HYBRID INTELLIGENCE CONTROLLER WITH POWER QUALITY FEATURES FOR GRID INTERCONNECTION OF RENEWABLE ENERGY SOURCES

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Abstract— The increased power demand, the depletion of the fossil fuel resources and the growth of the environmental pollution has led the world to think seriously of other alternative sources of energy. So renewable energy resources (RES) are being connected to the distribution systems, mostly done by using power electronic converters. A new control strategy for achieving maximum advantage from these grid-interfacing inverters which are when installed in 3-phase 4-wire distribution systems is given in this paper. With the inverter control, the inverter can be used as a multi-function device, which includes the function of: 1) power converter to inject power generated from RES to the grid, and 2) shunt APF to compensate current unbalance, load current harmonics, load reactive power demand and load neutral current. These functions of the inverter can be done either individually or simultaneously. The proposed inverter with the control when connected, helps the 3-phase 4-wire linear/non-linear, unbalanced load at point of common coupling appears as balanced linear load to the grid. In this control strategy fuzzy based hybrid system is used for performance improvement with MATLAB/Simulink simulation studies, the proposed control technique is demonstrated and evaluated here.

Key Words - Distributed generation (DG), Distribution system, Grid interconnection, Point of common coupling (PCC), power quality (PQ), renewable energy.

I. INTRODUCTION

Electrical power is the most widely used source of energy for our household’s equipment’s, industries and work places. Populationand industrial growth have led to significant increases in power consumption over the past decades. Natural resources likepetroleum, coal and gas that have driven our industries, power plants and vehicles for many decades are becoming depleted at avery fast rate. This is an important issue, which has motivated nations across the world to think about alternative forms of energywhich utilize inexhaustible natural resources. The combustion of conventional fossil fuel across the globe has causedincreased level of environmental pollution .Several international conventions and forums have been set up to address and resolvethe issue of climate change. These forums have motivated countries to form national energy policies dedicated to pollution control,energy-conservation, energy-efficiency, development of alternative and clean sources of energy. Renewable energy like solar,wind, and tidal currents of oceans is sustainable, inexhaustible and environmentally friendly clean energy. Due to all these factors,wind power generation has attracted great interest in recent years. Undoubtedly, wind power is today's most rapidly growingrenewable energy source.

Distributed generation (DG) is termed as the integration of Renewable energy source (RES) at the distribution level. The numberof distributed generation (DG) units, including both renewable and non -renewable sources, for small rural communities notconnected to the grid and for small power resources connected to the utility network has grown in the last years. The integration ofrenewable energy systems (RESs) in smart grids (SGs) is a challenging task, mainly due to the intermittent and unpredictablenature of the sources, typically wind or sun. So for the reliable operation of the system, continuous control is needed. This can beobtained by the help of digital control and power electronic devices which may improve the power quality of the system at thePCC. The quality of power in the system is mainly affected by the harmonic current produced by the non-linear loads and power electronic based instruments [1, 2].

In the distributed system, the intermittent RES is connected using current controlled voltage source inverters. New control strategies for grid connected inverters with PQ solution have been proposed. In [3] the inverter operates as active inductor at a certain frequency to absorb the harmonic current. The control performance may be decreased because of the complexity in exactcalculation of network impedance in real time. In [4] a cooperative control of multiple active filters based on voltage detection forharmonic damping throughout a power distribution system is proposed. In [5], a control strategy for renewable interfacing inverter based on p-q theory is proposed. This strategy includes both load and inverter current sensing which is required to compensate the load current harmonics. Voltage harmonics which is caused by non-linear load current harmonics can create serious PQ problem in the power system network. To compensate this, Active power filters (APF) are extensively used which may result in additional hardware cost. This papersuggests the inclusion of APF in the conventional inverter interfacing renewableresource's with the grid.

In this paper the grid-interfacing inverter can effectively be utilized to perform the following four important functions: 1) transfer of active power harvested from the renewable resources (solar &wind); 2) load reactive power demand support; 3) current harmonics compensation at PCC; and 4) current unbalance and neutral current compensation in case of 3-phase 4-wire system. All the four objectives can be accomplished either individually or simultaneously with adequate control of grid-interfacing inverter. So without additional hardware cost the PQ constraints at the PCC can therefore be strictly maintained within the utility standards.

