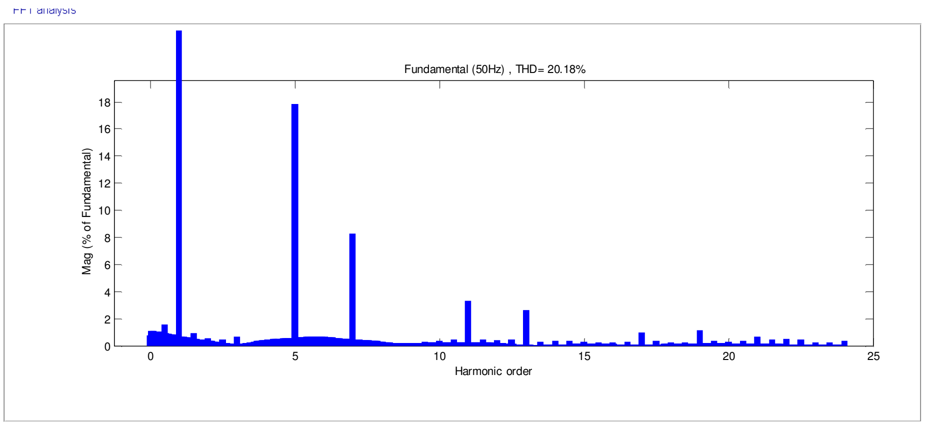


Fig6.13 (a): Source current (FFT) unless APF with THD =20.18%.

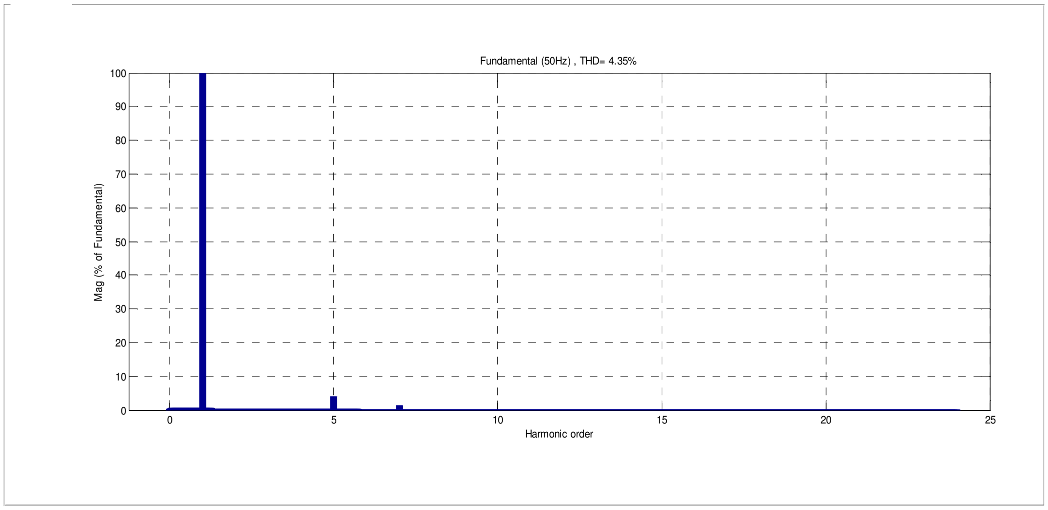


Fig 6.13 (b): (FFT) for source current cabled with single inverter (THD=4.35 %).

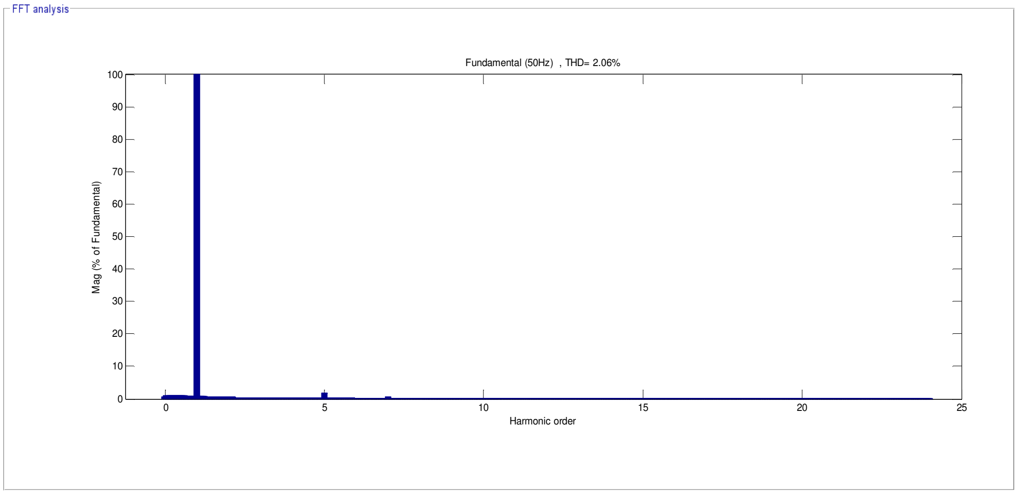


Fig 6.13 (c): (FFT) for source current with two inverter (THD =2.05%).

6.4 CASE 2 TRANSIENT STATE CONDITIONS:

In this condition of study, we consider to turn on both systems we can see that the effects on the transient system is grater then the steady state (harmonics), one inverter SHAPF and two inverters SHAPF model are presented to a transient condition. The transient test is used to evaluate the response and waveforms of the shunt active power filter (SHAPF). This simulation is modeled under environment of MATLAB/ Simulink to ensure that the shunt active power filter (SHAPF) is able to recover from this transient condition without affecting on the stability of the overall system.

To declare the idea the DC motor load is added in parallel during period of time and the transient behavior of the system was studied. The motor parameters summarized on table 6.1.

The current waveform and the Total Harmonic Distortion (THD) shown in Figure 6.14(a, b and c) respectively

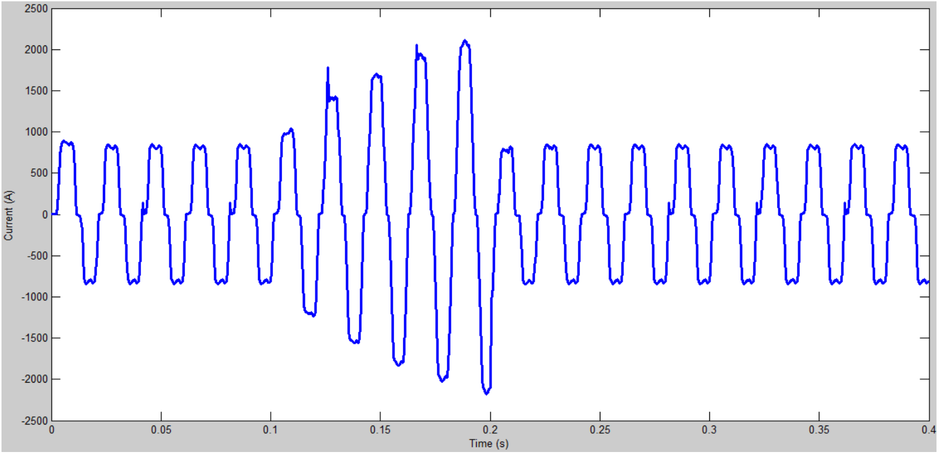


Fig.6.14 (a): transient condition with load current without filtering.

