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ADAPTIVE HYSTERESIS CURRENT CONTROLLER FOR 3-PHASE DISTRIBUTION SYSTEM BASED ON HYBRID PI-FUZZY CONTROLLER

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Abstract- This paper presents power system with active power filter using Park's transform and DQ Transformation with the adaptive hysterias current controller to get a sophisticated comparison between the performance of PI controller and fuzzy logic controller (FLL). The role and effect of adaptive hysteresis current controller is examined. Both two methods are applied to a 3-leg shunt active power filter which has connected to a 3-phase distribution system at the point of common coupling (PCC). Moreover, two these methods not only reduce current's total harmonic distortion (THD), but also compensate the reactive power. Both methods are simulated on a similar system and some parameters of them have been discussed, such as THD, system response time and calculation burden. These parameters have been considered as the comparison factors. This study accounts and results both advantages and disadvantages ofeach introduced methods. It should be mentioned that all studies are carried out using MATLAB & Simulink.

Keywords- Active power filter, Fuzzy Logic Controller, Power Quality, total harmonic distortion

I. Introduction

Power Quality (PQ) is an important measure of an electrical power system. The term PQ means to maintain purely sinusoidal current in phase with a purely sinusoidal voltage. The power generated at the generating station is purely sinusoidal in nature. The quality of electric power is deteriorating mainly due to current and voltage harmonics, zero and negative sequence components, voltage sag, voltage swell, flicker, voltage interruption, etc.An unavoidable increase of nonlinear loads in industrial, commercial and residential applications requires local supply of reactive and harmonic powers in order to reduce the power loss and maintain the quality of power in the system. The nonlinear loads and similar equipments draw non-sinusoidal unbalanced current from ac supplies resulting in reactive power requirement, current harmonic, excessive neutral currents and unbalanced loading [1]. Due to existence of current harmonics cause several weaknesses such as overheating of utility transformers, increased losses and harmonic resonances [2]. The large reactive power reduces lines transmission capabilities and augments power loss in distribution systems. Moreover, harmonics can distort the steadiness and reliability of distribution, decrease power quality, thus resulting lower power factor of the system.

To solve these problems, some methods have been considered: Active and passive filters [3], series and shunt capacitors [4-6], narrow band filters [7] synchronous machines, SVC's [8], reconfiguration [9-12], resizing and using distributed generation (DG) [13]. Eachof these suggested methods has some problems and weakness. Traditionally the passive filters consisting of tuned L-C and LCL components have some merits such as low cost, simple operation and high efficiency, although they have some drawbacks that have limited widespread use of passive filters: Aging of components [2].One more important problem of Passive filters is their disability of adapting to the network features and its variation. Shunt capacitors can form harmonic and resonance [14]. Also, they have inrush problems while either connection or disconnection [15].Synchronous machines are vast and have an unfavorable dynamic behavior [14] . Also,SVCs are harmonic polluters [8].

The use of active power filters (APF) as flexible solution for harmonic current compensation. The purpose of an active power filter is to generate harmonic currents having the same magnitude and opposite phase with harmonic current produced by the nonlinear loads and to ensure that the supply current consist of only fundamental component of current. The active filter topology can be connected in series for compensation of voltage harmonic and in parallel for compensation of current harmonic. Most of the industrial applications need current harmonic compensation so the shunt active filter is more popular than series active filter. The shunt active filter has the ability to balanced the mains current sinusoidal after compensation regardless of whether the load is non linear, balanced or unbalanced [2]. The shunt APF based on Voltage Source Inverter (VSI) structure is an attractive topology to solve harmonic current problems. The shunt active filter is a pulse width modulated (PWM) voltage source inverter (VSI) that is connected in parallel with the load [3]. Here voltage source inverter is chosen in place of current source inverter due to less complicated circuit and better filtering of load current [10] . It can be used to compensate unbalanced currents, current harmonics, and reactive power. The mains current obtained after

