# SIMULATION OF UNIVERSAL ACTIVE FILTER FOR CONTROLLING OF GRID CONNECTED SOLAR PHOTOVOLTAIC SYSTEM

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***Abstract: Nowadays there has been an increased proliferation of clean energy systems based on solar and wind energy in modern distribution system. However, due to their intermittent nature, voltage fluctuations have become a major issue in low voltage distribution systems. The nonlinear currents drawn by power electronic loads, lead to increased losses in distribution transformers, distortion of voltage at the point of common coupling (PCC), etc. Thus the future systems demand clean energy along with improved power quality. In this paper, the performance of adaptive filter based PV-UAPF (Universal Active Power Filter) system under both steady-state and dynamic conditions, have been analyzed in detail. The method of sampling the fundamental component of load current obtained through adaptive filter enables fast extraction of fundamental active component of nonlinear load currents for all phases in one sampling. The proposed topology and algorithm are suited for employing in conditions where PCC voltage sags/swells and load current harmonics are major power quality issues. Certain power quality issues not addressed include voltage distortions, flicker, neutral current compensation, etc. These power quality issues can be addressed by modification of topology and control algorithm according to the requirements in the distribution system. The PV-UAPF system provides dual benefit of distributed generation as well as improving power quality of the distribution system.***
***Keywords: PV, MPPT, UV-APF,etc.***

## I. INTRODUCTION

The recent development in power electronics led to development of solid-state controllers, which are in use with industry, commercial and domestic sectors extensively. The quality of power is being deteriorated due to use of these electronic controllers, which in turn demands quality power from source. A distribution system faces power quality (PQ) problems related to load current and supply voltage. Current related PQ issues are distorted and unbalanced source currents, poor power factor, and source neutral current, whereas voltage related PQ issues are sag, swell, unbalance, flicker, and distortion [1].Energy is required a wide range of applications such as transportation, industrial applications, agricultural application, household requirements and office application. It can have many forms like heat energy, electrical energy, chemical energy, nuclear energy, light energy and so on. The use of energy plays important role in one’s life. The availability and accessibility of sufficient amount of energy accelerate individuals and nation’s development. The relation between social developments and use of energy very clear nation with more use of energy are in more advance state of development.

Since the use of energy has become an integral part of our life, its supply should be secure and sustainable. At the same time, it should be economical, environmentally friendly and socially acceptable. The current trend in energy consumption is neither secure nor sustainable. The raising consumption of fossil fuel, together increasing greenhouse gas emission, threatens our secure energy supply.

There are two types of energy sources,

- Renewable Energy (Non-conventional)
- Non Renewable Energy (conventional)

After their installation they generate electricity from the solar irradiationwithoutemittinggreenhousegases. The lifetime of PV solar systemisaround25 years, which can produce power more than their manufacturing cost.Alsothey canbeinstalledinplaceswithnootheruse,suchasroofsanddeserts, orthey can produce electricity for remote locations, where thereisno electricity network. The latter typeof installationsis known as off-grid facilities and sometimes theyare themost economicalalternativetoprovideelectricityinisolatedareas.However,mostofthePV power generation comes from grid-connectedinstallations,wherethepowerisfedinthe electricity network. In fact,itis a growingbusinessin developedcountries such as Germany whichin 2010isbyfartheworldleaderin PVpowergenerationfollowedby Spain, Japan, USA and Italy. Ontheotherhand,due totheequipmentrequired,PV power generation is more expensive than other resources.

Governments are promotingit withsubsidiesorfeed-intariffs, expecting the developmentofthetechnologysothatin the nearfuture it will become competitive. Increasing the efficiency in PV plants sothepower generated increases whichisakeyaspect, as it will increase the incomes, reducingconsequentlythecostofthepowergeneratedsoitwillapproachthecostofthe powerproducedfromothersources.

Solar Energy

Solarenergyisoneoftheimportantsourceofrenewable energy. The sunradiates largeamountofenergywhichisenough tosatisfytheneedofwholeworld. Solar energy is usedfor providingheating, cooling, lightand for electricity. Oneofthe important technologies is Photo voltaic (PV), by photo electriceffectthe sunlight isdirectlyconvertedintoelectricity.

  

Solar Energy isgreenand clean. The productionofPV energydoesnotproducesgreenhousegaseshenceitissafe. Itis free frompollution, since manufacturerofPV are committedtominimizepollutionduringproduction.PVenergyisreliable, since powergenerationusing PV has nomovingparts hence it has less maintenance. When PV is used as distributed energy source it reduces the cost of transmissionlinesandimprovegridreliability.In electric power systems, integration of more Distributed Generators (DGs) in the network increases the short circuit level due to the short circuit current contribution of the DGs during faults [1].

Compared to the synchronous and induction machine based generators the inverter based generators, such as Photovoltaic (PV) solar systems, contribute lower fault current to the network due to the characteristics of PV panels and inverter operation [1]. The short circuit current contribution from a PV system inverter is typically in the range of 1.2 times rated current for the large size inverter (1MW), 1.5 times (500kW) for medium size inverter and between 2 - 3 times for smaller inverters [1]. Although, each PV solar farm may contribute short circuit currents as above, the total amount of fault current contribution may become unacceptably large for a feeder which has several PV systems connected. It is apprehended that short circuit current contributions from multiple solar systems in the distribution feeders may add up to levels that could be damaging to the circuit breakers. Hence circuit breakers will need to be upgraded and substations will need to be modified at significant cost to the utility.

## II. RESEARCH OBJECTIVES

The power demand always exceeds the available power generation in any developing country. Hence, renewable power generating systems such as PV and wind energy conversion systems are used to supplement the fossil fuel based power generation. But due to the non-linearity of the load that is diode bridge rectifier with RL- load, there is harmonics in the load currents.

Hence, harmonics reduction and reactive power compensation simultaneously can be done by using a voltage source inverter connected in parallel with the system which acts as an APF for reducing the distortions produced due to non-linear load in the load current. This active filter generates a compensating current which is of equal in magnitude as harmonic current and opposite in phase with it to reduce the harmonics present in the load current. APF is classified as series, or combination both series and but APF is preferred here as the principle of the APF is to produce compensating currents of equal in magnitude but opposite in-phase to those harmonics that are present due to non-linear loads. SAPF is a closed loop structure where non-linear loads act as linear. It can compensate reactive power and can also mitigate harmonics and distortions.

