IMPROVING THE ACTIVE POWER FILTER PERFORMANCE BY ROBUST SELF-TUNING FACE TO SUDDEN CHANGE OF LOAD

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Abstract:
Several different methods can be used to control active power filters, whereby they form a very important role in determining the active power filter performance. This paper presents a new control design of shunt active power filter to eliminate the undesired harmonics and compensate reactive power under fast load variation condition. For this purpose the control circuit using adaptive PI controller is proposed; the Parameters which guide the functioning of PI controller are dynamically adjusted with the assistance of fuzzy control; adaptive PI controller is used for pulse generation to trigger the MOSFETs of active power filter.
In order to investigate the performance of this method of control, the studies carried out have been accomplished using simulation with the MATLAB Simulink, Power System Toolbox. The results, of simulation study of new SAPF control technique presented in this paper, are found quite satisfactory by assuring good filtering characteristics and high system stability.

Key words: *PI, Adaptive fuzzy PI, Fuzzy controller, SAPF, Harmonics, Total Harmonic Distortion*

1. Introduction.

Due to proliferation of power electronic equipment and nonlinear loads in power distribution systems, the problem of harmonic contamination and treatment take on great significance .These harmonics interfere with sensitive electronic equipment and cause undesired power losses in electrical equipment[1,2,3]. In order to solve and to regulate the permanent power quality problem introduced by this Current harmonics generated by nonlinear loads such as switching power factor correction converter, converter for variable speed AC motor drives and HVDC systems, the passive filters have been used; which are simple and low cost. However, the use of passive filter has many disadvantages, such as large size, tuning and risk of resonance problems.
Lately, owing to the rapid improvement in power semiconductor device technology that makes high-speed and high-power switching devices such as power MOSFETs, MCTs, IGBTs , IGCTS , IEGTs etc. usable for the harmonic compensation modern power electronic technology, active power filter (APF) has been considered as an effective solution for this issue, it has been widely used.
One of the most popular active filters is the Shunt Active Power Filter (SAPF)[6,7,8,9,10,11]. SAPF has been researched and developed, that they have gradually been recognized as a workable solution to the problems created by non-linear loads. The functioning of shunt active filter is to sense the load currents and extracts the harmonic component of the load current to produce a reference current Ir , a block diagram of the system is illustrated in Fig. 1. The reference current consists of the harmonic components of the load current which the active filter must supply. This reference current is fed through a controller and then the switching signal is generated to switch the power switching devices of the active filter such that the active filter will indeed produce the harmonics required by the load. Finally, the AC supply will only need to provide the fundamental component for the load, resulting in a low harmonic sinusoidal supply.

Generally, the effectiveness of an SAPF depends on three design criteria: (i) design of power inverter; (ii) methods used to obtain the reference current; (iii) types of current controllers used. The presented work was oriented mostly on latter criterion.
Research has shown that conventional SAPF control methods such as, PI control (CPI) are able to perform optimally over the full range of operation conditions and disturbances and it is very effective with constant load, Moreover these non-linear loads are not fixed and change randomly. However SAPF with conventional PI control may not have satisfactory performance in such fast varying conditions, the system performance deteriorates. In addition to this, it is difficult to select a suitable control parameters Kp and Ki in order to achieve satisfactory compensation results while maintaining the system stability, due to the highly complex, non-linear nature of controlled systems. These are two of the major drawbacks of the PI control. In order to overcome these difficulties, adaptive PI controller by

fuzzy control has been applied both in stationary and variance states of the load, and is shown to improve the overall performance of SAPF

