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Grid Interconnection Renewable Energy Source at the Distribution level for Active, Reactive Power and Harmonics Compensation Using Fuzzy Logic Controller

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Abstract:
The design of a fuzzy logic controller using the voltage as feedback for significantly improving the dynamic performance of converter. A Power quality problem is an occurrence manifested as a nonstandard voltage, current or frequency that results in a failure or a misoperation of end user equipments. Utility distribution networks, sensitive industrial loads and critical commercial operations suffer from various types of outages and service interruptions which can cost significant financial losses. Renewable energy resources (RES) are being increasingly connected in distribution systems utilizing power electronic converters. This paper presents a novel control strategy for achieving maximum benefits from these grid-interfacing inverters using the closed loop fuzzy logic control, when installed in 3-phase 4-wire distribution systems. The inverter is controlled to perform as a multi-function device by incorporating active power filter functionality. The inverter can thus be utilized as: 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. All of these functions may be accomplished either individually or simultaneously. This new control concept is demonstrated with extensive MATLAB/Simulink .Finally the proposed shceme is applied for both balanced and unbalanced linear non linear loads.

Key words: *International electro-technical commission (IEC), power quality, Photo Voltaic (PV) System, Fuzzy Logic Controller (FLC).*

1.Introduction

Power quality is one of the most important topics that electrical engineers have been noticed in recent years. Voltage sag is one of the problems related to power quality. This phenomenon happens continuously in transmission and distribution systems. During a voltage sag event, amplitude of the effective load voltage decrease from 0.9 of the nominal load voltage to 0.1 in very short time (less than one minute). Short circuit, transformer energizing, capacitor bank charging etc are causes of voltage sag. Voltage sag has been classified in 7 groups from A to G [1]. According to this classification most of voltage sags are companion with a phase angle jump (types C, D, F and G). Phase angle jump for power electronics systems such as ac-ac and ac-dc converters, motor drives etc is harmful [2]. Therefore, phase angle jump compensation is one of the voltage sag mitigation goals.

Most industries and companies prefer electrical energy with high quality. If delivered energy to these loads has poor quality, products and equipment of these loads such as microcontrollers, computers, motor drives etc are damaged. Hurt of this phenomenon in companies that dealing with information technology systems is serious. According to a study in U.S., total damage by voltage sag amounts to 400 Billion Dollars [3]. For these reasons power quality mitigation in power systems is necessary. Nowadays, Custom Power equipments are used for this purpose.

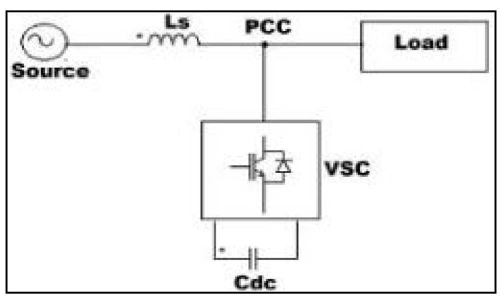

Figure 1: shows the basic structure of proposed inverter

Renewable energy source (RES) integrated at distribution level is termed as distributed generation (DG). The utility is Concerned due to the high penetration level of intermittent RES in distribution systems as it may pose a threat to network in terms of stability, voltage regulation and power-quality (PQ) issues. Therefore, the DG systems are required to comply with strict technical and regulatory frameworks to ensure safe, reliable and efficient operation of overall network. With the advancement in power electronics and digital control technology, the DG systems can now be actively controlled to enhance the system operation with improved PQ at PCC. However, the extensive use of power electronics based equipment and non-linear loads at PCC generate harmonic currents, which may deteriorate the quality of power [1], [2].

Grid-connected three-phase photovoltaic (PV) systems are nowadays recognized for their contribution to clean power generation. A primary goal of these systems is to increase the energy injected to the grid by keeping track of the maximum power point (MPP) of the panel, by reducing the switching frequency, and by providing high reliability. In addition, the cost of the power converter is also becoming a decisive factor, as the price of the PV panels is being decreased [2]. This has given rise to a big diversity of innovative converter configurations for interfacing the PV modules with the grid.