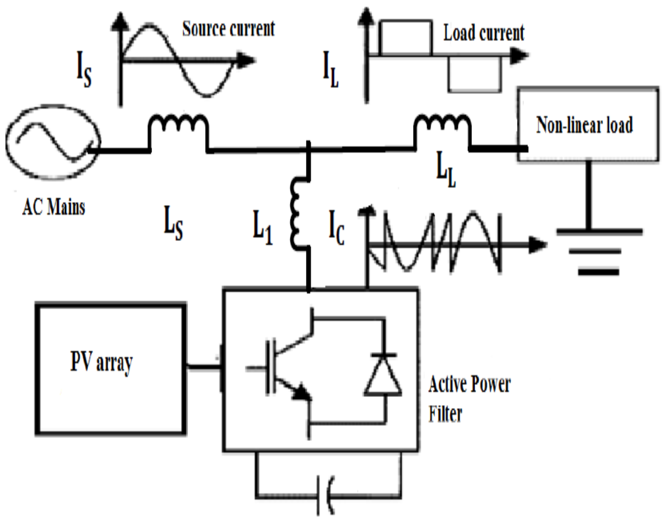


Fig.1.1 Principle of APF

In Fig. 1 AC mains is connected to the non-linear load that is diode bridge rectifier with RL-load where,

$IS$ - Source current

$IL$ - Load current produced due to non-linear load $IC$ – Compensating current produced by APF to mitigate harmonics

$LS$ - Source inductance

$LL$ - Load inductance &$L1$ – Coupling inductance

Here, the APF produced compensating currents of equal in magnitude but opposite in-phase to those harmonics that are present due to non-linear loads which results in mitigation of harmonics at load current. Generally, the voltage source inverters (VSI) are used to convert the power of the PV system to inject it to the distribution system. But here, the VSI act as a multifunctional device which is used for energy conversion and also for harmonics elimination as well as reactive power compensation simultaneously. This control strategy incorporate P-Q solution as in active power filter technique. This control technique is same as technique used in filter to reduce harmonics in the distribution network due to non-linear loads in the system.

## III. ENERGY MANAGEMENT SYSTEM

Universal active power filter with a PV system

A Universal Active Filter (APF) is the bidirectional current converter with six switches having combination of both switching network and filter-components. Structure of this power filter is dependent on the control technique of VSI having a capacitor for the purpose of DC energy storage and the inverter output has been connected to Non-linear load having diode Rectifier Bridge with a RL-load. In each of the switches the diodes are connected in anti-parallel arrangement with the IGBTs to permit current flow in either direction. For compensation of reactive power the PV interconnected Universal APF injects real PV power to a

  

 ISSN (Online): 2347 - 4718

distribution line at PCC and also reduces harmonic in load currents caused by nonlinear loads by injecting compensating current. This filter is connected in Universal that means in parallel with the nonlinear load. This active filter has capability of detecting the harmonic currents caused by the nonlinear loads and then injects a current of equal magnitude and opposite in phase with the non-linear load current which is called compensating current to reduce the harmonics present in load currents due to Non-linear load. Hence, the resulting current is in form of a fundamental frequency sinusoidal current which is drawn at PCC in distribution network.

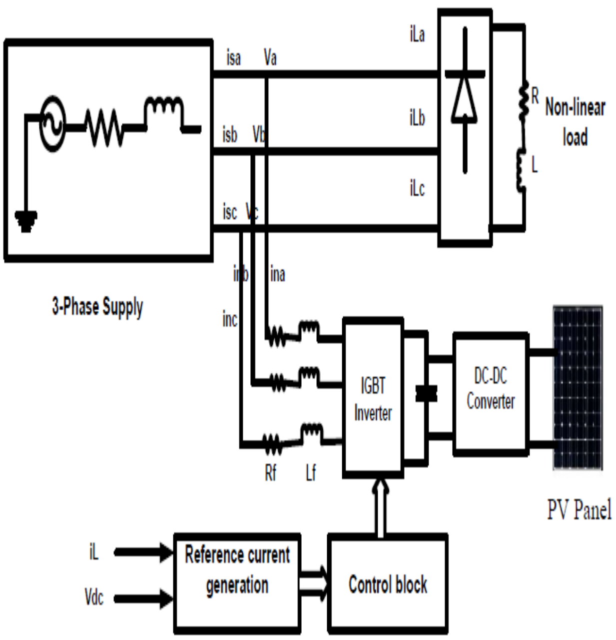


Fig.2 Schematic diagram of a PV system connected to a Universal APF

A Universal APF generally consists of the following Blocks:
i) IGBT based voltage source inverter (VSI)
ii) DC energy storage
iii) Active control unit

Operation and voltage source Universal APF control algorithm is presented in this chapter**.** Here, an instantaneous active-reactive power (p-q compensation) theory control algorithm have been used for Universal APF for compensating harmonics produced in current by providing equal but opposite in phase to current harmonics into system. Here, the Universal APF operation is considered as harmonics compensator produced by load with 180° phase. As a result, at the power distribution system nonlinear load and the APF have seen as an ideal resistor.For Universal APF harmonics reduction compensating current must be equivalent to the distorted current which can be achieved by shaping the compensating current waveform by using VSI switches. By evaluating the load current, the compensation current shape can be easily obtained by subtracting it from the reference current to obtain a sinusoidal source current which must be free from harmonics having only fundamental component of current.

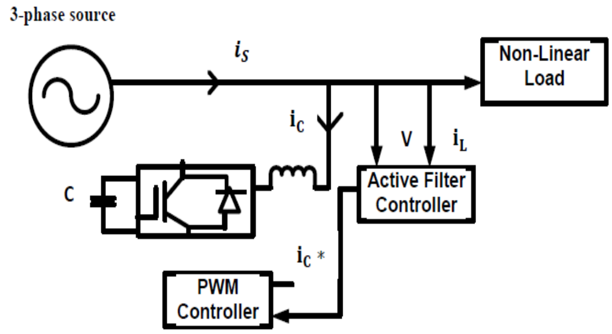


Fig.3 Schematic diagram of a Universal APF

Universal APF Reference current generation

Universal APF reference current may be generated by following various methods that are classified according to frequency, time and time-frequency.

