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A Control Technique For Unification of DG Units to the electrical network Using Fuzzy Logic Controller

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***Abstract*— This paper proposes with a control method for unification of distributed generation resources using fuzzy logic controller to the utility grid.The theme is to reduce total harmonic distortion reduction using fuzzy logic controller in utility grid while delivering to non linear loads. The proposed method provides compensation for active power reactive power and harmonic load current during connection of distributed generation resources to the utility grid. The method of proposed system is first viewed in stationary reference frame then transformed in to the synchronous orthogonal reference frame. The transformed variables are used to control the voltage source converter as heart of interfacing between DG resources and utility grid.matlab simulink model of the system is done using fuzzy logic controller.Simulation results based on total harmonic distortion reduction evenly presented**

***Index Terms*— Distributed Generation Un*it,* Fuzzy Logic Controller, Voltage Source Converter**

I. INTRODUCTION

Distributed Generation (DG) technology also known as district, decentralized and dispersed generation technology is electricity generated or stored by variety of small grid connected devices referred to as distributed energy resources connected to a distribution grid rather than the transmission network. Generation capacity ranging from KW to MW level usually connoted at distributed voltages 11KV or below.

Distributed generation resources usually include small hydro bio mass gasification co –generation biogas based engines bio-fuel engines hybrid systems such as solar-wind

Increasing number of DG units in electrical networks requires new approach for the controlling and maintenance of the power networks for the power supply reliability and quality in the subsequent situations. As a consequence, the control of DG unit should be improved to meet the requirements for the electrical network. Therefore, design of a control method, which considers different situations of the electrical networks, becomes of high interest for interconnection of DG units to the utility grid.

In this paper, a converter operates as an active inductor at other than fundamental frequency to absorb the harmonic current components. However, not knowing the grid inductance can reduce the performance of proposed control approach. Truely the power grids are facing disturbances with the design of a practical plug-and play converter-based DG interface.

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A rugged consolidate scheme for DG converters featuring mitigation of converter grid resonance at parameter variation, distortion, and current-control parametric instabilities is presented in [1]-[7].

In this a design of a multipurpose control approach for VSC [8] used in DG system using fuzzy logic controller. The idea is to unify the DG resources to the utility grid. With the proposed approach, the proposed VSC controls the injected active power flow from the DG source to the grid and also performs the compensation of reactive power and the nonlinear load current harmonics, keeping the main source current almost sinusoidal during connection of other non linear loads to the grid.

This control method using fuzzy logic controller[9]-[11] allows the decoupling of the currents and enhances their tracking of the changes in the active and reactive power. This paper shows the simulation of the proposed method for all its aspect, i.e., active and reactive power generation along with load current harmonic current compensation .

II. PROPOSED TECHNIQUE

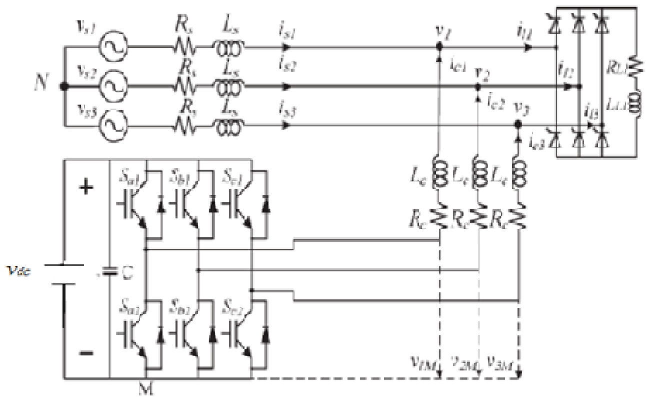

Fig. 1 schematic diagram of proposed technique

Fig. 1 represents the general diagram of the proposed technique. where Rc and Lc represent the equivalent resistance and inductance of the ac filter, coupling transformer, and connection cables; Rs andLs represent the grid resistance and inductance up to the point of common coupling (PCC), respectively ;vk is the supply voltage components at the PCC;v_{sk} is the grid voltage components ;v_{dc} is the dc-link voltage; and i_{sk}, i_{lk}, and i_{ck} are grid, load, and DG current components, respectively. In addition, the DG resources and additional components are represented as a dc voltage source which is connected to the dc side of the converter. Using clarke and park's transformation techniques we can convert three phase instantaneous voltages and currents in abc phases to instantaneous voltages and currents on the αβ –axes ,dq-components respectively. By means of this the control parameters become dc values ,thus filtering and controlling can be obtained easily

