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Hybrid Fuzzy Controller Design For Three-Phase Four-Wire Active Power Filter

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Abstract: This paper aims to design a hybrid fuzzy controller for three-phase four-wire active power filter. The simulation results have proved the effectiveness of the hybrid fuzzy controller compared with the traditional PI and single fuzzy controllers in some respects: minimum THD of supply current and amplitude of neutral line current.
Keywords: Active power filter, PI control, fuzzy logic control, ANFIS control

I. Introduction

Three-phase four-wire active power filter has played a very important role in the harmonic filter and improve the power factor in power distribution networks [1-5]. Work efficiency of the three-phase four- wire active power filter (APF) depends on many factors such as: the choice of parameters, control methods, the influence of resonance between the source and the load. In it the method of control depends very much on the controller. Currently the controllers are often used for three-phase four-wire APF is the traditional Pi, Hysteresis, fuzzy logic ... With the control method using a traditional PI controller is easy to implement but less flexible control capabilities [6-10]. Hysteresis controller is fast response but does not meet the minimum the error in establishing [11]. Fuzzy controller is easy to definite, do not need the mathematical model, membership functions are fixed in the process control, but is dependent on the experience and results is acceptable temporary [12-15].

With the advantages and disadvantages of the above controller, this paper give a fuzzy hybrid controller for three-phase four-wire active filter circuit in order to solve the problems: minimum THD of source current and amplitude of neutral wire current. This controller is the combination of neural network and fuzzy controller, so it has the advantages of both fuzzy controller and neural network. In this controller, in fuzzy sets and neural network's weights will be adjusted by one sample data set, which is trained in the Hybrid or back-propagation method. The simulation results are compared with the traditional PI and single fuzzy controllers in some respects: min THD of source current, min amplitude neutral wire current.

The structure of the thesis is presented consists of four parts: part I introduction to filter circuit, three-phase four-wire and the controller is used to it as well as control method using a fuzzy hybrid controller. Part II is operation of three-phase four-wire active power filter. Part III is the fuzzy hybrid controller design for three-phase four-wire active power filter. The simulation results and discussions embodied in part IV. Part V is the conclusion of the paper.

II. Operation Principle of Three-Phase Four Wire APF

Topology of three-phase four-wire APF is shown as in figure 1.

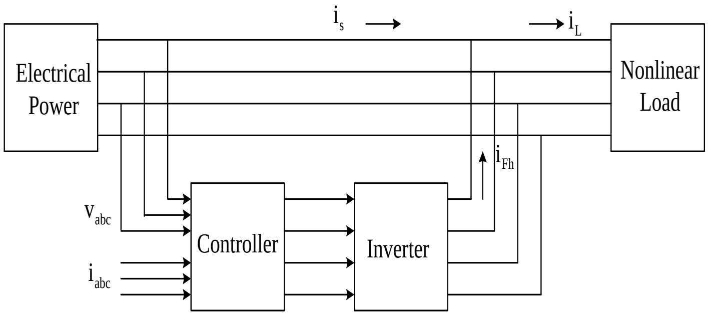

Fig 1. Topology of three-phase four-wire APF

When without APF, we have: $i_s = i_L$

According to Fig 1:

$$i_L = i_s + i_{Fh} \quad (1)$$

Analysis i_L out two components: fundamental component i_{Lf} and harmonic component i_{Lh}. Assume that APF compensation a component $i_{Fh}=i_{Lh}$, we have:

$$i_{Lf} + i_{Lh} = i_s + i_{Lh} \quad (2)$$

And then source current only remain fundamental component

$$i_s = i_{Lf} \quad (3)$$

Finally, neutral current will be toward zero

$$i_n = i_{sa} + i_{sb} + i_{sc} \to 0 \quad (4)$$

III. Hybrid Fuzzy Controller Design for Three-Phase Four-Wire Active Power Filter

Control diagram for three-phase four-wire active power filter shown as in Figure 2.

