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Regulation of the DC Bus Voltage of a Three Phase Active Power Filter by PI and Fuzzy Logic Controller

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ABSTRACT
In this paper ,two types of controls algorithms are proposed to regulate the DC bus voltage of a High three phase shunt active power filter (HSAPF), proportional integral (PI) and fuzzy logic controllers. Our objective here is to maintain the DC bus voltage of the inverter constant to bring down the total harmonic distortion (THD) of source current sufficiently below 5% at the point of common-coupling with variation of loads, in order to satisfy the IEEE 519-1992 Standard recommendations on harmonic limits. The synchronous reference frame phase locked loop (SRF PLL) algorithm I_d, I_q is used to extract the harmonic reference currents. The hysteresis band method is employed to derive the switching signals of the High shunt active power filter. The comparison made between the two types of DC bus voltage controllers shows that these control strategies gives the best results. A series of simulation by MATLAB/Simulink are presented and discussed to show the performance and the effectiveness of these control strategies.

KEYWORDS: *High three phase shunt active power filter (HSAPF), Total harmonic distortion (THD), Fuzzy logic controller,.*

I. INTRODUCTION

Electrical power quality has been, in recent years, an important and growing problem because of the proliferation of nonlinear loads such as power electronic converters in typical power distribution systems. Particularly, voltage harmonics and power distribution equipment problems result from current harmonics produced by nonlinear loads [1].The Nonlinear loads inject wide spread current harmonics into the power grid even if the supply is harmonic free sinusoidal voltages. The circulation of current harmonics through the grid impedance involves the appearance of voltage harmonics at the point of common coupling of different loads [2]. Active filters have grabbed huge attention as proficient devices in compensating the current harmonics and reactive power produced by non-linear loads. It can suppress different order harmonic components of non-linear loads simultaneously, by confining the harmonics at load terminals and hindering its penetration into AC lines. It automatically adapts to changes in network and load fluctuations. Few most important advantages of APF are: (i) intelligent filter (ii) can be used globally or locally, (iii) extremely efficient even when the harmonic content varies randomly, and (iv) more than one device can be installed on the same supply [3].The performance of an active filter depends mainly on the technique used to compute the reference current and the control method used to inject the desired compensation current into the AC line [4]. In this paper we have chosen the best method to give the high active power filter (HSAPF) the effectiveness and the dynamic necessary to obtain the best results of compensation. The synchronous reference frame phase locked loop (SFR PLL) used to extract the reference currents and for the HSAPF's pulse generation we have used the hysteresis band control.

The other important task in the HSAPF design is the maintenance of constant DC voltage across the capacitor connected to the inverter. This is necessary because there is energy loss due to conduction and switching power losses associated with the diodes and MOSFETs of the inverter in APF, which tend to reduce the value of voltage across the DC capacitor [4]. In this paper we have based our study about how to maintenance the DC bus voltage constant, for this reason we have introduced an tested by comparison two types of DC bus voltage controllers, the proportional integral (PI) controller and the fuzzy logic controller (FLC). The results obtained are very interesting, compared to many results got by other authors who work in the same domain, the proposed simulation model can be implemented in real time. The dynamic of the system is very good with and without variation of loads, the power factor is well corrected and the DC bus voltage is maintained constant at 800V. Finally, to verify our theoretical analysis, computer simulation in MATLAB-Simulink has been made to show the effectiveness and the important of this study.

II. SHUNT APF CURRENT DETERMINATION

Among the several methods presented in the literature [4] to generate the reference current of the compensator, the synchronous reference frame phase locked loop (SRF-PLL) is one of the most common and probably it is widely used method.One of the most important characteristics of this algorithm is that the reference currents are derived directly from the real loads currents without considering the source voltages. This is an important advantage since the generation of the reference signals is not affected by voltage unbalance or voltage distortion, therefore increasing the compensation robustness and performance [5].

III. DC LINK VOLTAGE REGULATION

For regulating and maintaining the DC link capacitor voltage constant, the active power flowing into the active filter needs to be controlled. If the active power flowing into the filter can be controlled equal to the losses inside the filter, the DC link voltage can be maintained at the desired value [8]. In order to do this [7], a PI and Fuzzy logic controllers branches are added to the d axis in d–q frame (see Fig. 1a,b) to control the active current component. The PI and Fuzzy logic controllers control this small amount of active current and then the current controller regulates this current to maintain the DC link capacitor voltage constant. To achieve this, the DC link voltage is detected and compared with the reference voltage setting by control circuit and then the difference is fed to the PI and fuzzy logic controllers.

