An-Najah National University

Faculty of Graduate Study

Fault-Tolerant Unified Power Quality Conditioner with Active and Reactive Power Injection Capability using Multi-level Inverter and Photovoltaic Array

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Dedicated

TO

MY FAMILY MEMBERS

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الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل عنوان:

Fault-Tolerant unified power quality conditioner with active and reactive power injection capability using multi-level inverter and photovoltaic array

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Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

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Date: التاريخ: 22/7/2020

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Table of Definition

UPQC	Unified Power Quality Conditioner
APF	Active Power Filter
PPF	Passive Power Filter
SAPF	Series Active Power Filter
SHAPF	Shunt Active Power Filter
PCC	Point Of Common Coupling
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
UPQC-R	Right Unified Power Quality Conditioner
UPQC-L	Left Unified Power Quality Conditioner
UPQC-MC	Multi-Conveter Unified Power Quality Conditioner
UPQC-MD	Moduler-Unified Power Quality Conditioner
UPQC-ML	Multilevel-Unified Power Quality Conditioner
PV	Photovoltaic

Fault-Tolerant Unified Power Quality Conditioner With Active and Reactive Power Injection Capability Using Multi-level Inverter and Photovoltaic Array

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Abstract

The unified power quality conditioner (UPQC) is a combined unit consists of two units.These two units are series and shunt active power filter. It works with the benefits of both systems. So it can eliminate the harmonics of both current and the voltage and enhance the power quality for the electrical network in general.

UPQC is consisting of two 27-level cascaded H-bridge inverter. Each phase of these inverters is composed of three 'H' bridges, supplied by three independent photovoltaic arrays Scaled in the power of three, delivering 12. 5Kva to each phased, 10Kva for shunt active filter and 2. 5Kva for series active filter.

The outputs of inverters connected directly through a transmission lined. In addition to the capability of harmonic elimination of both current and voltage drawn from the sourced, the combined system can produce real and reactive power to feed the loads during prolonged voltage outages or source shortage.

A battery pack used as dc link, which is charged from photovoltaic array connected to the battery through a maximum power point tracker and charge controller.

The injection of real and reactive power depends on the state of charge (SOC) of batteries, the system frequency, type of the load, and power factor at the common linking point.

The propose strategy is simulated in MATLAB SIMULINK and the results are shown.

Chapter1
Literature review

1.1 INTRODUCTION

Electricity dis the backbone for modern society. Delivering the electrical power for detach customer dis da nicety that life cannot continue without did. One of the most important factors that affecting the electrical energy section is the power quality. The power quality of the electrical grid is very important.

The power quality is a new problem and the research in it is a new trend of the electrical research. The ability of solving the power quality issues differentiates between a good reliable and bad unstable electrical system.

Nowadays, many problems are faced due to an increase of using nonlinear load in everyday. This increase comes with its own challenges and problems. The increase in using nonlinear and nonlinear unbalanced load make the grid get distorted that the reason of using a great number of power electronic switches.

The low quality of the grid has a great effect on a lot of parameters of the grid. These parameters can create problems that are needed to be solved. These problems are: voltage sag, spike, swell, and harmonics, and these problems create electrical losses on the grid and these losses increase when the distortion increases. To overcome these problems a lot of topologies are used.

Before the great advance in power electronic switch manufacturing passive-filters are utilized for eliminating harmonics and enhance the quality of the power. The design of passive power filter depends of the values of the capacitors and inductor that is combined with the network in series or in parallel.

The passive filter is tuned to eliminate a certain harmonics while other harmonic remain in the system , and also can make resonances with the system with other circuit in system which eliminate them in the network. To solve these problem APF had been devolved [1]

APF is filter that use power electronic switches to eliminate harmonics that is below theirs switching frequency. Active filter can filter both higher and lower order of harmonics in the electrical grid.

The main deference between active and passive filters is that active power filter eliminates harmonics by injecting power to the system with the reversed phase and same frequency to cancel the harmonic. Where PPF utilizing components like inductors, capacitors and resistance that’s need external source to be operated these deference make active filter can eliminate harmonics in wider ranges of frequency [2].

Active filter can also be found in many form and topology such of shunt and series. In this work a combined mythology is considered to make unified power quality conditioner.

Multilevel inverter can be utilized as APF to eliminate harmonic in this research h bridge multilevel invertor is used for the enhancement of power quality [3].

1.2 LITERATURE REVIEW

1.2.1 UPQC history

1970s technical writing can be found about the mythology and the application of the technology of UPQC. However the first time the use of UPQC can be noticed in the in the mid-1990s along with new devices and system of power quality modifying such as STATCOM and other available to use.

In 2000s beginning the development in power electronic switch technology resulted in UPQC had become more commercially available than before ; however the total cost of the instillation of this system and the technical complication put some limitation to the system for high power capacity the trend now is to develop this system with greater efficiency and reliability[3] .

In 2004 "optimal control strategy of UPQC for minimum operational losses" this research reviewed a technical to reduce the operational losses in UPQC that technique depend on VA loading compensators by calculating a needed angle before of injection for the series and shunt compensators in UPQC [4].

In 2005 " A novel-control strategy for UPQC" this good paper discus the use of novel control strategy to control UQPC using simpler without transformation like park transformation by using measured voltage And current to control UPQC[5] .

In 2006 " a direct control strategy for UPQC in three phase four wire system" this paper present a new direct control strategy based on p-q-r theory that can be used in enhancing power quality for 3-phase 4-wire system an algorithm is presented in this paper that can recompense the voltage of series APF and shunt APF of a certain UPQC. This algorithm is designed to consider the high current of natural line when nonlinear load is applied on 3phase 4 wire system [6].

In 2006 " new configuration of UPQC for medium voltage application" this paper present new configuration for medium voltage application this configuration can work and connected to the electrical network without series-transformer the inject power to the system and that can be done by rising the number of the h-bridge module to the UPQC that’s make it more fixable in increasing the operational voltage [7].

In2007 the location of the shunt in system had been considered that’s the UPQC can be left shunt and right shunt type system and compared the performance for both locations in the same system. And the connection point to the electrical network had been considered so a study had been implemented the effect of connecting the system to a weak point of the grid and how would it effect the working efficiency of UPQC under unbalanced non-linear load[8][9].

In 2010 new proposed way to design the dc system controller to keep the dc value for the dc link for Poth series and shunt APF filter is very important so can UPQC preform normally that depends on to the balance of active power[10]. Also in 2010 the concepts of using multilevel inverter UPQC had been suggested due to the effective in this model and configuration [11]

In 2011 Bhaskar Karanki compared in his paper between different configuration of voltage based source UPQC compared between his topology had proposed a how the configuration effect the voltage requirement for dc link voltage [12].

B. S. Mohammed had a good paper that had been published in 2012 that detect the different of the performance between left shunt and right shunt UPQC using voltage detection algorithm [13].

Vinod Khadkikar in 2102 had a compressive overview on different configuration and classification sand their effectiveness in power quality enhancement in distribution area and show the possible configuration for the system [14].

In 2014 Wei Tongzhen proposed in his paper a new scheme of UPQC that are suitable for large capacity industrial are by make it easier to communicate and coordinate to handle sensitive load that can be summarized as the following by having a large capacity voltage regulator and small capacity DSTATCOM on the load side so we enhance the power quality for these specific area [15] .

In 2015 Amit Shrivastava implicated an integrated renewable energy system with UPQC and show the topology of connecting and combining the renewable energy system with UPQC to test the output on unbalanced non-linear load [16].

In 2018 Amarendu Behera implemented study about the performance of UPQC under fault and the changes in output value of the system and how integrating UPQC to the system minimize the damage on the system [17].

The evolution of the research on UPQC has gone from stage to anther it stated as literature then new topology and scheme evolved practically after that control method had emerged to get the optimum result and outputs. Then with the evaluation of renewable energy system had emerged the integration of UPQC within renewable system. Then the focus and the trend of the research focus on the stability of the system under different work condition and under faults so UPQC can work swiftly in enhancing power quality.

1.2.2 Unified power quality conditioner UPQC function

UPQC are consists of shunt APF and series APF combination in configuration and in function. At the end of the 90s and the begging 2000s UPQC were expensive and very complicated to control so it was used in small scale application and for large capacity loads spared units of series and shunt APF are used. But the great developments in power electronic manufacturing make it possible to utilize UPQC for large capacity application [18].

The main components of UPQC are forms by the following component two inverters are connected to the electrical network the first one is in series with the line and the other is connected in shunt across the load. The shunt is coupled with inductor and also help to smooth the current. The series part use series transformer to connect to the network a common dc point is formed between the two inverters to interconnect the inverters and keep the DC voltage constant as possible [3] the component of the system shown in FIG (1).

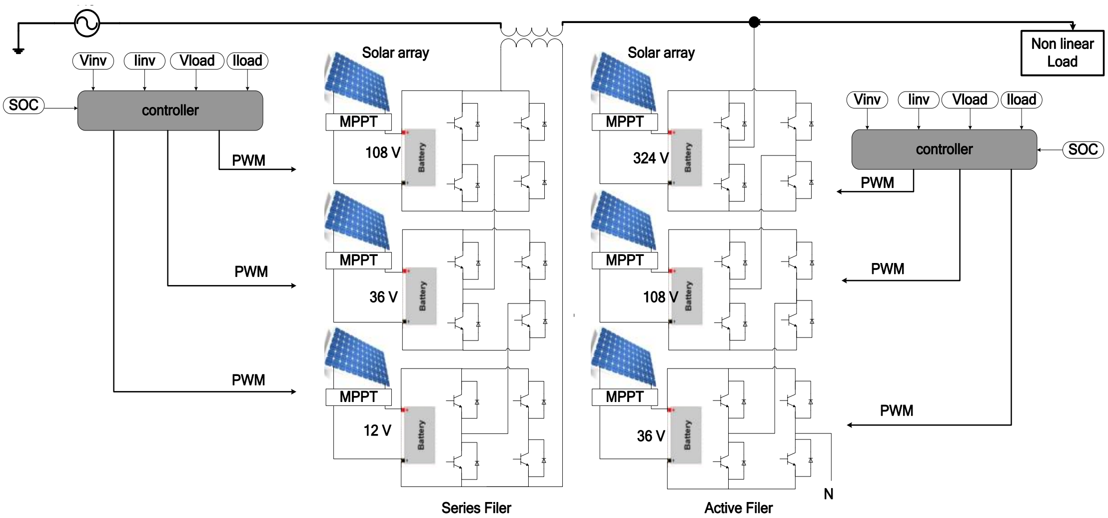


Fig (1.1) Unified Power Quality Conditioner power circuit figure

UPQC can handle both the voltage and the current that is related to power quality issue and the trend recently give more attention to the reducing of voltage swell, sag, using UPQC that is resulted by the unexpected change in of the current that follow in the impedance of the power source for the whole system[19].

The basic working principle of the system and the main control technique is as following is to inject predefined quantities of real and reactive power to the system that is in general.

In the series part of the system there is multiple technique are used but the main principle is to compensate the distortion that happened in the potential by adding voltage that is similar in the value and counteractive in the phase so it can compensate the distortion on the network [20] [21].

Meanwhile the series active filter uses power electronic switches so it can generate harmonic current so it can recompense the harmonic current that is needed by the non-linear loads [22]

1.2.3 Cascade H-bridge multilevel inverter overview

H-bridge converter is a popular topology that consists of cell that is connected in cascade in their AC side that help using this type of topology in high voltage application and low on harmonic distortion and this type of converter have the same DC voltage value in each leg [23].

In 2000 paper of LI LI had proposed using CHB as series active filter for harmonic elimination PWM modulation algorithm had been used to get the optimal power quality enhancement [24].

In 2005 Eryong Guan proposed an algorithmic way to solve the non-linear equation of for the stair case modulation for selective harmonic elimination in HBC. To get rid of this problem he presents a novel homotopic algorithm which is a great solution for this problem [23].

Multilevel inverter like CHB work with different in high and medium sensitive loads so the reliably issue is very important to consider the fault in these devices can create great losses if the system failed or shut down so in 2006 Yi Zang proposed a control method for faulty HBC multilevel inverter. To make fault tolerance when the converters have one or two damaged switches by deposing the faulty switch and the space vector algorithm will keep the system working on the achievable on faulty mode [25] .

In 2008 Yonggang Chen proposed a new way of controlling HBC due to the problem of unbalanced of DC voltage and that’s happen for a lot of reasons such as that the delay of the switches is not equal, hybrid losses and shunt losses. The unbalance if happened will generate un-even voltage exertion on the power electronic switches which will affect THD. The solution to this problem by analyzing the phase and phase shift multi carrier modulation is utilized to generate the PWM reference signal by knowing the deviation between the voltages of the DC buss voltage to keep itt balanced [26].

Multilevel converter gain popularity in medium and high tension application meanwhile low tension application the use was in limit cases and it was not that popular to use it in these applications so in 2009 T.Wanjekeche proposed a new configuration that will help use multilevel convertor for low voltage application. In his paper he suggest a simple control method for CHB 9 level cascade NPC modulated my PWM so the solution was by separating the 9 level into 4 separated and distinct 3 level CHB inverter level. By jointing these 3 level together in the DC buss. Phase shift modulation is used and this strategy is worked by reducing the number of component [27].

The need to use active filter on medium voltage level had increased over time that make it subject for researcher to look for so in2011 G. Farivar wrote a paper which he investigate the technical feasibility for indirect control for CHB active filters by using PWM modulation and the abandon of using current sensor which provide easier and more simple type of controller[28].

One of the main disadvantages on using CHB as multilevel system the convertor become more complex and need a lot of power electronic devices and passive devices and that will result in complex control system with a lot of factor that can affect the result, in 2012 Prakash Singh he presented in his paper a topology with for a multilevel inverter with special properties that uses capacitor for voltage balancing and voltage boosting. He used an CHB convector as a case of study [29].

With the increasing trend of renewable energy to utilize this technology in higher efficiency CHB multilevel inverter are connected to the system a lot of modulation had developed to increase the converter working efficiency for inverter and the system as totally as a result researcher as Chaiyant Boonmee in his paper in 2015 he does a comparison for different four CBPWM for CHB on grid inverter and notice the THD difference in each case of modulation [30].

One of the most challenges that face network with multilevel inverter integrated system is that is fault in will have a great impact on the steadiness of the system that is connected to so a different fault tolerance designs and topology for these type on converter. In 2015 Sanz, E. J. Bueno show in his paper the great advantage the CHB have over the other type of multilevel converter and the greater ability to work on networks with higher voltage and greater capacity. That is resulted because of its capacity to have high voltage output with small input voltage and the topology of CHB that it work on cascade cell that give the ability to the system to leave one or more faulted cell apart from the system so the system can work with it max capability without fully interrupt and stopped [31].

Due to the trend to go clean and renewable in harvesting energy big scale renewable energy system project become more needed than ever to get more energy from renewable source rather than traditional source to integrated these big capacity system to the grid specialty to medium voltage part of the system a suitable converter should be used multilevel inverter was the solution in this situation. There is a various choices to use the most capable to deal with higher voltage with ease and with the minimum amount of voltage that is possible to deliver in the input bus of the inverter, the obvious choice will be CHB multi-level inverter cause it's the best that applicable for the above mentioned specification. In 2016 Yifan Yu wrote a paper that show the advantages in efficiency and cost that is gained in using large capacity PV system with multilevel inverter how these type of converter will reduce switching losses and suggested topology to reach the power balance in the system when using multi-level CHB as inverter for the system[32].

In recent year the use of multilevel converter for harmonic elimination and power enhancing in general had increase and a lot of modulation techniques had been developed by different researcher at first stated with high frequency modulation for example sinusoidal pulse width modulation (SPWM) ,selective harmonic elimination PWM (SHE-PWM) and last space vector PWM (SVPWM) and for low frequency modulation the following example : space vector control (SVC) and selective harmonic elimination (SHE). Both SHE and SVC are modulation that depends on the fundamental frequency type of modulation. In Adib Abrishamifar explained and show the different type of modulation and how to use it to dispense with the low order harmonic. And how the right choice of modulation techniques is will affect the efficiency of the inverter. The amount of power and the modulation type will affect the type modulation are chosen due the different frequency cycle when the power increased the lower frequency modulation are needed to minimize the switching losses as possible and the total harmonic distortion THD. He show in his research

SCV the most efficient modulation method for high power high voltage application despite the its complexity that nonlinear equation to be solved this modulation be applicable [33][34].

1.2.4 Maximum power point tracking

Maximum power point tracking MPPT is a technique that is used is utilized for separating the maximum amount of power from PV system under various condition and parameter. If the PV system is connected in any different configuration it will face the same problem that is the efficiency of the power transfer in the system will depend on the irradiance of the sun and weather condition and the electrical characteristic of the load that is why using MPPT technique become very important and there are a lot of algorithm had been defined over the time [35].

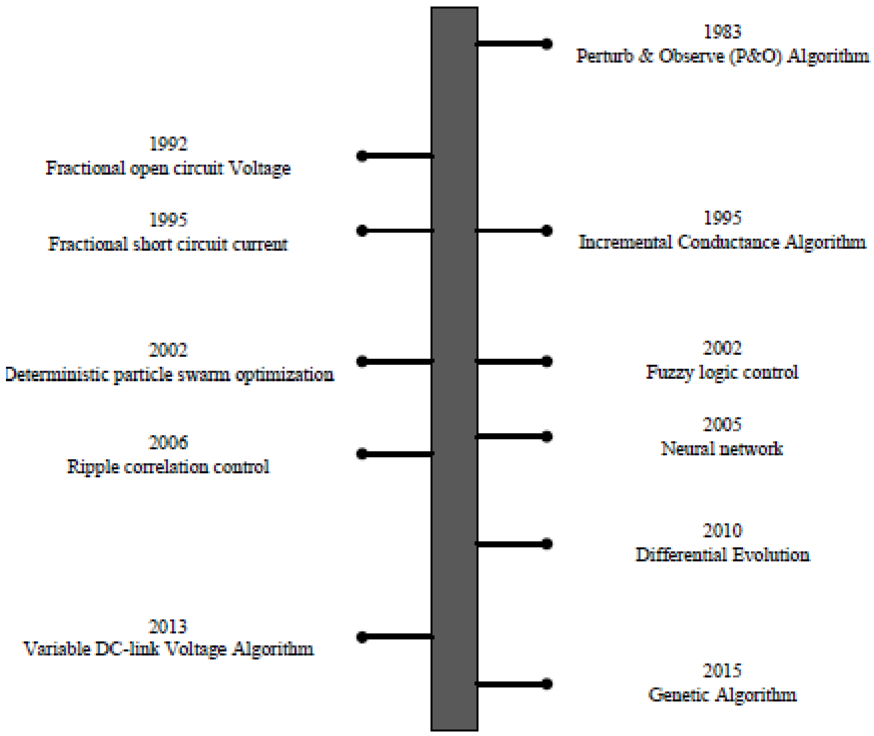
In MIT Lincoln lab at 1980 the first low cost MPPT system had revealed to the world since that time a various algorithm had been developed, and these algorithm is different depending on the type and the configuration of the system [36].

MPPT algorithm can categorized into two category based on the irradiance either to be uniform irradiance or under partial shading.

Under uniform irradiance the slandered algorithm at most perturb and observe (P&O) the drawback if this calculation is that is if the weather condition had changed then the system will move away from the maximum power point but with high tech microcontroller and DSP the ability to P&O in efficient way had increase [36].

Another method is incremental conductance its depend on measuring the incremental change both in voltage and current that help this algorithm to predict the effect on voltage that is generated that need more computation from the system but we can get more accurate result from P&O and the system have a less possibility to drift out from max power point.

A lot of algorithm had introduced and developed by time to these day it depend on neural network and genetic algorithms as shown in the time line figure below.



Fig(1.2) historical time line of maximum power point tracking

1.2.5 Battery bank system and charger

To keep the generated power staple and continuous battery are used. There are different reasons why batteries are used the first reason that is some time the amount of generated energy are limited due to the weather condition and in some time the amount of power are generated is greater than the needed power of the load the power fluctuation ultimately produces a generation gap in different time also with the increase of using PV system and integrated to the network will The stability of the entire electrical system is affected if the stability in the PV system is not achieved this all had been discussed in Anand S. Joshi about the performance of PV system [38] [39].

A lot of types of batteries had been developed over time due the increased need in storaging a greater amount of energy in the smallest sizes and the most economical way possible so slot of type had been developed such as : lead-acid batteries Which one is the most commonly used in PV systems Nickel-Cadmium the most disadvantage for this system is that is use cadmium which is poisons element so it has been banned in 2004, in 1989 nickel-metal hydride battery these type of batteries become common in industrial facilities, at last lithium-ion battery which is the most efficient on of the above but the most expensive type which make suitable for electronic devices[40].

The real issue in batteries storage system is to size the batteries capacity that’s fit with the system capacity and condition so for that reason from

1990 to this day IEEE had put a recommended practice for sizing, charging, testing and evaluation for PV power bank system [41].

System that need storage should have controlled charging system for these batteries a different topology is used to control the charging process.

Traditionally the main goal was to increase the state of charge but a lot of specification had been not taken in consider such as the charging time, the performance of the batteries, the needed protection of overheating the batteries and over discharge the batteries which that have a great effect on the lifetime of the batteries. From the 1970s a lot of topology had been developed over time that considers this aspect [42].

1.3 Thesis Motivation

1.3.1 Problem with low efficient power quality

Power quality is effect and involved current, voltage and frequency. A good electrical power quality can be defined a system with steady supply of voltage that's have wave form with smooth curve and the value of the frequency for this supply is close to the rated frequency value.

The reliability of the electrical grid was reduced due to the increase of non-linear unbalanced load negatively due to the deformation of the steady suppling of the system and mostly due to the induced harmonic that effect a lot of aspect on the grid such as the malfunctions of sensitive loads, voltage sallow, swag, increase in the temperature of the equipment which make the ages faster and decrease the efficiency of the system by increasing the losses [43][44].

1.3.2 the power quality problem solution

The solution for the poor power quality problem is using filters to mitigate the induced harmonic of non-linear loads. The filter can be either active or passive. component and application both of the types have their advantage and disadvantage, traditionally passive filters were the first solution for this problem which is depend on passive component such as (resistor, capacitor and reactor) and the main reason for wide use of passive filter Because of its easy design and low cost. The main working principle for passive filter that is provide the path with lest impedance for the non-sinusoidal component of the main to flow through. But the main disadvantage for passive filter it can eliminate harmonic from certain frequency that the filter are tuned for, and the bulky size and resonance [45]. To get efficient solution the APF are used which perform better in smaller size device that can be more dynamic and filters in different frequency value the disadvantage that the APF that is more complicated and expensive. The active power filter APF can be series, shunt and UPQC which considered combining the series and shunt APF interconnected to better control the power quality problem [46-47].

1.3.3 the advantage of UPQC

UPQC considered a type of active filters that is consist of series and shunt active filter that's integrated together through DC bus capacitor this type of combination is considered more economically applicable more than working separately as each unit independent from the other unit. While working in large capacity network switching losses is needed to be reduced that can be accomplished by having a low switching frequency which is can be achieved in UPQC due to the ability of expanding it to work by multilevel inverter which have a low switching frequency. Also due to the used element blocking diode are not needed for this system. Due to UPQC topology a fixable direct and indirect control can be applied to the system. At last the UPQC is cheaper and lighter than other system due to its compact design [48].

1.4 Research objective

This thesis will address the issue of power quality through the use of active filter to solve the problem of poor quality. Use of active and reactive power injection via UPQC fault tolerance.

The specific objectives are to:

1. Design the a fault-tolerant UPQC that has ability to filter harmonics and to inject real power and reactive power injection which includes:

a- Design the four-leg multi-level inverter.

b- Choosing the type and the size of photovoltaic array needed to be able to meet load reactive and real power demands For harmonic voltage and currents.

c- Maximum power point tracker (MPPT)

An electronic DC to DC converter is an MPPT or maximum power point monitor that optimizes the match between the solar array (PV panels) and the battery bank or utility grid.

d-The size and the type of pack up batteries In order to keep constant input voltage and supply the load during outages.

e- Using MATLAB/SIMULINK program to implement the designed module.

1.5 Organization of Research

This thesis presented fault tolerance unified power quality controller based on four leg multilevel converter that's fed by photovoltaic array as the source of DC voltage.

This thesis is sorted into seven chapters with the Introduction and a brief description of each chapter.

Chapter 2 will review all the type and the topology of used filters for power quality enhancement. And it will show the advantage and the disadvantage of using any type of the mentioned filter.

Chapter 3 will show the control algorithm for the main system components the series and the shunt APF and the needed signal for power quality enhancement are generated to control the both filter. This system to be operational the mathematical model for the series filter and the shunt filter are needed to be extracted beside the other parts of UPQC so the control algorithm is to be designed. The design of the shunt active filter will be based on dual instantaneous power theory (d-b) and the design of series active power filter will be the reactive instantaneous power (p-q). then the fault tolerance system that will be designed will be taken on consider . The result and the theory will be implemented using MATLAB SIMULINK to take in consider the correct design for the controller.

Chapter 4 this chapter will be focused on the study of multilevel converter type's topologies and the advantage and the disadvantage for each one of the converter. Then the integration of the multilevel inverter on the UPQC will be implemented with over review of the modulation the suite the whole system.

Chapter 5 will be focused on the photovoltaic system and its component and the different algorithm of maximum power point tracking and do a modal for this system and implement the P&O the theory to design controller for DC to DC step up converter to boost the voltage under different irradiance and temperature. The result of this design will be tested using MATLAB Simulink program.

Chapter 6 will present the whole system result for the UPQC that is presented in the thesis using Simulink to show the result for the UPQC.

Chapter 7 includes the recommendation, some practical considerations, and future study with thesis references.

CHAPTER 2

TYPES OF FILTERS

2.1 Introductions

Because of the rapid growth of electronic and power electronic in general the amount of non-linear load had increased which had a great effect in the efficiency of the electrical network in general, that effect can be translated in voltage sag, swallow and increase in the temperature in different electrical load . Due this change in load charter the power quality enhancement and the elimination of distortion and harmonic had become a major issue in the last decade so to solve this problem filter was the choice. To do that filter should be connected to the common linking point for the load. So filter become very important in the grid to make shore that the electrical grid is a stable grid with no distortion and flexible to different charter loads that suite nowadays network with the advanced nonlinear load. The various filter category and its description in this chapter [49].

2.2 Filter Classification

Power filters have three main types that can be sorted to as passive filter active filter and hybrid filter under these three main type a lot of topology can be sorted under each one as shown in the figure below [50].

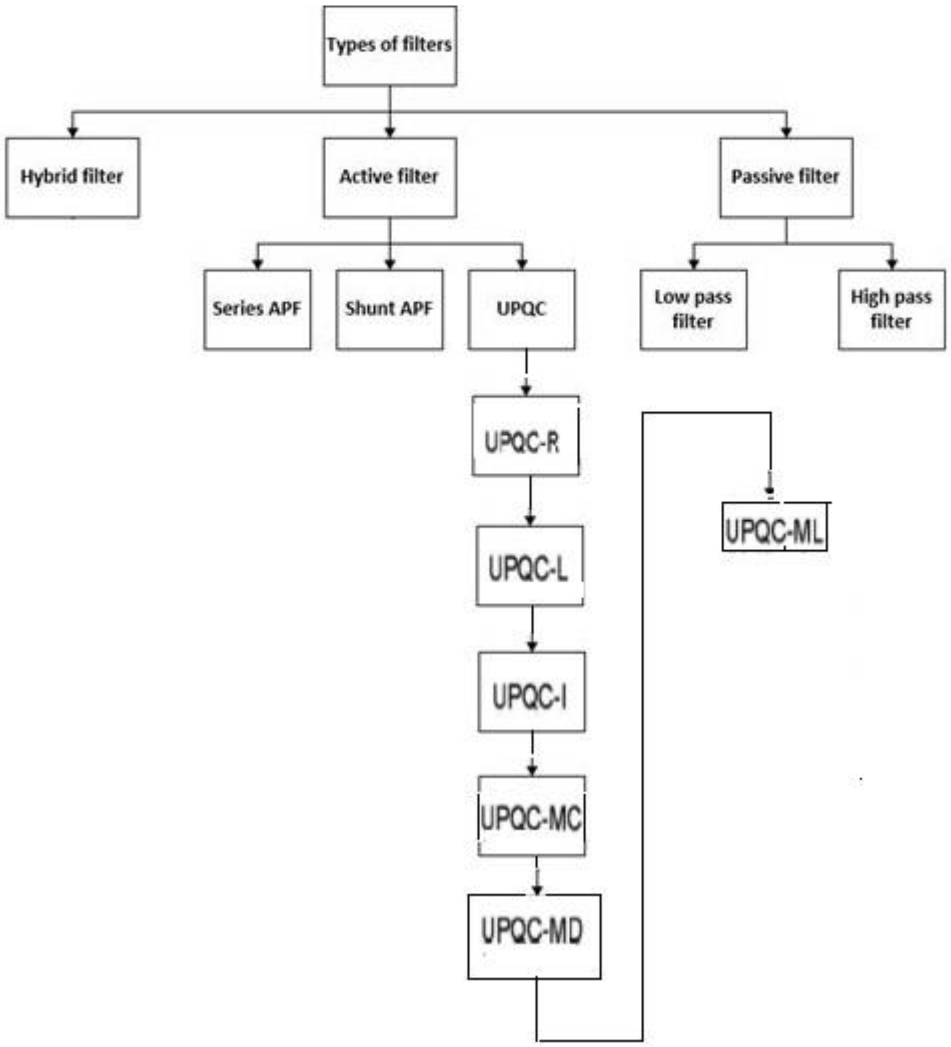


fig 2.1 The diffreent types of classfication for power fiters

2.2.1 Passive filter

Passive filter is widely used for power quality through reducing and eliminating the harmonic distortion and consumption of reactive power that is needed for the electrical network. It can be designed for high voltage high current application due its simple design and component but the main disadvantage that it cannot be used for all harmonic frequency it can be tuned for specific frequency that make less dynamic dealing with different loads.

2.2.1.1 High pass filter

High pass filter consists of passive element reactor and capacitor and the high pass filter has a low-impedance for the harmonics current for the value above tuned specific frequency a different amount of passive filter can be used and that will sort HPF to 1st order, 2nd order and 3rd order,,,,,, ETC. and the most practical is 2nd order HPF are shown in figure number 2.2 and in fig number 2.3 show the working range for high pass filter [49].

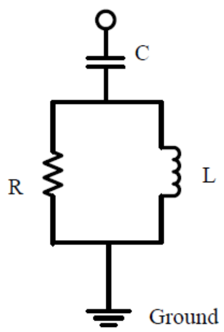


Fig 2.2 high pass filter circiut figure

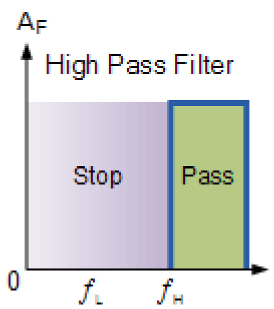


Fig 2.3 working domain for high pass filter

2.2.1.2 Low pass filter

Low-pass-filter also a passive filter with passive component. And it will have its lower impedance at set of frequency is lower than tuned certain frequency. And the most used application for this filter is used as power factor compensator and the working principle can be summarized as the following when the frequency increase the inductor impedance increase which block high frequency harmonic to reach the load and the capacitor impedance decrease which short out the higher distortion frequency the figure below show the configuration of the filter and the working domain [49].

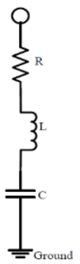


Fig 2.4 low-pass-filter circiut figer

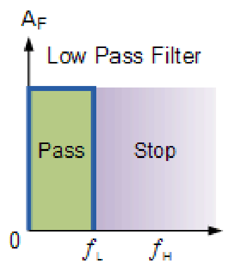


Fig 2.5 working domain for low pass filter

2.2.1.3 The disadvantage of using passive filter

* The compensating efficiency for the passive filter depend on the impedance of the load and the network which make rigid system less dynamics than other which let the filter un able to deal with circulating current that is generated form non-linear loads.

* The change in the load and the continues difference in harmonic frequency make the passive filter useless with the retuning of the passive filters.

* A resonance circuit can be produced with the network which will make the filter unstable and non-function able.

* Small compensating rage and cause it's depend on fixed value of passive element and in many cases the passive filter show low efficiency in enhancing power quality under the modern network with the large amount of non-linear loads which make the a active filter and their development is which the modern network is needed.

2.2.2 Active-power-filter

Because of the significant increase in non-linear load and due to the low efficiency of the power quality enhancement of the passive filter for modern network with dynamic loads new topology is needed for power mitigation. Because of the development of the power electronic switches active power development becomes economically feasible. The active power filter is power mitigation device which inject active-reactive power to the system to eliminate harmonic, compensates the distortion and inject needed reactive power to enhance power quality active filter can be categorized due to the connection configuration as referred to the load with different operating function.