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. In [3] an inverter operates as active inductor at a certain frequency to absorb the harmonic current. But the exact calculation of network inductance in real-time is difficult and may deteriorate the control performance. A similar approach in which a shunt active filter acts as active conductance to damp out the harmonics in distribution network is proposed in [4]. In [5], a control strategy for renewable interfacing inverter based on – theory is proposed. 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 in the power system network. Active power filters (APF) are extensively used to compensate the load current harmonics and load unbalance at distribution level. This results in an additional hardware cost.

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 [3]. With respect to their successful methodology implementation, this kind of methodology implemented in this paper is using fuzzy logic controller with feed back by introduction of voltage respectively. 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.

However, in this paper authors have incorporated the features of APF in the, conventional inverter interfacing renewable with the grid, without any additional hardware cost. Here, the main idea is the maximum utilization of inverter rating which is most of the time underutilized due to intermittent nature of RES. It is shown in this paper that the grid-interfacing inverter with fuzzy logic control technique can effectively be utilized to perform following important functions: 1) transfer of active power harvested from the renewable resources (wind, solar, etc.); 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. Moreover, with adequate control of grid-interfacing inverter, all the four objectives can be accomplished either individually or simultaneously.

2.Proposed Concept

A proposed converter consists of a two-level VSC, a dc energy storage device, controller and a coupling transformer\ connected in shunt to the distribution network. Fig. 2 shows the schematic diagram of proposed converter.

$$I_{out} = I_L - I_S = I_L - \frac{V_{th}-V_L}{Z_{th}} \qquad (2.1)$$

$$I_{out} < \gamma = I_L < (-\theta) - \frac{V_{th}}{Z_{th}} < (\gamma - \beta) + \frac{V_{th}}{Z_{th}} < (-\beta) \qquad (2.2)$$

Iout=output current I_L=load current

I_s=source current V_{th}=Thevinin voltage

V_L=load voltage Z_{TH}=impedance

Referring to the equation 2.2, output current, Iout will correct the voltage sags by adjusting the voltage drop across the system impedance, (Zth=*R*+*jX*). It may be mention that the effectiveness of proposed converter in correcting voltage sags depends on:

- The value of Impedance, Zth= *R*+*jX*
- The fault level of the load bus

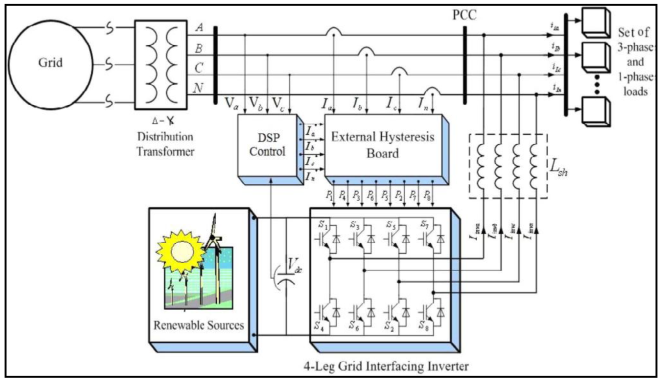

Figure 2: Schematic diagram of a proposed converter with RES

2.1.Voltage Source Converter (VSC)

A voltage-source converter 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. The VSC used to either completely replace the voltage or to inject the 'missing voltage'. The 'missing voltage' is the difference between the nominal voltage and the actual. It also converts the DC voltage across storage devices into a set of three phase AC output voltages [8, 9]. In addition, Proposed Converter is also capable to generate or absorbs reactive power. If the output voltage of the VSC is greater than AC bus terminal voltages, proposed converter is said to be in capacitive mode. So, it will compensate the reactive power through AC system and regulates missing voltages. These voltages are in phase and coupled with the AC system through the reactance of coupling transformers. Suitable adjustment of the phase and magnitude of the proposed converter output voltages allows effectives control of active and reactive power exchanges between proposed converter and AC system. In addition, the converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage [10].

2.2.Controller for proposed converter.

The three-phase reference source currents are computed using three-phase AC voltages (*v*ta, *v*tb and *v*tc) and DC bus voltage (*V*dc) of proposed converter. These reference supply currents consist of two components, one in-phase (*I*spdr) and another in quadrature (*I*spqr) with the supply voltages. The control scheme is represented in Fig. 2. The basic equations of control algorithm of proposed converter are as follows.