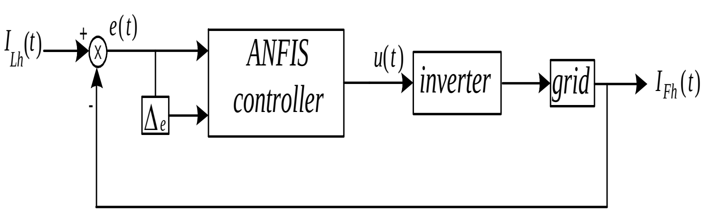

Fig 2. Control diagram for three-phase four-wire active power filter

The error between the $I_L(t)$ and $I_{Fh}(t)$ will be put into the controller. Here, the proposed controller is hybrid fuzzy, namely ANFIS controller; it is a combination of the fuzzy logic and neural network. The parameters of the hybrid fuzzy controller will be adjusted through the sample data set. Topology of the hybrid fuzzy controller is shown as in figure 3.

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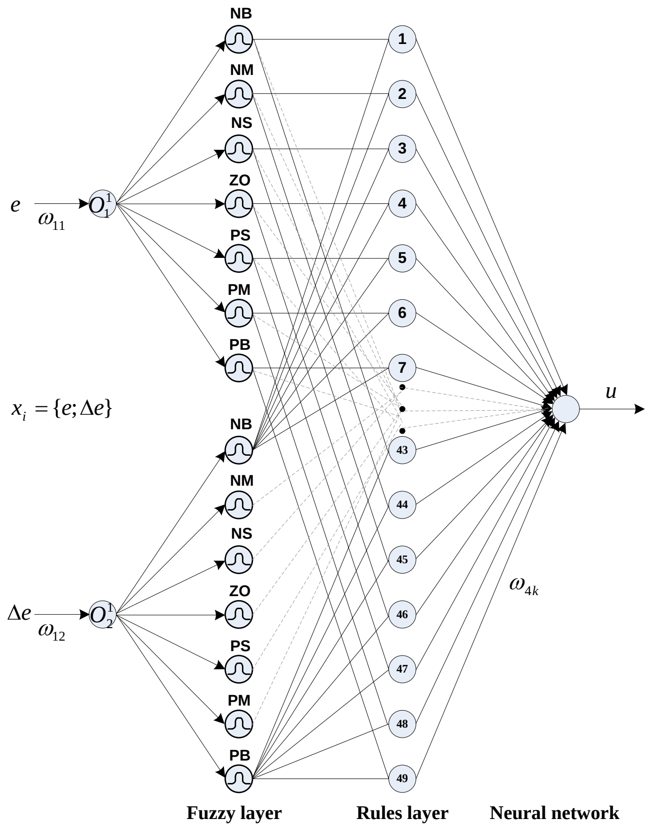

Fig 3. Topology of the hybrid fuzzy controller

Membership functions of the fuzzy layer is showns as in figure 4.

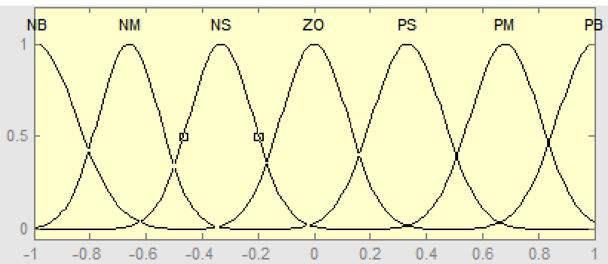

Fig.4 Membership functions of the fuzzy layer

+Nodes at *rules layer*, there are 49 rules.

$$O_k^{rules\,layer} = \prod_{i=1}^{2} \mu_{Ai}^{j} \;,\; i = 1,2 \;;\; j = 1,2,...7;\; k = 1,2,...,49. \quad (5)$$