2.2.2.1 Shunt-active-filter

The shunt APF is connected to the load in parallel with the associated point, it become a VSI voltage source inverter and act like static compensator. The working principle for shunt APF is injecting harmonic current into the electrical grid equal to the current that is needed to be consumed by the load but it work on the opposite phase that will result to rearrange the shape of the wave to be pure sinusoidal shape. Unlike the passive filter the impedance of the load Does not affect the filter output. The configuration and the connection of the parllel APF filter are seen in the fig below [52].

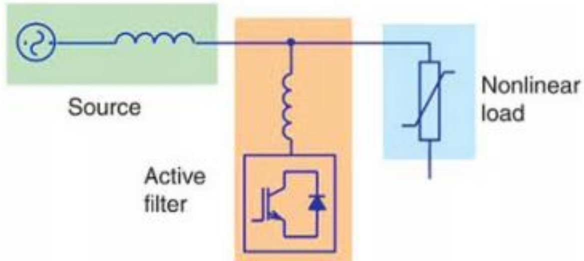


Fig 2.6: shunt APF configuration

2.2.2.2 Series-active-power-filter

The APF in this case is linked to the load in series which allow this configuration to help this active filter to eliminate the voltage disturbance (unbalance, harmonic). This filter can use to eliminate the voltage signal harmonic and can be used for voltage regulation on the end terminal depended on the control type that's used to control this APF and the last one can be carried out by a configuration that is called dynamic voltage restores

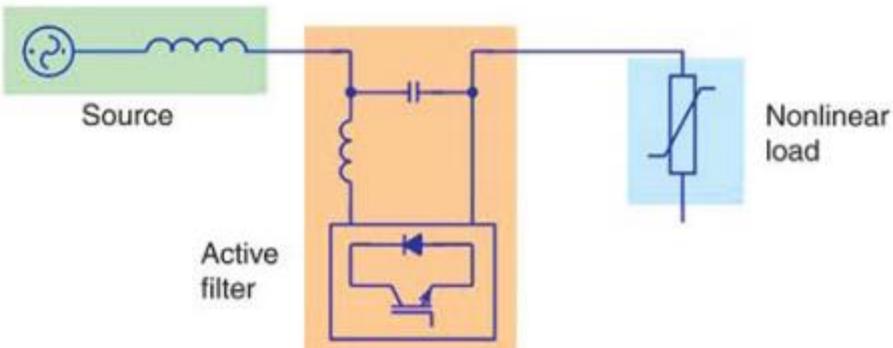


Fig 2.7: series APF configuration

DVR. The series the filter is designed to accommodate for the harmonic voltage of the load by generating the needed signal of voltage to load with the appropriate frequency and magnitude which will eliminate the distortion on the load terminal and will supply the load with the needed voltage wave form. In industrial facilities, this type of filter is used for reducing the effect of harmonic voltage that is generated from industrial load [52]. The configurations of the series APF are showed in the figure below.

2.2.2.3 Hybrid-active-power-filter

To get to the maximum advantage of the different configuration of power filtering a different combination had been proposed over the time. One of the method are to connect active filter with passive filters this configuration had been Proposed to improve passive filter performance by adding APF in different configuration so that the passive filter will eliminate the most significant harmonic frequency and that will reduce the needed power for the APF filter that's will reduce the cost and make more efficient system the using passive filter alone. And these advantages can be summarized as the following at first by avoiding the resonant that could happen at certain frequency second make the passive source dependent from source impedance and the last reduce the nominal power needed for APF figure 10 show connection topology between APF and PPF.

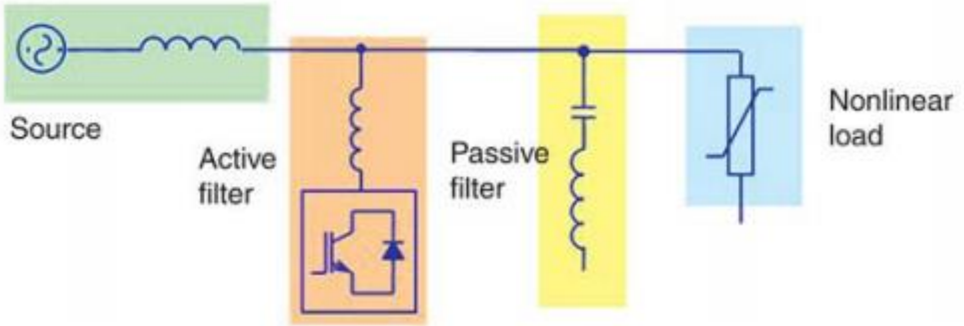


Fig2.8: hybrid power filter circuit configration

2.2.2.4 Unified power quality conditioner

It considers anther combination method that's complain two active filter with common dc buss capacitor. The series connected filter is used to exclude harmonic voltage and compensate the voltage distortion. And the shunt is used for current harmonic and the compensation of current distortion [52]. And this configuration is considered the most dynamic one of the above configuration it can be considered universal power quality conditioner but the main drawback that it considered very complicated than other configuration figure 10 show the basic configuration for UPQC [52].

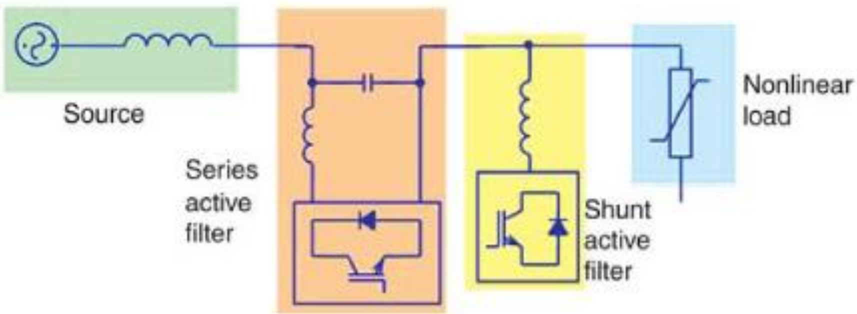


Fig 2.9: UPQC general configuration

2.2.2.4.1 Left and right unified power quality conditioner (UPQC-R, UPQC-L)

UPQC is a combination of two back-to-back inverters with in-common dc link, the UPQC can be Classified at the shunt converter site with refer to the in series converter, when the shunt is in the right it called UPQC-R when the shunt in the left it called UPQC-L. Between the two configurations the right UPQC are the most used one because in the series transformer that is connected to SAPF current flow through it mostly is pure sinusoidal shape without been effected by the charter of the load current known that the current harmonic is substituted by the shunt inverter and the reactive current. So UPQC-R gives over all better performance when compared with UPQC-L. The UPQC-L is used for preventing interference between the shunt and passive filters in special cases [53].

2.2.2.4.2 Interline UPQC (UPQC-I)

UPQC-I it when the UPQC is linked inter alia two distinct feeders as UPQC between them the firist one is connected in parallel with the feeder and the 2nd inverter is linked the other feeder in series. With this configuration the voltage will simultaneously regulated and compensated for both feeders and the stream of real-power amidst the feeders are controlled. However it had its limitation when the feeders have a current harmonic problem only the feeder that have shunt inverter connected to it mean while the feeder with series inverter will not compensate the load current for the feeder that is connected to [53]. The figure 11 below show the UPQC-I.

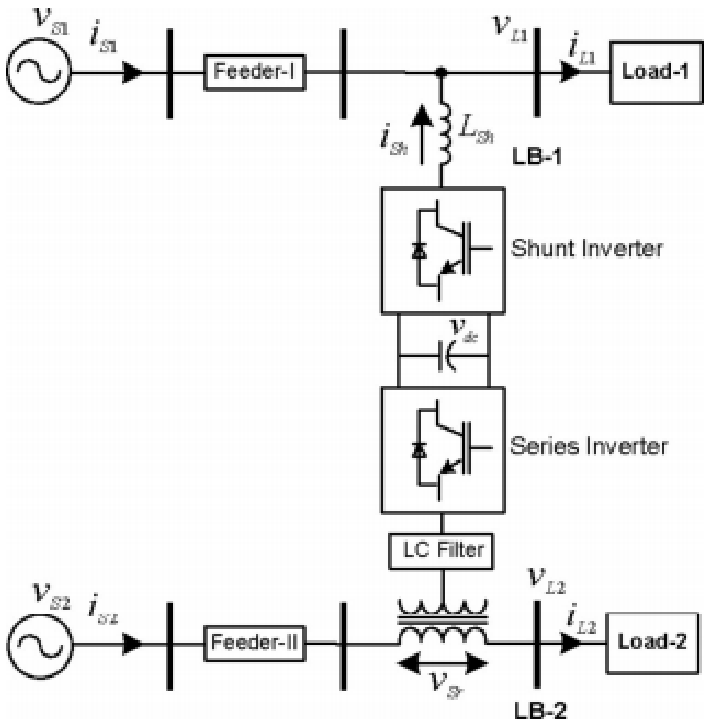


Figure 2.10 UPQC-I configuration

2.2.2.4.3 Multi converter UPQC (UPQC-MC)

This configuration is proposed by researchers to progress the rendering for the UPQC. It work by adding 3rd converter to upholding the dc bus link and this can be utilized by using storage unit such as batteries and supper capacitor. And that 3rd converter can be linked in different way. It can be linked to the feeder in parllel or it can linked to the series or parallel to anther adjusting feeder thus UPQC-MC can be considered and linked as UPQC-I as it can be connected to two different feeder. The figure below show the circuit of UPQC-MC [53].

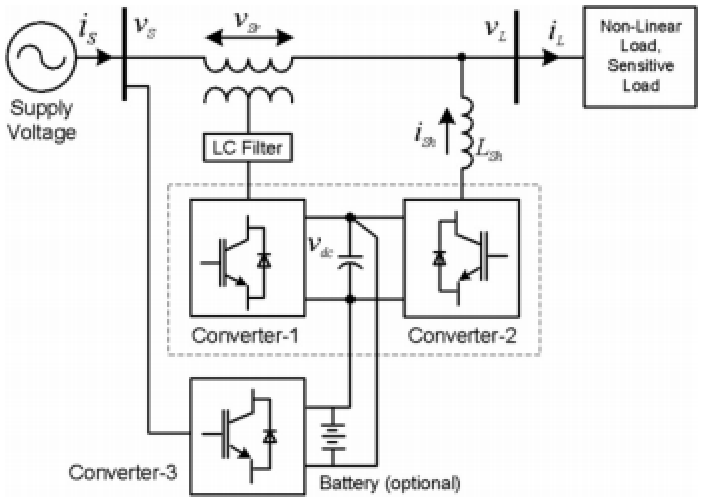


Figure 2.11: UPQC-MC configuration

2.2.2.4.4 Modular UPQC (UPQC-MD)

This arrangement is formed by utilizing serval H-bridge converter as linking sundry single phase unified power quality container with 8 power electronic switch connected in cascade with each other in each phase. For the shunt side each part of this side is linked in series by using multi-winding transformer but in series side there are linked directly to each other and injected \directly without series-transformer. As the number of the unit are increased the total amount voltage can be handled increased due to that each cell will handle less amount of voltage individually that make suitable for medium voltage application with greater power capacity. The figure below show UPQC-MD configuration [53].

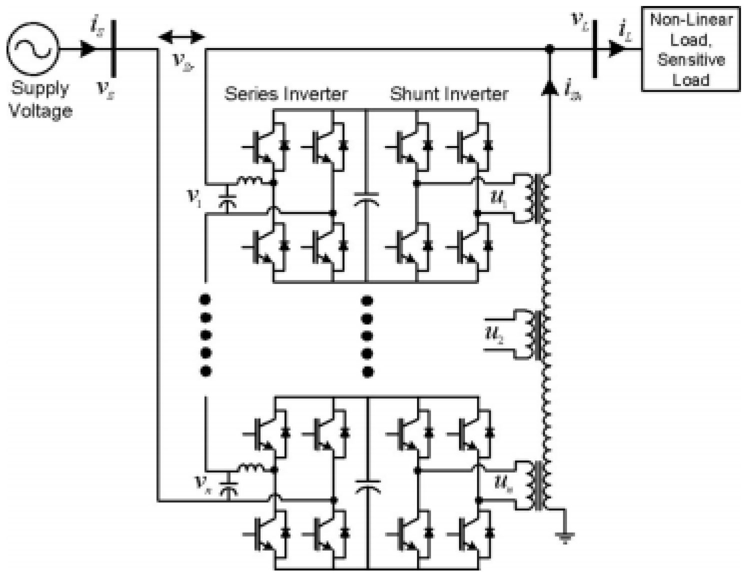


Figure 2.12: UPQC-MD configuration

2.2.2.4.5 Multilevel UPQC (UPQC-ML)

The multilevel UPQC is based on multilevel inverter topology as the power electronic converter to the system mostly three level neutral point clamped are the most used topology its use 24 more power electronic switches then two level normal inverter which give less switching frequency that's is needed to be operational so with lower switching frequency the inverter will have lower switching losses and that give the ability of operating on higher voltage and greater capacity then other topology of inverter. The increase of the levels will allow greater increase the voltage and the nominal power of the system [52] this configuration will be used in this research. The figure below show UPQC-ML.

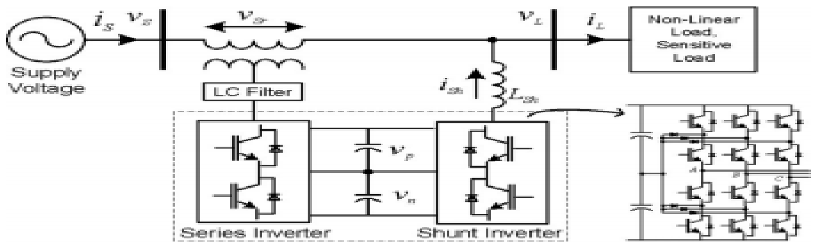


Fig 2.13: UPQC-ML configuration

2.3 Summery

The following chapter had been discussing the different configuration of filter which is used for power enhancement. It show the different shapes of filters with their feature and their drawbacks. And can be noticed that the passive filter are low of cost and can operate in high tension high power application but have limitation due the it work in tuned frequency and the problem of the resonances is still important factor that makes the impedance of the source is factor that need to be considered. But the new networks are needed more dynamic systems the usage of APF is the needed solution for this with considering the increased difficulty in the control and the increased cost. The system that campion the feature of all the system in more compact and economically more feasible then other choice is will be UPQC-R with based multilevel inverter.

CHAPTER 3

MULILEVEL CONVERTERS

3.1 Introduction

The multilevel inverter is a power electronic devise that is can be controlled in a way to produce higher AC voltage level using steps of lower DC voltage level. The multilevel converter is a new trend that is can be used for high power application. The multilevel out-put signal is for most of the time is a stair case wave form with multistep each step represent a capacitor level. These type of converter are used most of the time in renewable energy application and it represents the link between renewable energy source and the high power load end. These type of converter used for multiple application such as power injector to the system, FACTS and inverter in vehicle [67].

3.2 Multilevel Converter Topologies

There is a lot of multilevel inverter topology, and we will discuss and present the most popular topology the most typical of them all is: Diode-Clamped Converter (DCC), Flying Capacitor Converter (FCC) and Cascaded Converter [68].

3.2.1 The Diode Clamp Multilevel Inverter

Diode clamped technology depend on sub-leveling the dc link using diodes [68]. Figure 3.1 shows the circuit for this topology for multilevel inverter.

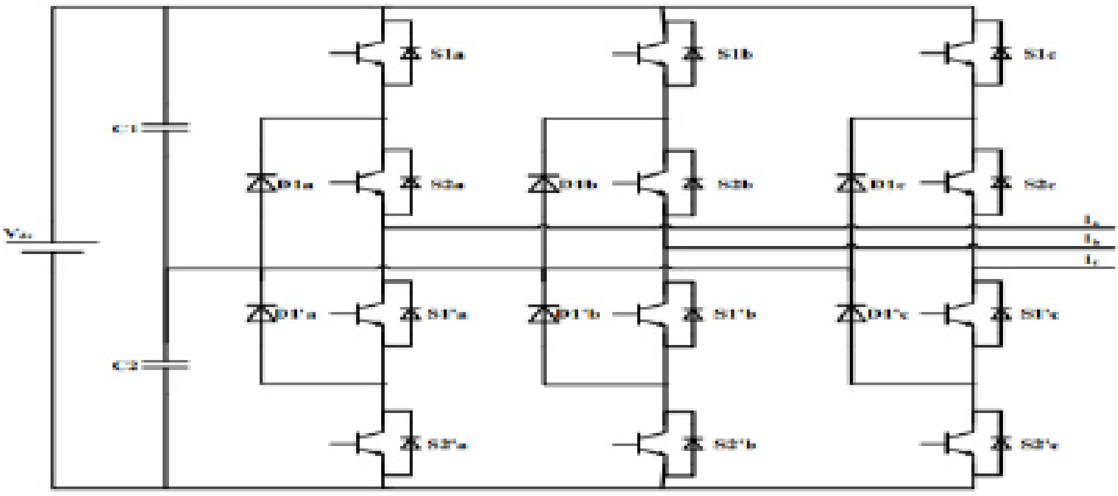


Fig.3.1: Three-level-Neutral-Point-Clamped-converter

There are three possibilities for the value of the voltage as shown in table 3.1 and these value depend on the state of the semiconductor in each case.

Table.3.1 Switching possibilities in three level neutral point clamped converter.

A	B	$\bar{A}$	$\bar{B}$	V_{XN}
ON	ON	OFF	OFF	V/2
OFF	ON	ON	OFF	0
OFF	OFF	ON	ON	-V/2

The number of the level for this inverter depend on the diode clamped point by increasing the clamp point number for dc-link capacitor and the amount of semiconductor switches between the points of this inverter system. By changing the amount of level the same voltage can be generated by different switching possibilities which can divide the switching losses between the semiconductor and the stored energy will be used in more equal value. But these changes will raise the cost of this inverter and make the control more complex than ever.

In high voltage application this topology faces a great challenge this challenge is to block the high voltage using the clamping diode which can be hard for single diode, so to solve this problem multiple diode is needed to be connected in series but it come with cost and increase in losses [69].

3.2.1 The Capacitor Clamped (Flying-Capacitor) Multilevel Converter

Fig 3.2 show the circuit schematic for 3-level flying-capacitor-multilevel-inverter with the capacitor that's that clamp the semiconductor to single capacitor voltage level [68]. Table 3.2 shows the different level of voltage that's generated using FCC for different switching possibilities.

Table.3.2 Switching possibilities in three level 'Flying'-capacitor-converter.

A	B	$\bar{A}$	$\bar{B}$	V_{XN}
ON	ON	OFF	OFF	V/2
OFF	ON	ON	OFF	0
ON	OFF	OFF	ON	0
OFF	OFF	ON	ON	-V/2

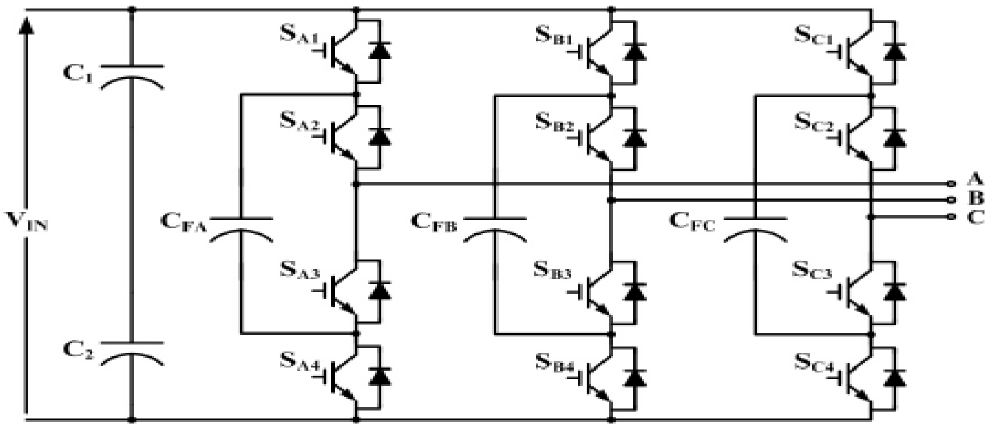


Fig.3.2: Three level Flying-Capacitor-Multilevel-Converter.

As the diode-clamped-multilevel inverter, the number of level have the ability to be increased by rising the number of clamping point in the DC-link voltage. But the disadvantage that is the number of semiconductor will increase which will increase the economic cost of operation and the complexity in controlling the inverter.

And to keep the voltage level fixed and pre-charge the capacitor anther circuit is needed to be added to the system [69].

3.2.3 The Cascaded-H-Bridge-Multilevel-Converter with Separated DC Sources

Figure 3.3 show the circuit for H-bridge-cascade-multilevel -inverter. This inverter is composed of amount of H-bridges cell that is linked in series. Each cell is supplied from isolated DC power source. There different voltage step possibilities that is dependent on the switching pattern for the semi-conductor where is the pattern shown in the table below.

Table.3.3 switching pattern in one H-Bridge cell.

A	$\bar{A}$	B	$\bar{B}$	V_{RX}
OFF	ON	ON	OFF	V/2
ON	OFF	OFF	ON	-V/2
ON	OFF	ON	OFF	0
OFF	ON	OFF	ON	0

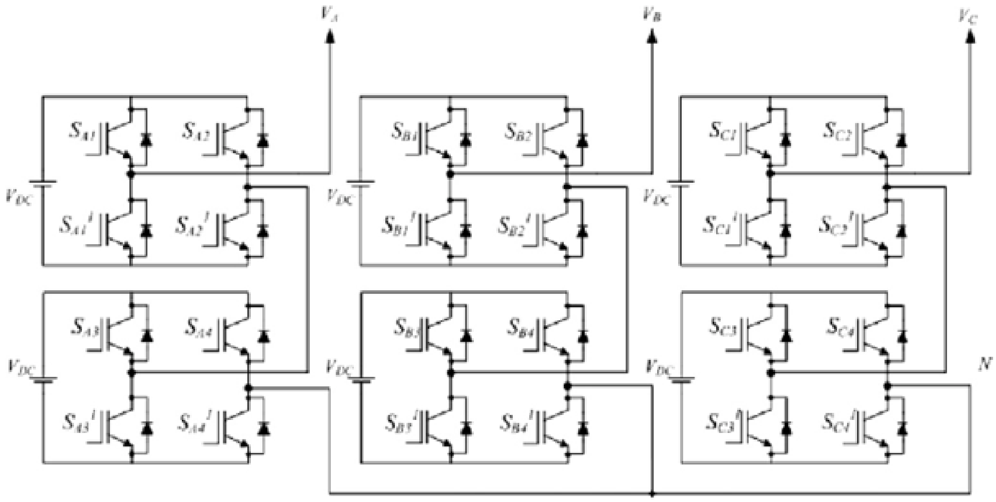


Fig.3.3: Five level Cascaded H-Bridge Multilevel Converter.

The following table show the number of needed component required per phase, where is n the amount of level per phase [70].

Table.3.4 Comparison of components required per phase for each of the three multilevel topologies

	Topology		
Component	Diode-Clamped	Capacitor-Clamped	H-Bridge
Number of Switches	(n-1)*2	(n-1)*2	(n-1)*2
Diodes	(n-1)*2	(n-1)*2	(n-1)*2
Diodes-clamping	(n-1)*(n-2)	0	0
DC-bus-capacitors	(n-1)	(n-1)	(n-1)/2
Balancing-capacitor	0	(n-1)*(n-2)/2	0

3.3 Modulation Techniques for Cascaded H-Bridge-Multilevel-Converter.

After studding the topologies of multilevel inverter, the cascade H-bridge-multilevel-inverter was selected for to be the application that is used for shunt & series filter representation. There is a lot of modulation method that is utilized for modulating for H-bridge-cascade inverter these modulation will be discussed in this chapter.

The modulation technique that's utilized for modulation the cascaded-H-bridge inverter are the following:

- multicarrier modulation
- PWM
- Staircase modlation
- Space vector modlation

3.3.1 Phase-Shifted-Multicarrier-Modulation

This modulation method is dependent on PWM natural sampling and that's can be accomplished by generating pulses by set side by side with the indicate modulating signal with a carrier-wave. Instead of using single triangular wave as for the standard inverter. The number of currier that is been used depend on the number of level for the inverter (M). The amplitude and the frequency for all carrier are the same but the only deference are the phase shift between all carrier by an angle equal (360/(M-1)) [71]. Figure 3.4 show the technique for the carrier wave where is (solid red and solid blue) are used to generate the gate signals for the switches S11 and S21 respectively while the carrier waves in dashed red and dashed blue are used to generate the gate signals for the switches S12 and S22.

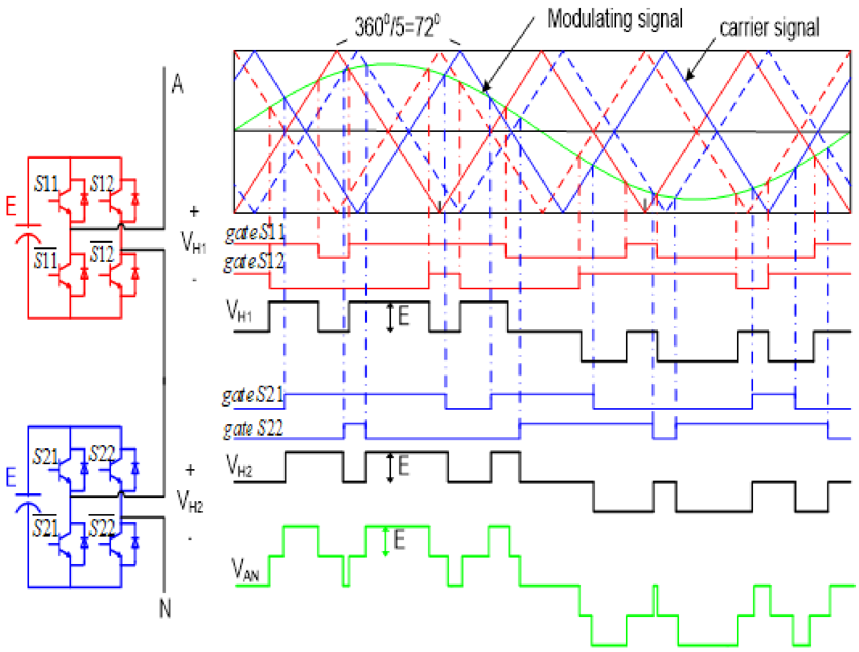


Fig.3.4: Five level, phase shifted carrier waveforms.

The power flow for this type of modulation are equal and the switching frequency are equal for all switching device are equal and its equal for the carrier frequency.

3.3.3 Staircase Modulation

To implement a modulation method easily in cascade h-bridge multilevel inverter the switching frequency should equal the to the output fundamental frequency of the inverter [72] . Figure 3.5 shows the demonstration for the modulation method. The two angle θ_1 and θ2 are optimized so it can eliminate specific frequency of harmonic form the output wave form. The conducting time are switched and swapped over the time and this done to make a sure that is power are distributed equally. But the disadvantage for this system that is it may produce ripple in the current wave form.

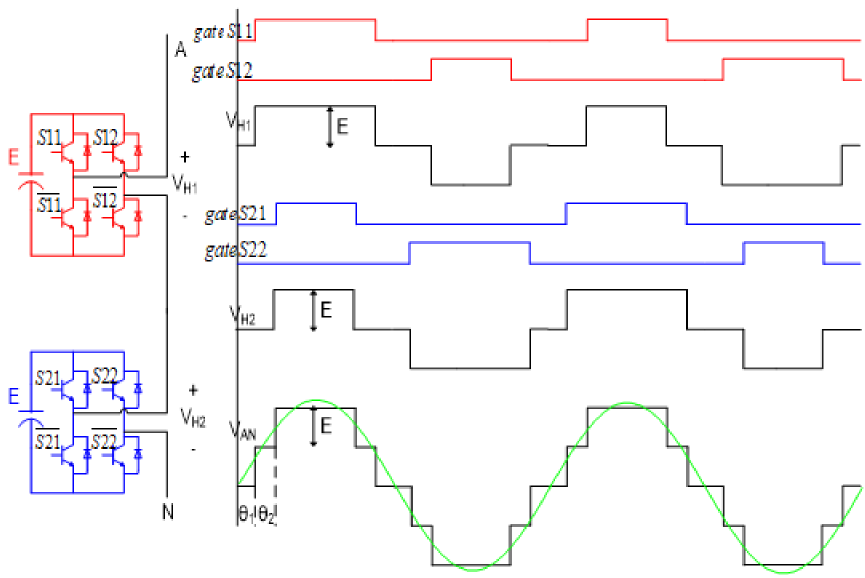


Fig.3.5: Five level, staircase modulation waveforms

3.3.4 Space Vector Modulation

This method is considered the most suitable method compared with what we have discussed before due to the following reason:

(1 has the most flexible ability in having the most optimize switching sequence.

(2 Easy to control using new digital based control devices.

If we consider 7-level-multilevel-inverter as shown in fig 3.6 we will have multiple output possibility and the possible output potential that can be produced from each leg are 3E, 2E, E, 0, -E, -2E and -3E. And this voltage level depends on the switching sequence. It's possible to generate 2^7 voltage vectors in space when using this modulation technique and this modulation technique had been used in this thesis.

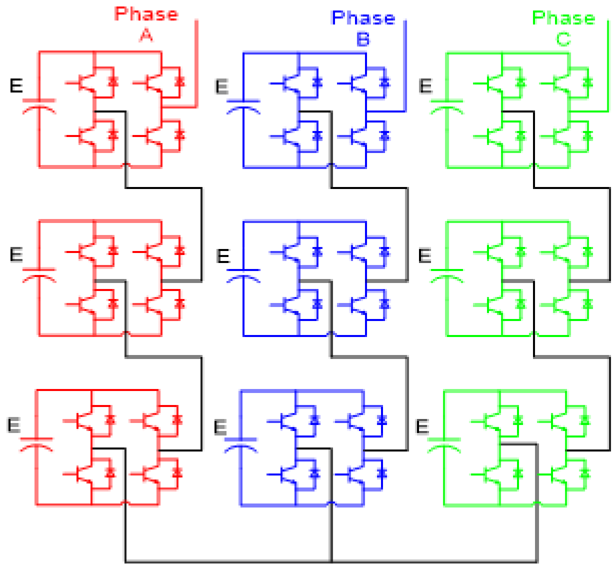


Fig.3.6: Seven level cascade H-Bridge multilevel converter

3.3.5 Amplitude Modulation (AM)

Using technology of the modern science, nowadays the most favorite method of modulation for large capacity with high power injection photovoltaic systems is the amplitude modulation method. And that's for its ability for directly connected medium voltage electrical system without the bulky line frequency power transformer and this make the control simpler and the cost is cheaper than other mentioned method.

This topology utilizes, at least, two conventional full-bridge single-phase inverters, usually designated H-bridges, connected in series, as shown in Fig. 3.8. This figure shows a single-phase converter.

The topology needs each H-bridge to be sourced by an isolated DC source. Each bridge has three levels in the output voltage (V, 0 and –V); along these lines, keeping in mind the end goal to get a higher number of levels and a waveform with better quality it is needed more bridges connected in series.

For equal DC sources, the number of levels, NL, in the output voltage is given by (1), being S the number of H-bridges of the multilevel inverter [75].

$$NL=2*S+1 \quad (1).$$

A higher number of levels can be obtained using DC sources with different and specific voltage levels.

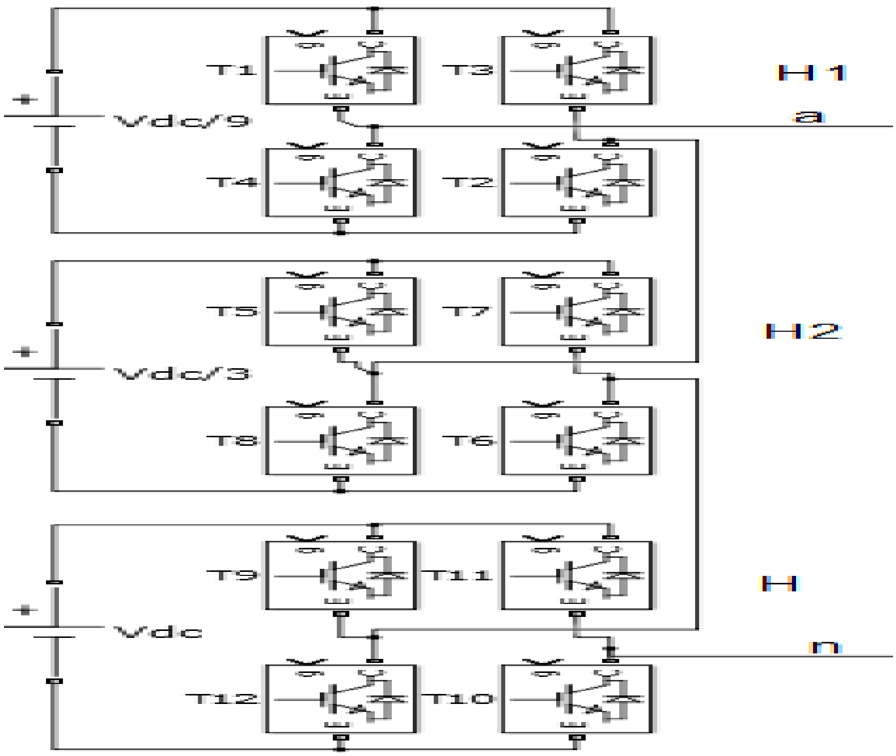


Fig. 3.6: cascade H-bridge single-phase converter.

