Shunt Active Power Filter Application in Grid-Tied Solar Photovoltaic System by Droop Control Strategy

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ABSTRACT

This paper presents the grid-tied Solar Photovoltaic generator system supplying to nonlinear loads based Shunt Active Power Filter for reactive power compensation and harmonic mitigation by droop control method. Solar PV system is a promising source of energy with great interest in clean and renewable energy sources. The rising number of power electronics-based equipment is resulting in quality problems of electric power supply. Both high power industrial loads and domestic loads cause many disturbances in the utility side such as harmonics, imbalance, sags, swells, flickers and frequency variation. Power quality problems may arise in the system or may be created by the consumer itself. In this paper, the proposed controller utilizing power references shows some significant improvements in theory and a simple control topology. The PV module is connected to the DC side of Shunt Active Filter through the DC-DC converter. Converter switch is controlled by Perturb & Observe (P&O) Maximum Power Point Tracking (MPPT) algorithm and it eliminates the drawback in the conventional PV system. An emulation using MATLAB Simulink is presented to validate the advantage of the proposed system.

KEYWORDS:
Photovoltaic, nonlinear loads, Shunt Active Power Filter, reactive power compensation

I. Introduction

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 a shunt 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, shunt or combination both series and shunt but shunt APF is preferred here as the principle of the shunt 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.

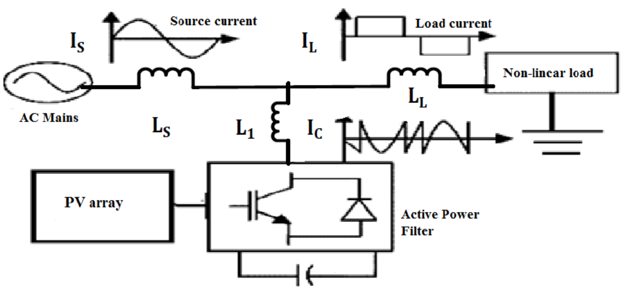

Fig.1 Principle of shunt APF

In Fig. 1. AC mains is connected to the non-linear load that is diode bridge rectifier with RL-load where,
I_S - Source current
I_L - Load current produced due to non-linear load IC – Compensating current produced by shunt APF to mitigate harmonics
L_S - Source inductance
L_L - Load inductance
L_1 – Coupling inductance

Here, the shunt 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 incorporates P-Q solution as in shunt active power filter technique. This control technique is same as technique used in shunt filter to reduce harmonics in the distribution network due to non-linear loads in the system.

This paper is organized as follows Section II provides overview on PV cell, its basic theory, connections modeling and effect of temperature and irradiation on PV panel. Section III described MPPT P & O algorithm and its implementation for maximum power extraction from a PV system connected to a DC/DC Boost converter and its need in PV power generation along with its waveforms. Section IV presents shunt APF design and its control algorithm with implementation of shunt APF control technique for inverter control. Section V describes the obtained simulation results and its discussions Section VI presents the conclusion along with scope for future work.

II. Photovoltaic Systems

PV cells are made of semiconductor materials, such as silicon. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current - that is, electricity. This electricity can then be used to power a load . A PV cell can either be circular or square in construction.

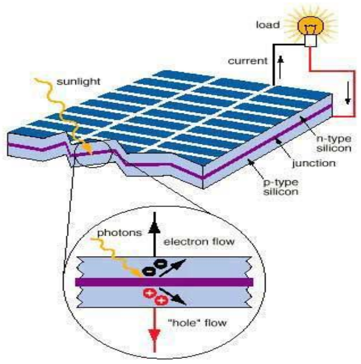

Figure 2 Basic Structure of PV Cell

A. Modeling of PV Array

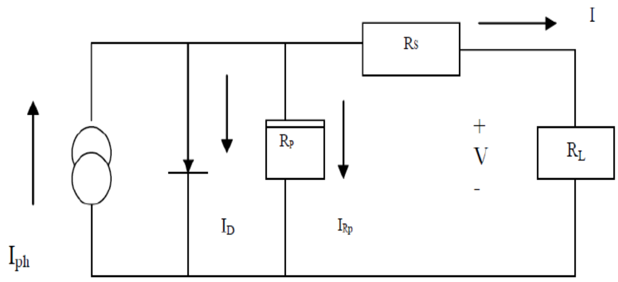

Figure 3 Equivalent circuit of a PV cell

The building block of PV arrays is the solar cell, which is basically a p-n junction that directly converts light energy into electricity: it has a equivalent circuit as shown below in Figure 3.