2.3.*Computation of in-phase components of reference supply current*

The instantaneous values of in-phase component of reference supply currents (*I*spdr) is computed using one PI controller over the average value of DC bus voltage of the proposed converter (*v*dc) and reference DC voltage (v_{dcr}) as

$$I_{spdr} = I_{spdr(n-1)} + K_{pd}\{V_{de(n)} - V_{de(n-1)}\} + K_{id}V_{de(n)}$$

Where Vdc (*n*) Vdcc-Vdc (*n*) denotes the error in Vdcc and average value of Vdc, *Kpd* and *Kid* are proportional and integral gains of the DC bus voltage PI controller. The output of this PI controller (*I*spdr) is taken as amplitude of in-phase component of the reference supply currents. Three-phase in-phase components of the reference supply currents (*i*sadr, *i*sbdr and *i*scdr) are computed using the in-phase unit current vectors (*u*a, *u*b and *u*c) derived from the AC terminal voltages (*v*tan, *v*tbn and *v*tcn), respectively.

$$U_a = V_{ta}/V_{tm} \;, U_b = V_{tb}/V_{tm} \;, U_c = V_{tc}/V_{tm}$$

Where *V*tm is amplitude of the supply voltage and it is computed as

$$V_{tm} = \sqrt{[(2/3)(V_{tan}^2 + V_{tbn}^2 + V_{tcn}^2)]}$$

The instantaneous values of in-phase component of reference supply currents (*i*sadr, *i*sbdr and *i*scdr) are computed as

$$I_{sadr} = I_{spds}U_a, I_{sbdr} = I_{spdr}U_b \;, I_{scdr} = I_{spdr}U_c$$

2.4.Computation of quadrature components of reference supply current

The amplitude of quadrature component of reference supply currents is computed using a second PI controller over the amplitude of supply voltage (*v*tm) and its reference value (*v*tmr)

$$I_{spqr(n)} = I_{spqr(n-1)} + K_{pq}\{V_{ac(n)} - V_{ac(n-1)}\} + K_{iq}V_{ac(n)}$$

Where Vac = Vtmc.Vmc(n) denotes the error in Vtmc and computed value *Vtmn* from Equation (3) and Kpq and Kiq are the proportional and integral gains of the second PI controller.

$$W_a = \{-U_b + U_C\}/\{\sqrt{3}\}$$

$$W_b = \{U_a\sqrt{3} + U_b - U_c\}/\{2\sqrt{3}\} W_c = \{-U_a\sqrt{3} + U_b - U_c\}/\{2\sqrt{3}\}$$

Three-phase quadrature components of the reference supply currents (*i*saqr, *i*sbqr and *i*scqr) are computed using the output of second PI controller (*I*spqr) and quadrature unit current vectors (*w*a, *w*b and *w*c) as

$$i_{saqr} = I_{spqr} W_a, i_{sbqr} = I_{spqr} W_b, i_{scqr} = I_{spqr} W_c,$$

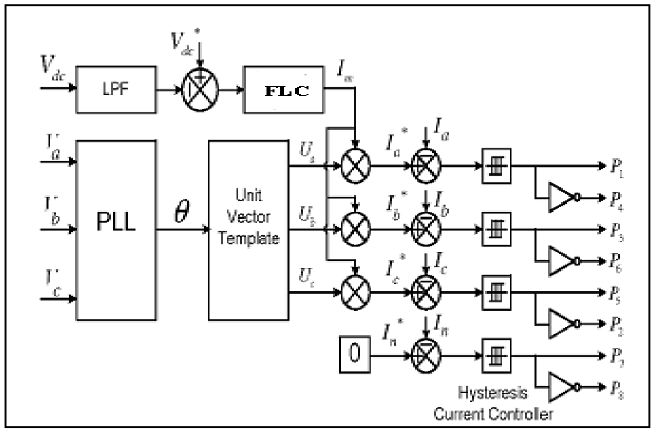

Figure 3: A FLC Control method for proposed converter

2.5.Computation of total reference supply currents

Three-phase instantaneous reference supply currents (*i*sar, *i*sbr and *i*scr) are computed by adding in-phase (*i*sadr, *i*sbdr and *i*scdr) and quadrature components of supply currents (*i*saqr, *i*sbqr and *i*scqr) as