A.DC link voltage regulation with PI controller

Fig. 1a shows the internal structure of the control circuit. 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.

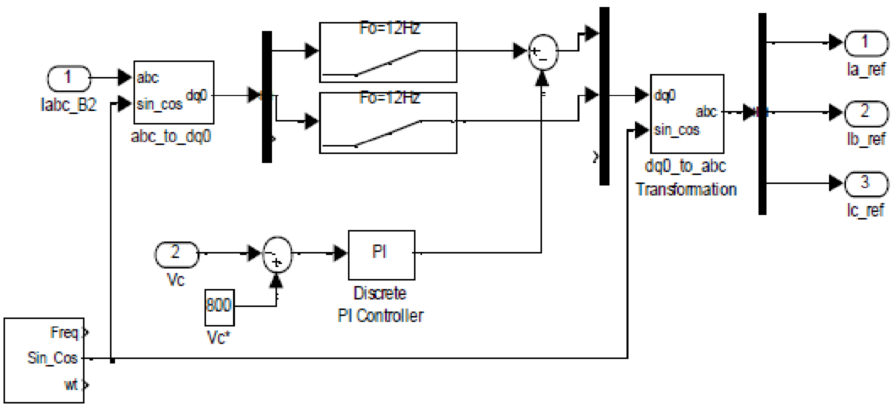


Fig. 1a DC link voltage regulation by PI controller

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[1].

B.DC link voltage regulation with fuzzy logic controller (FLC)

Fig. 1b shows the FLC based dc voltage (Vdc) controller for filter [9]. 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 and its derivative are then processed through a Fuzzy controller, which contributes to zero steady error in tracking the reference current signal [1]. The fuzzy inference system implementation is used in MATLAB. This FIS consists of Fuzzy Inference System (FIS) Editor, Membership Function Editor, Rule Editor, Rule Viewer and Surface Viewer. The FIS Editor handles the high-level issues for the system: How many inputs and output variables? What are their names? The Membership Function Editor is used to define the shapes of all the membership functions associated with each variable. The Rule Editor is for editing the list of rules that defines the behavior of the system. The Rule Viewer and the Surface Viewer are used for looking at, as opposed to editing, the FIS. They are strictly read-only tools. Used as a diagnostic, it can show which rules are active, or how individual membership function shapes are influencing the results. The Surface Viewer is used to display the dependency of one of the outputs on any one or two of the inputs—that is, it generates and plots an output surface map for the system [8].