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compensation are sinusoidal andin phase with the supply voltages [4].There are different methodsof detecting harmonic currents and calculating referencecurrent signals: digital signal processor (DSP), instantaneous power theory (IPT) which has been improvedby Clark'stransform (αβ0 frame) and Park's transform (dq0 frame)[18] .Some merits such as avoiding difficultyof mappingmatrices calculations and prime IPT limitationof only constant power condition, are the reasons that mentioned transformation are preferred. Furthermore, the disadvantage of Clark's transformation, the variation of its component, is the main reason of the priority of DQ frame. As a consequence, DQ frame is selected as harmonic detection method.

The most prevalent approach to control the compensating current APF is based on PI controller [19]. Its coefficients are usually calculated by conventional approaches based on linearised modulation. Therefore, the results are not sometimes quite satisfactory for a wide range of set points. Due to the mentioned points, a new method is required to improve the performance of the conventional controller, thus in this paper, a proportional-integral-derivative fuzzy logic controller (PI- FLC) [20] is proposed. Also in order to have a better approach to switching the inverter bridge of APF, the methods have been combined with adaptive hysteresis current controller.

II. Three Phase 3 –Leg Inverter Description

The power system consists of a three-phase distribution system connected to a 3-leg inverter, a DC link, a classical adaptive hysteresis current controller and nonlinear load. At the point of common coupling (PCC) and a sub system consists of a dqO frame controller which benefits a controller which is either a PI or a Fuzzy logic. A 3 -leg inverter is used in proposed system with role of APF switching. All above mentioned control methods are based on DC link voltage balance. Schematic of this system is shown in fig. 1 and the schematic diagram of the controlling system is displayed in fig .2. Also, System parameters are given in TABLE.I.

Table.I.:System Parameters

3-phase supply (Rms)	Vs = 415v , f=50Hz
3-phase nonlinear load	R = 45.5 Ω, L = 13.3mH
DC Link capacitance	C_{dc} =4mF
Coupling Inductance	L=9mH

I. Control Strategies And Simulation Results

A. Conventional DQ Strategy

The conventional DQ frame is based on instantaneous power theory [21]. It assumes the signal DC waveforms under steady- state conditions [22].With this it allows the utilization of compensators with simpler structures and lower dynamic orders [18]. The determination in this frame needs the convert abc-system into the DQ frame.

The equation is used for this conversion is given below :

$$\begin{bmatrix} I_d \\ I_q \\ I_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

(1)

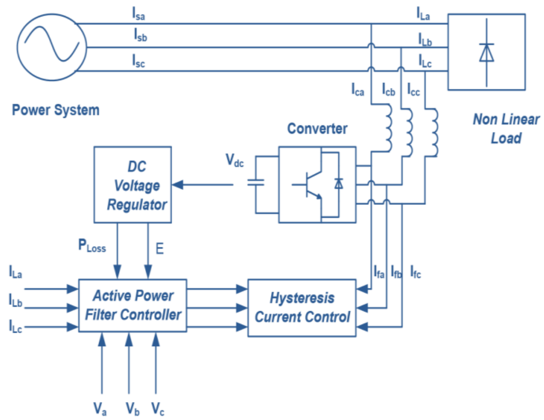


Fig.1. Schematic diagram of the Grid

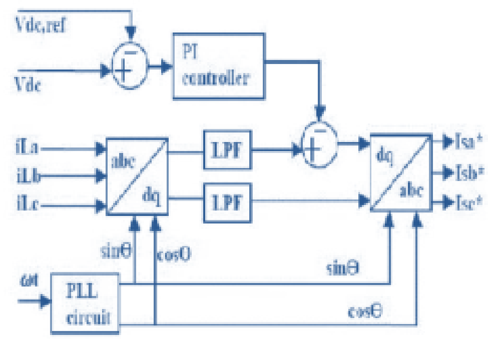


Fig.2 Schematic diagram of the control system(DQframe)

