ISSN 2249-6343
International Journal of Computer Technology and Electronics Engineering (IJCTEE)
Volume 2, Issue 4, August 2012

Power Quality Improvement in a PV Panel connected Grid System using Shunt Active Filter

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***Abstract*— This paper describes improved methodology of power quality at utility end in a grid system connected with renewable source of energy for power generation. With development of new functionalities solar energy based Photovoltaic cells are upcoming energy source with higher efficiency. Solar cells are more preferred as renewable source of energy. Solar energy being naturally available in abundance and non- polluting is one of the most promising sources. Excessive use of power electronics devices lead to power quality problems. Effects of poor power quality like sag, swell distortion in waveform, harmonics, reactive power generation has affected both grid as well as utility sectors. Harmonics are major problem diminishing the power quality. Active Power filter are powerful tool for mitigation of harmonics. Active filter suppress harmonic current and compensate reactive power simultaneously. This paper presents the performance of Shunt active filter with VSI topology using synchronous reference frame theory. By this methodology harmonic suppression is possible within permissible standards as defined by IEEE-519.**

***Index Terms*—Inverter, PV cells, Power quality, Shunt active Filter, Synchronous Reference Frame Theory.**

I. INTRODUCTION

This paper presented here shows unique and effective methodology for planning a grid connected to renewable source of energy as solar energy and Harmonic Mitigation in system using Active Filter on utility side. Solar power is harnessed through PV panels and harmonic distortion is filtered using Shunt Active filter.

Age of fossil fuel as source of energy is constantly getting extinct. Demand of fuel and energy is exponentially rising with time. At the same time energy cost is also continuously increasing. To overcome these critical situations we can use renewable resources at our disposal from which energy can be tapped; Photovoltaic cells converts solar energy to direct electric energy. Other virtues of solar energy are:

1. It requires less time to install and start up new unit for generation.
2. It has no rotating parts, hence no noise, no maintenance and long life with less maintenance.
3. Solar energy is abundantly available on earth.
4. Problem of low efficiency and higher initial cost can be overcome by advance technology solar PV panel.
5. This energy source is non-polluting and available continuously free of cost. [1]

It is anticipated that Photovoltaic system will be major source of energy fulfilling global energy needs. Photovoltaic system has been increasingly used in medium sized grid with domestic utilities. PV panels are connected in series and parallel to generate usable amount of voltage and current. By series connection voltage level can be built up and by parallel connection current density can be increased. In addition to that Converter configuration should be efficient and cost effective.

There are many topologies available for DC/DC step up and DC/AC conversion. For maximum power transfer DC Voltage is stepped up. Boost converter, cuk converter cascading convertor topology. Boost convertor is more preferable due to less no of devices and simple control. Inverters connected to output of dc/dc converter which incorporated a Maximum Power Point Tracker (MPPT) which continuously adjusts the load impedance to provide maximum power from PV panels.

Sinusoidal waveform of AC voltage is highly distorted by current due to non linear load at common point of coupling (PCC). Due to this other load on same grid systems are affected. This creates unbalancing effect on transmission and generation side. Active filters are the solutions to these problems of unbalancing, harmonics and reactive power.

For Harmonic mitigation passive filters were used traditionally, but due to certain drawbacks of resonance due to matching with line impedance, can compensate single harmonic at a time, bulky in weight they are not much in use. With development of semiconductor devices active harmonic filters with different current control strategies are extensively used. Shunt Active filter can be formed from topologies like CSI, VSI.. There are many current control methods used in active filters. Hysteresis current control method, synchronous reference frame, direct control method, fuzzy logic, dead beat control are used for PWM generation.

