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FUZZY CONTROLLED PARALLEL ACTIVE POWER FILTER

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Abstract:

Active filters are widely employed in distribution system to reduce the harmonics produced by non-linear loads. These results in voltage distortion and leads to various power quality problems. Shunt Active Power Filters are the best solution for the elimination of harmonics occurred in the power system. This paper presents the optimization of shunt active power filter parameters based on fuzzy logic control, which is employed to drive the switching signals and also to choose the optimal value of the coupling inductance. The fuzzy control is based on a linguistic description and does not require a mathematical model of the system. It can adapt its gain according to the changes in load. The indirect current control method is used for calculating the compensating currents. A fuzzy logic based controller is developed to control the voltage of the DC side Capacitor. The conventional hysteresis controller gives very fast response and good accuracy, but it causes uneven switching. This work presents and compares the performance of the fuzzy-controller with a conventional controller under constant load. The harmonic distortions are analysed and compared. The total Harmonic Distortion, Individual harmonic content with respect to % of fundamental in Supply current, have been analysed. The proposed systems are implemented with Matlab/Simulink.

Keywords—component; Parallel Active Filter; Generalized Theory of Instantaneous Power; micro grids

1. Introduction

The non-linear loads such as power electronic equipments produce harmonics. The harmonic and reactive power cause poor power factor and distort the supply voltage at the common coupling point or customer service point (Zheng ,2009). The international standards recommendation and requirements for harmonic control in electrical power systems imposed some harmonic limits [IEEE Standard,92]. In order to solve this problem, it is necessary to research the alternative solution, Firstly, different configuration are proposed of passive filters have been used to eliminate harmonics current and to compensate reactive power by increasing the power factor. But these filters have the disadvantages of large size; they are ineffective due to their inability to adapt to network parameters characteristic variation,

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problem of resonance, and deterioration of parameters (Mahalekshmi, 2010). The development of power electronic equipment, since the 1970s environment, active power filters (APFs) was been one of the most competitive modern solutions to suppressing harmonic pollution (Sasaki,2009), enhance power quality, and insure the better power distribution system. According to its procedure connection to the power system, there are two types of (APFs) as series active power filter and parallel (shunt) active power filter (Peng, 1993). Researches and application show that the series active power filter is preferable to compensate the harmonic voltage-source, while shunt active power filter is more suitable to compensate the harmonic current source [Mahalekshmi,10]. This paper present performance improvement of the shunt active power filter that consists of three principal parts, namely, the voltage source inverter, DC energy storage device (Cf) and coupling inductance (Lf). The inverter having six IGBTs switches is used to charge and to discharge the capacitor voltage source in order to provide the required compensation current, the capacitor voltage source is used to store energy and the inductance is used to smoothen the ripple of the harmonic current injected by shunt active power filter. The input supply voltage source provides the required active power and the capacitor voltage source of shunt active power filter provides the reactive power for the load.

2 Microgrid architecture

Wind diesel hybrid system with the average penetration coefficient is consists of a wind power plant, a diesel generator, a storage, and a set of charges. Diesel generator provides the active and reactive power required by the consumed charge in different modes; however, the main purpose of diesel generators in these systems is to control the voltage and frequency. Therefore, the speed governor regulates the frequency and voltage using the automatic voltage regulator. Speed governor determines a certain amount of fuel for diesel generators in order to keep the speed constant. Diesel generators regulate the frequency by maintaining the momentary balance between active production power and consumption power under the control of speed governor.Therefore, diesel generators are used as a control source of the active power. Wind power plant consists of a wind turbine and an induction generator (IG), which is directly connected to the network. The mechanical power produced by the wind turbine is obtained by the following equation:

$$P_{TM} = \frac{1}{2}\rho A v^3 C_p \tag{1}$$

Where ρ is the air density, v, is the wind speed, A is the area and Cp is the power factor. Here, Cp is a function of rotation speed and number of blades. Speed control is based on the TSR method and the equation (2).

