Mitigation of Harmonics in Grid Connected Hybrid Renewable Energy Sources at The Distribution Level

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***Abstract*—**Renewable energy resources are the important part of the power systems. These resources reduce the emission of greenhouse gases and also add flexibility by decreasing our dependence on fossil fuels. Renewable energy sources (RES) include solar and wind energies. The present power distribution system contains nonlinear loads that causes power quality issues like harmonics in source current, sag and swell in voltages etc. The main objective of the proposed project is to eliminate source current harmonics and improve THD (Total Harmonic Distortion) in grid connected hybrid renewable energy conversion system. The Voltage Source converter (VSC) will be controlled to perform multiple functions. The VSC can thus be utilized as: 1) power converter to inject power generated from RES to the grid, and 2) shunt APF to compensate current harmonics. All of the above functions may be done either individually or simultaneously. In this project fuzzy logic controller will be implemented to reduce the harmonic content of Hybrid Renewable Energy conversion system (HRECS) integrated on the electric grid. When the hybrid system is integrated to the grid, due to conversion (from DC to AC in solar and AC to DC in wind) and due to change in solar energy intensity, the generated power from the wind is variable due to the variations in wind speed, the electric utility shall experience undesired harmonics, so that will impact the quality of service to the customers connected to the grid. To improve THD in grid connected hybrid system a fuzzy logic controller will be implemented to control VSC.A comprehensive modelling and simulation will be carried out in MATLAB/SIMULINK to verify the proposed analysis.

Keywords*—*Shunt active power filter (SAPF), grid interconnection, distribution system, fuzzy controller, renewable energy.

I. INTRODUCTION

Electric utilities and the users of electric power energy are increasingly day by day. seventy percent of total global energy is distributed by the fossil fuels. but resent days due to increasing global warming and air pollution and sound pollution and cost also one of the reason to move towards alternative resources like renewable energy sources as a future solution for energy. Since the past decade, many other countries interest in renewable energy to generate the power. And one of the common problem is there renewable energy sources are connected to the grid it must consists of one interface unit between them because whenever the renewable energy is connected to the grid is can inject the harmonics that may cause power quality problems [1].

The nonlinear load is connected to grid then the reactive power will be increased so that the power losses also increased in the power system. Because of the nonlinear loads increases current harmonics in transmission lines, transformers, and rotating parts, and harmonics.so to reduce that harmonic currents by using shunt active power filter(SAPF).

This paper introduces a new method in that it consists of shunt active power filter it can simultaneously reduce the problems like current harmonics and current imbalance and power factor and also it can be injecting the power generated by the renewable energy source with low total harmonic distortion(THD).

And also there is no power or energy available from the renewable power source (when no sun and no wind is there) the SAPF (shunt active power filter) can still operate, and also it will increase the power quality of the grid. here a dc-dc converter is used to adjust the output voltage value of the renewable energy sources to the value of voltage in dc side capacitor of SAPF (shunt active power filter). then that available energy is managed by the shunt active power filter controller [2].

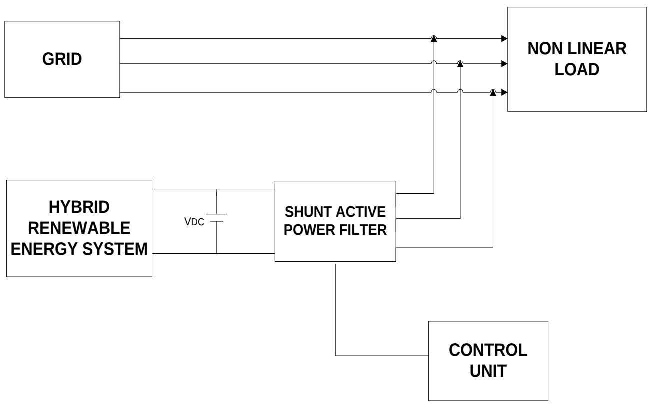


Fig. 1 Block diagram of the system

From the above block diagram shows the grid connected DG interface it consists of DG sources like as a wind, solar (pv).and bipolar VSI (voltage source inverter), nonlinear load.