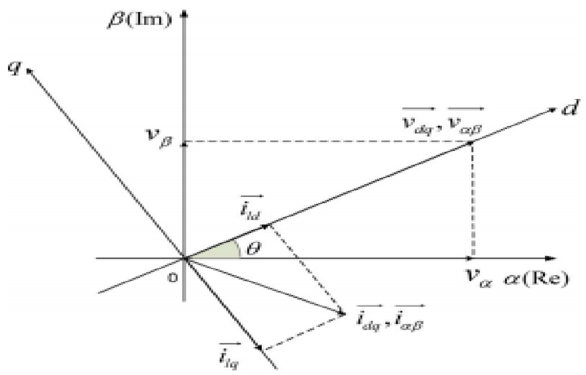

Fig. 2. Voltage and current components in special reference frames

.The instantaneous angle of utility grid can be obtained as

$$\theta = \tan^{-1}\frac{v_\beta}{v_\alpha} \qquad (1)$$

The magnitude of the voltage at the connection can be calculated as

$$v_{ref} = |\vec{v_d}| = |\vec{v_{dq}}| = |\vec{v_{\alpha\beta}}| = \sqrt{v_\alpha^2 + v_\beta^2} \qquad (2)$$

A. CALCULATION OF REFERENCE CURRENT TO SUPPLY LOAD ACTIVE POWER

At fundamental frequency, the active power injected from DG link to the utility grid is

$$P = \frac{3}{2}\left(v_d I_{cd} + v_q I_{cq}\right) \qquad (3)$$

By considering v_q=0.d-component of reference current to provide active current at fundamental frequency is given by

$$I_{cd}^{*} = \frac{2}{3}\frac{P_{ref}}{v_d} \qquad (4)$$

Where P_{ref} is maximum power of the voltage source converter at fundamental frequency and depends on DG system capacity, capacity of power electronic interfacing devices.

B. B.CALCULATION OF HARMONIC COMPONENTS OF D-AXIS REFERENCE CURRENT

In the dq reference frame, the fundamental current component can be seen as a dc component, and as a result, the harmonic load currents can be obtained with low-pass filter (LPF). LPF is designed such that it can pass fundamental and block other than fundamental Then the harmonic currents can be obtained simply by the difference between the input signal and the filtered one, which is equivalent to performing $1-H_{LPF}(s)$. Therefore,i_{ld} can be expressed as

$$i_{ld} = \widetilde{i_{ld}} + I_{ld} \qquad (5)$$

Where $\widetilde{i_{ld}}$ is alternative d-component of load current which is related to harmonic components of load current and I_{ld} is the dc term of load current which represents fundamental frequency of load current . To use DG link as an active power filter, harmonic components of the nonlinear load current must be obtained from DG. For this d-component of nonlinear link reference current is achieved by doing the sum of currents in (4) and alternative terms of load current in (5)

$$i_{cd}^{*} = \widetilde{i_{ld}} + I_{cd}^{*} \qquad (6)$$

C. C.CALCULATION OF REFERENCE CURRENT TO SUPPLY LOAD REACTIVE POWER

In dq frame, quadrature component of load current is perpendicular to direct component of voltage ($v_d \perp i_{lq}$). so q-component of load current indicates required reactive power of the load. To compensate load reactive power, DG unit must provide a current with q-component equal to ilq. it is sufficient to set q-component of DG's reference current equal to q-component of the load current as

$$i_{cq}^{*} = i_{lq} \qquad (7)$$

The term of i^{*}_{cq} is the q-component of DG link reference current.

III. MODELING OF THE PROPOSED DG SYSTEM

By applying kvl to the Fig 1 schematic diagram of proposed technique we get

$$\sum_{i=1}^{3} v_{iM} = \sum_{i=1}^{3}\left(L_c\frac{di_{ci}}{dt} + R_c i_{ci} + v_i + v_{NM}\right) \qquad (8)$$

A null value for the zero voltage components is assumed.

$$v_{NM} = \frac{(v_{1M}+v_{2M}+v_{3M})}{3} = \frac{1}{3}\sum_{i=1}^{3} v_i M \qquad (9)$$