$$\mathrm{TSR} = \frac{RW_r}{v} \tag{2}$$

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The length of the blades, w_r is the shaft speed of the wind turbines. Since the pitch control is not used in this paper, Cp is just a function of TSR. In addition, changes in the speed interval of IG in the wind power plant are very limited and consequently, Cp may be considered as a function of wind speed, because wind speed is quasi random.Speed governor determines a certain amount of fuel for diesel generators in order to keep the speed constant. Diesel generators regulate the frequency by maintaining the momentary balance between active production power and consumption power under the control of speed governor. Therefore, the diesel generators are used as a control resource of the active power. There is no method for controlling the active power of the wind power plant; thus, wind power plant can be regarded as an uncontrollable resource of the active power. Reactive power is used by IG. As a result, a capacitor bank is applied as a power compensator. In the average penetration rate, the wind power plant generates P_T that may be more than the consumed power of the charge, P_L. Thus, the active power balance of the system, P_L-P_T, is negative. This means that the power of the diesel generator should be negative (diesel generator power inversion) in order to obtain the equal active power for keeping the constant frequency (consumption production). Because the speed governor cannot regulate the synchronous generators with the consumed power, the diesel generators are not able to adjust the frequency, when P_L-P_T <0 In order to prevent the diesel generator power inversion; the adjustable charge should be included in the system. Wind diesel hybrid system controller commands the adjustable charge to use the extra power in order to keep the required produced power of the diesel generator positive. Thus, the diesel generator can control the frequency. Energy saving system is used for preventing the diesel generator power inversion. Additionally, this system is used for improving the dynamic response. This increases flexibility of the diesel generators, thereby improving the performance of the wind-diesel hybrid systems. Battery based energy saving system consists of a capacitor bank and a power converter that convert DC/AC voltage for different levels of voltage. Energy saving system can store or retrieve the required energy; as a result, it can be used as control resource of the active power.

3 Proposed controller of the parallel filter

If the voltage of charge terminal V(t) in a three wire three phase system consists of the positive and negative sequences (V(t)=V+ (t)+V- (t)), the resource current after compensation can be restructures using the optimal method:

$$i_s(t) = \lambda v^+(t) + \lambda v^-(t) = i_s^+(t) + i_s^-(t) \tag{3}$$

$$\lambda = \frac{\bar{p}(t)}{V(t).V(t)} \tag{4}$$

Equation (3) shows that the components of the charge terminal voltages are related to the current sequences of the resource. In other words, even after compensation, the voltage of the negative sequence of the charge, $v^{-}(t),\ i_s^{-}(t)$, causes a current of negative sequence in the resource that imposes the disturbance and imbalance in the resource current and reduces the power factor. In addition, V (t) .V (t) in equation (4) should be considered that causes the fluctuation due to the various harmonics and is added to the average amount and disturbs the resource current (in the form of different harmonics). The complementary theory GTIP (A_GTIP) proposes the following solutions in order to eliminate the errors in the equations of the comprehensive theory of the momentary powers GTIP:

- Solution for overcoming the components of the negative sequence of the replacement

$$i_s(t) = \frac{\bar{p}(t)}{V^{+}(t).V^{+}(t)} v^{+}(t) \tag{5}$$

There are $V(t)$ and $v^{+}(t)$ in the equation. Therefore, the new current of the resource is obtained using the following relationship:

Although the components of the negative sequence of the current are eliminated in the equation (5), the resource currents will be completely sinusoidal if there is no harmonic component for $V^{+}(t)$.If $v_1^{+}(t)$ is considered as the base part of the $v^{+}(t)$, the resource current will be obtained after compensation as follows:

$$i_s(t) = \frac{\bar{p}(t)}{v_1^{+}(t).\ v_1^{+}(t)}\ v_1^{+}(t) \tag{6}$$

In this way, $v_1^{+}(t)$ only contains the average part and the resource produces no 'reactive power'. Clearly, active power provided by the resource is equal to the size of average power transferred to the charge; therefore, the resource currents will be balanced and sinusoidal. The power factor will be unified. The remaining active power required by the charge (fluctuating active power) is provided by the compensator. Using the equation (6), the compensated reference currents using the developed GTIP are obtained using the following relationship:

$$i_c(t) = i(t) - \frac{\bar{p}(t)}{v_1^{+}(t).\ v_1^{+}(t)}\ v_1^{+}(t) \tag{7}$$

