International Journal of Engineering Research and Development
e-ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 10, Issue 11 (November 2014), PP.59-71

Comparative of Conventional and Intelligence Controller based Hybrid Generation Scheme Fed Active Filter Compensation Scheme for Power Quality Features

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Abstract:- Harmonic pollution of the power supply system has risen significantly in recent years due primarily to an increase of non-linear loads connected to the utility through residential, commercial and industrial customers. This paper, proposed a solution to eliminate the harmonics introduced by the nonlinear loads in steady and in transients. It presents a predictive current control strategy for achieving maximum benefits from these grid-interfacing inverters implementing conventional DC link controller and intelligence controller, when installed in 3-phase 4-leg voltage source inverter (VSI). The inverter is controlled to perform as a multi-function device by incorporating active power filter functionality. The use of a four-leg voltage-source inverter allows the compensation of current harmonic components, as well as unbalanced current generated by three-phase nonlinear loads. Renewable energy resources (RES) are being increasingly connected in distribution systems utilizing power electronic converters. The compensation performance of the proposed active power filter and the associated hybrid PV/Wind system generation scheme with new control scheme is demonstrated to improve the power quality features is simulated using MATLAB/SIMULINK.

Keywords:- Active Power Filter, Current Control, Hybrid Generation Scheme, Fuzzy Logic Controller, and Power Quality.

I. INTRODUCTION

The recent trends in small scale power generation using the increased concerns on environment and cost of energy, the power industry is experiencing fundamental changes with more renewable energy sources (RESs) or micro sources such as photovoltaic cells, small wind turbines, and micro turbines being integrated into the power grid in the form of distributed generation (DG) [1]. The fuel cells are electrochemical devices that convert chemical energy directly into electrical energy by the reaction of hydrogen from fuel and oxygen from the air without regard to climate conditions, unlike hydro or wind turbines and photovoltaic array. Fuel cells are different from batteries in that they require a constant source of fuel and oxygen to run, but they can produce electricity continually for as long as these inputs are supplied. This can be accomplished mainly by resorting to wind and photovoltaic generation, which, however, introduces several problems in electric systems management due to the inherent nature of these kinds of RES . In fact, they are both characterized by purely predictable energy production profiles, together with highly variable rates.

The large scale use of the non-linear loads such as adjustable speed drives, traction drives, etc. [2] and power converters has contributed for the deterioration of the power quality and this has resulted in to a great economic loss. Thus it is important to develop the equipment that can mitigate the problem of poor power quality. Power Quality (PQ) [3], is defined as "Any power problem established in voltage, current or frequency deviation which leads to damage, malfunctioning, mis-operation of the consumer equipment". Poor power quality causes many damages to the system, and has a contrary economical impact on the utilities and customers. The problems of harmonics can be reduced or mitigated by the use of power filters. The Active power filters have been proven very effective in the reduction of the system harmonics. One of the most severe and common power quality problem is current harmonics.

When a pure sinusoidal voltage is applied to a certain type of load, the current drawn by the load is proportional to the voltage and impedance and follows the envelope of the voltage waveform. These loads are referred to as linear loads (loads where the voltage and current follow one another without any distortion to their pure sine waves) [4]. Examples of linear loads are resistive heaters, incandescent lamps and constant speed induction motors. In contrast, some loads cause the current to vary disproportionately with the voltage during each half cycle. These loads are defined as non-linear loads. The current harmonics and the voltage harmonics are generated because of these non-linear loads. It is noted that non-sinusoidal current results in many problems for the utility of power supply company, such as: low-power factor, low energy efficiency, electro-magnetic

interference (EMI), power system voltage fluctuations and so on. Thus, a perfect compensator is necessary to avoid the negative consequences of harmonics. The THD [5] obtained without using the shunt active filter is much more than described in the IEEE standard-519. According to this standard the THD value should be less than 5%.
The THD equation for current harmonics is given by

$$\% THD(I) = \frac{\sqrt{I_2^2 + I_3^2 + - - I_n^2}}{I_1} \times 100 \qquad (1)$$

The proposed active power filters implemented with three-phase four-leg voltage-source inverters(VSI) have already been presented in the technical literature [6], the primary contribution of this paper is a predictive control algorithm designed and implemented specifically for this application. Traditionally, active power filters have been controlled using pre-tuned controllers, such as PI-type or adaptive, for the current as well as for the dc-voltage loops [7]. 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 [8]. 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.

II. SHUNT ACTIVE FILTERS

The power filters are used to mitigate the harmonics present in the electrical systems. Harmonics are considered as pollutants present in the power system. Traditionally a bank of capacitors or LC filters were used to filter out the system harmonics, as they have simple structure, easy to design, low cost and high efficiency. These are some examples of the passive power filters [9]. Apart from this there are several drawbacks of the passive power filters such as resonance, bulky in nature, tuning frequency is not accurate and it requires lot of calculations. Thus to overcome these drawbacks of the passive power filters, Active power filters (APF) [10]-[12] are introduced. The Active power filters uses power electronics devices to mitigate the harmonics content in the power system. The APF has been proven effective than the passive power filters in the mitigation of the harmonics. It overcomes the drawback of the passive power filters and has the advantages such as, smaller in size and accurate. Power filters are further divided into three categories, they are: series power filters, shunt power filters and hybrid power filters. The series active filters are used to mitigate the problems of the voltage harmonics and are placed in series with the power system. The shunt active filter is used to mitigate the current harmonics present in the system and they are placed in the system at a point of common coupling (PCC). The hybrid filters are used to mitigate the current as well as the voltage harmonics present in the power system. Here we are dealing with the mitigation of current harmonics and thus we consider the use of shunt active filter to perform the job. Fig. 1 shows the configuration of a typical power distribution system with renewable power generation. It consists of various types of power generation units and different types of loads. Renewable sources, such as wind and sunlight, are typically used to generate electricity for residential users and small industries. These converters perform maximum power point tracking to extract the maximum energy possible from wind and sun.

