AIJREAS VOLUME 1, ISSUE 6 (2016, JUNE) (ISSN-2455-6300) ONLINE
ANVESHANA'S INTERNATIONAL JOURNAL OF RESEARCH IN ENGINEERING AND APPLIED SCIENCES

COMPARATIVE ANALYSIS OF DIFFERENT CONTROL TECHNIQUE IN SAPF FOR RENEWABLE POWER GENERATION SYSTEMS

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ABSTRACT:
The Paper investigates about the execution of various control Techniques in Shunt active Power filter for improvement of Power Quality. It goes for outstanding compensation characteristics in steady state. Active Power Filter has the accompanying capacities; Harmonic Compensation, Voltage Regulation, Reactive Power compensation and Load Balancing. The APF current control is difficult because of it's non-sinusoidal reference and considered imperative to obtain desired compensation performance. Here we talked about PI, fuzzy and ANN controls for APF to enhance the power quality. Here a 4-leg VSC type APF is implemented which permits the compensation of current harmonic components, and in addition unbalanced current created by nonlinear loads. A comparison between PI based, ANN based and FLC based control is carried out. The analysis and performances are evaluated with simulation results. The simulation result accepts near studies among 3 controllers using MATLAB/SIMULATION software.

Index Terms: *Power Quality, Shunt Active power filter, Four-leg converter, Fuzzy Logic Controller, ANN controller.*

I. INTRODUCTION

Now-a-days Power quality problems had directly been affected the large number of computers, devices and other sensitive electrical loads connected to the grid. The critical issues is important to current harmonics produced by the persistently expanding number of nonlinear loads connected to the power grid, such as diode and thyristor front-end rectifiers etc. As a result, these harmonics can cause voltage distortions and additional losses in the power system also it can malfunctionate the sensitive electronic equipment. Therefore according to IEEE harmonic standards 529 the injecting harmonic current into the grid should be limited to a value. Generally the harmonics are two types i.e. Voltage harmonics and current harmonics. Among these current harmonics plays a major role in power quality issues. A simple and easy solution to compensate the current harmonics is to use shunt passive filters which consist of LC filter and high pass filter which has been followed conventionally. Nevertheless, their performance strongly depends on the grid impedance and can possibly cause the unwanted parallel resonance phenomena with the grid [2]. In the most recent decades, the expanding unwavering quality of Power semiconductor devices has spurred the improvement of power electronics solution for the issue of harmonic circulation into the grid. The shunt active power filter (APF), comprising essentially of a voltage source inverter (VSI) with a substantial capacitor on its dc link, is viewed as an entrenched answer for lessen the current harmonics to the prescribed standard limits. The non-uniform nature of power generation specifically influences voltage regulation and makes voltage distortion in power systems. Although Active power filters executed with three-phase four-leg voltage-source inverters (4L-VSI) have as of now been exhibited in the specialized writing, the essential commitment of this paper is a prescient control calculation outlined and actualized particularly for this application. For the most part, Active power filters have been controlled utilizing PI type or adaptive, for the current and in addition for the dc-voltage loops. PI controllers must be composed in light of the equivalent linear model, while predictive controllers utilize the nonlinear model, which is nearer to real operating conditions.

An exact model acquired utilizing predictive controllers enhances the execution of the Active power filter, particularly amid transient working conditions, since it can rapidly take after the current reference signal while keeping up a consistent dc-voltage. As such, usage of predictive control in power converters has been utilized for the most part as a part of induction motor drives. On account of motor drive applications, predictive control speaks to an exceptionally instinctive control scheme that handles multivariable qualities, disentangles the treatment of dead-time compensations, and allows Pulse width modulator substitution. In any case, these sorts of utilizations present weakness is identified with oscillations and instability made from unknown Load parameters. One point of preference of the proposed algorithm is that it fits well in Active power filter applications, since the power converter yield parameters are surely understood [3].

The converter output ripple filter is a piece of the Active power filter design and the Power system impedance is taken from well-known standard systems. In this Paper Essential Ideas of Active power filter is displayed in Part II. On account of unknown system impedance parameters, an estimation technique can be utilized to infer a precise R–L identical impedance model of the system. In this paper the scientific model of the 4L-VSIand the standards of operation of the proposed prescient control plan are introduced in section III. The complete depiction of the chose current reference generator actualized in the Active power filter is likewise displayed in section IV. The Control plan Of Dc bus voltage control and ANN control calculation is depicted in section V. At last, the simulation results are depicted in part VI.

