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Performance Improved Active Power Filter Using Fuzzy Based Adaptive Controller for Renewable Power Generation Systems

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Abstract- An Active power filter implemented with a four-leg voltage-source inverter utilizing a predictive control scheme is introduced. The utilization of a four-leg voltage-source inverter permits the pay of current consonant parts, and in addition lopsided current created by single-stage nonlinear burdens. A point by point yet straightforward numerical model of the dynamic power channel, including the impact of the identical power framework impedance, is determined and used to plan the prescient control calculation. The pay execution of the proposed dynamic power channel and the related control plan under enduring state and transient working conditions is shown through reproductions results. As of late, fuzzy logic controller was connected for active power filter (APF) control application, as the APF is only a current controlled VSI. In this paper, a fuzzy logic based shunt APF is displayed in light of the compelling time idea. The viable time idea disposes of the trigonometric counts and part ID, along these lines it lessens the computational exertion. Reenactment results show the viability of the APF with the fuzzy logic based control procedure. Reproduction results are acquired for both PI controller and fuzzy logic controller and the outcomes are thought about. In the fuzzy controlled four leg inverter APF is utilized for power quality change.

Keywords: Fuzzy Logic Controller, Active power filter, current control, four-leg converters, predictive control Harmonics, and Power Quality.

Introduction

Renewable generation influences power quality because of its nonlinearity, since sunlight based generation plants and wind power generations must joined with the framework through high power static PWM converters [1]. The non-uniform nature of power generation specifically influences voltage regulation and makes volt-age twisting in power frameworks. This new situation in power appropriation frameworks will require more modern remuneration generation strategies. Albeit dynamic power channels actualized with three-stage four-leg voltage-source inverters (4L-VSI) have as of now been introduced in specialized writing [2]–[6], the essential commitment of this paper is a prescient control calculation composed and executed particularly for this application. Active power filters actualized with three-stage four-leg voltage-source inverters (4LVSI) have as of now been displayed in the specialized writing, the essential commitment of this paper is a prescient control calculation planned and executed particularly for this application. Customarily, dynamic power channels have been controlled utilizing imagined controllers, for example, PI sort or versatile, for the present and in addition for the dc voltage circles. PI controllers must be composed in light of the proportional straight model, while prescient controllers utilize the nonlinear model, which is closer to genuine working conditions. An exact model got utilizing prescient controllers enhances the execution of the dynamic power channel, particularly amid transient working conditions, on the grounds that it can rapidly take after the present reference signal while keeping up a consistent dc-voltage. Be that as it may, in this paper we proposed a fuzzy logic controller rather than pi controller at dc join.

A precise model acquired utilizing fuzzy logic controllers enhances the execution of the dynamic power channel, particularly amid transient working conditions, in light of the fact that it can rapidly take after the present reference signal while keeping up a consistent dc-voltage. In this way, usage of fuzzy logic control in power converters have been utilized for the most part as a part of actuation engine drives[7]–[10].In the instance of engine drive applications, fuzzy logic control speaks to an extremely natural control conspire that handles multivariable attributes, rearranges the treatment of dead-time pay, and allows beat width modulator substitution. Then again, these sorts of uses present hindrances identified with motions and precariousness made from obscure burden parameters [11]. One point of preference of the proposed calculation is that it fits well in dynamic power channel applications, since the power converter yield parameters are surely understood [12].

The converter yield swell channel is a piece of the dynamic power channel outline and the power framework impedance is gotten from understood standard techniques. On account of obscure framework impedance parameters, an estimation technique can be utilized to determine a precise R–L identical impedance model of the framework .This paper shows the numerical model of the 4L-VSI and the standards of op generation of the proposed prescient control plan, including the configuration methodology. The complete depiction of the chose current reference generation actualized in the dynamic power channel is additionally displayed [13-16].

