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POWER QUALITY ENHANCEMENT USING FUZZY CONTROLLED ACTIVE POWER FILTER WITH DISTRIBUTED GENERATION INTEGRATION FEATURE

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ABSTRACT:

Power quality improvement is an important parameter in power system. Not only is to meet the demands, but also the quality power a major goal of power system. Distributed Generations such as Solar and Fuel cell integration solves the problem of power demand. Various FACTS controllers are proposed for mitigation of power quality problem in the distribution network for harmonic compensation Active power filter is proposed. Another major problem in the power system network is increasing load demand day by day to meet the increasing in load demands renewable energy sources (RES's) are inter connected to the distribution network. Recent scenario in the distribution system is harmonics created by Non-linear load and unbalance current. It affects not only the working of adjacent loads but also shorten the life of power equipment by creating excessive losses. In this paper, a fuzzy controlled shunt active power filter is described to maintain the (Total Harmonic Distortion) THD within the allowable limits defined by IEEE Std. 519-1992 and to reduce reactive power and improve power factor. This Filter draws the opposite harmonics containing current from the load so that source current remain sinusoidal and undistorted. Fuzzy logic controller is used to control the shunt active power filter and the performance of the shunt active filter control strategies has been evaluated in terms of harmonic mitigation. Three-phase reference current waveforms generated by proposed scheme are tracked by the three-phase voltage source converter in a hysteresis band control scheme. A fully functional MATLAB based Simulink model of Shunt Active Power Filter for different types of load (nonlinear, unbalance, both) has been designed based on `Instantaneous Power Theory' or `p-q Theory'. The results of simulation comply with all the features described by the theory, justifying employment of Shunt Active Power Filter (SAPF) with fuzzy controller improves power quality compared to conventional Proportional Integral (PI) controller.

Index Terms-Renewable Energy Sources (RES), Distributed Generation (DG), Multifunctional grid connected inverter (MFGCI), Power quality, Total Harmonic Distortion (THD).

I. INTRODUCTION

In recent years, power quality distortion has become serious problem in electrical power systems due to the Increase of nonlinear loads drawing non sinusoidal currents Active filters have been widely used for harmonic mitigations well as reactive power compensation, load balancing, voltage regulation, and voltage flicker compensation In three-phase four-wire systems with nonlinear loads a high level of harmonic currents in both the three line conductors and more significantly in the neutral wire has been enrolled. Unbalanced loads also results in further declination of the Supply quality [1]. Various harmonic mitigation techniques have been proposed to reduce the effect of harmonics. These techniques include phase multiplication, passive filters, active power filters (APFs), and harmonic injection. One of the most popular APFs is the shunt active power filter. It is mainly a current source, Connected in parallel with the non-linear loads. Conventionally, a shunt APF is controlled in such a way as to inject harmonic and reactive compensation currents based on calculated reference currents. The injected currents are meant to cancel the harmonic and reactive currents drawn by the nonlinear loads [2]. Recently, fuzzy logic controller has generated a great deal of Interest in various applications and has been introduced in the power electronics field [3]-[4]. The advantages of fuzzy logic controllers over the conventional PI controller are that they do not need an accurate mathematical model; they can work with imprecise inputs, can handle nonlinearity, and may be more robust than the conventional PI controller. Use of fuzzy logic for minimization of harmonics and improvement of power quality is not a new issue rather various authors have introduced some innovative methodologies using these tools [5].

The most important observation from the work reported by various researchers for power quality improvement is the Design of active power filter under ‘fixed load’ conditions or for loads with slow and small variation [6]. As loads in practical life are mostly variable, there is the need to design an active power filter, which is capable of maintaining the THD well within the IEEE norms [7], under variable load conditions. Generally, current controlled voltage source inverters are used to interface the intermittent RES in distributed system. Recently, a few control strategies for grid connected inverters incorporating PQ solution have been proposed. The primary contribution of this paper is a d-q control algorithm designed and implemented specifically for this application. Traditionally, active power filters have been controlled using pre-tuned controllers [8], [9].The introduction of change in voltage in the circuit will be fed to fuzzy controller to give appropriate measure on steady state signal. The fuzzy logic controller serves as intelligent controller for this propose. This paper presents the mathematical model of the 4L-VSI and the principles of operation of the proposed predictive control scheme, including the design procedure [10]. Active power filters are usually employed to solve the power quality problems. In this paper, a PV generating system is connected to grid and the PQ is maintained without using APF (Active Power filter) [11] .There are different ways by which PQ can be maintained. Here, we have Conventionally, PI, PD and PID controller are most popular controllers and widely used in most power electronic appliances however recently there are many researchers reported successfully adopted Fuzzy Logic Controller (FLC) to become one of intelligent controllers to their appliances. Two independent fuzzy controllers have been designed for DG interface and that controllers will perform the function of active power filtering (eliminating harmonics), thereby increasing efficiency, reliability and quality [12].