II. SHUNT ACTIVE POWER FILTER

Shunt active power filter is utilized as a part of the load side of the system. Since major reason for the current harmonics is the non linear load in the system.

A. Basic idea of active power filter

Fig.1 demonstrates the arrangement of active power filter with non-linear load. The essential working rule of active power filter is that a non sinusoidal waveform at a bus can be amended to sinusoidal by injecting current of legitimate magnitude and waveform.

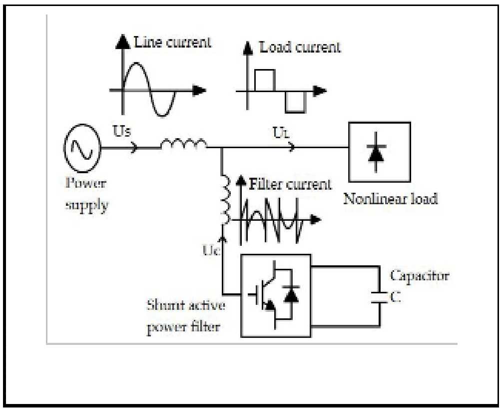

Fig.1 Basic concept shunt active power filter

The current equation at node is

IL = IS + IF (1)

The load current having fundamental and harmonic content, and IF is the harmonic compensating current.

IL + IH = IS + IH (2)

Filter provide harmonic requirement of the load

IL + IH = IS + IH (3)

IL= IS (4)

Thus the supply current represents the fundamental waveform input output harmonics.

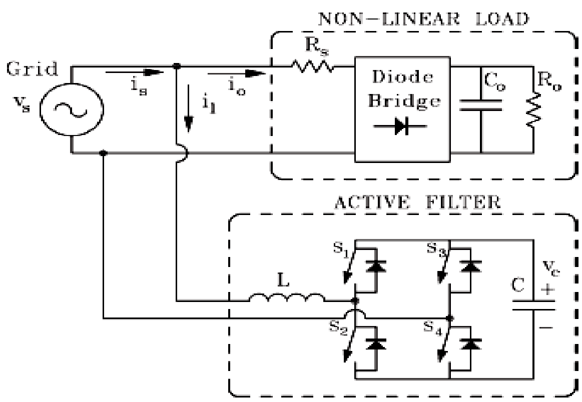

Fig.2 Shunt APF with non-linear load and the full-bridge converter

Fig.2. shows the configuration of active shunt filter with non-linear load and the full bridge converter which is almost widely used to eliminate current harmonics, reactive power compensation and balancing the unbalanced currents. [4]

B. Non-linear loads

Non-linear loads are considered as the second category of loads. The purpose of sinusoidal voltage does not result in a sinusoidal flow applied sinusoidal voltage for non-linear devices. In this system the nonlinear load consists of a diode bridge, a series resistance (Rs), a load resistance (Ro).

III. THREE PHASE FOUR-LEG CONVERTER MODEL

Fig. 3 demonstrates the design of a typical power distribution system with renewable power generation. It comprises of different sorts of power generation units and different types of loads. Renewable sources, for example wind and photovoltaic are normally used to generate electricity for residential users and little commercial enterprises. Both types of power generation use ac/ac and dc/ac static PWM converters for voltage conversion and battery banks for long term energy storage. These converters perform maximum power point tracking to extract the maximum energy possible from wind and sun. An active power filter is associated in shunt at the point of common coupling to compensate, current unbalance, current harmonics and reactive power.

In Fig.4. The circuit considers the power system equivalent impedance *Zs*, the converter output ripple filter impedance *Zf*, and the load impedance *ZL*. The four-leg PWM converter topology is appeared in Fig 5. This converter topology is similar to the conventional three-phase converter with the fourth leg connected to the neutral bus of the system which builds switching states from 8 to16, enhancing control adaptability and output voltage quality, and is appropriate for current unbalanced compensation.