II. Four-Leg Converter Model

It comprises of different sorts of power generation units and distinctive sorts of burdens. Renewable sources, for example, wind and daylight, are commonly used to produce power for private clients and little commercial enterprises. Both sorts of power generation use air conditioning/air conditioning and dc/air conditioning static PWM converters for voltage change and battery banks for long haul vitality stockpiling. These converters perform greatest power direct following toward concentrate the most extreme vitality conceivable from wind and sun. The electrical vitality utilization conduct is arbitrary and unusual, and accordingly, it might be single-or three-stage, adjusted or unequal, and straight or nonlinear. A dynamic power channel is joined in parallel at the purpose of basic coupling to repay current music, current unbalance, and responsive power. It is created by an electrolytic capacitor, a four-leg PWM converter, and a first-request yield swell channel, as appeared in Fig. 1. This circuit considers the power framework identical impedance Zs, the converter yield swell channel impedance Zf, and the heap impedance ZL.

The four-leg PWM converter topology is appeared in Fig. 2. This converter topology is like the traditional three-stage converter with the fourth leg joined with the nonpartisan transport of the framework. The fourth leg increments changing states from enhancing control adaptability and yield voltage quality, and is suitable for current lopsided remuneration.

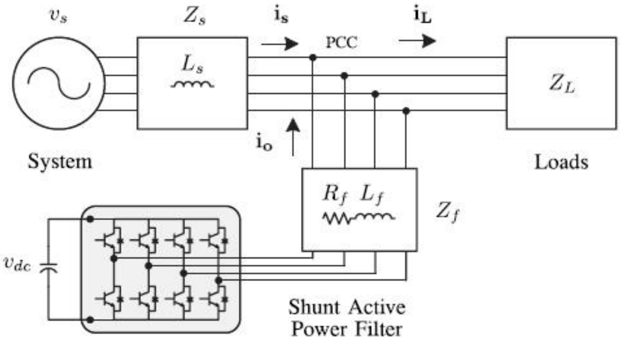

Fig.1.Three-Phase Equivalent Circuit of the Proposed Shunt Active Power Filter.

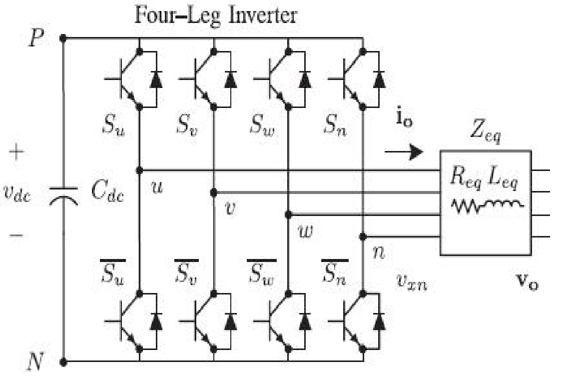

Fig.2. Two-level four-leg PWM-VSI topology

The voltage in any leg x of the converter, measured from the unbiased point (n), can be communicated as far as exchanging states, as takes after:

$$v_{xn} = S_x - S_n v_{dc}, \qquad x = u, v, w, n. \tag{1}$$

The scientific model of the channel got from the identical circuit appeared in Fig. 1 is

$$V_o = v_{xn} - R_{eq} i_o - L_{eq} \frac{di_o}{dt} \tag{2}$$

Where Req and Leq are the 4L-VSI yield parameters communicated as Thevenin's impedances at the converter yield terminals Zeq. In this way, the Thevenin's proportionate impedance is controlled by an arrangement association of the swell channel impedance Zf and a parallel game plan between the framework identical impedance Zs and the heap impedance ZL.

$$Z_{eq} = \frac{Z_S Z_L}{Z_S + Z_L} + Z_f \approx Z_s + Z_f \tag{3}$$

For this model, it is expected that ZL _ Zs, that the resistive piece of the framework's proportionate impedance is ignored, and that the arrangement reactance is in the scope of 3–7% p.u., which is an adequate estimation of the genuine framework. At long last,