The current source Iph represents the cell photo current; Rj is used to represent the non-linear impedance of the p-n junction; Rsh and Rs are used to represent the intrinsic series and shunt resistance of the cell respectively. Usually the value of Rsh is very large and that of Rs is very small, hence they may be neglected to simplify the analysis. PV cells are grouped in larger units called PV modules which are further interconnected in series-parallel configuration to form PV arrays or PV generators[3].The PV mathematical model used to simplify our PV array is represented by the equation:

$$I=n_pI_{ph}-n_pI_{rs}[\exp(\frac{q}{KTA}*\frac{V}{n_S})\ -1] \quad (1)$$

where I is the PV array output current; V is the PV array output voltage; ns is the number of cells in series and np is the number of cells in parallel; q is the charge of an electron; k is the Boltzmann's constant; A is the p-n junction ideality factor; T is the cell temperature (K); Irs is the cell reverse saturation current. The factor

A in equation (3.5) determines the cell deviation from the ideal p-n junction characteristics; it ranges between 1-5 but for our case A=2.46 [3].

The cell reverse saturation current Irs varies with temperature according to the following equation:

$$I_{rs}=I_{rr}[\frac{T}{T_r}]^3\exp(\frac{qE_G}{KA}[\frac{1}{T_r}-\frac{1}{T}]) \quad (2)$$

Where Tr is the cell reference temperature, Irr is the cell reverse saturation temperature at Tr and EG is the band gap of the semiconductor used in the cell.
The temperature dependence of the energy gap of the semi conductor is given by [20]:

$$E_G= E_G(0)-\frac{\alpha T^2}{T+\beta} \quad (3)$$

The photo current Iph depends on the solar radiation and cell temperature as follows:

$$I_{ph}=[\ I_{scr} + K_i(T - T_r)]\ \frac{S}{100} \quad (4)$$

where Iscr is the cell short-circuit current at reference temperature and radiation, Ki is the short circuit current temperature coefficient, and S is the solar radiation in mW/cm2. The PV power can be calculated using equation (3.5) as follows:

$$P=IV= n_pI_{ph}V[(\frac{q}{KTA}*\frac{V}{n_s})-1] \quad (5)$$

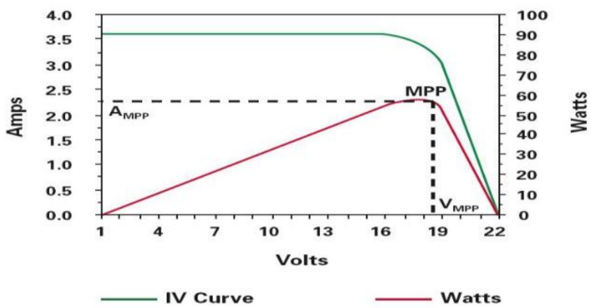

Figure 4 I-V and PV curve characteristics

The current to voltage characteristic of a solar array is non-linear, which makes it difficult to determine the MPP. The Figure below gives the characteristic I-V and P-V curve for fixed level of solar irradiation and temperature.

III. Maximum Power Point Tracking System

Maximum power point tracking is an essential part of a photovoltaic system. Photovoltaic systems have a distinct operating point that provides maximum power. An MPPT actively seeks this operating point. Maximum Power Point Tracking, normally known as MPPT, is an electronic arrangement that find the voltage (V_{MPP}) or current (I_{MPP}) routinely at which a PV modules should operate to achieve the maximum power output (P_{MPP}) under rapidly-changing environmental conditions. It operates the PV modules in a way that permits the modules to generate all the power they are capable of.

Solar irradiation that hits the photovoltaic modules has a variable character depending on the latitude, orientation of the solar field, the season and hour of the day. During the course of a day, a shadow may be cast on the cell that may be foreseen, as in the case of a building near the solar field or unforeseeable as those created by clouds. Also the energy produced by each photovoltaic cell depends on the irradiation and temperature. From these considerations, the necessity to identify instant by instant that particular point on the V-I characteristic of the PV generator in which there is the maximum amount of power transfer to the grid occurs. The generated energy from PV systems must be maximize as the efficiency of solar panels is low. For that reason to get the maximum power, PV system is repeatedly equipped with maximum power point (MPP) tracker. Several MPP pursuit techniques are proposed and implemented in recent years