Grid connected to Solar panels with inverter and active power filter for compensating harmonic current of non linear load is shown in fig.1

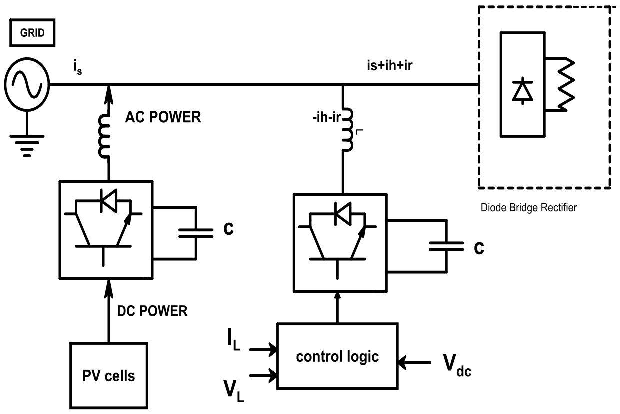

Fig. 1. PV system connected to grid with non linear load and Active Filter.

II. PV PANELS

Solar cell is basically a photovoltaic cell form of p-n junction. It when exposed to sunlight absorbs some energy greater than band-gap. This creates some hole-electron pairs proportional to incident radiations. These carriers are affected by internal electric fields of p-n junction and forms photo current proportional to solar insolation. PV cells have non linear characteristics which vary with radiation intensity and temperature.

PV cells produces less than 3W at 0.5 to 0.6 Volts, so cells are connected in series to produce enough power.[2] The terminal equation for the current and voltage of the array of PV panels are given as under:[2]

$$I_{pv} = I_p - I_D - I_{sh} = 0 \qquad (1)$$

$$V_{PVcell} = V_D - R_S I_{PV} \qquad (2)$$

$$I_{sh} = \frac{V_{pv}+R_S I_{pv}}{R_{sh}} \qquad (3)$$

$$I_D = I_0\left(e^{\frac{q(V_{pv}+R_S I_{pv})}{NkT}} - 1\right) \qquad (4)$$

I_p = Light generated current
V_{pv} = Terminal voltage of the cell
I_D = Diode current
I_o = saturation current
I_{sh} = shunt current
q = electron charge
k = Boltzmann constant
T = Temperature
R_s = Series Resistance
R_{sh} = shunt Resistance

III. BOOST CONVERTER AND INVERTER

Boost converter increases voltage level for inverter and control MPPT. Output voltage of boost converter is higher than input voltage. Input current is same as inductor current and hence it is not discontinuous as buck convertor and hence input filter requirements are relaxed in boost convertor.

If solar panels of high rating are implemented then requirement of boost converter can also be relaxed and switching loss in converter can be saved.

PV Panels generate DC Voltage and to connect panels to grid DC power has to be converted to AC Power. We require inverter to convert DC to sinusoidal AC before connecting to grid. Output voltage and frequency should be same as that of grid voltage and frequency. Many inverter topologies are available. In proposed scheme PWM (pulse width modulated) Voltage Source Inverter is selected d-q theory with phase. [3] Output of the Inverter is near to Sinusoidal. 6 switches are used and its switching is controlled by discrete PWM signals. Electrical diagram for inverter is shown in Fig. 2. [4]

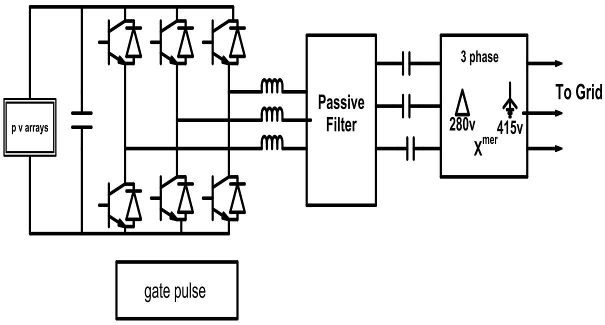

Fig. 2 PWM 3 phase inverter with passive filter

IV. ACTIVE FILTERS

Harmonics results in voltage distortion which is a major problem on utility side. Other problems related to harmonics such as line loss reactive power, resonance problem, heating of equipments leads to reduction in stability of system. Active filters provide a fair solution to mitigate problems encountered due to harmonics on utility side. Harmonic resonance is not an issue with this type of filter. The active filters are used for nonlinear load having time dependent harmonics.