*R*eq = *Rf* and *L*eq = *Ls* + *Lf* (4)

III. Reference Current Generation Scheme

A dq-based current reference generator plan is utilized to acquire the dynamic force channel current reference signals. This plan introduces a quick and precise sign following capacity. This trademark maintains a strategic distance from voltage vacillations that disintegrate the present reference signal influencing pay execution. The present reference signs are gotten from the comparing load streams as appeared in Fig. 4. This module ascertains the reference signal streams required by the converter to repay responsive force, current consonant and current lopsidedness. The relocation power variable (sin φ(L)) and the most extreme aggregate symphonies contortion of the heap (THD(L)) characterizes the connections between the clear power required by the dynamic force channel, as for the heap, as appears.

$$\frac{S_{APF}}{S_L} = \frac{\sqrt{\sin \emptyset_{(L)} + THD_{(L)}^{\,2}}}{\sqrt{1 + THD_{(L)}^{\,2}}} \tag{5}$$

Where the value of THD $_{(L)}$ includes the maximum compensable harmonic current, defined as double the sampling frequency *fs*. The frequency of the maximum current harmonic component that can be compensated is equal to one half of the converter switching frequency. The *dq*-based scheme operates in a rotating reference frame; therefore, the measured currents must be multiplied by the sin (*wt*) and cos(*wt*) signals. By using *dq*-transformation, the *d* current component is synchronized with the corresponding phase-to-neutral system voltage, and the *q* current component is phase-shifted by 90◦. The sin(*wt*) and cos(*wt*) synchronized reference signals are obtained from a synchronous reference frame (SRF) PLL. The SRF-PLL generates a pure sinusoidal waveform even when the system voltage is severely distorted. Tracking errors are eliminated, since SRF-PLLs are designed to avoid phase voltage unbalancing, harmonics (i.e., less than 5% and 3% in fifth and seventh, respectively), and offset caused by the nonlinear load conditions and measurement errors [3], the relationship between the real currents *iLx*(*t*) (*x* = *u*, *v*,*w*) and the associated *dq* components (*id* and *iq).*

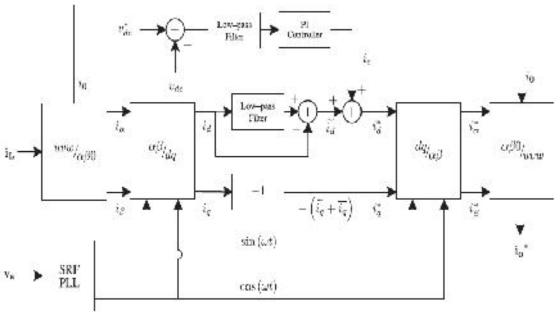

Fig.3. *Dq*-Based Current Reference Generator Block Diagram.

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin\omega t & \cos\omega t \\ -\cos\omega t & \sin\omega t \end{bmatrix} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{Lu} \\ i_{Lv} \\ i_{Lw} \end{bmatrix} \quad (6)$$

A low-pass filter (LFP) extricates the dc part of the stage streams id to produce the consonant reference segments id . The receptive reference segments of the stage streams are gotten by stage moving the relating air conditioning and dc parts of iq by 180◦. So as to keep the dc-voltage steady, the abundancy of the converter reference current must be adjusted by including a dynamic force reference flag i.e. with the d-segment. The subsequent signs i*d and i*q are changed back to a three-stage framework by applying the converse Park and Clark change, The cut off recurrence of the LPF utilized as a part of this paper is 20 Hz.

$$\begin{bmatrix} i^*_{ou} \\ i^*_{ov} \\ i^*_{ow} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 \\ 0 & \sin\omega t & -\cos\omega t \\ 0 & \cos\omega t & \sin\omega t \end{bmatrix} \begin{bmatrix} i_0 \\ i^*_d \\ i^*_q \end{bmatrix} \quad (7)$$