II. NETWORK AND CONVERTER DESCRIPTION

The converter considered here consists of a two-level VSC,a dc energy storage device, controller and a coupling transformer connected in shunt to the distribution network.Fig. 1 shows the schematic diagram ofconverter.

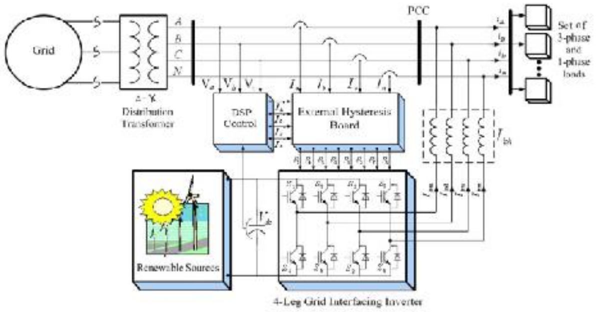


Fig.1 Schematic diagram of a proposed converter with RES

A. DC-Link Voltage and Power Control Operation

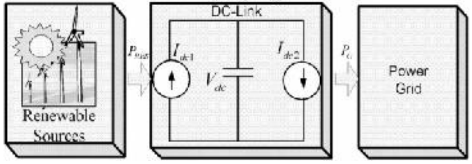


Fig.2 DC-link equivalent diagram

Due to the intermittent nature of RES, the generated power is of variable nature. The dc-link plays an important role in transferring this variable power from renewable energy source to the grid. RES are represented as current sources connected to the dc-link of a grid-interfacing inverter. Fig2.shows the systematic representation of power transfer from the renewable energy resources to the grid via the dc link. The dc-capacitor decoupled the RES from grid and allows the independent control of inverter on either side of dc link. P1 to P8 are the switching signals of inverter where P7 and P8 are multiplied with constant zero to compensate the neutral current.

B. Control of Grid Interfacing Inverter

The control diagram of grid- interfacing inverter for a 3-phase 4-wire system is shown in Fig. 3. To compensate the neutral current of load, a fourth leg is provided to the inverter. The proposed approach is mainly concerned about the regulation of power at PCC during three conditions like, when 1) PRES = 0; 2) PRES < total power (PL); and 3) PRES > PL. During the power management operation, the inverter is controlled in such a way that it always draws/ supplies fundamental active power from/ to the grid. If the load connected to the PCC is non-linear or unbalanced or the combination of both, the given control approach also compensates the harmonics, unbalance, and neutral current. By the control, duty ratio of inverter switches are varied in a power cycle in order to get the combination of load and inverter injected power to be appearing as balanced resistive load to the grid

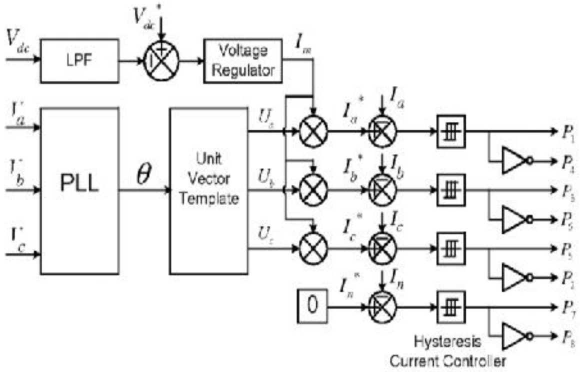


Fig.3 Block diagram representation of grid-interfacing inverter control.

The exchange of active power in between renewable source and grid can be obtained from the regulation of dc-link voltage. Thus the output of dc-link voltage regulator results in an active current (I_m). The multiplication of this active current component (I_m) with unity grid voltage vector templates (U_a,U_b, and U_c) generates the reference grid currents (Ia*,Ib* , and Ic*) for the control process. The reference grid neutral current (In*) is set to zero, being the instantaneous sum of balanced grid currents. Phase locked loop (PLL) is used to generate unity vector template from which the grid synchronizing angle (0) is obtained.

$$U_A = \sin\boldsymbol{\theta} \qquad (1)$$

$$U_A = \sin(\boldsymbol{\theta} - \tfrac{2\pi}{3}) \qquad (2)$$

$$U_A = \sin(\boldsymbol{\theta} + \tfrac{2\pi}{3}) \qquad (3)$$

The actual dc-link voltage (VDC) is sensed and passed through a first-order low pass filter (LPF) to eliminate the presence of switching ripples on the dc link voltage and in the generated reference current signals. The difference of this filtered dc-link voltage and reference dc-link voltage (VDC*) is given to a discrete-PI regulator to maintain a constant dc-link voltage under varying generation and load conditions.