The switching function s_k of the k^{th} leg of the VSC can be expressed as

$$S_k = \begin{cases} 1, \text{if } T_k \text{is on the and } T_k' \text{ is off.} \\ 0, \text{if } T_k \text{is on the and } T_k' \text{ is on.} \end{cases} \qquad (10)$$

Thus, with $v_{kM}= S_k v_{dc}$ and substituting in (8) and (9)

$$\frac{di_{ck}}{dt} = -\frac{R_c}{L_c}i_{ck} + \frac{1}{L_c}\left(s_k - \frac{1}{3}\sum_{j=1}^{3} S_j\right)v_{dc} - \frac{v_k}{L_c}$$

K=1,2,3. (11)

The switching state function can be defined as

$$D_{nk} = \left(S_k - \frac{1}{3}\sum_{j=1}^{3} S_j\right) \qquad (12)$$

Dynamic equation of the proposed model can be expressed as

$$\frac{d}{dt}\begin{bmatrix} i_{c1} \\ i_{c2} \\ i_{c3} \end{bmatrix} = -\frac{R_c}{L_c}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} i_{c1} \\ i_{c2} \\ i_{c3} \end{bmatrix} + \frac{1}{L_c}\begin{bmatrix} D_{n1} \\ D_{n2} \\ D_{n3} \end{bmatrix} v_{dc} - \frac{1}{L_c}\begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix}$$

(13)

IV. STATE-SPACE MODEL OF PROPOSED SYSTEM

By use of Park transformation matrix, the dynamic equations of proposed technique can be transformed to the dq frame as

$$\frac{d}{dt}\begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} = \begin{bmatrix} -\frac{R_c}{L_c} & \omega \\ -\omega & -\frac{R_c}{L_c} \end{bmatrix}\begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} + \frac{1}{L_c}\begin{bmatrix} D_{nd} \\ D_{nq} \end{bmatrix} v_{dc} - \frac{1}{L_c}\begin{bmatrix} v_d \\ v_q \end{bmatrix}$$

(14)

As the sum of the three-phase currents is zero, there is no homopolar component (i_{c0}=0); therefore, the ac neutral point voltage does not affect any transformed current. This voltage can be deduced as

$$v_{nm} = \frac{v_0 - v_{0M}}{\sqrt{3}} \quad (15)$$

By taking (v_q=0), and the other vector's value will be equal to EL(v_d=EL), which is the value of the line-to-line rms voltage of grid voltage. Therefore, (14) can be written as

$$\frac{d}{dt}\begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} = \begin{bmatrix} -\frac{R_c}{L_c} & \omega \\ -\omega & -\frac{R_c}{L_c} \end{bmatrix} \begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} + \frac{1}{L_c}\begin{bmatrix} D_{nd} \\ D_{nq} \end{bmatrix} v_{dc} - \frac{1}{L_c}\begin{bmatrix} E_L \\ 0 \end{bmatrix} \quad (16)$$

By assuming **λ=Lc(dic/dt)+Rcic, switching state functions can be calculated as**

$$D_{nd} = \frac{\lambda_d - L_c \omega i_{cq} + v_d}{v_{dc}} \quad (17)$$

$$D_{nq} = \frac{\lambda_q + L_c \omega i_{cd}}{v_{dc}} \quad (18)$$

λ_d and λ_q are the outputs of fuzzy logic controller in the current control loop.

V. DC VOLTAGE REGULATION

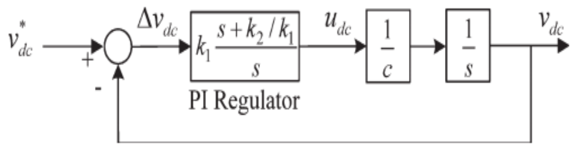

Fig. 3. Control loop of the dc voltage.

The error value of the dc-bus voltage $\Delta vdc = v^*_{dc} - v_{dc}$ is passed through a PI-type controller to regulate the voltage of dc bus (v_{dc}) .Therefore, u_{dc} will be obtained as

$$u_{dc} = k_1 \Delta v_{dc} + k_2 \int \Delta v_{dc}\, dt \quad (19)$$

where k_1 and k_2 are proportional and integral gains of the proposed PI controller. Fig. 3 shows the equivalent control circuit loop of the dc-bus voltage for proposed converter.