There are several topologies are considered to meet IEEE 519 harmonics standards at plant-utility PCC interface. Shunt active filter, series active filter, hybrid active filter with CSI and VSI inverter topologies are available. These filters are sized based on how much harmonic current is to be filtered. The filter consists of a VSI or CSI with a special electronic controller which injects harmonic current on to the system 180^0 out of phase to the system harmonics. This results in a cancelling effect of the harmonics. For example if the non linear load creates 100 amps of 5th harmonic current and the active filter produced 75 Amps of 5th harmonic current, the amount of 5th harmonic current exported to the utility grid would be 25 Amps. [5]

Shunt active filter is cost effective for low to medium industrial load. It does not create power factor displacement problem. Supply side Inductance does not affect harmonics compensation capability of active filter system. It requires simple current control implementation.[5] It provides immunity against ambient harmonic load.

In active filter protection and sequencing is relatively easy and does not require expensive isolation and switchgear. Shunt Active filters are scalable for higher KVA loads by paralleling units [6]

A. Shunt Active Filter

Shunt active filter is based on the principle of injection of load harmonic current and is characterized by non sinusoidal current reference tracking. Shunt harmonic filter requires suitable current controller for extraction of load harmonic current. [5] Proposed model of Shunt Active filter includes switching ripple filter of rating which filters current. The shunt Active filter constitutes of IGBT inverter with switching frequency of 20k Hz and rated current 200A. Active filter has output voltage V_p = 380 V and current rating of I_p = 170 Amp. DC bus voltage of Shunt Active filter is V_{dc} = 620 for nominal supply voltage of 415V. The dc bus capacitance is 1.5mF. Inverter output filter inductance is L_f = 350µH. [6]

In Proposed model of Shunt Active filter, shown in Fig.3 load harmonic current is injected with 180^0 phase shift. Synchronous reference frame theory is implemented as control logic for controlling and extraction of load harmonic current and generating pulse for inverter.

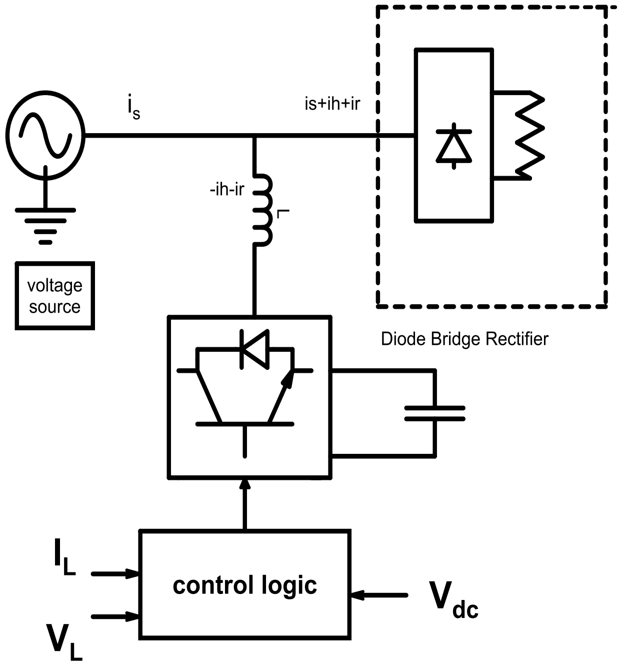

Fig. 3. Shunt Active Filter connected to non linear load

B. Synchronous Reference Frame Theory

In this paper synchronous Reference frame theory based d-q model for SAPF is discussed. Instantaneous voltage and current in three phase circuit it is mathematically expressed in space vector form. [8] These three vectors R, Y, B are displaced by an angle of 120^0 from each other is shown in fig.4.