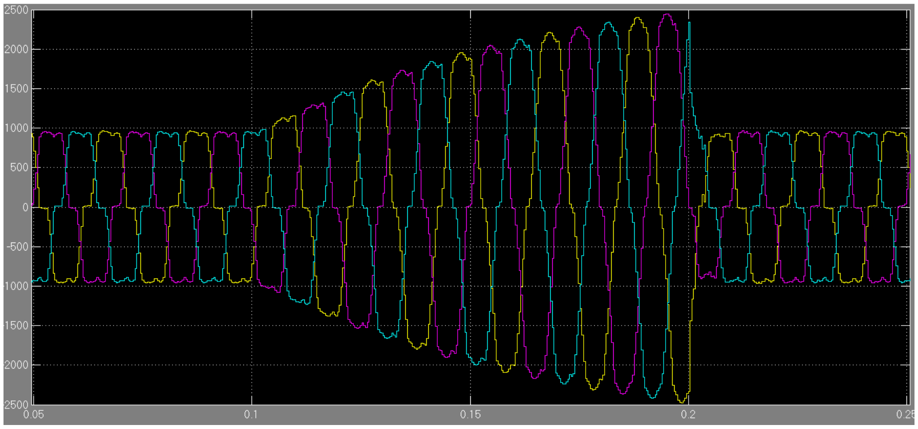


Figure 6.14 (b): transient condition of 3-phase load current without filter.

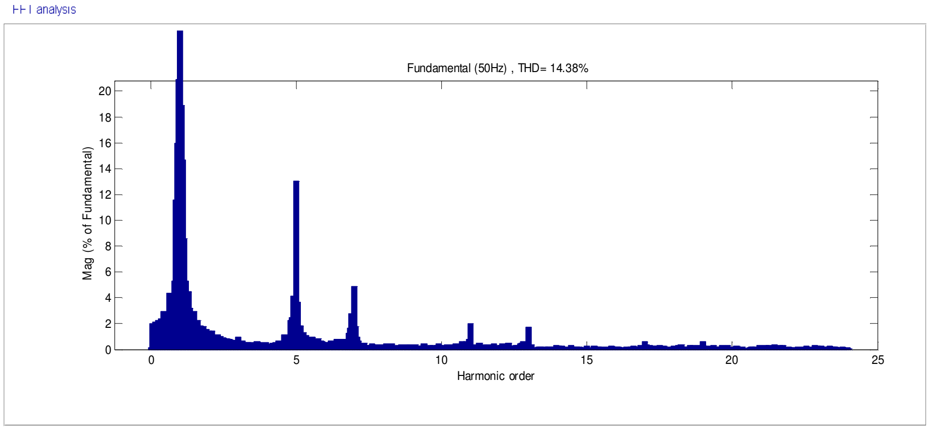


Fig 6.14 (c) : Source current (FFT) unless two inverters (THD =14.38%).

Figure 6.15a represents the current source for particular phase after compensation with one inverter SHAPF, we can mention and shows that the current is more sinusoidal and in this area the harmonic is decrease between 0.1 to 0.2, the three phase's current is shown in Figure 6.15b.also the THD by using two inverter SHAPF is shown in figure 6.15.c.

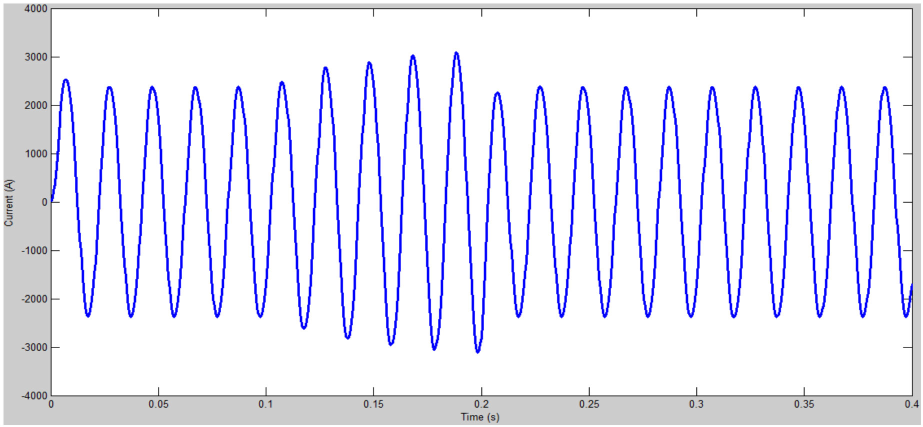


Fig 6.15 (a): transient source current filter with APF.

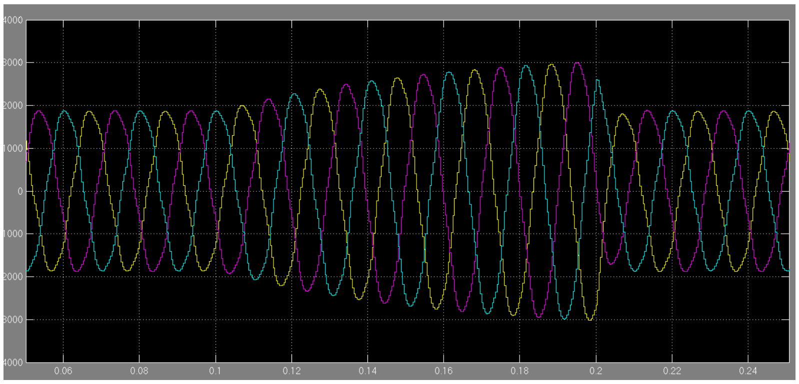


Figure 6.15 (b): transient of 3-phase source current with filtering.

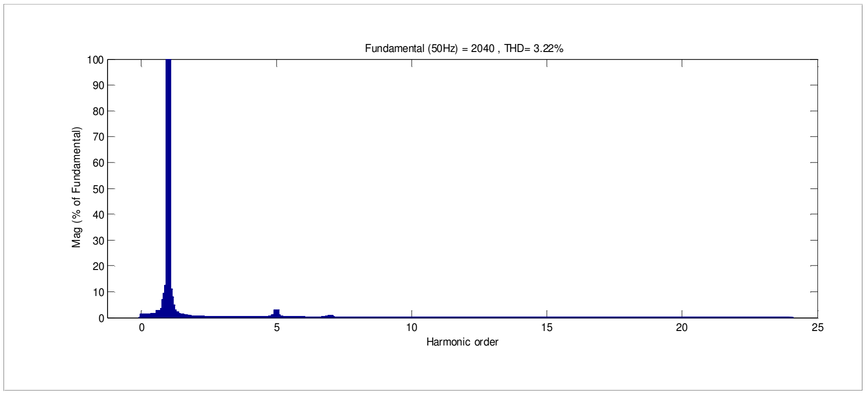


Fig 6.15 (c): (FFT) for source current by using single inverter (THD =3.22%).