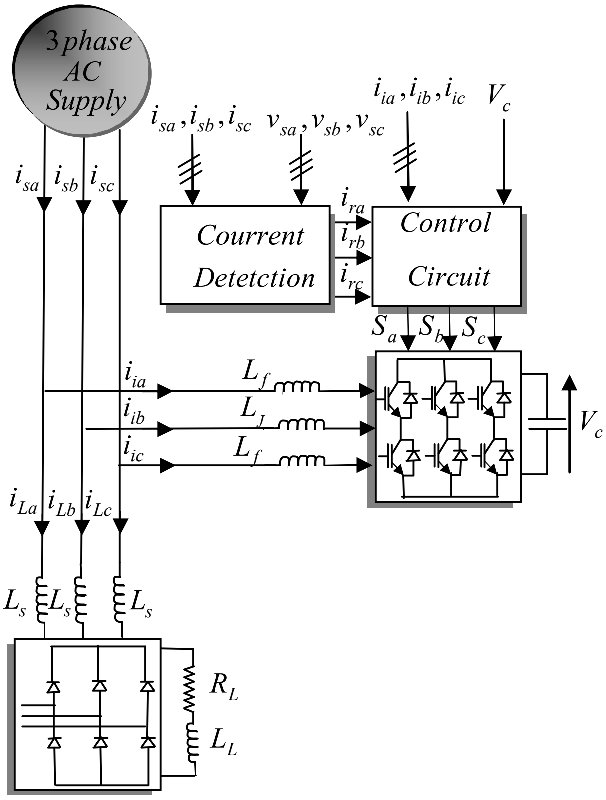

Fig. 1 Schematic diagram of shunt APF

2. Conventional PI Controller.

The reason behind the extensive use of proportional integral controller or named simple PI controller (CPI) is its effectiveness in the control of steady-state error of a control system and also its easy implementation. However, one disadvantage of this conventional compensator is its inability to improve the transient response of the system [11,12,13,14]. The conventional PI controller (Fig.2) has the form of Eq. (1), where Y is the control output which is fed to the PWM signal generator. K_P and K_I are the proportional and integral gains respectively, these gains depend on the system parameters. ε is the error signal, which is the difference of the injected current to the reference current.

$$y(t) = K_p * e(t) + K_i \int_0^t e(t)dt \qquad (1)$$

Equation (1) shows that the PI controller introduces a pole in the entire feedback system, consequently, making a change in its original root locus. Analytically the pole introduces a change in the control system's response. The effect is the reduction of steady-state error.

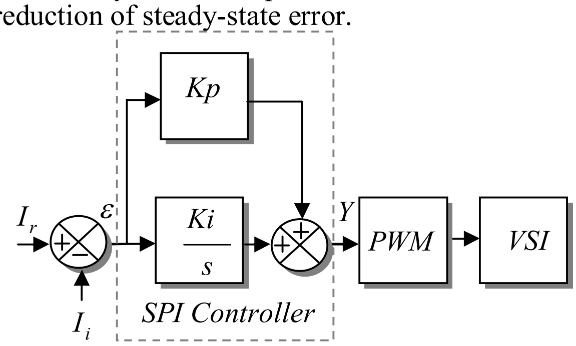

Fig. 2 Control of the injected current using conventional PI controller (CPI)

On the other hand, the constants KP and KI determine the stability and transient response of the system, in which, these constants rely on their universe of discourses:

$K_P \in [K_P\min, K_P\max]$ and $K_I \in [K_I\min, K_I\max]$.

Where the values of the minimum and maximum proportional and integral constants (gains) are practically evaluated through experimentation and using some iterative techniques. This makes the design of the conventional PI controller dependent on the knowledge of the expert. When the compensator constants exceed the allowable values, the control system may come into an unstable state. After the determination of the domain of the proportional and integral constants, the tuning of the instantaneous values of the constants takes place. Depending on the value of the error signal, ε, the values of the constants adjusts formulating an adaptive control system. The constants KP and KI changes to ensure that the steady-state error of the system is reduced to minimum if not zero

3. The Fuzzy Adaptive PI Control.

Fuzzy controllers have been widely applied to industrial process. Especially, fuzzy controllers are effective techniques when either the mathematical model of the system is nonlinear or no the mathematical model exists. In this paper, the fuzzy control system adjusts the parameter of the PI control by the fuzzy rule.
Recently, several authors have described methods for dynamic adjustment of the gains of a PI controller by Fuzzy controller. Thus we obtain a qualified PI for adaptation, since his operating

parameters are dependent on the state of the system. The adaptive PI realized is no more a linear regulator according to this principle. In most of these studies, the Fuzzy controller used to drive the PI is defined by the authors from a series of experiments [4,5].

The expression of the PI is given in the equation (2).

$$y(t) = K_p * [e(t) + \frac{1}{T_i}\int_0^t e(t)dt] \qquad (2)$$

Where:

$y(t)$: the output of the control .

$e(t)$: the input of the control . The error of the reference current $Ir(t)$ and the injected current $Ii(t)$

Kp: the parameter of the scale

Ti: the parameter of the integrator.

The discrete equation:

$$y(t) = K_p * [e(t) + \frac{1}{T_i}\Sigma_{j=1}^{k} e(j)T] \qquad (3)$$

Where:

$y(k)$: the Output on the time of k th sampling.