II. GRID CONNECTED DG SYSTEM

RES (renewable energy sources) that are integrated at the distribution level is named as distributed generation (DG). the voltage source inverters are used to interconnect the renewable energy sources in the distributed system. In this proposed method no need of external hardware device to control the active power flow, the combination of renewable generation units with APF (active power filter) play an important role in management of power quality in future power systems. In this paper, the DG (distributed generation) is interconnected to the grid with the help of shunt active power filter (SAPF).

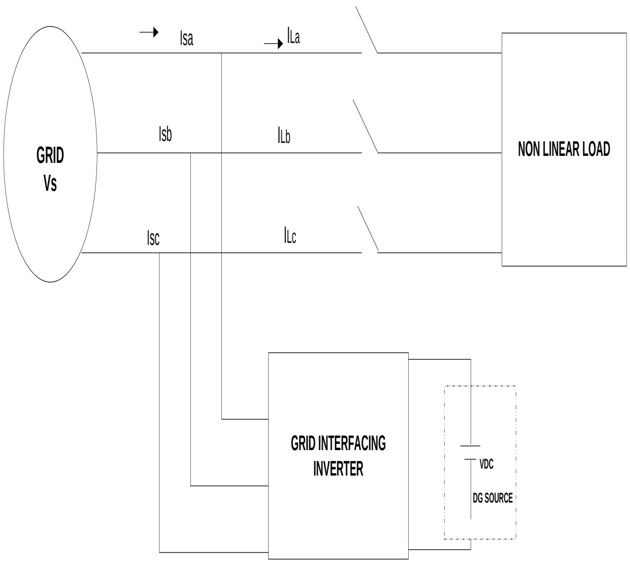


Fig. 2 Grid connected DG interface

The above diagram shows the three-phase grid connected DG (distribution generation) interface Where VS and IS are the grid voltage and current respectively and IL are load current [3].

A. Non-Linear Load

The main nature of the nonlinear loads is to generate the current harmonics that means distortions in current waveforms this distortion also effects the voltage waveforms also that means it leads to distortion of voltage waveforms. Nonlinear load contains ODD harmonics.it can be divided into two types leading loads and lagging loads. If load is nonlinear load the impedance value changes with supply voltage at that time when impedance changing the current drawn by the nonlinear load not be a sinusoidal even it connected to the sinusoidal voltage. This current means non sinusoidal current contains harmonic current and also it creates voltage distortions that affects both loads which is connected to it and equipment of distribution system. Examples of nonlinear loads are like as a computer, TV, Rectifiers, Refrigerators etc.

III. SHUNT ACTIVE POWER FILTER

. In modern years, the power electronic converters are extensively used in industrial and also domestic applications to control the power flow. These power converters take the advantages of improvements of power electronics which affect from the non-sinusoidal current and reactive power from the supply. The SAPF (shunt active power filter) is very popular method for cancelling the harmonics in power system, and the selection of active power filter for a specific application is very difficult and important task for the application engineers and end users. There are various applications such as three-phase and single-phase, three-phase four wire system are required for voltage and current based compensation. The cost and size of the APF (active power filter) depends on reactive power and harmonics to be compensated.

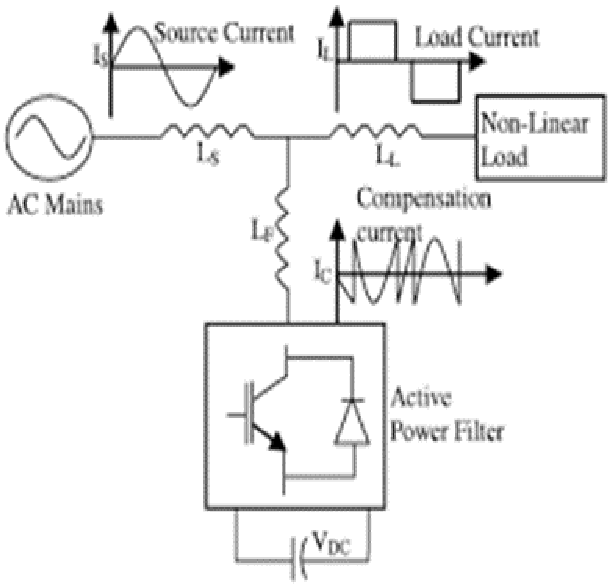


Fig. 3 Shunt active power filter

From the above figure shows the basic principle of SAPF (shunt active power filter).in that we can see shunt active power filter draws the current from the load that current containing opposite harmonics.so the source current remains undistorted and sinusoidal. The two main components in the shunt active power filter is the control unit and power converter [4]. In this paper proposed a control algorithm for shunt active power filter (SAPF) to reduce the harmonics and maintain equal distortion in the compensated current as like present in the voltage.so nonlinear load behaves like linear load and resultant source current have the same waveform like supply voltage.so that harmonics are reduced and reactive power is compensated.