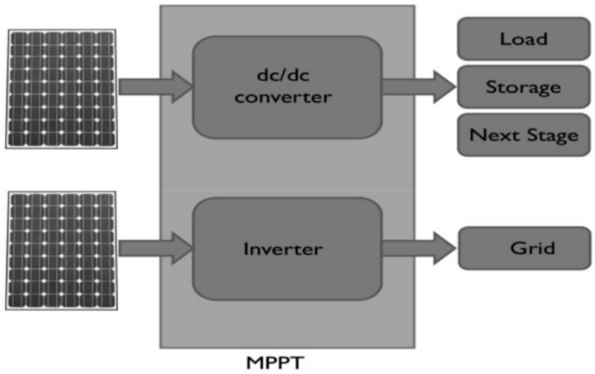

Figure 5 Need of MPPT

Based on the approach used for generation of the control signal as well as the PV system behavior around the steady state conditions, they are usually classified into the following groups:

1. Offline methods
   - Open circuit voltage (OCV) method
   - Short circuit current method (SCC)

- Artificial intelligence

2. Online methods
   - Perturbation and observation method (P&O)
   - Extremum seeking control method (ESC)
   - Incremental conductance method (Inc Cond).
3. Hybrid methods

A. Perturb and Observe (P&O)

The most commonly used MPPT algorithm is P&O method. This algorithm uses simple feedback arrangement and little measured parameters. In this approach, the module voltage is periodically given a perturbation and the corresponding output power is compared with that at the previous perturbing cycle. In this algorithm a slight perturbation is introduce to the system. This perturbation causes the power of the solar module various. If the power increases due to the perturbation then the perturbation is continued in the same direction. After the peak power is reached the power at the MPP is zero and next instant decreases and hence after that the perturbation reverses.

When the stable condition is arrived the algorithm oscillates around the peak power point. In order to maintain the power variation small the perturbation size is remain very small. The technique is advanced in such a style that it sets a reference voltage of the module corresponding to the peak voltage of the module. A PI controller then acts to transfer the operating point of the module to that particular voltage level. It is observed some power loss due to this perturbation also the fails to track the maximum power under fast changing atmospheric conditions. But remain this technique is very popular and simple.

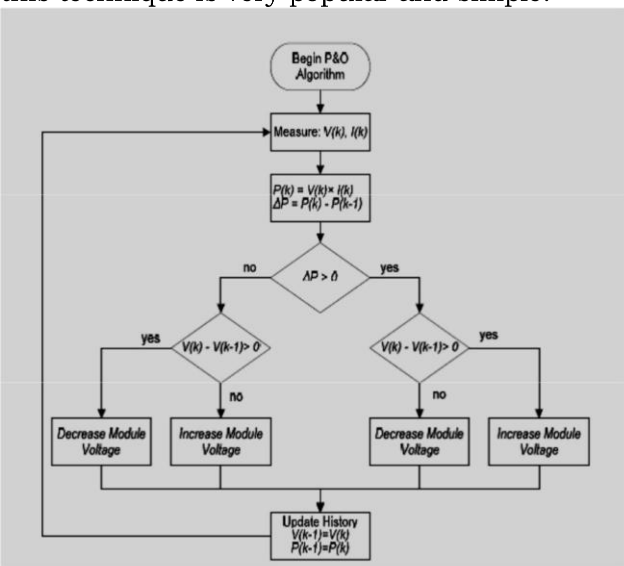

Figure 6 The flow chart of the P&O algorithm

IV. Shunt Active Power Filter with PV System

A Shunt Active Filter (SAPF) 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 shunt APF injects real PV power to a distribution line at PCC and also reduces harmonic in load currents caused by nonlinear loads by injecting compensating current. This filter is connected in shunt 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.

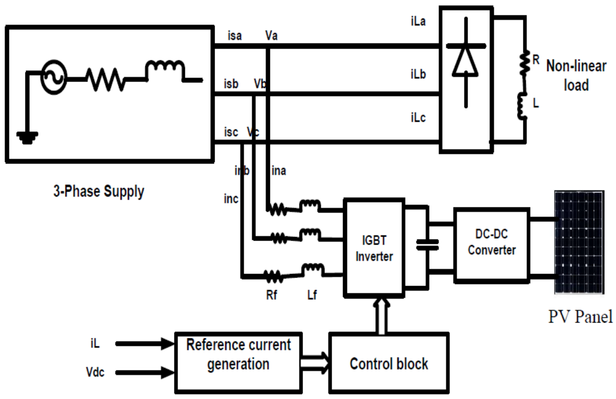

Fig.7 Schematic diagram of a PV system connected to a Shunt APF

A Shunt APF generally consists of the following Blocks:

i) IGBT based voltage source inverter (VSI)
ii) DC energy storage
iii) Active control unit

1 *p–q* theory Based Control

Akagi et al in 1983 [3] 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.