1. In frequency domain
    - Fast Fourier Transform(FFT)
    - Adaptive Neural Network(ANN)

2. In time domain
    - d-q-0 theory (that is SRF)
    - P-Q theory

3. In time with frequency domain
    - Small wave method
    - One cycle control or digital/analogue filters separation

Various control strategies have already proposed for harmonic reduction but active-reactive Power (P-Q) theory is most preferable till now. This theory is allowed for steady-state or transient state operations where it is used for controlling APF in real-time.

*p–q*theory based control

Akagi et al in 1983 was developed P-Q theory or "instantaneous active-reactive Power theory" for controlling *the* active filters. This can be achieved by transforming the voltage and load current into α-β co-ordinates.

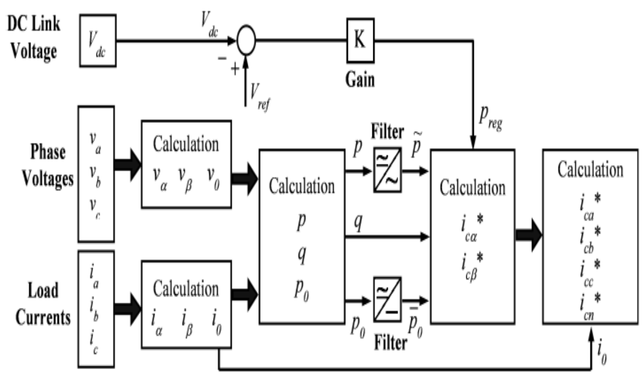


Fig.4 Block diagram of p-q compensation theory

  

P-Q theory can be achieved by transforming the voltage and load current into α-β co-ordinates as following

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix}$$

The instantaneous active power $pL$ and reactive power $qL$can be expressed as

$$\begin{bmatrix} p_L \\ q_L \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix}$$

These $pL$and $qL$ power can be divided into oscillatory and average terms as following

$pL=\bar{P}+p$

$qL=\bar{Q}+q$

Where,

$\bar{P}$= Instantaneous real power Mean value and is treated as desired power component that can be transferred from source to load.

$p$= Instantaneous real power alternated value and has to be compensated as it is not involve in power transfer between the source to load.

$\bar{Q}$= Instantaneous imaginary power mean value and it is related to the exchanges of power between the load phases which results in undesired current, so it has to be compensated.

q= Instantaneous imaginary power alternated value and is same as conventional reactive- power that has been compensated by using the APF.

In p-q theory assumed voltages are sinusoidal in nature so the power is to be calculated using these sinusoidal voltages.

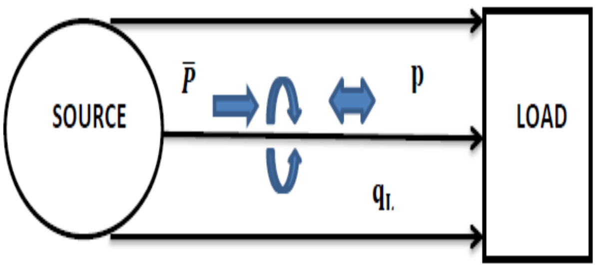


Fig.5 p-q theory power components

## IV. SIMULATION AND RESULT DISCUSSION

Matlab Simulation of Solar PV with UAPF- Fig. 6 shows the configuration of a PV-UAPF system. This a three phase system consisting of a shunt active filter and series active filter with a common DC-bus. The shunt active filter is interfaced near the nonlinear load whereas the series active is interfaced in series with the PCC. Other major components of the system include interfacing inductors, ripple filters and injection transformers. The PV array is coupled directly to the DC-bus of PV-UAPF system. A diode is used while integrating the PV array with PV-UAPF to prevent reverse power flow into PV array.

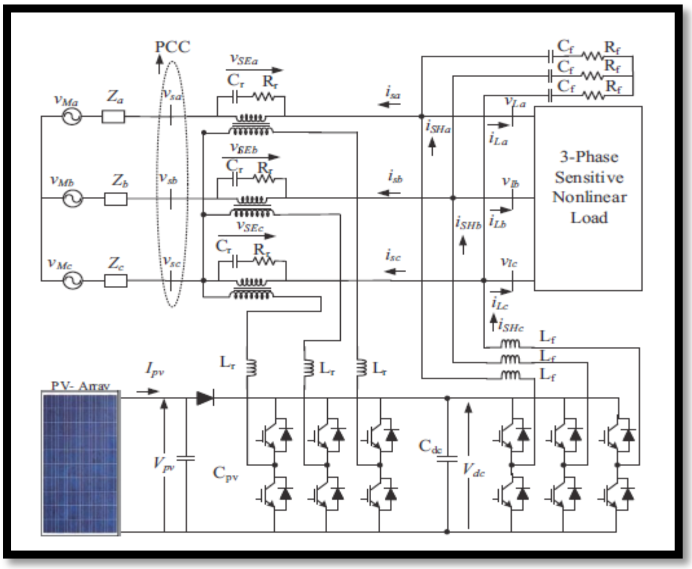


Fig.6 System Configuration of Solar Photovoltaic Integrated Unified Active Power Filter [1]

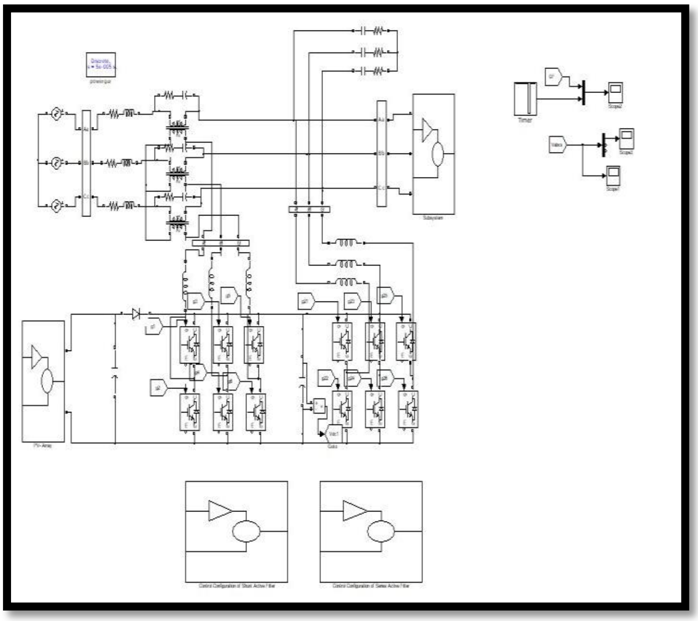

Fig 7-Simulation of PV-UAPF System

  