The dc-link voltage error VDCerr(N) at nth sampling instant is given as:

$$V_{DCerr(N)} = V_{DC(N)}^{\ *} - V_{DC(N)} \qquad (4)$$

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

$$I_{m(N)} = I_{m(N-1)} + K_{PVdc}\left(V_{DC(N)} - V_{DC(N-1)}\right) + K_{IVdc}\, V_{DCerr(N)} \qquad (5)$$

Where K_{PVdc} and K_{IVdc} are proportional and integral gains of dc-voltage regulator. The instantaneous values of reference three phase grid currents are computed as

$$I_A^{\ *} = I_m \,.\, U_A \qquad (6)$$

$$I_B^{\ *} = I_m \,.\, U_B \qquad (7)$$

$$I_C^{\ *} = I_m \,.\, U_C \qquad (8)$$

The neutral current, present if any, due to the loads connected to the neutral conductor should be compensated by forth leg of grid-interfacing inverter and thus should not be drawn from the grid. In other words, the reference current for the grid neutral current is considered as zero and can be expressed as:

$$I_N^{\ *} = 0 \qquad (8)$$

The reference grid currents (I_A*, I_B*, I_C* and I_N) are compared with actual grid currents (I_A, I_B, I_C and I_N) to compute the current errors as:

$$I_{Aerr} = I_A^{\ *} - I_A \qquad (9)$$

$$I_{Berr} = I_B^{\ *} - I_B \qquad (10)$$

$$I_{Cerr} = I_C^{\ *} - I_C \qquad (11)$$

$$I_{Nerr} = I_N^{\ *} - I_N \qquad (12)$$

These current errors are given to hysteresis current controller. The hysteresis controller then generates the switching pulses (P1, P2, P3, P4, P5, P6, P7, and P8) for the gate drives of grid-interfacing inverter.

The switching pattern of each IGBT inside inverter can be formulated on the basis of error between actual and reference current of inverter, which can be explained as:

If I_{InvA}< (I_{InvA}*- hB), then upper switch will be OFF (P1=0) and lower switch S4 will be ON (P4=1) in the phase “A” leg of inverter.

If I_{InvA}> (I_{InvA}*- hB), then upper switch will be ON (P1=1) and lower switch S4 will be OFF (P4=0) in the phase “a” leg of inverter.

Where h_b is the width of hysteresis band. Similarly switching pulses are derived for other three legs.

III. ADDING INTELLIGENCE TO CONVERTER

A new language was developed to describe the fuzzy properties of reality, which are very difficult and sometimes even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to converter system. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior of converter and performance of proposed controllers. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has potential ability to improve the robustness of converters. The basic scheme of a fuzzy logic controller is shown in Fig 5. which consists of four principal components such as: a fuzzyfication interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action.

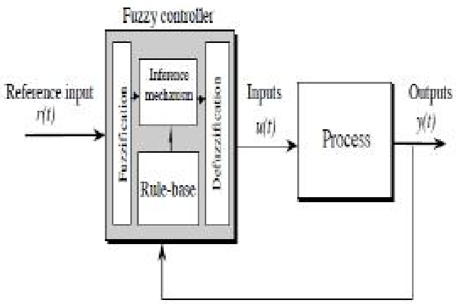


Fig.4.General Structure of the fuzzy logic controller on closed-loop system

The fuzzy control systems are based on expert knowledge that converts the human linguistic concepts into an automatic control strategy without any complicated mathematical model [10]. Simulation is performed in buck converter to verify the proposed fuzzy logic controllers.

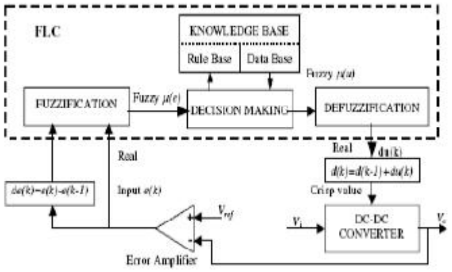


Fig.5. Block diagram of the Fuzzy Logic Controller (FLC) for converters

Fuzzy Logic Membership Functions:

The converter is a nonlinear function of the duty cycle because of the small signal model and its control method was applied to the control of converters. Fuzzy controllers do not require an exact mathematical model. Instead, they are designed based on general knowledge of the plant. Fuzzy controllers are designed to adapt to varying operating points. Fuzzy Logic Controller is designed to control the output of converter using Mamdani style fuzzy inference system. Two input variables, error (e) and change of error (de) are used in this fuzzy logic system. The single output variable (u) is duty cycle of PWM output.