$$\frac{v_{dc}(s)}{v^*_{dc}(s)} = 2\zeta\,\omega_{nv} \frac{s + \frac{\omega_{nv}}{2\zeta}}{s^2 + 2\zeta\,\omega_{nv} s + \omega_{nv}^2} \quad (20)$$

where the proportional and integral gains are derived from

$$k_1 = 2\zeta\,\omega_{nv} C \qquad k_2 = \omega_{nv}^2\, C \quad (21)$$

The control effort is obtained from

$$i^*_{do} = \frac{u_{dc} - D_{nq} i_q}{D_{nd}} = \frac{u_{dc} v_{dc} - D_{nq} v_{dc} i_q}{D_{nd} v_{dc}} \quad (22)$$

However, assuming that the current loop is ideal and in normal operation of the active filter, the following properties hold, assuming the supply voltages are given by:

$$v_1 = v\cos(\omega t)$$
$$v_2 = v\cos\left(\omega t - \frac{2\pi}{3}\right)$$
$$v_3 = v\cos\left(\omega t - \frac{4\pi}{3}\right) \quad (23)$$

The transformation to the synchronous reference frame yields

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = T^{12}_{dq}\begin{bmatrix} v_1 \\ v_2 \end{bmatrix} = \sqrt{\frac{3}{2}}\begin{bmatrix} v \\ 0 \end{bmatrix} \quad (24)$$

As a result, $D_{nq} v_{dc} \approx v_q = 0$ and $D_{nd} v_{dc} \approx v_d = \sqrt{3/2}\, v$.
Hence, the control effort can be approximated by

$$i_{d1h+} \approx \sqrt{\frac{2}{3}} \frac{v_{dc}}{v} u_{dc} \quad (25)$$

The reference current in (25) is added to the reference current i^*_{cd}. i_{dlh+} is a dc component, and it will force the active filter to generate or to draw a current at the fundamental frequency. Therefore reference current for d component of distributed generation unit as obtained

$$i^*_{cd} = \widetilde{i_{ld}} + I^*_{cd} + i_{dlh+} \quad (26)$$

V. FUZZY LOGIC CONTROLLER

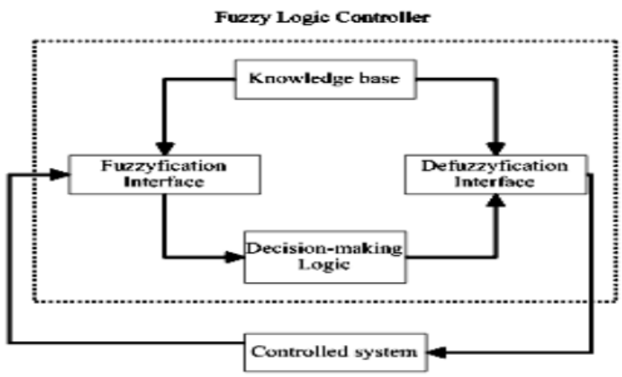

Fig. 4: Basic configuration of FL controller

Unlike Boolean logic, fuzzy logic allows states (membership values) between 0 or 1. Its major features are the use of linguistic variables rather than numerical variables. Linguistic variables, defined as variables whose values are sentences in a natural language (such as small and big), may be represented by fuzzy sets [6]. The general structure of an FLC is represented in Fig.4 and comprises four principal components:

- 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 control rule set;

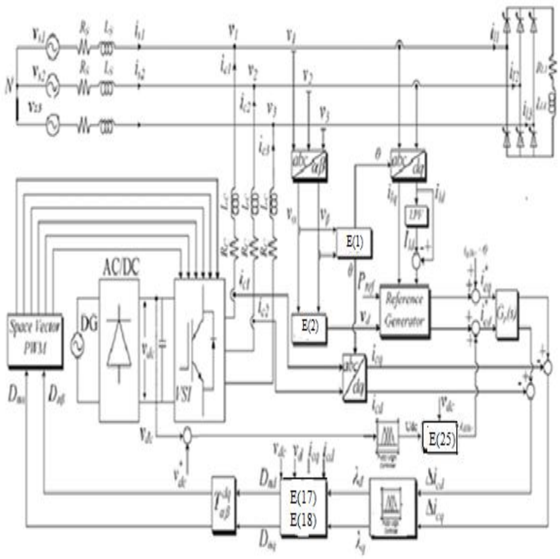

Fig. 5 Block diagram of the control method for the DG systems

- a decision making logic which, simulating a human decision process, infers the fuzzy control action from the knowledge of the control rules and the linguistic variable definitions; and

• a defuzzyfication interface which yields a non fuzzy control action from an inferred fuzzy control action.