$$i_{sar} = i_{sadr} + i_{saqr}$$

$$i_{sbr} = i_{sbdr} + i_{sbqr}$$

$$i_{scr} = i_{scdr} + i_{scqr}$$

A hysteresis pulse width modulated (PWM) current controller is employed over the reference (*i*sar, *i*sbr and *i*scr) and sensed supply currents (*i*sa, *i*sb and *i*sc) to generate gating pulses for IGBTs of proposed converter.

3.Introduction To 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 converter. 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 converters. The basic scheme of a fuzzy logic controller is shown in Fig 4 and consists of four principal components such as: a fuzzy fication 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].

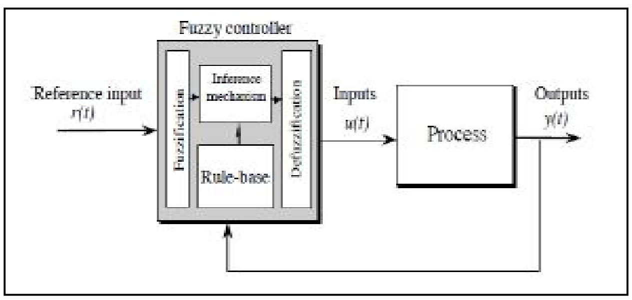

Figure 4: General Structure of the fuzzy logic controller

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].

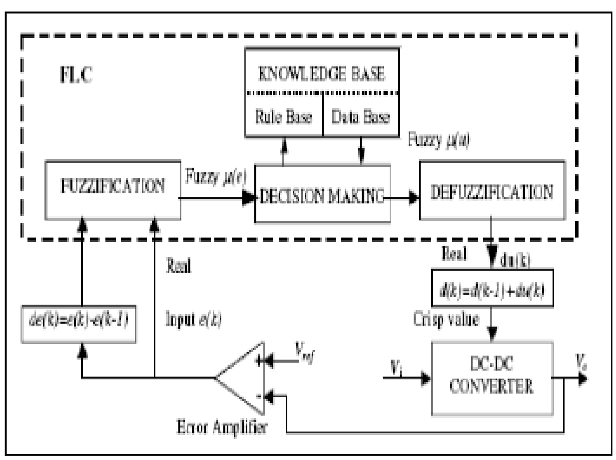

Figure 5: Block diagram of the Fuzzy Logic Controller (FLC) For proposed converter

4.Matlab/Simulink Modeling Of Proposed Converter

4.1.Modeling of power circuit

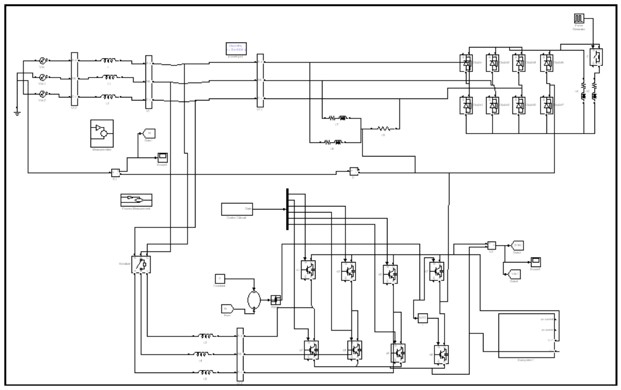

Figure 6: Matlab/Simulink Model of Proposed Power Circuit

Fig. 6 shows the complete MATLAB model of proposed power circuit along with control circuit. The power circuit as well as control system are modeled using Power System Block set and Simulink. The grid source is represented by three-phase AC source. Three-phase AC loads are connected at the load end. Converter is connected in shunt and it consists of PWM voltage source inverter circuit and a DC capacitor connected at its DC bus. An IGBT-based PWM inverter is implemented using Universal bridge block from Power Electronics subset of PSB. Snubber circuits are connected in parallel with each IGBT for protection. Simulation of proposed system is carried out for non-linear load. The non-linear load on the system is modeled using R and R-C circuits connected at output of the diode rectifier. Provision is made to connect loads in parallel so that the effect of sudden load addition and removal is studied. The feeder connected from the three-phase source to load is modeled using appropriate values of resistive and inductive components.