The interaction between the DG inverter nonlinear current and distorted PCC voltages may contribute power control errors in the steady state [13]. Hence a closed loop power control strategy is necessary for accurate power tracking in the case of distorted voltages at the PCC. In [14], a closed loop power control strategy for single phase inverters with active harmonic filtering in stationary frame is proposed for harmonic compensation. The objective of this paper is to develop a control strategy for harmonic current filtering in a three phase grid connected DG system without using extra compensating device. The proposed closed loop control is able to track the active power reference and improve the power quality in the presence of unbalanced and distorted supply voltages. The effectiveness of the control scheme is validated by elaborate simulation studies for different operating modes of the DG inverter under ideal and non-ideal supply conditions.

II SYSTEM DESCRIPTION

A schematic representation of the proposed system is given in Fig 1$R_g$and L_g represents the grid resistance and inductance up to the point of common coupling; $R_{dg}$and L_{dg} represents the equivalent resistance and inductance of the inverter filter, coupling transformer and connecting cables; $L_s$represents the smoothing inductance inserted in series with the load to reduce the spikes in the grid current due to switching transients; v_a, v_b ,$v_c$represents the voltages at the PCC and i_{la},i_{lb},i_{lc}represents the load currents.

III REFERENCE CURRENT GENERATION PRINCIPLE

The control technique employed is based on the analysis of load voltage, load current and inverter currents in the dq synchronous rotating frame. Independent control of active and reactive power can be achieved with more effectiveness in dq frame. The instantaneous angle of the voltage at PCC is obtained by using a phase locked loop (PLL).

a) Calculation of d-axis and q-axis reference currents to supply load active and reactive power:

The active and reactive power injected from the DG link to the grid at the fundamental frequency is

$$P_{dg} = \frac{3}{2}\left(v_d I_{dgd} + v_q I_{dgq}\right) \qquad (1)$$

$$Q_{dg} = \frac{3}{2}\left(v_q I_{dgd} - v_d I_{dgq}\right) \qquad (2)$$

Where ,I_{dgd} and,I_{dgq} and are the dq- components of DG invertercurrent at fundamental frequency to manage the active powerand reactive power exchange between the grid and RES. $v_d$andv_q are the the PCC voltages in dq frame.The currents at fundamental frequency required to deliver the active and reactive power from the RES has to be supplied by the DG inverter. The corresponding reference currents at fundamental frequency areI^*_{dgd} andI^*_{dgq}, which can be calculated using

the open loop and the proposed closed loop power control strategy as explained below,

B) Open Loop Power Control:

In a practical case, the PCC voltages may contain ripple due to the unexpected power fluctuations and excessive use of harmonic polluted loads connected to the system. Hence to generate the fundamental current components, the PCC voltages are filtered in dq frame [13].

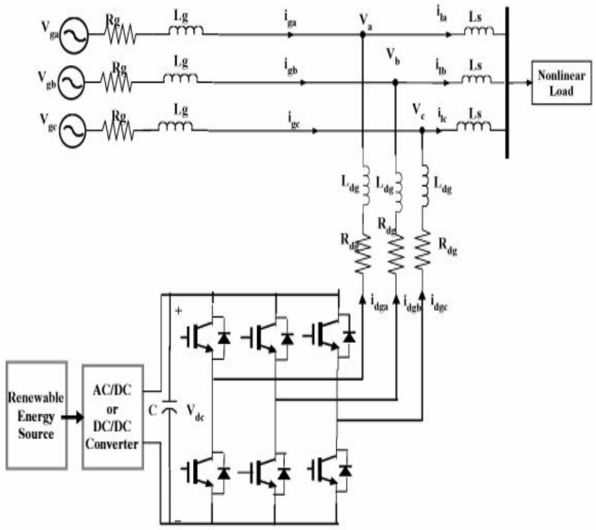

Fig.1.Schematic of the proposed distribution generation system connected to the electrical network.