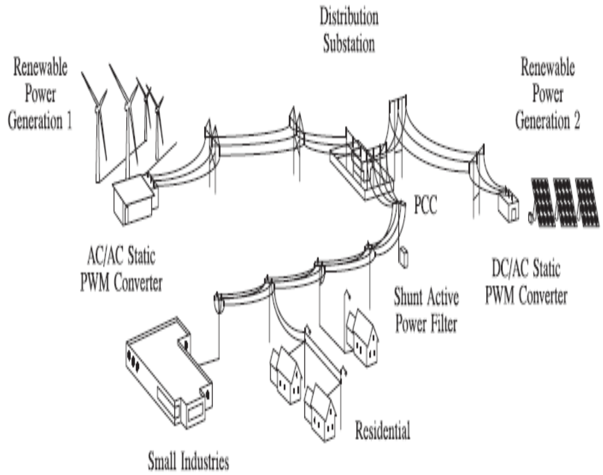

Fig. 3 Stand-alone hybrid power generation system with a shunt active power filter

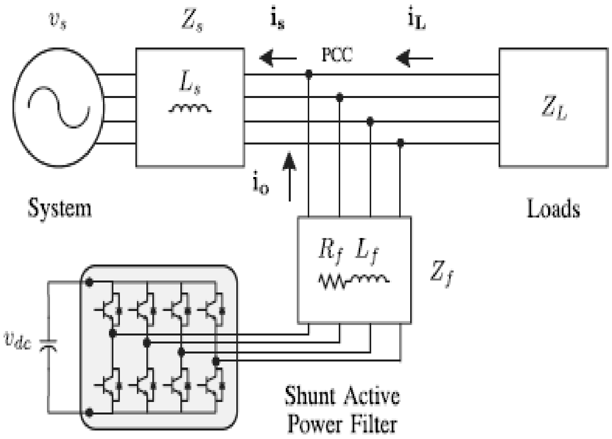

Fig. 4 Three-phase equivalent circuit of the proposed shunt active power filter

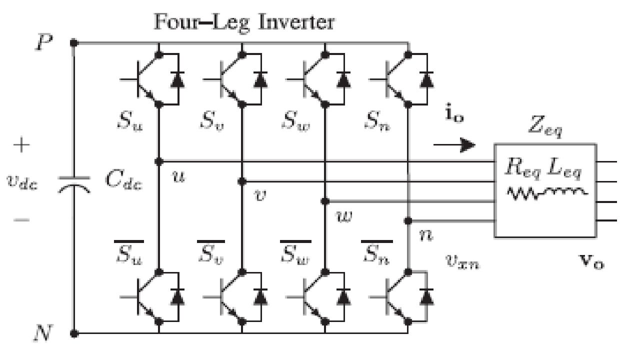

Fig. 5 Two-level four-leg PWM-VSI topology

The voltage in any leg *x* of the converter, measured from the neutral point (*n*), can be expressed in terms of switching states ,as takes after:

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

The numerical model of the filter derived from the equivalent circuit shown in Fig. 2 is

$$\mathbf{v_o} = v_{xn} - R_{\text{eq}}\,\mathbf{i_o} - L_{\text{eq}}\frac{d\,\mathbf{i_o}}{dt} \qquad (2)$$

Where *R*eq and *L*eq are the 4L-VSI output parameters expressed as Thevenin impedances at the converter output terminals *Z*eq. Along these lines, the Thevenin equivalent impedance is determined by a series connection of the ripple filter impedance *Zf* and a parallel arrangement between the system equivalent impedance *Zs* and the load impedance *ZL*

$$Z_{\text{eq}} = \frac{Z_s Z_L}{Z_s + Z_L} + Z_f \approx Z_s + Z_f. \qquad (3)$$

For this model, it is assumed that *ZL*>>*Zs*, that the resistive part of the system's equivalent impedance is ignored, and that the series reactance is in the scope of 3–7% p.u., which is an satisfactory approximation of the real system. Finally, in (2)*R*eq = *Rf* and *L*eq = *Ls*+ *Lf.*

IV. CURRENT REFERENCE GENERATION

A *dq*-based current reference generator plan is utilized to get the active power filter current reference signals. This plan shows a quick and precise signal tracking ability. This characteristic maintains a strategic distance from voltage fluctuations that fall apart the current reference signal influencing compensation performance. The current reference signals are acquired from the corresponding load currents as appeared in Fig. 5. This module computes the reference signal currents required by the converter to compensate reactive power, current harmonic and current imbalance. The displacement power factor (sin *φ*(*L*)) and the maximum total harmonic distortion of the load (THD(*L*) defines the relationships between the apparent power required by the active power filter, with respect to the load, as appeared

$$\frac{S_{\text{APF}}}{S_L} = \frac{\sqrt{\sin\phi_{(L)} + \text{THD}_{(L)}{}^2}}{\sqrt{1 + \text{THD}_{(L)}{}^2}} \qquad (7)$$