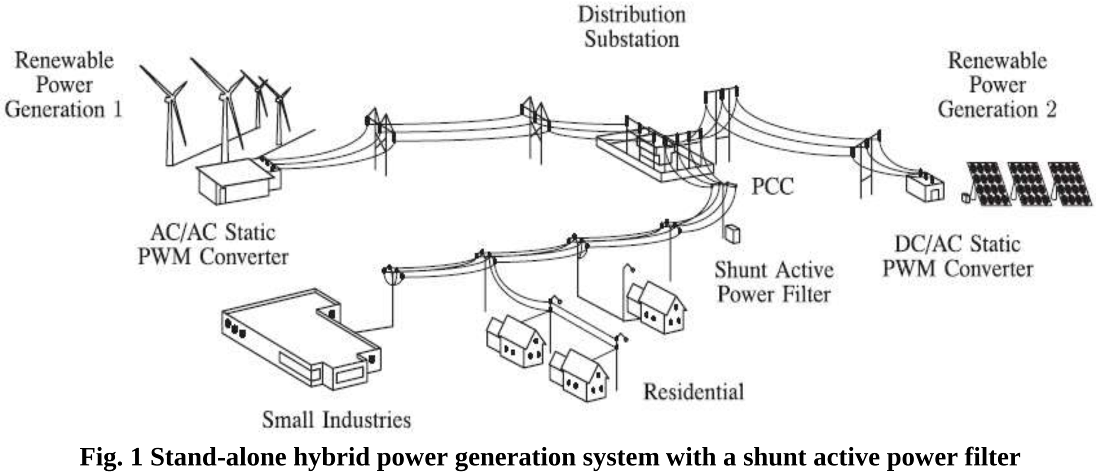

Fig. 1 Stand-alone hybrid power generation system with a shunt active power filter

The electrical energy consumption behavior is random and unpredictable, and therefore, it may be single- or three-phase, balanced or unbalanced, and linear or nonlinear. An active power filter is connected in parallel at the point of common coupling to compensate current harmonics, current unbalance, and reactive power. It is composed by an electrolytic capacitor, a four-leg PWM converter, and a first-order output ripple filter, as shown in.

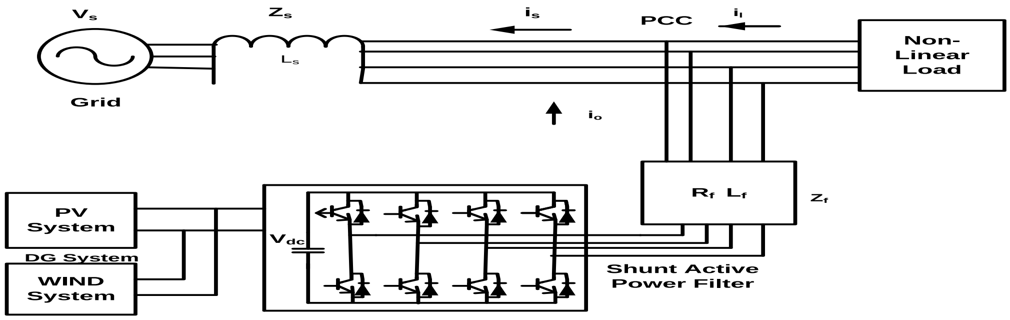

Fig. 2. Equivalent circuit of Hybrid Generation Scheme of the proposed shunt active power filter.

In Fig.2. This circuit considers the power system equivalent impedance Z_s , the converter output ripple filter impedance Z_f , and the load impedance Z_L. The thevenin's equivalent impedance is determined by

$$Z_{eq} = \frac{Z_s Z_l}{Z_s + Z_l} + Z_f \sim Z_s + Z_f \qquad (2)$$

Four-leg converter topology is similar to the conventional three-phase converter with the fourth leg connected to the neutral bus of the system. The fourth leg increases switching states from improving control flexibility and output voltage quality [13], and is suitable for current unbalanced compensation.

III. PROPOSED CONTROL SCHEME

A .Digital Predictive Current Control:

The new proposed control scheme is digital predictive current control scheme. This control scheme is basically an optimization algorithm and, therefore, it has to be implemented in a microprocessor.[15], The main characteristic of predictive control is the use of the system model to predict the future behavior of the variables to be controlled. The controller uses this information to select the optimum switching state that will be applied to the power converter, according to predefined optimization criteria[16]–[19].The predictive control algorithm is easy to implement and to understand, and it can be implemented with three main blocks which is shown in Fig.3.

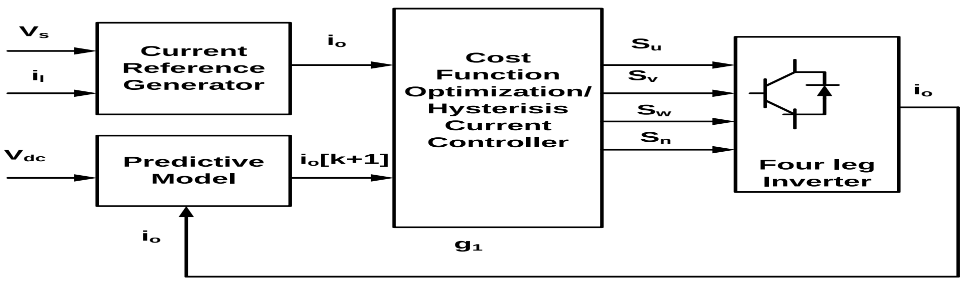

Fig 3. Proposed Equivalent circuit for digital predictive current control block.