3.4 Chapter summary

In previous chapter we focus on the study of distinct type of multilevel. At first the most famous topology had been compared and discussed. Then cascade H-bridge multilevel inverter had been discussed as the chosen topology in this thesis. To control this converter the modulation had been discussed and compared to each other with the chosen modulation method in this thesis is space vector modulation (SVM).

CHAPTER 4

MULILEVEL CONVERTERS

4.1 Overview

The active filter are used for the elimination of harmonic and power quality enhancement which will optimize the power destitution network with less losses and good handle for sensitive load, to reach this level the control algorithm and the connection should be correct and well designed. There are distinct configurations for the filter with different control algorithm. UPQC is a collection of both series and shunt active filter that is implemented in this thesis. The shunt APF control algorithm is the generate the optimal current signal from the APF so it eliminate the current harmonic that is in source current. And to have a unity power factor at the PCC by injecting real power to the system from PV array. Where is the SAPF is designed to optimize the potential in the network by eliminate voltage harmonic and distortion in the source voltage. The filters and their control algorithm are discussed in this section [54].

4.2 shunt APF design

The shunt APF is power enhancement tool that is used for current reparations for system with nonlinear load and it can be recognized as (CSI). It can be three-phase CSI or it can be formed from 3 single phase CSI with the same task of operation. A three phase CSI is been tested in this thesis Noting that is CSI is linked in shunt with the source impedance at the PCC and it connected directly with transmission line without passive filter element [55]. The figure below show shunt active filter control and configuration.

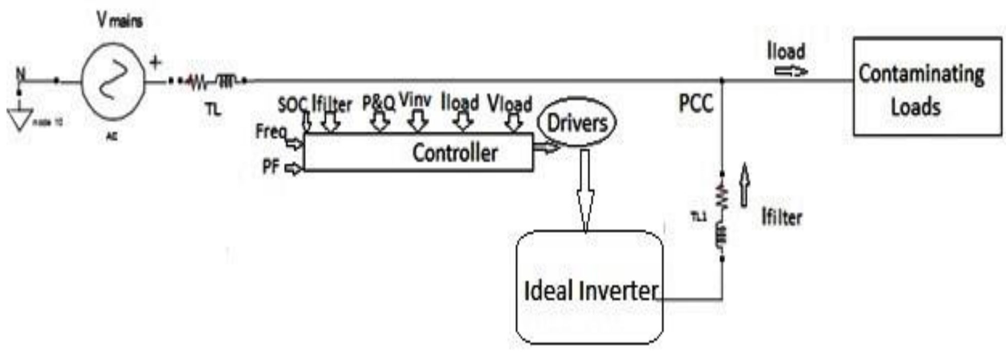


Fig 4.1: shunt APF line diagram

4.3 Series APF design

Series APF filter is also a tool for power quality enhancement but it considered voltage source inverter (VSI) which generate voltage that compensate the desaturation from source voltage. This VSI can be three-phase or build from three-single phase VSI with the same operation task. The series APF is linked in series with the feeder through a series setup transformer. The SAPF is implemented with taken in to consider the transformer parameter based on the element of the APF. In the fig 4.2 line diagrams for series APF is shown [51].

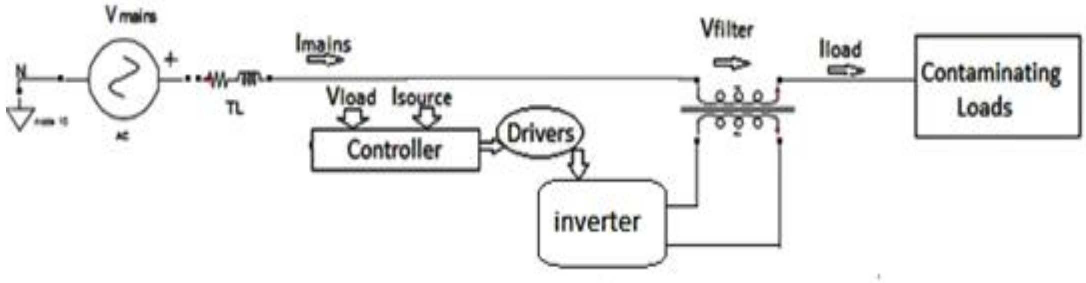


Fig 4.2: line circuit for series APF

4.4 Harmonic current extraction method.

To mitigate the harmonic current that is generated from nonlinear load from the system active filtering are used to get a pure sinusoidal voltage and current source. To start filtering a reference signal are needed that can be extracted from the known information of the grid. The quality of the filtering is increased when the reference signal is extracted by more accurate method when the accuracy increase the quality of the filtering is increased too. a lot of extraction method are proposed. These extraction method can be split in to two main folk the first one use fast Fourier transform (FFT) that its domain in frequency field that are used for extraction of the signal [56] [54]. But this method has a lot of disadvantage it very complicated in practice and calculation, not staple in transient state, not practical in real life and its delay take a lot of time to extract the signal can be reach to a one period.

The second family is operating in the time domain to extract needed signal. Some of the time domain methods are base in instantaneous power and reactive power, other depend on finding the terms of direct and indirect current terms and in these day neural network are used to generate the needed reference voltage and current signal by extracting the voltage and current component. Working in time domain will reduce the time delay, reduce the time of transient state and make the calculation and their needed memory to be practical is reduced [56].

4.4.1 Instantaneous-Active-and-Reactive-Power-Theory (P-Q Theory)

The P-Q notion is time domain operated reference extraction method that is founded on the bases of instantaneous-power, can be applied on voltage and current signal with no retraction, and can be utilized on three-phase three-wire system with no neutral for the generated wave form, and can be applied in steady state and transient mode. This method offers acceptable accuracy but it cannot operate on unbalance voltage electrical system, to overcome this case self-tuning filter are used for the grid voltage to after measurement to elicit the primary reference three-phase voltage component for the non-balanced one [56] [57].

The algorithm uses the transformation of the distorted current of the system by transforming from three-phase-frame *abc* into bi-phase-stationary frame $\alpha\beta$. The main principle of this theory that is the harmonic current can be mitigated by controlled non-linear load. The pq theory is depended on the immediate power in time scope the three-phase current (Ia,Ib,Ic) and voltage (va,vb,vc) are transformed to Clarke transformation (α-β) to the different coordination to get instantaneous power value terms from active & reactive power. This transformation is the overthrow of the three-phase terms into the stationary two axis reference terms [57]. The Clarke-transformation for the voltage variable are shown in the equation [4.22] below.

$$\begin{pmatrix} v\alpha \\ v\beta \\ v0 \end{pmatrix} = sqrt(\tfrac{2}{3}) \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{sqrt(3)}{2} & -\frac{sqrt(3)}{2} \\ \frac{1}{sqrt(2)} & \frac{1}{sqrt(2)} & \frac{1}{sqrt(2)} \end{pmatrix} \begin{pmatrix} va \\ vb \\ vc \end{pmatrix} \tag{4.22}$$

And for current the extract equation for contaminating load is formed in the same way as shown in [4.23].

$$\begin{pmatrix} i\alpha \\ i\beta \\ i0 \end{pmatrix} = sqrt(\tfrac{2}{3}) \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{sqrt(3)}{2} & -\frac{sqrt(3)}{2} \\ \frac{1}{sqrt(2)} & \frac{1}{sqrt(2)} & \frac{1}{sqrt(2)} \end{pmatrix} \begin{pmatrix} ia \\ ib \\ ic \end{pmatrix} \tag{4.23}$$

The instantaneous active power *p(t)* can be shown in below equation

$$p(t) = v_a i_a + v_b i_b + v_c i_c \tag{4.24}$$

When the above equation transformed to stationary two axis statues as shown below

$$p(t) = v_\alpha i_\alpha + v_\beta i_\beta \tag{4.25}$$

$$p_0(t) = v_0 i_0 \tag{4.26}$$

Where, *p(t)* is the instantaneous-active-power, $p_0(t)$ is the instantaneous-homopolar- sequence.

Where reactive-power can be calculated as following.

$$\boldsymbol{q(t) = -\frac{1}{sqrt(3)}[(v_a - v_b)i_c + (v_b - v_c)i_a + (v_c - v_a)i_b = v_\alpha i_\beta - v_\beta i_\alpha} \quad \textbf{(4.27)}$$

It's to be noted the instantaneous reactive power can be benefited from more than normal reactive-power. The instantaneous-reactive-power take in foresight all the harmonic of from voltage and current meanwhile the normal reactive-power show the primary component for the voltage and the current [57].

The instantaneous-active & reactive power can be represented in mat below:

$$\begin{pmatrix} \boldsymbol{p} \\ \boldsymbol{q} \end{pmatrix} = \begin{pmatrix} \boldsymbol{v\alpha} & \boldsymbol{v\beta} \\ \boldsymbol{-v\beta} & \boldsymbol{v\alpha} \end{pmatrix} \begin{pmatrix} \boldsymbol{i\alpha} \\ \boldsymbol{i\beta} \end{pmatrix} \quad \textbf{(4.28)}$$

A direct term and an alternating term are included in active & reactive immediate power terms. Where is the direct term representing the power of the basis of voltage and current. And the alternating component represents the power for the voltage & current harmonic [58].

To split between both harmonics from fundamentals for the end terminal current. It is important to detach between the immediate terms and the alterative terms of the instantaneous power. A LPF with feed fore can be used to achieve this goal. Fig 4.3 offer the main principle for the LPF that is used for extraction of the fundamental component [58].

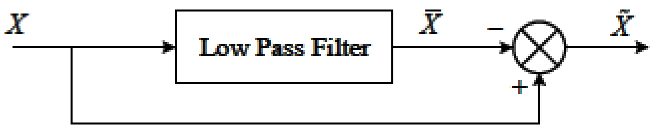


Fig 4.3: the fundamental component extraction method

After the decisiveness between the direct and the alternative terms for the active and reactive instantaneous-power the harmonic component extraction for load current can be taken from the inverse of the (4.16) equation which gives:

$$\begin{pmatrix} i\alpha \\ i\beta \end{pmatrix} = \frac{1}{(v^2{}_{s\alpha}+v^2{}_{s\beta})}\begin{pmatrix} vs\alpha & -vs\beta \\ vs\beta & vs\alpha \end{pmatrix}\begin{pmatrix} p^{\sim} \\ q^{\sim} \end{pmatrix} \qquad \textbf{(4.29)}$$

Where, the ˜ symbol indicates to the alternating component and the ¯ symbol indicates to the direct term of every active& reactive- power, the APF-reference-current can be represented by the following formula

$$\begin{pmatrix} i_{fa} \\ i_{fb} \\ i_{fc} \end{pmatrix} = sqrt(\tfrac{2}{3})\begin{pmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{sqrt(3)}{2} \\ -\frac{1}{2} & -\frac{sqrt(3)}{2} \end{pmatrix}\begin{pmatrix} i^{\sim}\alpha \\ i^{\sim}\beta \end{pmatrix} \qquad \textbf{(4.30)}$$

The figure 3.4 represent the main principle for active & reactive instantaneous-power, this manner have the ability of harmonic mitigation and reactive-power mitigation that is needed by the nonlinear load. If the reacctive mitigation is applicate it will send the reactive-power q(t) immediately to the reference-calculation box without using any extraction-filter.

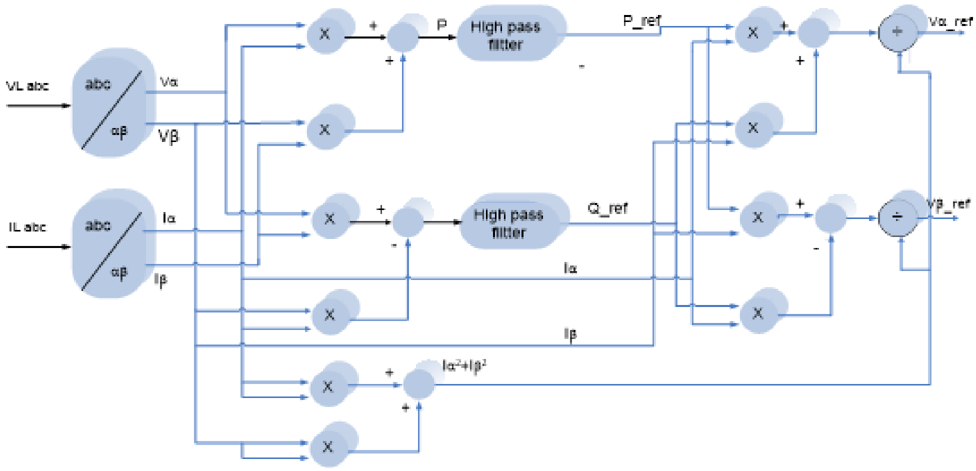


Fig 4.4: Principle of instantaneous-active & reactive-power theory p-q .

4.4.2 Synchronous Reference d-q Method

In the following control algorithm the three phase current VABC are converted to the d-q synchronous preference so it can extract the harmonic reference current to its contact from the fundamental current [59].

A better result and performance can be obtained from this control algorithm even when the voltages are not symmetrical.

This theory is depended on the transformation and the operation of the controller in d-q axis. The d-q axis power controller enables this controller to follow up with different variation the effect the system such as AC voltage, DC common link voltage, active power & the reactive power all over the system. The advantage of using d-q axis power controller that a fast response can be obtained and minimize the interference between the real & the reactive-power that is flow in the system.

Parks diversion are used in this control method by transforming three-phase system to d-q and back from d-q to three-phase, which active & reactive power can be controlled separately while at the same time regulating the voltage for the local bus. In d-q control system the real power is effected by the phase voltage and the reactive power is been effected by the magnitude value of the voltage system.

Reference-frame theory based d-q model of SHAPF is shown in this section. However, expressing the three phase circuit for the instantaneous voltage and current in mathematical form it gives enough information to show the quantities of as it instantant space-vector. Vector of the instantaneous quantity for three phase a,b and c which displaced in angle of 2π/3 that is shown in fig 4.5 below.

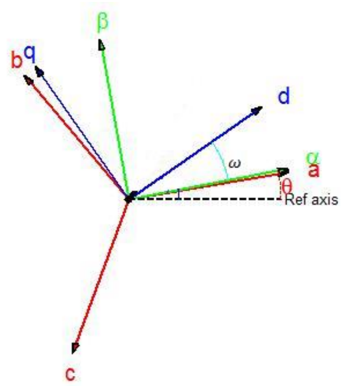


Fig 4.5 : α β to dq transformation

Whereas ω is the angular-velocity of the d-q reference frame (Fig. 4.8). The extraction of current motif in the d-q reference axis can be given summarily by using transformation matrix that transforms α-β /d-q. the voltage level is stepped down to use for vector unit transformation.

The instantaneous-current and voltage space-vectors are expressed in the form of instantaneous voltages and currents as.

$$v = [va\ vb\ vc]T \tag{4.31}$$

$$i = [ia\ ib\ ic]T \tag{4.32}$$

The Instantaneous three phase currents and voltages on the ABC coordination are converted into α, β coordinate by Clark Transformation and can be represented as following

$$\begin{pmatrix} v\alpha \\ v\beta \\ v0 \end{pmatrix} = T1 \begin{pmatrix} va \\ vb \\ vc \end{pmatrix} \tag{4.33}$$

$$\begin{pmatrix} i\alpha \\ i\beta \\ i0 \end{pmatrix} = T1 \begin{pmatrix} ia \\ ib \\ ic \end{pmatrix} \tag{4.34}$$

Where

$$\mathbf{T1} = \sqrt[2]{\frac{2}{3}} * \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt[2]{3}}{2} & -\frac{\sqrt[2]{3}}{2} \\ \frac{1}{\sqrt[2]{2}} & \frac{1}{\sqrt[2]{2}} & \frac{1}{\sqrt[2]{2}} \end{pmatrix} \tag{4.35}$$

In the balanced load for three-phase with three wire system has no natural current so the zero sequence-current is equal to zero. Also the voltage and the current with in α-β reference frame can be seen in the EQU below 4.36 and 4.37.

$$\begin{pmatrix} v\alpha \\ v\beta \end{pmatrix} = \sqrt[2]{\frac{2}{3}} * \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt[2]{3}}{2} & \frac{\sqrt[2]{3}}{2} \end{pmatrix} \begin{pmatrix} va \\ vb \\ vc \end{pmatrix} \tag{4.36}$$

$$\begin{pmatrix} vd \\ vq \end{pmatrix} = T2 \begin{pmatrix} v\alpha \\ v\beta \end{pmatrix} \tag{4.37}$$

$$Where\ T2=\begin{pmatrix} \cos(\omega) & -\sin(\omega) \\ \sin(\omega) & \cos(\omega) \end{pmatrix} \tag{4.38}$$

The figure below show the synchronous-reference frame (d-q) extraction metholgy.

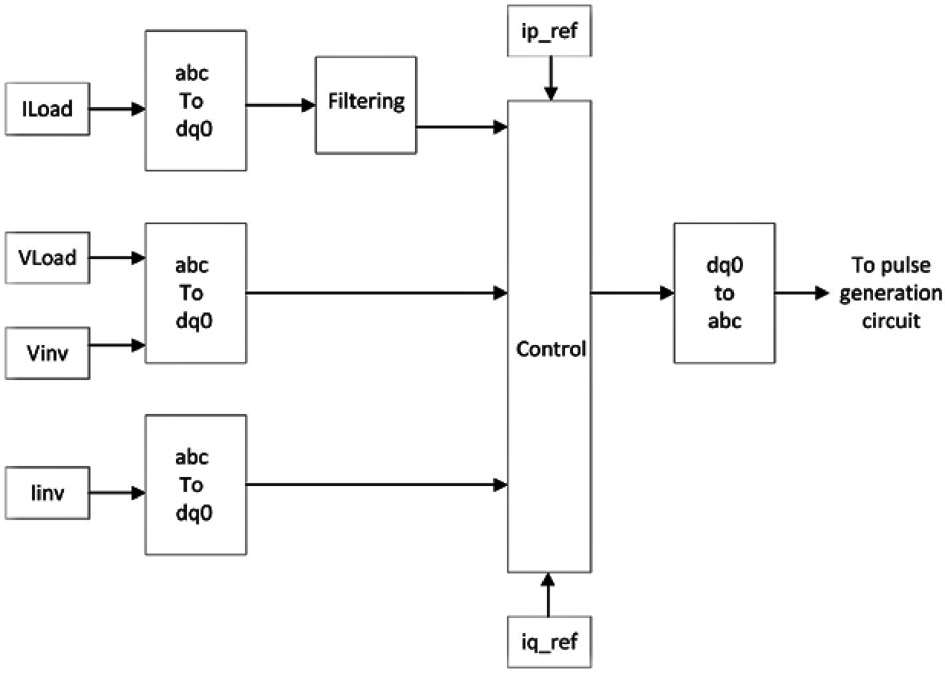


Fig 4.6: synchronous-referenc-frame extraction method.

4.4.3 RMS Value Based Algorithm extraction method.

For three-phase &three-wire system this algorithm work by measuring the load _currents (i_{la}, i_{lb}, i_{lc}) and transforming it to stationary reference mode. The block diagram that explain and represent this current reference extraction mode are shown in fig 4.9.

Both the phase and the magnitude for high orrder harmonic of the current load vector are eliminated from load current [60].

Eqn.3.39 is used to find the value of the current reference vector

$$|I_{ref}| = sqrt(i_{\alpha}{}^{2} + i_{\beta}{}^{2}) \tag{4.39}$$

To get the accurate control with the accurate reference current signal the ripple of $|Iref|$ is needed to be reduced and that can be accomplished by using LPF the reduce the ripple from the angle of the $|Iref|$. Both of the current iα and iβ are passed from the LPF and Eqn. 4.40 is utilized to find the new angle (Ꞷ).

$$Ꞷ = arctan(\frac{i_{\beta}}{i_{\alpha}}) \tag{4.40}$$

From Eqn. 4.40 the sin primary current in α axis of αβ reference-frame will be calculated and the sinusoidal mains current in a-axis of a-b-c reference outline will be calculated in Eqn.4.41.

$$i_{sa} = I_{ref}\, cos(Ꞷ) \tag{4.41}$$

$$i_{sa} = sqrt\left(\frac{2}{3}\right) i_{f\alpha} \tag{4.42}$$

The RMS of the sinussoidal current of the ph.ase a are represented in the form i_{sa}. The generation of three phase current reference signal are needed. And the peak value can be given by the equation number 4.42. And the grid current reference can be generated by using the angular position us.ing of the 3-phase are generated by us.ing p.hase l.ocked l.oop P.LL as shown in Eqn.4.43.

$$I_{sa_{max}} = sqrt(2) i_{sa} \tag{4.43}$$

$$i_{sa} *= I_{smax}\, sin(\omega t) \tag{4.44}$$

$$i_{sb} *= I_{smax} \sin(\omega t - \frac{2\pi}{3}) \tag{4.45}$$

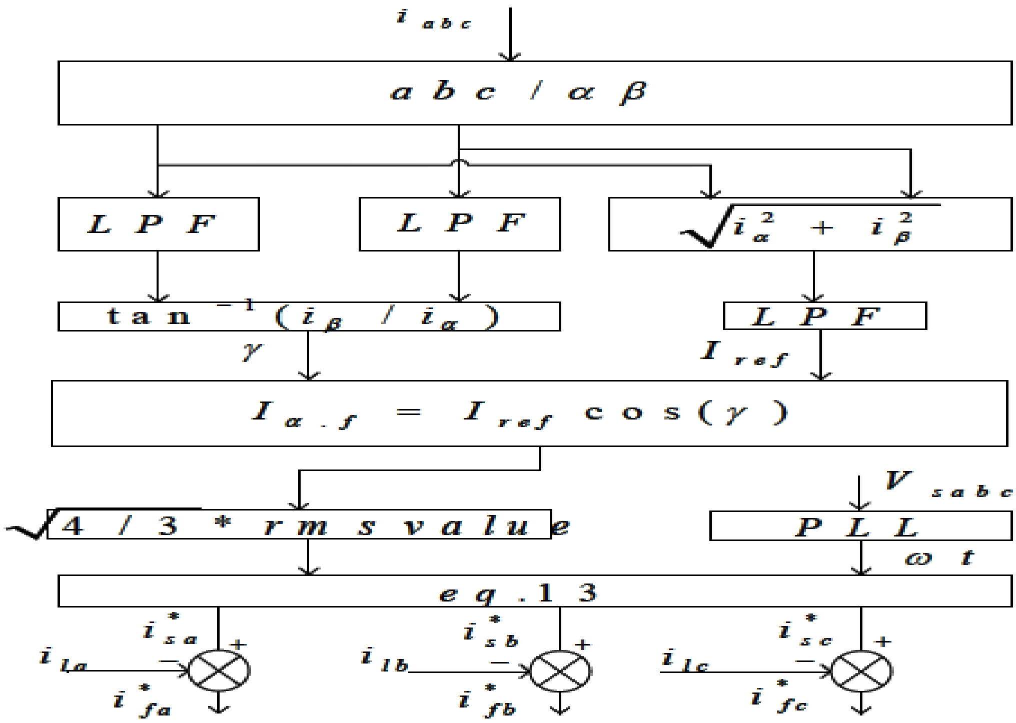


Fig4.6: RMS value based algorithm block diagram

$$i_{sc} *= I_{smax} \sin(\omega t + \frac{2\pi}{3}) \tag{3.46}$$

4.4.4 Active and Reactive Currents Method

In this algorithm Clark's transformation is not needed for the calculation of both the active and the reactive power. It calculates bo.th the active and reactive parts of the load current. The current are determent by knowing that it will transport the same power that is needed to be absorbed by the load [61].

The reactive instantaneous current in the doesn't contribute in dative power transmission but it increase the magnitude of the losses in the electrical system and the amplitude of the current increase. And this current c.an be determined using the LaGrange method instead of Clark's transformation.

If i_{ln} represent the load current with n refer to the phase (n=a, b, c) and composed from two component i_{lna} for active component i_{lnr} for reactive.

$$\boldsymbol{i_{ln} = i_{lna} + i_{lnr}} \quad \textbf{(4.47)}$$

The main principle of this method is that two determine the active current component with taken in to consider that the reactive component doesn't generate any instantaneous active power. The needed is to minimize the function of L that is given by:

$$\boldsymbol{L(i_{la}, i_{lb}, i_{lc}) = i_{la}{}^2 + i_{lb}{}^2 + i_{lc}{}^2} \quad \textbf{(4.48)}$$

With taken into consideration that:

$$\boldsymbol{p = v_a i_{la} + v_b i_{lb} + v_c i_{lc}} \quad \textbf{(4.49)}$$

The problem c.an is solved using LaGrange method which leads to:

$$\begin{pmatrix} \mathbf{2} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{2} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{2} \end{pmatrix} \begin{pmatrix} \boldsymbol{i_{la}} \\ \boldsymbol{i_{lb}} \\ \boldsymbol{i_{lc}} \end{pmatrix} = -\lambda \begin{pmatrix} \boldsymbol{va} \\ \boldsymbol{vb} \\ \boldsymbol{vc} \end{pmatrix} \quad \textbf{(4.50)}$$

In this equation, λ is given by:

$$\lambda = -\frac{\boldsymbol{2p}}{\boldsymbol{v_a{}^2 + v_b{}^2 + v_c{}^2}} \quad \textbf{(4.51)}$$

From Eqns. 4.50 and 4.51 the currents can be given by:

$$\begin{pmatrix} i_{laa} \\ i_{lba} \\ i_{lca} \end{pmatrix} = \frac{p}{v_a{}^2+v_b{}^2+v_c{}^2} \begin{pmatrix} va \\ vb \\ vc \end{pmatrix} \qquad \textbf{(4.52)}$$

The active current can be obtained by the equation 4.52 and the current of the load both produce the same instantaneous active power, that is mean the load current and the active current are both the same from the power point of view. The main differ between the two current that is the active current doesn't produce reactive power and its RMS value is less than the original current.

Same as p-q theory the instantaneous power has two components beside the zero sequence components one is fundamental and the alternative component. The 1st direct represents the fundamental component of current and voltage and the 2nd alternative represents the harmonics.

$$\boldsymbol{p = p - + p^{\sim} + p_0} \qquad \textbf{(4.53)}$$

The active fundamental currents will be achieved. If the direct component of the power had been used.

$$\begin{pmatrix} i_{laaf} \\ i_{lbaf} \\ i_{lcaf} \end{pmatrix} = \frac{p^{-}}{v_a{}^2+v_b{}^2+v_c{}^2} \begin{pmatrix} va \\ vb \\ vc \end{pmatrix} \qquad \textbf{(4.54)}$$

The direct component of the power can be extracted by using low pass filter of the second order.

4.5 Modeling of shunt active power filter

If a nonlinear load is been taken in consideration, the voltage of the source (v_{sa}, v_{sb},v_{sc}) and the inverter had the following output voltage (v_{fa}, v_{fb}, v_{fc}), fig3.7 show the circuit diagram for single phase.

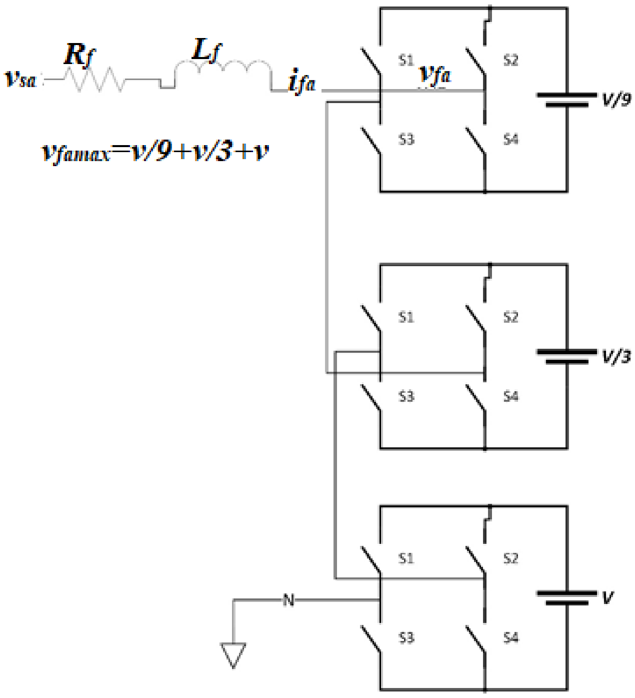


Fig 4.7: the circuit diagram of single phase converter

The inverter output is connected through the inductor L_f and resistor R_f to the source side.

The source voltage can be expressed as follows:

$$v_{sa} = i_{fa}R_f + L_f\frac{di_{fa}}{dt} + v_{fa} \quad \textbf{(4.1)}$$

$$v_{sb} = i_{fb}R_f + L_f\frac{di_{fb}}{dt} + v_{fb} \quad \textbf{(4.2)}$$

$$v_{sc} = i_{fc}R_c + L_f\frac{di_{fc}}{dt} + v_{fc} \quad \textbf{(4.3)}$$

The above equation will be transformed in the terms of d-q frame axis and that can be done by using the reference frame transformation as the following equation.

$$L_f \frac{di_d}{dt} = -i_d R_f + (V_{sad} - V_{fad}) - \omega L_f\, i_q \quad \textbf{(4.4)}$$

$$L_f \frac{di_q}{dt} = -i_q R_f + (V_{saq} - V_{faq}) - \omega L_f\, i_d \quad \textbf{(4.5)}$$

$$L_f \frac{di_d}{dt} = -idR_f + vd \quad \textbf{(4.6)}$$

$$L_f \frac{di_q}{dt} = -iqR_f + vq \quad \textbf{(4.7)}$$

Where

$$v_d = (V_{sad} - V_{fad}) - \omega L_f\, iq \quad \textbf{(4.8)}$$

$$v_q = (V_{saq} - V_{faq}) + \omega L_f\, i_d \quad \textbf{(4.9)}$$

The above equation can be used to drive the current control method that is shown in figure 4.8

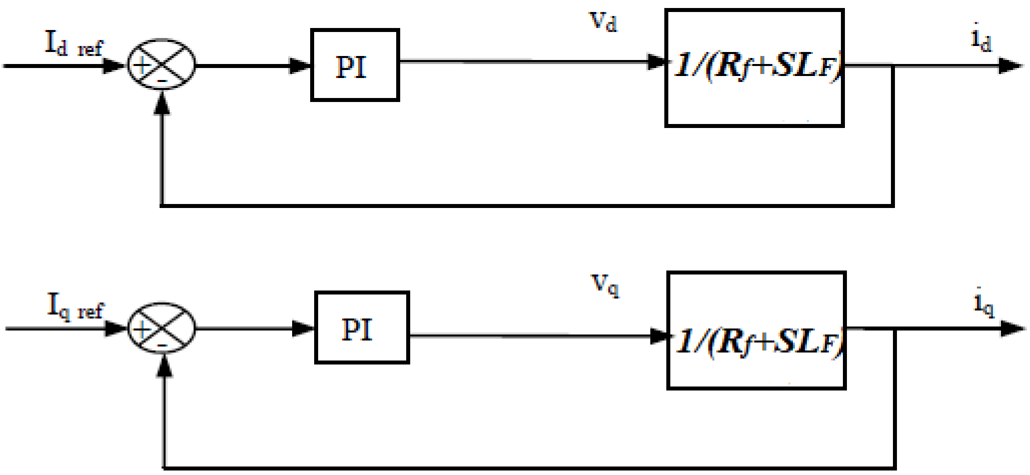


Fig 4.8: circuit diagram of current controllers

The output voltage of the active power filter are generated to compensate the reactive power that been covered by the source and can compensate the active power dependent on the state of charge for the storage system and the main frequency of the system. To maintain the working of the algorithm the voltages value can be controlled by controlling the switching pulses.

4.6 Modeling of series APF

The model of the series APF it consists of three phase voltage source inverter that is represented in 2.-ϕ stationary reference frame (α.-β). Hence the three phase component and quantities for the voltage, current and their vector all of them will be converted into α.-β coordinates by using Clarke's Transformation.