$e(k)$: the error on the time of k sampling

T: the cycle of the sampling

$$\Delta e(k) = e(k) - e(k-1)$$

$$y(k) = K_p * [e(t) + \frac{1}{T_i}\Sigma_{j=1}^{k} e(j)T]$$

$$y(k) = K_p * e(t) + K_i \Sigma_{j=1}^{k} e(j)$$

In case:

$T_i = 5T = 0.5T_u$

Tu: The cycle of the critical surge resonance.

$$\Delta e(k) = K_p[1.2e(k) - e(k-1)] \qquad (4)$$

The value of the $\Delta e(k)$ will be adjust when the value of The Kp is be changed. It is easy to be found from the equation (4). The frame of the fuzzy adaptive PI (AFPI) controller is illustrated in Fig.3.

The input of the fuzzy adaptive PI controller (AFPI) is $e(k)$ and $\Delta e(k)$. Y is the perfect output of the PI. $Ii(t)$ is the actual output of the active power filter.

$e(k) = Ir(t) - Ii(t)$

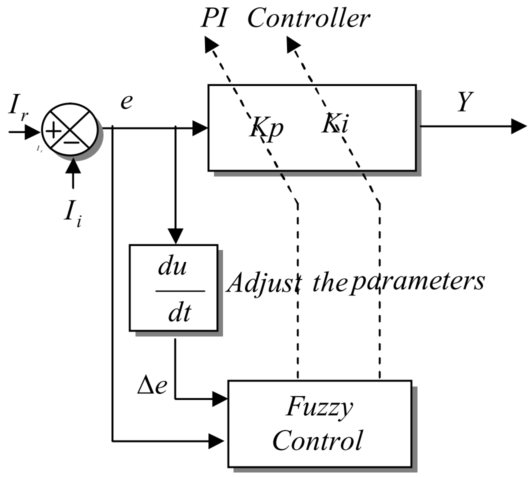

Fig. 3the fuzzy adaptive PI controller

In other way the output of the adaptive PI controller (y) is used over the reference currents (Ira, Irb, Irsc) and sensed supply currents (Isa, Isb, Isc) to generate switching signals for the MOSFETs of three legs of PWM converter.

In response to switching signals generated by controller, the shunt active power filter shapes the supply currents to sinusoidal and it compensates the power factor, lower order harmonics and unbalance of the nonlinear load.

In the rule of the fuzzy controller, the value of the e(k) ,Δ e(k) is separated into “NB” , “NM” “NS” , “ZE” , “PS” , “PM”, “ P B”.

The Membership function is illustrated in the Fig 5.6.7.9.10.11.