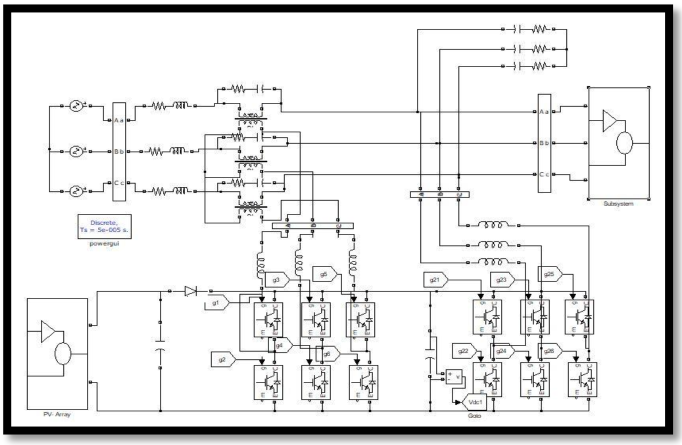

Fig 8-Simulation of PV system with APF

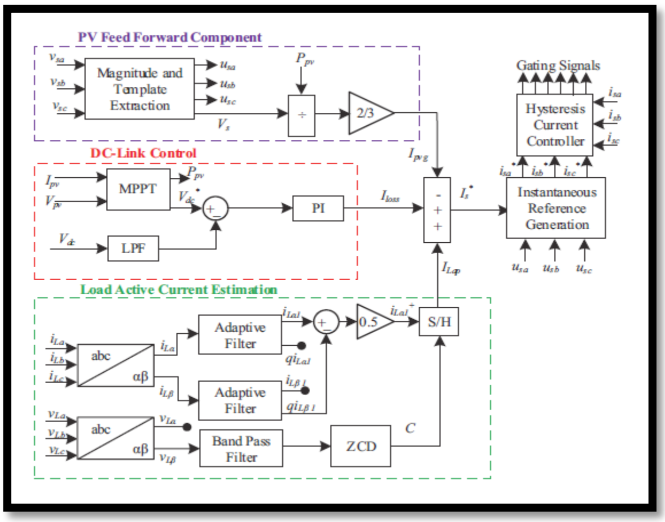

Fig 9-Control Configuration of Shunt Active Filter

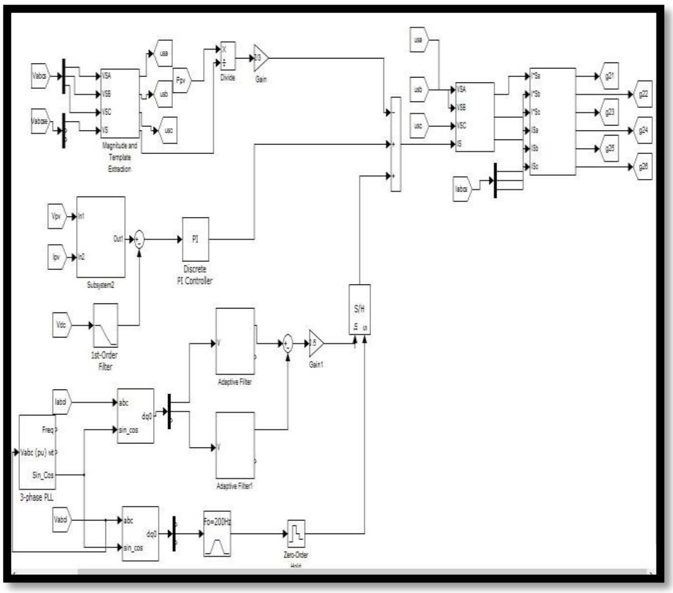

Fig 10-Simulation of Shunt Active Filter control

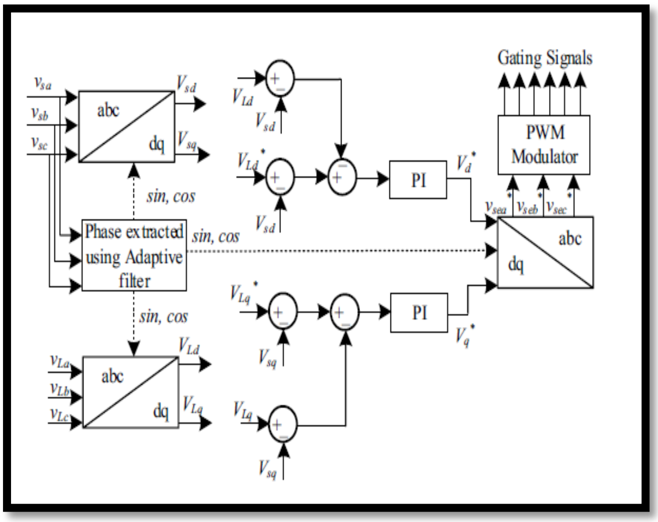

Fig 11- Control Configuration of Series Active Filter

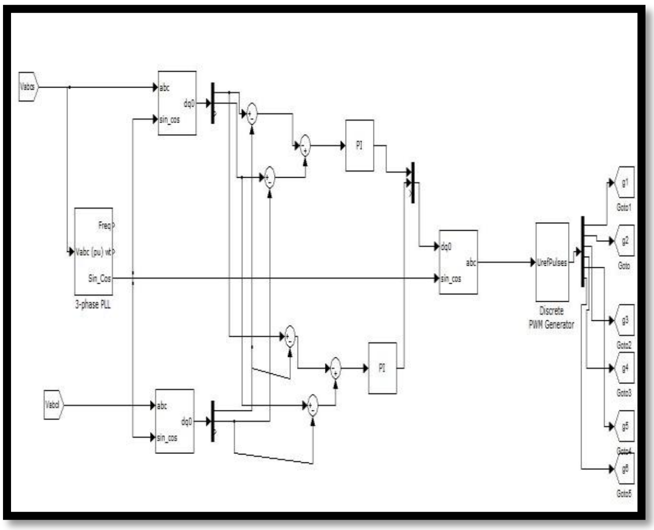