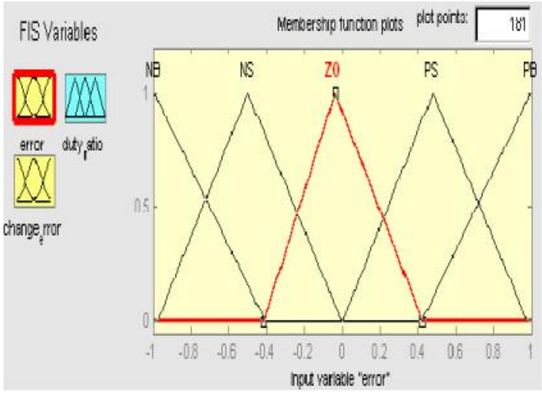


Fig. 6.The Membership Function plots of error

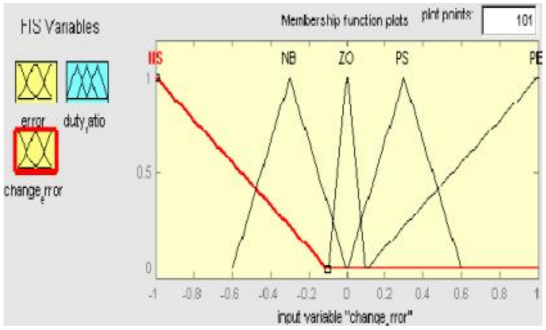


Fig.7.The Membership Function plots of change error

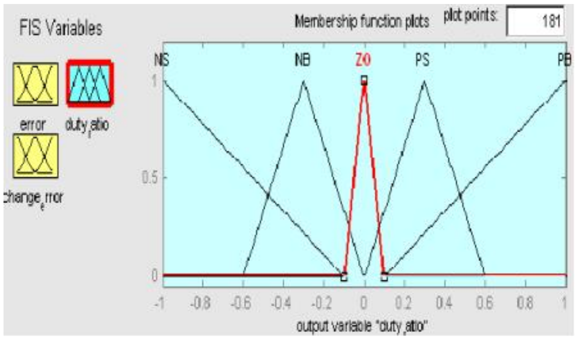
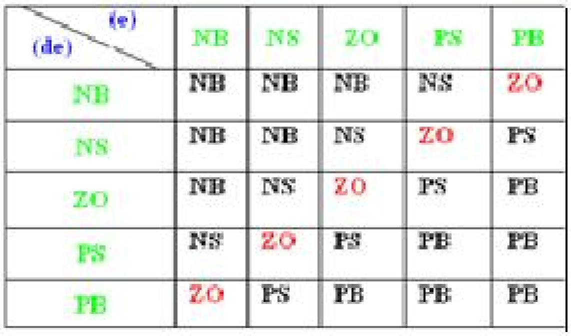


Fig.8.The Membership Function plots

Fuzzy Logic Rules:

The objective of this dissertation is to control the output voltage of the converter. The error and change of error of the output voltage will be the inputs of fuzzy logic controller. These 2 inputs are divided into five groups; NB: Negative Big, NS: Negative Small, ZO: Zero Area, PS: Positive small and PB: Positive Big and its parameter. These fuzzy control rules for error and change of error can be referred in the table that is shown in Table II as per below:

Table II
Table rules for error and change of error



(de) \ (e)	NB	NS	ZO	PS	PB
NB	NB	NB	NB	NS	ZO
NS	NB	NB	NS	ZO	PS
ZO	NB	NS	ZO	PS	PB
PS	NS	ZO	PS	PB	PB
PB	ZO	PS	PB	PB	PB

IV.MATLAB/SIMULINK RESULTS

Case 1: proposed system with PI controller

Matlab based simulation diagram is developed for the converter with PI controller in controlling the output of PWM inverter. The wave forms are analysed from Fig.9 to Fig.14. The results shows that the souce current harmonics with PI controller is 3.82% which reduced the harmonic content from 10.82%.