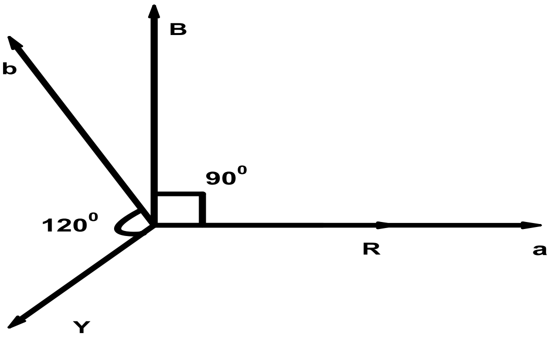

Fig. 4. Vector representation of synchronous reference frame

Reference frame theory based d-q model for SAPF presented. Instantaneous voltages and currents in the RYB coordinates are transformed to two axis coordinates represented by α and β. [4]

$$V = [V_R \;\; V_Y \; V_B]^T \tag{5}$$

$$i = [i_R \;\; i_Y \; i_B]^T \tag{6}$$

By Clarke Transformation

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix} = T_1 \begin{bmatrix} V_R \\ V_Y \\ V_B \end{bmatrix} \tag{7}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_o \end{bmatrix} = T_1 \begin{bmatrix} i_R \\ i_Y \\ i_B \end{bmatrix} \tag{8}$$

$$T_1 = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \tag{9}$$

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_R \\ V_Y \\ V_B \end{bmatrix} \tag{10}$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = T_2 \begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \tag{11}$$

$$T_2 = \begin{bmatrix} \cos \omega_r & -\sin \omega_r \\ \sin \omega_r & \cos \omega_r \end{bmatrix} \tag{12}$$

In three phases balanced system neutral current is zero, and zero sequence current does not exist. Voltage and currents in α and β reference frame is express as shown in equation. Both current and voltage equations of three phase are transformed to 2 phase called alpha and beta as shown in vector diagram fig. 4.

The Voltage in α and β reference frame is further transform in rotating reference frame with ω_r as angular velocity in d-q reference frame. Transformation from α, β to d-q reference frame can be similarly obtained. Unit vector generation for this transformation is generated by step down grid voltage. [9]

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} \sin wt & \cos wt & 1 \\ \sin(wt - \frac{2\pi}{3}) & \cos(wt - \frac{2\pi}{3}) & 1 \\ \sin(wt + \frac{2\pi}{3}) & \cos(wt - \frac{2\pi}{3}) & 1 \end{bmatrix} \times \begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} \quad (13)$$

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin wt & \sin(wt - \frac{2\pi}{3}) & \sin(wt - \frac{2\pi}{3}) \\ \cos wt & \cos(wt - \frac{2\pi}{3}) & \cos(wt - \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \times \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (14)$$

This control scheme shown in Fig. 5 consists of inner current control loop and outer voltage control loop. The PI controller of the voltage control loop gives a current command required to maintain the DC bus voltage to set value. This is added to the AC component of d axis of the load current. This gives the current reference for d axis. The reference for q axis is obtained after the orientation of load current. [8]

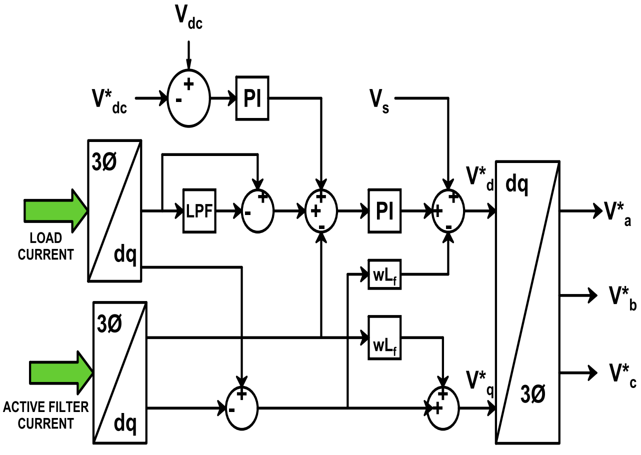

Fig. 5. Block diagram of closed loop current control scheme using synchronous reference frame theory