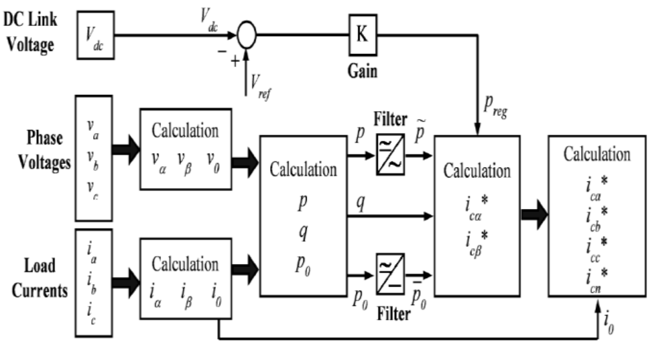

Fig.8 Block diagram of p-q compensation theory

V. Simulation Results

A. Conventional Simulation Circuit

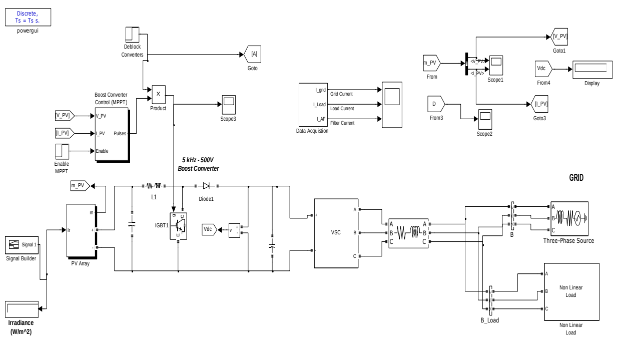

Fig 9 Conventional Simulation Circuit

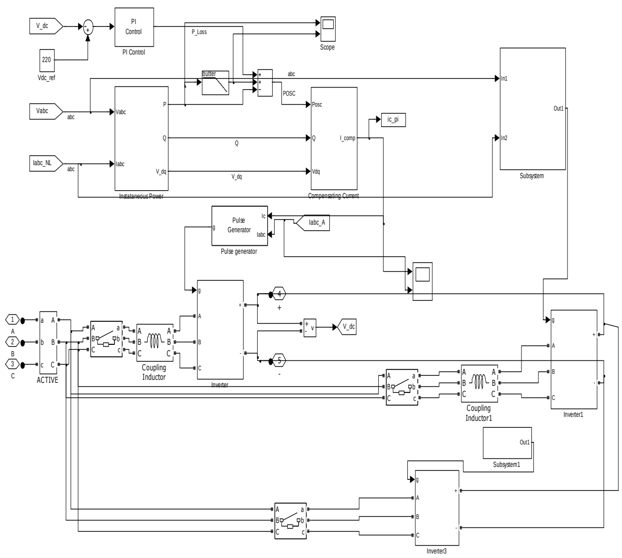

Fig 10 VSC with Filter

(i) Case Study for Balanced and unbalanced load:

To analyze the performance of the proposed system under balanced and unbalanced load conditions, source voltage as well as source current is set as sinusoidal but not in phase. The SAF is required to compensate the reactive power only. At t=0.05 to 0.4, the inverter is switched on. At this instant the inverter starts injecting the compensating current so as to compensate the phase difference between the source voltage and current. The supply current is the sum of load current and injected SAF output current. During the initial period, there is no load deviation in the load. Hence, the programmable three-phase AC voltage source feeds the total active power to the load. Figure 7.3 shows the waveforms of (a) Grid Current, (b) Load Current, (c) Inverter current. The real power generated from PV system is supply to the load required demand.