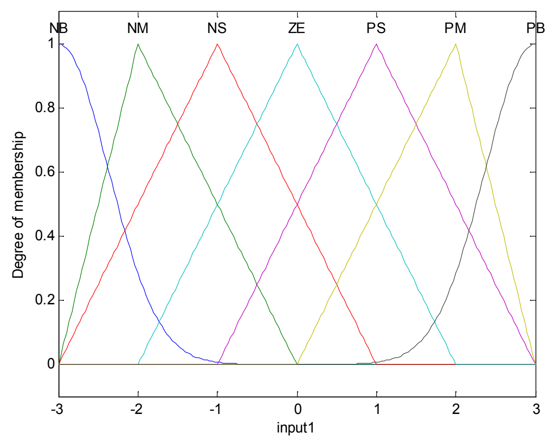

Fig.4 The Membership function of e(k) input for ki

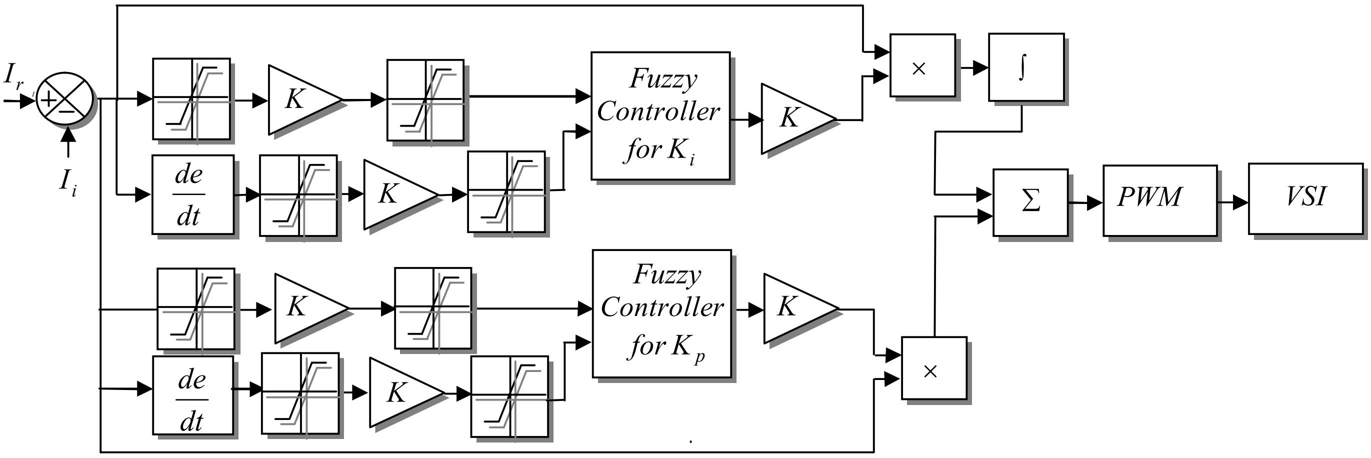

Fig 5 Model SIMULINK of the proposed (AFPI) controller

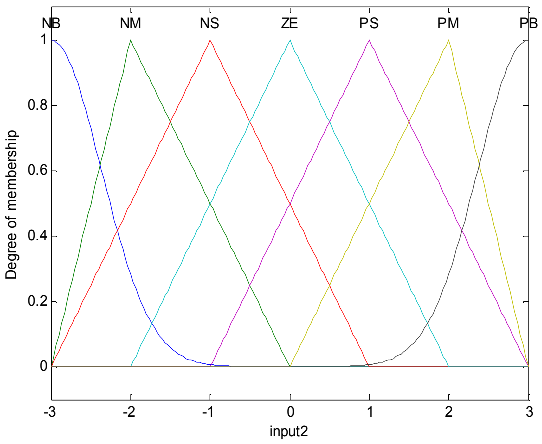

Fig 6 .The Membership function of Δe(k) input for ki

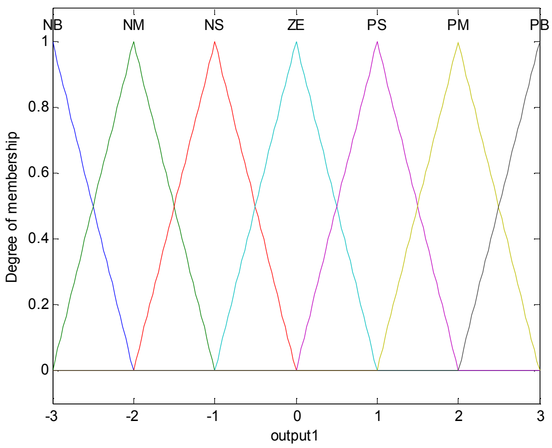

Fig . 7 The Membership function of the output for ki

Table1. Fuzzy tuning rules for ki

k_i		e(k)						
		NB	NM	NS	ZE	PS	PM	PB
Δe(k)	NB	NB	NB	NS	NM	NM	ZE	ZE
	NM	NB	NB	NB	NM	NS	ZE	ZE
	NS	NM	NM	NS	NS	ZE	PS	PS
	ZE	NM	NS	NS	ZE	PS	PS	PM
	PS	NS	NS	ZE	PS	PS	PM	PM
	PM	ZE	ZE	PS	PM	PM	PB	PB
	PB	ZE	ZE	PS	PM	PB	PB	PB