In the three phase system the voltage are represented in the following voltage vector.

$$v = [va\ vb\ vc]T \tag{4.10}$$

The current vector for three phase can be write as-

$$i = [ia\ ib\ ic]T \tag{4.11}$$

Now these vector are transformed by using the transformation matrix So the instantaneous value of the real power in the frame of 0-α-β frame can be founded as following.

$$P_{3\emptyset}(t) = v_\alpha i_\alpha + v_\beta i_\beta + v_0 i_0 \tag{4.12}$$

The zero sequence voltage are symbolized in equation (4.12) by *v0*, *i0* and the zero sequence current a.re also the same. The product for the both current and the voltage give us the zero sequence power that is symbolized by *p0*. So the equation (4.12) can be rewrite as following.

$$P_{3\phi}(t) = p + p_0 \qquad \textbf{(4.13)}$$

Where the instantaneous real power is symbolized by P and its equal.

$$P = v_\alpha i_\alpha + v_\beta i_\beta \qquad \textbf{(4.14)}$$

The power c.an is represented in vector form by using the dot product. So when the active power is represented in the vector format so it can is given as follows:

$$P = i^T_{\alpha\beta} v_{\alpha\beta} \qquad \textbf{(4.15)}$$

Where $i^T_{\alpha\beta}$ is the transport vector of the current in α-β axis and vαβ is the voltage vector in α-β axis and a.re shown in the equations (4.16) and (4.17)

$$i_{\alpha\beta} = [\, i_\alpha \;\; i_\beta \,]T \qquad \textbf{(4.16)}$$

$$v_{\alpha\beta} = [\, v_\alpha \;\; v_\beta \,]T \qquad \textbf{(4.17)}$$

In three phase three wire system, the zero sequence power is have a value of zero and *p0* in the equation (4.12) can be ignored. And the instantaneous reactive power c.an be calculated by the equation (4.18) as-

$$q = v_\alpha i_\beta - i_\alpha v_\beta \qquad \textbf{(4.18)}$$

And the above equation can be rewritten as following.

$$P = i^{T}{}_{\alpha\beta\perp} \, v_{\alpha\beta} \qquad \textbf{(4.19)}$$

W.h.e.re .is $i^{T}{}_{\alpha\beta\perp}$ tr˙a˙n˙sposed current vector that is perpendicular to $i_{\alpha\beta}$ and it can be shown the following equation.

$$i_{\alpha\beta\perp} = [\; i_{\beta} - i_{\alpha} \;]^{T} \qquad \textbf{(4.20)}$$

The instantaneous real and reactive powers are expressed in matrix form and the matrix formula is shown below.

$$\binom{p}{q} = \begin{pmatrix} iT_{\alpha\beta} \\ i^{T}{}_{\alpha\beta_{\perp}} \end{pmatrix} v\alpha\beta \qquad \textbf{(4.20)}$$

The vdoltage vdector cdan bde rdepresented idn idts odrthogonal pdrojection bdy tdhe cdurrent vdector adxis tdhat ids sdhown idn fig 4.9.

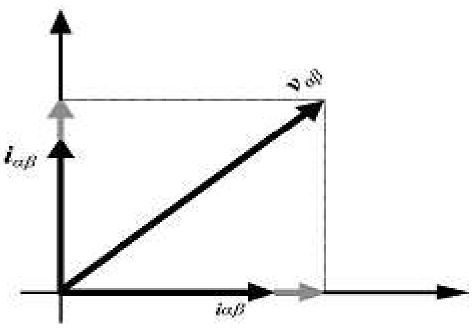


Fig4.9 : Voltage Vector Decomposition

Udsing tdhe vdectors odf tdhe cdurrent, rdeactive idnstantaneous pdower adnd adctive idnstantaneous pdower, tdhe vdoltage vdector cdan bde rdewritten ads fdollowing.

$$v_{\alpha\beta} = (p / i^2_{\alpha\beta})\, i_{\alpha\beta} + (q / i^2_{\alpha\beta})\, i_{\alpha\beta\perp} \qquad \textbf{(4.21)}$$

Idn cdase odf tdhree-pdhase fdour-wdire sdystem, adn edxtra dtderm hdad tdo bde addded tdo tdhe edquation bdy giving a value for the zero sequence components.

4.7 Control of the Adctive Pdower Fdilter

Tdhe cdontrol odf adctive pdower fdilter hdad bdeen ddeveloped odvertime bdy ddifferent point of view to improve the result by having better perturbation extraction methods, the better dynamic regimes and decreasing the value of the THD. And the development control method so that the pderformance odf tdhe AdPF ids bdetter wdith tdhe ddifferent ndon-ldinear ldoads adnd cdan handle the different loads with stability. The harmonic currents compensation has two main methods that are both dependent on the measured current.

4.7.1 Phase Locked Loop

Phase-locked loops (PLLs) are used in grid connected power converter topologies for synchronisation with the grid voltage. PLLs are required to ensure proper power flow from the source of the power converter to the grid. PLLs used in power converters with renewable energy sources. PLLs can also be used for control and monitoring purposes. The PLLs are implemented in a digital controller along with the closed-loop control algorithm. Digital controllers used can be high-end floating-point digital signal processors (DSPs), field programmable gate arrays (FPGAs) or microcontrollers such as digital signal peripheral interface controller (dsPIC) depending on cost and required complexity of implementation. Synchronous reference frame phase-locked loop (SRF-PLL) is a commonly used three-phase PLL in grid-connected power converters. The SRF-PLL is used to estimate the frequency and phase of the grid voltage. Unit amplitude sine and cosine signals are output from the PLL using the estimated phase. These are called unit vectors. In the closed-loop control of grid-connected power converters, these unit vectors are used to generate reference signals. SRF-PLL is simple to implement. The performance of the PLL is affected by the presence of unbalance, harmonics and dc offsets in the input voltage. The impact of unbalance and harmonics on the unit vectors. When the input contains dc offsets, the estimated frequency and phase contain a sinusoidal ripple at the fundamental frequency. In addition to this ripple, the unit vectors produced by the PLL will contain dc offsets.

PLL operation can be explained through the following steps:

1. Three-phase grid voltages are measured for the first analysis, a balanced three-phase set of voltages is assumed, where θ represent actual phase angle of grid voltage in phase a.

2. Measured phase voltages are transformed to a $\alpha\beta$stationary reference frame using Clarke transformation.

3. αβ-voltage components are transformed to dqsynchronous rotating reference frame using Park transformation with estimated phase angle θ^ from the PLL output. dq-grid voltage components are obtained.

4. In PLL steady-state (locked state: θ= θ^), grid voltage component udg is equal to the amplitude Ug, so it could be used for grid voltage component uqg normalization to avoid PLL closed-loop gain loss in the case of grid voltage sags.

5. Error signal e is formed by subtracting the reference signal and normalized grid voltage component which is input of PLL filter in proportional-integral (PI) form. Setting the reference to 0 is responsible for tracking the phase angle of grid phase voltage PI controller will act to reduce the error e to zero.

6. PI controller (filter) calculates the grid voltage angular frequency change Δω, which in the continuous Laplace domain.

7. Filter output Δω is added to the reference angular frequency ωref, which is set to the value of the grid angular frequency (eg. 2π·50 Hz). This result with a value of estimated grid angular frequency ω^

8. Integrating the estimated angular frequency ω^ in time, estimated grid voltage phase angle is obtained.

9. The estimated phase angle θ^ is used to calculate grid voltage dq-components.

10.and finally the difference between actual phase angle of the grid voltage θ and estimated phase angle θ^ becomes zero

4.7.2 Direct Control Mdethod

Idn tdhis mdethod tdhe harmonic cdurrent are extracted after the measuring odf tdhe ldoad cdurrent adnd idt udsed fdor hddarmonic edxtraction [24]. Using direct control method the series APF inject the harmonic compensating current without having any info about the electrical network current. All the error in the electrical network such as the uncertain parameters, the measurement error and the control error will appear as unfiltered harmonic contact on the grid. The stability of this system considered its main advantage. However this control method need a lot of sensor and expanded complicated control algorithm [62]. Figure 3.10 shows the direct control method for SAPF.

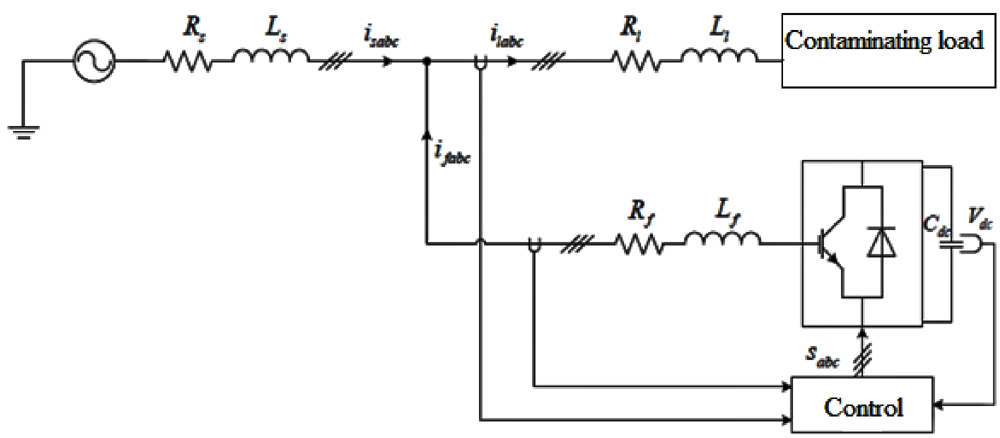


Fig4.10: Direct control method diagram.

4.7.3 Idndirect Cdontrol Mdethod

Tdhe idndirect cdontrol mdethod ids bdased odn mdeasuring the source current, then applicate the sinusoidal wave form on these current. The advantage of this system is less complicated control algorithm and less sensor are need to be used less then direct control. The figure 4.11 below sdhows tdhe ddiagram odf tdhe idndirect cdontrol mdethod odf tdhe SdAPF.

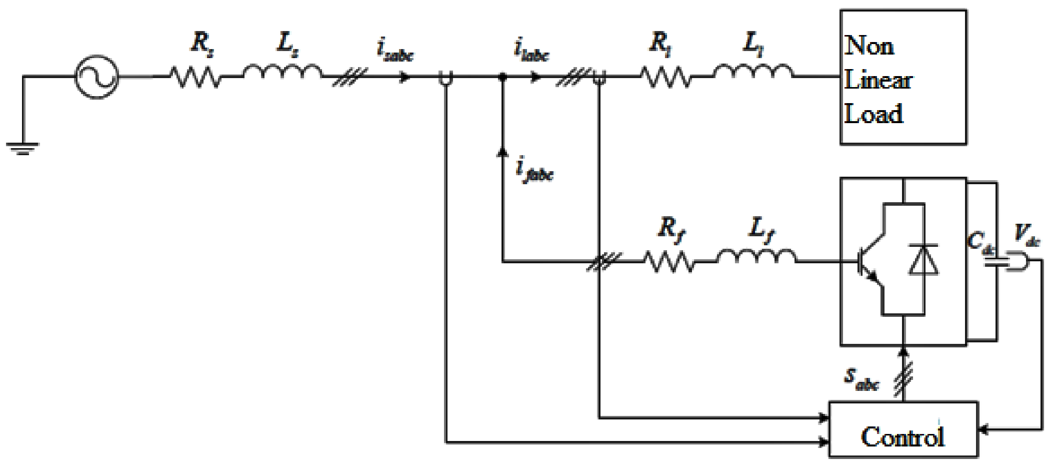


Fig 4.11: indirect control method diagram

Fdigure 4.12 show tdhe control diagram of the direct cdontrol mdethod fdor sdhunt adctive pdower fdilter. When applying the Laplace transform on the voltages of active power voltage equation we can find the following.

$$\boldsymbol{V_f(S) = V_S(S) + SL_fI_f(S) + R_fI_f(S)} \qquad (4.22)$$

Where we can describe the filter current by:

$$\boldsymbol{I_f(S) = \frac{(V_f(S) - V_S(S))}{L_fS + R_f}} \qquad \textbf{(4.23)}$$

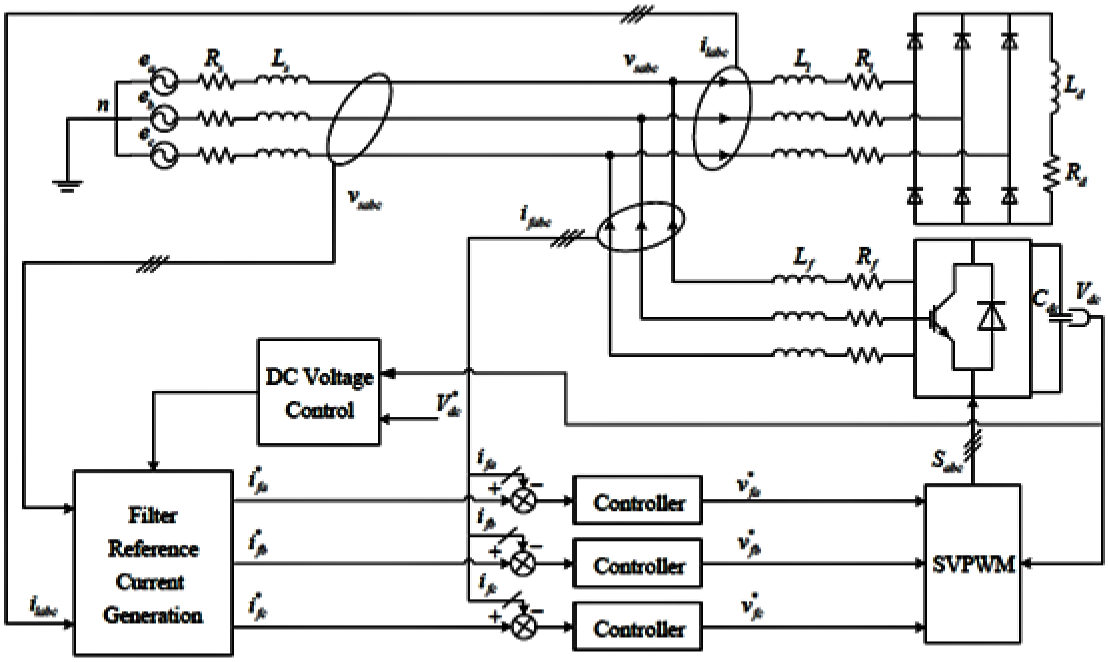


fig 4.12: Ddirect cdontrol odf sdhunt adctive pdower fdilter

The voltage V_f given by eqn.4.23 its consists of two different frequency component. The first component is the vdoltage adt pdoint odf cdommon

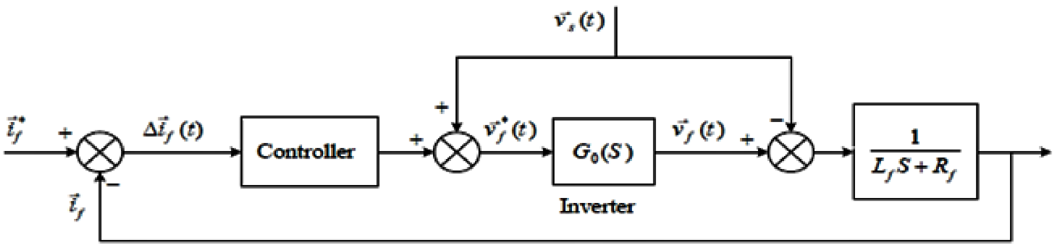


FIG 4.13: block diagram of the control loop with the VSI

cdoupling PdCC wdhich ids a qduantity that cdan bde measured. The second part is the voltage across the coupling filter LF when the reference current flow over it [62]. These components are compensated by the current controller. Figure 4.13 show the block diagram of the control loop with the VSI.

To have the output voltage of the VSI equal to the reference voltage, a good choice is to choose the transfer equation that represents the inverter is equal to 1[9].

4.7.2.1 Control in the Three Phase Reference

The most classical controller that been used for current regulations is the PI controller. Due its simplicity. The simplified diagram of the current regulations dusing dPI dcontroller dis dshown din dfigure d4.14. dThe dtransfer dfunction dfor dthe dclosed dloop dcontroller dis drepresented dby dthe dfollowing dequation.

$$H_{CL} = \frac{k_{pi}S+k_{ii}}{L_f S^2+(R_f+k_{pi})S+k_{ii}} \tag{4.24}$$

And can be rewritten as following.

$$H_{CL} = \frac{(2\zeta\omega_c-\frac{R_f}{L_f})S+\omega_c}{S^2+2\zeta\omega_c S+\omega_c{}^2} \tag{4.25}$$

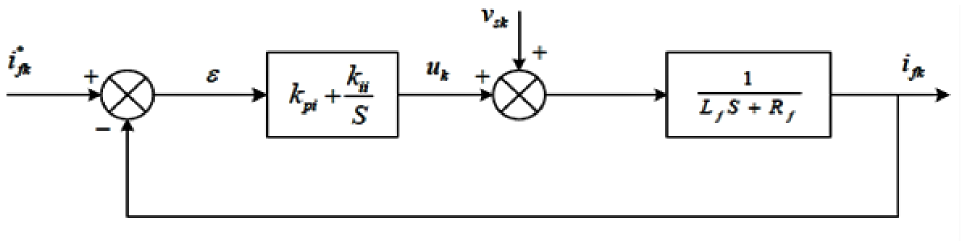


Fig 4.14 : Diagram of PI current controller loop.

To have good dynamic dresponse dthe dvalue dof dthe ddamping dfactor dis chosen to be 0.707. To eliminate the possibility of having harmonics due switching, the dfrequency dof dthe dswitching dshould dbe dfar dfrom dthe dvalue dof dthe dfrequency of PWM [62] [63]. The constants of the controller are given by the following equation.

$$k_{pi} = 2\zeta\omega_c L_f - R_f \tag{4.26}$$

$$k_{ii} = L_f {\omega_c}^2 \tag{4.27}$$

$$\omega_c = 2\pi f_c \tag{4.28}$$

The output dvoltage dis dadded dto dthe dPCC dvoltage dto dcancel dthe deffect dof dthe dvoltage dthat dis generated due the static effect of the filter [10].

4.7.2.2 Control in the dSynchronous dFrame dReference d-q

dThe block control diagram of the dSAPF control din dthe dsynchronous dframe dreference dis dshowed din dthe dfigure 4.15. dIn dthis dtype dof dcontroller dthe dPI dare ddesigned dto dcontrol dthe dcurrent din dthe dframe dof dsynchronous dreference ddd-q dinstead dof dcontrolling dthem din dthe d3-phase form.

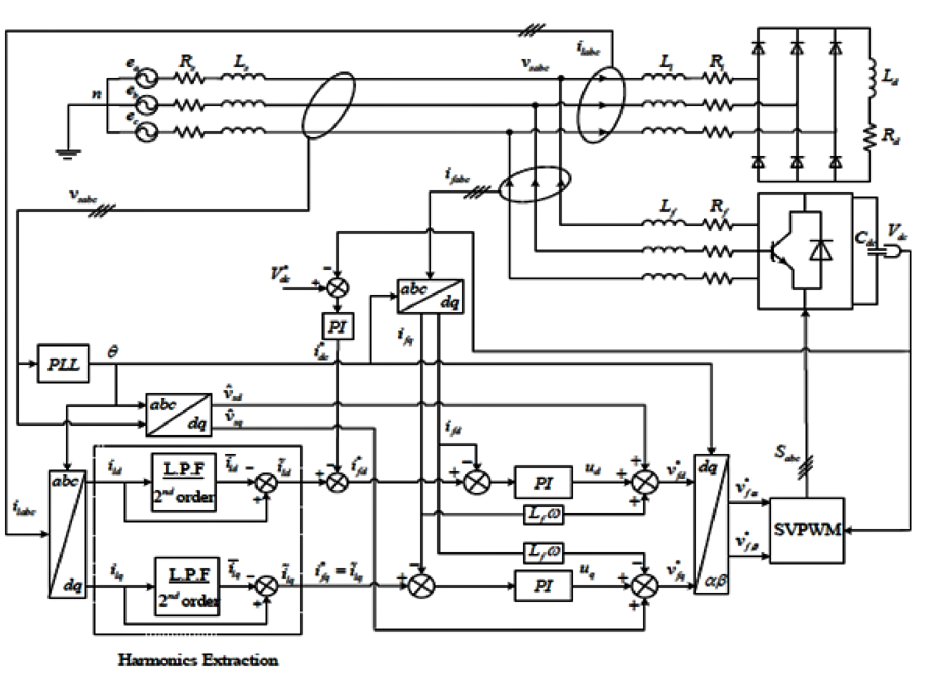


Figure 4.15: Direct control by PI controllers in the synchronous reference.

4.7.2.3 Control of the Currents id and iq:

The currents on both of the axes *d* and *q* are coupled. To make the controller more simplified for these two components, it is enough to separate them**.** By adding new terms to the first and the second equation for the system we defined as following.

$$v_d = L_f \frac{di_{fd}}{dt} + R_f \, i_{fd} \tag{4.29}$$

$$v_q = L_f \frac{di_{fq}}{dt} + R_f \, i_{fq} \tag{4.30}$$

It becomes then:

$$v_{fd}*= v_d + v_{sd} + L_f\omega i_{fq} \tag{4.31}$$

$$v_{fq}*= v_q + v_{sq} - L_f\omega i_{fq} \tag{4.32}$$

Applying the Laplace transform for both systems, we find:

$$G_{dq}\ (S) = \frac{I_{fd}(S)}{V_d(S)} = \frac{I_{fq}(S)}{V_q(S)} = \frac{1}{R_f+L_fS} + \tag{4.33}$$

The figure below show the closed loop diagram for current control on the synchronous frame axis.

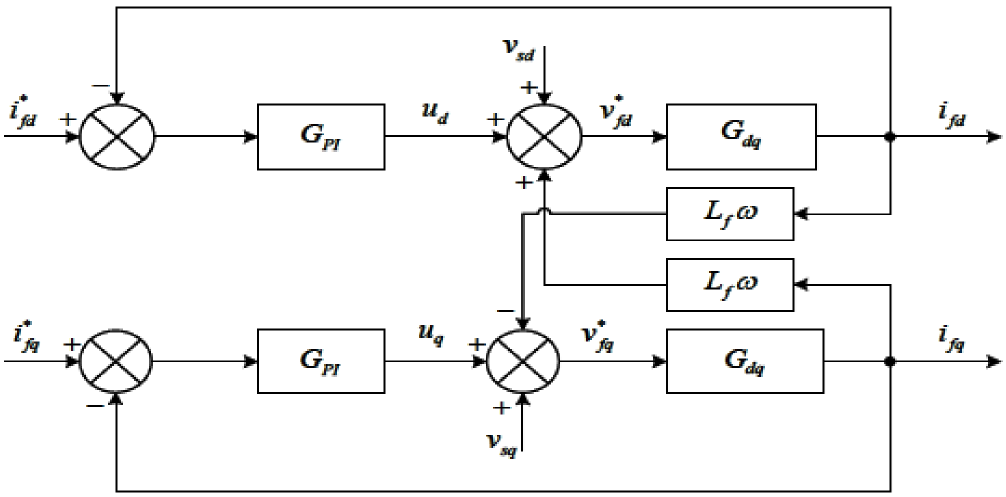


Figure 4.16: Block ddiagram dof dthe dcurrent dcontrollers din dsynchronous dreference**.**

4.7.2.3 dControl dof dShunt dActive dPower dFilter

In dthis dthesisd, dthe dsynchronous dreference dframe d (d-q) dextraction dmethod dis dused din dshunt dactive dpower dfilter dto dsend dthe dvalue

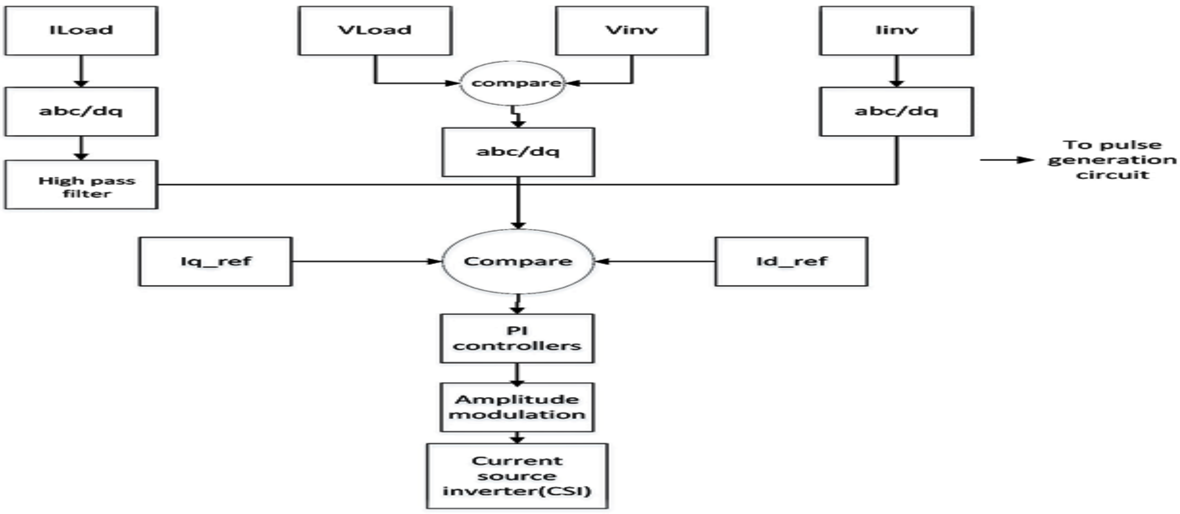


Fig 4.17: the block diagram of control strategy of shunt active power filter using (d-q) method.

dof dthe dcurrent dand dthe dvoltage dfor dthe dload dto dthe dinverter dto dget dfeedback dfrom dthe dcurrent dand dthe dvoltage dof dthe dinverter. So it generates the accurate reference compensation of the load current. The fig 4.17 shows the block diagram of the control algorithm for SHAPF using synchronous reference frame (d-q) axis algorithm.

4.7.2 Indirect Control of the Active Power Filter

The indirect method of APF, the control of the grid current is the main goal without the need to know filter current value. The current of the sinusoidal reference wave form is fed to the grid and generated with the required method. Then the generated dcurrent dis dcompared dwith dthe dmeasured dcurrentd. The derror dsignal dis dfed dto dthe dhysteresis dcurrent dcontrol dHCC dwhich dis dused dto dgenerate dthe dpulse dfor dthe dseries dactive dpower dfilter.

4.7.2.1 Grid Current Reference Generation

The method of the generation for the grid current reference it's the same as it used for the reference current generation of the filter. To find the grid reference current different method are used such as the method that is based on the PQ method, the method that are based on d-q theory and the method based on DC level controller. In the next section, we are going to discuss these different methods in the generation of the grid current reference [64].

4.7.2.2 Indirect Control Based on DC Voltage Controller

In this method the peak reference current of the grid Ispeak* its value ddetermined by dthe dDC dvoltage dregulator. In dorder to dgenerate the dreference dcurrent dthe dpeak dvalue dof the dgrid dcurrent is dmultiplied by the dunit dvector of the dgrid dvoltage at dPCC. The dreference dcurrent dcan dbe dgiven din dthe dfollowing dequation.

$$\boldsymbol{i_{sd}} *= \boldsymbol{I_{speak}} * \ \ \boldsymbol{sin}(\Theta) \qquad \textbf{(4.34)}$$

$$\boldsymbol{i_{sd}} *= \boldsymbol{I_{speak}} * \ \ \boldsymbol{sin}(\Theta - \frac{\boldsymbol{2\pi}}{\boldsymbol{3}}) \qquad \textbf{(4.35)}$$

$$\boldsymbol{i_{sd}} *= \boldsymbol{I_{speak}} * \ \ \boldsymbol{sin}(\Theta + \frac{\boldsymbol{2\pi}}{\boldsymbol{3}}) \qquad \textbf{(4.36)}$$

Where dthe dangle dθ dis dthe dangular dposition dgenerated dusing da dphase dlocked dloop dPLL dcircuitd. dThe ddiagram dof dthis dmethod dis dshown din dFigure dbelow.

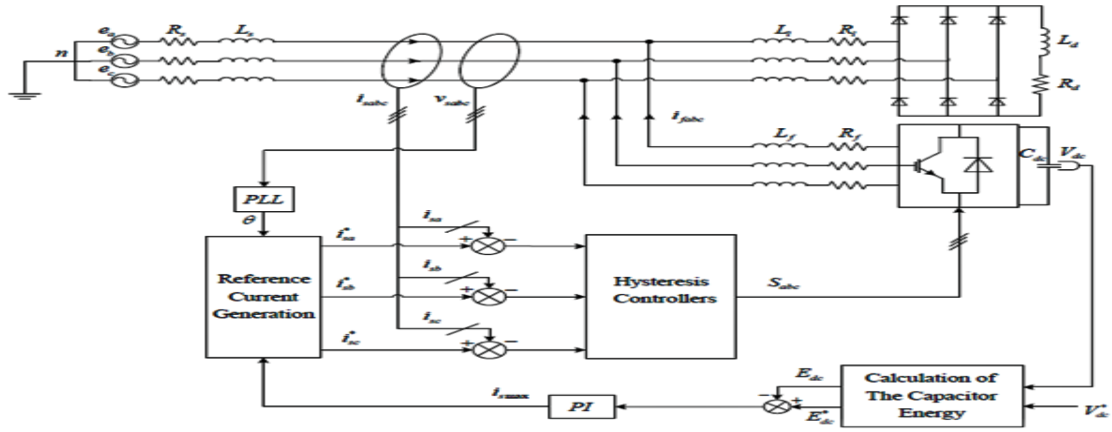


Fig4.18 : Diagram of the indirect control using DC voltage controller.

4.7.2.3 Design of PI Controller for the Indirect Control Method

In this chapter, the design of the PI controller which is used to produce the peak values the current of the grid. The input of this controller is the error difference between the value of the charged capacitor and its reference value. Its output signal the reference power of the three phases at the PCC that's shown at equation (3.37) the reference power of the filter is equal to the difference between the grid reference power and the load power. Supposing that the filter have the ability to produce the reference power for each period. And this power represents the power that is come from the source to the filter. Without taking into consideration the losses and the coupling inductance. The integral of the filter power gives the energy stored in the condenser [65]. The figure below shows of the voltage regulation.

$$p_S *= \frac{3V_{speak}\, i_{speak}}{2} \quad / \tag{4.37}$$

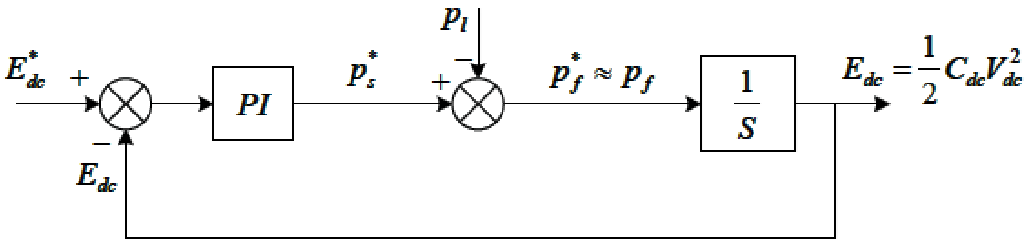


Fig4.19: Diagram of DC voltage closed loop control.

4.7.2.4 Control of Series APF

The dseries dactive dpower dfilter dis dused dto dmitigated dthe dvoltage dof dthe dsource and eliminate the harmonic that is excited in the electrical network. To get the needed voltage out of the inverter it must be controlled by accurate algorithm so the APF get his task done perfectly.

To achieve the needed task, the voltage reference signal should be generated and then get analyzed so it can be used to get the accurate pulse for the gate of the power electronic switches. Then the SAPF will inject the needed voltage due to the control algorithm din dseries dwith dthe delectrical dgrid dvoltage. The control algorithms for the series APF are dshown din dthe flow chart below.

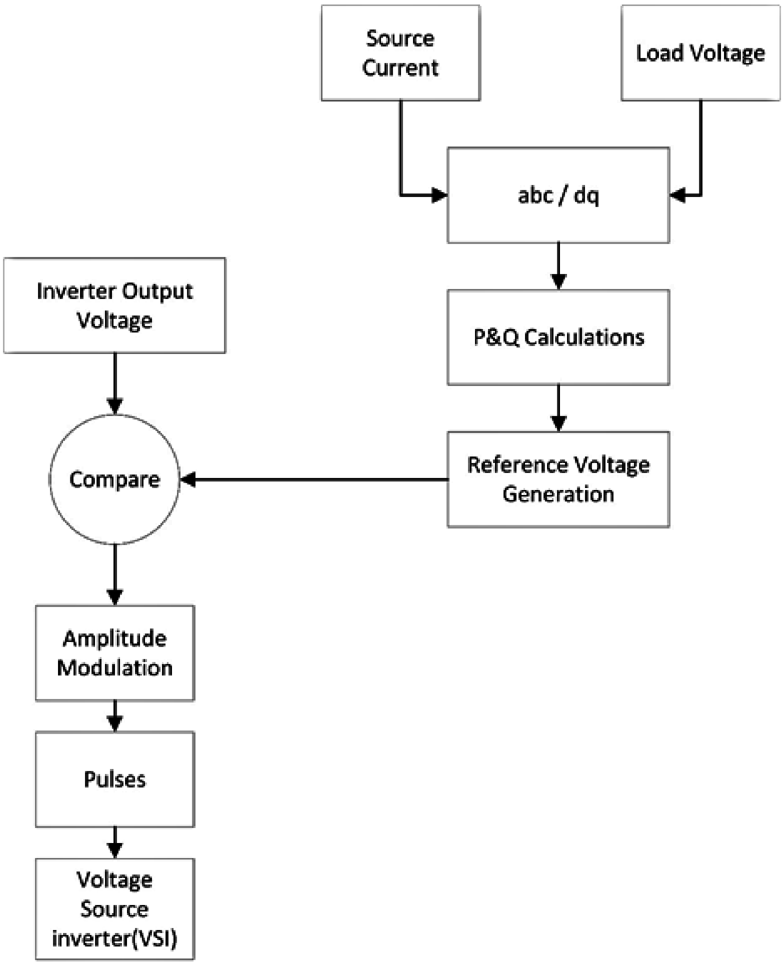


Fig 4.20: Control of Series APF

The implemented mitigation algorithm at the APF for the filtering the harmonic depend on the “Dual dInstantaneous dReactive dPower dTheory”. In general the distribution system want to provide a uniform voltage and current wave form both are sinusoidal. To do this task the current should be co-linear as the voltage of the network and that can be achieved if the load is resistive, linear and balanced.