+ The *neural network layer*

$$O_{neuralnetwork} = u = \frac{\sum_{k=1}^{m} O_k^{ruleslayer}\omega_{4k}}{\sum_{k=1}^{m} O_k^{ruleslayer}} \;;\; m = 49 \quad (6)$$

where: ω_{4k} is connecting weights

The core of ANFIS controller is must have a sample data set. The sample data set here is built based on two principles: the first is

$$\text{when } e = i_{Lh} - i_{Fh} = \begin{cases} > 0 \text{ then } i_{Fh} \text{ increased} \\ = 0 \text{ then } i_{Fh} \text{ unchanged} \\ < 0 \text{ then } i_{Fh} \text{ reduced} \end{cases}$$

And the second is how much increasing, reduction is based on experience.

In order to achieve the aim of control, the learning algorithm based on back-propagation method is used to change connecting weights and membership function parameters of network. The training ways are given as follows:

$$\begin{cases} \omega(k+1) = \omega(k) - \eta\dfrac{\partial J}{\partial \omega} + \alpha[\omega(k) - \omega(k-1)] \\ m_{ij}(k+1) = m_{ij}(k) - \eta\dfrac{\partial J}{\partial m_{ij}} + \alpha[m_{ij}(k) - m_{ij}(k-1)] \\ \sigma_{ij}(k+1) = \sigma_{ij}(k) - \eta\dfrac{\partial J}{\partial \sigma_{ij}} + \alpha[\sigma_{ij}(k) - \sigma_{ij}(k-1)] \end{cases} \quad (7)$$

Where α is a smoothness factor, $0 < \alpha < 1$. η is a learning rate, $\eta > 0$

The differential coefficients $\frac{\partial J}{\partial \omega}, \frac{\partial J}{\partial m_{ij}}$ and $\frac{\partial J}{\partial \sigma_{ij}}$ are calculated by back-propagation method.

$$\begin{aligned} \frac{\partial J}{\partial \omega_{4k}} &= -\left(I_{Lh}(t) - I_{Fh}(t)\right)\frac{\partial I_{Fh}(t)}{\partial \omega_{4k}} = \\ &= -\left(I_{Lh}(t) - I_{Fh}(t)\right)\frac{\partial I_{Fh}(t)}{\partial O_k^{rule\,layer}}\cdot\frac{\partial O_k^{rule\,layer}}{\partial \omega_{4k}} = \\ &= -\left(I_{Lh}(t) - I_{Fh}(t)\right)f'(O_k^{rule\,layer}).O_k^{rule\,layer} \\ &= \delta_k^4.O_k^{rule\,layer} \end{aligned} \quad (8)$$

With $\delta_k^4 = -(I_{Lh} - I_{Fh})f'(O_k^{rulelayer})$

The adjusted formula of weight ω_{4k} can be shown as

$$\omega_{4k}(k+1) = \omega_{4k}(k) + \eta\delta_k^4 O_k^{ruleslayer} + \alpha[\omega_{4k}(k) - \omega_{4k}(k-1)] \quad (9)$$

Similarly, the adjusted formula of weight ω_{1i} can be shown as

$$\omega_{1i}(k+1) = \omega_{1i}(k) + \eta\delta_i^1 x_i + \alpha[\omega_{1i}(k) - \omega_{1i}(k-1)] \quad (10)$$

The differential coefficients can be calculated as follows

$$\begin{cases} \dfrac{\partial J}{\partial m_{ij}} = \dfrac{\partial J}{\partial O_{ij}^{fuzzy\,layer}}\dfrac{\partial O_{ij}^{fuzzy\,layer}}{\partial m_{ij}} = -\delta_k^{fuzzy\,layer}\dfrac{2(x_i - m_{ij})}{\sigma_{ij}^2} \\ \dfrac{\partial J}{\partial \sigma_{ij}} = \dfrac{\partial J}{\partial O_{ij}^{fuzzy\,layer}}\dfrac{\partial O_{ij}^{fuzzy\,layer}}{\partial \sigma_{ij}} = -\delta_k^{fuzzy\,layer}\dfrac{2(x_i - m_{ij})^2}{\sigma_{ij}^3} \end{cases} \quad (11)$$