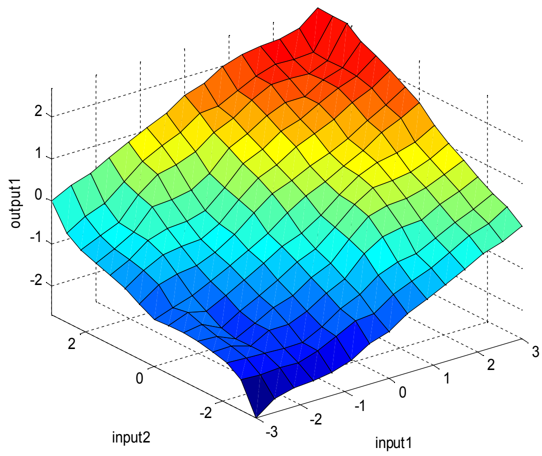

Fig.8 View plot surface of fuzzy controller for ki

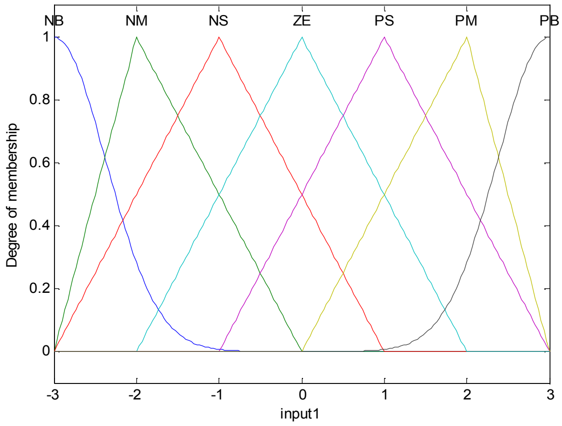

Fig. 9 The Membership function of e(k) input for kp

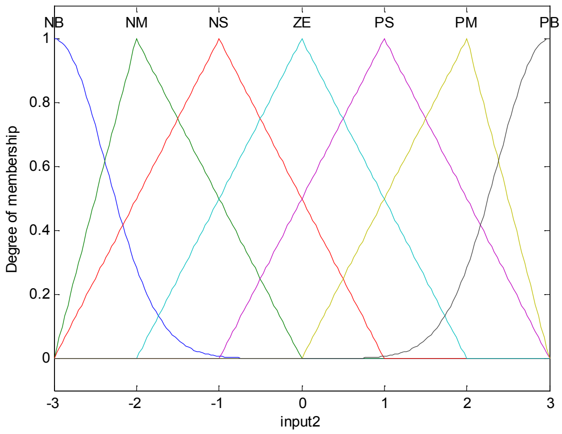

Fig. 10 he Membership function of Δe(k) input for kp

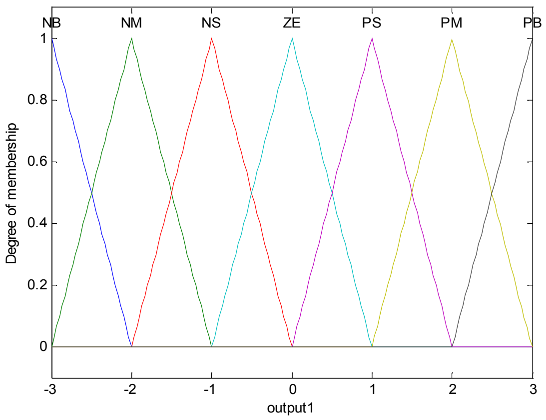

Fig.11 The Membership function of the output for kp

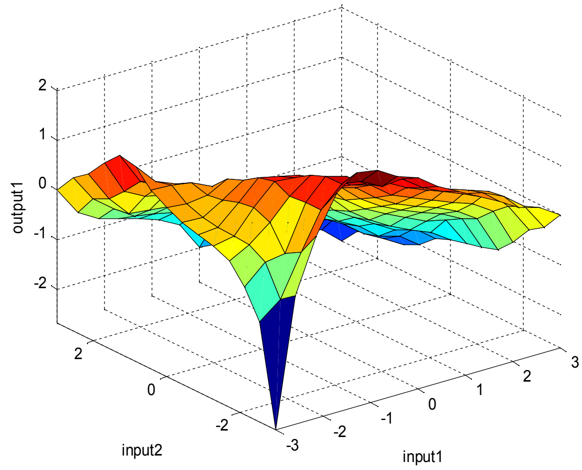

Fig. 12 View plot surface of fuzzy controller for kp

Table. 1 Fuzzy tuning rules for kp

kp	e(k)							
Δe(k)	NB	PB	NS	PM	PS	PS	ZE	NB
	PB	PB	PM	PM	PS	ZE	ZE	PB
	PM	PM	PM	PS	ZE	NS	NM	PM
	PM	PS	PS	ZE	NS	NM	NM	PM
	PS	PB	ZE	NS	NS	NM	NM	PS
	ZE	ZE	NS	NM	NM	NM	NB	ZE
	ZE	NS	NS	NM	NM	NB	NB	ZE
	NB	PB	NS	PM	PS	PS	ZE	NB

The AFPI controller is used to bring all the control signal of the MOSFETs
This peripheral allows for pulse width modulation, three phase sine wave generation with The fuzzy adaptive PI control is realized by the program .The input of the fuzzy-PI control is the error of the inverter's output . The output of the fuzzy adaptive PI control is the width of the pulse which controls the MOSFETs in the push-pull circuit. It adjusts the width of the pulse which controls the MOSFETs in the push-pull circuit to keep an unchangeable output of the inverter. The fuzzy adaptive control makes the inverter for active power filter system more stably.It products sine pulse width modulation single which control the MOSFETs.