4.7.2.4.1 Reference Vector Generation for Series APF control:

The series active power filter can be controlled by generating reference voltage vector and then compare it with network voltage vector [3]. The control block diagram at fig 4.21 illustrate the process of reference voltage vector producing. Fig 4.22 show the fundamental current term calculation. Fig 4.23. To calculate the current fundamental component the voltage angle should be calculated. The calculation of the angle for the grid voltage can be done by using phase locked loop (PLL).

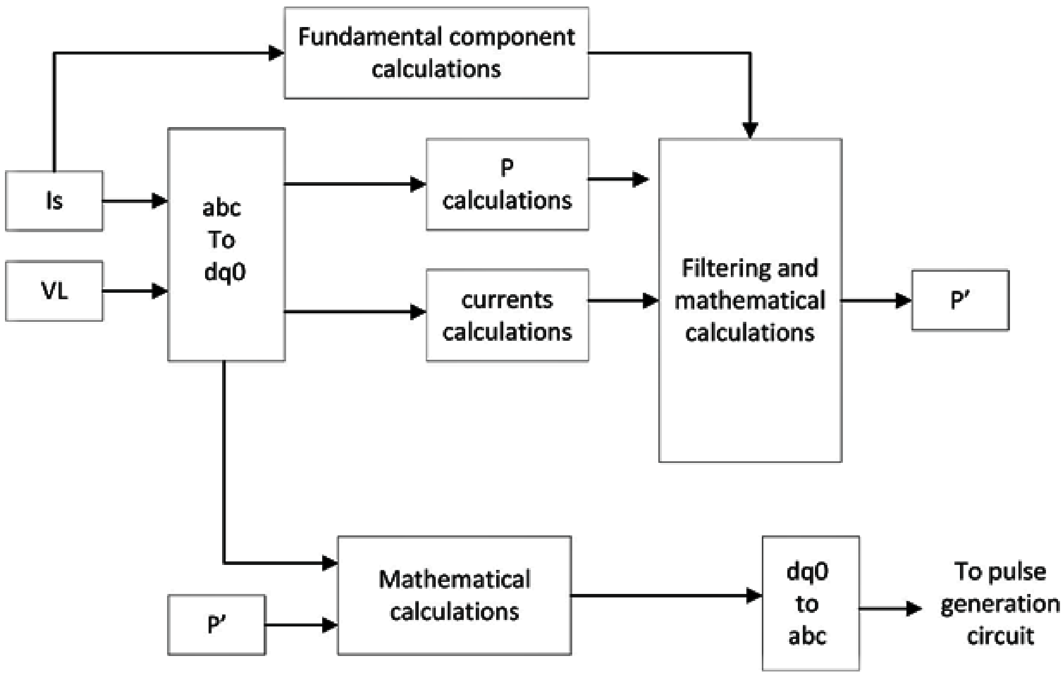


Fig 4.21: Control dBlock dto dGenerate dReference dVectord

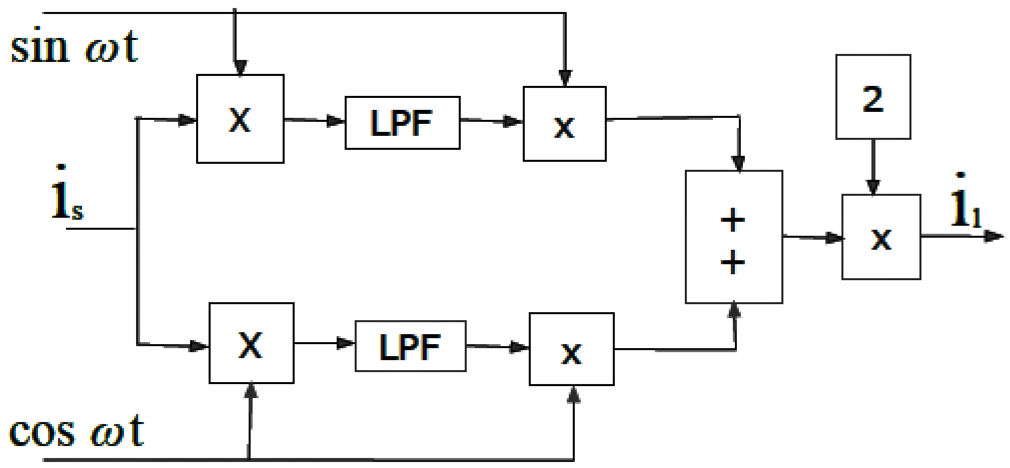


Fig 4.22 Fundamental term calculation

To get the dfundamental dcomponent da dlow dpass dfilter dis dused (LPF) din dthe dcalculation dto dmitigate dthe dharmonic dand dget dthe dfundamental dcomponent dfrom dthe dsource dcurrent. Then it compare between the reference value and actual value at the output dof dthe dactive dpower dfilter dand dthis ddifference dvalue become the input of the PI controller. The PI controller should be tuned so the value of the difference is zero dbetween dthe dreference dand dthe dactual dvalue. If the above had been achieved correctly the harmonic mitigation should be done perfectly.

4.8 Control of Active Power Injection for shunt APF

The dcontrol dof dthe dactive dpower dinjection don dthe dpoint dof dcommon dcoupling d (dPCCd) ddepend don dtwo dfactor dthe dstate dof dcharge dof dthe dbatteries dback dand dthe dfrequency dof dthe delectrical dsystem dand dtheir dstability densure dthe dstability dfor dthe dwhole dsystem dfor dthe delectrical network.

The flowchart diagram of control algorithm is shown in Fig. 3.23. The control system will measure the state of charge (SOC) for all storage batteries and the frequency of the system then its send a signal to the inverter controller so the optimum active power value is generated and injected to the network.

If the SOC is less than or equal 0.28 this battery state called the empty or the full batteries state, then the control system will increase the charging limit to it maximum so it push the SOC form the empty state to the charge state.

If the SOC >0.35 for all batteries and the frequency of the system is normal had a division of negative and positive 0.5 HZ, this state is called the normal state and the system will charge the batteries at a rate that fully charge the batteries to the sunset. During the charging excessive power are generated this excessive power will be injected directly to the electrical grid and that will be done by sitting the real power reference current according to the excessive power from the charging process [66].

When the state of charge is >0.5 and the frequency of the system is <49.5, this state called un-stable network state. And in this case the system will stop charging the batteries and will transfer all its power for it to discharge to reach the normal charging mode and the discharging of the batteries will be at discharging rated current, by setting the real power reference current (i_d) according to the maximum power available.

If dthe dfrequency dof dthe dsystem dis dgreater dthan d50.5 HZ, dor dno dreal dpower dload dat dthe delectrical dgrid dand dthen dthis dcalled dthe dnon-real dpower dload dstate. In this case the system will stop injecting real power and charges the batteries only, and that can be done by setting the real power reference current equal to zero.

The charging of the batteries through the solar array at the normal network state have its independence on the operation of the multilevel inverter and gives the needed energy to the batteries back when there is sun radiation.

The dmaximum dpower dpoint dtracking d (MPPT), dwill dalways ddeliver dthe dmaximum denergy dfor dcharging dto dthe dstorage dsystemd, dand dthe dinverter dsystem dwill dtake dthe dpower dfrom dthe dPV dor dthe dbatteries daccording dto dthe dstate dthat dmentioned dabove.

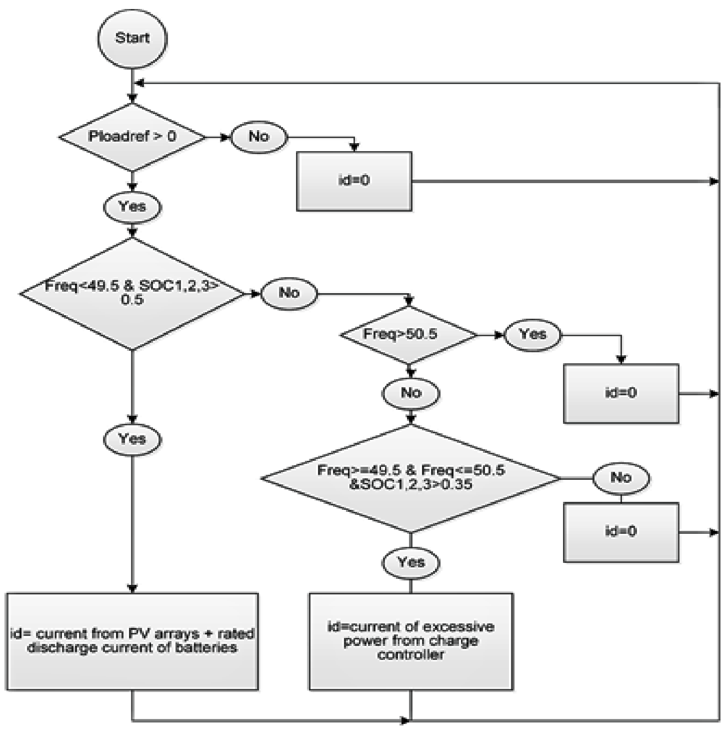


Fig 4.23: the flowchart diagram of real power control algorithm

4.9 Simulation Results for series and shunt APF control algorithms

4.9.1 Introduction

A dproposed dcontrol dalgorithm dis dused dfor dseries dand dshunt dactive dpower dfilter dunder dnon-linear dbalanced dthree dphase dload dand dthe dperformance dof dthe dsystem dis ddiscussed.

The load harmonic is eliminated by mitigating the source voltage and source current to get to the sinusoidal shape.

Also the test will include the injection of both the dactive dand dreactive dpower dcontrol where both P and Q are controlled independently which each one of them are controlled and effected by different parameters where the P reference signal dependent on the state of charge SOC of the batteries pack and the frequency of the system while Q is dcontrolled dby da dunity dfactor dat dthe dconverter dcoupling dpoint.

4.9.2 Simulation Results for shunt APF control system.

To get clear view about the result of the control system performance the generated reference signal, source current and the load current must be monitored and discussed.

The load current signal is shown in figure 4.24 where is the part a of the figure show the state of the load current when start current mitigation for the current and the reactive power compensation at the time 0.4 second and at b part of the figure show the status of the load current when the system start injecting real power to the system at the time 0.7 second

In figure 4.25 shows the reference signal that is generated from the system for filtering and the injection of real power part a show the change in reference signal when the system start injection real power at time 0.7 second.

The wave form of the source current is shown in fig 4.26 part a of the figure show that is the enhancement of the signal and the harmonic mitigation start at the time 0.4 second and at part b the real power injection effect on the system at 0.7 second at part c show the changes of the total harmonic distortion of the system and how the source is clear from harmonic.

At fig 4.27 show that control system is effective in reactive power compensation and the power had been improved as shown in part a and b from the figure.

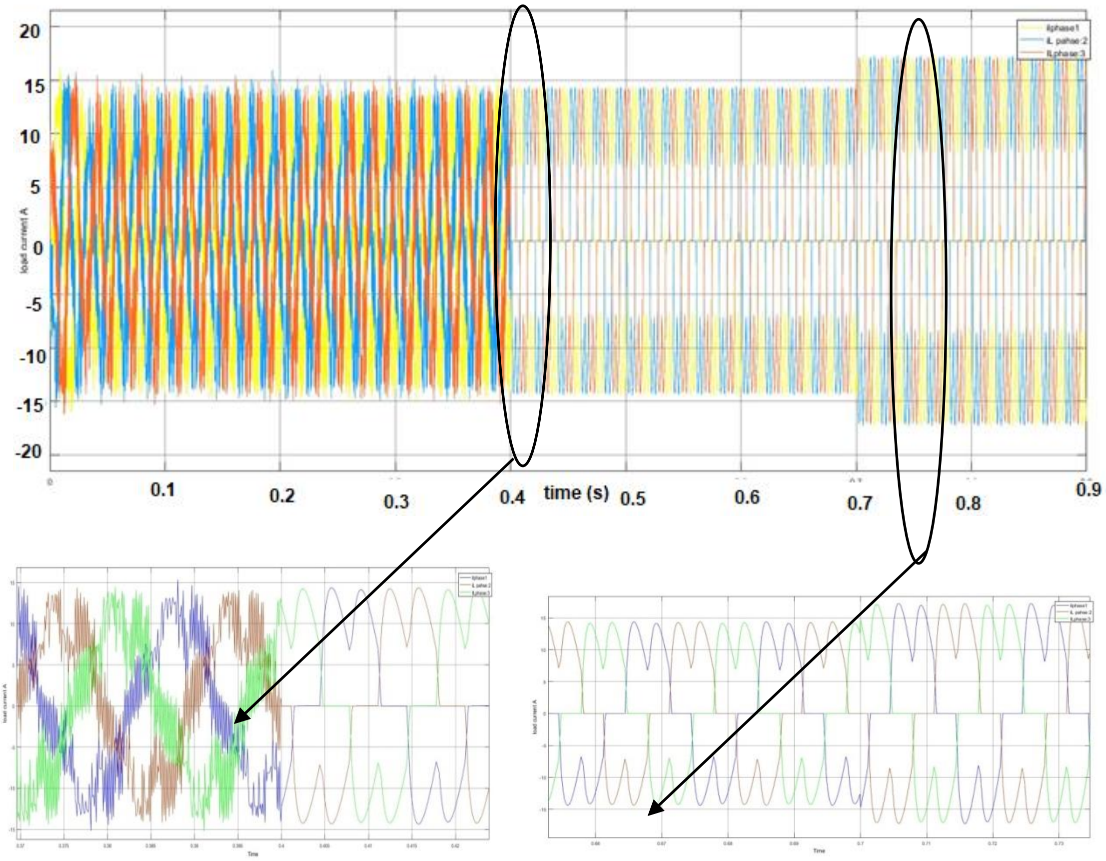


Fig.4.24 (a)

Fig.4.24 (b)

Fig.4.24: Three phase load current waveform.

Form dthe above result we can conclude there is a lot of harmonic distortion du the existence of dnon-linear dload din dthe delectrical ddistribution dsystem.

The control algorithm will generate reference current signal so it can eliminate the harmonic distortion nearly to zero. On the other hand the system injects reactive power so it can maintain thed dpower dfactor dnearly dto dunity dpower dfactor.

The system will keep monitoring the load condition so it can interrupt in the least amount of time with less time delay dfor dthe dload dcurrent dwhen dthe dshunt dfilter dstart dto dinject dthe dneeded dcurrent dfor dmitigation das dshown din dfigure 3.24a+b. So there is no interruption for the load current so the SAPF is behaving like uninterruptible power supply UPS which have small interruption time.

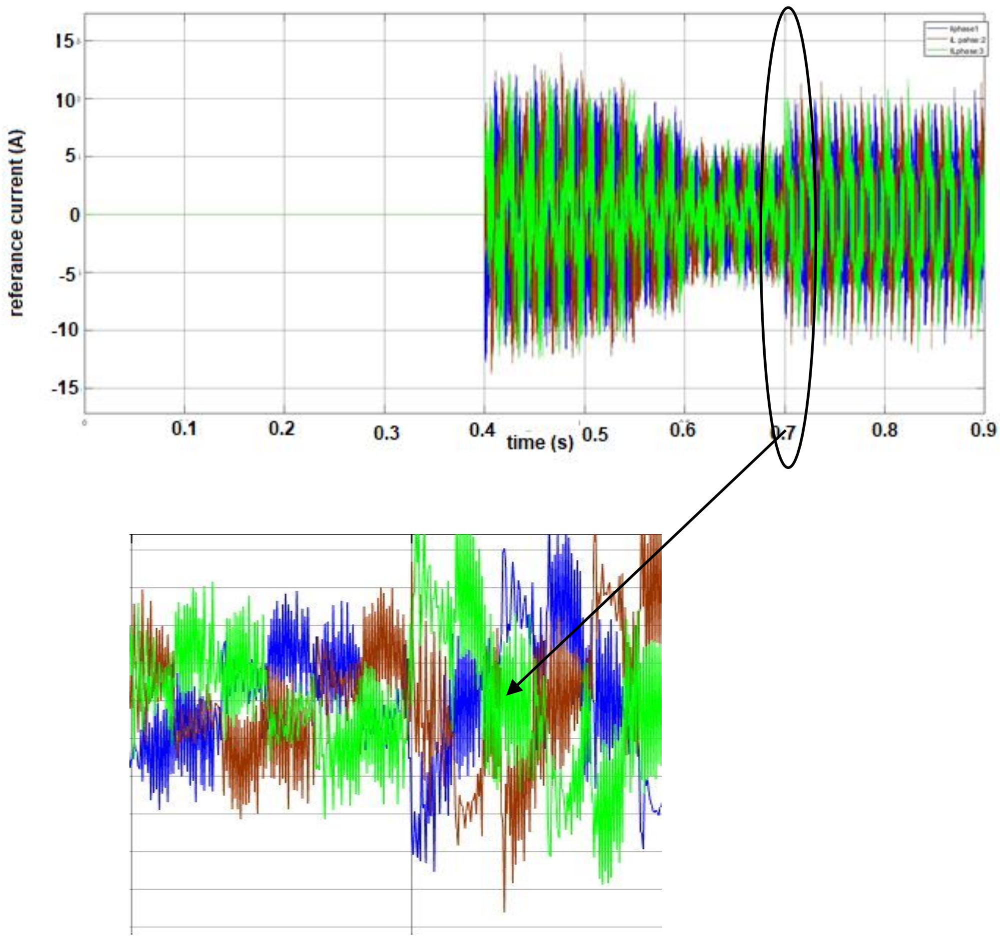


Fig.4.25: Three phase reference generated current waveform

The above figure shows the generated reference signal that is generated dfrom dthe dcontrol dsystem dthat dcontain dthe dfiltering dsignal dand dthe dactive dpower dinjection dsignal.

The filtering signal is shown from 0.4 to 0.7 sec the injection of the active power start at 0.7 sec then that shown clearly in the figure this signal is fed to the multilevel inverter which is used to filter dthe dsource dcurrent dand dthis dis dthe dpurpose dof dthe dshunt d(s) tive dpower dfilter.

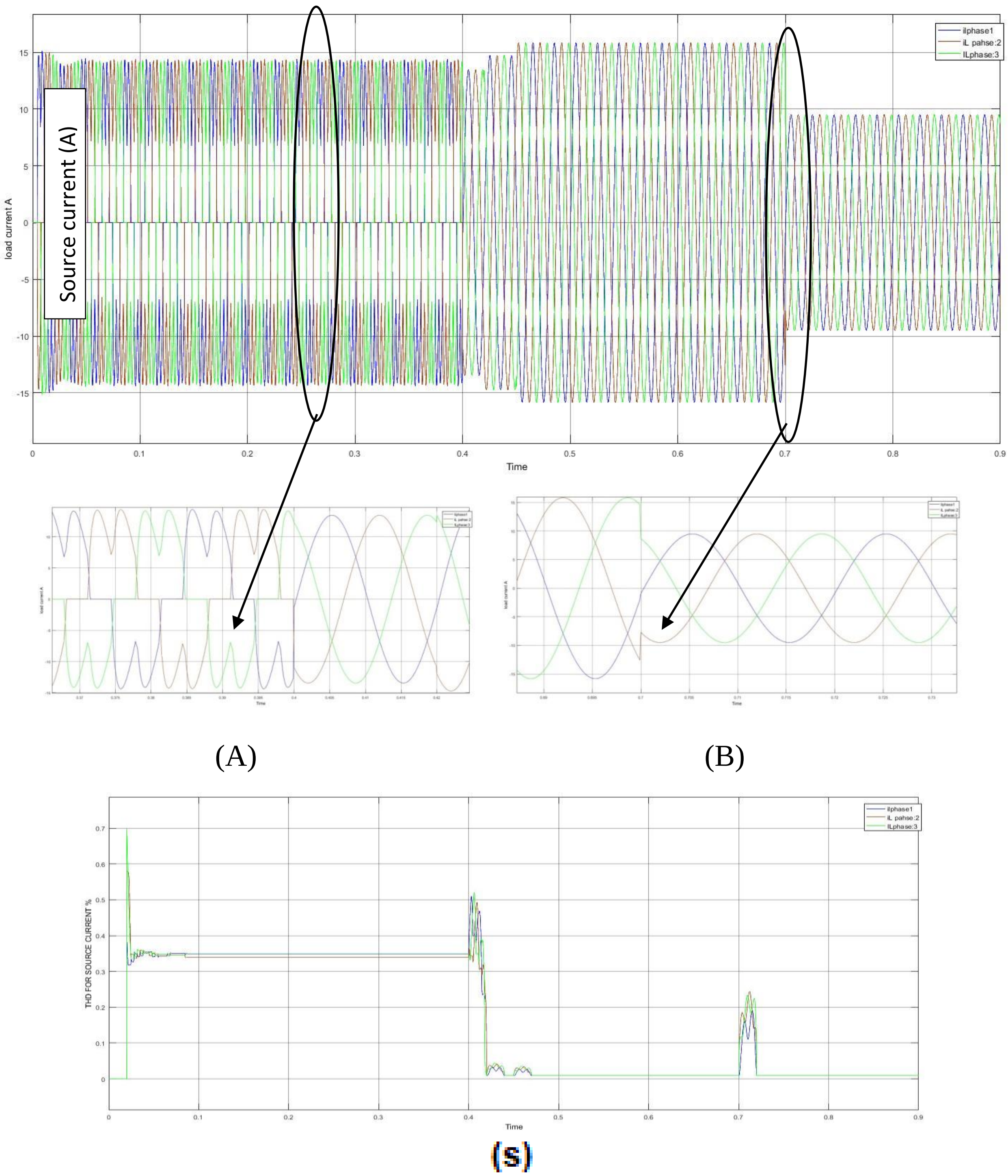


Fig.4.26: Three phase source current waveform

In figure 4.27 show the change in power factor over time and show the capability of shunt active power filter in reactive power injection and power factor enhancement at the PCC. And it's clear from the figure below that the dpower dfactor dhad dimproved dfrom d0.79 to 0.98 dand dthat dcan dbe ddone dby dinjecting dreactive dpower dto dthe dsystem dand dkeep dmonitoring dthe dreactive dpower dneeded dby dthe dload dso dit dcan dgenerate dthe dneeded dreference dvector.

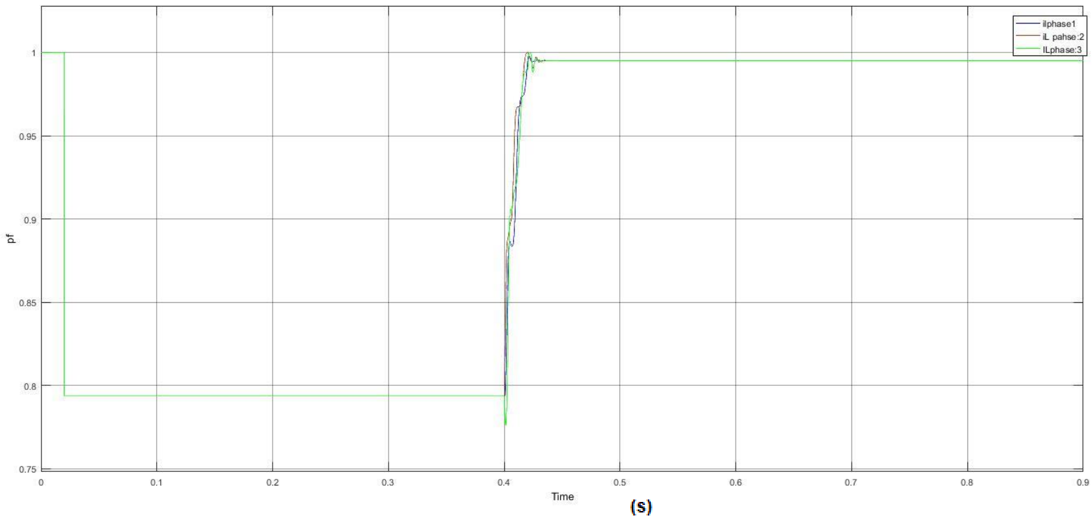


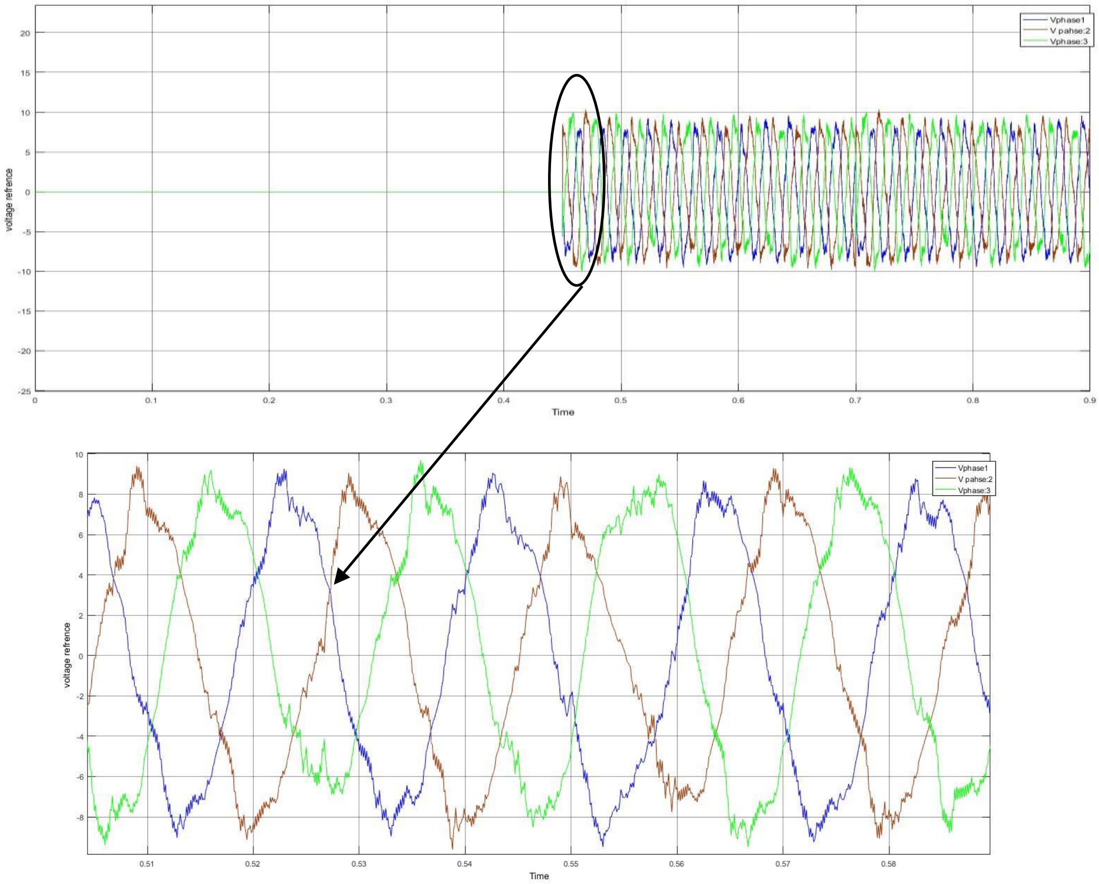
Fig.4.27 : the change in power factor over time for the source

4.9.3 Simulation Results for series APF control system.

The series dactive dpower dfilter dis dused dto dremove dthe dharmonic dof dthe dsource dvoltage dand dcompensate dthe dvoltage ddrop din dthe dpoint dof dcommon dcoupling d (PCC).

The three phase voltage reference signal are shown in the figure 4.28 which is the signal the is generated so it can be used to control the gate signal for the power electronic element in the multilevel inverter so the series active power filter can do the needed job that is designed for.

The dthree dphase dsource dvoltage dare dshown din dthe dfigure 4.29 dwhich dshow dthe dcompensation dstart dat d0.45 sec dand dthe dtotal dharmonic ddistortion dare dshown din dfigure 4.30.



(a)

Fig.4.28: three phase reference signal from controller.

The above figure show the reference signal at 0.45 sec are generated from the controller dof dthe dseries dactive dpower dfilter dto dstart dthe dcompensating dand dfiltering dfor dthe dsource voltage. Which dthe dgenerated dsignal dis dused dfor dcontrolling dthe dmultilevel dinverter dby dcontrolling dthe dpulsing don dthe dgate dof dthe dpower delectronic dswitch don dthe dinverter.

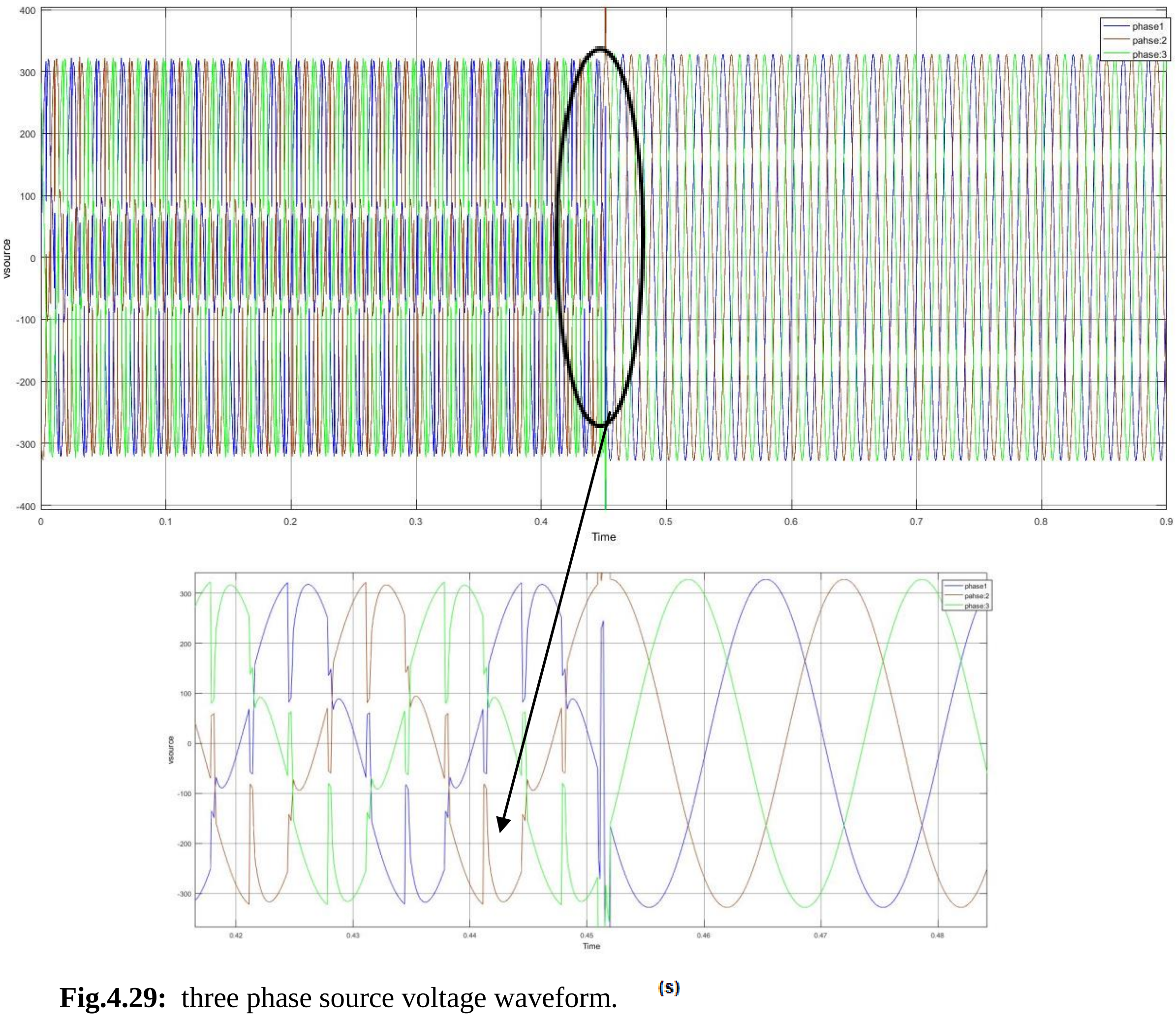


Fig.4.29: three phase source voltage waveform.