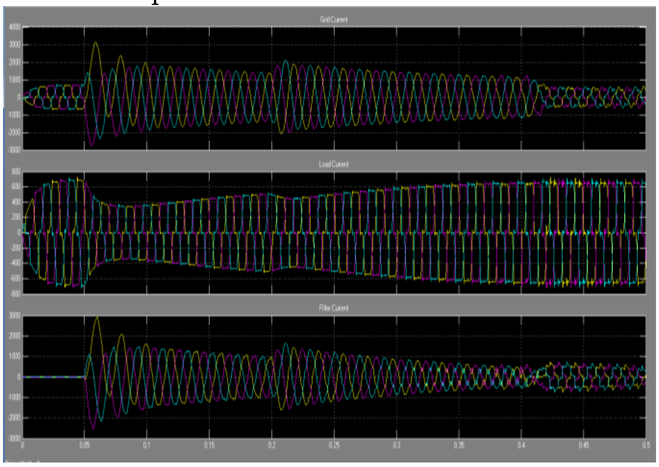

Fig 11 Grid, Load, Filter Current waveforms (Filter on from 0.05 to 0.4)

During the unbalanced load condition, the transient load current changes occur. The Active Power filter is switched on at time between t = 0.05 to 0.4. From figure 11 it is observed that the Grid current is distorted from t= 0 to 0.05. At 0.05 filter is switched on then the current oscillates at 0.05 and it stabilizes at 0.1 and again the grid current gets distorted due to the switch off of filter at 0.4

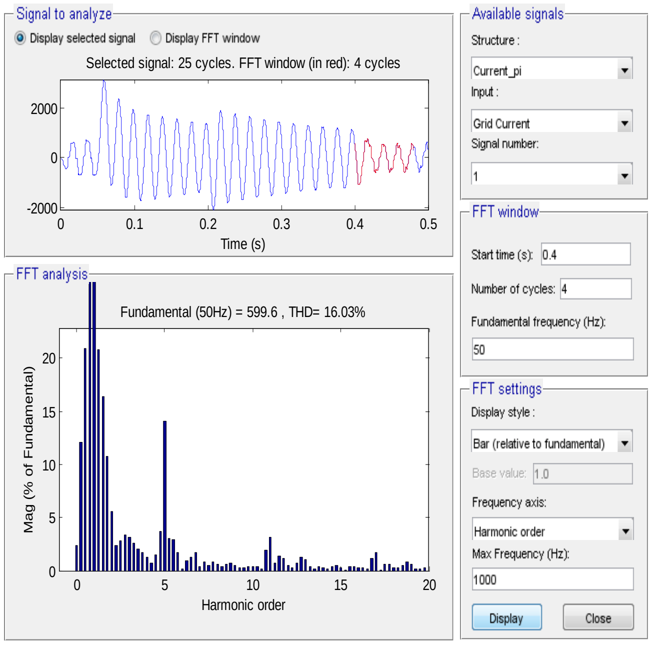

Fig 12 Conventional Circuit THD analysis without filter (16.03%)

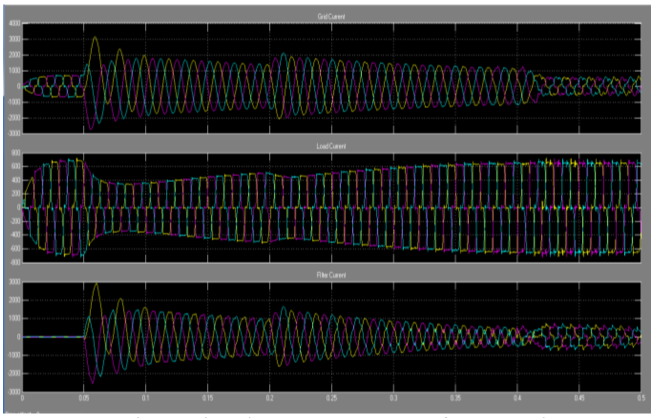

Fig 13 Grid, Load, Filter Current waveforms (Filter on from 0.05 to 0.4)

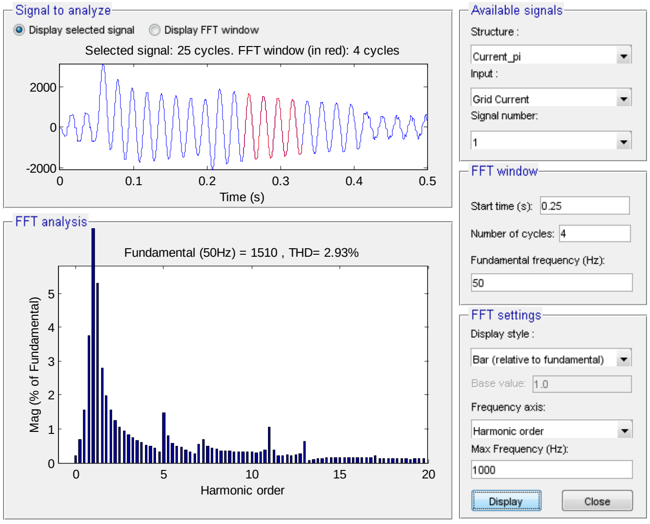

Fig 14 Conventional Circuit THD analysis with filter (2.93%)