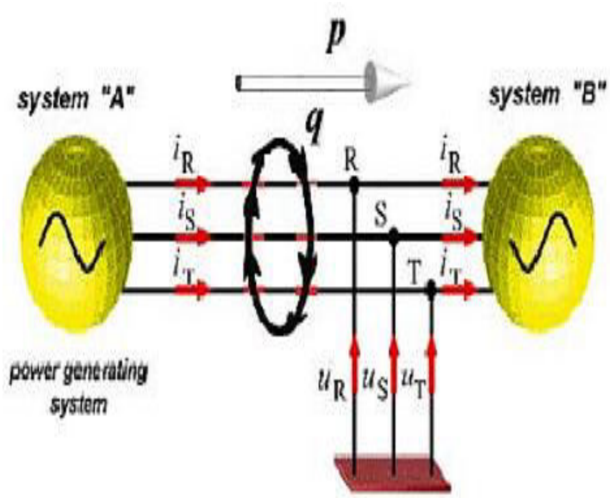

Fig. 1. diagram of the exchange

Power in the three-wire three-phase system. In this figure, power of q is shown in a circle between the phases of a, b, and c. if the real power, p, is positive, it shows the energy current from system A to system B. if it is negative, the energy current is from B system to A system. Figure 3 shows a diagram of the proposed method for controlling the parallel active filter based on the above relationships and exchanges. The above equations are used for simulation in addition to showing the performance of the active filter and effective control process.Now, the current harmonics are successfully removed. The equations (5) and (6) should be replaced with the equation (8) in order to facilitate exchanging the saving power with the network by the shunt active filter and controlling the power:

$$i_{s\_new}(t) = \frac{\bar{P}(t)-\bar{P}_g(t)}{U_1^+(t).U_1^+(t)} U_1^+(t)$$

$$i_{c\_new}(t) = i(t) - \frac{\bar{P}(t)-\bar{P}_g(t)}{U_1^+(t).U_1^+(t)} U_1^+(t) \quad (8)$$

Where Pg is the power that should be injected into the network. After adding this power, the amount of the reference current and compensating current are rewritten. So, the Kirchhoff's law is written in the connecting point of the parallel active filter and the network as follows (9):

$$i_{s\_new}(t) = i_s(t) - i_{sh}(t)$$

$$i_{c\_new}(t) = i(t) - i_s(t) + i_{sh}(t)$$

$$i_{sh}(t) = \frac{\bar{P}_g(t)}{U_1^+(t).U_1^+(t)} U_1^+(t) \quad (9)$$

Output current of the active filter ic_new(t) is equal to the network current i(t), distracted from the reference current is(t), added to the saving current ish(t). In this way, the amount of the saving current in the frequency control strategy is obtained.

4 Proposed work:

A IMPORTANCE OF FUZZY LOGIC

Fuzzy logic is all about the relative importance of precision: use as Fuzzy Logic Toolbox software with MATLAB technical computing software as a tool for solving problems with fuzzy logic. Fuzzy logic is a fascinating area of research because it does a good job of trading off between significance and precision something that humans have been managing for a very long time. In this sense, fuzzy logic is both old and new because, although the modern and methodical science of fuzzy logic is still young, the concept of fuzzy logic relies on age-old skills of human reasoning.

B USAGE OF FUZZY LOGIC

Fuzzy logic is a convenient way to map an input space to an output space. Mapping input to output is the starting point for everything. Consider the following examples:

- With information about how good your service was at a restaurant, a fuzzy logic system can tell you what the tip should be.
- With your specification of how hot you want the water, a fuzzy logic system can adjust the faucet valve to the right setting.
- With information about how far away the subject of your photograph is, a fuzzy logic system can focus the lens for you.
- With information about how fast the car is going and how hard the motor is working, a fuzzy logic system can shift gears for you.

To determine the appropriate amount of tip requires mapping inputs to the appropriate outputs. Between the input and the output, the preceding figure shows a black box that can contain any number of things: fuzzy systems, linear systems, expert systems, neural networks, differential equations, interpolated multidimensional lookup tables, or even a spiritual advisor, just to name a few of the possible options. Clearly the list could go on and on.Of the dozens of ways to make the black box work, it turns out that fuzzy is often the very best way. As Lotfi Zadeh, who is considered to be the father of fuzzy logic, once remarked: "In almost every case you can build the same product without fuzzy logic, but fuzzy is faster and cheaper".