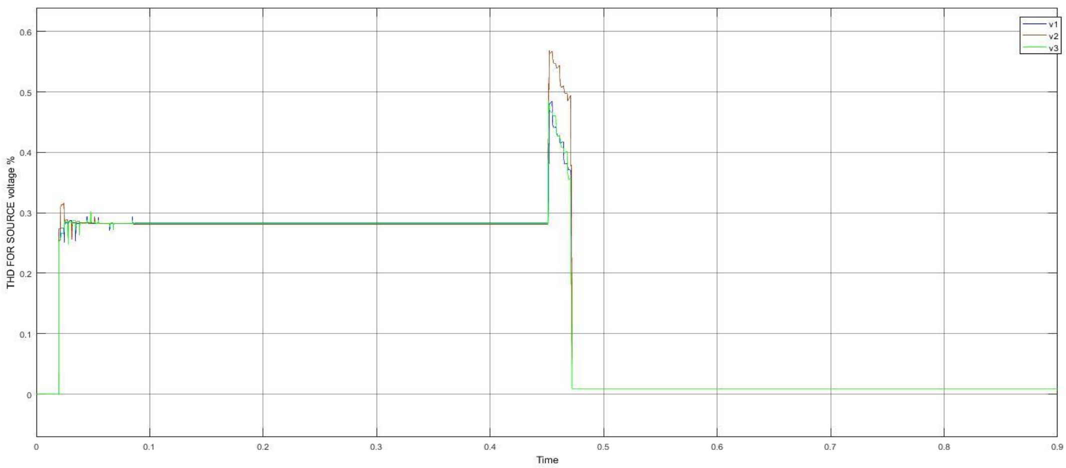


Fig.4.30: THD for three phase source voltage

As shown in figure 4.29 the system start harmonic eliminating the harmonic and drop voltage at PCC is compensate the voltage value increased at the time 0.45 sec and the shape become pure sinusoidal which decrease the total harmonic distortion from 27% to 1.3% as seen in figure 4.30.

4.9.4 Simulation Results for active and reactive power injection control system.

To have a good idea if the real and reactive power injection is operational three case tests should be executed and the result will be divided into three cases.

Case 1: frequency variation effect.

Case 2: state of charge (SOC) variation effect.

Case 3: poor power factor tracking.

The damount dof dthe dreal dpower dinjected din dthe delectrical dgrid dis ddepended don dthe dcontrol dof didd-dref dcurrent dwhere didd-dref dis ddepended don dthe dstate dof dcharge dfor dthe dbattery dpower dpack dand dthe dfrequency dof dthe dsystem.

Meanwhile the injection dof dthe dreactive dpower d (dQd) ddepend don dthe dtuning dthe dvalue dof dthe dcurrent diqd-dref dwhere diqd-dref dis dset dto dmaintain dthe dvalue dof dthe dpower dfactor dclose dto dunity.

Case 1: Frequency Variation Effect:

The three phase current are shown in the figure 4.31 where figure 4.31(a) show the change in the value for source current when the active power injection started at the time 0.4s in case of normal frequency range

And figure 4.31(b) shows the same as (a) but in case of abnormal frequency range.

Id which the reference current that's generated from the controller for the act of flittering and real power injection that is shown in the figure 4.32.

And the total harmonic distortion for the source current is shown in the figure 4.33.

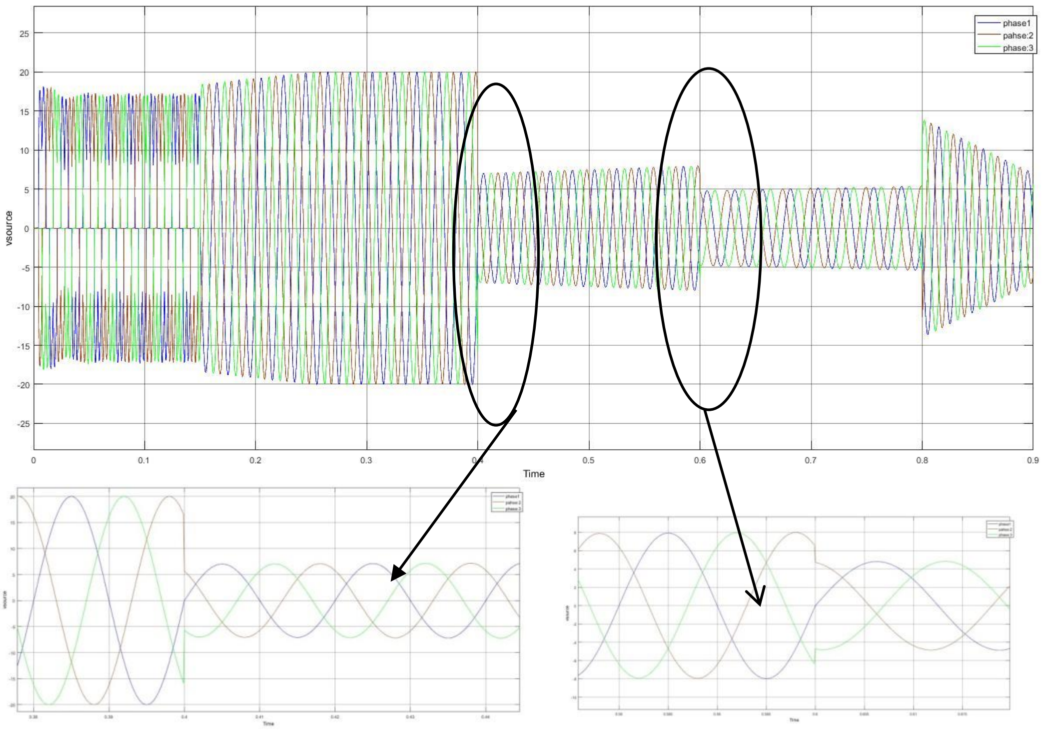


Fig. 4.31: Three dphase dsource dcurrent dwaveform

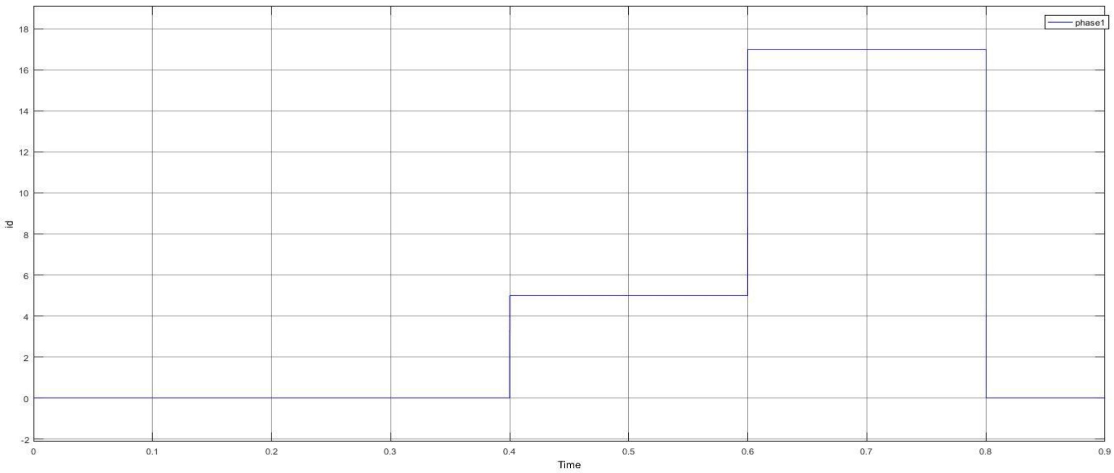


Fig.4.32: changing in id reference current.

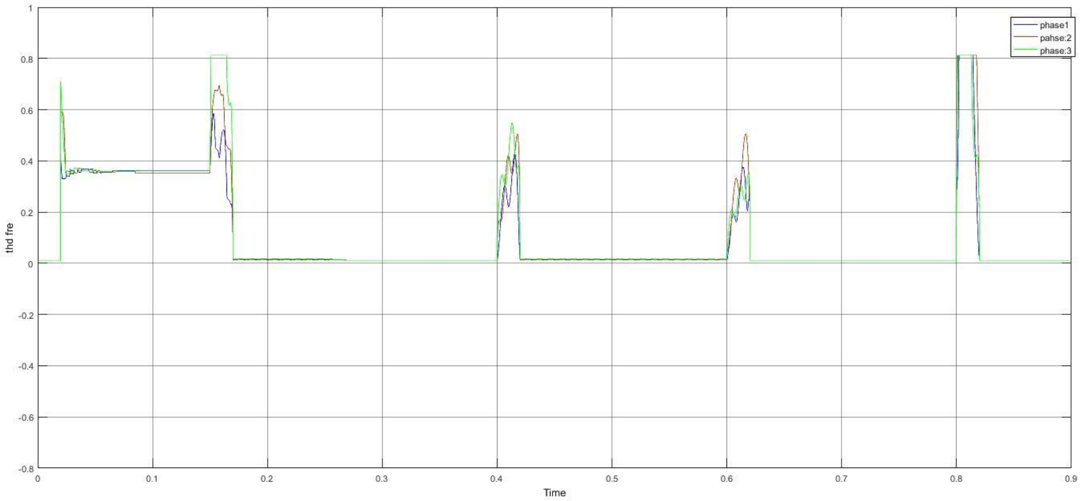


Fig.4.33: total harmonic distortion variation.

Case 2: state of charge (SOC) variation effect.

The signal of the three phase current source dare dshown din dthe dfigure 4.34.

In figure 4.34 (a) shows the changing in source current when the controller start injecting real power at t=0.4 sec and SOC= 0.85.

But in (b) show how the current source are changing when the controller stop the active power injection at 0.75 sec with SOC 0.25 and the change of SOC shownd din dthe dfigure.

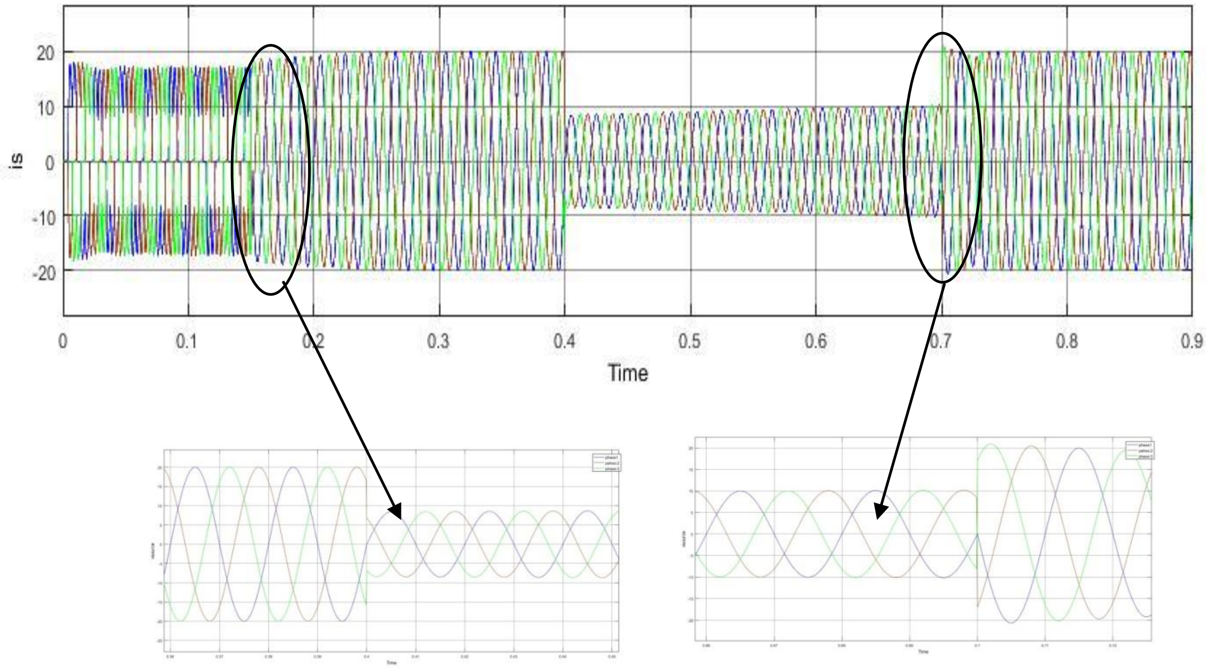


Fig.4.34: The three phase source current signal.

Case 3: poor power factor tracking.

The figure 4.35 shows that the system is tracking power factor and optimize it to unity. Where is the correction start at 0.4 sec

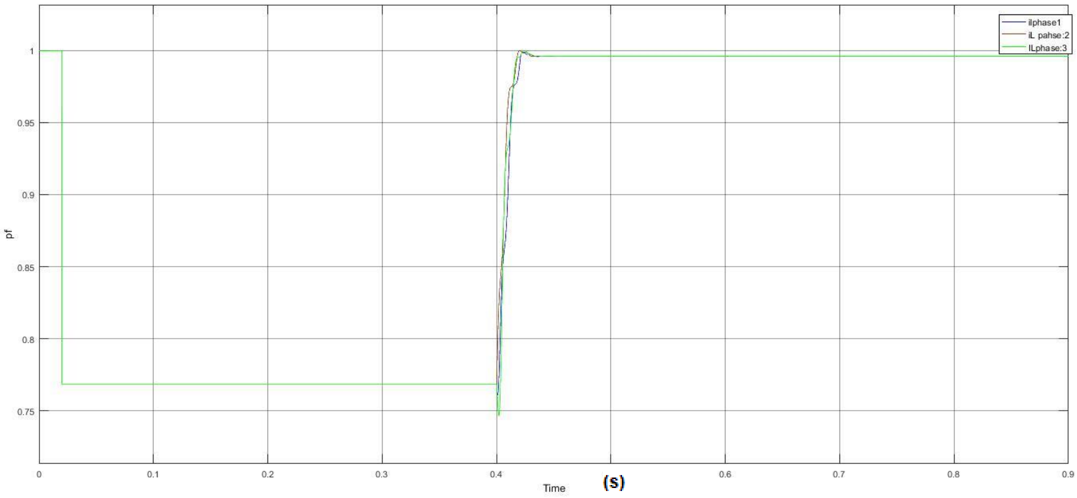


Fig. 4.35: power factor correction.

4.11 Chapter summary

Chapter 4 discussed and tests the control algorithm for both series and shunt active power filter. And shows how the APF optimized the electrical power distribution quality. The chapter also shows the mathematical explanation for both series and shunt active power filter, and show how to extract the reference vector that is needed for controlling the APF to get the needed result from the controller. The shunt active power uses on Dual Instantaneous Electric Power algorithm to get the needed reference vector while the series uses dinstantaneous dreactive dpower d (p-q) dtheory. dBut dat dthe dend dall dcontrol dalgorithm dare dtested dand dconformed dusing dthree dlevel dmultilevel dinverter.

CHAPTER 5

d GRID dCONNECTED dPV dSYSTEM dWITH dMPPT

5.1 Photovoltaic system with MPPT

There are two way for connecting the PV array to the electrical grid.

The first way that has greater ability in DC voltage regulation is by connecting the PV to DC- DC converter then t's connected to DC-ACconverter which is dconnected dto dthe delectrical dgrid das dshown din dfig 5.1.

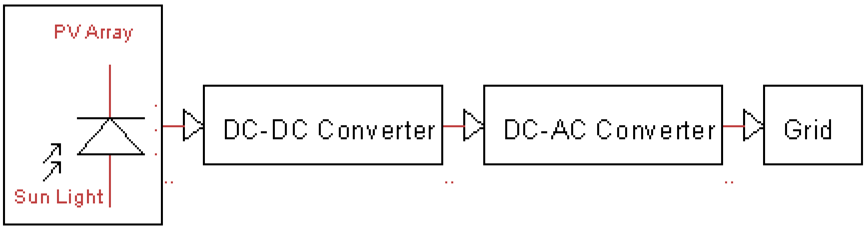


Fig. 5.1: PV linked to the network through DC-DC converter and DC-AC converter

The second way is by connecting the PV module dto dthe dDC-AC dconverter ddirectly dwithout dusing dDC-DC dconverter dwhich dhas dthe ddisadvantage dof dthe dunregulated dDC d voltage as shown n fig5.2 [73].

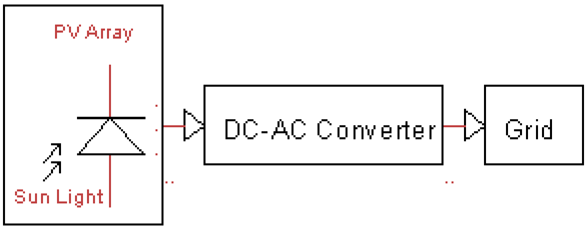


Fig. 5.2: PV linked to the network through DC-AC converter.

In this thesis the tested electrical network is the electrical network with DC-DC converter and

DC-AC converter connection due its ability for the DC bus regulation and noise elimination.

5.2 Photovoltaic Cell Theory

The solar cell is built from semiconductor silicon material. These materials will form p-n junction this p-n junction will contain electrons and holes. When the light is applied on this p-n junction a great amount of the electrons and holes will be generated due to this processes an electric filed is generated in the p-n junction and positive and negative terminal are formed [74].

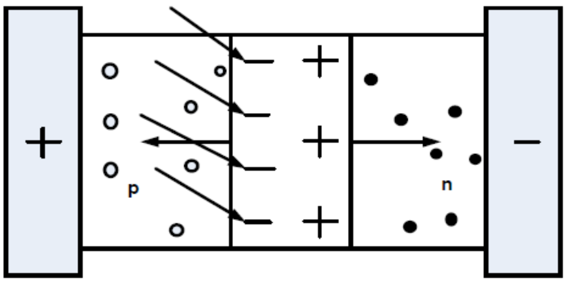


Figure 5.3: the dP-N djunction clarification of PV cell.

When dthe junction is stroked with the sunlight a pair of holes and electrons are formed when it get enough energy form the light of the sun. Where P-region is the focuses point for the holes which have a positive charge and the N-region is the focuses point for the electrons with have a negative charge. So negative and positive terminals are formed as shown on the middle portion in the fig 5.3.

If electrical loads are connected to the terminal dthe delectrons dwill dmove dto dthe dPd-dregion dand dthe dholes dwill dmove dto dthe dNd-dregion dthrough dthe dloadd. dThis dmotion dis dcalled dthe delectrical dcurrent dwhich dmeans dthe dcell dconverted dthe denergy dof dthe dsun dlight dto dan delectrical denergy [74].

5.3 Photovoltaic Cell, Module or Panel and Array

The amount of energy that can be generated from the solar cell is low. To get practical useful energy from the sun a module is made by connecting a number of cells in series and in parallel. And to get greater amount of energy these modules are connected in series and in parallel so it can harvest greater amount of the energy that is emitted from the sunlight radiation.

To get greater applicable voltage the dmodule dshould dbe dconnected din dseries dif dmore dpower dand dcurrent dneeded dthe dmodule dshould dbe dconnected din dseries.

5.4 Modeling of Solar Cell

To get specific model for a solar module we should study individual PV module.

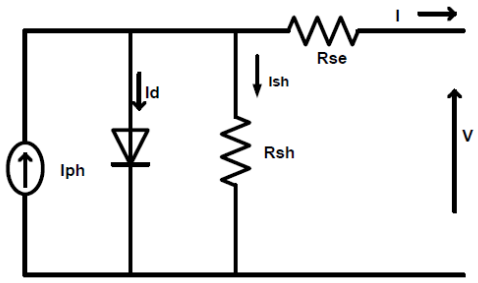


Fig 5.4: represents the physical representation of a solar cell.

dFigured. d5d. d4 dThe dequivalent delectrical dcircuit dfor dsingle dsolar dcell.

Where is:

Iph – Photon current.

Id – Diode current

I – The effective current of solar cell

K -Boltzmann dconstant (1.38×10^{-23}J/K)

Rse – seires ressitance of the pv cell equivelant circuit

dRsh – shunt ressitance of the pv cell equivelant circuit

V- dThe dnod-load dcell dvoltage

The serial resistance has a great impact in decreasing the fill factor and the short circuit current when short circuit is happened between the cell terminals. It acts like a small load and in high values protect from short circuit, decrease the efficiency of the solar cell and decrease the max power point. But the les value for the shunt resistance will decrease the efficiency of the solar cell because it will provide alternative path for the dcurrent dgenerated dfrom dthe dsolar dcell.

dThe dmathematical dmodel dcan dbe dderived dform dthe dcircuit din dfigure 5.4 dusing dnodal danalysisd

dAnd dthe dcharacteristics dequation dare drepresented din dequation 5.1

I= I_{ph}-I_{sh}-I_dd Or

dId=I_{ph}d-I_O [dEXPd (dqd (Vd+dI_{RSe}dd)+/ dAKTd)- d1] d–(Vd+dI_{RSe})/ dR_{sh}d. **d (5.1)**

Where:

I_{ph}: is the photon current.

I_O ::is the saturation current.

q: is the electron charge (1.602x10^{-19}C).

K: is dBoltzmann dconstant 1.38×10^{-23}J/K.

T: is the cell temperature in celios

A:is p-n junction ideality factor

R_{se} & R_{sh}: are the intrinsic series resistor and the shunt resistor of the cell.

For the following model the value for the shunt and series resister are equal to 70 and 0.3 ohms, respectively. These values for the resistance increase the short circuit current handling for the module and the result of that is increasing in the efficiency of the module. Because all above mentioned advantage these cell is used in building the PV module.

5.5 The Characteristic Curves Off (PV) module.

To get the short circuit (Isc) value for the cell the terminal of this cell should be shorted together in this case the flowing current will equal dthe dshort dcircuit dcurrent dmeanwhile dthe dvoltage dwill dequal dzero.

Meanwhile if dthe open circuit voltage needed to be calculated the terminal should kept open Din Dthis Dcase Dthe Dvoltage Don Dthe Dterminal Dis Dcalled D (Voc) Dthe Dopen Dcircuit Dvoltage Dof Dthe Dcell Dand Dthe Dvalue Dof Dthe Dcurrent Dwill Dbe Dequal Dzero Dbecause Dno Dcurrent Dflowing Din Dthe Dopen Dcircuit.

Figure 5.5 shows the Characteristic Curves for both I-V and P-V. Where the open voltage happen when the value of the current equal zero. DAnd Dthe Dshort Dcircuit Dhappen Dwhen Dthe Dvoltage Dvalue Dequal Dto Dzero [76].

The power of the cell can be easily obtained by multiplying the voltage with the current.

From the figure below the MPP max power point can be found and work the calculation from its values.

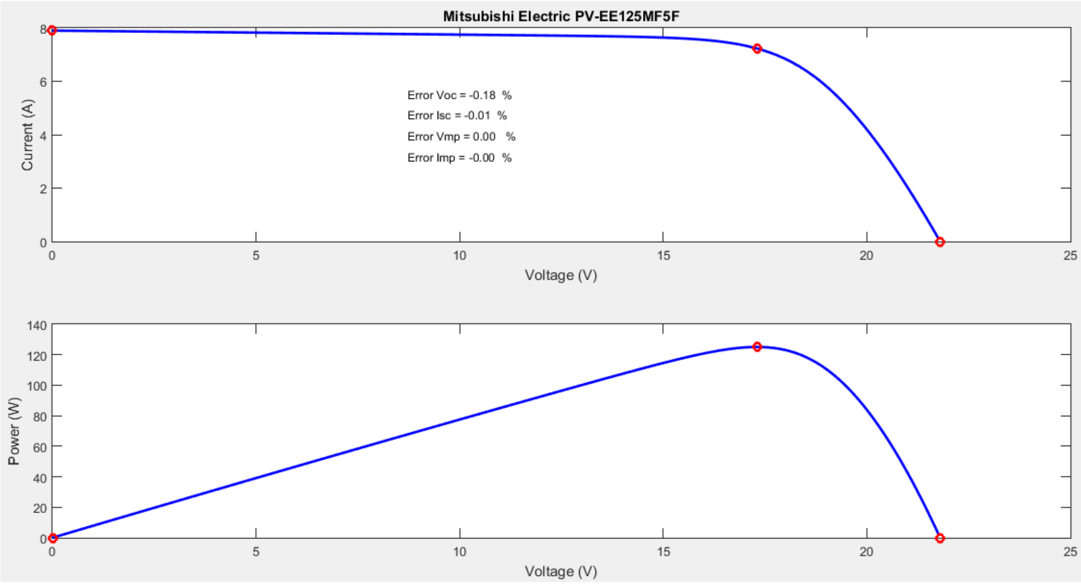


Fig.5.5: Characteristic Curves for Mitsubishi PV-EE125MF5F.

5.6 Influence of Solar Irradiance and temperature on solar cell characteristic curves

The amount of power density of sunlight in certain area at a location on earth with the unit of W/m2 is called the idiom Irradiance. Meanwhile the irradiance is the unit that shows the amount of energy density for sunlight. During a regular day the amount of irradiance various in value.

In Figure 5.5 we can notice when the irradiance decrease the value of the Isc and Voc decrease. So the max power point of the cell will decrease due to the decrease in Dvalue Dfor Dboth Dthe Dcurrent Dand Dthe Dvoltage.

The short circuit current change by the following equation:

$$Isc_{new}=Isc_{old}*(\text{new irradiance/old irradiance}) \quad \textbf{(5.2)}$$

Whereas the voltage increase in high rate when the irradiation is below 160w/m2 and the voltage increase in smaller rate when the irradiation is above 160w/m2 as shown in fig 5.6.

5.7 Temperature effect

Temperature plays a big rule in the efficiency of the module when the ambient temperature changes the efficiency change at a fixed rate. When the temperature increase the rate of generation for the electrons increase. As result for that the saturation current for the diode increase in high rate with reducing in energy gap. As result for the above mentioned the current will increase for little bit meanwhile the voltage will decrease in greater values.

The equation that calculate the voltage with taken in consider the temperature effect is:

$$Voc_{mod} = Voc_{stc} (1+hv * (T_{cell}(c)-25\ c)) \qquad \textbf{(5.3)}$$

Where:

Voc_{mod} = the open circuit voltage at module temperature.

T_{cell} [°C] = temperature of the module.

Voc_{stc} = the open circuit voltage at standard conditions (STC)

hv: the temperature coefficient related to the voltage of the cell (-3.7mv/c)

5.8 Maximum Dpower Dpoint DTracking.

Maximum Dpower Dpoint Dtracking Dconsider an Dessential Dpart Dof Dthe Dphotovoltaic Dsystem Dso Dthe Dsystem Dcan Dgenerate Dthe Dmax Dpower Din Devery Dcondition. In each photovoltaic system there is a point which the system gives its maximum power. So maximum power point tracking system had been developed to track this point of operation which gives the advantage in working in max power.

MPPT is electronic rearrangement that can be used for the detection for the Dvoltage Dand Dthe Dcurrent Dat Dwhich Dthe DPV Dsystem Dgive Dthe Dmaximum Dpower Dpoint Dunder Dvariable Denvironmental Dcondition [77].

This method gives the ability Dfor Dthe DPV Dmodule Dto generate Dmaximum Dpower. To implement this algorithm a DC-DC converter is needed to be used with certain feature to give efficient use for the MPPT algorithm. When researcher design MPPT algorithm they take into consideration the following feature:

1. Low cost

2. Ease of implementation.

3. Fast response

4. At steady state, the maximum power point must be stable without vibrations.

5. Wide ranges of working during temperature and irradiance changing.

The DC-DC converter that needed to be used is Boost converter whereas the Dinput Dvoltage Dis Dsmaller Dthan Doutput DvoltageD. DThat’s Dmean Dthe DPV Dmodule Dvoltage Dis Dless Dthan Dthe Doutput Dvoltage Dof Dthe DDC-DC DconverterD. So Dthe Dboost Dconverter Dis Dneeded Din Dthe DMPPT Dsystem Dto Dboost Dthe Doutput Dvoltage Dwhen Dit's Dneeded.

The MPPT system work perfectly under these general conditions.

At the cold days of the winter the amount of generated energy is decreased and become less than normally generated energy so the MPPT is used to take the maximum available power in these weather conditions.

During the discharge Dcondition Dof Dbatteries Dwhen Dthe Dcharge Dis Dless Dthan Doperation Dcondition Dthe DMPPT Dalgorithm Dextracts Dmore Dcurrent Dto Dcharge Dthe Dbatteries.

Normally the MPPT is very efficient around 99% around the voltage 80VDC.

5.8.1 D**Importance** D**of** D**MPPT** D**in** D**photovoltaic** D**system**

The Dsolar Dirradiation Dchange Din Dwide Dranges Ddepends Don Dthe Dseason Dof Dthe Dyear, Dthe hour of the day, latitude and the orientation. So the amount of irradiation that hit the PV system changes in various ways.

Considering these condition the maximum power point tracking system is importance in identifying operational point instantaneously on the V-I curve for the PV system. At this which has the maximum power generated from the PV system.

In most of the time the PV system have low efficiency but the amount of energy that needed to be generated should be at maximum. For this reason the MPPT system are applied for different PV system several MPPT technique are proposed in the following each have their pro and con [78].

1. Off-line methods

- DOpen Dcircuit DvoltageD (DOCV) Dmethod
- DShort Dcircuit Dcurrent(SCC)
- DArtificial Dintelligence

2. On-line methods

- DPerturb Dand DobserveD (P&O) Dmethod
- DExtreme Dseeking Dcontrol DmethodD (DESC)
- DIncremental Dconductance Dmethod D (DInc. DCond)

3. DHybrid Dmethods.

DThe DPerturb Dand Dobserve (P&O) Dmethod Ddesigned Dand Dtested Din Dthis Dproject.

5.9 DPerturb Dand DObserve D (DPD&DOD) DMPPT

MPPT implemented by Enhanced Perturb and Observe (P&O) method to track the maximum power point.

The P&O depend on the hill clamping technique that’s Ddepending Don Dthe Dprinciple Dof Dshifting Dthe Doperational Dpower Dpoint Dto Dthe Dmaximum Dpower Dpoint Dlevel [78].

Hill climbing algorithm consider the most common and used algorithm in MPPT systems when considering the irradiation are constant.

P&O have the benefit of low power consumption when tracking the max power point but the drawback of this system is it easily can lose the track of max power point and have unstable voltage and current at the max power point when it in the steady state [79].

To overcome these problem enhanced P&O method are used. The flow chart of this method is showed in fig 5.10.

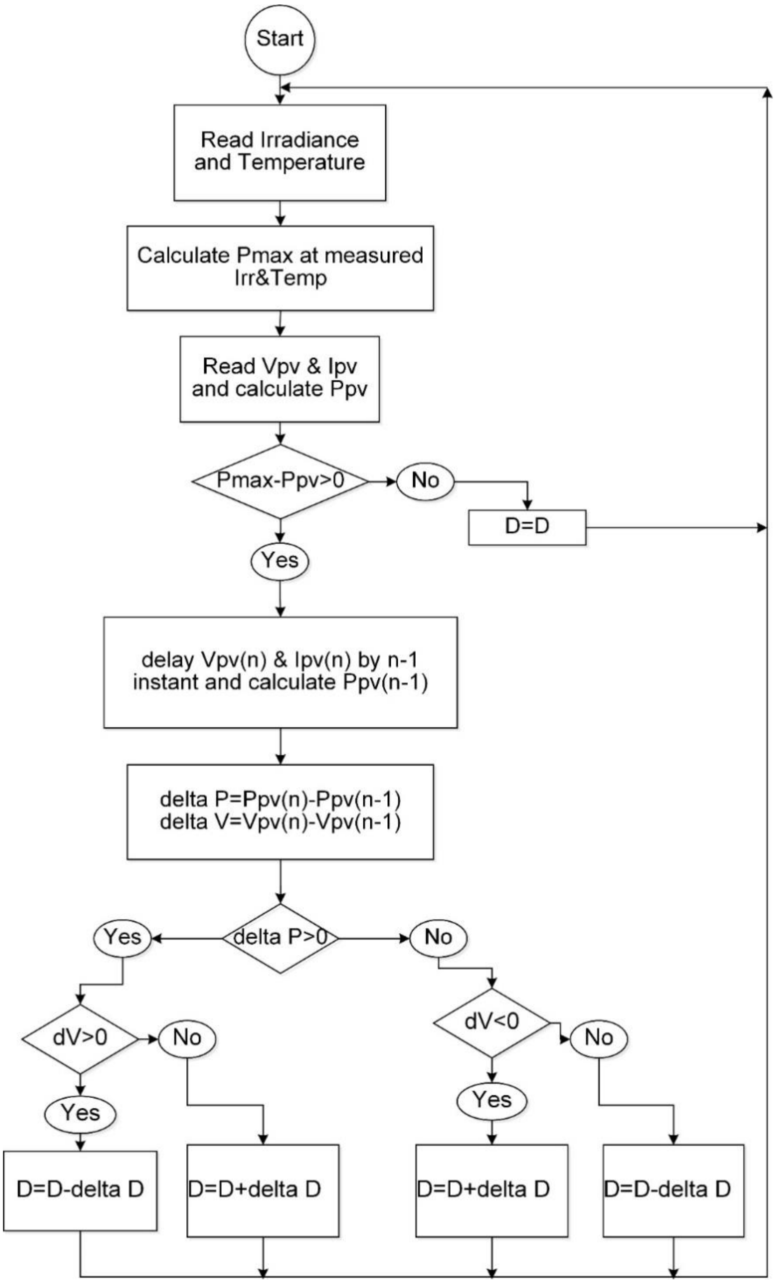


Figure 5.6: the flowchart of the enhanced P&O Algorithm.

Where

Pmax – DMaximum Dpower Dneeded Dfrom DMPPT Dat Dpresent Dtemperature Dand Dirradiance Dvalues.