A1. Current Reference Generator:

This scheme presents a fast and accurate signal tracking capability. This characteristic avoids voltage fluctuations that deteriorate the current reference signal affecting compensation performance . The current reference signals are obtained from the corresponding load currents. In this case, the system voltages, the load currents, and the dc-voltage converter are measured, while the neutral output current and neutral load current are generated directly from these signals. A *dq*-based current reference generator scheme is used to obtain the active power filter current reference signals[16].This module calculates the reference signal currents required by the converter to compensate reactive power, current harmonic, and current imbalance. 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 .

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

Since SRF-PLLs are designed to avoid phase voltage unbalancing, harmonics (i.e., less than 5% and 3% in fifth and seventh, respectively).A low-pass filter (LPF) extracts the dc component of the phase currents *id* to generate the harmonic reference components *id* . The reactive reference components of the phase-currents are obtained by phase-shifting the corresponding ac and dc components of *iq* by 180◦. In order to keep the dc-voltage constant, the amplitude of the converter reference current must be modified by adding an active power reference signal i_e with the *d*-component. The resulting signals *i*d* and *i*q* are transformed back to a three-phase system by applying the inverse Park and Clark transformation.

A 2. Prediction Model:

The main characteristic of predictive control is the use of the model of the system for the prediction of the future behavior of the controlled variables. This information is used by the controller in order to obtain the optimal actuation, according to a predefined optimization criterion.The optimization criterion in the hysteresis-based predictive control is to keep the controlled variable within the boundaries of a hysteresis area, while in the trajectory based, the variables are forced to follow a predefined trajectory. The converter model is used to predict the output converter current. Since the controller operates in discrete time, both the controller and the system model must be represented in a discrete time domain, [14]. The discrete time model consists of a recursive matrix equation that represents this prediction system in fig 3. This means that for a given sampling time *Ts* ,knowing the converter switching states and control variables at instant *kTs* , it is possible to predict the next states at any instant [*k* + 1]*Ts* .

$$i_0[k+1] = \frac{T_s}{L_{eq}}\left(v_{xn}[k] - v_0[k]\right) + \left(1 - \frac{R_{eq}T_s}{L_{eq}}\right) i_0[k] \qquad (4)$$

As shown in (4), in order to predict the output current **io** at the instant (*k* + 1), the input voltage value **vo** and the converter output voltage *vxN* , are required. The algorithm calculates all 16 values associated with the possible combinations that the state variables can achieve.

A 3. Hysteresis Current Controller:

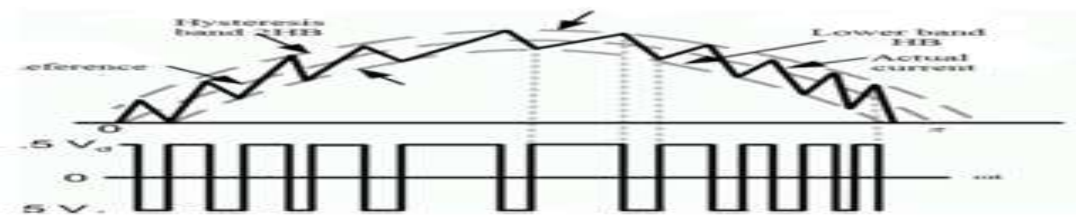

Fig.4. Hysteresis current Modulation

In order to select the optimal switching state that must be applied to the power converter, the predicted values obtained for $\mathbf{i_o}[k+1]$ are compared with the reference using a cost function *g* as follows. With the hysteresis control, limit bands are set on either side of a signal representing the desired output waveform [5]. The inverter switches are operated as the generated signals within limits. The control circuit generates the sine reference signal wave of desired magnitude and frequency, and it is compared with the actual signal [24]. As the signal exceeds a prescribed hysteresis band, the upper switch in the half bridge is turned OFF and the lower switch is turned ON. As the signal crosses the lower limit, the lower switch is turned OFF and the upper switch is turned ON. The actual signal wave is thus forced to track the sine reference wave within the hysteresis band limits.

IV. INTRODUCTION TO FUZZY LOGIC CONTROLLER

Mamadain's method was among the first control systems built using fuzzy set theory. Here we use Mamdani's fuzzy inference method it is most commonly seen fuzzy methodology. 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 power system [8]. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. 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 fuzzification interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [22].

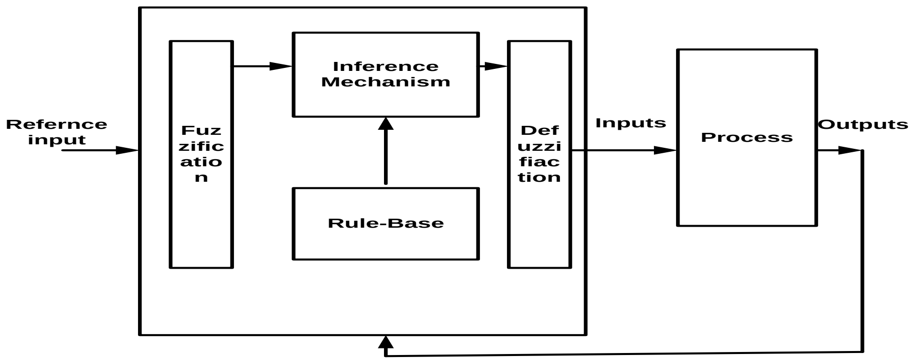

Fig.5. General Structure of the fuzzy logic controller

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 [20]-[24]. To convert these numerical variables into linguistic variables, the following five fuzzy levels or sets are chosen in fig 5 are as: NS (negative small),NL(negative large)NM(negative medium), ZE (zero), PS(positive small), PL (positive large),P M(positive medium).