After this transformation, the current is calculated in the rotating reference frame [18]. The direct component of the current is called I_d and quadrature component is I_q.these two components consist of two parts one is oscillating component and another is DC part, therefore following equation could be defined:

$$I_d = i_d + \bar{\imath}_d \quad (2)$$

$$I_q = i_q + \bar{\imath}_q \quad (3)$$

After the conversion of the abc system into DQ frame, resulting three components, twoof them are direct and quadrature which werediscussed. Third part only appears when there is anyunbalanced load which is called I_0. It should be noted that in order to Park' s transform, thesynchronous angle is required. PLL (Phase Lock Loop) needsa sample of the proposed wave to reach its angle. In order tohave this sample, this sample is given to the PLL block, thenby the internal operationof PLL, (wt+θ) is resulted. In our system, any unbalanced load has not been assumed,andIO is only effective when there is unbalanced load, hence the magnitude of IO is zero. Iq is the part of current which cause reactive power. Thus, this part has to be eliminated. id which is related to the load ripples has to be totally compensated. In the other hand, mean value of Id has to be subtracted from Id which result its oscillation part. This magnitude has to be added to the output of PI controller and this amplitude is considered as the final amount of direct current component for transformation matrix to abc system.

PI controller role is to calculate the reference current required for input of hysteresis band current controller. Two inputs of PI controller are first DC link voltage and second a constant number . PI controller receives these inputs to be able to compensate charge and discharge of DC link.

The transform DQ frame to abc system is calculated by below equation:

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 1 \\ \cos(\theta - \frac{2\pi}{3}) & \sin(\theta - \frac{2\pi}{3}) & 1 \\ \cos(\theta + \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) & 1 \end{bmatrix} \begin{bmatrix} I_d \\ I_q \\ I_0 \end{bmatrix} \quad (4)$$

Due to the KCL law, the subtraction the network measured current (load current) from result of our calculation (finalmagnitudeof the transformation of DQ frame to the abc-system) is proposed as the reference current for hysteresis band currentcontroller.

The results of APF performance by conventional DQ frame are shown in fig .3 and fig. 4.

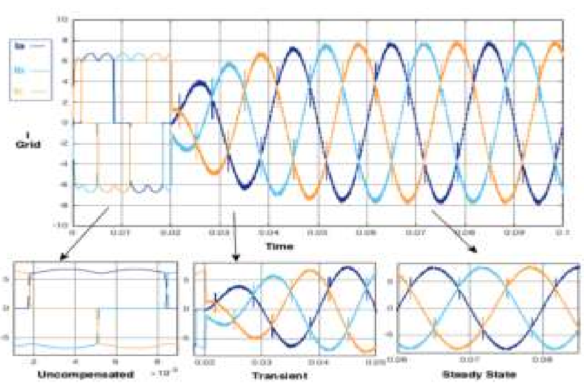


Fig 3. 3-Phase Grid Current (Uncompensated, Transient,Steady State), using conventionalDQ frame