IV. CONTROL METHODOLOGY

The main purpose is the method of control to give correct gate pulse to the VSI (voltage source inverter) to draw the current which containing opposite harmonics. In this proposed shunt active power filter dc link capacitor voltage is sensed and also compared with reference set value. And from the error and rate of error fuzzy controller gives a reference power. That power to be regulated for the shunt active power filter to the reference current generator.by applying instantaneous p-q theory (active and reactive power theory) to the current controller the reference current generator generates a reference current with the help of source voltage and load current. Then the current controller means hysteresis controller compare the reference value with the filter current and give gate pulse to the VSI (voltage source inverter).and the output of the inverter goes through the inductor filter to the line and draw the harmonics from the line. And by this process source current harmonics are reduced and compensate reactive power also and improve the power factor [5].

A. Fuzzy Controller

Fuzzy logic unlike crisp logic or Boolean, this logic deals with the problems that have uncertainty, vagueness or imprecision and also uses membership functions with varying values between zero and one(0&1).it proven that an excellent choice for many applications for control system. The capacitor voltage is compared with the set reference value. The error signal is generated from the fuzzy logic controller(FLC). which is nearly zero steady error in tracking reference current signal. Based on the error in dc link voltage fuzzy set are chosen.in that we have considered 7*7 membership function. Seven membership functions are same for the input and also output. We are using {NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), PB (positive big)} for the flexibility of program. [6][7]in a fuzzy logic controller to control the output variable a rule base is constructed, fuzzy rule is a IF-THEN simple rule with condition and also a conclusion. The rule control table is show below.

TABLE-I

ΔE / E	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

Surface view is given below figure,

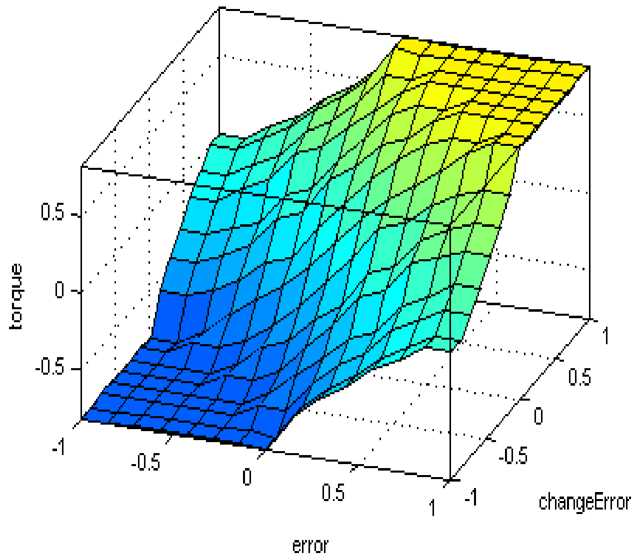


Fig. 4 Surface view of applied fuzzy rules

B. Reference Current Generator

The active power filter performance depends on many factors, but mainly on the selected scheme that is reference generation scheme. If the filter current is same as that reference current, then the filter objective is fulfilled. there are many techniques, but here used instantaneous active and reactive power theory (p-q theory) [8]. There are five steps mainly for generate the reference current. They are Clarke transformation, instantaneous pq calculation and selection of compensating power, reference αβ calculation and finally inverse Clarke transformation. The p-q theory defined by using the "αβ0-transformation", which consists of real matrix and that transforms 3φ voltage and current into αβ0-stationary reference frame voltage and current.

The below equation shows the Clarke transformation voltage for 3 phase 4 wire system.