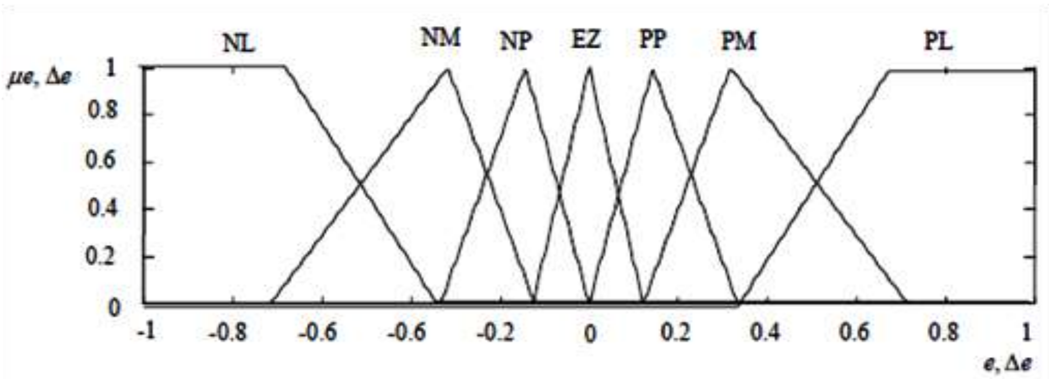

Fig.6. Membership functions for Input, Change in input, Output.

Rule Base: the elements of this rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse in-put/output variables; in the steady state, small errors need fine control, which requires fine input/output variables. Based on this the elements of the rule table are obtained as shown in Table 1, with '*Vdc*' and '*Vdc-ref*' as inputs.

Table I Rules Based System

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. DC LINK VOLTAGE

A. Dc Link Voltage Regulation:

Whenever there is a sudden change in the load condition, the real power flowing in the system is disturbed and this needs to be settled down. The DC link voltage is used to balance the real power flow in the system and thus the voltage across the DC link capacitor changes. If the active power flowing into the filter can be controlled in such a way that it is equal to the losses inside the filter, the DC link voltage can be maintained at the desired value[14]. Thus the main purpose of the active power filter is to maintain the DC link voltage and to give the compensating current to mitigate the current harmonics present in the system. This paper represents the control offered by two different controllers to control the shunt active filter. PI controller which is a linear controller and fuzzy logic controller which is a non-linear controller, are used to control SHAF and the results are analyzed.

B. Dc Link Voltage Regulation Using Pi Controller:

Fig. 7 shows the internal structure of the control circuit. The control scheme consists of PI controller, limiter and three phase sine wave generator for reference current generation and generation of switching signals [25]. It is known that the real power of the system changes and that is compensated by the DC link capacitor voltage. The new capacitor voltage is now compared with a reference voltage and a difference signal or error signal is given to the PI controller.

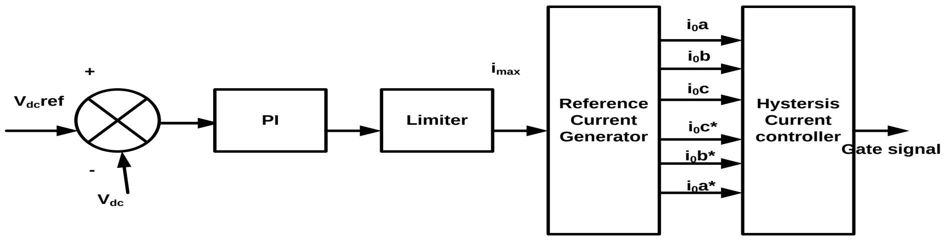

Fig 7. Conventional PI controller

The error signal is then processed through a PI controller, which contributes to zero steady error in tracking the reference current signal. The output of the PI controller is considered as peak value of the supply current (Imax), which is composed of two components: (a) fundamental active power component of load current and (b) loss component of APF; to maintain the average capacitor voltage to a constant value. This peak value of the current (Imax) so obtained, is multiplied with the respective source voltages to obtain the reference compensating currents. These estimated reference currents (I^*_0a, I^*_0b, I^*_0c) and sensed actual currents (I_0a, I_0b, I_0c) are compared at a hysteresis band, which gives the error signal.

C. Dc Link Voltage Regulation Using Fuzzy Logic Controller:

Fig. 8 shows the internal structure of the control circuit for fuzzy logic controller. The control scheme consists of FLC[12], limiter and three phase sine wave generator for reference current generation and generation of switching signals.

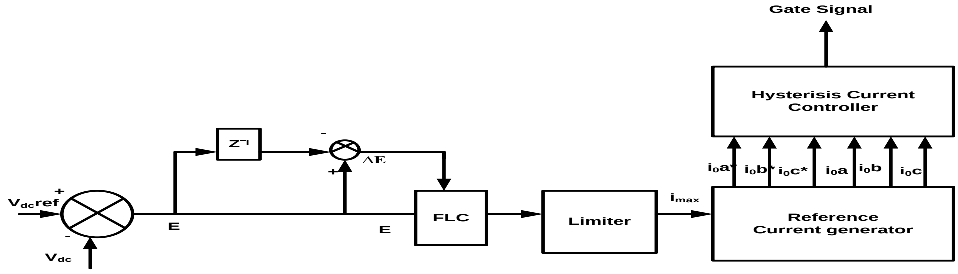

Fig 8. Fuzzy Logic Controller

The peak value of reference currents is estimated regulating the DC link voltage. It is known that the real power of the system changes and that is compensated by the DC link capacitor voltage. The new capacitor voltage is now compared with a reference voltage and a difference signal or error signal is given to the FLC[12]. The error signal is then processed through a FLC, which contributes to zero steady error in tracking the reference current signal. The output of the FLC is considered as peak value of the supply current (I_{max}) and using it the reference currents are generated and then through them the gating signals are generated.