Fig 12-Simulation of Series Active Filter control

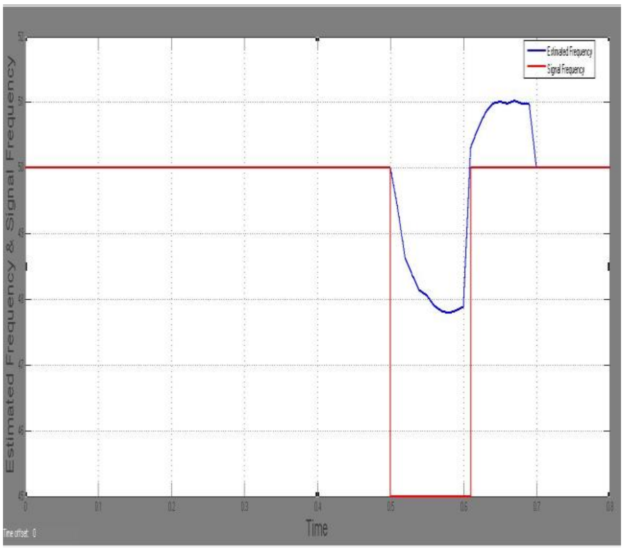

Fig13-Frequency Tracking Response of the Adaptive Filter

  

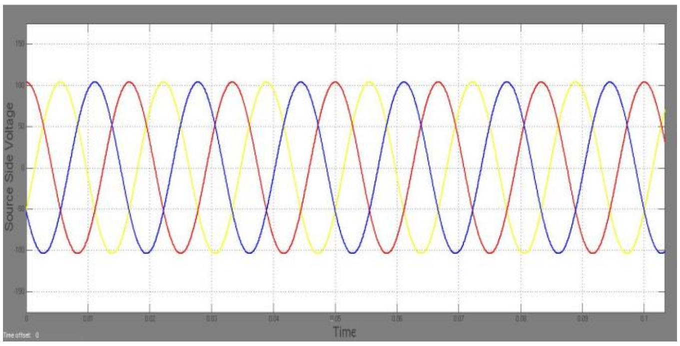


Fig 14-Source side voltage Waveform

Case-I Internal Signals for PV-UAPF System Control

Fig.15 presents the performance of the adaptive filters in extraction of fundamental positive sequence component of load currents.