Figure 6.16a represents the current source for a particular phase after compensation with two SHAPF inverters which is depicted, we can see that the current is enhanced to be more sinusoidal and in this area the harmonic is decrease between 0.1 to 0.2, the three phase's current is shown in Figure 6.16b.also the THD by using two inverters SHAPF is shown in figure 6.16.c.

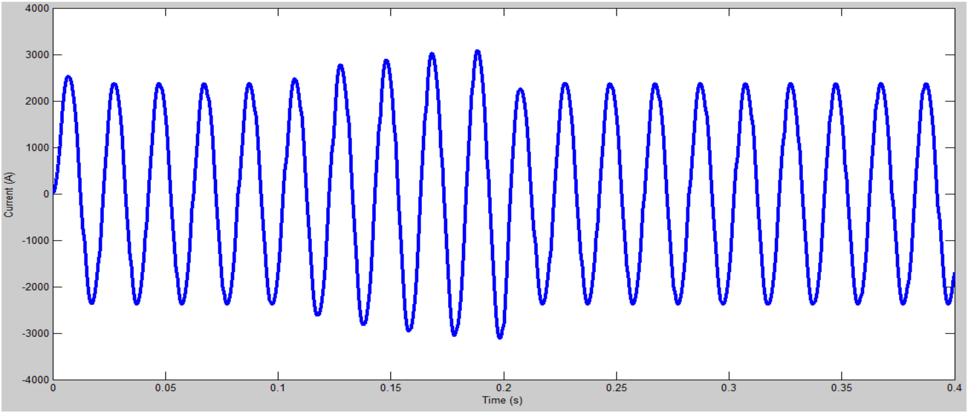


Fig 6.16 (a): transient source current filter with two inverter.

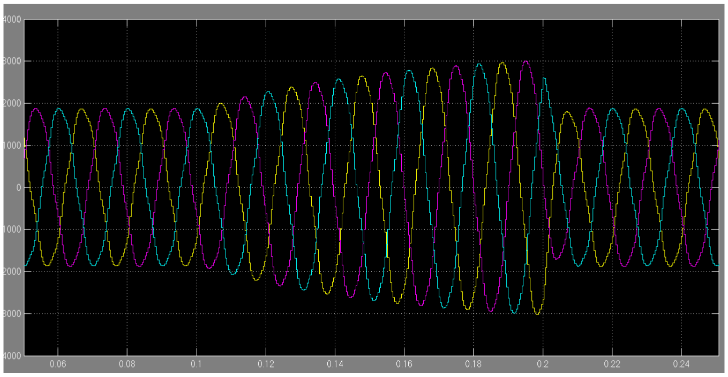


Figure 6.16 (b): transient of 3-phase source current with filtering.

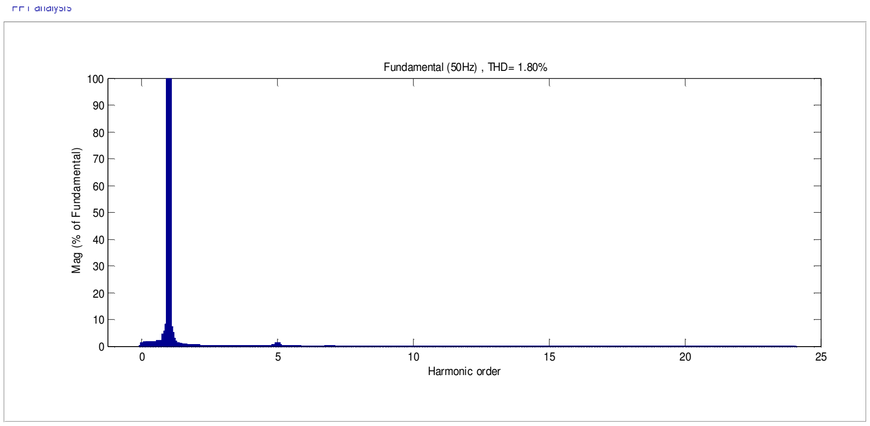


Fig 6.16 (c): (FFT) for source current with two inverters (THD =1.80%).

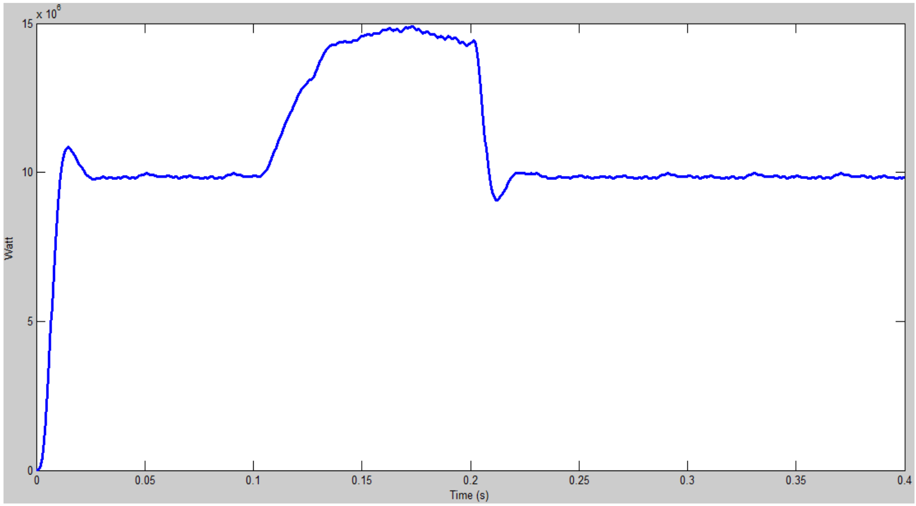


Fig 6.17 (a): Active power of the load.

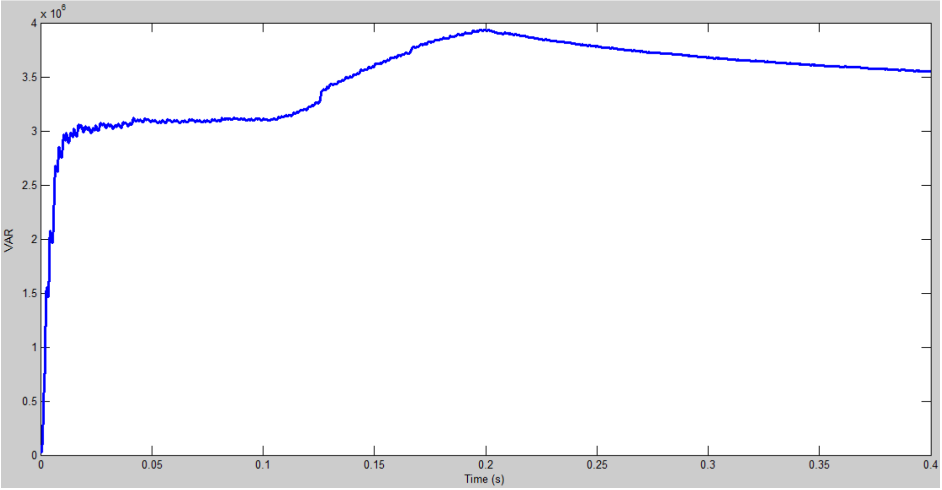


Fig 6.17 (b): Reactive power of the load.