C CONVENIENCE OF FUZZY LOGIC

Fuzzy logic is not a cure-all. When should you not use fuzzy logic? The safest statement is the first one made in this introduction: fuzzy logic is a convenient way to map an input space to an output space. Fuzzy logic is the codification of common sense — use common sense when you implement it and which will probably make the right decision. Many controllers, for example, do a fine job without using fuzzy logic. However, it take the time to become familiar with fuzzy logic, it can be a very powerful tool for dealing quickly and efficiently with imprecision and nonlinearity.

D The Fuzzy Logic Concept

Fuzzy logic arose from a desire to incorporate logical reasoning and the intuitive decision making of an expert operator into an automated system. The aim is to make decisions based on a number of learned or predefined rules, rather than numerical calculations. Fuzzy logic incorporates a rule-base structure in attempting to make decisions. However, before the rule-base can be used, the input data should be represented in such a way as to retain meaning, while still allowing for manipulation. Fuzzy logic is an aggregation of rules, based on the input state variables condition with a corresponding desired output. A mechanism must exist to decide on which output, or combination of different outputs, will be used since each rule could conceivably result in a different output action.Fuzzy logic can be viewed as an alternative form of input=output mapping. Consider the input premise, x, and a particular qualification of the input x represented by Ai. Additionally, the corresponding output, y, can be qualified by expression Ci . Thus, a fuzzy logic representation of the relationship between the input x and the output y could be described by the following:

R1: IF x is A1 THEN y is C1

R2: IF x is A2 THEN y is C2

. . . .

. . . .

. . . .

Rn: IF x is An THEN y is Cn

where x is the input (state variable), y is the output of the system, Ai are the different fuzzy variables used to classify the input x and Ci are the different fuzzy variables used to classify the output y. The fuzzy rule representation is linguistically based .Thus, the input x is a linguistic variable that corresponds to the state variable under consideration. Furthermore, the elements Ai are fuzzy variables that describe the input x. Correspondingly, the elements Ci are the fuzzy variables used to describe the output y. In fuzzy logic control, the term ‘‘linguistic variable’’ refers to whatever state variables the system designer is interested in . Linguistic variables that are often used in control applications include Speed, Speed Error, Position, and Derivative of Position Error. The fuzzy variable is perhaps better described as a fuzzy linguistic qualifier. Thus the fuzzy qualifier performs classification(qualification) of the linguistic variables. The fuzzy variables frequently employed include Negative Large, Positive Small and Zero. Several papers in the literature use the term ‘‘fuzzy set’’ instead of ‘‘fuzzy variable’’, however; the concept remains the same. Table 4.1 illustrates the difference between fuzzy variables and linguistic variables. Once the linguistic and fuzzy variables have been specified, the complete inference system can be defined. The fuzzy linguistic universe, U, is defined as the collection of all the fuzzy variables used to describe the linguistic variables .i.e. the set U for a particular system could be comprised of Negative Small (NS), Zero (ZE) and Positive Small (PS). Thus, in this case the set U is equal to the set of [NS, ZE, PS]. For the system described by , the linguistic universe for the input x would be the set Ux . .A1A2 . . . An.. Similarly,

TABLE 1 Fuzzy and linguistic variables

Linguistic Variables		Fuzzy Variables (Linguistic Qualifiers)	
Speed error	(SE)	Negative large	(NL)
Position error	(PE)	Zero	(ZE)
Acceleration	(AC)	Positive medium	(PM)
Derivative of position error	(DPE)	Positive very small	(PVS)
Speed	(SP)	Negative medium small	(NMS)

The linguistic universe for the output y would be the set Uy . .CaC2 . . . Cn.

The Fuzzy Inference System (FIS) The basic fuzzy inference system (FIS) can be classified as: Type 1 Fuzzy Input Fuzzy Output (FIFO)

Type 2 Fuzzy Input Crisp Output (FICO)

Type 2 differs from the first in that the crisp output values are predefined and, thus, built into the inference engine of the FIS. In contrast, type 1 produces linguistic outputs.