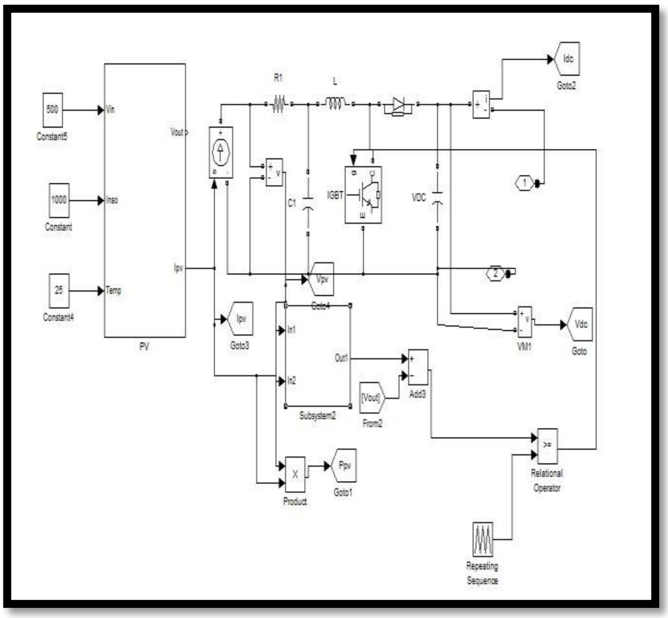


Fig 15 Internal Signals for PV-UAPF System Control

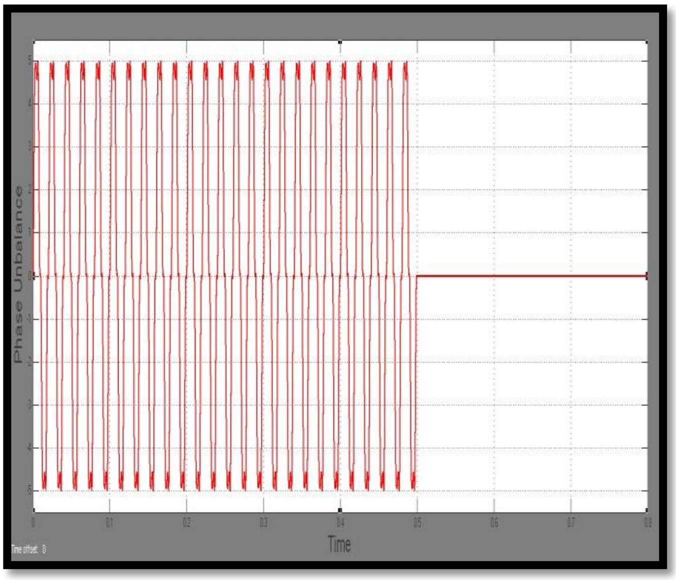


Fig 16-Phase Unbalance in source side current Phase-R

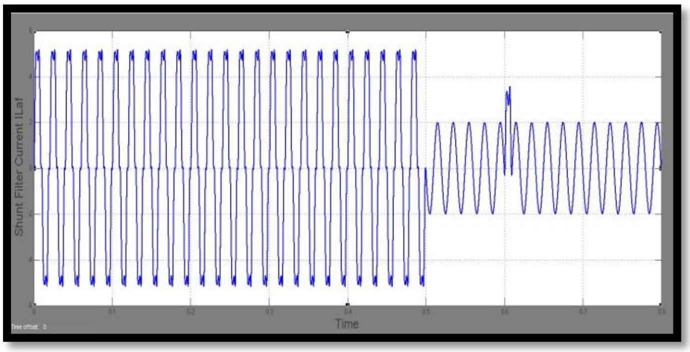


Fig 17-Shunt filter current control- Ila

Performance of PV-UAPF during Steady State Condition

The steady state PV-UAPF system capability in load compensation and voltage regulation, is evaluated under conditions of nominal conditions, PCC voltage sags/swells. The steady state waveforms of a phase of PV-UAPF are given in simulation results. The recorded signals are *vsa*, *isa*, *vLa*and *iLa*. In order to present both load side and PCC side information, only phase 'a' signals are recorded. The PCC current contains only fundamental active component while the load current is of a nonlinear quasi square wave shape. The voltage at load side is regulated and maintained in-phase with voltage of PCC during all conditions. The voltage at the load side is maintained at the desired RMS value of 220 V even though the voltage at PCC undergoes variation from 170 V during sag condition to 270 V during swell condition.

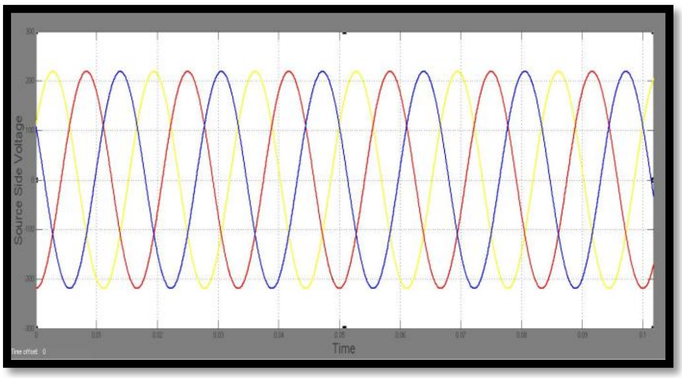


Fig.18-Source side voltage during Steady State Condition

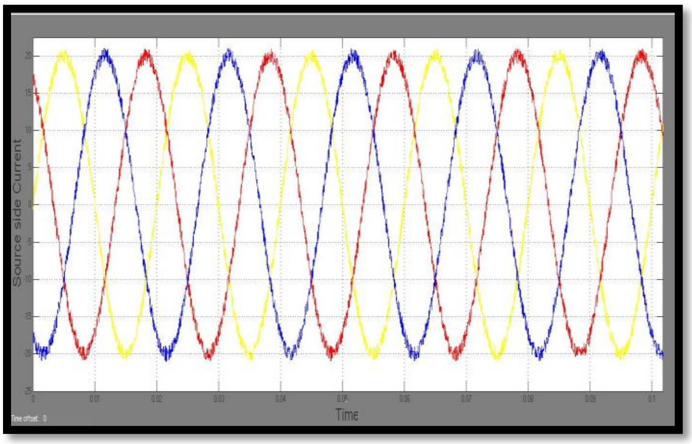


Fig.19-Source side Current during Steady State Condition

  