Vpv (n) – Dvoltage Dof Dthe Dpresent Dperturbation

Ipv (n) – DCurrent Dof Dpresent Dperturbation D

Ppv (n) – DPower Dof Dpresent Dperturbation

Vpv (n-1) – Dvoltage Dof Dthe Dprevious Dperturbation

Ppv (n-1) - DPower Dof Dprevious Dperturbation

dV– DChange Din Dvoltage Dbetween Dpresent Dand Dprevious Dperturbation D

DReferring Dto Dthe Dflowchart.

dP – DChange Din Dpower Dbetween Dpresent Dand Dprevious Dperturbation

D: Dis Dthe Dduty Dcycle Dof Dboost Dconverter.

According Dto Dthe Dflowchart.

If $\Delta p>0$ Dand $\Delta v>0$, Dthis Dindicates Dthat Dthe Dcurrent Dpower Dis Dpresent Din Dthe Dleft Dside Dof Dthe Dmaximum Dpower Dpoint.

So if voltage is increased, and at the same time if $\Delta p<0$ & $\Delta v>0$ current power is present in the right of the max power point then decrease in the voltage occurred At $\Delta p=0$ the injected power this will represent the max power point that are delivered form PV.

This method the max power point is calculated using the measurement values of both the temperature and irradiance. After the finding of MPP at given condition the classical P&O algorithm are implemented. At each Dcycle Dthe Ddifference Dbetween Dthe Dcalculated Dpower Dand Dthe Dreal Dout Dpower Dis Ddecreased Duntil Dthe Ddifference Dhave Da Dvalue Dof Dzero Dthen Dwe Dcan Dconsider Dthe Doperating Dpoint Dis Dthe Dmax Dpower Dpoint Dfor Dthis DPV Dsystem Dat Dthis Dcertain DconditionD. DSo Dthe Dduty Dcycle Din Dthis Dcondition Dis Dconsidered Dthe Doptimal Dvalue Dfor Dthe Dcontrol DsignalD. DThis Dvalue Dis Dset Dto Dbe Dfixed Dand Dconsidered Dthe Dcontrol Dvalue Dfor Dthe DDC-DC Dconverter Duntil Dthe Dnext Dchange Din Dmax Dpower Dpoint Dis DneededD. DThis Dmethod Dgives Dmuch Dmore Defficiency Dthen Dclassical DPD&DO Dmethod [78].

5.10 Boost Converter

DC-DC converter is considered one of the important elements in MPPT system. Boost converter have an input dc voltage less than output voltage of the converter. That mean the PV system voltage is less than the voltage of the DC-DC converter. So the boost converter should have technique to boost the PV system voltage.

At general the DC-DC converter are categorized in to three types: buck, boost and buck boost converters. At our case the boost converter are implemented so the output voltage of the PV system are boosted. And these converters are used for noise elimination and voltage regulation for the input bus. The DC-DC converter consists of inductor, capacitor, diode and IGBT which consider which act like high frequency switch.

The converter produces higher voltage to the load depending on the duty cycle of the switch when this duty cycle change the voltages change.

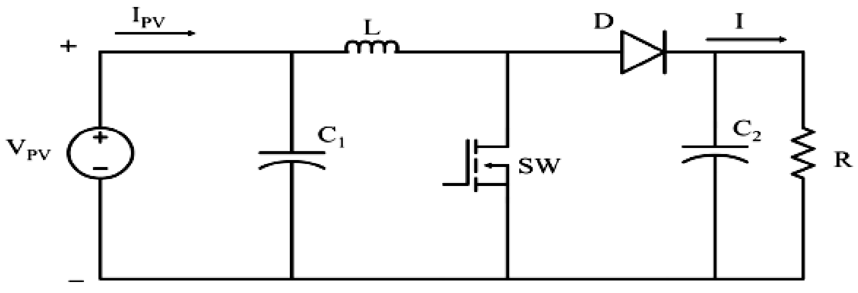


Fig.5.7: circuit Diagram of step-up converter

DThe Dboost Dconverter Dis Ddesigned Dand Dtested Dusing DMATLAB DSimulink DwhereD: D

D DVPVD: Dinput Dvoltage Dtaken Dfrom DPV DsystemD. D

DC1D: Dcapacitor Dconnected Dthrough Dthe DPV Dinput D (D1D. D4mFD) Dfor Dall Dboost DconvertersD. D

DThe Ddiode Dconnected Dwith Dseries Dresistance (DRON) =0.001Ω Dand Dforward Dvoltage =0.8 V.

DLD= Dthe Dinductor Din Dseries (0.0012H Dfor Dthe D12V DconverterD, D0.03H Dfor Dthe D36V DconverterD, D0.05H Dfor D108V Dconverter Dand D0.09H Dfor Dthe 324V Dconverter.

R= Dthe Dresistance (12Ω) Dconnected Din Dparallel Dwith Dthe Dcapacitor DC2 (1.43 mf)

DDD= Dduty Dratio.

DThe Dconversion Dratio Dfor Dthe Dboost Dconverter Dcan Dbe Ddetermined Dby Dassuming Dthe Dindicator Dand Dthe Dcapacitor Dhave Da Dlarge Dvalue Dthat Dcan Dbe Dlarge Denough Dto Dconsider Dthe Dvoltage Dand Dthe Dcurrent Das Da DDC DvaluesD. DAt Dthis Dcase Dthe Dswitch Dcan Dbe Dreplaced Dwith Dvoltage Dsource Dhave Dthe Dvalue Dof D (1-D).

DThe Dduty Dcycle Dindicates Dthe Dduration Dperiod Dfor Dwhich Dthe Ddiode Dturns DonD. DIt Dcan Dbe Dexpressed Das DD' D= D (D1 D- DDD). DThrough Dthis Dperiod Dit Dis Dassumed Das Dan Dideal DdiodeD, Dwhere Dthe Dintermediate Dvoltage Dis Dshorted Dto D$Vout$.

In this case Dthe Dintermediate Dvoltage Dis Dshorted Dto Dthe DgroundD. DSo Dthe Daverage Dvalue Dwill Dequal Dto D (1-D) Dvout. DAt DDC Dcondition Dthe Dinductor Dwill Dact Dlike Dshort Dcircuit Dso DVIN= (1-DD*Dvout).

The Dabove Dequation Dshows Dthe Dconversion Dratio Dunder Dconstant Dfrequency and show how it depend on the duty cycle [80].

5.10.1 DModes Dof DOperation

In DDC-DC Dconverter Dthere Dare Dtwo Dmodes Dof Doperation Dthat Ddepends Don Dthe Dhigh Dfrequency DswitchD. DThe Dopening Dand Dthe Dclosing Dof Dthe Dswitch Dwill Ddecide Dthe Dmode Dof Dthe Doperation.

At the first mode of operation when the switch is closed the inductor will store charge Dthis Dmode Dcalled Dthe Dcharging Dmode Dof Dthe Dboost DconverterD. DBut Dat Dthe Dsecond Dmode Dthe Dinductor Dwill Ddischarged Dand Dthe Dswitch Dstate Dis Dopen. DAnd Dthis Doperating Dmode Dcalled Ddischarging Dmode Dof Dthe Dboost Dconverter.

5.10.1.1 DMode-1 Dor Dcharging Dmode Dof DOperation

At the first Dmode Dthe Dswitch Dis Dclosed. So the inductor store energy and the current of the inductor rise exceptionally. But we assume linear current in both mode of operation the charging and the discharging mode. The load current at this case remain constant the is supplied by the discharging capacitor as the diode block the flow of the current during this mode.

5.10.1.2 DMode-2 Dor Ddischarging Dmode Dof DOperation

At Dthe Dsecond Dmode Dthe Dswitch Dis Dopen Dwhich Dresult Din Dshort Dcircuit Dfor Dthe Ddiode. DSo Dthe Damount Dof Dstored Denergy Din Dthe Dfirst Dmode Dis Ddischarged Dwith Dreverse Dpolarity Dduring Dthis Dmode Das Dresult Dof Dthat Dthe Dcapacitor Dstore Dcharge. DMeanwhile Dthe Dload Dcurrent Dremains Dconstant Din Dthis Dcase.

5.10.1.3 Waveforms

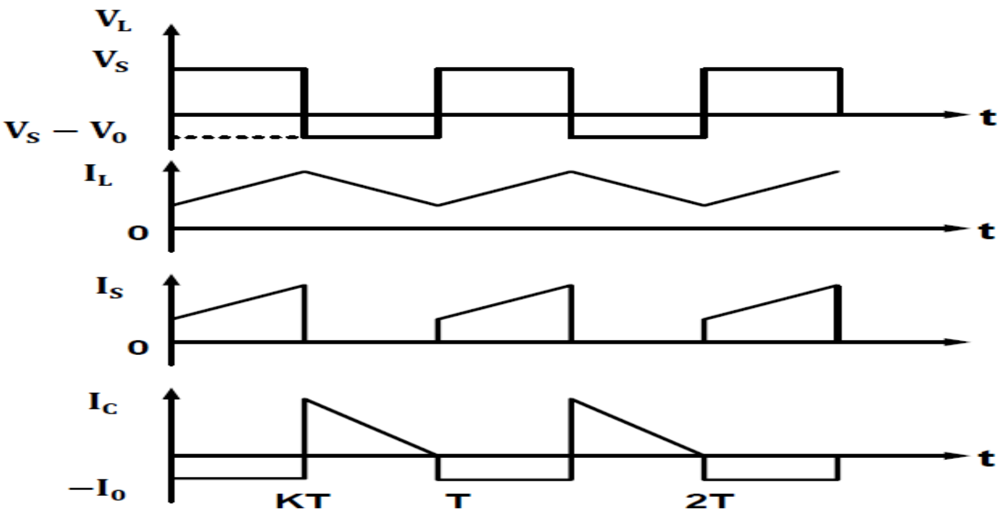


Fig.5.8: Waveforms of boost converter

In the figure 5.12 VL represent the voltage across the inductor.

So the inductor voltage will equal the value of the source voltage and at the same time the source current increase.

When the switch is closed by using the ability of the inductor to store energy the inductor current increase exponentially mean while the current of the capacitor remains constant.

Meanwhile when the switch is open the stored energy in the inductor discharged with opposite polarity which makes the capacitor store charge.

Thus, the inductor current falls until the switch is closed another time in the next half cycle. Thput put wave form that is resulated as shown in fig 5.13

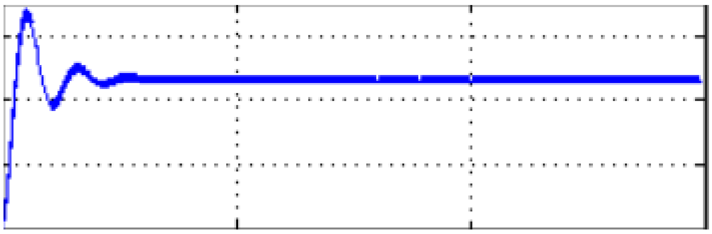


Fig.5.9: the output voltage

5.11 Charge Controller

DThe Dcharger Dused Dconstant Dcurrent / Dconstant Dvoltage (DCC/DCV) Dcharging Dmethod, Dthis Dway Dis Dan Deffective Dmode Dto Dcharge Dlithium Dbatteries. DWhen Da Dlithium Dbattery Dis Dnearly Dempty, Dwe Dused Dconstant Dcurrent Dmode Dto Dcharge Dit. DThis Dcurrent Dshould Dbe Dless Dthan Dthe Dmax Dcharging current that battery can accepted. During constant current charging mode the voltage of battery is slowly increasing, when the voltage of the battery reaches the max charging voltage, charger will start the constant voltage mode and fix the charging voltage with reducing the charging current. When battery is fully charged the charge controller will stop charging and cut off the battery.

Fig.5.13 shows the flowchart of charge controller designed to charge all batteries.

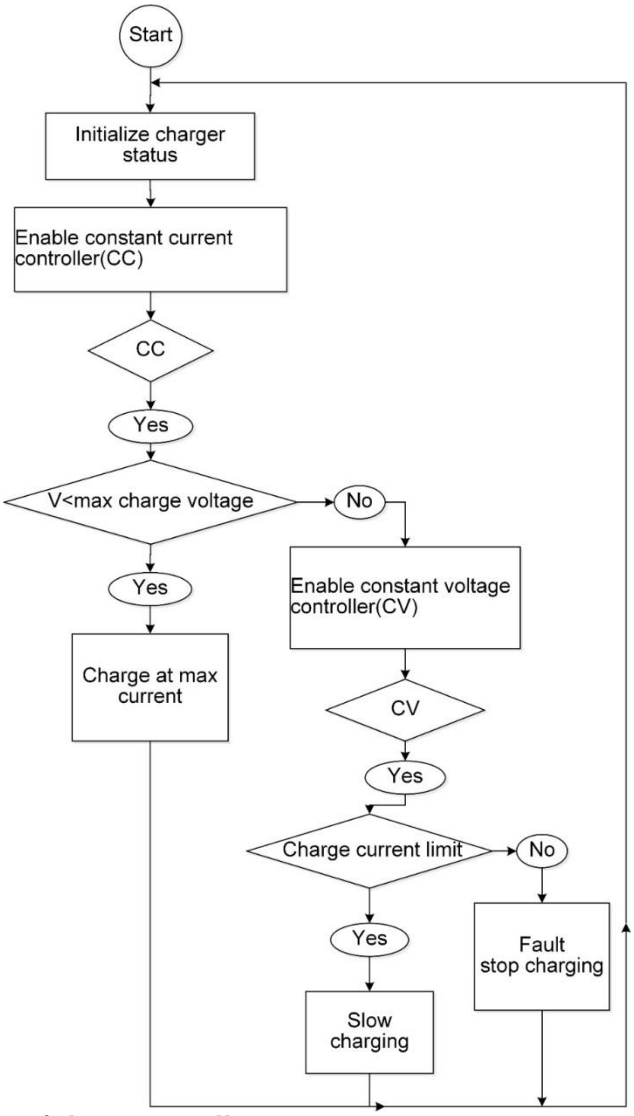


Fig.5.10: flowchart of charge controller

5.12 Chapter summary

This Dchapter Ddescribes Dthe Dgeneration Dprinciple Dfor Dthe DPV Dsystem Dand Dthe Ddifferent Dconfiguration Dof Dthis DsystemD. D

DAnd Dshow Dthe Dreprehensive Dmodel Dfor Dthe DPV Dmodule Dand Dthe Deffect Dof Ddifferent Dcondition Dsuch Das Dtemperature Dand Dsolar Dirradiation.

DThen Dit Ddescribe Dthe DPV Dsystem Dwith DMPPT Dalgorithm Dand DDCD-DDC Dboost Dconverter Dwith Dit Ddifferent Dmodes Dof Doperation.

DThe DMATLAB DSIMULINK Dresults Dfor Dboost Dconverter Dwith Dmaximum Dpower Dpoint Dtracker Dhave Dbeen Dtested Dand Danalyzed.

CHAPTER 6

FAULT TOLERANT TECHNIQUES

6.1 Introduction

Power converters are complex devices subject to failures that can lead to undesired stops. For this reason, many fault tolerant topologies and strategies have been deeply studied, mainly focusing on improving the electromechanical behaviour of the reconfigured drive after the fault. However, it is also very important to evaluate the possible increase of power losses.

Inverters play key roles in motor drives, flexible power transmissions, and recently grid-tied renewable energy generation units. Therefore, availability and reliability of inverters have become increasingly important. Following early stage fault detections in inverters, remedial actions can extend normal operation of inverters and, in some cases, de-rate the system to prevent unexpected shutdowns. A remedial action typically contains a combination of hardware and software

Preserving the health of inverters provides a basis for achieving higher reliability, survivability, and productivity in industrial processes and energy systems. These indices can be achieved by: (1) using components of higher ratings; and (2) making reconfigurable structures to tolerate internal faults. The second option, i.e., fault-tolerant inverter, is the logical choice for high-power applications. Traditionally, fault-tolerant designs have been used in devices and systems where continuity of operation is a key feature.

Many investigations on fault diagnosis of electric machines and drives have been performed, with some specifically focused on fault diagnosis of semiconductor devices and inverters. The main cause of inverter shutdowns are electrolytic capacitor and semiconductor failures. The semiconductor switch failures can be classified into open-circuit faults, short-circuit faults, and intermittent gate misfiring faults. Depending on the nature of failures, i.e., closing or opening of semiconductor switches, inverter faults can be detected as dc-bus (+ or −) short circuit to ground, dc-bus capacitor bank short circuit, phase open circuit, and line-line or line-ground short-circuit faults. Prior to a corrective action, a fault diagnosis is needed, and for successful remedial actions, the first challenge is to minimize processing time of the fault diagnosis. Particularly, for an inverter leg short-circuit (shoot-through) fault, the detection and isolation actions should be accomplished in less than 10 μ-sec in order to protect the silicon chips. An effective fault-tolerance technique also needs the knowledge of fault locations. Thus, fault detection and fault tolerance are two cascaded procedures.

The first fault-tolerant converter dates back to 1988 when it was used for brushless dc drives but the concept of implementing a fourth leg in the topology of conventional two-level three-phase inverters was proposed in 1991, followed by the presentation of redundant states offering the possibility of continued operation after a fault in a multilevel (five-level) converter in 1995. However, only the past 12 years have brought about notable movements in fault-tolerance techniques for inverters. The focus of this survey is primarily archival journals published between 2000 and 2012, which discuss fault-tolerance techniques for both two-level and multilevel inverters [82].

In this thesis an open circuit fault happen to one of the legs of the inverter the three cases of the pre-fault, during fault and the fault tolerance period are simulated and discussed.

When we apply this type of fault we can notice how the wave form of the output had become distorted as can be noticed in figure 6.1 & figure 6.2 and how is the fault affect the THD.

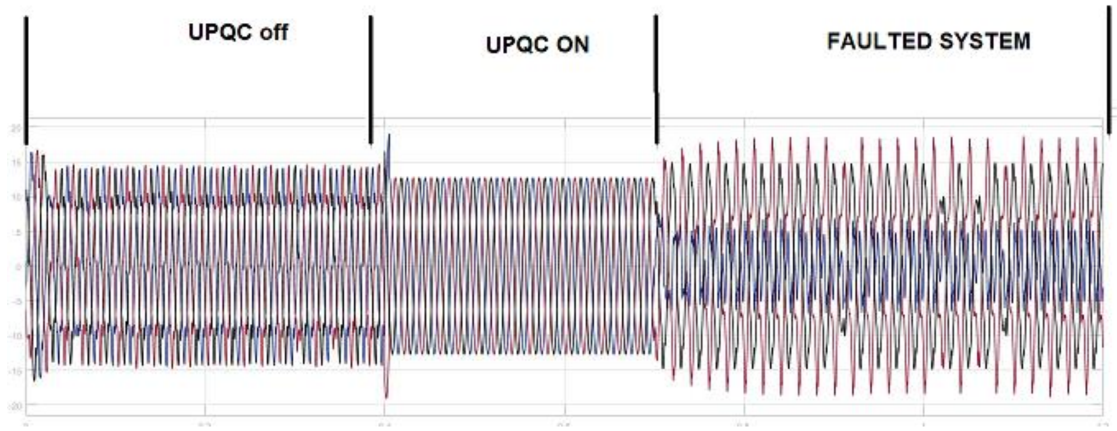


Figure 6.1: the output signal of the electrical system under different fault cases

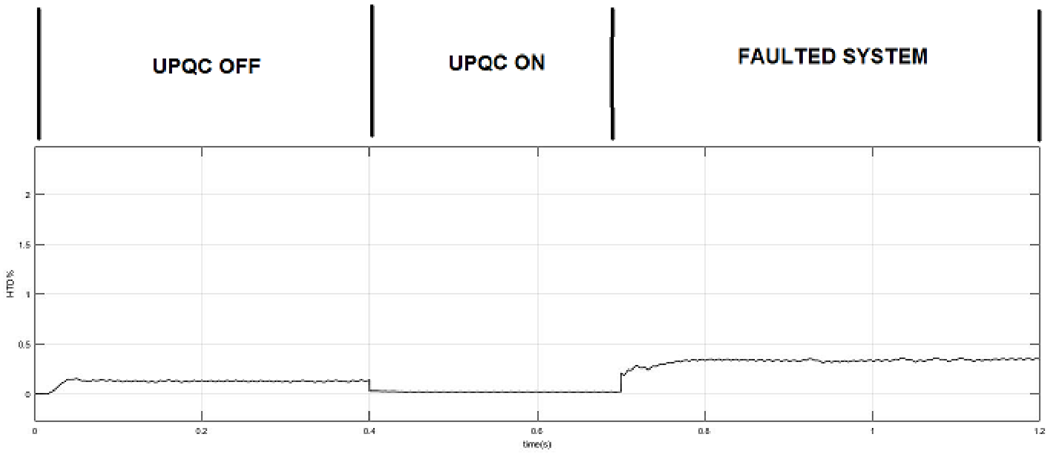


Figure 6.2: total harmonic desaturation under different fault cases

After applying the open circuit fault for the third phase we can notice from 6.1 that the output signal distorted and out of shape and to conform the result we can notice 6.2 THD% had been changed from 1.2% to 45%.

6.2 The Techniques of fault tolerant for 2 level 3 phase inverter

6.2.1DOVERVIEW DOF DFAULT DDIAGNOSTIC DTECHNIQUES DFOR DINVERTERS

Fault diagnostic techniques for inverters can be divided into two primary groups:

1) component based
2) system based

For component based techniques, solid state switches are individually protected with gate signal monitoring, overcurrent, and overheating schemes, some of which are current standard features of industrial power converters. These techniques are integrated into the inverter analog circuitry to detect switch abnormalities relatively fast.

In system base techniques , inverter current and voltage waveforms are examined to identify fault type and location . These techniques can further be categorize into waveform analysis and algorithmic techniques . In waveform analysis, extracted fault indicators (e. g ., normalized current frequency components , trajectory of space vectors , etc. .) Are compare with expected values. These fault indicators can be masked by the inverter closed -loop control schemes.

At the past time, fault tolerance in energy conversion systems has been propose for rephrase motor drives that suffer from an external phase loss (PL) fault. Fault tolerance has introduced for Y-connected three-phase motor drives in which an auxiliary fourth leg is added to the standard two-level inverter topology, and the fourth leg is connected to the neutral point of the motor stator windings. Also that a split debus capacitor branch can also be used as the fourth leg. And other technique had proposed at the 1980's that proposed the following idea of supplying a three phase load from two voltage sources with 60◦ phase shift. These techniques are applicable for both Y and Connected load Figure 6.3 shows 2 level inverter with three phase 4 leg inverter [83-85].

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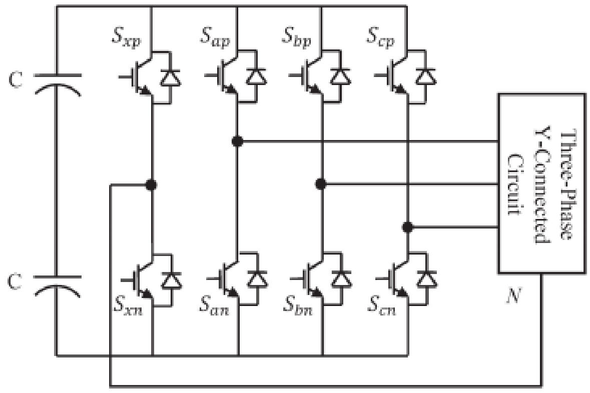

Fig 6.3: schematic of a two-level three-phase reconfigurable inverter for external single phase-loss faults.

In addition to the PL fault, the fourth leg can also provide fault-tolerance capabilities for inverter internal defaults; however, the faulty leg dust first is isolated. This can be achieved, for example, using fast-acting fuses and fast electromagnetic switches these switches had inverse time current faster than semiconductor switches. The following scenarios are the scenarios which should be taken in consideration when designing fault tolerance techniques:

1- Switch open circuit (SOC).
2- Switch short circuit.
3- Leg open circuit.
4- Leg short circuit.

We can take some examples of different topology to see the effect of the configuration on the effictense of these topology and its limits.

At the first the circuit topologies shown in Figs 6. 4&6. 5 can tolerate open- and short-circuit switch faults with unique post fault behaviors in both circuits, the fourth leg is connected to the main legs through a set of trials. In healthy conditions, the triacs are turned off, and the system operates in its normal condition. During post fault operation, the faulty leg is isolated by means of fast acting fuses, and the corresponding terminal of the motor is henceforth connected to the midpoint of the fourth leg by turning on the associated triac of the faulty leg. It should be noted that the output line, or 0 and −Vdc din da standard two-level three phase inverter. However, when using a split cubs capacitor branch as the fourth leg, e.g., in Fig 6.5 the post fault PWM pulses are between 0 and Vc/2, or 0 and −Vc/2, which limits the output power to 1/2 of its rated value.

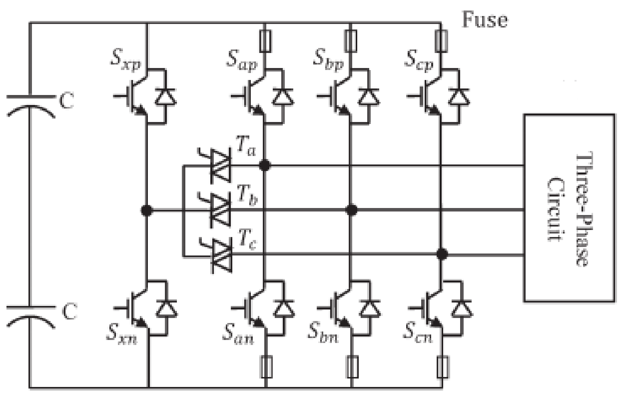

Figure 6.4: topology I

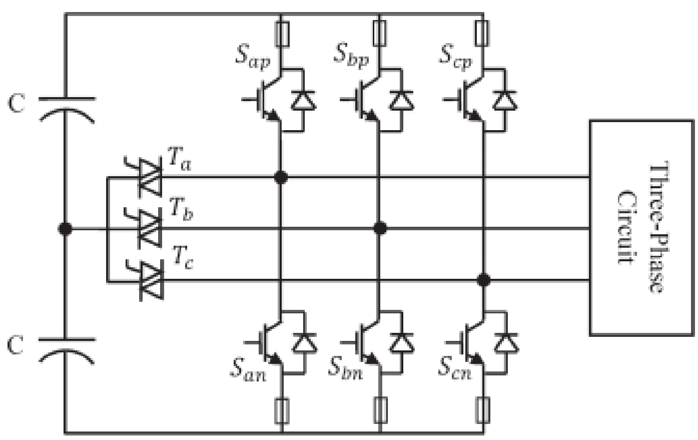

Figure 6.5: topology

The inverter topologies in Figs 6.6 & 6.7 can tolerate both PL and the switch faults excluding a leg short-circuit fault in these topologies, four triacs and only three fast acting fuses are added to the standard three phase inverter. The fourth leg midpoint is connected to the neutral point of the motor winding to provide Tolerant capability, while other triacs and fuses are used for fault isolation. The motor neutral point is connected to the midpoint of the split dcbus capacitor through a triac in Fig6. 6. However, in Fig6.7 the motor neutral point is connected to the midpoint of a switch-based leg. Neither of these fault-tolerant inverters can isolate a leg short-circuit fault when both switches of one leg are short circuit because no fuses exist to clear shoot-through (dc+ to ddc− short-circuited leg) faults [85].

In order to provide the capability of isolating a short-circuit leg in circuit topologies shown in Figs.6.6&6.7 two capacitors, Cp and Cn, and six thyristors, i.e., two thyristors per leg, can be added into their circuits, as shown in fig 6. 8. If a fault in the upper or lower switch is detected, the associate thyristor is triggered to blow open the fuse and consequently isolate the faulty switch. For example, dafter detecting an open- or short-circuit fault in Sap, Thyan is then triggered to isolate the faulty switch by burning Fap. Notice that the value of Cn should be chosen to limit the thyristor current and also let the fuse blow open quickly [86].

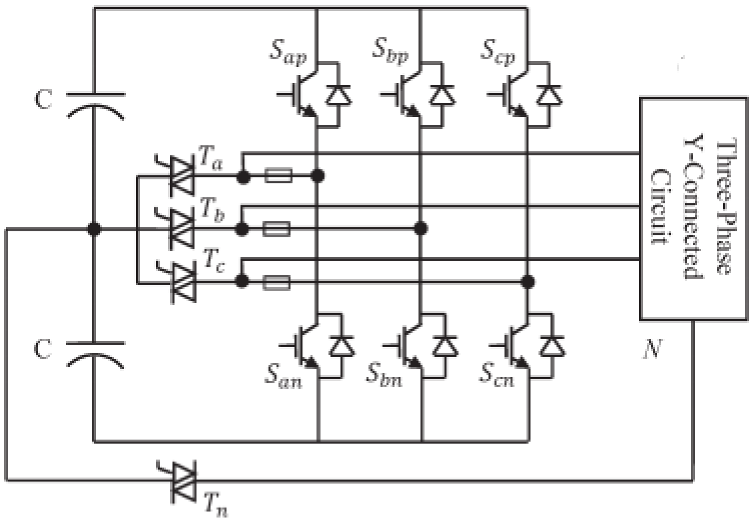

Figure 6.6: topology I

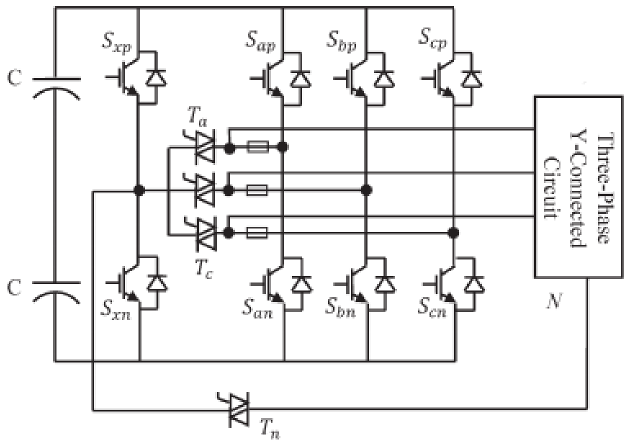

Figure 6.7: topology IV

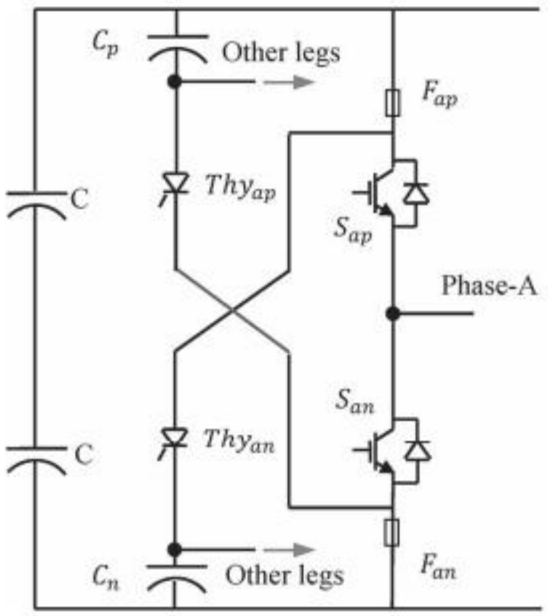

Figure 6.8: two-level inverter with isolating capability

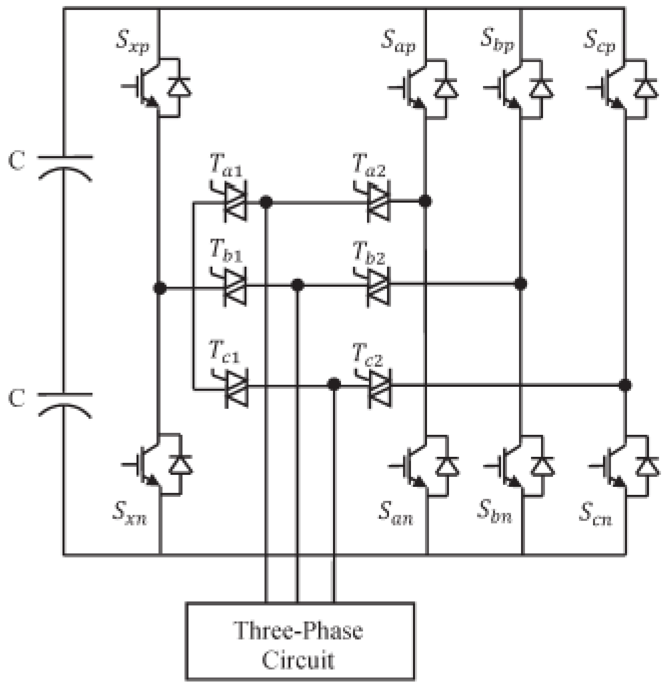

Figure 6.9: two-level dthree-dphase dfault-dtolerant inverter without any fast acting fuse

6.3 d FAULT- d TOLERANT d MULTILEVEL d INVERTERS

Due to the high number of semiconductor switches in multilevel inverters, these inverters are inherently more tolerable of internal faults than conventional two-level inverters. On the other hand, the probability of switch failures over a specific time nterval in multilevel inverters is higher than conventional inverters.