VI. HYBRID GENERATION SCHEME

The photovoltaic (PV) power generation systems are renewable energy sources that expected to play a promising role in fulfilling the future electricity requirements[26]. The PV systems principally classified into stand-alone, grid connected or hybrid systems. The grid-connected PV systems generally shape the grid current to follow a predetermined sinusoidal reference using hysteresis-band current controller, which has the advantages of inherent peak current limiting and fast dynamic performance. The model of grid connected photovoltaic system to control active and reactive power injected in the grid is presented. Compare to single sourced system in DG, hybrid source have much more favorable features, such as maintain grid stability, increase the power density and achieve high reliability.

A. Photovoltaic Array Modeling

The grid integration of RES applications based on photovoltaic systems is becoming today the most important application of PV systems, gaining interest over traditional stand-alone systems. This trend is being increased because of the many benefits of using RES in distributed (aka dispersed, embedded or decentralized) generation (DG) power systems .Numerous PV cells are connected in series and parallel circuits on a panel for obtaining high power, which is a PV module. A PV array is defined as group of several modules electrically connected in series-parallel combinations to generate the required current and voltage. The building block of PV arrays is the solar cell, which is basically a p-n semiconductor junction that directly converts solar radiation into dc current using photovoltaic effect. The simplest equivalent circuit of a solar cell is a current source in parallel with a diode, shown in Fig. 9.

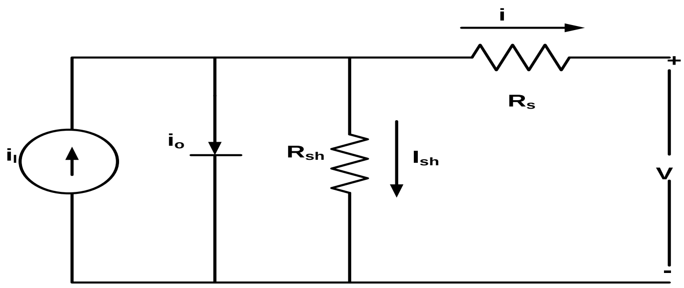

Fig 9: Circuit Diagram of a Solar Cell

The series resistance R_S represents the internal losses due to the current flow. Shunt resistance R_{sh}, in parallel with diode, this corresponds to the leakage current to the ground. The single exponential equation which models a PV cell is extracted from the physics of the PN junction and is widely agreed as the behavior of the PV cell.

B. Wind Energy System

Wind power is a very simple process. A wind turbine converts the movement energy of wind into mechanical energy that is used to generate electricity. The energy is fed through a generator, converted again into electrical energy, and then transmitted to a power station. Wind turbines transform wind energy into electricity. The wind is a highly variable source, which cannot be stored, thus, it must be handled according to this characteristic. The principle of operation of a wind turbine is characterized by two conversion steps. First the rotor extract the kinetic energy of the wind, changing it into mechanical torque in the shaft; and in the second step the generation system converts this torque into electricity. In the most common system, the generator system gives an AC output voltage that is dependent on the wind speed[26]. As wind speed is variable, the voltage generated has to be transferred to DC and back again to AC with the aid of inverters. However, fixed speed wind turbines are directly connected to grid.

TABLE II Specification Parameters of Fig 2

Units	Specifications	Values
V_s	Source Voltage	415V
f	Frequency	50Hz
V_{dc}	dc Voltage	800V
C_{dc}	dc Capacitor	10000µF
L_f	Filter Inductor	1mH
T_s	Sampling time	50µs
T_e	Execution time	0.25s

TABLE III Fuzzy Parameters

FIS type for FLC	Mamadani
Membership function for FLC	7x7 Triangular
Implication for FLC	Min
Defuzzification	Centroid

TABLE IV Ideal Hybrid Scheme Parameters
WIND PARAMETERS:

Wind Speed	Ns	10rpm
Voltage	V	800V
Current	I	20amps
TotalPower Generated	P	16Kw

SOLAR PARAMETERS:

Open Circuit Voltage	V	800V
Short Circuit Current	I	18amps
Total Power Generated	P	14.4Kw

VII. MATLAB MODELEING AND SIMULATION RESULTS

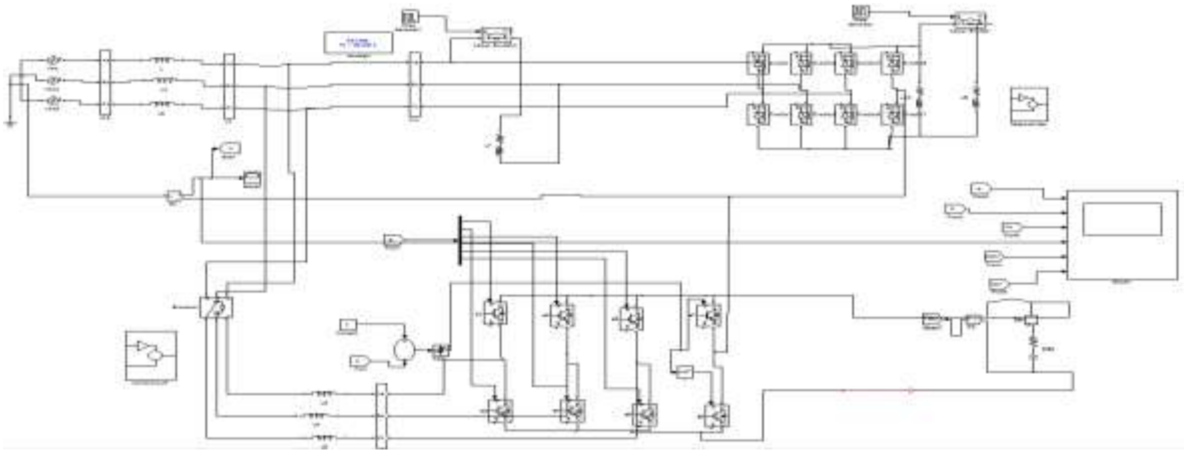

Fig.10 Matlab/Simulink Model of Proposed RES Fed 4-Leg APF system with formal PI Controller