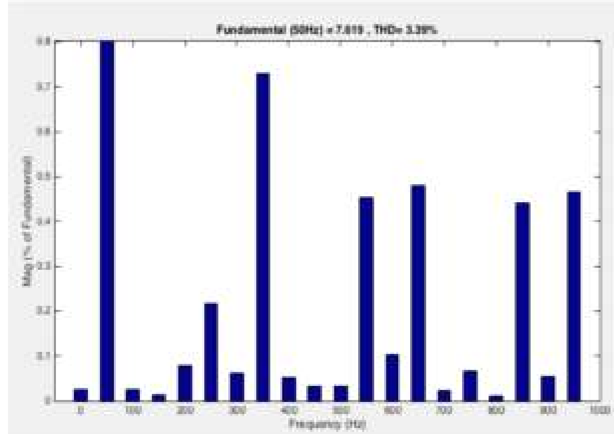


Fig.4. THD for compensated current (phase a), using conventional DQ frame

B. DQ Strategy by AHCC

There is a variety of controlling approaches to switching the APFs. The regular hysteresis band current controller has been known as a simple and appropriate controlling method. This strategy has some advantage such as its fast response feature, stability, acceptable accuracy and few hardware [22]. The hysteresis band current controller operates on the basis of comparing of reference current and APF current, thus reaching the aim of controlling the current in a band. The outputs of hysteresis band current controller are gate pulses for inverter bridge of APF. Despite all mentioned benefits of hysteresis band current controller, it owns some unfavorable characteristics that limit its use. More oscillation switching frequency, higher losses and producing resonance are some of mentioned disadvantages [22] , [19]. The explained reasons lead us to use a modified strategy, adaptive hysteresis current controller that below equation expresses hysteresis band:

$$HB = \frac{0.125 v_{dc}}{f_c L}\left[1 - \frac{4L^2}{{v_{dc}}^2}\left(\frac{v_{sa}}{L} + m^2\right)^2\right] \quad (5)$$

The fig. 5 and fig.6 show the result of applying adaptive hysteresis current controller to the proposed APF.

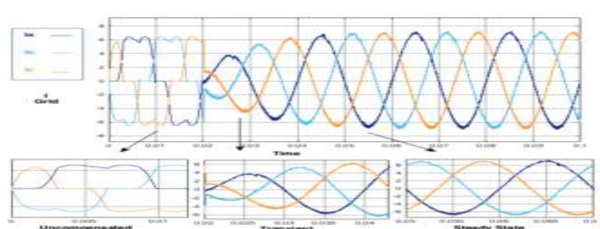


Fig .5. Grid 3-Phase Current (Uncompensated, Transient, Steady State), using DQ frame by AHCC

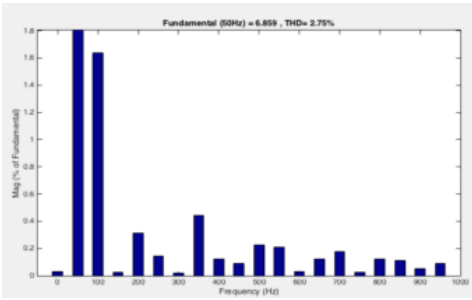


Fig. 6. THD for compensated current (phase a), using DQ frame by AHCC

C.. Modified Controlling Strategy by AHCC and FLC

The fuzzy logic controller is one of the advantageous control methods for systems facing difficulties in obtaining mathematical models or having performance restrictions with traditional linear control methods. In a fuzzy logic controller, the control signal is determined from the assessment of a set of linguistic rules (if-then rules), these rules are obtained from our understanding of the process to be controlled. To design fuzzy controller, variables that can represent the dynamic performance of the system to be controlled must be taken as the inputs to the controller [49]. Subsequently the supply voltage $v_S(t)$ and its derivative $\Delta v_s(t)$ are chosen as inputs to the fuzzy controller, and the hysteresis band (*HB*) is taken as the output as shown in Fig. 5