Type 1 is more general than type 2 as it allows redefinition of the response without having to redesign the entire inference engine. One drawback is the additional step required, converting the fuzzy output of the FIS to a crisp output. Developing a FIS and applying it to a control problem involves several steps:

1. Fuzzification

2. Fuzzy rule evaluation (fuzzy inference engine)

3. Defuzzification.

The total fuzzy inference system is a mechanism that relates the inputs to a specific output or set of outputs. First, the inputs are categorized linguistically (fuzzification), then the linguistic inputs are related to outputs (fuzzy inference) and, finally, all the different outputs are combined to produce a single output (defuzzification). Figure 4.1 shows a block diagram of the fuzzy inference system.

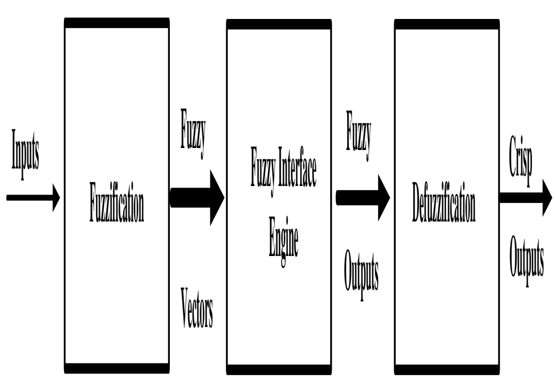

Fig .2 Fuzzy inference system.

E Fuzzification:

Fuzzy logic uses linguistic variables instead of numerical variables. In a control system, error between reference signal and output signal can be assigned as Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZE), Positive small (PS), Positive Medium (PM), Positive Big (PB). The triangular membership function is used for fuzzifications. The process of fuzzification convert numerical variable (real number) to a linguistic variable (fuzzy number). Simply the process of converting a numerical variable (real number) convert to a linguistic variable (fuzzy number) is called fuzzification.

F.Defuzzification:

The rules of fuzzy logic controller generate required output in a linguistic variable (Fuzzy Number), according to real world requirements; linguistic variables have to be transformed to crisp output (Real number). This selection of strategy is a compromise between accuracy and computational intensity.The rules of FLC generate required output in a linguistic variable (Fuzzy Number), according to real world requirements, linguistic variables have to be transformed to crisp output (Real number).

Database: the Database stores the definition of the membership Function required by fuzzifier and defuzzifier.

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 4.2, with' Vdc' and 'Vdc-ref' as inputs.

G FUZZY LOGIC CONTROLLER

Fuzzy logic is a method of rule-based decision making used for expert systems and process control that emulates the rule-of-thumb thought process used by human beings. The basis of fuzzy logic is fuzzy set theory which was developed by Lotfi Zadeh in the 1960s. Fuzzy set theory differs from traditional Boolean (or two-valued) set theory in that partial membership in a set is allowed. Traditional Boolean set theory is two-valued in the sense that a member belongs to a set or does not and is represented by 1 or 0, respectively. Fuzzy set theory allows for partial membership, or a degree of membership, which might be any value along the continuum of 0 to 1. A linguistic term can be defined quantitatively by a type of fuzzy set known as a membership function. The membership function specifically defines degrees of membership based on a property such as temperature or pressure. With membership functions defined for controller or expert system inputs and outputs, the formulation of a rule base of IF-THEN type conditional rules is done. Such a rule base and the corresponding membership functions are employed to analyze controller inputs and determine controller outputs by the process of fuzzy logic inference. By defining such a fuzzy controller, process control can be implemented quickly and easily. Many such systems are difficult or impossible to model mathematically, which is required for the design of most traditional control algorithms. In addition, many processes that might or might not be modeled mathematically are too complex or nonlinear to be controlled with traditional strategies. However, if a control strategy can be described qualitatively by an expert, fuzzy logic can be used to define a controller that emulates the heuristic rule-of-thumb strategies of the expert. Therefore, fuzzy logic can be used to control a process that a human can control manually with expertise gained from experience. The linguistic control rules that a human expert can describe in an intuitive and general manner can be directly translated to a rule base for a fuzzy logic controller.Figure 4.2 shows the internal structure of the control circuit. The control scheme consists of Fuzzy controller, limiter, and three phase sine wave generator for reference current generation and generation of switching signals. The peak value of reference currents is estimated by regulating the DC link voltage. The actual capacitor voltage is compared with a set reference value. The error signal is then processed through a Fuzzy controller, which contributes to zero steady error in tracking the reference current signal. A fuzzy controller converts a linguistic control strategy into an automatic control strategy, and fuzzy rules are constructed by expert experience or knowledge database. Firstly, input voltage *Vdc* and the input reference voltage *Vdc-ref* have been placed of the angular velocity to be the input variables of the fuzzy logic controller. Then the output variable of the fuzzy logic controller is presented by the control Current *I*max. To

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convert these numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen as: NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big) as shown in Figure 4.3.