4. Simulation Results.

The performance of the proposed fuzzy adaptive PI control method was examined through simulations. The system model was implanted in Matlab / Simulink environment. The SAPF was designed to compensate harmonics caused by nonlinear loads.

The system model parameters are shown in Table I.

Table.2 system parameters

Active Filter Parameters	
Supply phase voltage U	220 V
Supply frequency fs	50 Hz
Filter inductor Lf	0.7 mH
Dc link capacitor Cf	0.768474 mF
Smoothing inductor Lsmooth	70 µH
Sample time Ts	4 µs

A three-phase diode rectifier with an RL load was used as a harmonic producing load. The initial load (resistance was 10/3 Ω and the inductance 60 mH.) In the first place, the Load current were raised with the following percentage 25%, 50%, 75% at 0.2 , 0.4 , 0.6 ,then the total harmonic distortion has been taken up to 2.5 kHz (THD2,5 kHz) for each case .A phase-a load current waveform is presented in Fig. 13.

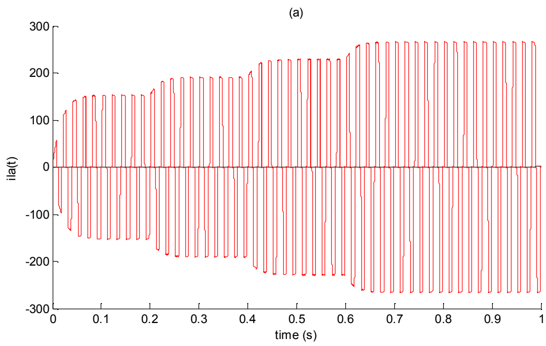

Fig.13 Simulated phase-a the load current waveforms

The result of simulation makes clear that the increase of the Load current value yield to exceed of the harmonic in supply current or the conventional controller can not react enough against the variation of load as they shown in Table.4.

A. case of Conventional PI Controller

When a method based on (CPI) controller has been used, the deformations can be seen in the supply current waveform during the load changes by the first load to the last load as they shown in the Fig.14.15. 16.17. They are caused by the fixed value of the proportional and integral gains Kp=1100 Ki=80 and the SPAF system dynamics. The harmonics content of the supply current waveform in Fig. 15. is presented in Table 4. and we can notice that the growth rate of THD are 424.87%, 70.42%, -53.67%, for the case(1) to the case(5)

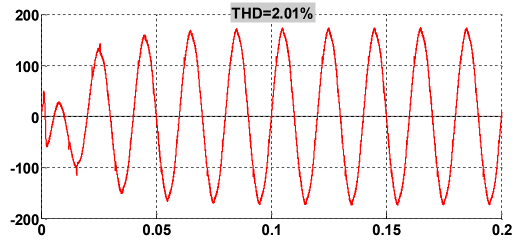

Fig. 14 Simulated phase-a the supply current waveforms with a CPI method case (1).

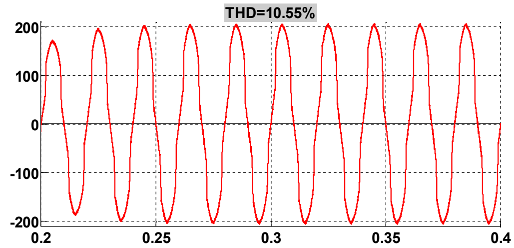

Fig. 154 Simulated phase-a the supply current waveforms with a CPI method case (2).

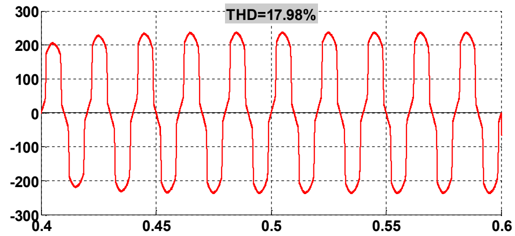

Fig. 16 Simulated phase-a the supply current waveforms with a CPI method case (3).

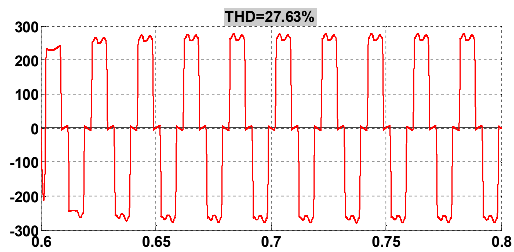

Fig. 17 Simulated phase-a the supply current waveforms with a CPI method case (4).