The current that flows through the neutral of the load is compensated by injecting the same instantaneous value obtained from the phase-currents, phase-shifted by 180◦, as shown next.

$$i^*_{on} = -(i_{Lu} + i_{Lv} + + i_{Lw}) \quad (8)$$

One of the major advantages of the dq-based current reference generator scheme is that it allows the implementation of a linear controller in the dc-voltage control loop. However, one important disadvantage of the dq-based current reference frame algorithm used to generate the current reference is that a second order harmonic component is generated in id and iq under unbalanced operating conditions. The amplitude of this harmonic depends on the percent of unbalanced load current (expressed as the relationship between the negative sequence current iL, 2 and the positive sequence current iL, 1). The second-order harmonic cannot be removed from id and iq , and therefore generates a third harmonic in the reference current when it is converted back to abc frame. Since the load current does not have a third harmonic, the one generated by the active power filter flows to the power system.

A. DC Link Voltage Control

The dc-voltage converter is controlled with a traditional PI controller. This is an important issue in the evaluation, since the cost function is designed using only current references, in order to avoid the use of weighting factors. Generally, these weighting factors are obtained experimentally, and they are not well defined when different operating conditions are required. Additionally, the slow dynamic response of the voltage across the electrolytic capacitor does not affect the current transient response. For this reason, the PI controller represents a simple and effective alternative for the dc-voltage control. The dc-voltage remains constant (with a minimum value of sqrt of 6vs (rms) until the active power absorbed by the converter decreases to a level where it is unable to compensate for its losses. The active power absorbed by the converter is controlled by adjusting the amplitude of the active power reference signal ie, which is in phase with each phase voltage. In the block diagram shown in Fig. 4, the dc-voltage vdc is measured and then compared with a constant reference value v*dc. The error (e) is processed by a PI controller, with two gains, Kp and Ti. Both gains are calculated according to the dynamic response requirement. Fig. 4 shows that the output of the PI controller is fed to the dc-voltage transfer function Gs which is represented by a first-order system.

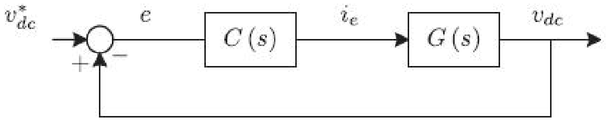

Fig.4. DC-voltage control block diagram.

$$G(s) = \frac{v_{\mathrm{dc}}}{i_e} = \frac{3}{2}\frac{K_p v_s \sqrt{2}}{C_{\mathrm{dc}} v^*_{\mathrm{dc}}} \quad (9)$$

The equivalent closed-loop transfer function of the given system with a PI controller

$$C(s) = K_p\left(1 + \frac{1}{T_i \cdot s}\right)$$

$$\frac{v_{\mathrm{dc}}}{i_e} = \frac{\frac{\omega_n^2}{a}\cdot(s+a)}{s^2 + 2\zeta\omega_n \cdot s + \omega_n^2} \quad (10)$$

Since the time response of the dc-voltage control loop does not need to be fast, a damping factor $\zeta = 1$and a natural angular speed $\omega n = 2\pi \cdot 100$ rad/s are used to obtain a critically damped response with minimal voltage oscillation. The corresponding integral time $Ti = 1/a$ (13) and proportional gain Kp can be calculated as

$$\zeta = \sqrt{\frac{3}{8}\frac{K_p v_s \sqrt{2} T_i}{C_{\mathrm{dc}} v_{\mathrm{dc}}^*}}$$

$$\omega_n = \sqrt{\frac{3}{2}\frac{K_p v_s \sqrt{2}}{C_{\mathrm{dc}} v_{\mathrm{dc}}^* T_i}}. \tag{11}$$