4.2.Modeling of Control Circuit using fuzzy logic controller.

Fig. 7 shows the control algorithm of proposed converter with fuzzy logic controller. Fuzzy logic controller regulates the DC link voltage. The in-phase components of inverter reference currents are responsible for power factor correction of load and the quadrature components of supply reference currents are to regulate the AC system voltage at PCC.

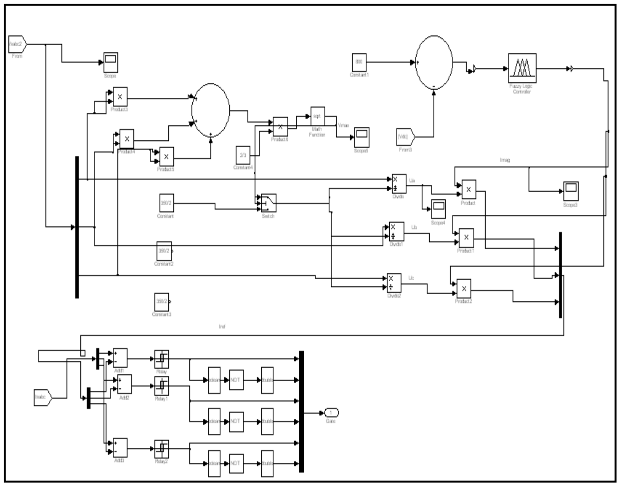

Figure 7: Control Circuit

The output of fuzzy logic controller over the DC bus voltage (*I*spdr) is considered as the amplitude of the in-phase component of supply reference currents and the output of fuzzy controller over AC terminal voltage (*I*spqr) is considered as the amplitude of the quadrature component of supply reference currents. The instantaneous reference currents (*i*sar, *i*sbr and *i*scr) are obtained by adding the in-phase supply reference currents (*i*sadr, *i*sbdr and *i*scdr) and quadrature supply reference currents (*i*saqr, *i*sbqr and *i*scqr). Once the reference supply currents are generated, a carrier less hysteresis PWM controller is employed over the sensed supply currents (*i*sa, *i*sb and *i*sc) and instantaneous reference currents (*i*sar, *i*sbr and *i*scr) to generate gating pulses to the IGBTs of converter. The controller controls the converter currents to maintain supply currents in a band around the desired reference current values. The hysteresis controller generates appropriate switching pulses for six IGBTs of the VSI working as converter.

4.3.Fuzzy Logic Membership Functions

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 change in voltage of the 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 steady state signal of the converter, nothing but error free response is directly fed to the system.

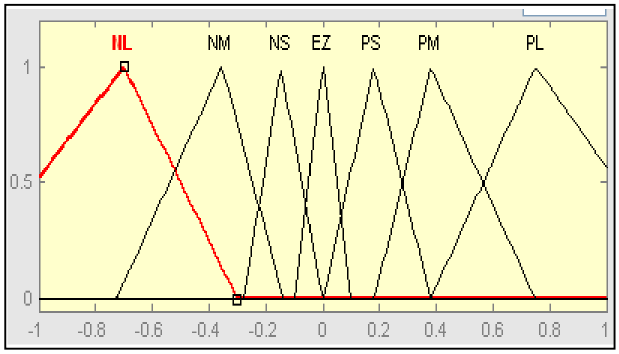

Figure 8: Membership functions for Input, Change in input, Output

Fig.8. Shows the membership functions for input (error (e)), Change in input (change of error (de)), Output variable (u).