Where the value of THD (*L*) incorporates the maximum compensable harmonic current, defined as double the sampling frequency *fs*. The frequency of the maximum current harmonic component that can be repaid is equal to one half of the converter switching frequency. The *dq*-based plan works in a rotating reference frame ;in this way, the measured currents must be multiplied by the sin(*wt*) and cos(*wt*) signals. By utilizing *dq*-transformation, the 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 gotten from a synchronous reference frame (SRF) PLL. The SRF-PLL produces a pure sinusoidal waveform notwithstanding when the system voltage is extremely 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 bought on by the nonlinear load conditions and measurement errors. Equation (8) shows the relationship between the real currents *iLx*(*t*) (*x* = *u*, *v*,*w*) and the associated *dq* components(*id* and *iq*)

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin\omega t & \cos\omega t \\ -\cos\omega t & \sin\omega t \end{bmatrix} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{Lu} \\ i_{Lv} \\ i_{Lw} \end{bmatrix}. \qquad (8)$$

A low-pass filter (LFP) separates the dc component of the phase currents *id* to produce the harmonic reference components −_*id.* The reactive reference components of the phase-currents are acquired by phase-shifting the corresponding ac and dc components of *iq* by 180◦. So as to keep the dc-voltage constant ,the amplitude of the converter reference current must be altered by including an active power reference signal *ie* with the *d*-component, as will be explained in Section V-A. The subsequent signals *id* and *iq* are changed back to a three-phase system by applying the inverse Park and Clark transformation, as shown in (9). The cutoff frequency of the LPF used in this paper is 20 Hz

$$\begin{bmatrix} i_{ou}^* \\ i_{ov}^* \\ i_{ow}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 \\ 0 & \sin\omega t & -\cos\omega t \\ 0 & \cos\omega t & \sin\omega t \end{bmatrix} \begin{bmatrix} i_0 \\ i_d^* \\ i_q^* \end{bmatrix}. \quad (9)$$

The current that flows through the neutral of the load is remunerated by injecting the same instantaneous value acquired from the phase-currents, phase-shifted by 180◦, as appeared next

$$i_{on}^* = -(i_{Lu} + i_{Lv} + i_{Lw}). \quad (10)$$

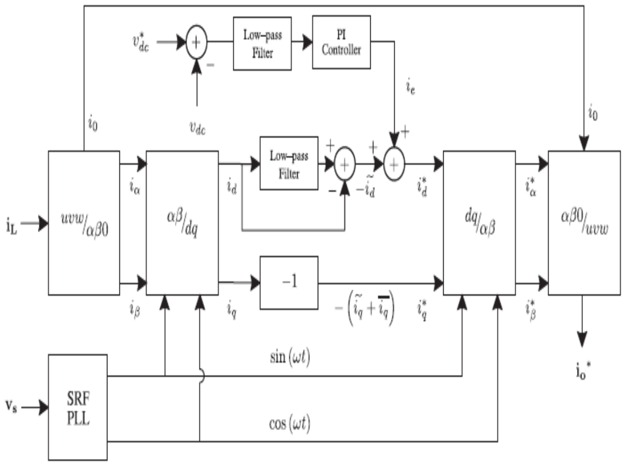

Fig. 7*dq*-based current reference generator block diagram

One of the real points of interest of the *dq*-based current reference generator plan is that it permits the implementation of a linear controller in the dc-voltage control loop. In any case, one important disadvantage of the *dq*-based current reference frame algorithm used to create the current reference is that a second order harmonic component is produced in *id* and *iq* under unbalanced operating conditions. The amplitude of this harmonic relies on upon 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 expelled from *id* and *iq*, and along these creates a third harmonic in the reference current when it is changed over back to abc frame. Fig. 6 demonstrates the percent of system current imbalance and the percent of third harmonic system current, in function of the percent of load current imbalance. 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-Voltage Control

The dc-voltage converter is controlled with a traditional PI controller. This is a vital issue in the assessment, since the cost function (6) is designed using just current references, so as to evade the use of weighting factors. By and large, these weighting factors are acquired experimentally, and they are not well defined when different operating conditions are required. Furthermore, the slow dynamic response of the voltage across the electrolytic capacitor does not influence the current transient response. Therefore, the PI controller represents a straightforward and effective alternative for the dc-voltage control. The dc-voltage stays constant (with a least value of6 *vs*(rms)) until the active power consumed by the converter declines to a level where it can't make up for its losses.

