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Control of Grid Interconnection of Renewable Energy Resources at Distribution Level with Power-Quality Improvement

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***Abstract*— There is growing interest in renewable energy around the world. Since most renewable sources are intermittent in nature, it is a challenging task to integrate renewable energy resources into the power grid infrastructure. Distribution systems provide standby service during utility outages and when operated during peak load hours, potentially reduce energy costs. This paper presents a grid interfacing inverter that compensates power quality problems and it can also interface renewable energy sources with the electric grid. The grid interfacing inverter can effectively be utilized to perform following functions such as transfer of active power harvested from the renewable resources, load reactive power demand support, current harmonic compensation at PCC and current unbalance and neutral current compensation in case of 3-phase 4-wire system. Hysteresis current control method is used to generate gate pulses. Total Harmonic Distortion of the grid connected system is analysed. The grid interface inverter configuration with IGBT is designed and the graphic models of the Grid Interfacing inverter are developed.Total Harmonic Distortion of the grid connected system is analysed and it is reduced using Harmonic Current Extraction Method using SRF theory are done using MATLAB/SIMULINK.**

Index Terms* — *Active power filter(APF),Distributed Generation(DG),ditribution system,grid interconnection,power quality(PQ),point of common coupling(PCC),hysteresis current control,grid interfacing inverter,renewable energy sources(RES).

I. INTRODUCTION

The energy demand for electric power is increasing day by day. End users and electric utilities are concerned about meeting the growing energy demand. Distributed generation(DG) systems are presented as a suitable form to offer high reliable electrical power supply[1].The concept is particularly interesting when different kinds of energy resources are available such as photovoltaic panels, fuel cells, or speed wind turbines [2],[3].Most part of these resources need power electronic interfaces to make up local ac grids [4],[5].This way inverters are connected to an ac common bus with the aim to share properly the disperse loads connected to the local grid. The integration of Renewable Energy Resources at the distribution level is termed as Distributed Generation (DG).In this grid integration, communication systems are crucial technologies, which enable the accommodation of distributed renewable energy generation and plays an extremely important role in monitoring, operating, and protecting both renewable energy generators and power systems. Maximum amount of energy demand is supplied by the non-renewable sources, but increasing air pollution, global warming concerns, diminishing fossil fuels and their increasing cost have made it look towards renewable energy sources. Among Renewable sources, wind energy generation has been noted as the most rapidly growing technology; being one of the most cost-effective and environmental friendly mean to generate electricity from renewable sources. High penetration of RES causes issues in stability, voltage regulation and power quality of the system. Because of the application of sophisticated and more advanced software and hardware for the control systems the power quality has become one of the most important issues for power electronic engineers. RES is connected to the grid through grid interfacing inverter for power quality improvement. With great advancement in all areas of engineering, particularly, in signal processing, control systems, and power electronics, the load characteristics have changed completely. In addition to this, loads are becoming very sensitive to voltage supplied to them. The loads based on power electronic device generally pollute the nearby network by drawing non-sinusoidal currents from the source. The rapid switching of electronic devices creates additional problems. This makes voltages and currents at point of common coupling (PCC) highly distorted.

Most suitable energy sources supply energy in the form of electrical power Distributed Generation (DG) systems are often connected to the utility grid through power electronic converters. A grid-connected inverter provides the necessary interface of the DG to the phase, frequency and amplitude of the grid voltage, and disconnects the system from the grid when islanding. Such a DG system can be designed to operate in both stand-alone and grid-connected modes flexibly according to grid conditions [1], [2]. When the utility grid is not available or the utility power is accidentally lost, the DG is used as an on-site power or standby emergency power service, effectively being an extended uninterruptible power supply (UPS) that is capable of providing long-term energy supply.