V. MAT LAB SIMULATION AND WAVEFORMS:

Matlab is very powerful tool for the simulation. Here simulation of Shunt Active filter in Matlab is shown in Fig.6. Here three phase AC source is supplied to load. Simulation of PV panels connected with inverter is not shown. Control circuit for active filter is shown in Fig.7. Simulation results and waveforms are shown. Waveforms of Load current and Source current before and after filtering are shown in Fig.7 and Fig.8. After implementation of Shunt Active harmonic Filter source current has become nearly sinusoidal this is shown in Fig. 11 Compensating harmonic current which is to be injected in source current is also shown in Fig.12.

FFT analysis results are shown in Fig.13. and Fig. 14. This shows harmonic reduction before and after using shunt active filter. Here fundamental frequency is 50Hz. THD reduces from 27. 32% to 3.94% which is in range of IEEE 519 standards.

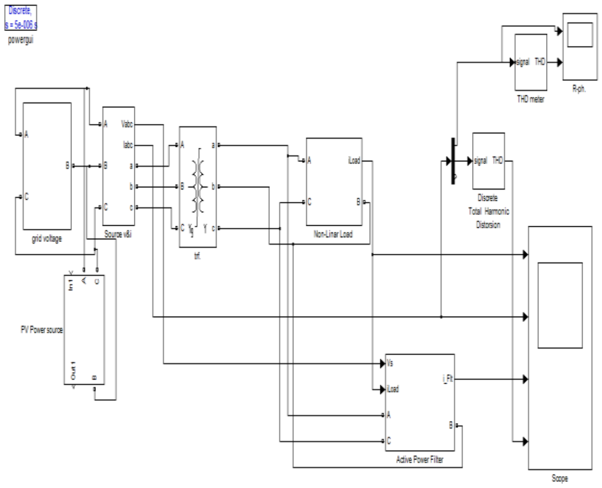

Fig. 6. Simulink model of Grid connected SAPF

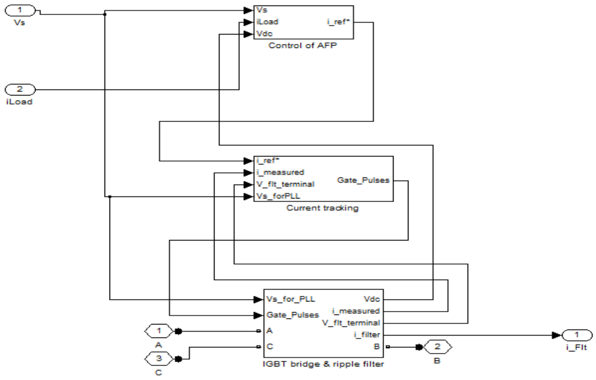

Fig. 7. Simulink model of current control scheme of SAPF

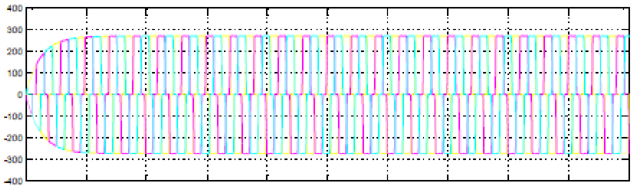

Fig. 8. Load current waveform before filtering

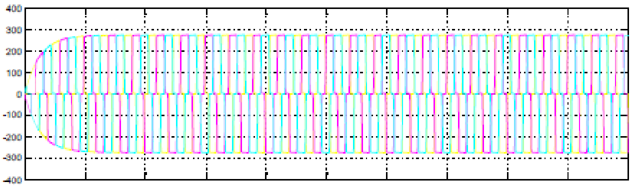

Fig. 9. Source current waveform before filtering

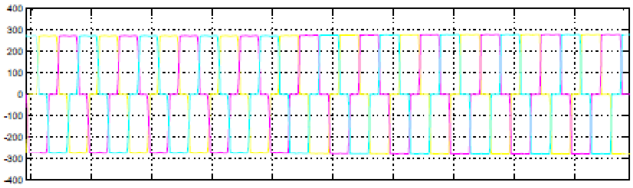