The Active Power filter responds to the current transient and injects a reactive power of to restore the reactive power of the load. The results confirm the good dynamic performance of the APF for a rapid change in the load current. The FFT of the grid current before and after compensation is carried out. The current THD is reduced from 16.03% to 2.93% as shown in Fig.14.

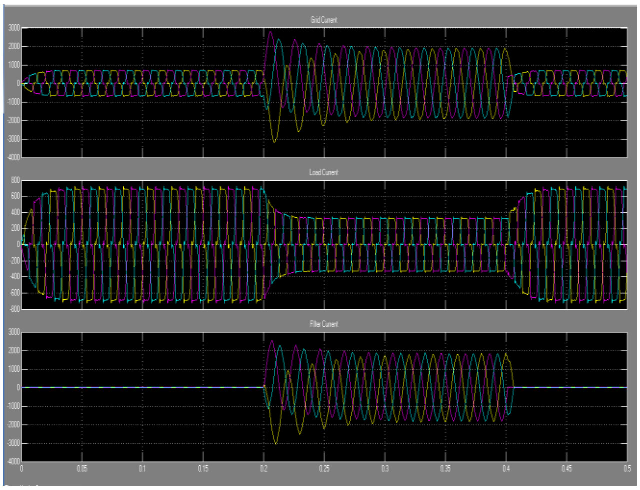

Fig 15 Proposed Method Grid, Load, Filter Current waveforms (Filter on from 0.2 to 0.4)

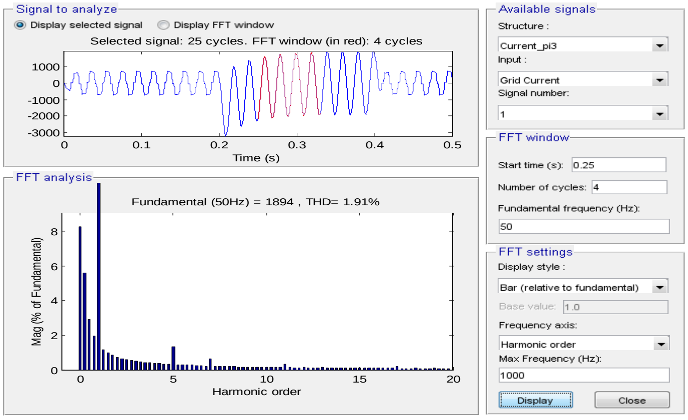

Fig 16 Proposed Circuit THD analysis with filter (1.91%)

It is observed that it shows a good dynamic response of APF when a droop control method is applied to it. The FFT of the grid current with conventional and proposed method is carried out. The current THD is reduced from 2.93% to 1.91% as shown in Fig.16.

Comparison Table

	THD Value
Without Filter THD	16.03
Conventional circuit THD	2.93
Proposed circuit THD	1.91

VI. Conclusion

In this paper the Simulink implementation of grid connected inverter control technique has done by SIMULINK where the inverter control involves the P-Q compensation theory and hysteresis control for generation of gate pulse for the VSI. This inverter control is applied at the PCC to get the sinusoidal load current. The load current before and after inverter control application is done by Simulink and the waveforms shows the effect of inverter control, where the result after inverter control is almost sinusoidal with less harmonic content. For the THD analysis of load current before and after the inverter control technique application, on the SIMULINK page FFT analysis option in the powergui is chosen which results in display of THD percentage of the load current before and after compensation. Hence, it is seen that in case of inverter control technique total harmonic distortion in load current is 13.69% before inverter control and it reduces to 2.86% after inverter control and also grid current is in same phase with grid voltage that is unity power factor(UPF) occurs. So inverter plays a novel role to control the harmonics and reactive power compensation to provide only real power at the PCC of the distribution system. Hence, it can be concluded that by use of Shunt APF the harmonics due to a non-linearity of load is compensated to a large value to provide sinusoidal output current of multiple of fundamental frequency and also reactive power is compensated to provide only real power at the distribution system.

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