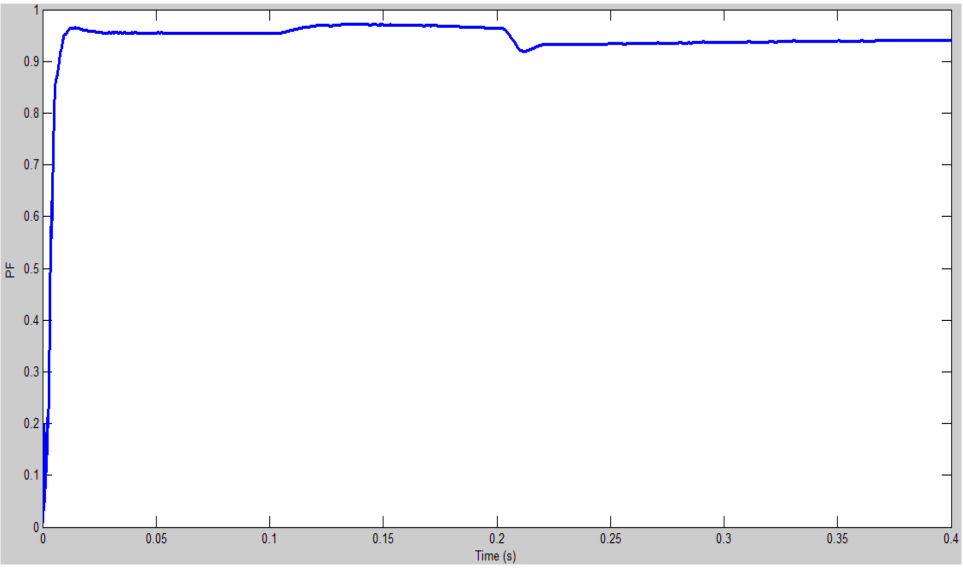
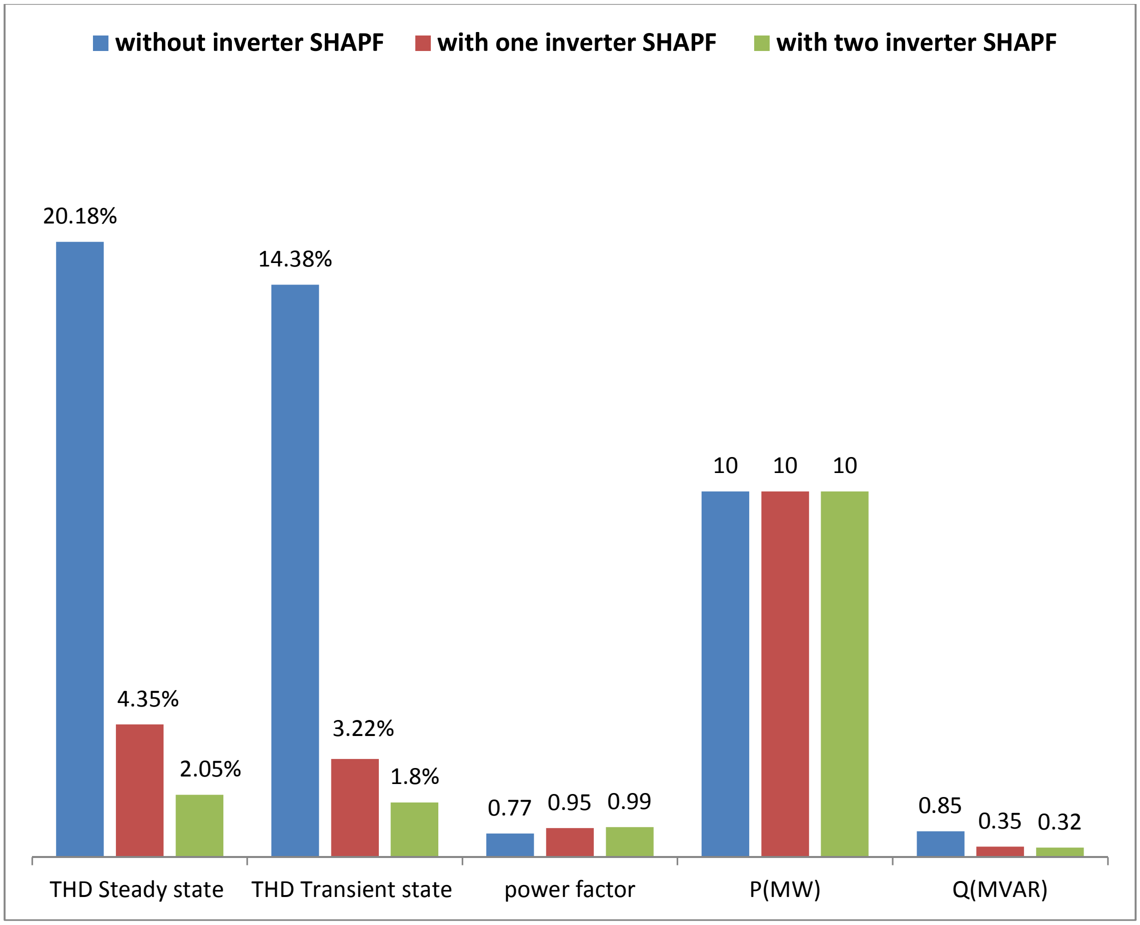


Fig 6.18: Total power factor with (APF).

Table 6.2: Summary results of this thesis.



7-CONCLUSIONS AND FUTURE WORKS

7.1 CONCLUSIONS:

In recent years, most researchers studied a Shunt Active Power Filters (SAPF) based on conventional two-shunt inverter with conventional controllers that requires a complex and a complicated mathematical model. In order to overcome this problem in the literature a Hysteresis band controller based diode clamped multilevel inverter has been implemented and extended. In my thesis deal with implementing and design of three phase two inverters shunt Active Power Filter (APF), in distribution system 11KV to enhance the reactive power and so eliminate harmonics from a typical non-linear load, composed from (uncontrolled bridge rectifier with inductive load and DC motor). In this research, almost a unity power factor and sinusoidal current source is achieved. The current source total harmonic distortion (THD) after compensation by single inverter is 4.35% but by using two inverters it decreases to 2.05% which is agreed and less than the harmonic limit imposed by the IEEE-519 standard (3%), by using two parallel inverters with 11-Step diode clamped multi-level inverter the circuit is simulated by using MATLAB/ Simulink.

System which is taken account eliminates most of the harmonics in the transmission system to make the source voltage and source current waveforms sinusoidal

Comparison of three models against proposed model is given at table 7.1.

Table 7.1: Comparison of Investigated Compensation Systems.