IV.Fuzzy Logic Control

L. A. Zadeh displayed the first paper on fuzzy set hypothesis in 1965. From that point forward, another dialect was produced to depict the fuzzy properties of reality, which are extremely troublesome and at some point even difficult to be portrayed utilizing traditional techniques. Fuzzy set hypothesis has been broadly utilized as a part of the control territory with some application to power framework [5]. A basic fuzzy logic control is developed by a gathering of tenets in view of the human information of framework conduct. Matlab/Simulink recreation model is constructed to examine the dynamic conduct of converter. Moreover, plan of fuzzy logic controller can give attractive both little flag and substantial sign element execution at same time, which is impractical with direct control method. In this way, fuzzy logic controller has been potential capacity to enhance the heartiness of compensator.

The fundamental plan of a fuzzy logic controller is appeared in Fig 5 and comprises of four central parts, for example, a fuzzy fication interface, which changes over info information into suitable etymological qualities; a learning base, which comprises of an information base with the important semantic definitions and the control guideline set; a choice making logic which, reenacting a human choice procedure, deduce the fuzzy control activity from the learning of the control rules and phonetic variable definitions; a de-fuzzification interface which yields non fuzzy control activity from a construed fuzzy control activity [10]

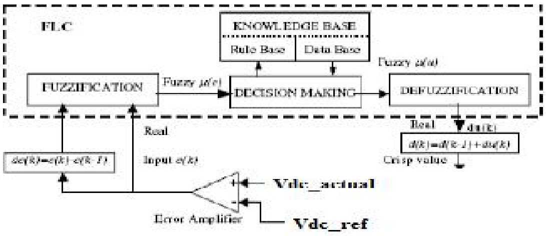

Fig.5. Block diagram of the Fuzzy Logic Controller (FLC) for proposed converter.

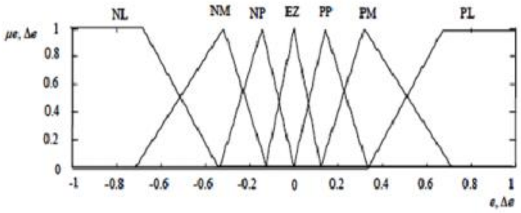

Fig.6. Membership functions for Input, Change in input, Output.

Standard Base: the components of this principle base table are resolved taking into account the hypothesis that in the transient state, extensive blunders need coarse control, which requires coarse in-put/yield variables; in the enduring state, little mistakes require fine control, which requires fine data/yield variables. Taking into account this the components of the standard table are gotten as appeared in Table 1, with "Vdc" and 'Vdc-ref' as inputs.

Δe \ e	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	EZ
NM	NL	NL	NL	NM	NS	EZ	PS
NS	NL	NL	NM	NS	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PS	NM	NS	EZ	PS	PM	PL	PL
PM	NS	EZ	PS	PM	PL	PL	PL
PL	NL	NM	NS	EZ	PS	PM	PL

V. Matlab Modeling And Simulation Results

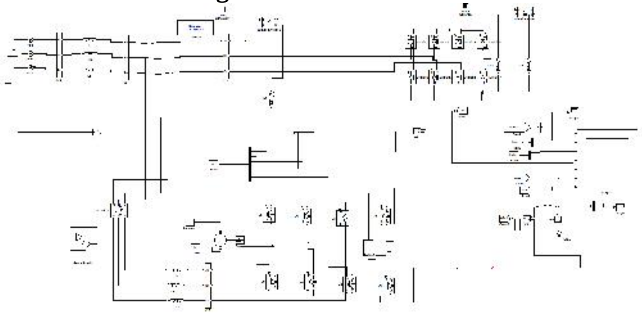

Fig.7. Matlab/Simulink Model of Proposed RES Fed 4-Leg APF system with formal PI & Intelligence Controllers.

Fig.7. Matlab/Simulink Model of Proposed RES Fed 4-Leg APF system with formal PI & Intelligence Controllers.