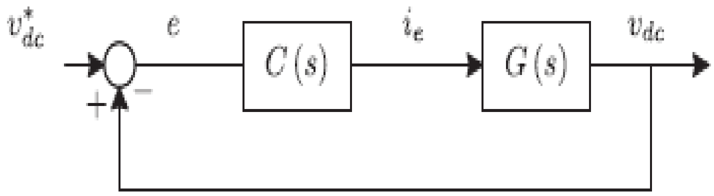

Fig. 8 DC-voltage control block diagram

The active power consumed by the converter is controlled by modifying the amplitude of the active power reference signal *ie*, which is in phase with each phase voltage. In the block diagram appeared in Fig. 5, the dc-voltage *vdc* is measured and afterward compared with a constant reference value *v∗*dc. The error(*e*) is handled by a PI controller, with two gains, *Kp* and *Ti* .Both gains are ascertained according to the dynamic response requirement. Fig. 7 demonstrates that the yield of the PI controller is fed to the dc-voltage transfer function *Gs*, which is represented by a first-order system (11)

$$G(s) = \frac{v_{dc}}{i_e} = \frac{3}{2}\frac{K_p v_s \sqrt{2}}{C_{dc} v_{dc}^*}. \quad (11)$$

The equivalent closed-loop transfer function of the given framework with a PI controller (12) is appeared in (13)

$$C(s) = K_p\left(1 + \frac{1}{T_i \cdot s}\right) \quad (12)$$

$$\frac{v_{\mathrm{dc}}}{i_e} = \frac{\frac{\omega_n^2}{a}\cdot(s+a)}{s^2 + 2\zeta\omega_n \cdot s + \omega_n^2}. \quad (13)$$

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

$$\zeta = \sqrt{\frac{3}{8}\frac{K_p v_s \sqrt{2T_i}}{C_{\mathrm{dc}} v_{\mathrm{dc}}^*}} \quad (14)$$

$$\omega_n = \sqrt{\frac{3}{2}\frac{K_p v_s \sqrt{2}}{C_{\mathrm{dc}} v_{\mathrm{dc}}^* T_i}}. \quad (15)$$

B. *FUZZY LOGIC*

In advanced years, the quantity of uses of fuzzy logic has raised drastically. The applications range from shopper items, for example, cameras, camcorders, clothes washers, and microwave stoves to modern procedure control and medicinal instrumentation. Fuzzy logic (FL) is verging on synonymous with the hypothesis of fuzzy sets, a hypothesis which identifies with classes of items with unsharp limits in which enrollment involves degree. The fundamental idea basic FL is that of a semantic variable, that is, a variable whose qualities are words instead of numbers. As a result, quite a bit of FL might be seen as a system for processing with words. In spite of the fact that words are naturally less exact than numbers, they can be seen quickly and effectively. Another essential idea in FL, which assumes a noteworthy part in the vast majority of its applications, is that of a fuzzy if-then rule or, just, fuzzy guideline. Despite the fact that rules based frameworks have a long history of utilization in Artificial Intelligence (AI), what is lost in such frameworks is the component for managing fuzzy consequents and fuzzy precursors. In fuzzy logic, this system was given by the analytics of fuzzy rules. The fuzzy logic tool box is exceptionally amazing in all regards. It makes fuzzy logic a compelling device for the origination and outline of keen frameworks. The fuzzy logic tool box is difficult to actualize and advantageous to utilize. It gives a pursuer amicable and cutting-edge prologue to approach of fuzzy logic and its boundless applications. Fuzzy logic Controllers, The word Fuzzy means unclearness. Fuzziness happens when the limit of bit of data is not obvious. In 1965 Lot fi A. Zahed propounded the fuzzy set hypothesis. Fuzzy set hypothesis shows awesome potential for powerful fathoming of the vulnerability in the issue. Fuzzy set hypothesis is a superb numerical device to handle the instability emerging because of ambiguity. Understanding human discourse and perceiving written by hand characters are some basic cases where fuzziness shows. Fuzzy set hypothesis is an augmentation of traditional set hypothesis where components have differing degrees of participation. In FLC the info variables are mapped by sets of enrollment capacities and these are called as "Fuzzy SETS". Fig.5 demonstrates fundamental Fuzzy module.