Using equations (1) and (2),

$$\begin{bmatrix} I^*_{dgd} \\ I^*_{dgq} \end{bmatrix} = \frac{1}{\tilde{v}_d^{\,2} + \tilde{v}_q^{\,2}} \begin{bmatrix} P* & Q* \\ -Q* & P* \end{bmatrix} \begin{bmatrix} \tilde{v}_d \\ \tilde{v}_q \end{bmatrix} \frac{2}{3} \qquad (3)$$

Where $\tilde{v}_d$and $\tilde{v}_q$are the voltages after passing through a low pass filter. P * and Q*are the active and reactive power references.

c) Proposed Closed Loop Power Control:

In the proposed closed loop control strategy, the calculated DG active and reactive power are filtered through a low pass filter and compared with the reference powers to get the error signal. The dq - components of inverter reference current at fundamental frequency can be generated by passing the error signal through a PI controller and can be expressed as

$$I_{dgd}^{*} = (P* - \bar{P}_{dg})(k_{p1} + \frac{k_{i1}}{s}) \quad (4)$$

$$I_{dgq}^{*} = (Q* - \bar{Q}_{dg})(k_{p2} + \frac{k_{i2}}{s}) \quad (5)$$

Where P_{dg}andP_{qg} represent the filtered real and reactive power of the DG inverter, $k_{p1}.k_{i1}k_{p2}$and$k_{i2}$are theproportional and integral gains for minimizing the real and reactive power control errors, As per IEEE 1547 the inverters in a distributed generation system are not permitted to inject reactive power to the grid [5]. As such, the total q-axis reference current for the inverter is limited to meet only the reactive power demand of the load so that I_{dgq}^{*}= O. Hence only active power control is done in both open loop and closed loop control schemes. In rotating synchronous frame the quadrature component of load current i1q is perpendicular to the direct component of voltage ($i_{lq} \perp v_d$). Accordingly the q-axis reference current of the DO inverter can be expressed as

$$i_{dgq}^{*} = i_{lq} \quad (6)$$

d) Calculation of Total D-Axis Reference Current:

The d-axis component of the load current can be expressed as

$$i_{ld} = i_{ld_1} + \tilde{i}_{ld} \quad (7)$$

Where in$i$■$_{ld}$ is the oscillating component of the load currentand i_{ld1} is the fundamental component of load current. In dqframe the fundamental frequency component of the load current appears as a dc component. The harmonic components of the load current can be obtained by using a high pass filter. But due to the excessive phase lag associated with the high pass filter, a second order low pass filter having a cut off frequency of 25 Hz is used to extract the harmonic component of the load current.

i■$_{ld}$Can be expressed as

$$\tilde{i}_{ld} = \sum_{n=2}^{\infty} i_{ld_n} \quad (8)$$

$$\sum_{n=2}^{\infty} i_{ld_n} = i_{ld}(1 - LPF) \quad (9)$$

The DO inverter has to supply the d-axis component of harmonic load current given by equation (8) and the d-axis component of current at fundamental frequency given by equation (3) or (4) depending upon the type of the power control scheme. Hence the total d-axis reference current for the DG inverter can be expressed as

$$i_{dgd}^{*} = \tilde{i}_{ld} + I_{dgd}^{*} \quad (10)$$

e) DC Link Voltage Control:

When the power from the RES is equal to zero, the inverter operates in shunt active filter mode. The DO inverter draws an active power component of current for maintaining the dc bus voltage constant and to meet the losses in the inverter. The DC link voltage error can be expressed as

$$v_{dcerr} = v_{dc}^{*} - v_{dc} \quad (11)$$

The current can be obtained by passing the error through a PI controller and is given by

$$i_{dc} = k_p v_{dcerr} + k_i \int v_{dcerr} dt \quad (12)$$

Where kp and k; are the proportional and integral gain constants.

f) Hysteresis Current Control Scheme:

A Hysteresis band current controller is used to generate the switching pulses for the DO inverter. The reference currents generated in dq frame are transformed to natural ABC frame and compared with the inverter currents to generate the error signals.