Differences	(Ibrahim.A. Altawil,2011)	(Siriroj Sirisukprasert ,1999)	Adnan Tan, (2011)	**Proposed model**
1-Topology	Shunt Active Power Filter, current source	Comparison between two techniques to reduce THD multilevel voltage source inverter using cascaded inverters with separated DC sources.	shunt hybrid active power filter system, for current source inverter based induction furnace(CSI-IF),	Two inverter Shunt Active Power Filter Current source
2-load	Nonlinear load with Inductive load.	In each phase, a resistor and inductor are connected in series.	Nonlinear (CSI-IF).	Nonlinear load (rectifier load bridge, inductive and DC motor).
3-simulation model	Three phase 9-Step diode clamped multi level inverter. (MATLAB program)	3-phase 7-steps Multilevel voltage source inverter using cascaded inverters with separated DC sources using triangular-carrier method. (MATLAB program)	Three phase 3-Step bridge inverter.(MATLAB program)	Three phase 11-Step diode clamped multi-level inverter.(MATLAB program)
4-results	THD=2.8% PF=0.95 P= 20 kW Q= 6 kVAR	Line voltage THD = 12.3% P=1.8KW PF=0.92 Q=2.5KVAR	THD=1.8-3.2% P= 31.5KW PF=0.95 Q=4MVAr	THD=1.80% PF=0.99 lagging P=10MW Q=0.32MVAR

7.3 FUTURE WORK:

In recent decades the interest about semiconductors material and its applications was increased, because the power electronic devises are widely used in different applications and practical fields, and it negatively effect to the power quality. On the other side the capacitor voltage in this thesis is controlled by conventional Pronominal Integral (PI) controller; it can be used some alternatives instead of control (PI) such as artificial intelligent technique, fuzzy logic control, simulated annealing, artificial neural network (ANN), etc. Furthermore, Hardware implementation of the three phase SAPF system is recommended as an extension to the simulation project for verification purpose.

REFERENCES

Books

R. C. Dugan, M. F. McGranaghan, S. Santosa, and H. W. Beaty, “Electrical Power Systems Quality”, second edition, McGraw-Hill, 2002.

C. Sankaran, “Power Quality, the Electric Power Engineering Series”, CRC PRESS, 2002.

Philippe FERRACCI, “Power Quality, Cahier technique”, Cahiers Techniques Electric, 2001, – No. 199.

Lund quist, Johan, Associated power technologies," Total harmonic distortion and effects in electrical power systems", 2001.

Alexander Kusko, Marc Thompson, McGraw Hill P.C. Power Quality in Electrical Systems, 2007.

Angelo Baggini. ‘Hand book of power quality’, John Wiley and Sons, Ltd. The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England.

Francisco C. De La Rosa, Harmonics and Power Systems, The Electric Power Engineering Series, Taylor & Francis Group, 2006.

J. David Irwin, Power electronics handbook, Auburn University, Series editor.

Lander, Cyril W. (1993). “Rectifying Circuits". Power electronics (3rd ed. ed.). London: McGraw-Hill. ISBN 9780077077143.

Periodicals

IEEE Standards Board “Guide for Harmonic Control and Reactive Power Compensation of Static Power Converters”, IEEE Std. 519-1981

Supratim Basu and Tore M.Undeland, “Diode Recovery Characteristics, June 2006 Considerations for Optimizing Performance & Cost of Continuous Mode Boost PFC Converters”, Published in EPE Journal Vol. 16. No 1, February 2006.

Ewald F. Fuchs, Mohammad A. S. Masoum, “Power Quality in Power Systems and Electrical Machines”, Elsevier, 2008.

H. Johan, Frederik S. Van Der Merwe, “Voltage Harmonics Generated by Voltage- Fed Inverters Using PWM Natural Sampling,” IEEE Transactions on Power Electronics, Vol.3, July, 1988, pp.297-302,

Smruti Ranjan Prusty “FPGA Based Active Power Filter for Harmonics Mitigation” Roll No: 209EE2172. National Institute of Technology Rourkela .June 2011

Po-taicheng and Z.lin, "Distributed Active Filter Systems (DAFS): A new approach to Power System Harmonics",0-7803-8486-5/04/$20.00©2004, IEEE.

M.T. Benchouia, A.Ghamri, M.E.H. Benbouzid, A. Golea, S.E. Zouzou,"Fuzzy Model Reference Adaptive Control of power converter for unity power factor and harmonics minimization”, Proceeding of International Conference on Electrical Machines and Systems 2007, Oct. 8~11, Seoul, Korea.

Y.Qu, W.Tan, Y.Dong, Y.Yang, "Harmonic Detection Using Fuzzy LMS Algorithm for Active Power Filter", 987-981-05-9423-7©2007 RPS.

Tain-SyhLour, "Influence of Load Characteristic on Applications of Passive and Active Harmonic Filters", 0-7803-6499-6/00/$10.00©2000 IEEE.

Z. F. Hussien. N. Atan, I. Z. Abidin, "Shunt active power filter for harmonic compensation of nonlinear loads", 0-7803-8208-0/03/$17.00©2003 IEEE.

L.Asiminoaei, E.Aeloiza, P.N.Enjeti, F.Blaabjerg, "Shunt Active Power Filter Topology Based on Parallel Interleaved Inverters", IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 55, NO. 3, MARCH 2008.

H. Ezoji, M. Fazlali, A. Ghatresamani, M. Nopour, "A Novel Adaptive Hysteresis Band Voltage Controller for Dynamic Voltage Restorer", 1450-216X Vol.37 No.2 2009 pp 240-253, European Journal of Scientific Research.

Dianguo, G. Jianjun, L. Hankui, and G.Maozhong, "Unified Power Quality Conditioner (UPQC): The Principle, Control and Application", Power conversion conference 2002, pcc-Osaka, Vol. 1, pp 80-85.

P. Boonchiam and N. Mithulananthan, "Diode-Clamped Multilevel Voltage Source Converter for Medium Voltage Dynamic Voltage Restorer".

K. Derradji Belloum, and A. Moussi, "A Fixed Band Hysteresis Current Controller for Voltage Source AC Chopper", World Academy of science, Engineering and Technology, 45, 2008.

Keith A. Corzine, "A Hysteresis Current Regulated Control for Multilevel Drives", IEEE Transactions, 0885-8969/00$10.00©2000, IEEE.

XuDianguo, GuJianjun, Liu Hankui, and Gong Maozhong, "Improved Hysteresis Current Control for Active Power Filter", 0-7803-7912-8/03/$17.00©2003, IEEE.

Luis A. Morán, Juan W. Dixon, José R. Espinoza And Rogel R. Wallace “using active power filters to improve power quality”.5th Brazilian power electronics conference cobep99, 1999.

Zhongtingjian, Fanyouping, Xieyouhui“the research on hybrid shunt active power filter” Nanchang, p. r. china, may 22-24, 2009, pp. 100-103.

Grino, R., Cardoner R., Costa-Castello R., Fossas E, “digital repetitive control of a three phase four-wire shunt active filter” IEEE trans. industrial electronics, vol. 54, (2007):pp.1495- 1503.