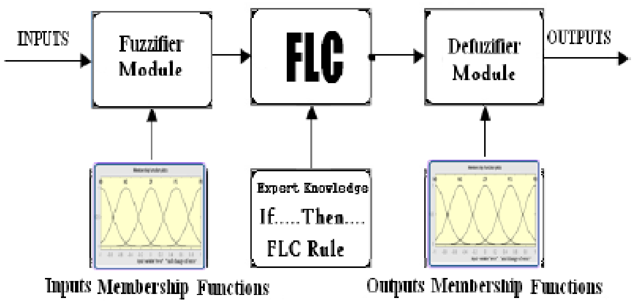

Fig 9. Fuzzy Basic Rule

Fuzzy set involves from an enrollment capacity which could be characterizes by parameters. The quality somewhere around 0 and 1 uncovers a level of enrollment to the fuzzy set. The procedure of changing over the crisp input to a fuzzy quality is called as" Fuzzificaton [9]." The yield of the Fuzzier module is interfaced with the principles. The essential operation of FLC is built from fuzzy

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control rules using the estimations of fuzzy sets by and large for the mistake and the change of error and control activity. The outcomes are joined to give a crisp output controlling the yield variable and this procedure is called as the "DEFUZZIFICATION." The PI controllers are supplanted with FUZZY controller and results are watched. The outcomes are enhanced when fuzzy controller is associated.

e/de	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NB	NB	NB
NM	NB	NM	NM	NM	NS	NS	NS
NS	NB	NM	NM	NS	NS	NS	Z
Z	Z	Z	Z	Z	Z	Z	Z
PS	Z	PS	PS	PS	PM	PM	PB
PM	PS	PS	PS	PM	PM	PB	PB
PB	PB	PB	PB	PB	PB	PB	PB

Table 1: Control strategy based on 49 Fuzzy control Rules with combination of seven error states multiplying with seven changes of error states.

C. Training of ANN

An ANN is basically a bunch of reasonably interconnected nonlinear components of extremely straightforward structure that have the capacity of learning and adjustment. These systems are portrayed by their topology, the path in which they speak with their surroundings, the way in which they are prepared and their capacity to process data.

Their usability, inalienable unwavering quality and adaptation to internal failure have made ANNs a suitable medium for control. A contrasting option to fuzzy controllers much of the time, neural controllers share the need to supplant hard controllers with smart controllers keeping in mind the end goal to expand control quality. A food forward neural system acts as pay signal generator. This system is outlined with three layers. The input layer with seven neurons, the concealed layer with 21 and the output.

The preparation calculation utilized is Levenberg–Marquardt Back engendering (LMBP).
Training is given as follows:-

```
net=newff(minmax(P),[7,21,3],
{„tansig‟,‟tansig‟,‟purelin‟},‟trainlm‟);
net.trainParam.show =50;
net.trainParam.lr = .05;
net.trainParam.mc = 0.95;
net.trainParam.lr_inc = 1.9;
net.trainParam.lr_dec = 0.15;
net.trainParam.epochs = 1000;
net.trainParam.goal = 1e-6;
[net,tr]=train(net,P,T);
a=sim(net,P);
gensim(net,-1);
```

The compensator output relies on upon input and its advancement. The picked design has seven inputs three each for reference load voltage and source current respectively, and one for output of error (PI) controller. The neural network prepared for outputting fundamental reference currents. The signals in this manner acquired are compared in a hysteresis band current controller to give switching signals.

VI. SIMULATION RESULTS

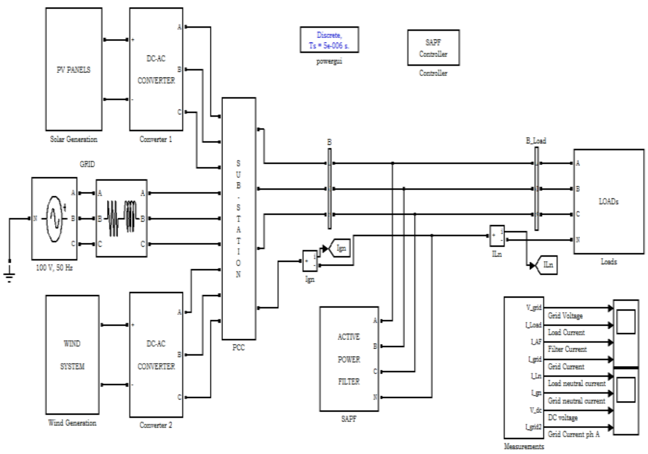

Fig. 10 hybrid power generation system with a shunt active power filter.