So, center and width of membership functions can be updated as follows

$$\begin{cases} m_{ij}(k+1) = m_{ij}(k) - \eta\left(\delta_k^{fuzzy\,layer}\dfrac{2(x_i - m_{ij})}{\sigma_{ij}^2}\right) + \alpha[m_{ij}(k) - m_{ij}(k-1)] \\ \sigma_{ij}(k+1) = \sigma_{ij}(k) - \eta\left(\delta_k^{fuzzy\,layer}\dfrac{2(x_i - m_{ij})^2}{\sigma_{ij}^3}\right) + \alpha[\sigma_{ij}(k) - \sigma_{ij}(k-1)] \end{cases}$$

(12)

IV. Simulation Results and Discussion

To demonstrate the effectiveness of the controller is given. The simulation results are done on the APF model for three controllers: traditional PI, single fuzzy and hybrid fuzzy. The parameters of the model: 3 phase source 380V- 50 Hz, nonlinear load is three-phase uncontrolled bridge rectifier has R = 3 Ω, L = 1.5 mH and plus phase-A a has R = 30 Ω and L = 2mH to create unbalance load, DC bus voltage of the VSI is 800V.

Before the APF is connected into the grid, the source current and load current are equally expressed as in Figure 5

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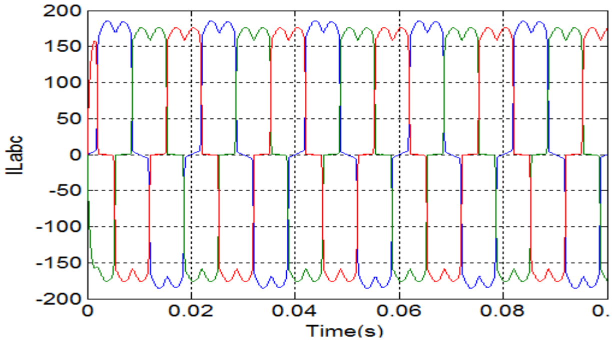
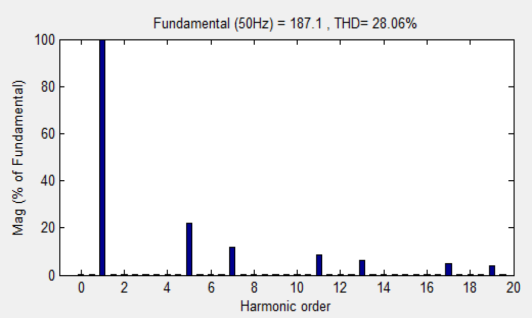
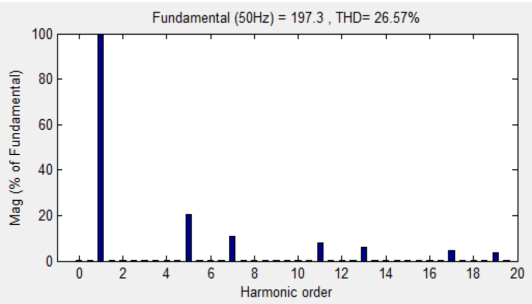


(a) waveforms of the load current before compensate



(b) Frequency spectrum of the phase A



(c) Frequency spectrum of the phase B and C

Fig 5. Waveform and THD of the load current

Current in the neutral wire is shown as in figure 6.