Siriroj Sirisukprasert, “Optimized harmonic stepped-waveform for multilevel inverter” September 15, 1999blacksburg, Virginia.

F. Z. Peng, J-S Lai, “multilevel converters – a new breed of power converters” ieee transactions on industry applications, vol.32, no.3, may/June, 1996, pp.509-517.

Z. Salam, T. P. Cheng, and A. Jusoh, “Harmonic mitigation using active power filter: A technological review,” Electrical, vol. 8, no. 2, pp. 17–26, 2006.

Hirofumi Akagi, Edson Hirokazu Watanabe, Mauricio Aredes. ‘Instantaneous power theory and applications to power conditioning’, A John Wiley & Sons, Inc., Publication.

Z. F. Hussien. N. Atan, I. Z. Abidin, "Shunt active power filter for harmonic compensation of nonlinear loads", 0-7803-8208-0/03/$17.00©2003 IEEE.

F. P. Zeng, G. H. Tan, J. Z. Wang and Y. Ji, "Five level voltage-source inverter for shunt active power filter", 978-1-4244-1874-9/08/$25.00©2008 IEEE.

V. Micah E, Rodrigo E. Carmi, Juan W. Dixon “Voltage-Source Active Power Filter Based on Multilevel Converter and Ultra-capacitor DC Link” IEEE Transactions on industrial electronics, Vol. 53, No. 2, April 2006.

H. Akagi, Y. Kanazawa, and A. Nabae, “Generalized theory of the instantaneous reactive power in three-phase circuits,” in Proc. IPEC, Tokyo,Japan, 1983, pp. 1375–1386.

M. K. Syed, B. V. Sanker Ram, "Instantaneous Power Theory Based Active Power Filter: A Mat lab/Simulink Approach", Journal of Theoretical and Applied Information Technology, ©2005-2008, JATIT.

R. S. Herrera, P. Salmeron, "Instantaneous Reactive Power Theory: A Reference in Nonlinear Loads Compensation", IEEETRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 56, NO. 6, JUNE 2009.

M. Mohapatra, B. C. Babu, "Fixed and Sinusoidal- Band Hysteresis Current Controller for PWM Voltage Source Inverter with LC Filter", IEEE Student's Technology Symposium 2010, IIT Kharagpur,03-04/April/2010.

S. Buso, S. Fasolo, L. Malesani, P. Mattavelli, "A dead beat adaptive hysteresis current control", IEEE Transactions on industry applications, Vol.36, no.4, pp1174-1180, July 2000.

M. Kale, E. Ozdemir, "A novel adaptive hysteresis band current controller for shunt active power filter", 0-7803-7729-X/03/$17.00©2003 IEEE.

Mohammadreza Derakhshanfar, Göteborg, “Analysis of different topologies of multilevel inverters”, Sweden, 2010.

Adnan TAN modeling and analyses of power quality compensation system for current source inverter based induction furnace, turkey 2011.

Ibrahim A. Altawil, shunt active power filter based on diode clamped inverter and hysteresis band current controller, 2011, Jordan.

APPENDICES

Appendix A.System Parameters of the Simulated System.

Parameter	Value
Source Voltage V_s	11KV$_{p\text{-}p}$
Source frequency f	50 Hz
Voltage phase angle	**0^o**
Source resistance R_s	0.1 Ω
Source Inductance L_s	10 mH
Load inductance L_r	1.5 mH
Load Resistance R_r	**20 Ω**
Armature Dc Motor Load inductance L_r	**3 H**
Armature Dc Motor Load Resistance R_r	**2 Ω**
Field Dc Motor Load inductance L_r	13 **H**
Field Dc Motor Load Resistance R_r	84Ω
Field of Dc Motor	**400 V**

Table A.1 parameters of the simulated.

Appendix B. Simulation System Configuration.

Appendix B.1 Simulation Implementation of current measurements.

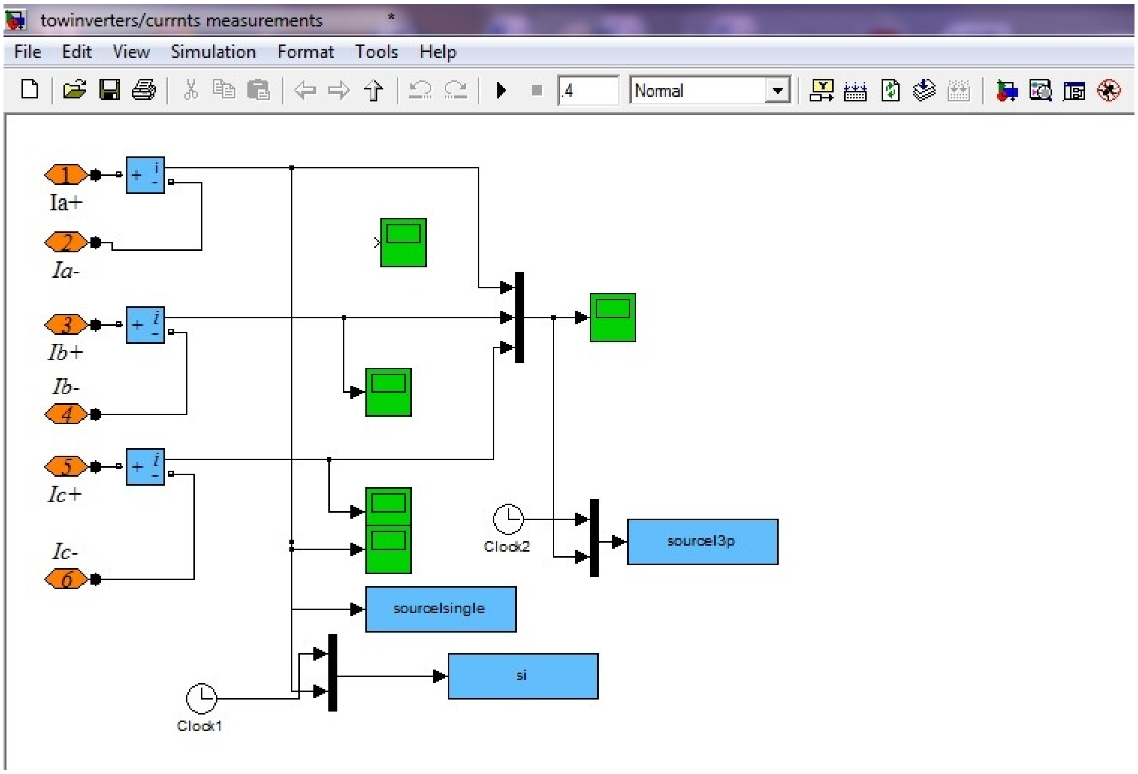


Figure B.1 System configuration of current measurements simulation.