Table . 4 Harmonic supply current phase-a-component with CPI method

n	Harmonic Supply Current Components Isa(n)/Isa(1) [%]			
	Case1	Case2	Case3	Case4
5	0.93	7.70	13.16	21.58
7	1.38	5.19	9.04	12.49
11	0.16	3.23	5.37	7.60
13	0.45	2.49	4.28	6.46
17	0.24	1.82	2.90	4.05
19	0.25	1.41	2.36	3.48
23	0.26	1.10	1.64	2.27
25	0.13	0.83	1.33	1. 79
29	0.28	0.66	0.91	1.20
31	0.07	0.47	0.74	0.92
35	0.25	0.40	0.53	0.67
37	0.08	0.28	0.44	0.63
41	0.23	0.25	0.37	0.53
43	0.11	0.20	0.34	0.53
47	0.20	0.19	0.31	0.48
49	0.13	0.16	0.30	0.43
$THD_{2.5kHZ}$	2.01	10.55	17.98	27.63

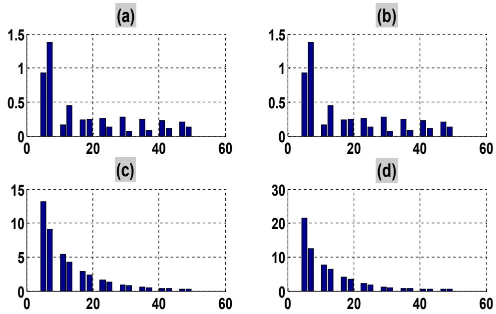

Fig.18Harmonic spectrum of supply current Phase 'a', with a CPI method. (a) Case 1, (b) Case 2, (c) Case 3, (d) Case 4

B. case of Adaptive Fuzzy PI Controller

Secondly to react the sudden changes in the error signal, ε, an active filter performance was examined with the method of control fuzzy adaptive PI controller (AFPI) by keeping the same rate of load changing. When the proposed Adaptive PI has been used, the resulting supply current waveform can be seen in Fig.19.20.21.22. and the harmonic content of that in Table 5.During the load change the THD value were taken and also the growth rate of THD between each two successive cases which are 56.12%, 39.87%, 28.97%.

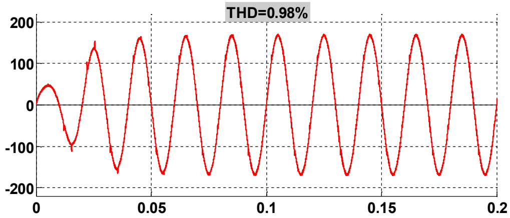

Fig. 19 Simulated phase-a the supply current waveforms with a AFPI method case (1).

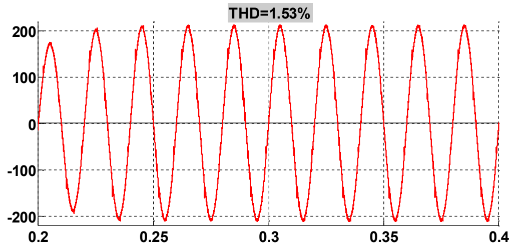

Fig. 20 Simulated phase-a the supply current waveforms with a AFPI method case (2).

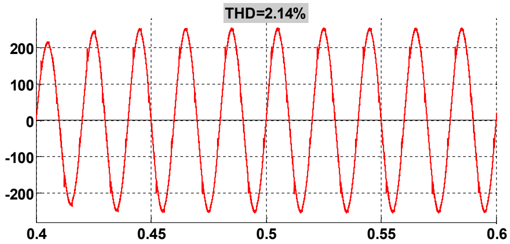

Fig. 21 Simulated phase-a the supply current waveforms with a AFPI method case (3).

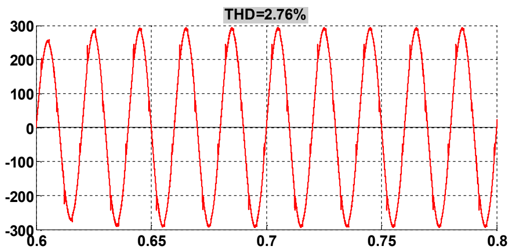

Fig.22 Simulated phase-a the supply current waveforms with a AFPI method case (4).