Case 1: Proposed RES Fed APF with Conventional PI Controller

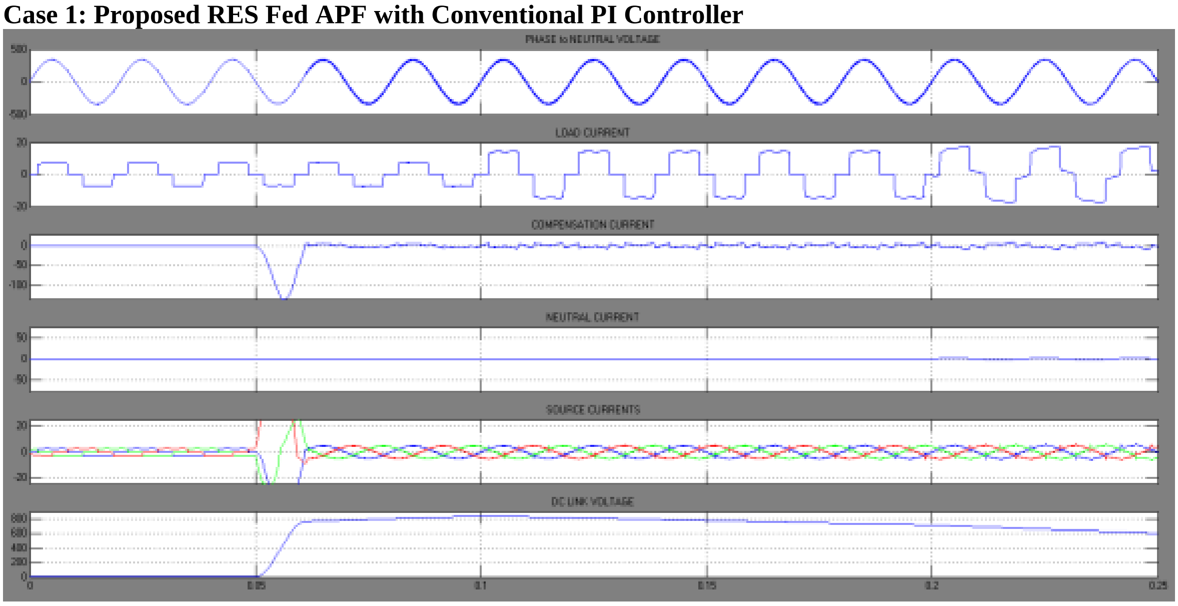

Fig.11 Simulation results for APF with Formal PI Controller (a) Source Voltage. (b) Load current. (c) Compensator Current.
(d) Neutral Current, (e) Source Current (f) DC Link Voltage.

Fig.11Here 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.

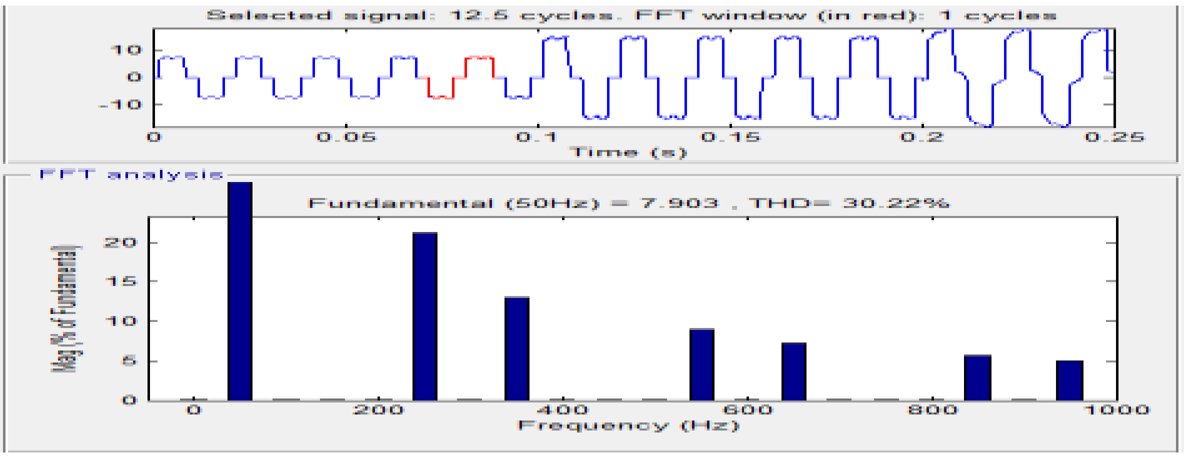

Fig. 13 FFT Analysis of Phase-A Source Current for without compensation scheme
Fig.13 shows the FFT Analysis of Phase-A Source Current without any compensation,

here we get 30.22%.