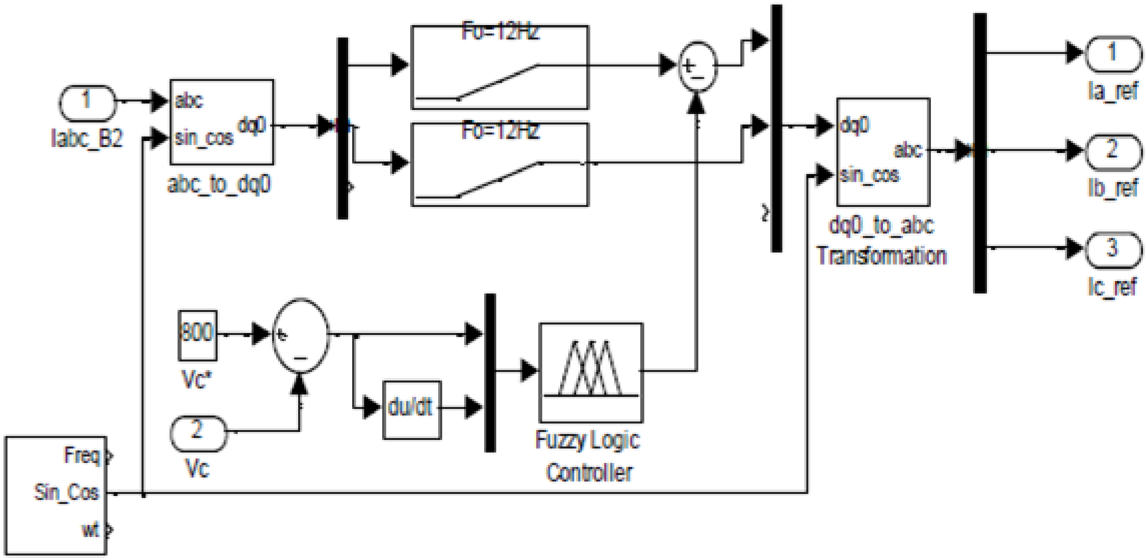


Fig. 1b DC link voltage regulation by FLC

FLC converts a linguistic control strategy into an automatic control strategy, and fuzzy rules are constructed by expert experience or knowledge database [16]. Firstly, input error (e) and change in error (de) 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 Imax. To convert these numerical variables into linguistic variables [1], the following seven fuzzy levels or sets are chosen as: NL(Negative Large), NM(Negative Medium), NS (Negative Small), ZE (Zero), PS(Positive Small), PM(Positive Medium) and PL (Positive large). The fuzzy variables (e) and (de) are processed by the inference engine, by executing the set of control rules contained by rule matrix (7 x 7) as given in Table 1. Various inference mechanisms have been developed to de-fuzzifies the fuzzy rules. In this paper, we applied min-max inference method to get implied fuzzy set of the turning rules. The imprecise fuzzy control action generated from the inference engine must be transformed to a precise control action in real applications. The centroid method is used to de-fuzzify the implied fuzzy control variables.

e / de	**NL**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PL**
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
NS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	NL	NM	NS	ZE	PS	PM	PL

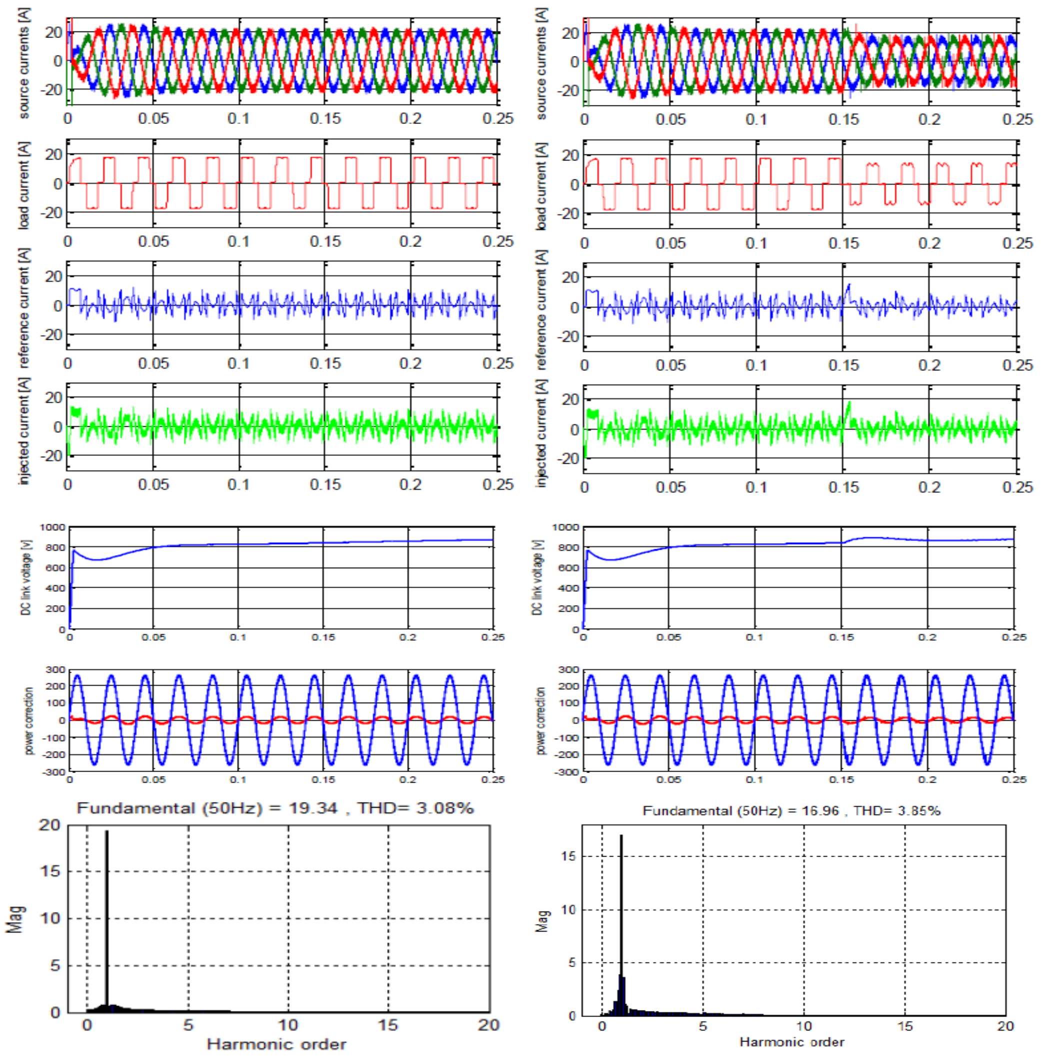
Table 1. Rule base table.