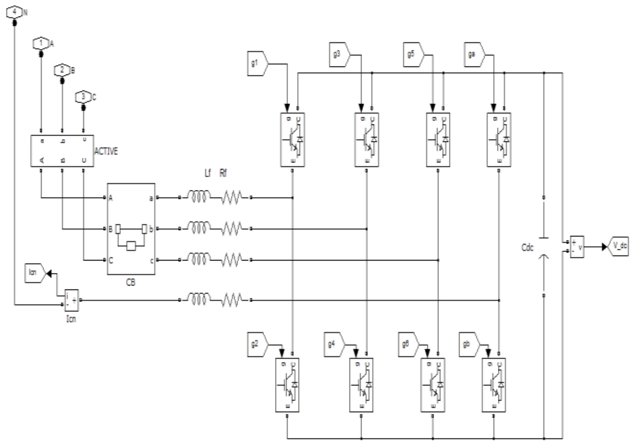

Fig. 11 circuit of the proposed shunt active power

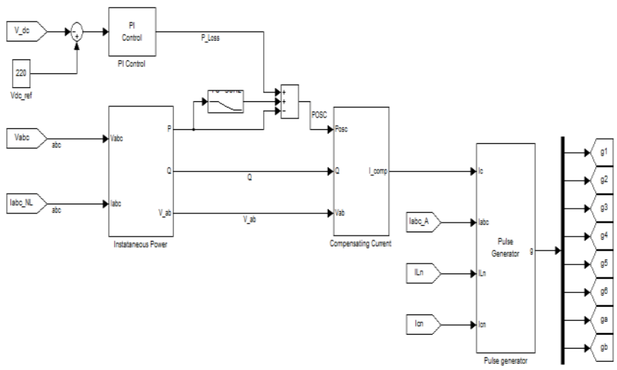

Fig. 12 dq-based current controller

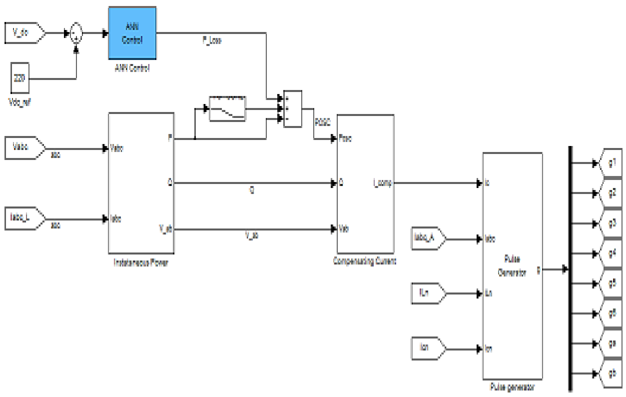

Fig. 14 ANN based current controller

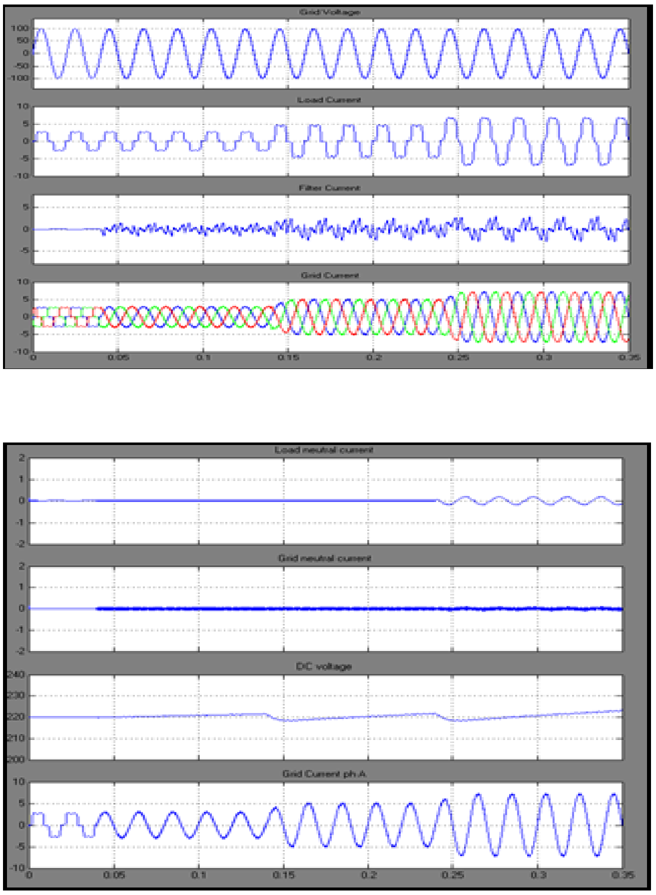

Fig. 15 Simulated waveforms of the proposed control scheme (a) Phase to neutral source voltage (b) Load Current (c) Active power filter output current (d) Load neutral current (e) System neutral current (f) System currents. (g) DC voltage converter (h) grid current