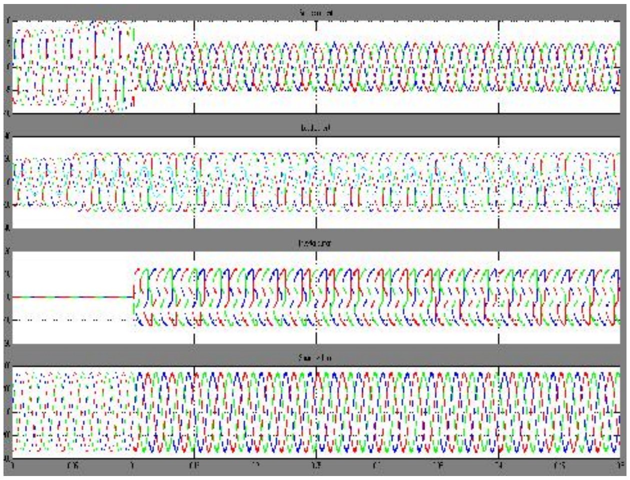


Fig9.Simulation result for source currents, load currents, inverter currents and source voltage

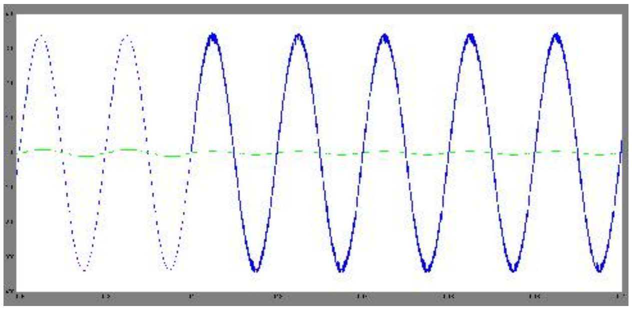


Fig10.Simulation result for source power and power factor

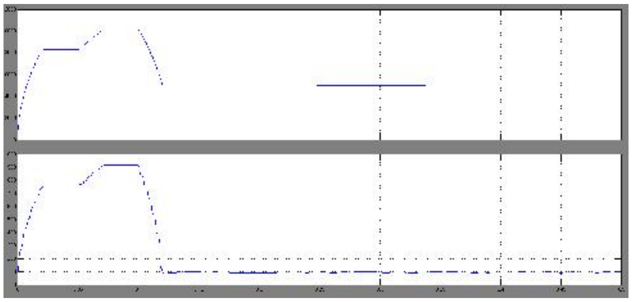


Fig11. Simulation result for rms values of source active and reactive power

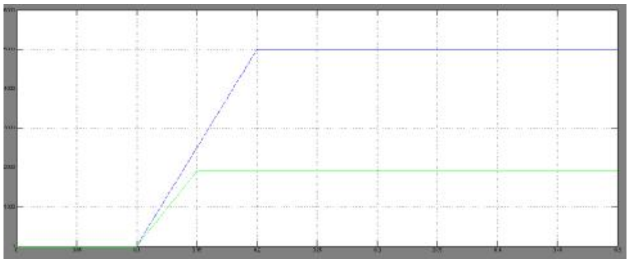


Fig12. Simulation result for inverter active and reactive power

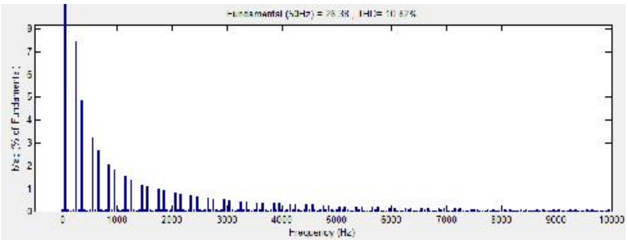


Fig13.FFT analysis for source current without controller

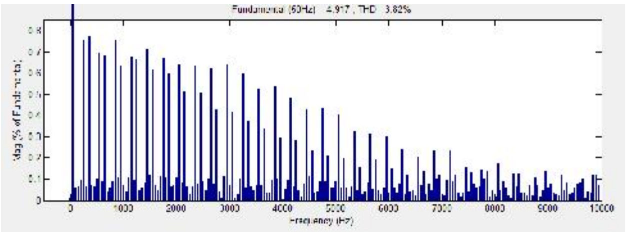


Fig14.FFT analysis for source current with PI controller

Case 2: proposed system with Hybrid controller

Fuzzy Logic Controller is designed to control the output of converter using Mamdani style fuzzy inference system. Two input variables, error (e) and change of error (de) are used in this fuzzy logic system. The single output variable (u) is duty cycle of PWM output. The fuzzy rules are designed as in Table II and the verified output waveforms are shown in Fig 15 to Fig 18. Analysis of source current wave form from FFT shows that THD is reduced to 1.07%.