Appendix B.2 Simulation Implementation of AC voltage source

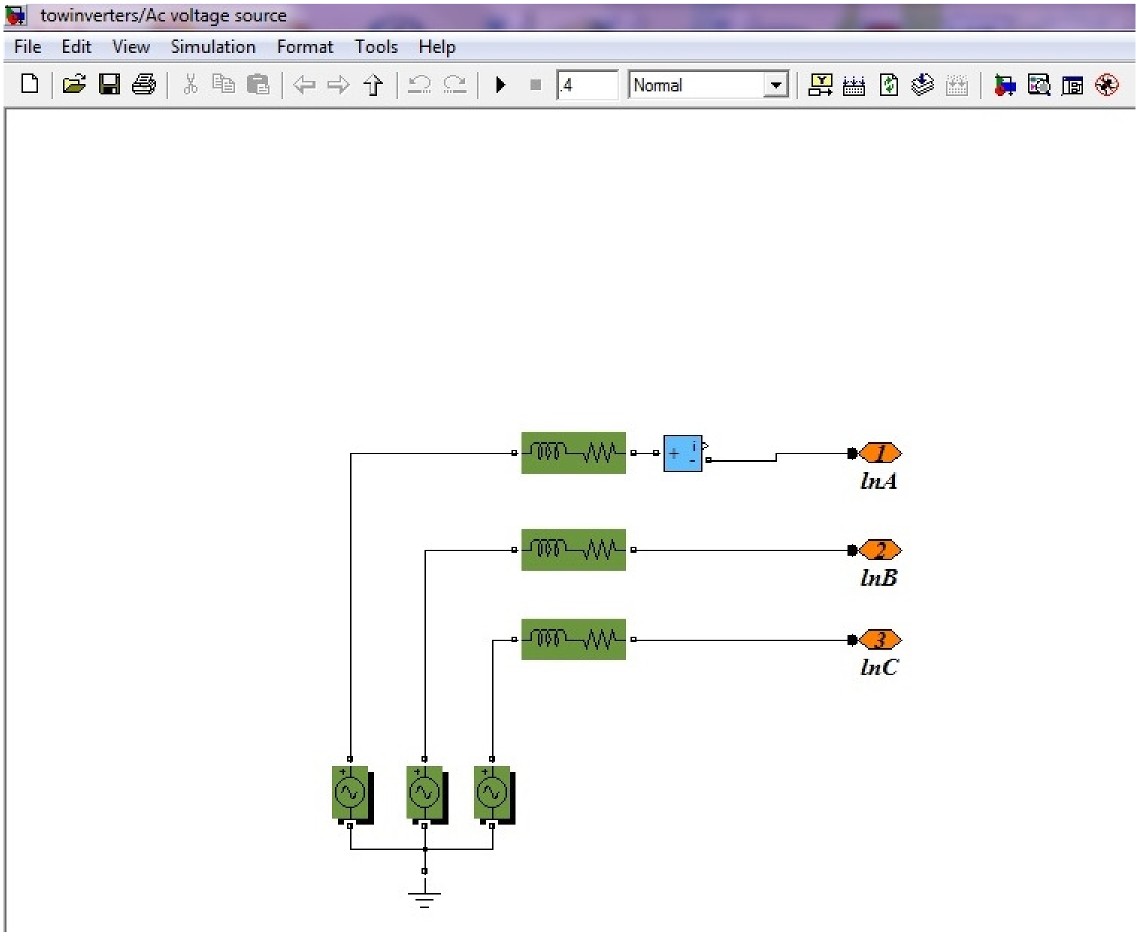


Figure B.2 System configuration of AC voltage source simulation.

Appendix B.3 Simulation Implementation of SAF

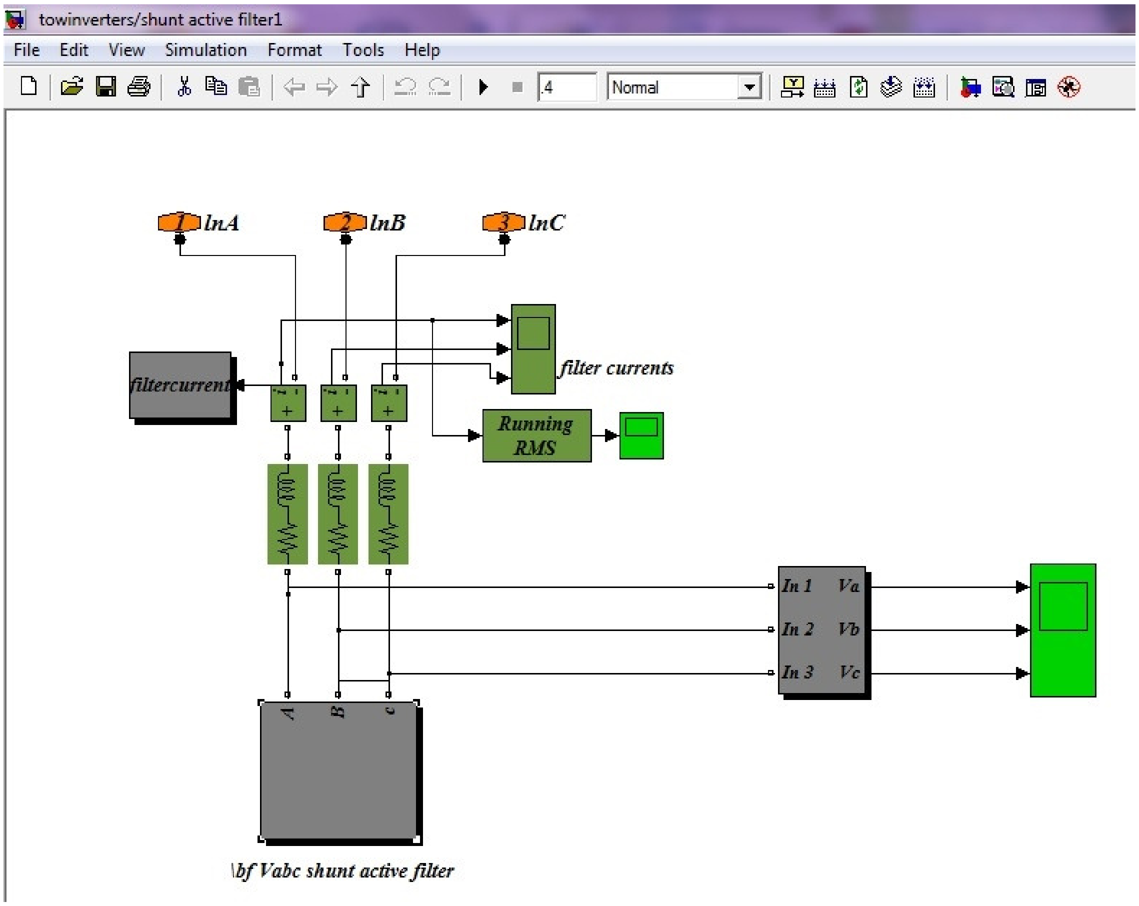


Figure B.3 System configuration of SAF simulation.

Appendix B.4 Simulation Implementation of non-linear load.