Case 1: Proposed RES Fed APF with Conventional PI Controller

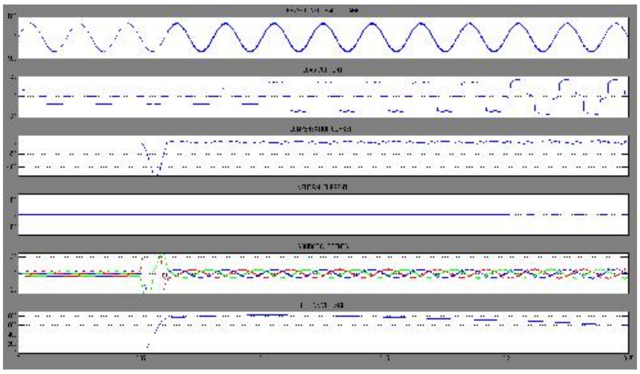

Fig.8. Simulation results for APF with Formal PI Controller

(a) Source Voltage. (b) Load current. (c) Compensator Current.
(d) Neutral Current, (e) Source Current (f) DC Link Voltage.

Fig.8. Simulation results for APF with Formal PI Controller (a) Source Voltage. (b) Load current. (c) Compensator Current, (d) Neutral Current, (e) Source Current (f) DC Link Voltage. Here compensator is turned on at 0.05 seconds, before we get some harmonics coming from non-linear load, then distorts our parameters and get sinusoidal when compensator is in on.

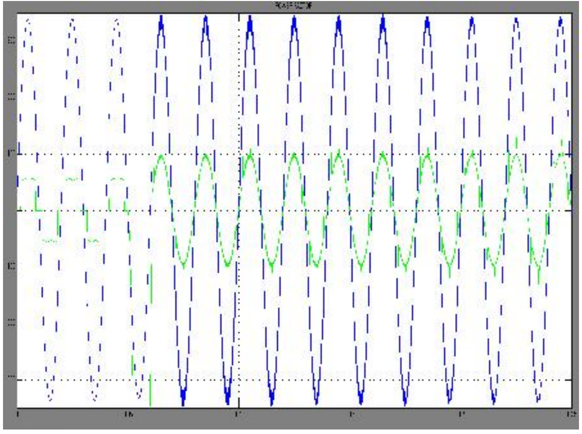

Fig.9. Power Factor for APF with Conventional PI Controller.

Fig.9. shows the power factor it is clear from the figure after compensation power factor is unity.

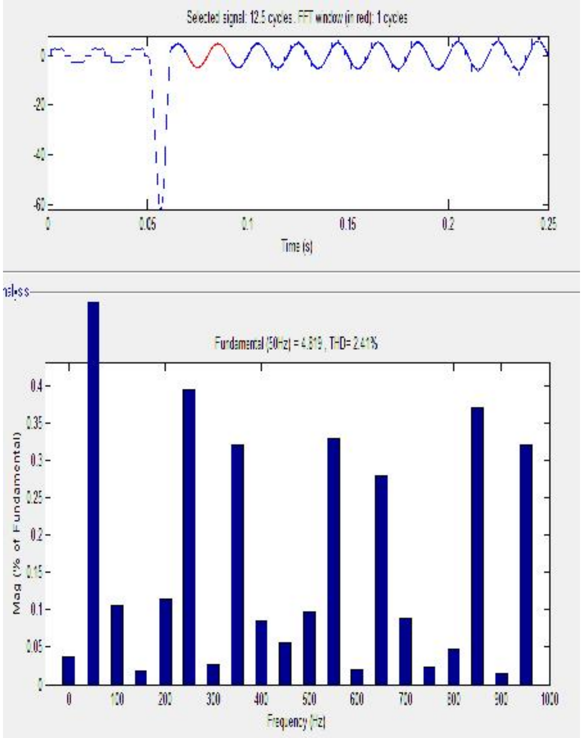

Fig.10. FFT Analysis of Phase-A Source Current with PI Controlled APF

Fig.10. shows the FFT Analysis of Phase-A Source Current with PI Controlled APF, here we get 2.41%.