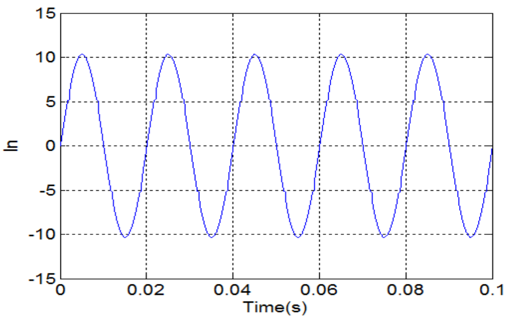


Fig 6. Neutral wire current

A. Simulation result with the traditional PI controller

Parameters of traditional PI controller are K_p=10 and K_i=0.01. Simulation result with the traditional PI controller is represent in figure 7.

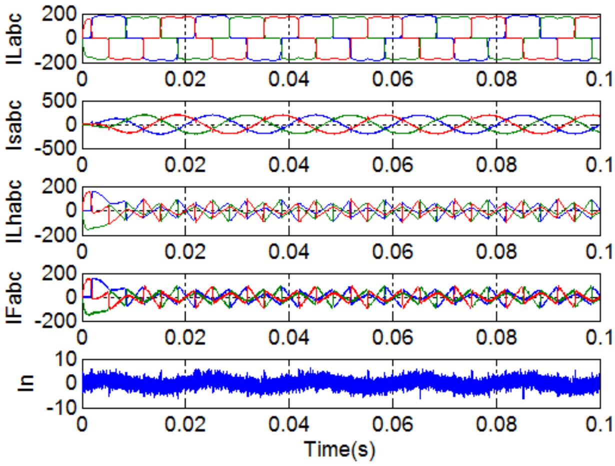
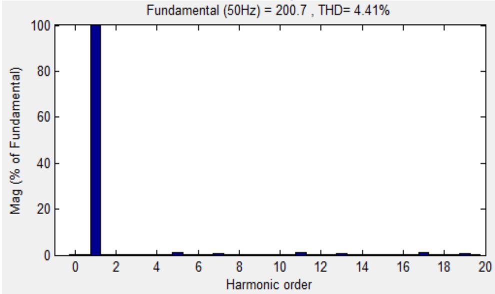
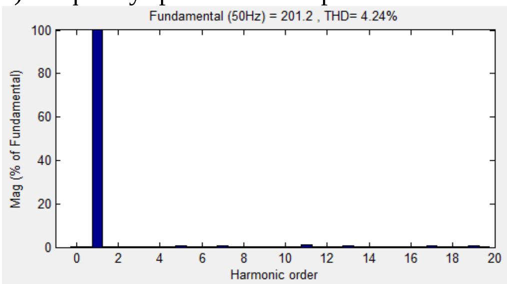


Fig 7. Simulation result with the traditional PI controller

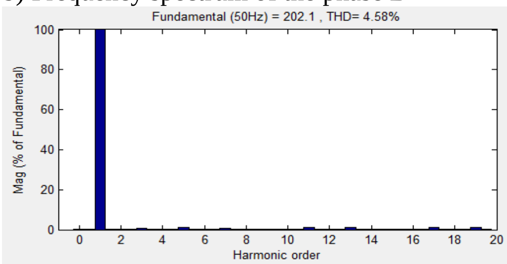
Frequency spectrum of the source current with the traditional PI controller is shown as in figure 8.



a) Frequency spectrum of the phase A



b) Frequency spectrum of the phase B

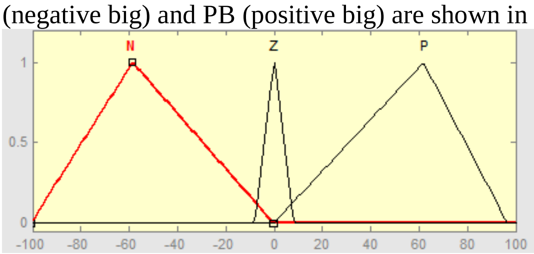


c) Frequency spectrum of the phase C

Fig 8. Frequency spectrum of the source current with the traditional PI controller