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

As per our subject it deals with 3 phase 3 wire system so we can eliminate or neglect zero sequence current and voltage.so v0 can be neglected from the above equation and also same equation applied for current also for simplification. the below equations shows that after eliminating the zero sequence current and voltage.

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

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (3)$$

From the above equations (2) and (3) we got the voltage and current in the frame of α-β by using Clarke transformation. And now by using vα and vβ,iα and iβ we have to calculate the instantaneous active and reactive power.

The equation is

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (4)$$

Where p and q are the real and imaginary instantaneous powers respectively. And then reference Iα* and Iβ* can be found from below equation

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad (5)$$

The reference αβ axis currents are calculated then by using inverse transformation of Clarke equation. the reference abc frame current for the active filter can be found. And then the inverse Clarke transformation is

$$\begin{bmatrix} i_\alpha^* \\ i_b^* \\ i_c^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} \quad (6)$$

C. Hysteresis Current Controller

To track the reference current, VSI (voltage source inverter) need proper gate pulse that is given to the current controller

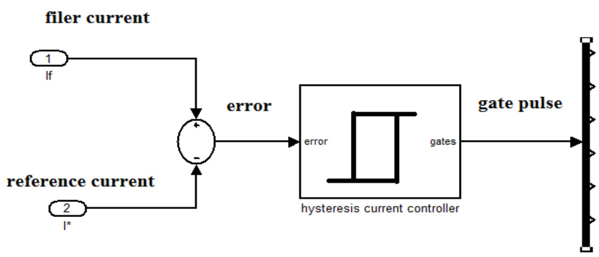


Fig. 3 Hysteresis current controller

Here current controller is used to control the power converter's gate pulse. The main source current is monitored instantaneously, and then it compared to the reference currents that are generated by the proposed algorithm.to get the accurate control, IGBT switching device should be such that the signal means error signal much be approaches to zero, then that provides quick response. The hysteresis current control is very fast response, and good accuracy. And the reference current is compared with the system actual current. If it exceeds the upper limit of the band, the inverter arm upper switch is turned off and the lower is on.as a result the current starts to decay. And the process is vice versa if current crosses lower limit of band as a result current back into the hysteresis band.in this process the actual current is forced to track the reference current with in the hysteresis band [9].

V. SIMULATION RESULTS AND ANALYSIS

To check the working of the proposed SAPF (shunt active power filter) under nonlinear load simulations was studied by using (ACSL)advanced continuous simulation language, and simulation tools.

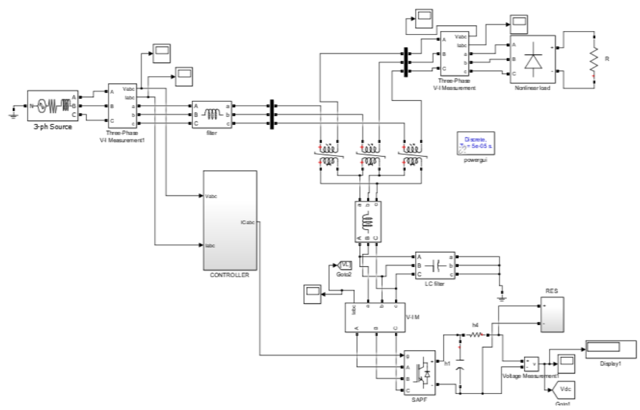


Fig 5 MATLAB simulated schematic diagram of proposed system

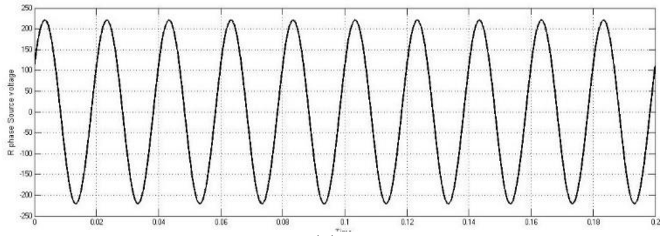
Table 2 shows system parameters under unbalance load