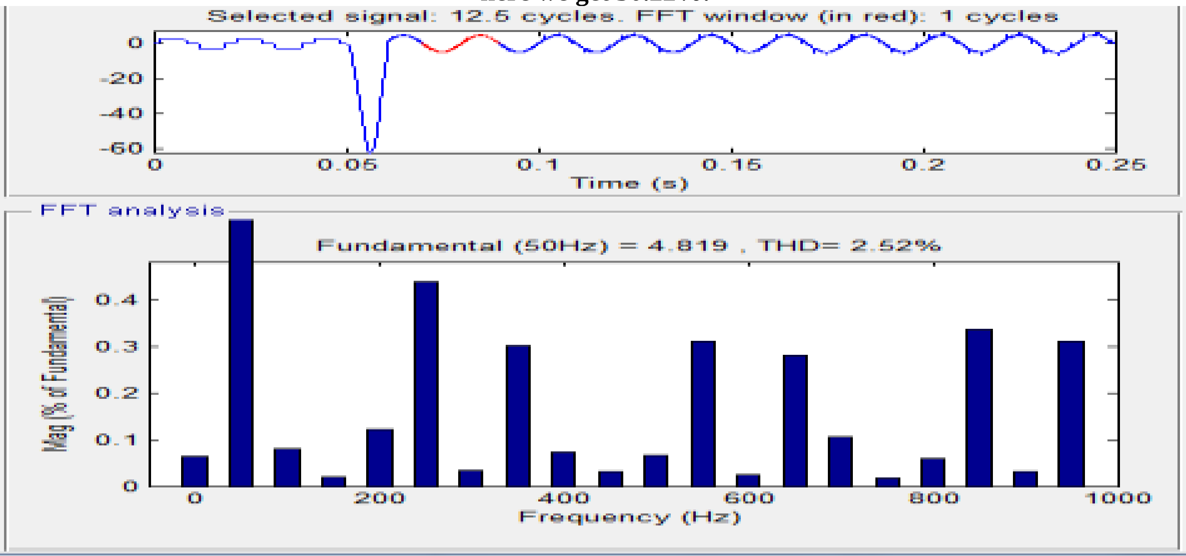

Fig. 14 FFT Analysis of Phase-A Source Current with PI Controlled APF

Fig.14 shows the FFT Analysis of Phase-A Source Current with PI Controlled APF, here we get 2.52%.

Case 2: Proposed APF with Intelligence based Fuzzy Controller with Hybrid Generation Scheme

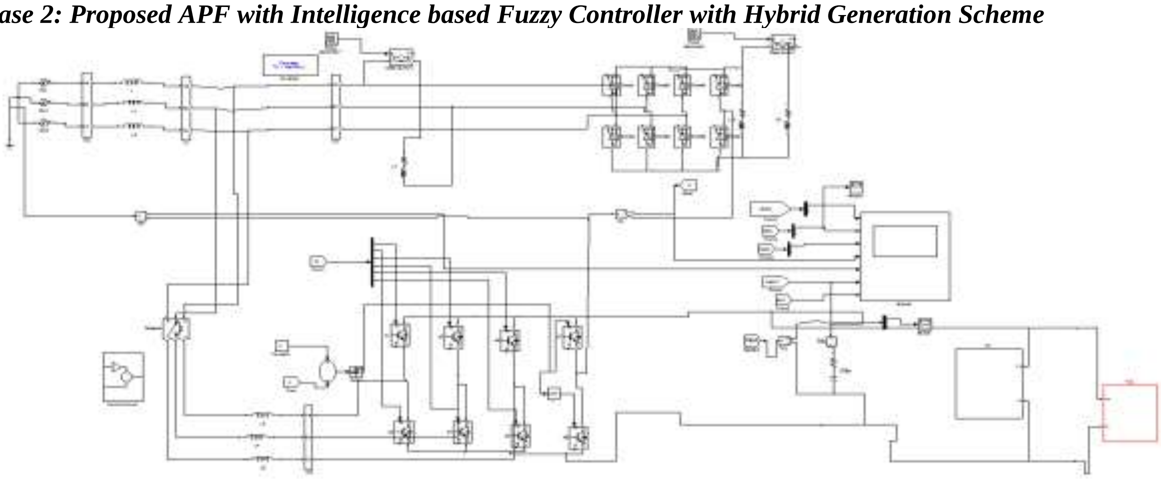

Fig.15 MATLAB/SIMMULINK Model of Proposed RES Fed 4-Leg APF system with formal Fuzzy Controllers