B. Simulation result with the single fuzzy controller

Linguistic variables: N (negative), Z (zero), P (positive), NB (negative big) and PB (positive big) are shown in Fig. 8:



a) Membership functions of input 1 and input 2

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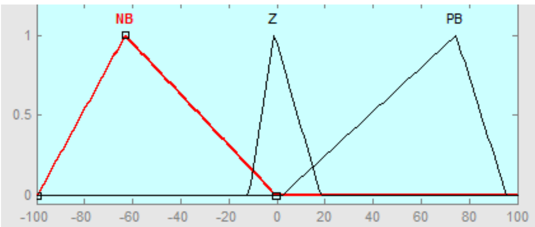


b) Membership functions of output

Fig 8. Membership functions of inputs and output

Rules fuzzy:

If (input1 is Z) then (output is Z)
If (input1 is P) then (output is PB)
If (input1 is N) then (output is NB)
If (input1 is Z) and (input2 is P) then (output is NB)
If (input1 is Z) and (input2 is N) then (output is PB)

Simulation result with the single fuzzy controller is shown as in figure 9.

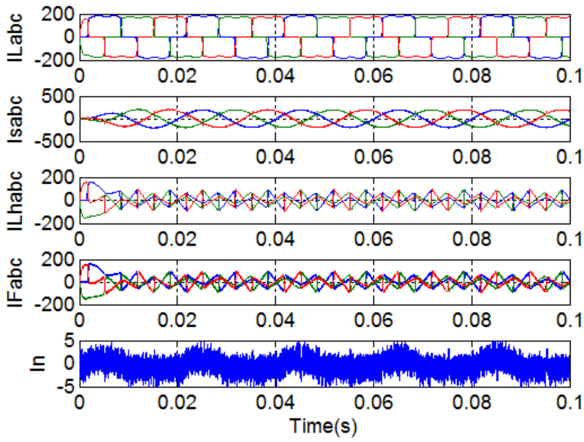
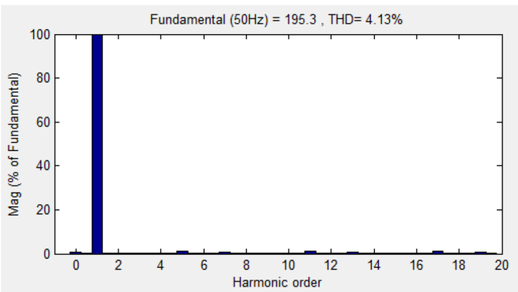
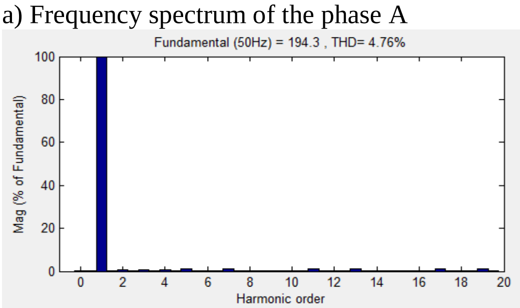


Fig 9. Simulation result with the single fuzzy controller

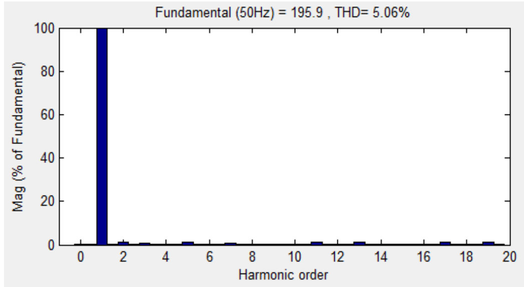
Frequency spectrum of the source current with the single fuzzy controller is shown as in figure 10.



a) Frequency spectrum of the phase A



b) Frequency spectrum of the phase B



c) Frequency spectrum of the phase C

Fig 10. Frequency spectrum of the source current with the single fuzzy controller

C. Simulation result with the hybrid fuzzy controller

Simulation result with the hybrid fuzzy controller is shown as in figure 11.