If $I^*_{dga} - i_{dga} > h_b$,then upper switch is switched ON andlower switch is switched OFF in the inverter leg of phase 'a'.

If$I^*_{dga} - i_{dga} < h_b$then upper switch is switched OFF andlower switch is switched ON in the inverter leg of phase 'a',

Where h_b is the assigned hysteresis band? Using the same principle switching pulses for the other switches in phase 'b'&'c' are produced. The hysteresis band directly controls the amount of ripples in the current injected into the grid. The main advantages of hysteresis current controller are ease of implementation, extremely good dynamic response, outstanding robustness and independence of load parameter changes. The switching frequency depends on the width of hysteresis band, the size of interfacing inductor Ldg to the grid and the DC voltage. As per, the relation between switching frequency and the filter inductance can be expressed as

$$L_{dg} = \frac{2V_{dc}}{9h_b f_{sw.\max}} \qquad (13)$$

Where$v_{dc}$is the DC link voltage, h_b is the hysteresis band and f_{bswmax} is the maximum switching frequency.

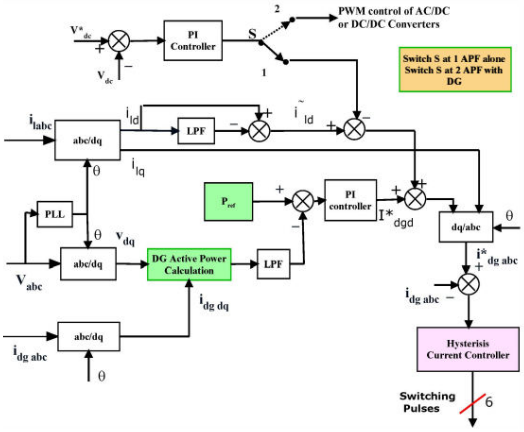

Fig. 2. Control block diagram for generation of switching pulses for the DG inverter.

IV.FUZZY LOGIC CONTROLLER

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, a new language was developed to describe the fuzzy properties of reality, which are very difficult and sometime even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to dc-to-dc 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 dc-to-dc 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 been potential ability to improve the robustness of dc-to-dc converters. The basic scheme of a fuzzy logic controller is shown in Fig 6 and consists of four principal components such as: a fuzzification 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 [10].

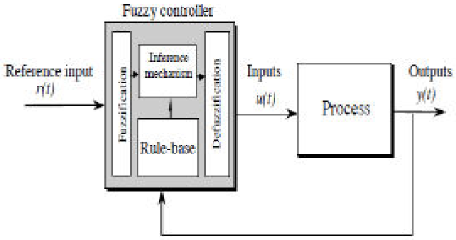

Fig.3. General Structure of the fuzzy logic controller on closed-loop system

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.

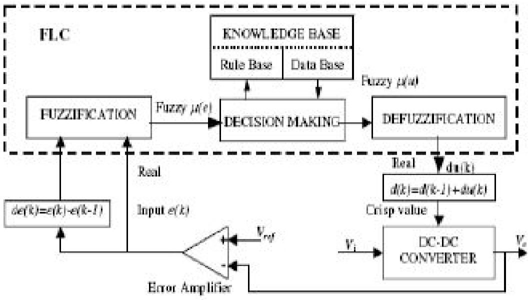

Fig.4. Block diagram of the Fuzzy Logic Controller (FLC) for dc-dc converters

A. *Fuzzy Logic Membership Functions:*

The dc-dc 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 boost 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 boost dc-dc 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.