SYSTEM PARAMETERS

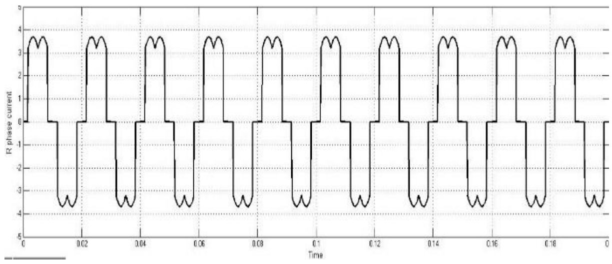
Line-to-line grid RMS voltage	156V
Grid frequency	50HZ
3-phase Nonlinear load	R=60Ω
DC Capacitor	1000µF
DG Voltage	0-220V
DG Resistor	10Ω

Basically we know that linear load is connected to grid the source side voltage and current is sinusoidal at that time we don't need any compensation. But whenever nonlinear load is connected to grid there is changes in source current that means nonsinusoidal so we required some compensation methods to get that source current sinusoidal.

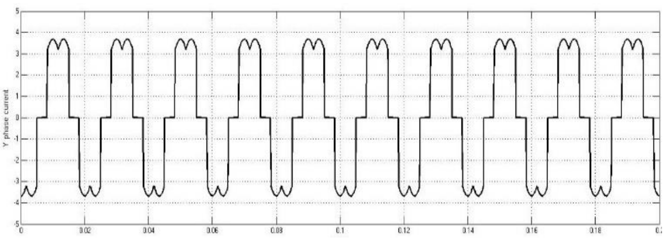
First consider nonlinear load condition without any compensation at the time, the following experimental result will be obtained, that non sinusoidal source current and source voltage is shown in the fig 6,



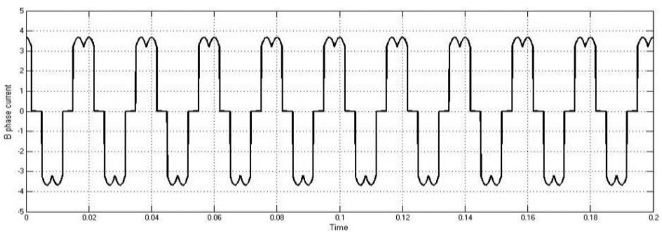
(a)



(b)



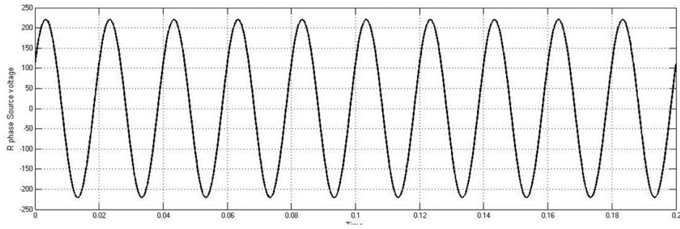
(c)



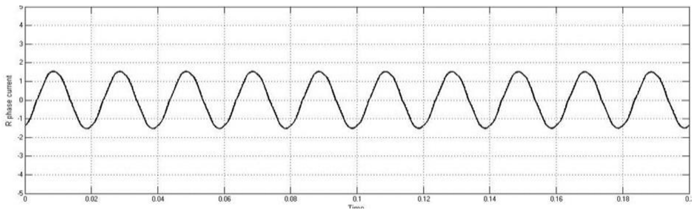
(d)

Fig. 6 when nonlinear load connected to grid
(a). R phase grid voltage, (b). R phase grid current, (c). Y phase grid current, (d). B phase grid current

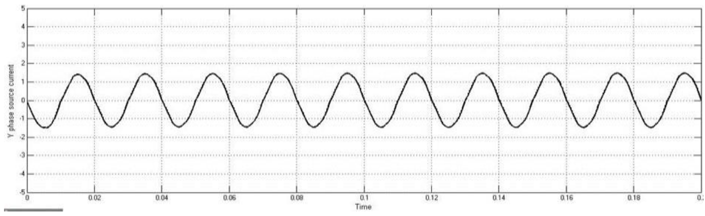
And now consider nonlinear load with SAPF (shunt active power filter) to reduce the source current harmonics. The simulation results from MATLAB we observed from the below fig 7,