In this paper, Fuzzy Logic controller block is used for error signal as shown in Fig.3. The process also same as before except the controller now is Fuzzy Logic. For block the Fuzzy Logic controller consists of seven linguistic variables from input which is; Negative High (NH), Negative Medium (NM),Negative Small (NS), Zero Equivalent (ZE) and Positive Small (PS),Positive Medium (PM), Positive High (PH). Each parameter from linguistic variables for error signal is shown in Fig.. For delta error, there seven linguistic variables from input which is; Negative High (NH), Negative Medium (NM),Negative Small (NS), Zero Equivalent (ZE) and Positive Small (PS),Positive Medium (PM), Positive High (PH) Both variables can be depicted as in Figure

Fuzzy control replaces the proportional integral control , the role of the mathematical approach and replaces it with another that is build from a number of smaller rules that in general only describe a block of the whole system Fig-5.The method of inference binding them together to produce the desired outputs.That is, a fuzzy model has replaced the mathematical one. The inputs and outputs of the system remain the same. Fuzzy controller replaces the proportional integral control in the control loop of dc voltage and current control loop of proposed technique [12] . Harmonics reduced due to multi switching and output is approxmately sine wave so filter design and cost reduced DC link voltage is also reduced because of splitted sources using space vector pulse width modulation technique