The fuzzy controller is characterized as follows:

1) Seven fuzzy sets for each input and output;

2) Fuzzification using continuous universe of dis-course;

3) Implication using Mamdani's 'min' operator;

4) De-fuzzification using the 'centroid' method.

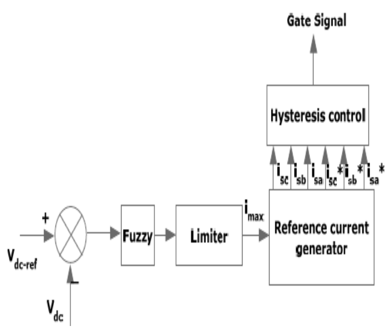

Fig.3.Conventional fuzzy controller

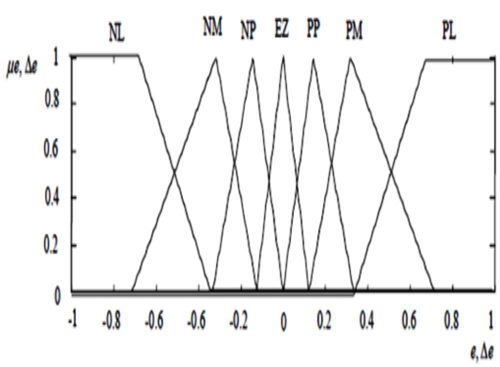

Fig.4. Input Vdc normalized membership function;