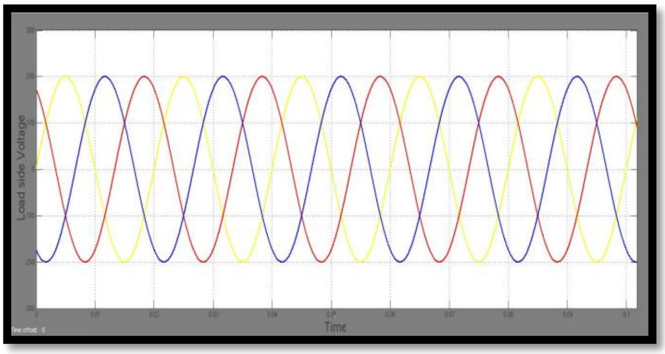

Fig.20-Load side voltage during Steady State Condition

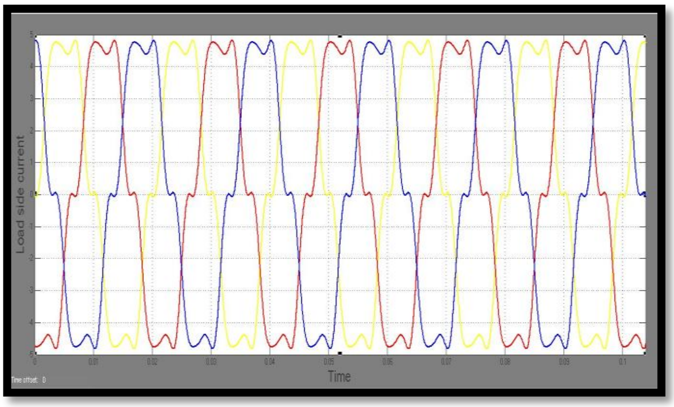

Fig.21-Load side current during Steady State Condition

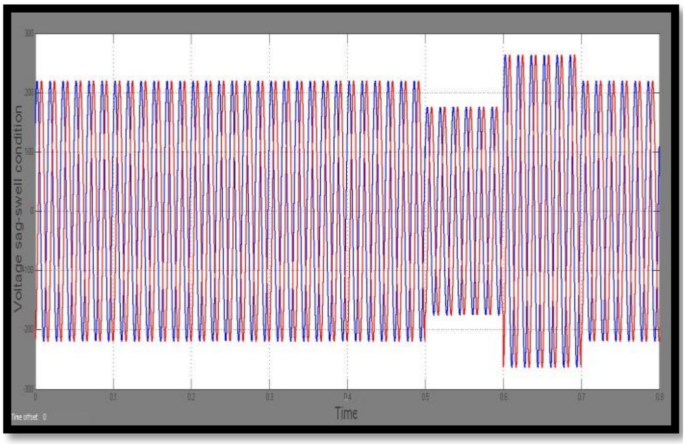

Fig.22-Sag-Swell condition in Source side voltage

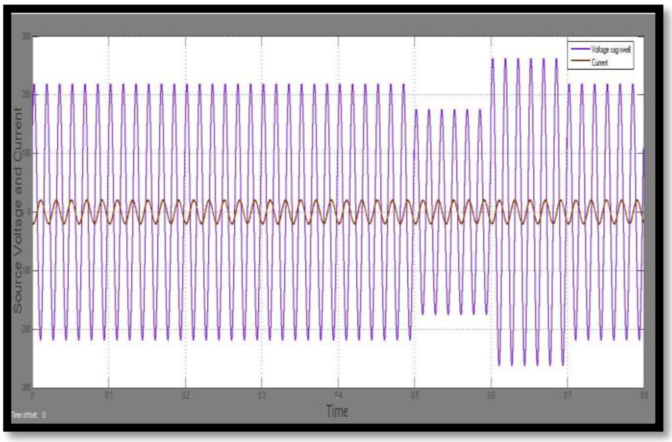

Fig.23-Sag-Swell condition in Source side voltage and Current

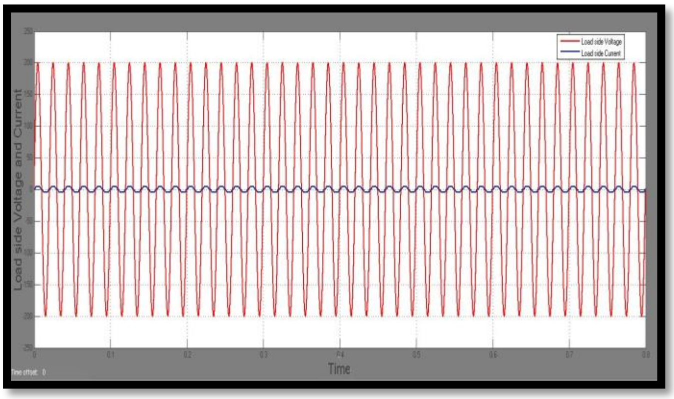

Fig.24-Sag-Swell mitigation in Load side voltage and Current

Performance under Fault Conditions

The operation of the system under three phase short circuit is presented in Fig.25. Simulated performance is presented of fault condition in laboratory environment. The system control is implemented such that, the gating to the system automatically shuts down in the event of fault. It can be seen from Fig.6.52 that a fault occurs at PCC from t=0.3s to t=0.36s The PCC voltage is limited to drop across the short circuit impedance. It can be observed that during this instant though PCC current is (A) rises to large value, the load current is nearly zero.

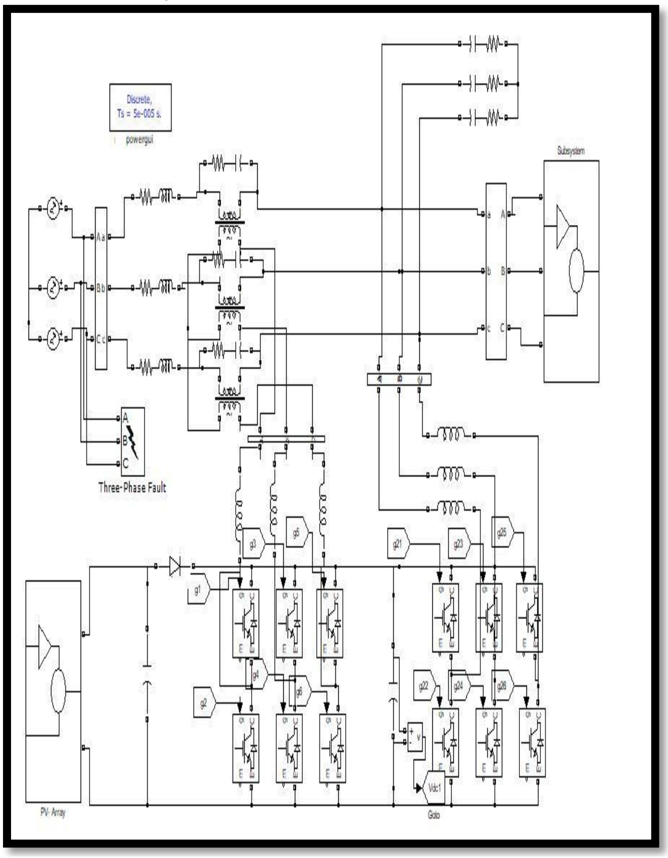

Fig 25 Performance of PV-UAPF under Three Phase Short Circuit Fault

  