A control strategy for renewable interfacing inverter based on theory is proposed [19]-[21]. In this strategy, both load and inverter current sensing is required to compensate the load current harmonics. The non-linear load current harmonics may result in voltage harmonics and can create a serious PQ problem C_Y in the power system network [6].Active Power Filter (APF) is extensively used to compensate the load current harmonics and load unbalance at distribution level [14]-[16]. This results in an additional hardware cost. Another solution is to incorporate the feature of APF in the conventional inverter interfacing renewable with the grid, without any additional hardware costs. Here, the main idea is the maximum utilization of inverter rating which is most of the time underutilized due to intermittent nature of RES [7]. The grid-interfacing inverter can effectively be utilized to perform functions as transfer of active power harvested from the renewable resources, load reactive power demand support, current harmonics compensation at PCC, current unbalance and neutral current compensation in case of 3-phase 4-wire system. Moreover, with adequate control of grid- interfacing inverter, all the four objectives can be accomplished either individually or simultaneously. The PQ constraints at the PCC can therefore be strictly maintained within the utility standards without hardware cost.

II. SYSTEM DESCRIPTION

In this paper, it is shown that using an adequate control strategy, with a four-leg four wire grid interfacing inverter, it is possible to mitigate disturbances like voltage unbalance. RES is connected to the DC-link of a grid-interfacing inverter as shown in Fig. 1 and its overall representation in Fig.2. RES may be a DC source or an AC source with rectifier coupled to dc-link. In this paper wind energy is used as a RES, the variable speed wind turbine generate power at variable ac voltage [22]-[24]. Thus the power generated from these renewable sources need to convert in dc before connecting on dc link [9]-[11].The performance of the proposed control approach is validated with the help of system parameters as given in Table1.

A. Topology

Active Power Filters are power electronic devices that cancel out unwanted harmonic currents by injecting a compensation current which cancels harmonics in the line current [11]-[13].Shunt active power filters compensate load current harmonics by injecting equal but opposite harmonic compensating current. Generally, three-wire APFs have been conceived using three leg converters. In this paper, it is shown that using an adequate control strategy, even with a three phase three-wire system. The topology of the investigated APF and its interconnection with the grid consists of a three phase four wire voltage source inverter. In this type of applications, the VSI operates as a current controlled voltage source. A voltage source inverter is a power electronic device that connected in shunt or parallel to the system. It can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. It also converts the DC voltage across storage device into a set of three phase AC output voltages. It is also capable to generate or absorbs reactive power [25]. If the output voltage of the VSC is greater than AC bus terminal voltage, is said to be in capacitive mode. So, it will compensate the reactive power through AC system. The type of power switch used is an IGBT in anti-parallel with a diode.

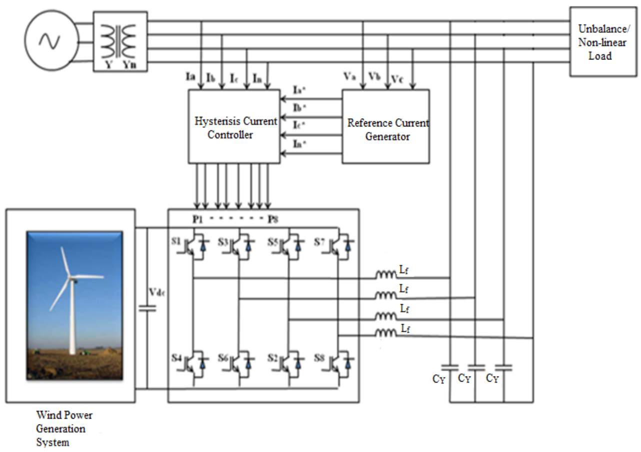

Fig.1. Basic system configuration

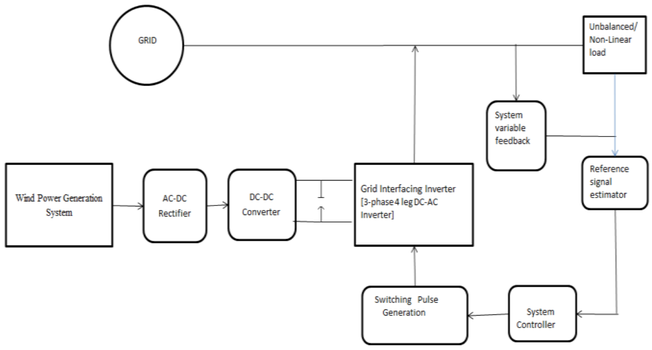

Fig.2. Block Diagram Representation of Overall System

B. Control Strategy

The controller requires [8] the three-phase grid currents (I_a,I_b,I_c), the three-phase voltage at the PCC (V_a,V_b,V_c) and the DC-link voltage (V_{dc}).As shown in Fig.3, the sinusoidal waveform and the phase of the grid current reference (I_a^*,I_b^* ,I_c^*) comes from the line voltage.