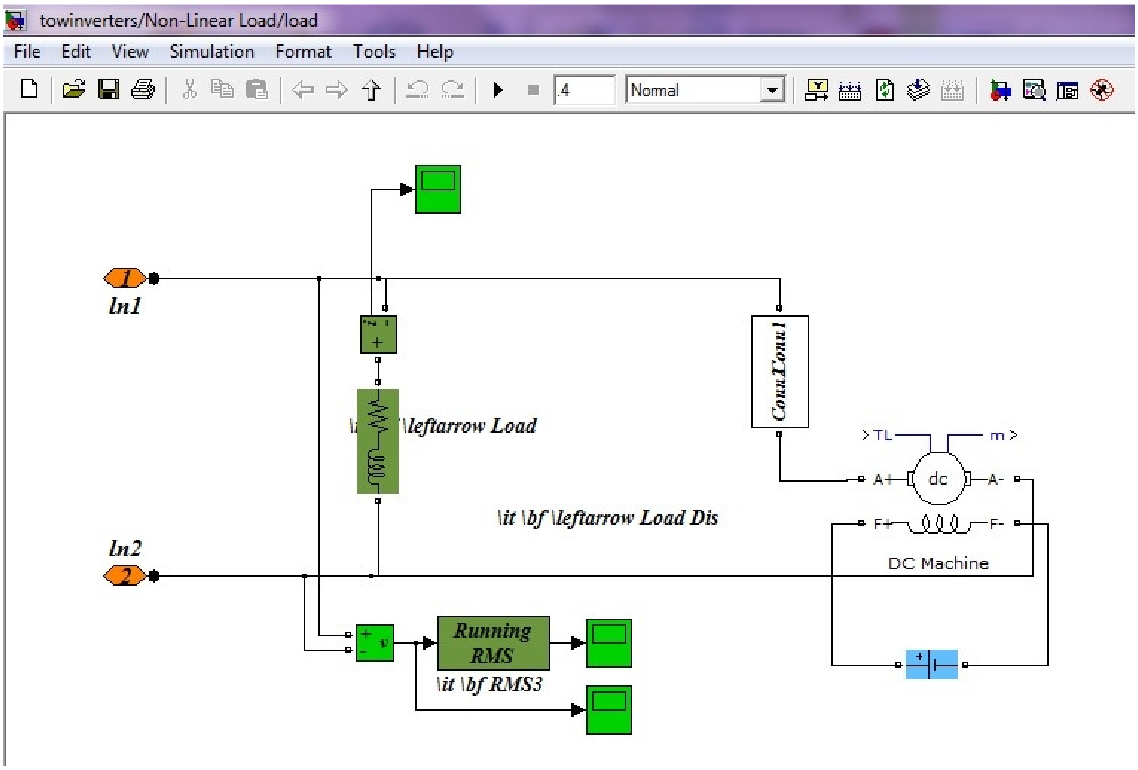
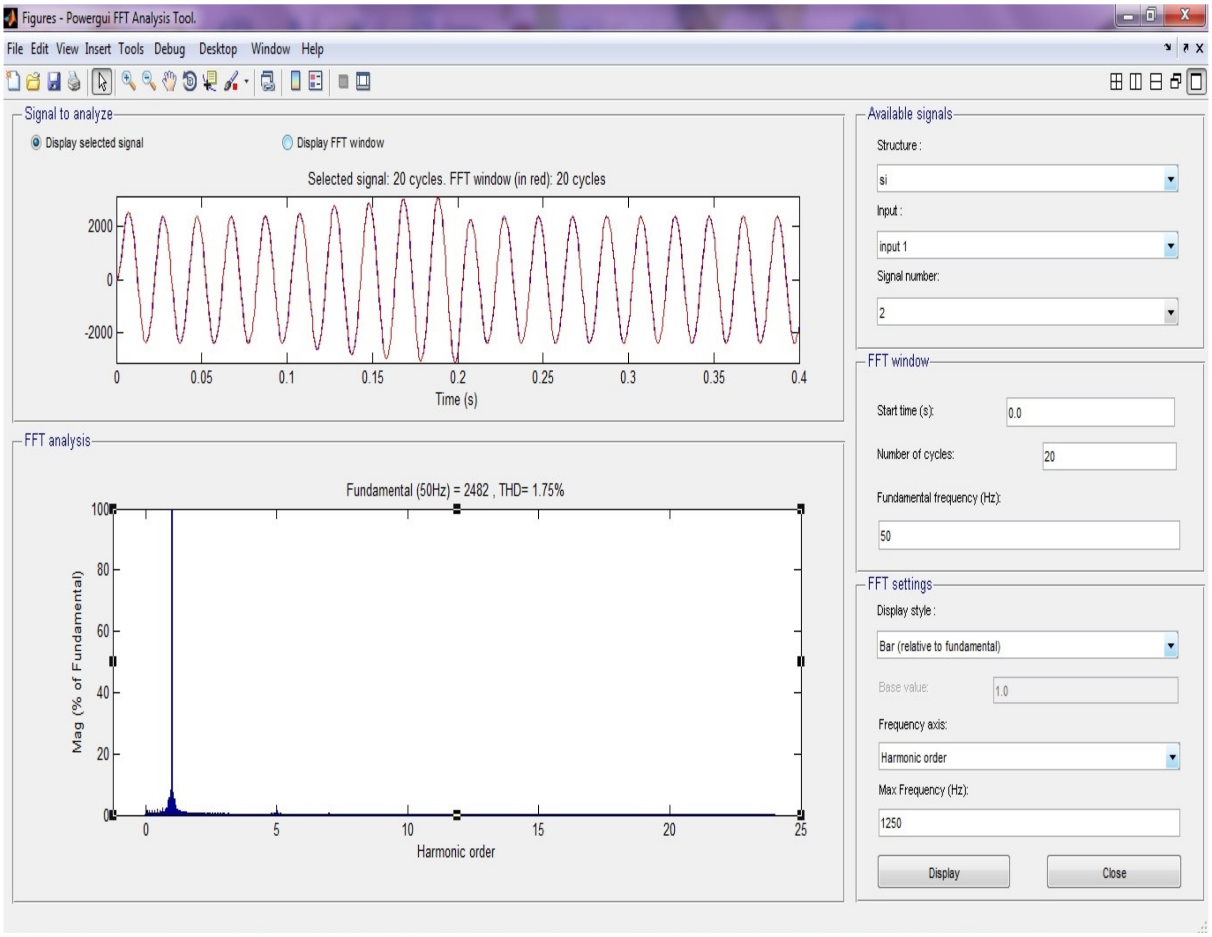


Figure B.4 System configuration of non-linear load simulation.

Appendix B.5 Simulation Implementation of FFT analysis.



Signal to analyze

● Display selected signal

○ Display FFT window

Selected signal: 20 cycles. FFT window (in red): 20 cycles

FFT analysis

Fundamental (50Hz) = 2482 , THD= 1.75%

Available signals

Structure : si

Input : input 1

Signal number: 2

FFT window

Start time (s): 0.0

Number of cycles: 20

Fundamental frequency (Hz): 50

FFT settings

Display style : Bar (relative to fundamental)

Base value: 1.0

Frequency axis: Harmonic order

Max Frequency (Hz): 1250

Figure B.5 System configuration of FFT analysis simulation.