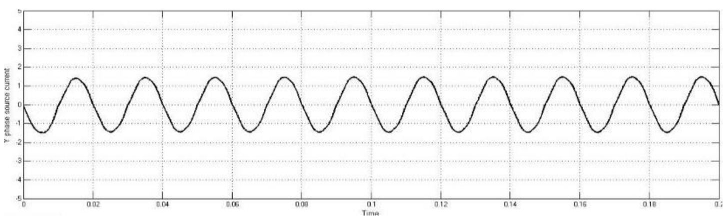
(a)



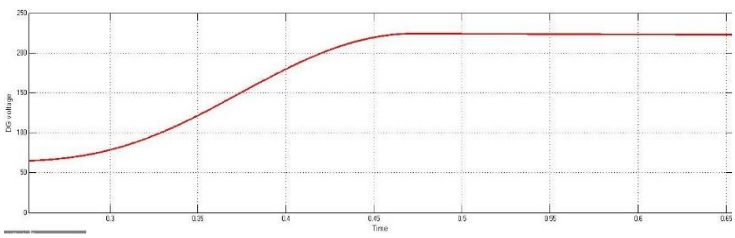
(b)



(c)



(d)



(e)

Fig. 5 SAPF response of nonlinear system
(a). R phase grid voltage, (b). R phase grid current, (c). Y phase grid current, (d). B phase grid current, (e) DC link voltage

That SAPF reduces harmonics in source current and the total harmonic distortion value of current from 30% to 2.44% for nonlinear load condition.

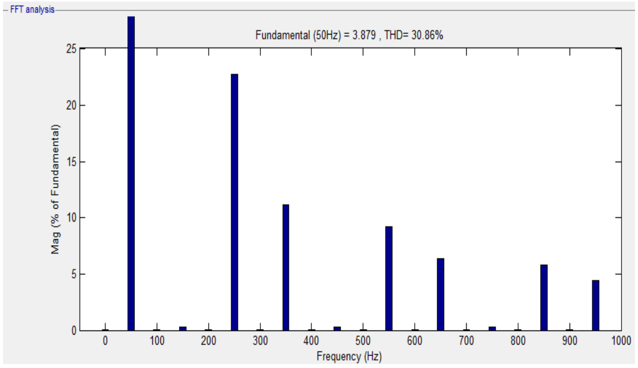


Fig. 6 shows Before compensation with nonlinear load the source current harmonics are high, and THD was 30%.

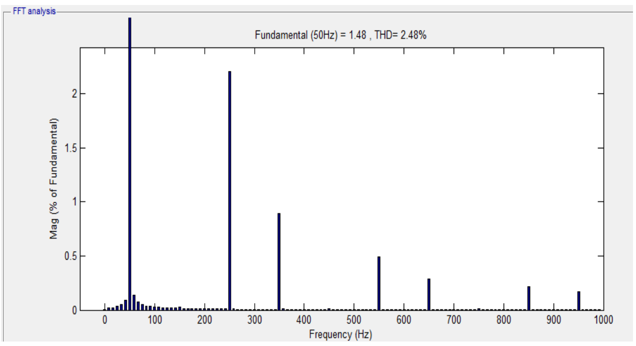


Fig. 7 shows using SAPF the source current harmonics are reduced with low THD that means 2.44%.

VII. Conclusions and Future work

This paper presented a new control of grid interfacing inverter to improve the power quality. And the grid interfacing inverter can be effectively used for power conditioning without affecting real power transfer. The proposed approach can be utilized to;

1) Generated real power from renewable energy system inject to the grid, and

2) Operate as a SAPF (shunt active power filter).

The SAPF (shunt active power filter) has capability of injecting currents that is in sinusoidal with low THD, and also compensate problems like power factor, current harmonics and unbalance. And also this process eliminates the requirement for extra power conditioning equipment for quality power improvement. MATLAB/Simulink simulation results show the results that the grid-interfacing inverter can be used as a multi-function device.

Therefore, the multifunction behavior replaces the requirement of other power electronic compensators to increase the performance of the distribution system.by using these proposed method, grid current into sinusoidal current and in phase with waveforms of grid voltage. The simulation and implementation results shows that SAPF works perfectly and feasibility of the proposed control strategy to fulfill the objectives.

The authors are currently researching for other switching techniques to the inverter of shunt active power filter, to improve the performance of the power by reducing the noise injected in the grid.

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