$$U_a = \sin(\theta) \quad (1)$$
$$U_b = \sin(\theta - 2\pi/3) \quad (2)$$
$$U_c = \sin(\theta + 2\pi/3) \quad (3)$$

The magnitude I_m of the same current is obtained by passing the error signal between the DC-link voltage (V_{dc}) and a reference voltage (V_{dc}^*) through a PI controller. Using this magnitude and phase displacement of 120 and 240 respectively, the reference three-phase grid currents I_a^*,I_b^*,I_c^*can be expressed as:

$$I_a^* = I_m \sin(\theta) \quad (4)$$
$$I_b^* = I_m \sin(\theta - 2\pi/3) \quad (5)$$
$$I_c^* = I_m \sin(\theta + 2\pi/3) \quad (6)$$

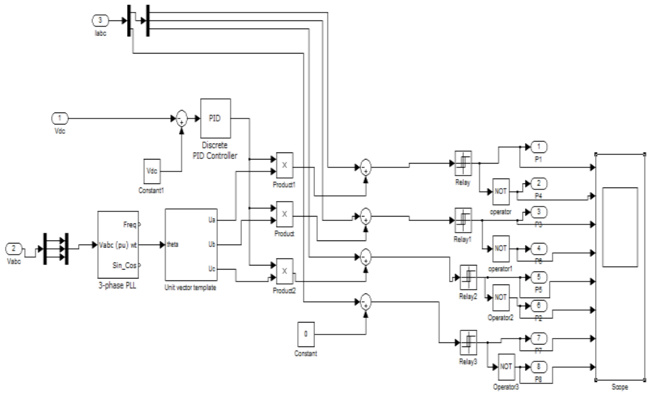

Fig.3.Control technique of grid interfacing inverter

a. PI Controller

The controller used is the discrete PI controller that takes in the reference voltage and the actual voltage and gives the maximum value of the reference current depending on the error in the reference and the actual values. The difference of this filtered dc-link voltage and reference dc-link voltage (V_{dc}^*) is given to a discrete-PI regulator to maintain a constant dc-link voltage under varying generation and load conditions. The mathematical equations for the discrete PI controller are shown below.
The voltage error $V_{dcerr(n)}$ at the nth sampling instant is given as:

$$V_{dcerr(n)}= V_{dc}^*{}_{(n)} – V_{dc(n)} \qquad (7)$$

The output of discrete-PI regulator at the nth sampling instant is expressed as:

$$I_{m(n)} =I_{m(n-1)} +K_{PVdc}(V_{dcerr(n)}-V_{dcerr(n-1)}) + K_{IVdc}V_{dcerr(n)} \qquad (8)$$

where K_{PVdc}=0.5 and K_{IVdc}=1 are proportional and integral gains of dc-voltage regulator.

b. Hysteresis Based Current Controller

The hysteresis control, limit bands are set on either side of a signal representing the desired output waveforms. The inverter switches are operated as the generated signals within limits. Hysteresis band PWM is basically an instantaneous feedback control method of PWM where the actual signal continually tracks the command signal within a hysteresis band. In this controller compares the measured and reference compensating and gives gate signals to inverter [17], [18].