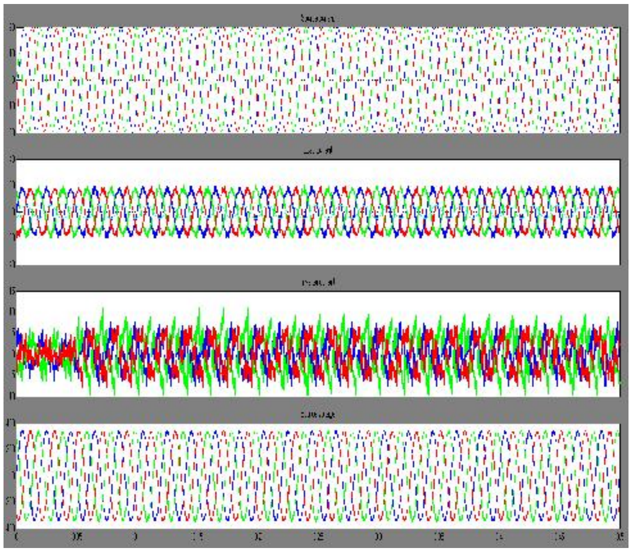


Fig15.Simulation result for source currents, load currents, inverter currents and source voltage

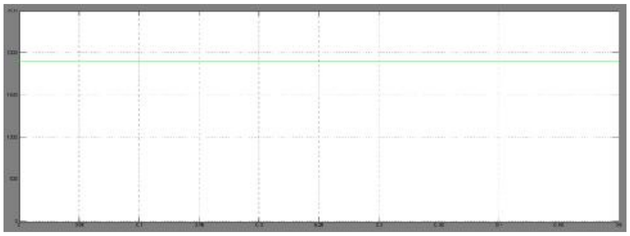


Fig16. Simulation result for load active and reactive power

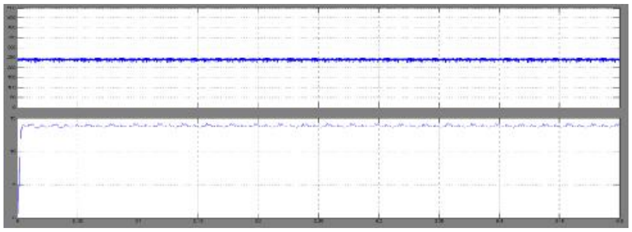


Fig17. Simulation result for rms values of source voltage and current

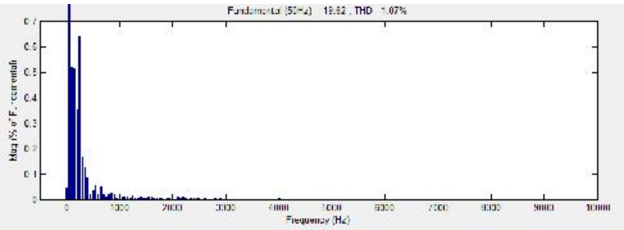


Fig18.FFT analysis for source current by using hybrid controller

V. CONCLUSION

A control algorithm for a power filter constituted by a shunt active filter is connected in parallel with the load is proposed. The control strategy is based on the unit vector template to generate the reference currents and is proposed with hybrid controller strategies. The new controlapproach achieves the required targets. Therefore, with theproposed control algorithm, the active filter improves the harmonic compensation features and the power factor of the load. This paper has presented a novel control of an existing grid interfacing inverter using conventional PI controller & fuzzy logic controller toimprove the quality of power at PCC for a 3-phase 4-wireDG system. Proposed compensator is a flexible device which can operate in current control mode for compensating voltage variation, unbalance and reactive power and in voltage control mode as a voltage stabilizer. The simulation results show that the performance of converter system has been found to be satisfactory for improving the power quality at the consumer premises. By using conventional controller we get THD value as 3.82%, but using the fuzzy logic controller THD value is 1.07%.

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