4.4.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 seven groups; NL: Negative Large, NM: Negative Medium, NS: Negative Small, ZO: Zero Area, PS: Positive small, PM: Positive Medium and PL: Positive Large and its parameter [10]. These fuzzy control rules for error and change of error can be referred that is shown as below:

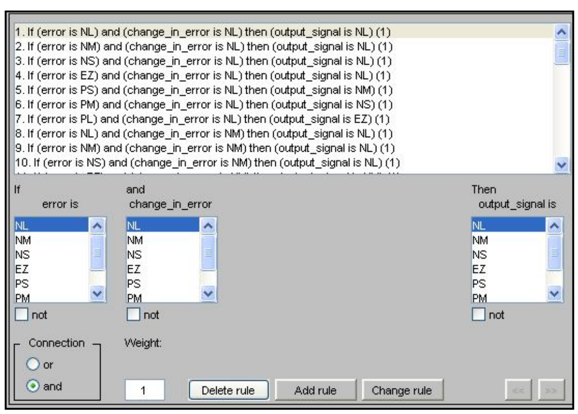

Figure 9: Rules for fuzzy logic controller

5.Simulation Results

Here the simulation is carried out in two cases 1.Implementation of proposed converter using conventional PI controller. 2. Implementation of proposed converter using fuzzy logic controller.

5.1.Case 1: Implementation of proposed converter using conventional PI controller with PV model.

Performance of proposed converter connected to a weak supply system is shown in Fig.5 for power factor correction and load balancing. This Fig. shows variation of performance variables such as supply voltages (vsa, vsb and vsc), terminal voltages at PCC (vta, vtb and vtc), supply currents (isa, isb and isc), load currents (ila, ilb and ilc), inverter currents (ica, icb and icc) and DC link voltage (Vdc).

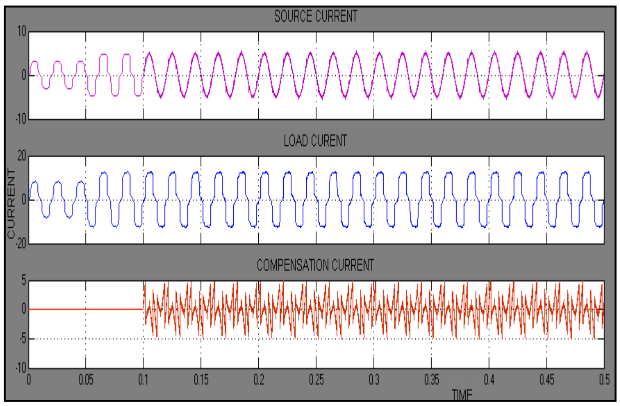

Fig.10. Simulation results for Un Balanced Non Linear Load using PI controller (a) Source current (b) Load current. (c) Inverter injected current.

Fig.10. shows the source current, load current and compensator current respectively. Here compensator is turned on at 0.1 seconds.

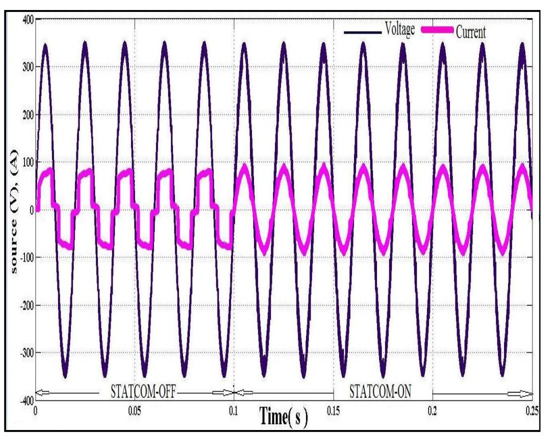

Figure 11: Simulation results power factor for Unbalanced Non linear Load

Fig.11 shows the power factor it is clear from the Fig. after compensation power factor is unity.

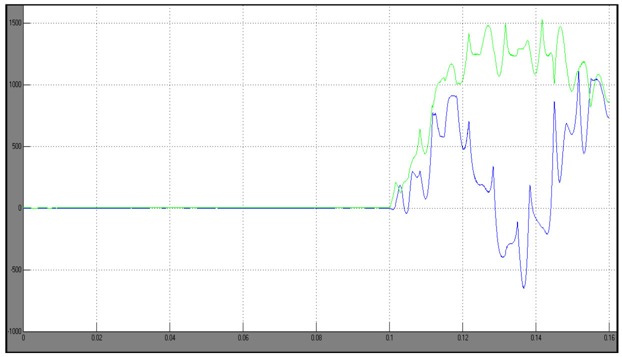

Figure 12: Active and reactive power from inverter with Battery

From the above Fig. it is clear that inverter is compensating both active and reactive power.