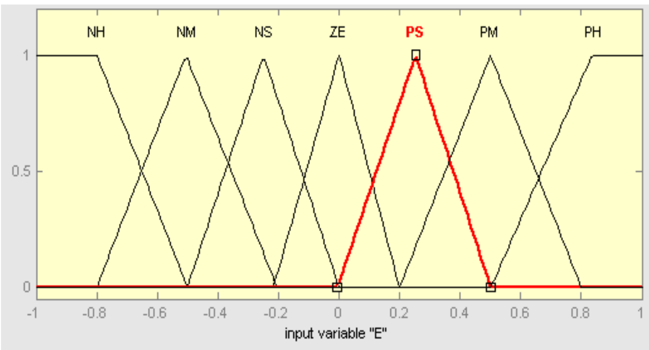

Fig. 6 Linguistic variables from error

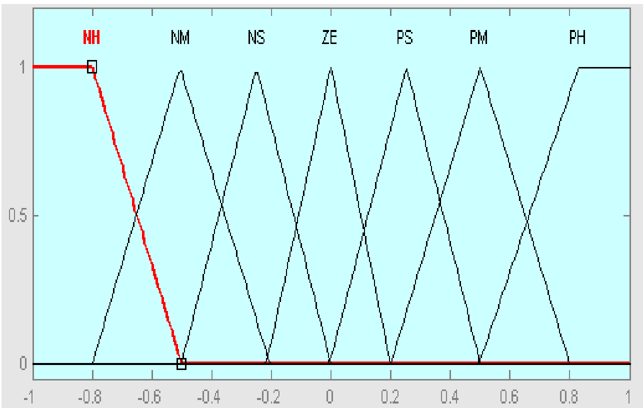

Fig. 7 Linguistic variables from delta error

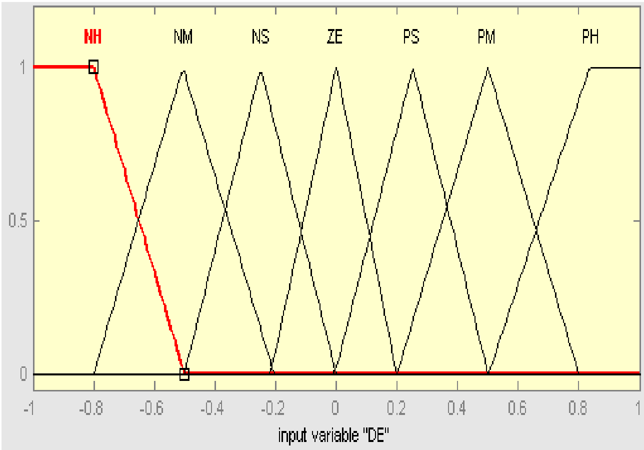

Fig. 8 Shows each parameter for output signal

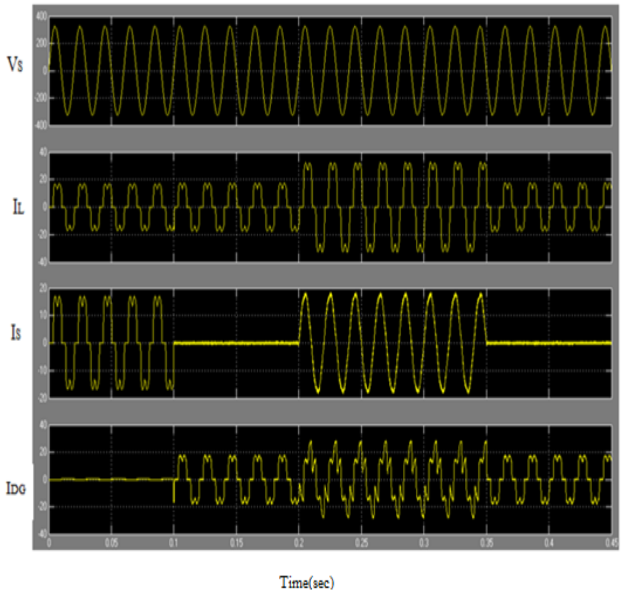

Fig. 9 Source voltage and current waveforms

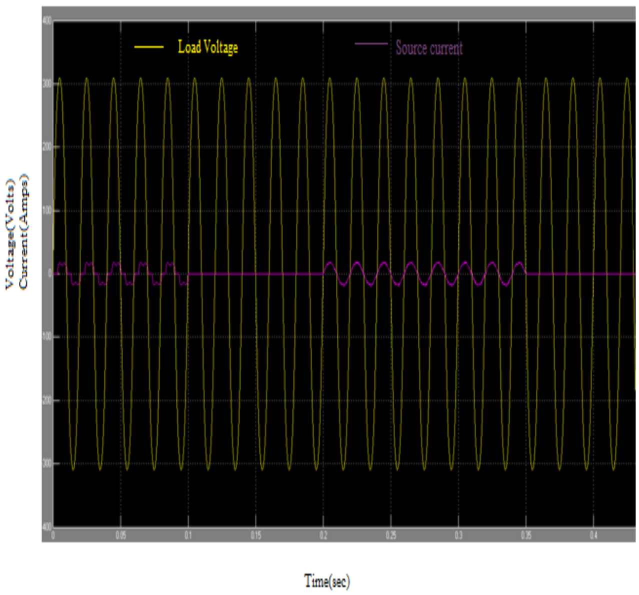

Fig. 10 Load voltage and source current waveforms

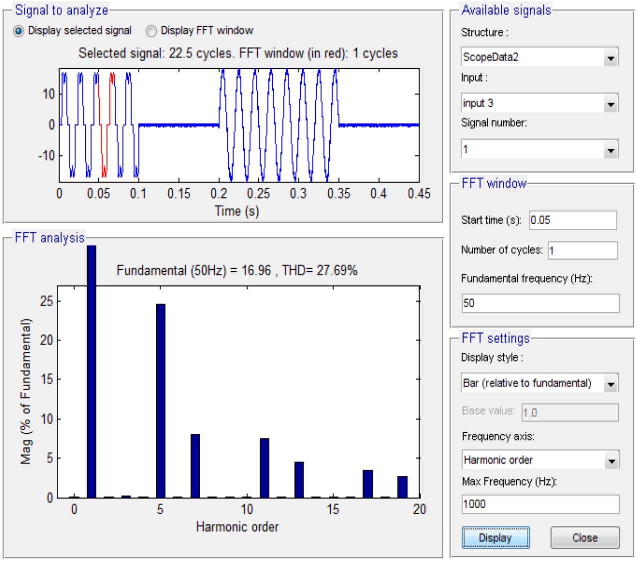

Fig. 11 Before compensation THD of source current

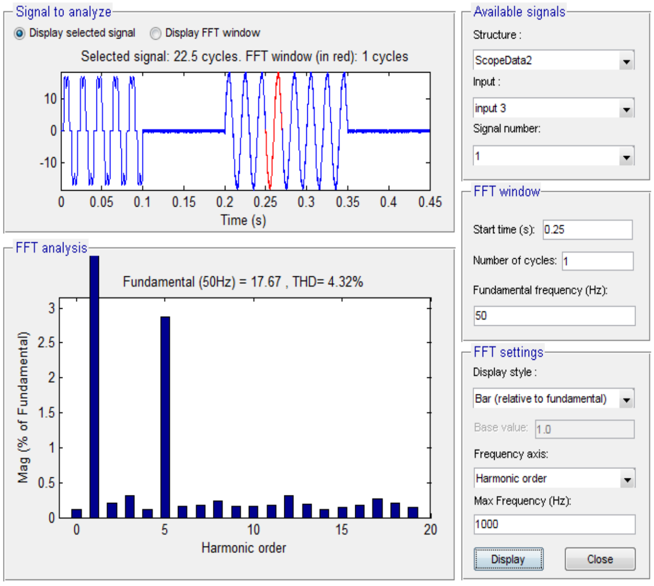

Fig. 12 After compensation THD of source current using pi controller.

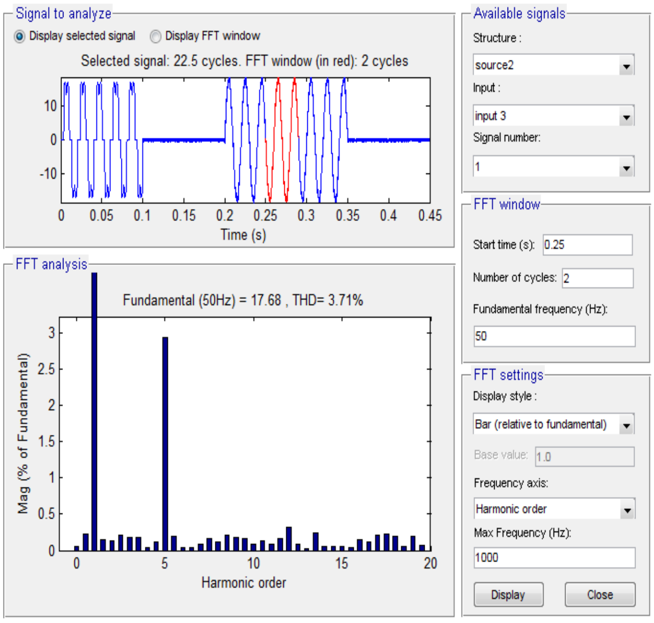

Fig. 13 After compensation THD of source current using fuzzy logic controller

VI. SIMULATION RESULTS

Before the connection of DG link to the grid, a full controlled thyristor converter delivers a load with resistance of 20Ω and 10-mH inductance in each phase. This nonlinear load draws harmonic currents from the utility grid continuously. The DG link is connected to the utility grid at t=0.1s. continued until t=0.2s;, another full-controlled thyristor converter with non linear load of 20 ohms and 10 mH inductance is connected, and it is disconnected from the utility grid at t=0.35s.. Fig-9 shows the load voltage(v_l), load current(i_l), grid current(i_{grid}), and DG Current (i_{DG})in one phase . As shown in this figure, after the connection of DG link to the grid at t=0.1s, the grid current becomes zero, and all the active and reactive current components and fundamental and harmonic frequencies are provided by DG link Fast fourier transform analysis results of load and grid currents indicate that the DG link can largely improve the THD of the grid currents while delivering to nonlinear loads. Thus