Fig. 10. Load Current waveform after filtering

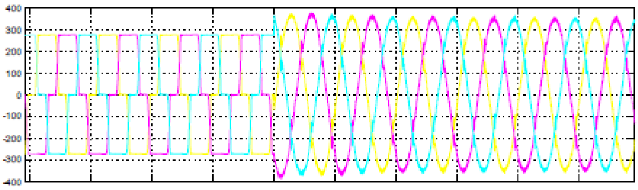

Fig. 11. Source current waveform after filtering

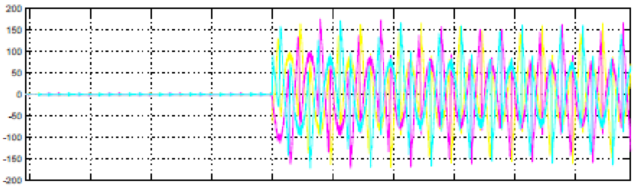

Fig. 12. Compensating harmonic current

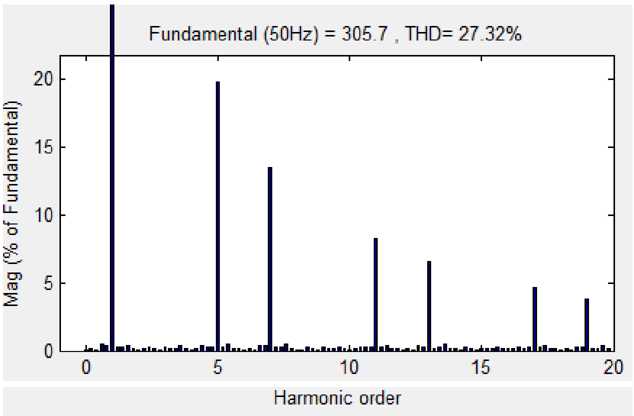

Fig.13. FFT analysis of source current before filtering

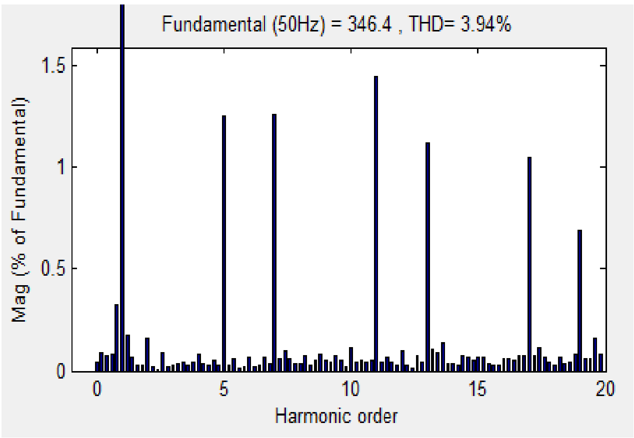

Fig.14. FFT analysis of source current after filtering

VI. CONCLUSION

PV panels are connected in series and parallel to match with grid voltage. Parallel connection increases current level. This DC power is converted to AC using inverter. Inverter is control to feed active power to the grid using discrete PWM signals. There is harmonic injection in the grid due to non linear load on utility side. To mitigate this harmonics to IEEE 519 standards Shunt active filter with VSI topology is used. Synchronous reference frame for current control scheme is implemented for better results.

Active filters operation rating and control is briefly analyzed. Important terms like switching frequency, ripple suppression dc bus voltage are addressed to meet systems performance objective. Harmonic level in Supply current is 27.32% without active filter implementation, which is improved to 3.94% with Shunt active filter implementation.

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