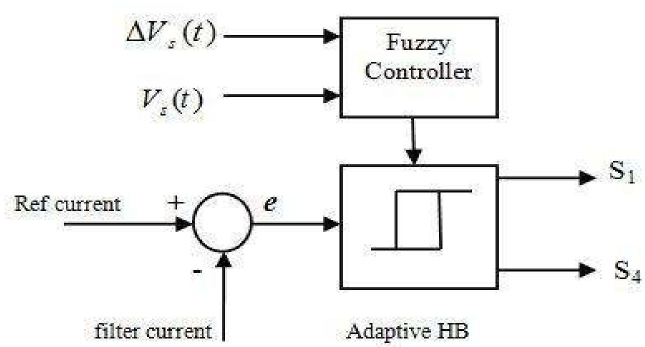
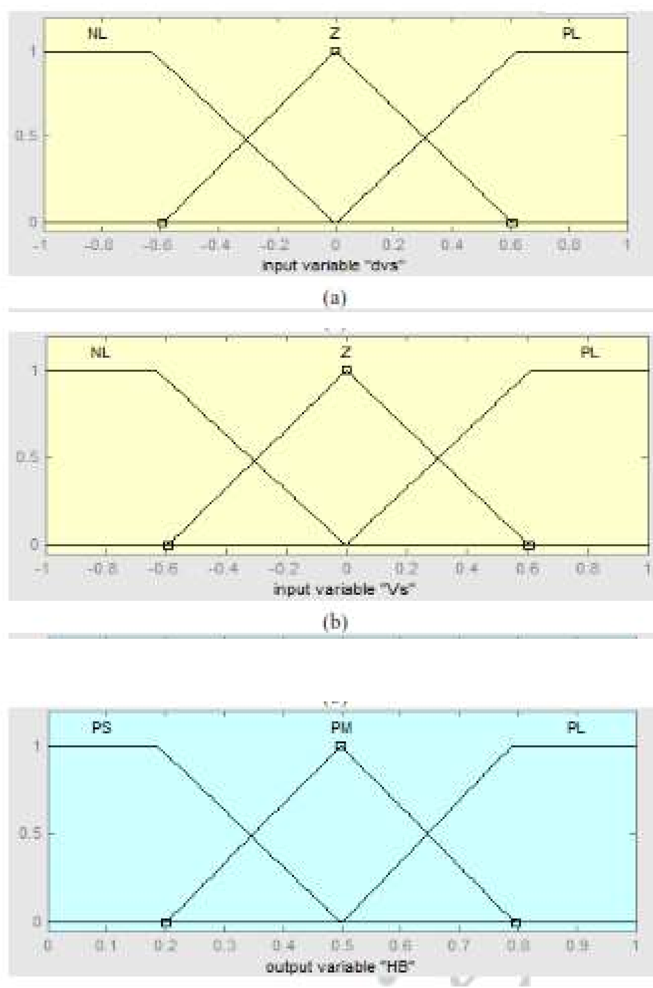


Fig.7. The proposed fuzzy hysteresis band current controller

Three linguistic variables are set to the inputs and output of the controller as NL (Negative Large), ZE (Zero), PL (Positive Large) for inputs and PS (Positive small), PM (Positive Medium), PL (Positive Large) for output, triangular membership functions as shown in Fig.8, have been used forinput and output variables because of its simplicity, the fuzzy rules are given in Table II.Fig.9.(a)-(e) highlights theperformance of proposed fuzzy hysteresis current controller,gives the details of source voltage, source current, load current, reference current, filter current, tracking shunt active Filter for phase (a),from the harmonic spectrum of the supply currentthe THD of the supply current has decreased from 3.39% to 2.66% as it is clear from Table III and harmonic spectrum of the compensated source current and theundesired portions of the real and reactive powers of the load that related to the presence of harmonics have been compensated by the SAPF and the source supplies only fundamental real power and zero reactive power to the load. It is seen that the switching frequency becomes nearly constant and the switching ripple components of the

source current has been concentrated to a narrow range around (15 KHz), this means that the proposed fuzzy hysteresis band current controller has worked properly and the modulation frequency of the shunt active power filter is held in 15 KHz, Hence select the appropriate filter to mitigate the ripple components in the filter current, determine convenient switching device and calculate switching losses has become easier.



(c)

Fig. 8. Membership functions of the input variables and output variable(a) Source voltage (b) rate of change of source voltage (c) hysteresisband

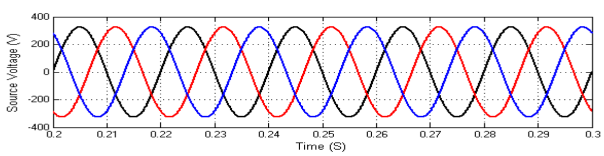
Table II:Fuzzy inference rule

Vs(t)/ ΔVs(t)	PL	Z	NL
PL	PS	PS	PS
Z	PM	PL	PM
NL	PS	PS	PS

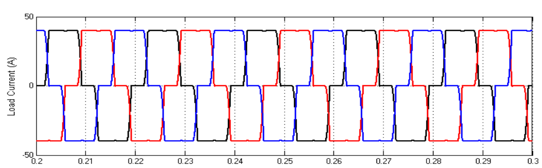
D. Fuzzy Inference System (FIS):