TABLE-1
%THD OF SOURCE CURRENTS USING PI, FUZZY AND ANN CONTROLLERS

Controller	PI	FUZZY	ANN
%THD(Source current)	4.18%	3.32%	2.97%

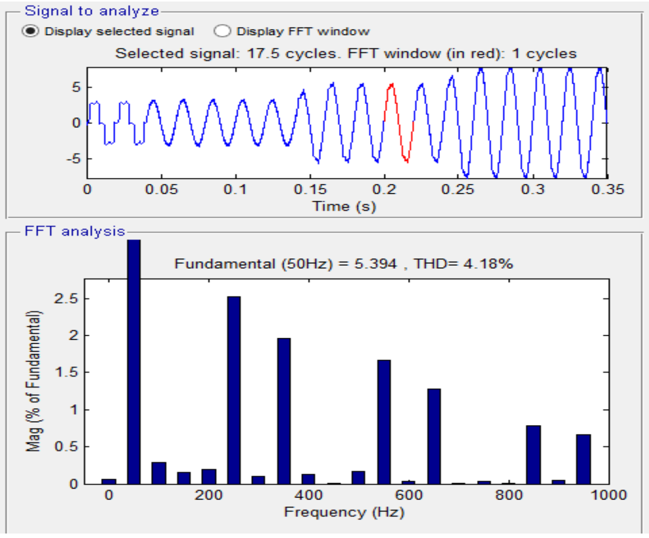

Fig 16 %THD using PI controller

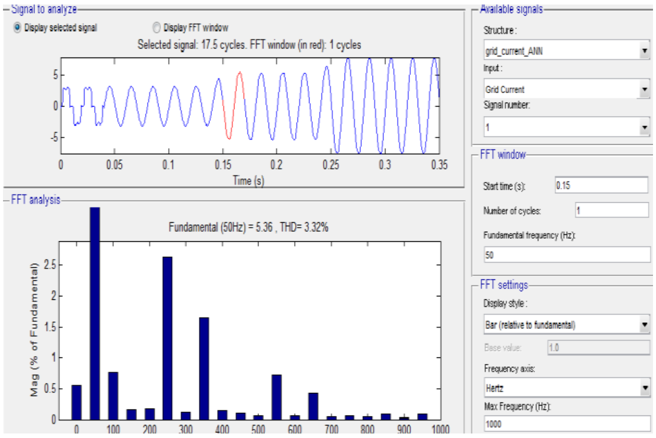

Fig 17.%THD using FUZZY Logic Controller

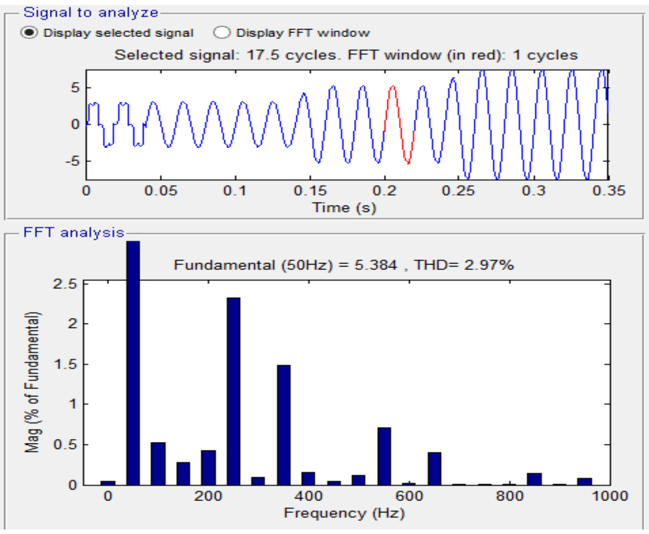

Fig 18 %THD using ANN controller

CONCLUSION

The paper has proposed a shunt active power filter with ANN controller which has been simulated in SIMULINK..The active power filter enhances the power quality of distribution system by eliminating harmonics and reactive power compensation of non-linear load. It is seen from the simulation results that the THD of source current using PI controller is 4.18% where as using Fuzzy logic controller it is 3.32% and using ANN controller it is 2.97% .It is likewise tested under different nonlinear Load conditions and the comparison has been tabulated. Consequently from the simulation results we can presume that ANN controller is more effective than Fuzzy controller and PI controller`.

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