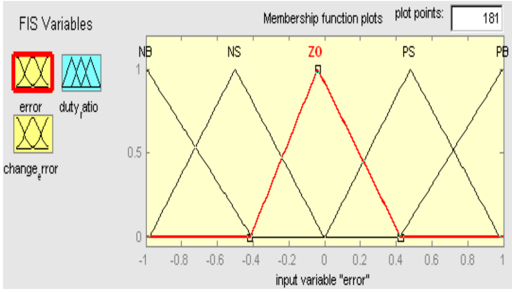

Fig. 5.The Membership Function plots of error

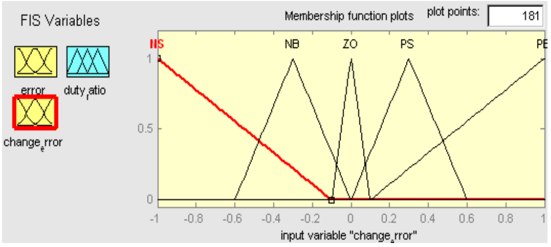

Fig.6. The Membership Function plots of change error

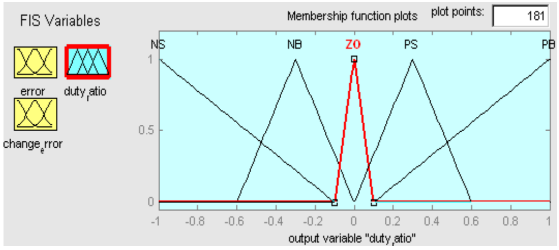

Fig.7.the Membership Function plots of duty ratio

B. *Fuzzy Logic Rules:*

The objective of this dissertation is to control the output voltage of the boost 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 [10]. 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

V MATLAB/SIMULINKRESULTS

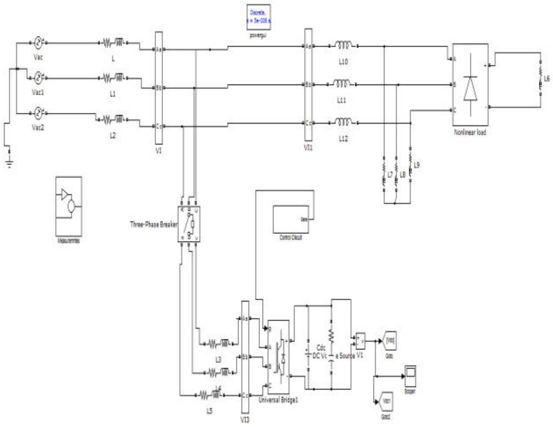

Fig.8.Simulation model for generation of switching pulses for the DG inverter

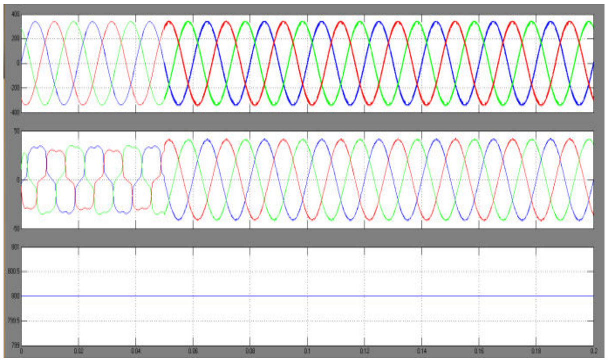

Fig.9.Simulation waveform for Grid voltage, Grid currents and DC link voltage during shunt active filter mode of the DG inverter

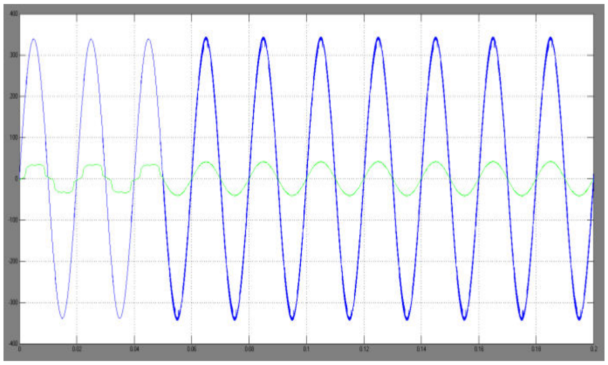

Fig.10.Simulation waveform for source voltage, source currents

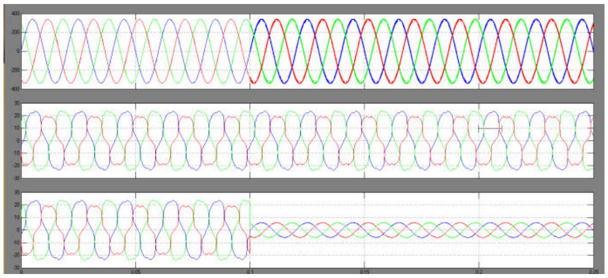

Fig.11.Simulation waveform for Grid voltage, Grid current and DG current in phase a under forward power flow mode