Fuzzy rules are based on perception rather than anexplicit model [24]. The rules and shapeof thememembership functions are developed through the behaviorof the system and duty cycle effect on the output voltageof converter. Furthermore, following the reference voltagelead us to correctly set the output according to the inputsituations. By considering the mentioned points, the rule tablein table-II is likely proposed.

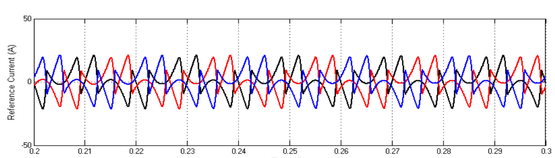
In this section fuzzy logic controller has been used asthe strategy with aimof compensating charge and dischargeof DC link. Moreover, adaptive hysteresiscurrent controller is used in order to have an efficientinverter switching procedure. Fig.9 (a-g)show the resultsof using this strategy.



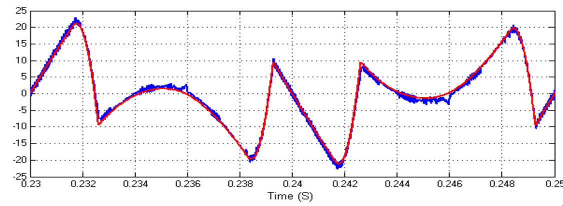
(a)



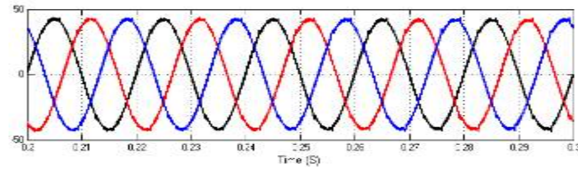
(b)



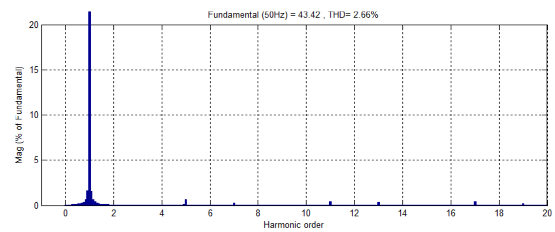
(c)



(d)



(e)



(f)

Fig.9.Simulation results of proposed fuzzy HCC (a) source voltage (b) load current (c) reference current (d) filter current (e) supply current (f)) harmonic spectrum of the supply current

All the abovementioned methods are simulated on the same system. The elaborated information about THD havebeen stated in the TABLE III. It should be emphasized that all simulations have been doneby MA TLAB/SIMULINK

Table III:TheResult Of Simulation, Thds Of 3-Phase Grid Current

APF controlling Method	*Source /Grid Current THD*
Conventioonaldq Frame	*3.39*
dq Frame by AHCC	*2.75*
dq frame by FLC and AHCC	*2.66*

III. Conclusion

In this study, three noted strategies have been reviewed andcompared. Due to the simulation results, the aimsof controlling APFs are achieved by all these strategies. These methods have the capability to control active power filters to be qualified to be used in distribution systems. By analysis of TABLE III, it can be inferred that DQ) frame can satisfactorily compensate the total harmonic distortion, appeared by nonlinear load. The results prove that DQ strategy by adaptive hysteresis current and fuzzy logic controller has the most efficiency among the introduced methods. However, calculation burden of this approach owns the highest calculation burden, its benefits have higher priorities, itsTHD is minimum, in addition its transient time strategy is almost zero.

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