III. SIMULATION RESULTS

In order to verify the proposed control approach to achieve multi-objectives for grid interfaced DG systems connected to a three-phase four-wire network, an extensive simulation study is carried out using MATLAB/SIMULINK. The Simulink design of distribution system and wind energy system are shown in Fig.4 and Fig.5. A four-leg current controlled voltage source inverter is actively controlled to achieve balanced sinusoidal grid currents at unity power factor (UPF) despite of highly unbalanced nonlinear load at PCC under varying renewable generating conditions. A Renewable energy source with variable output power is connected on the dc-link of grid-interfacing inverter. An unbalanced three-phase four-wire nonlinear load, whose unbalance, harmonics, and reactive power need to be compensated, is connected on PCC. The waveforms of grid voltage (V_a,V_b,V_c), grid currents (I_a,I_b,I_c,) and neutral current before compensation in Fig.6 and waveforms of grid voltage, grid current and neutral current after compensation in Fig.7.The output of wind turbine and DC regulator are shown in Fig.8 and Fig.9. Corresponding Switching pulses in Fig.10. Output of Inverter Voltage is shown in Fig.11. Positive values of grid active-reactive powers and inverter active-reactive powers imply that these powers flow from grid side toward PCC and from inverter towards PCC, respectively. The active and reactive powers absorbed by the load are denoted by positive signs. Total Harmonic Distortion (THD) of grid currents for 60 cycles using hysteresis current controller is shown in Fig.12.

TABLE.1
SYSTEM PARAMETERS

3-phase supply (r.m.s)	V= 400 V; 50 Hz
3-phase non-linear load	R=26.66Ω; L=10mH
1-phase linear load(A_N)	R=36.66Ω; L=10mH
1-phase nonlinear load (C-N)	R=26.66Ω; L=10 mH
Dc link capacitance & voltage	Cdc= 3000 µ F; Vdc=300v
Coupling inductance	Lsh=20mH

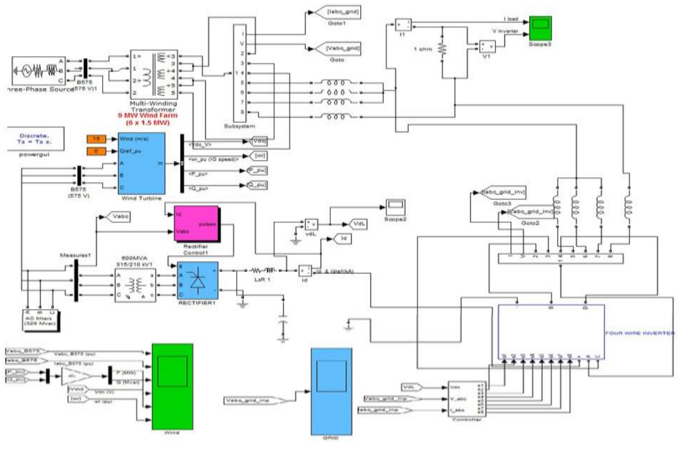

Fig.4. Simulink model of the distribution system

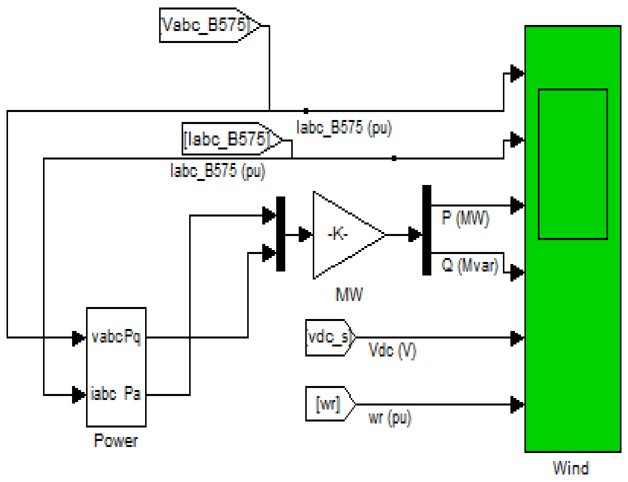

Fig.5. Simulink model of the wind energy system

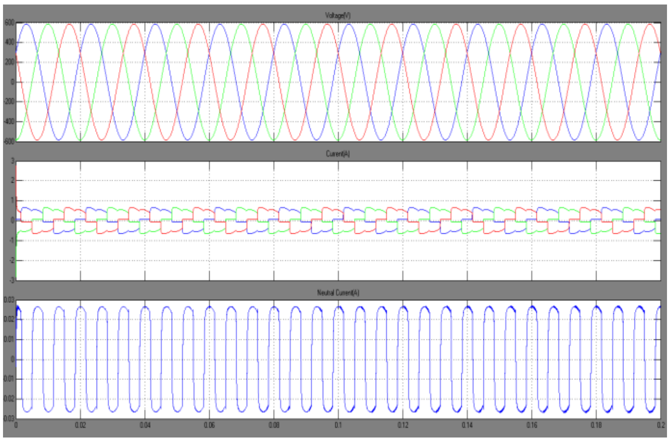

Fig.6. Waveforms of grid voltage, grid current and neutral current (before compensation)