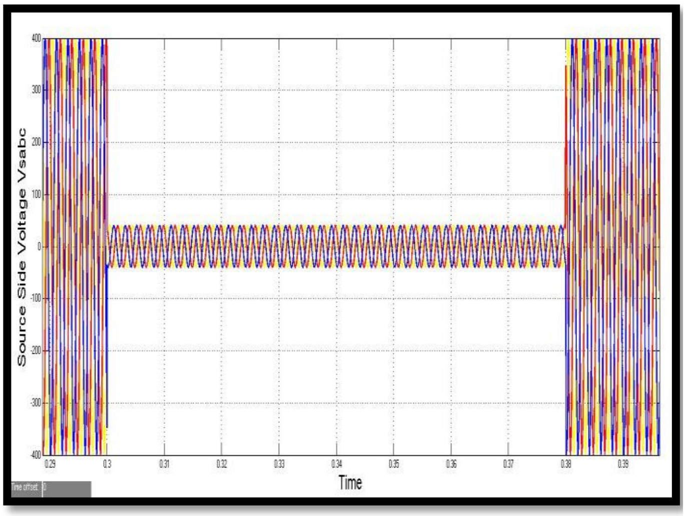


Fig.26-Source Side voltage under Three Phase Short Circuit Fault

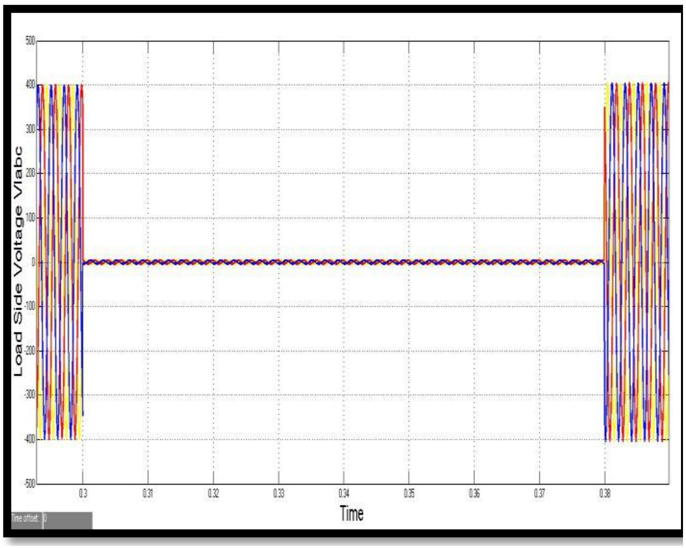


Fig 27-Load Side voltage under Three Phase Short Circuit Fault

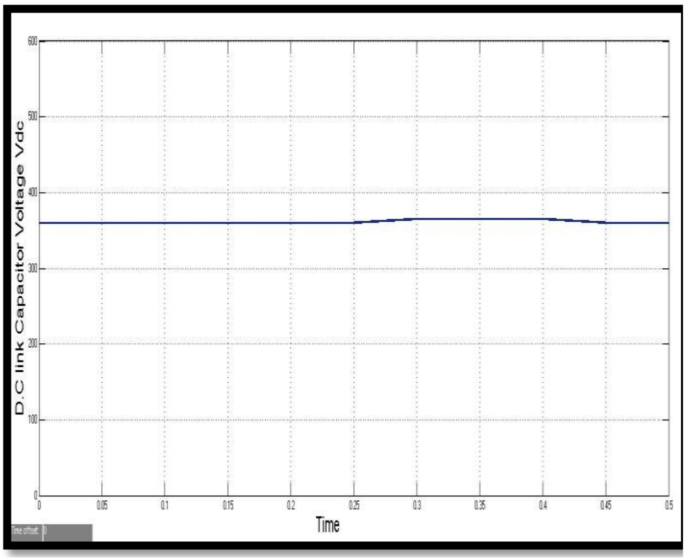


Fig 28-D.C bus voltage Vdc under Three Phase Short Circuit Fault

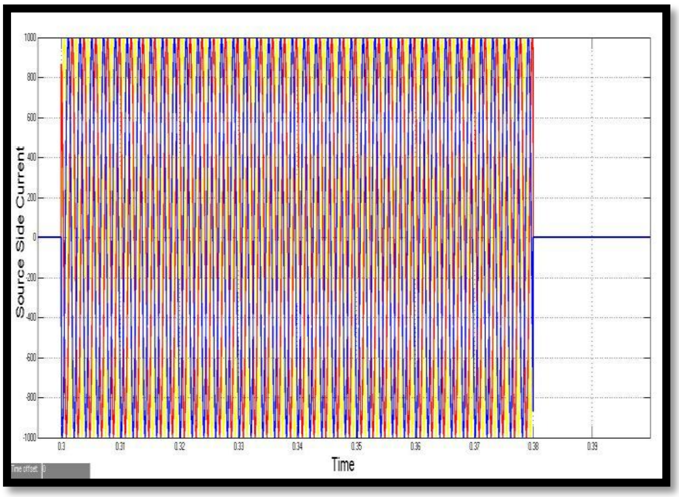


Fig 29-Source Side current under Three Phase Short Circuit Fault

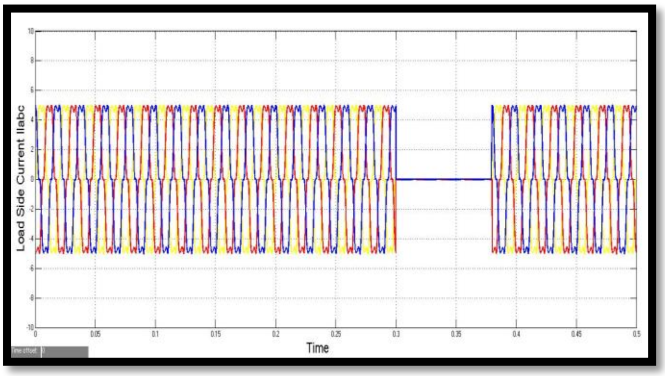


Fig 30-Load Side voltage under Three Phase Short Circuit Fault

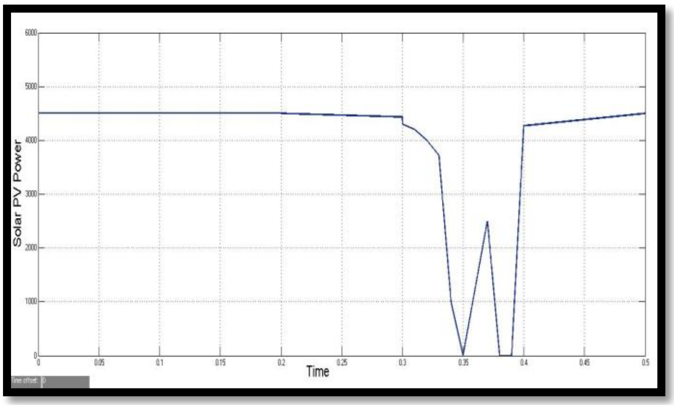


Fig 31-Solar PV power under Three Phase Short Circuit Fault

## V. CONCLUSION

The performance of adaptive filter based PV-UAPF system under both steady state and dynamic conditions, have been analyzed in detail. The method of sampling the fundamental component of load current obtained through adaptive filter enables fast extraction of fundamental active component of nonlinear load currents for all phases in one sampling. Only two adaptive filters are required to extract magnitude of active component of three phase load currents. This technique requires reduced computational resources while achieving good dynamic and steady state performance in extraction of fundamental active component of nonlinear load current. The system performance has been found to be satisfactory under various disturbances in load current, PCC voltage and solar irradiation. The proposed topology and algorithm are suited for employing in conditions where PCC voltage sags/swells and load current harmonics are major power quality issues. Certain power quality issues not addressed include voltage distortions, flicker, neutral current compensation etc. This power quality issues can be addressed by modification of topology and control algorithm according to the requirements in the distribution system.

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