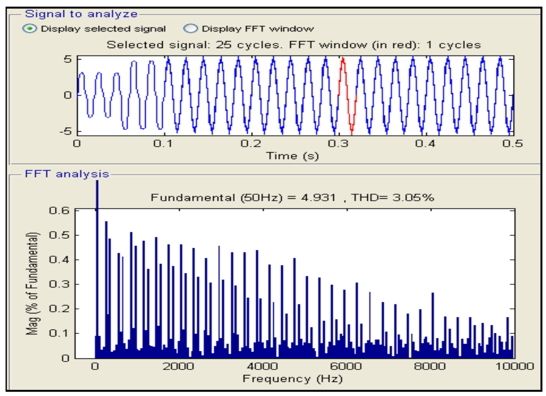

Figure 13: THD for inverter using PI controller

Fig.13. shows the THD analysis of the source current using the PI controller, we get 3.05%.

5.2.Case 2: Implementation of proposed converter using fuzzy logic controller:

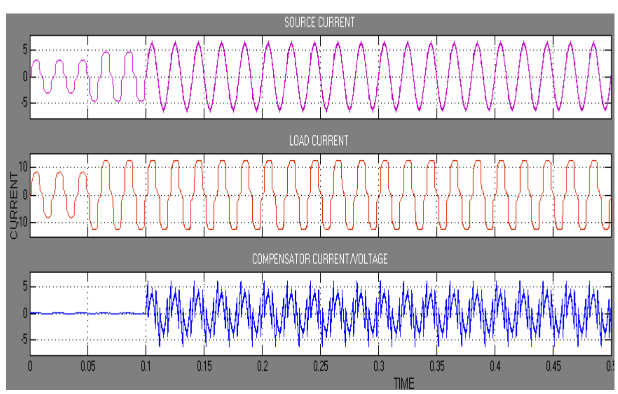

Figure 14: Simulation results for Un Balanced Non Linear Load using fuzzy controller (a) Source current. (b) Load current. (c) Inverter injected current

Fig.14. shows the simulation results of proposed converter using fuzzy logic controller, Source current, load current, compensating current respectively.

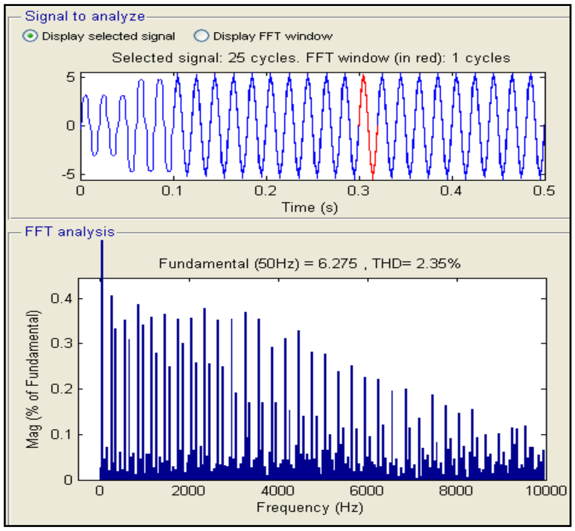

Figure 15: THD for inverter using fuzzy controller

Fig.15 shows the THD analysis of the source current using the fuzzy controller, we get 2.35%.

6.Conclusion

This paper has presented a novel control of an existing grid interfacing inverter using conventional PI controller & fuzzy logic controller to improve the quality of power at PCC for a 3-phase 4-wire DG system. It has been shown that the grid-interfacing inverter can be effectively utilized for power conditioning without affecting its normal operation of real power transfer. The proposed converter with RES system is an efficient mean for mitigation of PQ disturbances introduced to the grid by DERs. 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 latter feature enables its application for compensation of dips coming from the supplying network. 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. Rectifier-based non-linear loads generated harmonics are eliminated by inverter.. When single-phase rectifier loads are connected, inverter currents balance these unbalanced load currents. By using conventional controller we get THD value is 3.05%, but using the fuzzy logic controller THD value is 2.35%. Finally Matlab/Simulink based model is developed and simulation results are presented.

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