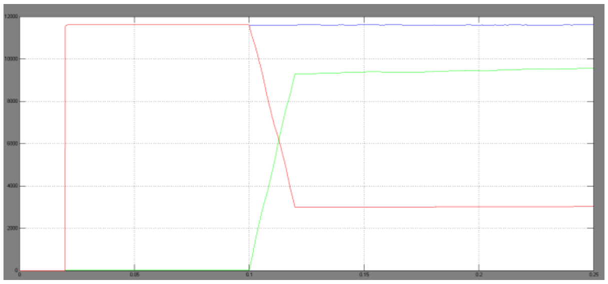

Fig.12. Simulation waveform for forward reactive power

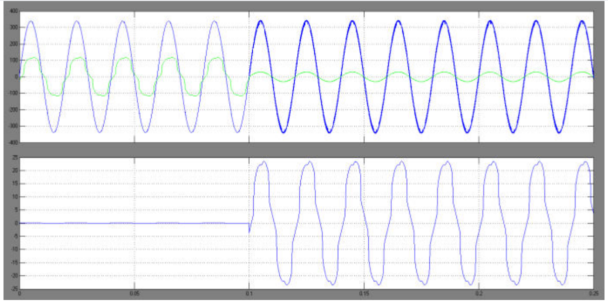

Fig.13.Simulation waveform for Grid voltage, Grid current and DG current in phase a under forward mode

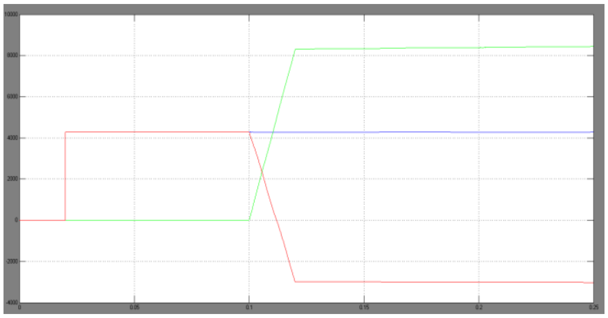

Fig.14.Simulation waveform for reverse reactive power

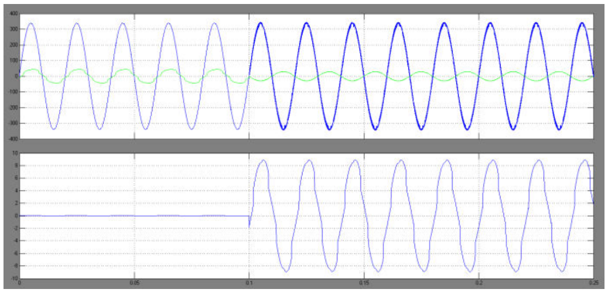

Fig.15.Simulation waveform for Grid voltage, Grid current and DG current in phase a under reverse mode

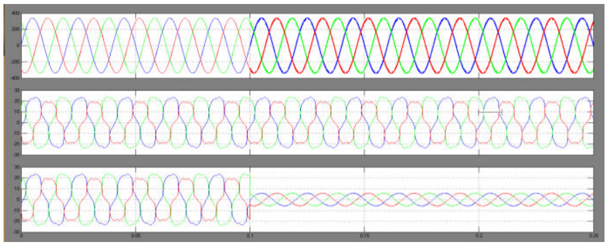

Fig.16.Simulation waveform for Grid voltage, Grid current and DG current in phase a under reverse power flow mode

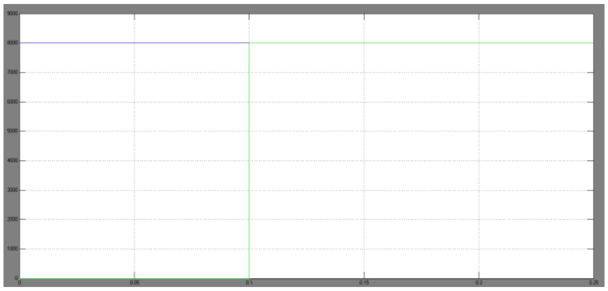

Fig.17.Simulation waveform for DG Real power under non ideal supply conditions using open loop and closed loop control

Fig.18.Simulation waveform for Fundamental current tracking in Closed loop control