THDs of the grid currents are reduced from 27.69%, before compensation to 4.32% after compensation using pi controller and then to 3.71% by replacing pi controller with fuzzy controller . Result confirm the capability of the proposed DG link using fuzzy logic controller to compensate harmonic currents of the nonlinear loads and reduction in total harmonic distortion.Fig. 11 Fig. 12and Fig. 13 shows FFT analysis of total harmonic distortion reduction results before and after connection dg unit using pi controller and fuzzy logic controller

VII. CONCLUSION

A multi objective control technique for the utility grid-connected converter-based DG unified using fuzzy logic controller has been presented in this paper. Adaptable of the proposed DG using fuzzy logic controller in both steady-state and transient operations has been observed through simulation result., The problems due to synchronization between DG and grid will not exist, and DG link can be connected to the utility grid without any current overshoot. By the use of the proposed control method, DG system is introduced as a new way for distributed FACTS device in distribution network. The results shows that, in all conditions, the load voltage and source current are in phase and power factor at the point of decoupling is improved DG systems can act as power factor corrector devices. The results shows that proposed DG system using fuzzy logic controller can provide required harmonic load currents in all situations compared to proportion integral control . Thus, by reducing THD of source current, acting as active filter. The control approach technique can be used for different types of DG resources as power quality improvement devices in distribution network.

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