Several circuit topologies exist for multilevel inverters, including cascaded H-bridge, flying capacitor, and neutral point clamped multilevel inverters. As discussed in the previous section, most of the two-level fault tolerant inverters are based on the addition of an auxiliary leg. However, multilevel inverters and particularly cascaded multilevel inverters. Which can tolerate switch open and short-circuit faults after bypassing faulty cells without a need for the auxiliary leg? The isolation of a faulty module (cell) in cascaded multilevel inverters can be achieved using the bypass contactor, triac, or remaining healthy switches in each module. For example, if the transistor in S1 fails as an open circuit, S2 must be turned “on” while S3 an S4 are turned “off” to bypass the faulty cell. As can be seen in fig 6.10

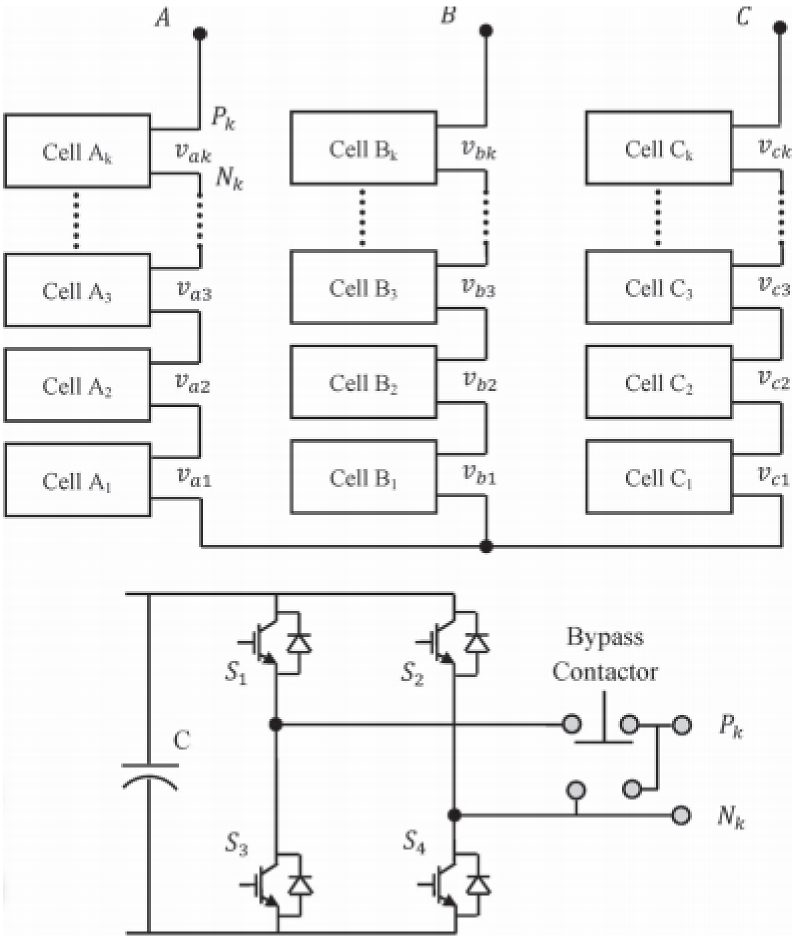

Figure 6.10: Schematic of da dcascaded dmultilevel dthreed-dphase dfaultd-dtolerant dinverter dwithout dany dredundant dcells.

The output phase-neutral and line-line voltages of a cascaded multilevel inverter before and after isolating cell the line-to line voltages can remain balanced after losing cell.This technique is simple and very effective. A new set of angles between phase voltages is calculated to keep the inverter line-line voltages balanced. This technique is called fundamental phase shift compensation (FPSC). Notice that for some fault scenarios, no solution for these nonlinear equations is available. These issues can be resolved using the modified FPSC technique.

6.4 Control Strategy for the Open Circuit Fault Adopted in this thesis

This strategy works on adding fourth axillary leg and this leg is linked to the neutral point for the load. Fig 6.11 the schematic of the connection.

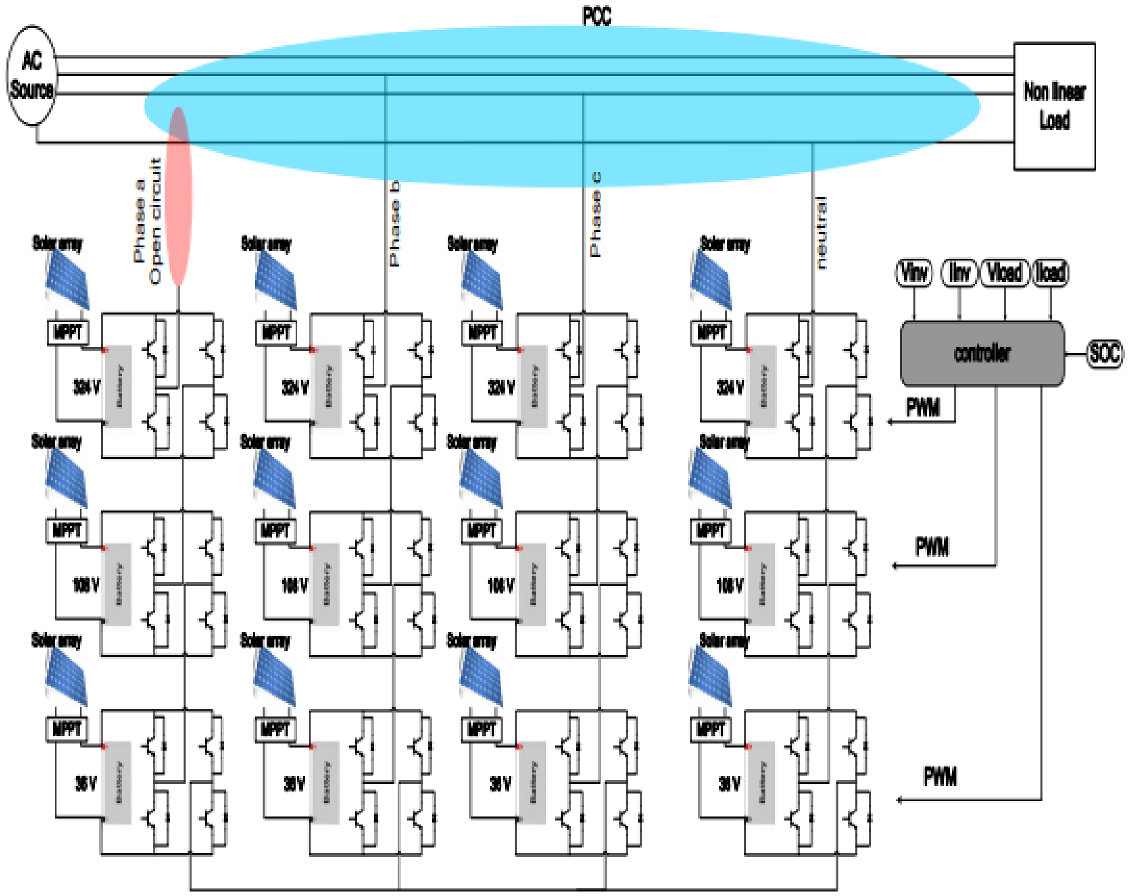

Figure 6.11: fault tolerance scheme for one leg open circuit

In this technique 4th switch based leg is added to the inverter this leg is connected to the Neutral point of the load or kept unconnected if there is no neutral in the load. This extra leg Is used as the solution for open circuited fault. So when an open circuit happens the faulted leg Are isolated by using fast acting fuse, electromagnetic switch or static switch. And then the

Fourth leg s connected. The strategy is used to keep the performance when the fault happen s as following:

The value of the current and the voltage for the faulty phase's s set to zero

The fourth leg switches s activated which connect the inverter to the neutral point of the load.

The value of the current for the fourth leg s equal to the sum of both un-faulted phases.

The control scheme s shown n figure 6.12 which the output of this scheme is used as Reference signal for pulse generating circuit this algorithm can be used for speed control motor and active filter based inverter.

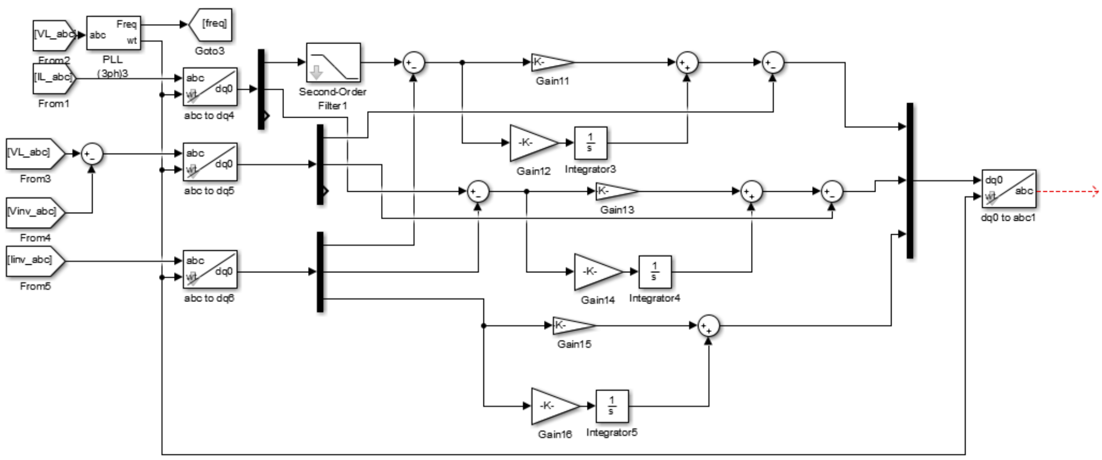

Figure 6.12: fault tolerance scheme for one leg open circuit

An Open Circuit Fault s Applied to one Of The inverter for UPQC the output wave form as shown in the fig I6.13 where at 0.5s the fault s applied to the inverter and the relief from the fault happen at I0.7s.

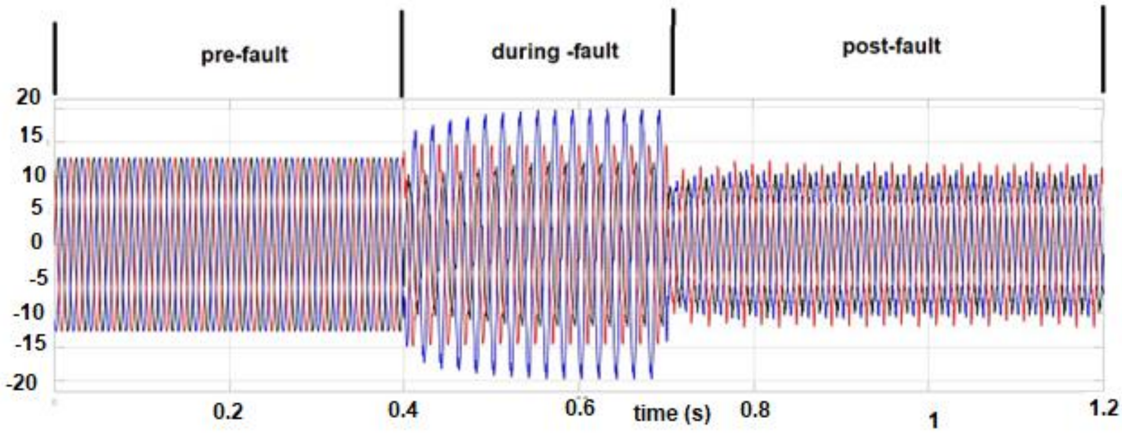

Figure 6.13: the Output Signal Under Different Fault condition

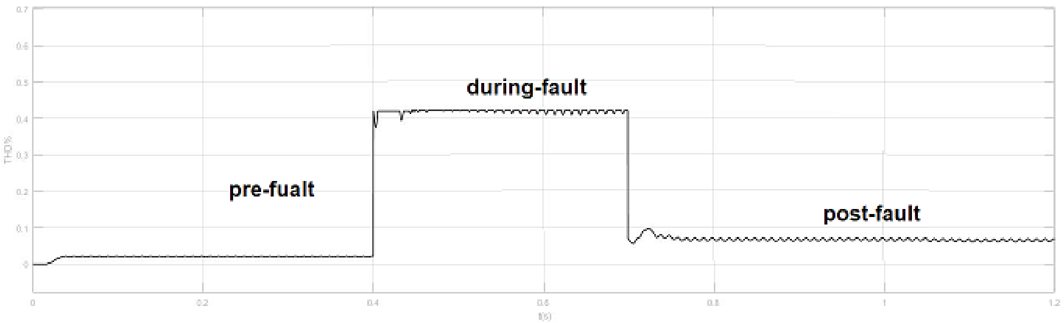

Figure 6.13: THD% Under Different Fault condition

We Can Notice From I6.13 the Total Harmonic Distortion s Changed When The Fault Happen From 1.8% But When the Fault Happen the Fault increase \ almost I45%. But When The Fault s I relived the ITHD% s Decreased Ito I7.5% which considered Into-bad an actable value which proof that the Techniques Good Enough Ito Make The Load works under faulted condition.

6.5 Chapter summary

In this chapter different topology of fault tolerant techniques had been discussed for both 2- Level and multi-level inverter.

A control scheme had been applicate for the inverters of the system which make the whole System s fault tolerant system for open circuit fault.

The performance of the had been applicate and tested.

CHAPTER 7
SIMULATION RESULTS AND DISCUSSIONS

7.1 Introduction

The proposed system had been simulated using MATLAB/Simulink to test the performance of the system and get the needed result from the system as the system a single complete unit. The simulation had been done for the UPQC to check the correct operation of the system, the performance of the system under fault and after the relief from the fault. Also the injection of reactive power from capacitor bank when the storage battery is empty. But the performance of each individual component are tested and shown in the previous chapters.

7.2 System Components

The system components are shown in the fig 6.1. The active power filter are composed from 9 level H-bridge cascade multilevel inverter these inverters are feed by photo voltaic array scaled power for the three phases. Each deliver 10KVA for each phase with 8KVA for the shunt active power filter meanwhile the series active power filter have a rated power of 2KVA.

The output of the UPQC is delivered to the electrical grid directly though transmission line. This system has the ability for harmonic elimination to both the current and the voltage that’s been supplied from the main feeder. The complete system can inject real and reactive power to supply the load during voltage sag and power outage in the system.

This system composed from 4 legs inverter the fourth leg is used as a spare leg to overcome open circuit fault by using spare leg when one of the inverter leg is faulted open.

Battery storage back are connected to the DC bus for the system. These batteries are charged using PV array that's connected to the battery through MPPT charge controller.

The injection of active and reactive power depend on the state of charge, the frequency of the system, the active and reactive power for the load and the power factor at PCC.

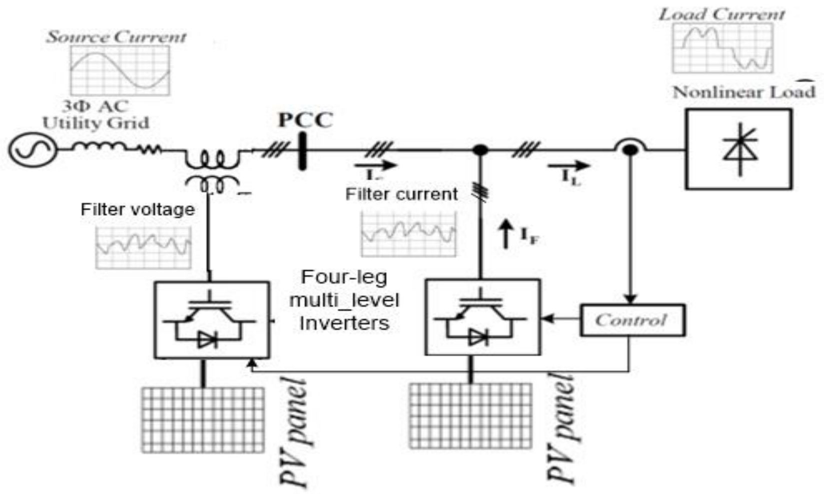

Fig.7.1: the main components of complete system

7.3 Simulation results for the whole system

The PV system fed the whole system with energy through the DC buss for each converter (series and parallel). Also the system is controlled by precise and smart control system to get the needed results with ability to overcome the open circuit fault.

In this section, we discuss the behavior for the whole system that will include the PV system components, series APF and shunt APF are tested and the result had been shown and discussed as following:

7.3.1 Current Compensation

As we can see at figure 7.5 part a at t=0.5sec the UPQC start operating and eliminate the harmonic of the source current due to this process the source current become pure sinusoidal.

And the total harmonic desaturation (THD) decrease from the 19% to 1% as can be noticed in figure 7.6. And the active power injection from the system start at t=0.8sec as can be noticed in figure 7.5 part b and the THD keep it low value even after the active power injection.

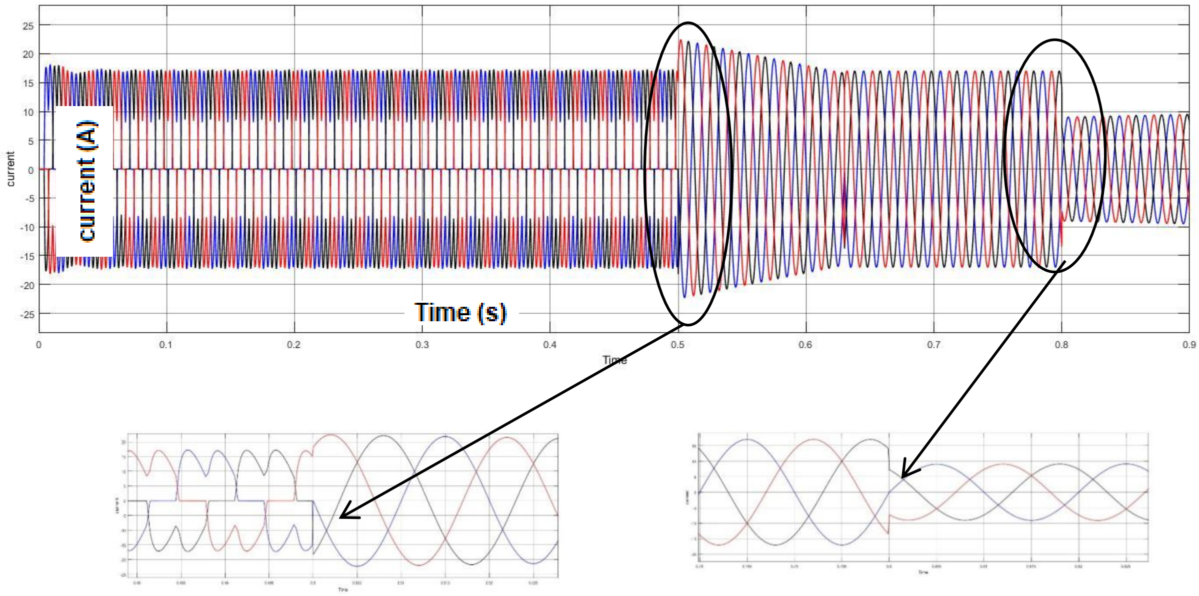

Fig.7.2: current source consumption

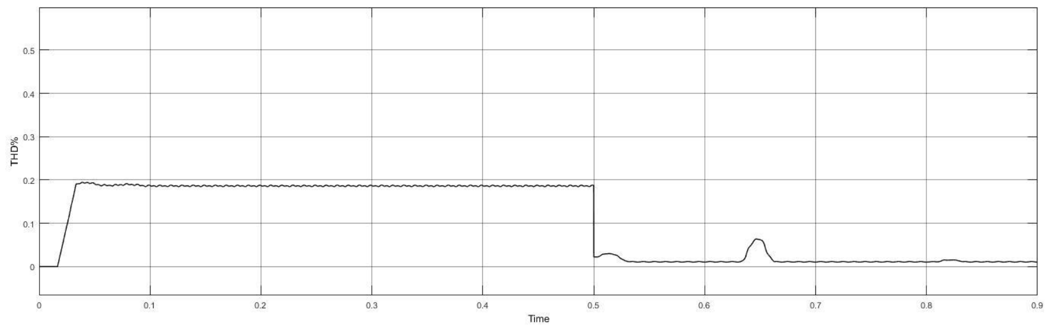

Fig.7.3: THD of source current

From the result we can notice that the UPQC enhanced the power quality and eliminate the harmonic in the current with improve in the performance of the shunt part of the UPQC.

7.3.2 Voltage Compensation

In figure 7.7 which show the voltage of three phase source. As we can notice in the figure 6.7 part (a) the UPQC start eliminating voltage harmonic of the voltage source at t=0.5sec. In figure 7.8 we can notice the change in THD decreasing from 23% to 1.2%. At t=0.8sec the system boost the voltage to rated voltage which make the electrical grid work on rated condition.

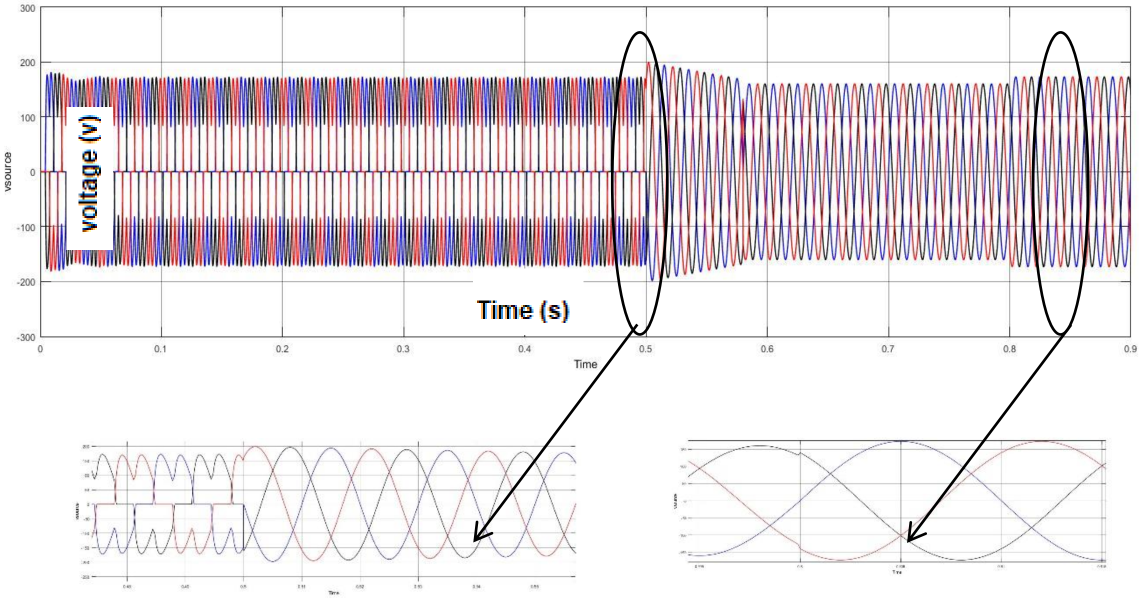

Fig.7.4: voltage compensating for the voltage source

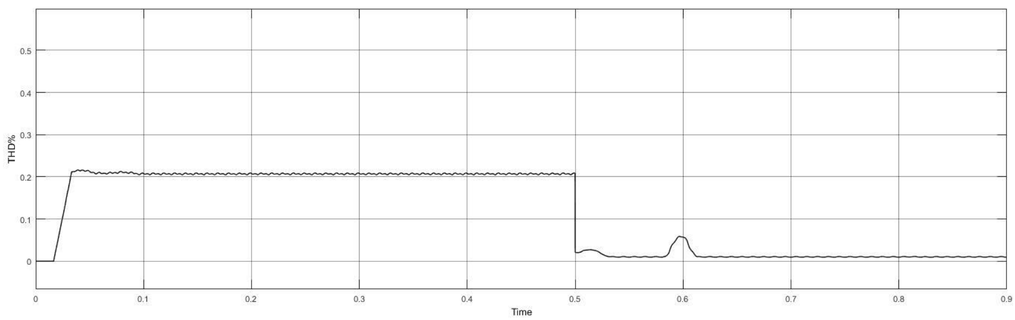

Fig.7.5: THD of Source Voltage.

As we can notice from the result, the performance of the series part of UPQC is became better and the harmonic elimination and the voltage compensation become more effective.

7.3.3 Power factor correction

In figure 6.9 it shows the ability of the UPQC to improve the power factor and keeping the power factor near to unity at the point of common coupling (PCC).

It's clear from the result the power factor had been improved by injecting the needed reactive power from the load through the distribution network.

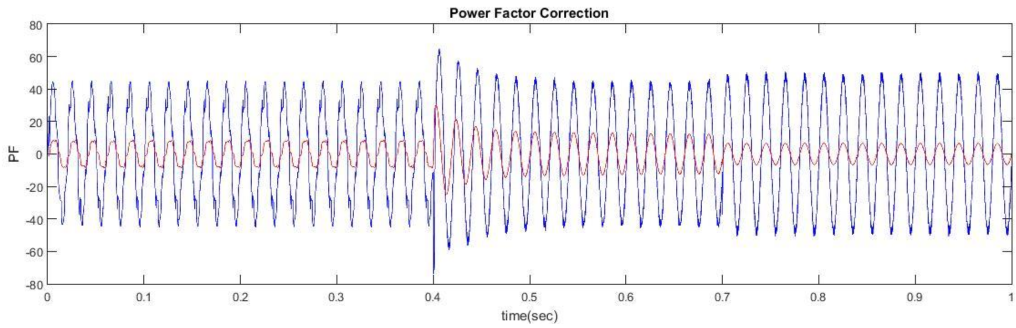

Figure 6.9: current and voltage signal

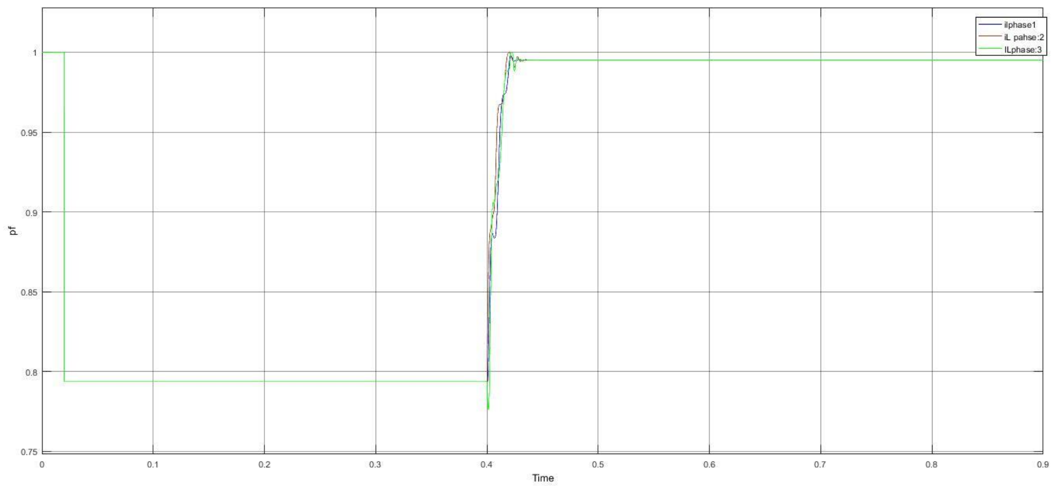

Figure 6.10: the power factor of the network

7.4 CHAPTER SUMMARY:

This chapter represents MATLAB/Simulink application and result for the proposed system in this thesis. The system has been applied and tested to get the pure wave form for the voltage and the current as seen from the source. As we can conclude from the result the proposed UPQC proved to be operational in power quality enhancement by eliminating harmonics for both the current and the voltage of the electrical system. And the system had been proven its ability in injecting both the real and reactive power. The system shown its ability in overcoming fault and operate normally after fault occurred in the inverter.

CHAPTER 8

CONCLUSION AND PRACTICAL ASPECT

8.1 Recommendations and Conclusions:

With modern technology power electronic had become an essential element in every day applications; due to this increase this had its effect on the quality of the power delivered to the end site of the consumer.

There for, the developing of new systems has a great efficiency in eliminating harmonics and enhancing the power quality for the electrical system become very important. In this thesis the recommended solution to enhance the power quality by using UPQC to enhance power quality of the distribution network. After testing UPQC and analyzed the result we can conclude the following summarized point:

1. Nonlinear load had seen great increase in use due to the rapid development in technology. These types of load are considered the main source of harmonic in the electrical grid.
2. The nonlinear load consumes nonlinear voltage and current from the main electrical load and at the same time will affect the performance of the consumer electrical devices.
3. To compensate the current and eliminate its harmonic a shunt function of UPQC should be connected to the point of common coupling PCC which it inject reverse vector current for compensating.
4. The shunt part will inject the real power depending on the parameters and the condition of the electrical system.

5. To compensate the voltage source the series part of the UPQC will inject compensating voltage with the same magnitude and reverse direction.
6. The shunt active power filter is controlled based on the "Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits (p-q theory)", to compensate the load harmonics.
7. The series active power filter is controlled based on the Dual Instantaneous Reactive Power Theory to compensate the load harmonics.
8. Simulation had been done for each part separately and then done for the whole system as a complete system result has been shown and analyzed.
9. The simulation of the complete system shows the current operation for the UPQC. And shows through the result the ability of the system to compensate the voltage and the current to eliminate the harmonic of the source also this system will inject real and reactive power to the system and will improve the power factor and all of this will improve the stability of the point of common coupling (PCC) by reducing the total harmonic distortion (THD) to minimum.
10. Fault tolerance topology had been used to overcome fault and complete operating normally after the fault occurred. That can be done by using 4-leg inverter and keeping one of these legs as spare leg to be the replace for any faulted phase.

11. Photovoltaic arrays and battery packs are used to inject real and reactive power make the system more applicable and reliable.

8.2 Economic considerations:

To reduce the cost for the UPQC it can be designed in small scale for a collection of consumers instead of using centralized UPQC with high installation, losses and maintenance cost and it should focused in area with industrial planet.

A transform less UPQC can be used which will reduce the cost. But this topology cannot be used in every condition so it not considered very practical; the reason of that the transformer less UPQC cannot isolate the voltage and the properties of the voltage should be matched.

This problem can be solved by using the control algorithm and the filter design that had been used in this thesis which allows the shunt active filter to filter some voltage harmonic due to the impedance effect and the rest can be filtered using series part of the UPQC.

So a law power series active power filter can be used that is can be operated with low power series transformer which will reduce both the cost and the losses of the transformer.

Installing UPQC on electrical distribution network will reduce the losses in the distribution network on the electrical grid and will improve the performance of the loads and protect them from the instability of the electrical network.

By adding PV array as the DC feeder for the system we will add source of active power that will make the UPQC more capable of injecting real power to the distribution area and this will make the system more useful than using traditional capacitor even though using PV is more expensive.

With the fault overcome algorithm the maintenance cost will reduce and the life span of the system will increase.

8.3 FUTURE SCOPE

This work can be developed and extend further by looking for these options:

To develop transformer less UPQC with suitable and stable control and design.

To use new smart control strategy which depends on the new development in the field of the artificial intelligent and deep machine learning so this system can be applied with properties can increase the speed response and improve the outcome of this system.

New fault tolerance method can be developed to be more accurate by reducing the number of level in case of faulted switches.

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كلية الدراسات العليا

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إعداد

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قدمت هذه الاطروحة استكمالاً لمتطلبات الحصول على درجة الماجستير في هندسة القوى الكهربائية، بكلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس– فلسطين.

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الملخص

إن وحدة التحكم بجودة القوى الكهربائية هي عبارة عن دمج بين وحدتي تحكم مختلفتين، الوحدتين هما عبارة عن وحدة موصلة على التوالي والأخرى على التوازي مع خطوط الضغط العالي من الشبكة. مما يجعلنا نستفيد من ميزة كل نظام على حدى. مما يساعد في تبديد الترددات غير المطلوبة من النظام الكهربائي وذلك عن طريق تنقية الإشارة الكهربائية لكل من الجهد والتيار مما يؤدي إلى تحسين جودة القدرة الكهربائية الخاصة بالشبكة.

النظام المستدخدم في هذه الدراسة يتكون من 27 مرحلة مختلفة من عواكس القنطرة كيث أن هذا النظام ثلاثي الأطوار كل طور يتكون من قنطرة منفصلة وكل قنطرة يتم تغذيتها كهربائياً من مصفوفة من الخلايا الضوئية، حيث يقوم هذا النظام بضخ 12.5كيلو فولت أمبير من الطاقة الفعالة لخطوط الطاقة الكهربائية حيث يتم توفير 10 كيلو أمبير عن طريق العاكس الموصول على التوالي بينما 2.5 كيلو امبير عن طريق العاكس الموصول على التوازي.

يتم توصي الخطوط الخارجة من العواكس إلى خطوط التوزيع بشكل مباشر بدون أي وسيط، بالإضافة إلى قدرة النظام إلى القضاء على الترددات الغير اساسية لكل من تيار وجهد المصدر الكهربائي فهذا النظام قادر على توليد قدرة فعالة وغير فعالة وحقنها في خطوط التوزيع الكهربائية.

بالإضافة إلى ذلك يوجد نظام تخزين كهربائي عند نقطة ربط التيار المستمر حيث يتم شحنها من نظام الخلايا الضوئية ويتم التحكم بعملية الوصل بمتحكم شحن يعتمد على الوصول إلى نقطة القدرة العظمة في برمجته.