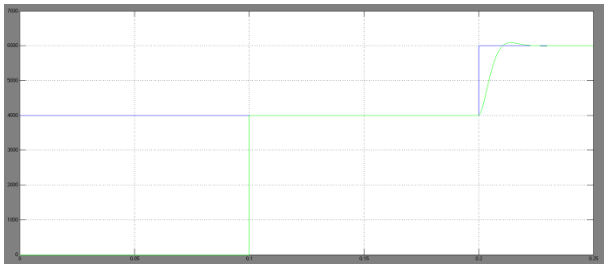

Fig .19.Simulation waveform for Dynamic performance of the proposed closed loop power control

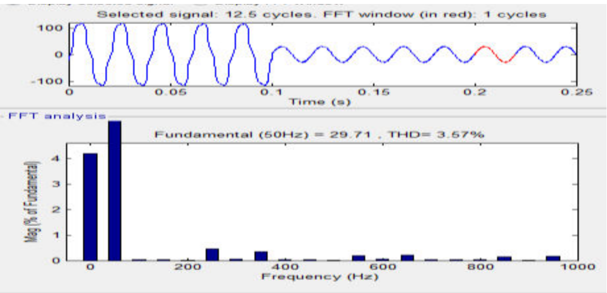

Fig 20. source current THD with PI controller3.57%

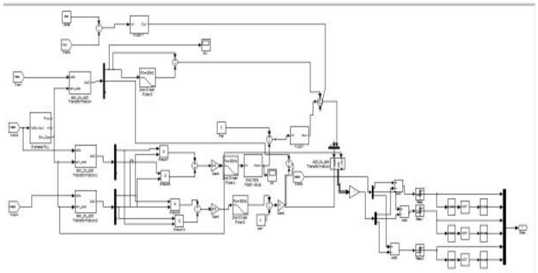

Fig.21.Fuzzy logic control block diagram for generation of switching pulses for the DG inverter.

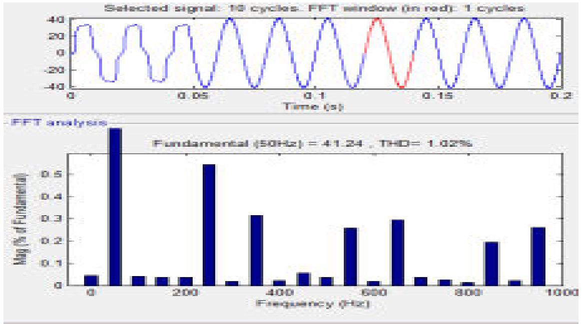

Fig.22.source currentTHD is 1.02 with fuzzy logic controller

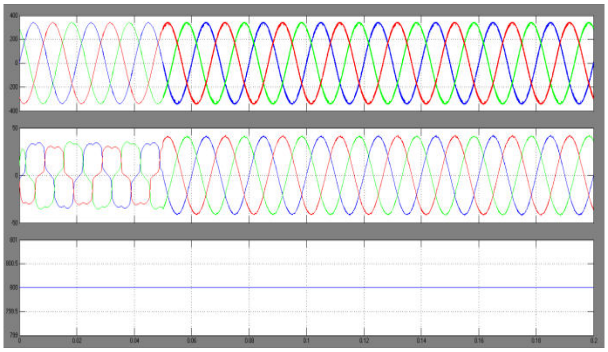

Fig.23.simulation wave form of Grid voltage, Grid current and DC voltage with Fuzzy logic controller

VI.CONCLUSION

The proposed closed loop active power control strategy achieves accurate power tracking with zero steady state errors under ideal and non-ideal supply conditions and can be used as a control technique for integration of DG inverters to the utility grid. The method laminates the need of extra power conditioning devices to improve the power quality. The effectiveness of the control scheme is verified under balanced and unbalanced nonlinear load conditions. With the proposed method the combination of nonlinear loads and the DG inverter is seen as a resistive load at the PCC and the grid currents re maintained sinusoidal. Instead of using separate converter for DG integration separate converter for power quality improvement, here we are integrating DG with APF. The APF is controlled by d-q theory with hysteresis controller is used to generate gate pulses to inverter. Here simulation results are presented for without DG integration, with DG and PI controller and With DG and fuzzy controller. The THD s at PI and fuzzy controller is presented compared to PI, fuzzy have less THD% in system. To proposed with fuzzy logic controller to reduce the THD and improve the power quality and maintain the grid currents re maintained sinusoidal

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