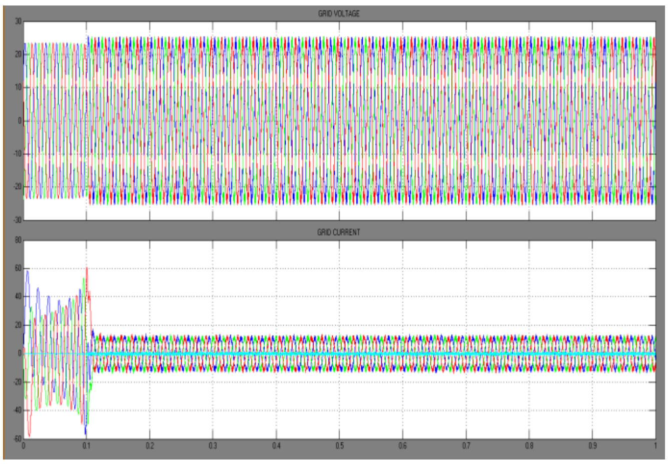

Fig.7. Waveforms of grid voltage, grid current and neutral current (In=0) (after compensation)

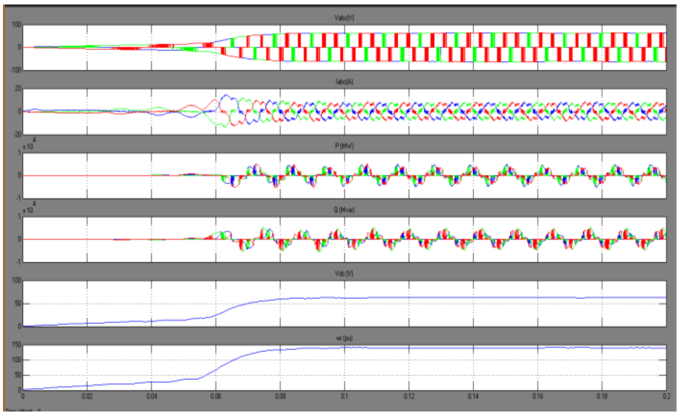

Fig.8. Output of Wind Turbine

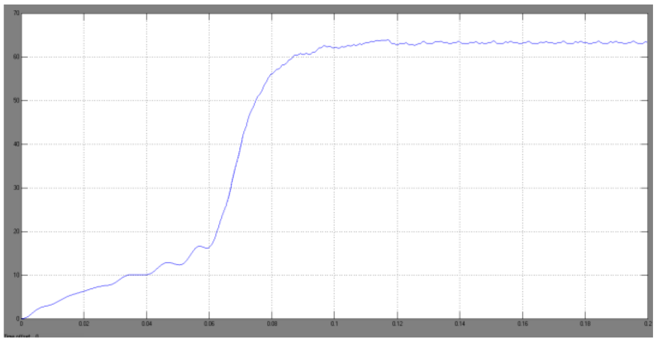

Fig.9. Output of DC Regulator

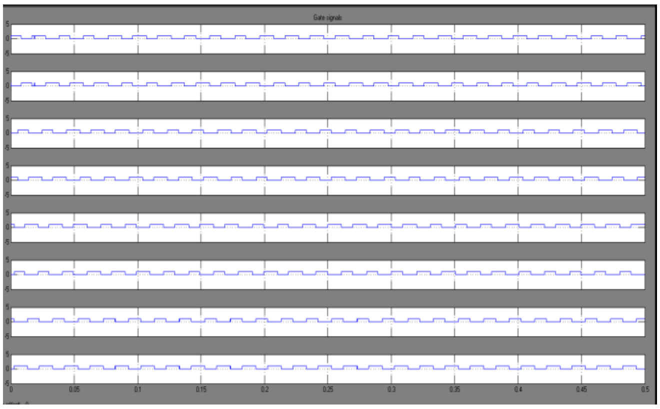

Fig.10. Gating signals to inverter

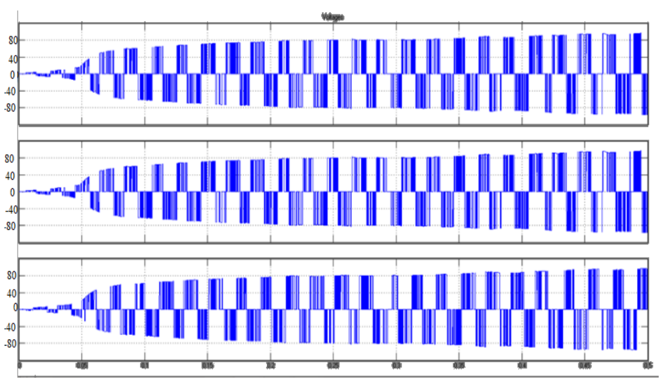

Fig.11. Waveform of Inverter Voltage

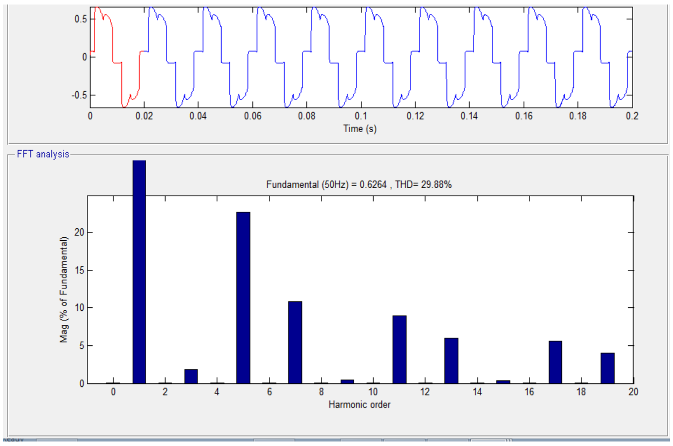

Fig.12. FFT analysis without compensation

IV. HARMONIC CURRENT EXTRACTION

This section explains the control strategy implemented for the proper operation of the grid-interfacing inverter. The control scheme is modelled such that it continuously monitors the actual system conditions and is compared with that of the reference conditions. Thus it generates the switching pulses for the grid-interfacing inverter by controlling the system parameters according to the requirements for the normal operation of the system. By using the control scheme, the existing grid-interfacing inverter is aimed to operate as a shunt active power filter also.