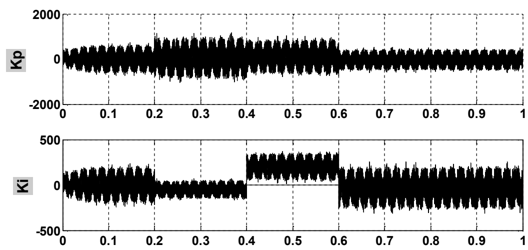

Fig. 23 Gain Ki and Kp of adaptive fuzzy PI controller.

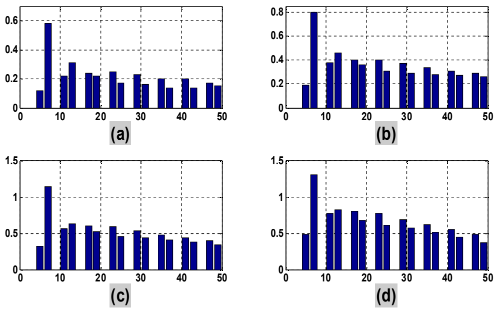

Fig. 24 Harmonic spectrum of supply current Phase 'a', with a AFPI method. (a) Case 1, (b) Case 2, (c) Case 3, (d) Case 4

Table 5. Harmonic supply current phase-a-component with AFPI method

	Harmonic Supply Current Components Isa(n)/Isa(1) [%]			
n	Case1	Case2	Case3	Case4
5	0.12	0.19	0.32	0.49
7	0.58	0.80	1.14	1.30
11	0.22	0.38	0.56	0.77
13	0.31	0.46	0.63	0.82
17	0.24	0.40	0.60	0.80
19	0.22	0.36	0.52	0.68
23	0.25	0.40	0.59	0.77
25	0.17	0.31	0.46	0.61
29	0.23	0.37	0.53	0.69
31	0.16	0.29	0.44	0.57
35	0.20	0.34	0.48	0.62
37	0.14	0.28	0.41	0.51
41	0.20	0.31	0.44	0.55
43	0.14	0.27	0.38	0.45
47	0.17	0.29	0.40	0.49
49	0.15	0.26	0.34	0.37
$THD_{2.5kHZ}$	0.98	1.53	2.14	2.76

C. comparative Study of two method of controlling

In simulations the two different methods to control the SAPF were used .Because of the sweeping of the Kp on the interval [-1000 1000] and the Ki on the interval [-400 400] as shown in the Fig. 23,the Fuzzy Adaptive PI Control method improves the active filter performance. The filtering result can be seen in Fig. 20.21.22. The deformations have now been reduced and the harmonic distortion calculated up to 2.5 kHz (THD2.5kHz) has been weakened. Although the filtering performance especially with the low order harmonics has been improved, the high order harmonics have been few damped. This can be seen in Table 5, where the THD calculated up to 2.5 kHz remains less than the case of CPI controller throughout the growth of the load as shown in the Fig. 25.

Tableau 3 the comparison between the THD of the two methods according to the cases

	THD of (CPI)	THD of (AFPI)	Rate of improvement
Case1	2.01%	0.98%	-51.24%
Case2	10.55%	1.53%	-85.49%
Case3	17.98%	2.14%	-88.09%
Case4	27.63%	2.76%	-90.0.1%

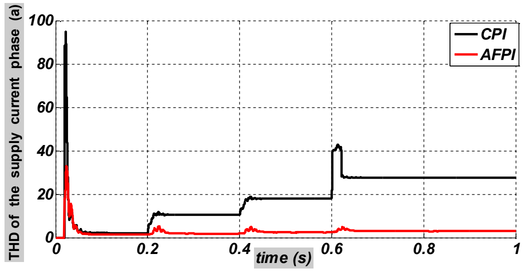

Fig . 25 the variation of THD of the two methods according to the load change

5. Conclusions.

With the variation of non-linear loads the harmonics and reactive power are deteriorating the performance of the utility system. In this paper, a control strategy based on adaptive fuzzy PI controller for high performance three-phase shunt active has been proposed. The performance of the proposed AFPI was verified through simulation studies with Matlab and confronted with CPI Controller. The simulation results showed that PI with adaptive Fuzzy control is able to adapt itself the a suitable control parameters which are the proportional and integral gains Kp and Ki to the variations in the value load of direct side. However, the merit of the adaptive fuzzy PI controller is that the effects due to the change load at the steady state can not act rapidly on performance of SAPF.

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