IV. SIMULATION RESULTS AND DISCUSSION

Extensive simulations in MATLAB/Simulink were carried out. Table 2 gives the values of parameters used during simulation.

Network	Vsrms=320V,ƒ=50HZ Rs=0.5mΩ,Ls=15µH
Non linear load	Rc=1.2 mΩ,Lc=50µH Rd=25 Ω,Ld=50mH =45 °
Shunt active filter	C=485µF,Rf=1.5 mΩ Lf=1200µH
Hysteresis control	ΔI=2A
<u>Iref calculation:</u> -2ndorder HPF -2ndorder band-pass filter	ƒc=12HZ, =0.7 ƒc=12HZ, =0.707
PI controller Reference voltage	KP=2,Ki=1.5 Vc*=800V

Table 2. System Parametres



(a) (b)

Fig. 2 Simulation results after introducing HSAPF with PI (a) without load variation (b) with load variation

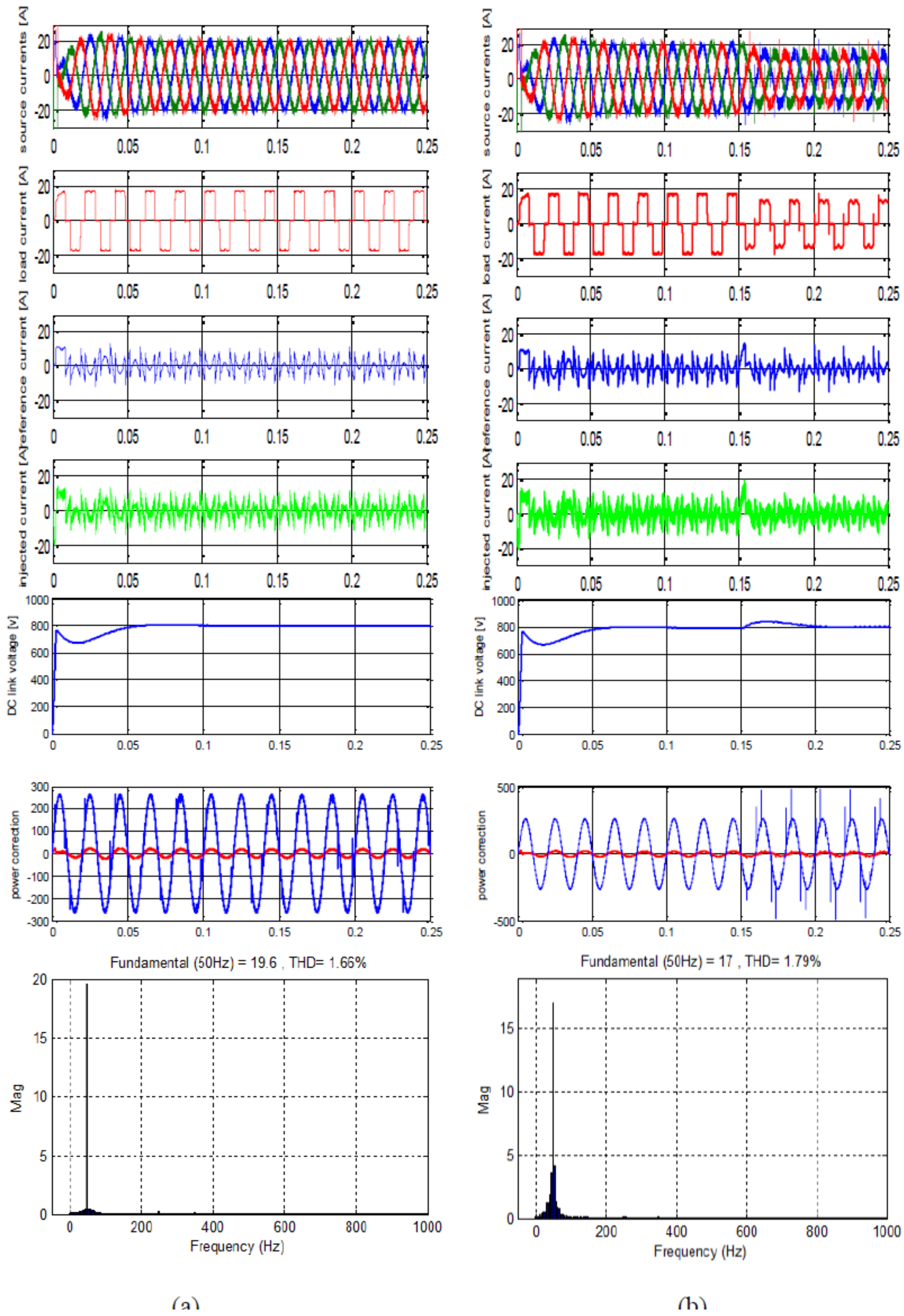


Fig. 3 Simulation results after introducing HSAPF with FLC (a) without load variation (b) with load variation

Figs. 2a and 2b illustrates the performance of the high shunt active power filter using PI controller, we can notice that the source current takes a sinusoidal form and the harmonic currents injected by HSAPF followed their references. The DC capacitor voltage is well regulated and maintained at a constant value of 800V with a very limited fluctuation. THD of source current is 2.10% with load changing and the power factor is well corrected.

Figs. 3a, 3b gives the details of source current, reference current of phase a, injected current of phase a, load current, DC link voltage, power correction and THD after compensation with and without load variation using fuzzy logic controller (FLC).It is observed that the source currents are balanced and sinusoidal, the wave forms of these currents are good and the notches are eliminated. We can say that PI and FLC are converging to the same compensation characteristics. However, without and with load variation the Id-Iq method with FLC shows superior performance, we can see this in THD value which is 1.66% and 1.79%. Here we do a comparison between the convergence characteristics of Vdc for PI and FL controllers. The simulation wave forms for Vdc shows that:

1. Before load variation , the PI controller present an over shoots especially in the first 5ms but FLC present no over shoots which justify the effectiveness of the fuzzy logic controller.
2. After load variation at t=0.15s the over shoots presented by PI controller are less than the case of FLC . With load variation the dynamic of the PI controller is the best.

The THD's of source currents before and after compensation with and without load variation have been listed and compared in Table.3.

THD of source current (%)							
Before compensation		After compensation without PI and FLC		After compensation with PI controller		After compensation with FLC	
Without	With	Without	With	Without	With	Without	With
28.17	26.38	3.08	3.85	2.68	2.10	1.66	1.79

Table. 3. The THD results

V. CONCLUSION

In the present paper the PI and FL controllers are considered to maintain the DC bus voltage of the three phase high shunt active power filter constant. The synchronous reference frame PLL algorithm is used to extract the harmonic reference currents. The control scheme using hysteresis current controllers has been implemented. The MATLAB/Simulink results showing response of the control strategies under load variation are presented. All these control schemes are effective in harmonic compensation and satisfy the IEEE 519-1992 Standard recommendations on harmonic limits. The DC link voltage has been regulated successfully, minimizing the undesirable power losses responsible for degradation of the HSAPF performance, thereby providing optimal load compensation. The THD'[s] results in table 3 confirm the viability of the proposed control strategies and prove that the HSAPF, thanks to robust DC link voltage controllers, allows improving power quality by compensating current harmonics. The future step in this work is to build a practical experiment and to validate the proposed three phase and Affiliations

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