Table 2: Rules for Fuzzy 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

5 MATLAB/SIMULATION RESULTS

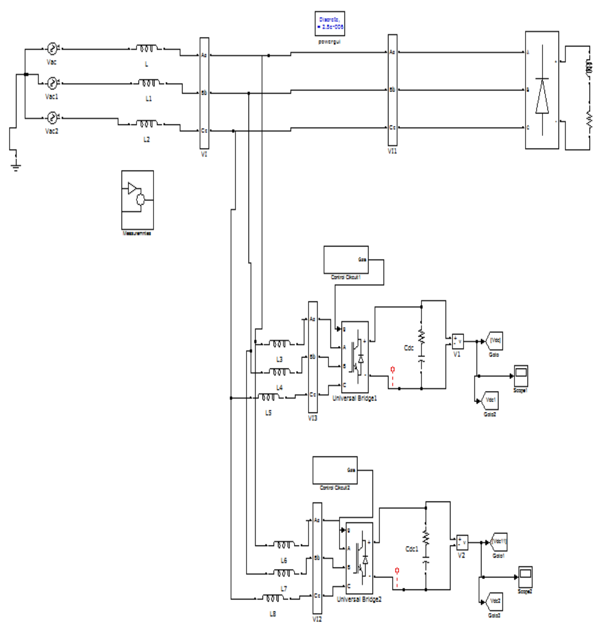

Fig 5 simulink diagram of prosed concept balanced nonlinear condition

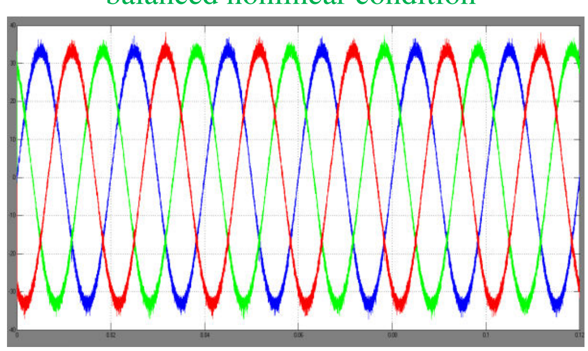

Fig6 source currentof balanced nonlinear condition

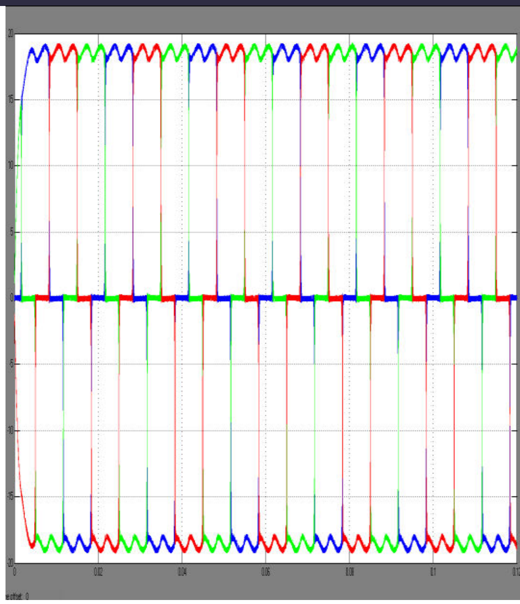

Fig7 Load currentof balanced nonlinear condition

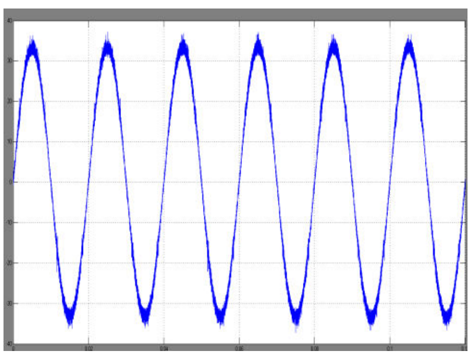

Fig8 source voltage of balanced nonlinear condition

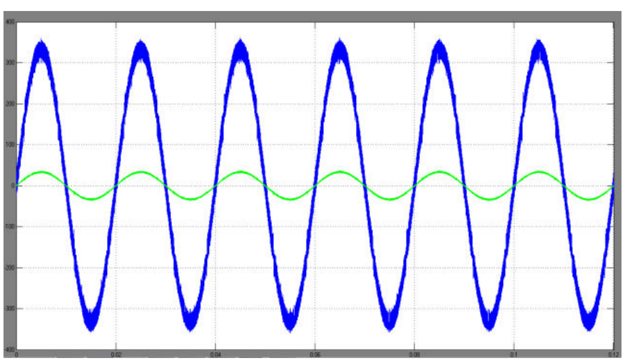

Fig9 power factor of balanced nonlinear condition

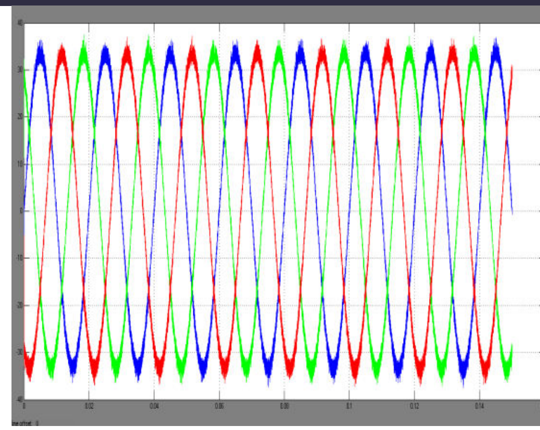

Fig 10source currentof unbalanced nonlinear condition

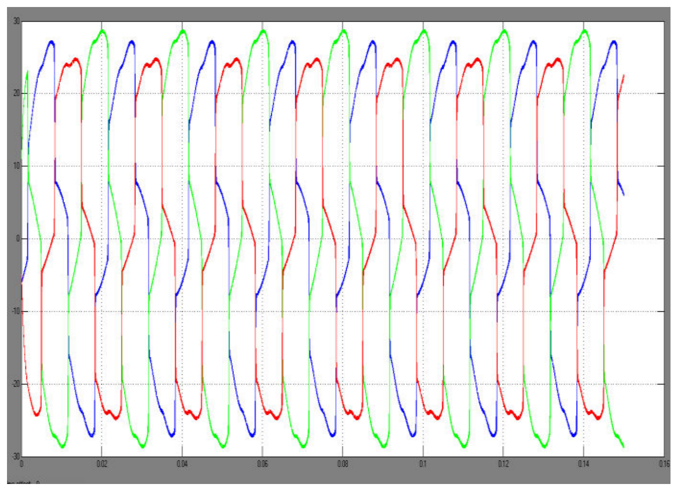

Fig 11Load current of balanced nonlinear condition

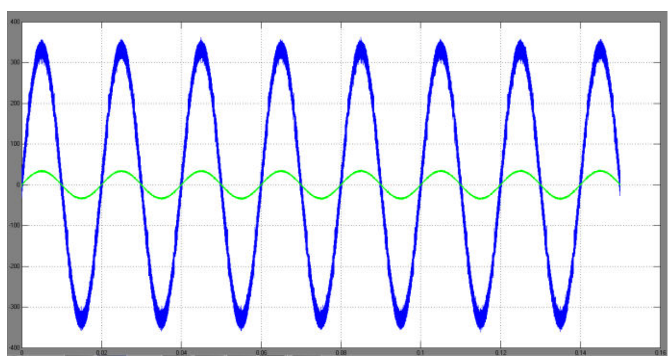

Fig 12power factor of unbalanced nonlinear condition

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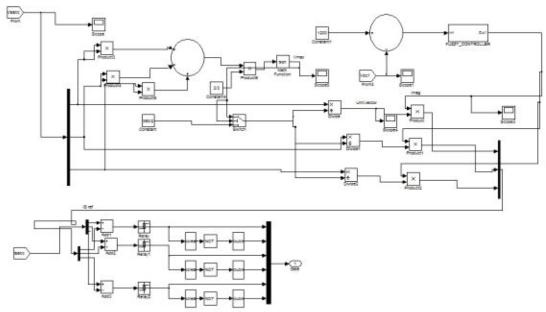