Case 2: Proposed APF with Intelligence based Fuzzy Controller

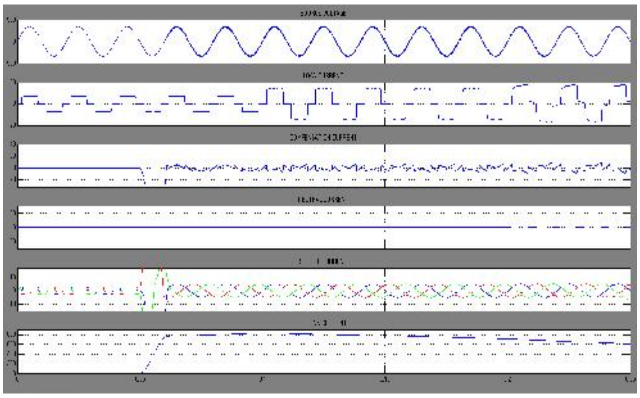

Fig.11. Simulation results for APF with Fuzzy Controller
(a) Source Voltage. (b) Load current. (c) Compensator Current.
(d) Neutral Current, (e) Source Current (f) DC Link Voltage.

Fig.11. Simulation results for APF with Fuzzy Controller (a) Source Voltage. (b) Load current. (c) Compensator Current, (d) Neutral Current, (e) Source Current (f) DC Link Voltage. Here compensator is turned on at 0.05 seconds, before we get some harmonics coming from non-linear load, then distorts our parameters and get sinusoidal when compensator is in on.

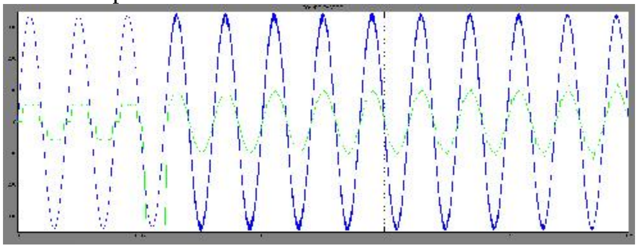

Fig.12. Power Factor for APF with Fuzzy Controller

Fig.12.shows the power factor it is clear from the figure after compensation power factor is unity.

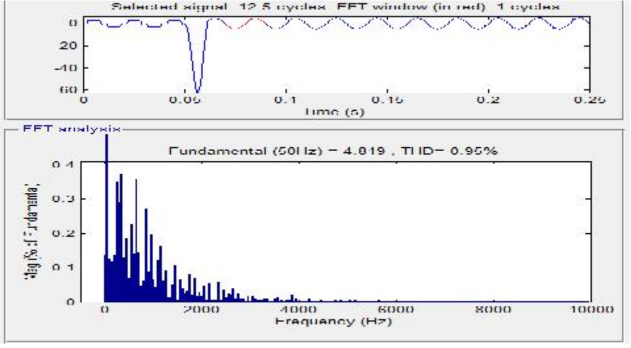

Fig.13. FFT Analysis of Phase-A Source Current with Fuzzy Controlled APF.

Fig.13. shows the FFT Analysis of Phase-A Source Current with Fuzzy Controlled APF, here we get 0.95%.

VI. Conclusion

This paper has presented a novel control of an existing RES interfacing APF using conventional PI controller & fuzzy logic controller to improve the quality of power at PCC for a 3-phase 4-wire system. It has been shown that the APF system can be effectively utilized for power conditioning without affecting its normal operation of real power transfer. By using conventional controller we get THD value is 2.41%, but using the fuzzy logic controller THD value is 0.95%. Simulated results have proved that the proposed predictive control algorithm is a good alternative to classical linear control methods.

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