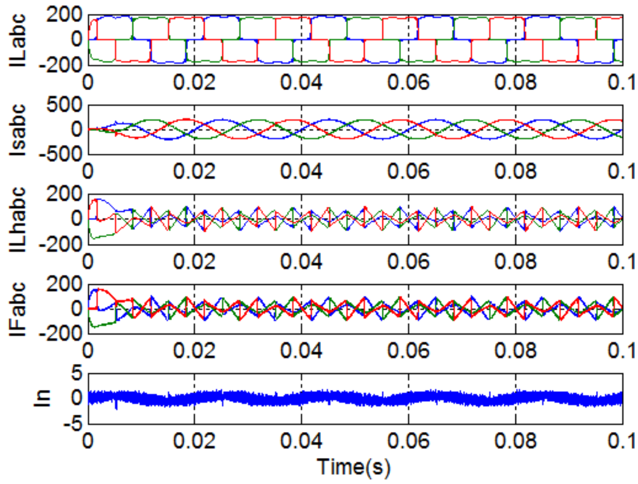
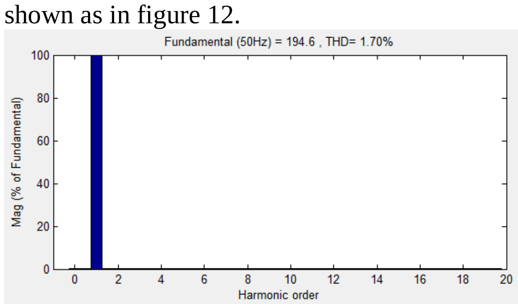
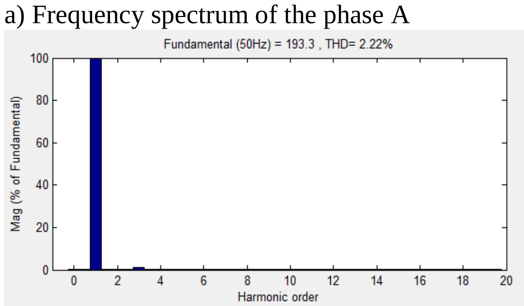


Fig 11. Simulation result with the hybrid fuzzy controller

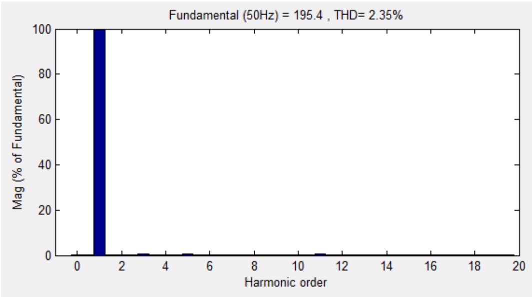
Frequency spectrum of the source current with the hybrid fuzzy is shown as in figure 12.



a) Frequency spectrum of the phase A



b) Frequency spectrum of the phase B



c) Frequency spectrum of the phase C

Fig 12. Frequency spectrum of the source current with the hybrid fuzzy controller

From the simulation results we can see that the hybrid fuzzy controller more effective traditional PI controller and single fuzzy controller in criteria: minimum THD of supply current and amplitude of neutral line current and summarized as in the following table:

Comparion of the controllers in steady-state

Controller	THD %			I_n (A)
	I_{sa}	I_{sb}	I_{sc}	
Without controller	28.66	26.7	26.57	±12
Traditional PI	4.41	4.24	4.58	±5
Single fuzzy	4.13	4.76	5.06	±5
Hybrid fuzzy	1.7	2.22	2.35	±2

V. Conclusion

The paper has successfully designed hybrid fuzzy controller for three-phase four-wire active power filter. The simulation results have proved that the proposed controller be effectively better than the traditional PI and single fuzzy controllers in some respects: min THD of source line, min amplitude neutral wire current.

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