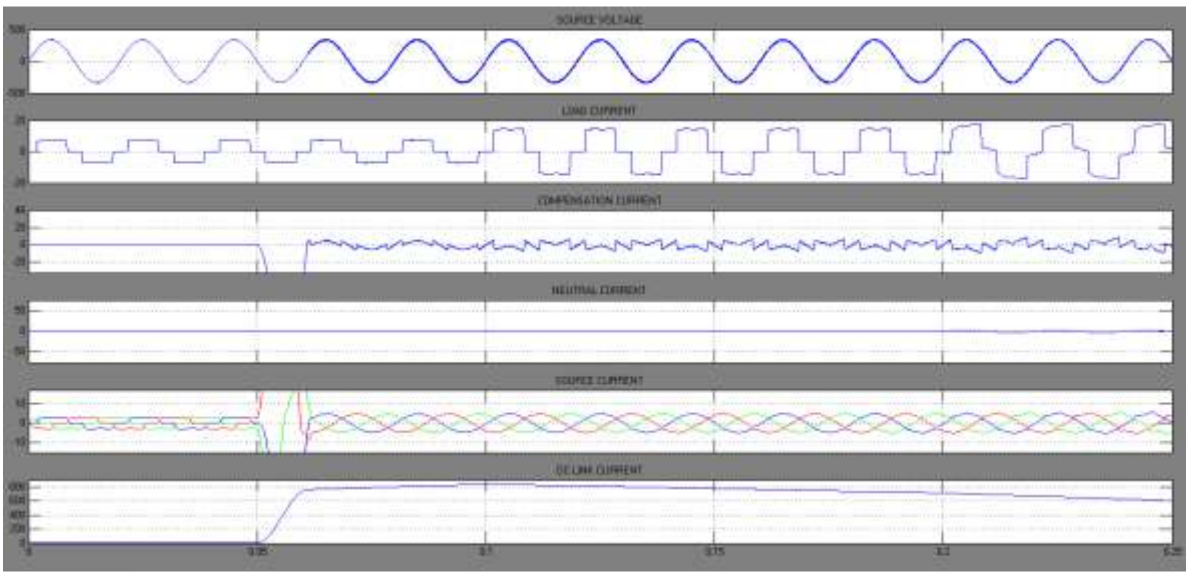

Fig.16 Simulation results for APF with Fuzzy Controller (a) Source Voltage. (b) Load current. (c) Compensator Current. (d) Neutral Current, (e) Source Current (f) DC Link Voltage.

Fig.16 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.

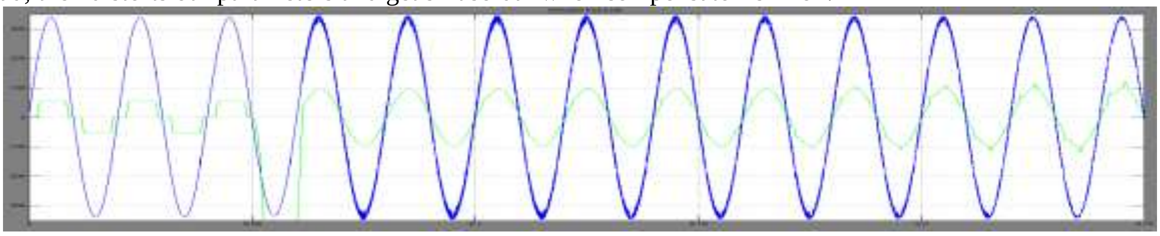

Fig.17 Power Factor for APF with Fuzzy Controller

Fig. 17 shows the power factor it is clear from the figure after compensation power factor is unity.

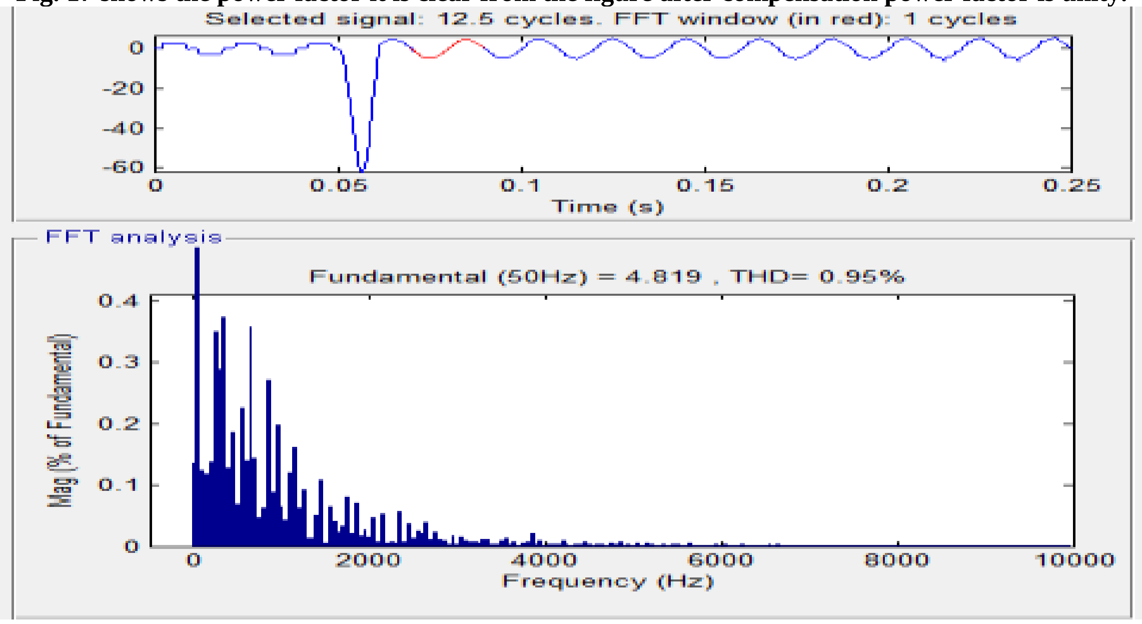

Fig. 18 FFT Analysis of Phase-A Source Current with Fuzzy Controlled APF
Fig.18 shows the FFT Analysis of Phase-A Source Current with Fuzzy Controlled APF, Here we get 0.95%.

VIII. CONCLUSION

By using this hybrid generation scheme instead of single sourced system, attains high power density, low voltage fluctuations, improve the grid stability, may increase the reliability. The use of an intelligent based predictive control for the converter current loop proved to be an effective solution for active power filter applications. This proposed model is implemented using MATLAB/Simulink software and the obtained resultant waveforms were evaluated and the effectiveness of the system stability and performance of power system have been established. Improved dynamic current harmonics and a reactive power compensation scheme for power distribution systems with generation from renewable sources has been proposed to improve the current quality of the distribution system. Advantages of the proposed scheme are related to its simplicity, modeling, and implementation. This paper has presented a novel control of an existing PV/Wind interfacing APF using conventional PI controller & fuzzy logic controller to improve the quality of power at PCC for a 3-phase four leg 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 2.52%, but using the fuzzy logic controller THD value is 0.95%.

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