The control loop starts from the output of the ac-dc rectifier. The various parts of the control scheme implemented consist of a dc-link voltage control, extraction of unit vector templates, harmonic current extraction, reference current generation and hysteresis current controller which are explained in the subsequent sections. A simplified block diagram of the overall control system is shown in the Fig.13.

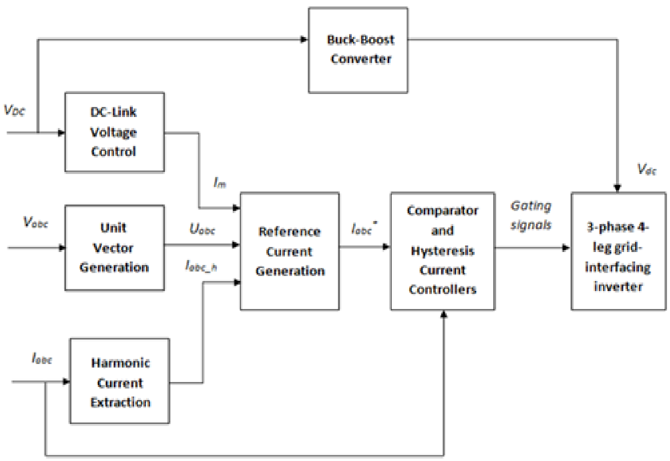

Fig.13. Block of overall control strategy

The existence of non-linear loads injects harmonic currents into the distribution lines. Active power filters are used for mitigating the harmonic components. The existing grid-interfacing inverter is used as the shunt active power filter. The working of active filter is based on the principle of injecting the harmonic currents with 180^0 phase shift. Hence it requires a suitable controller for the extraction of current harmonics. Here a technique called Synchronous Reference Frame (SRF) theory is used for extracting the harmonics present in the grid currents. This technique has been widely used for most of the recent APFs. The basic SRF method uses the direct and inverse Park's transformation method, which allows the evaluation of the harmonic components of the input signal. The block diagram representation of the SRF theory for harmonic current extraction is shown in Fig.14.