Fig 13 simulink diagram of fuzzy controller

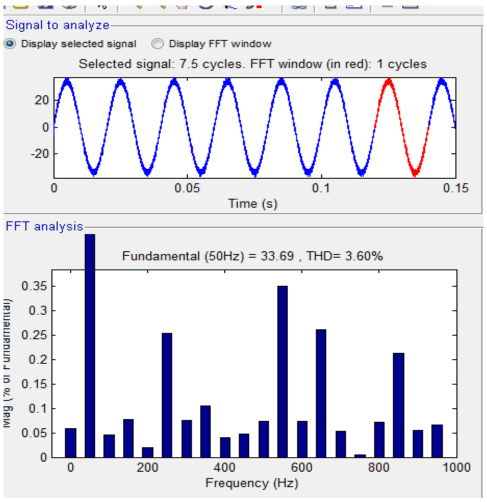

Fig14 Thd of proposed with PI controller

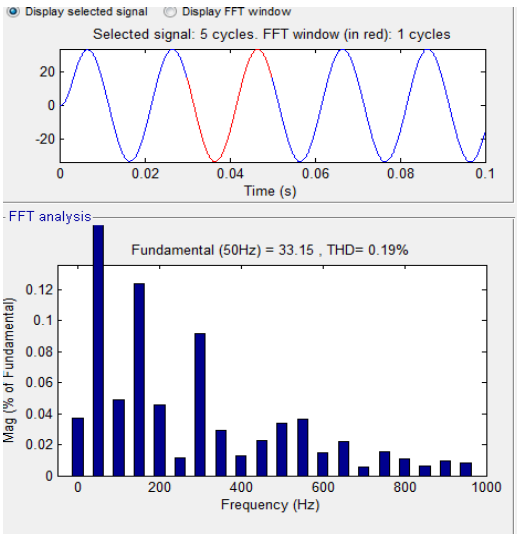

Fig 15 Thd of fuzzy controller

6. Conclusion

We introduce to Parallel Active Filter. Fuzzy logi controller is used to regulate DC link capacitor voltage and to compensate harmonic current. Using Matlab, the implemented shunt active power filter has high performance characteristics. The input currents are sinusoidal waveforms with a unit factor. The total harmonic distortion (THD) has been reduced clearly, that is within the limit of the harmonic standard recommendation on harmonics level. The compared to the conventional system, simulation results analysis reveal that the Parallel Active Filter performs perfectly in conjunction with fuzzy logic controller. simulation results are introduced to validate the proposed system.

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