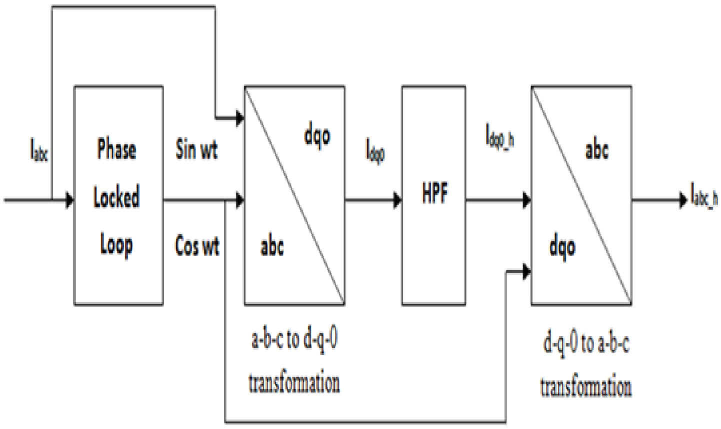

Fig.14. Harmonic Extraction Block

The three phase grid currents are sensed and are passed through a PLL to obtain the grid current frequency, *wt* (rad/sec). For current harmonic compensation, the distorted grid currents in the a-b-c frame are transferred into two phase rotating reference frame using Park's transformation method, i.e., the a-b-c frame is transferred into d-q-0 frame and I_d, I_q, I_0 are the corresponding currents. The d-axis current *Id* is the positive sequence current which is in phase with the voltage, q-axis current I_q is the negative sequence current which is orthogonal to I_d and I_0 is the zero sequence current. The transformation is done using the cosine and sine functions of the fundamental frequency obtained from the PLL. It helps to maintain the synchronization with the supply voltage. These currents are then passed through a high pass filter (HPF) inorder to separate the harmonics and fundamental frequency components easily. The edge band frequency of the HPF is selected as 50 Hz to eliminate the higher order harmonics. Then these two axis components are transformed back into the three phase components using inverse Park's transformation method. They represent the harmonic components extracted from the actual grid currents. FFT analysis with compensation is shown in Fig.15.

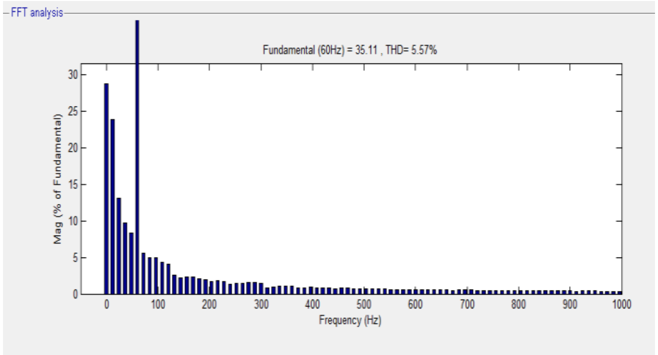

Fig.15. FFT analysis with compensation

V.CONCLUSION

A 3-phase 4-wire renewable energy system with grid interfacing inverter to improve the quality of power at PCC is modelled. Hysteresis current control method is used to generate gate pulses. The inverter is controlled to perform as a multi-function device by incorporating active power filter functionality. The Voltage, Current and Power flow waveforms are obtained. Reactive power demand of the grid is compensated and current harmonics are reduced. It has been found that the total harmonic distortion of grid and load current are reduced and setting of the system is improved. Hence, hysteresis current controller has fast response, high accuracy of tracking the DC-voltage reference, and strong robustness to load sudden variations. Total Harmonic Distortion of the grid connected system is analysed and it is reduced using Harmonic Current Extraction Method from 29.88% to 5.57% using SRF theory are done using MATLAB/SIMULINK.

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