THE EFFECTING OF NON-IDEAL-LOAD ON THREE-PHASE-POWER SYSTEMS USING FUZZY CONTROL ACTIVE POWER FILTER

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Abstract: *In this paper, a Simulink modeling of Active Power Filter was established to reduce the harmonic with high adaptability for kinds of loads. As can be seen in the paper, the effectings of Active Power Filter are based on the Loads' characteristics, and performance of adaptive with the change of the different types of loads. Fuzzy logic controller was used to proccess the stability of the capacity voltage's level that was setting up in the Active Filter which was based on the two level three phases inverter.*

Keywords: *nonlinear load, non – ideal load, three-phase active filter, PI controller, Fuzzy logic controller (FLC), unbalanced load, Active Power Filter (APF), Rectifier load, power quality.*

Classification number: *2.2*

1. Introduction

The use of nonlinear loads such as variable speed drivers, electric arc welders, and switching power suppliers causes large amounts of harmonic currents inject into distribution systems. These harmonic currents are responsible for voltage distortion, increasing power losses and heat on networks and transformers, and causing operational failure of electronic equipments.

Using the traditional passive filters such as inductance (L), inductance capacitance (LC), and inductance capacitance inductance (LCL) to eliminate line current harmonics and to improve the load power factor presents many disadvantages such as aging and tuning problems, series and parallel resonance, and the requirement to implement one filter per frequency harmonic that needs to be eliminated. In order to overcome these problems, active power filter (APFs) has been proposed by N.V.Nho in [1-2] to study in the power-qualification. The author and his group have continued seeking the newer control methodology for the Active Filter (AF).

In recent years, APFs based on current controlled PWM converters have been widely investigated and considered as a viable solution. Yet most of them are based on sensing harmonics [3] and reactive volt-ampere requirements of non-linear load [4–6], and require complex control system. S. Musa, M.A.M. Radzi, H. Hisham, N.I. Abdulwahab [7] have proposed a scheme in which the required compensating current is determined using a simple synthetic sinusoid generation technique by sensing the load current. This scheme is further modified by sensing line current only [8], which is simple and easy to implement.

Raphael Ceni Gomez in [5], Nitin Gupta in [6] and S. Musa in [7] have mentioned about the fuzzy logic control method and point out the advantage and disadvantage for these applications. This paper, with SCC (Sample Current Control) method using Fuzzy logic control in three phase two level inverter modulation making progress in results, and the improves were shown in matlab simulink's oscilloscopes.

2. Active Filter's model with types of load

A model of three-phase Active Filter with kinds of loads in detail was shown as Table 1 and Fig 1. As its was viewed, there are three parts connecting together. The first called "three – phase emf", the second was named "Active Filter" and the third was known as "Loads". The first stands for three – phase – Grid, in that the voltages were established based on the vector on alpha/beta frame. The second is the Active Power Filter contained the main controller inside. The last is the complex load including three kinds of load's functions: no load, Symmetric RL Load and Non – ideal load.

Table 1. *Signs of the signals for the Model.*

Signals	Description
E_line	Source in Amplitude
Psi_line	Power invariant emf vector on alpha/beta frame
Theta_line	Source's phase
In1	For E_line inside
In2	For Psi_line inside
In3	For Theta_line inside
Load current in ab	Signals for load currents
U_line	Signals for source's Amplitude
Theta	Signals for source's phases

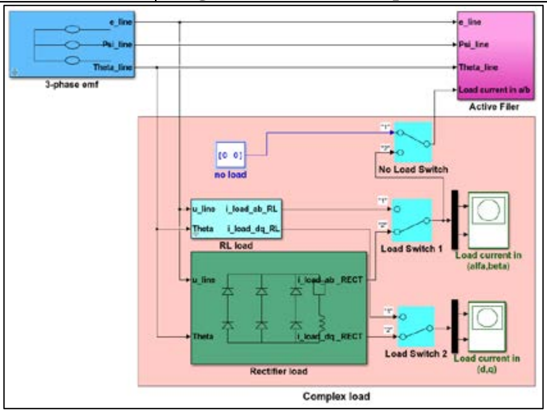

Fig 1. *Active Filter with types of Load's model.*

2.1. Model of Source

The three-phase-four-wire system can be generally declared by the following equations, (1) for voltage and (2) for current [1].

$$V_k(t)=\sum_{n=1}^{\infty}\sqrt{2}V_{kn}\sin(\omega_n t+\phi_{kn}) \quad k=(a,b,c) \tag{1}$$

$$I_k(t)=\sum_{n=1}^{\infty}\sqrt{2}I_{kn}\sin(\omega_n t+\phi_{kn}) \quad k=(a,b,c) \tag{2}$$

With n was defined as the harmonic order. The two equations above can be modified by making alpha degree for mainly view, including fundamental harmonic (n=1) and order n harmonic [1].

$$\dot{V}_k=\sum_{n=1}^{\infty}V_{kn}\angle\phi_{kn}=\sum_{n=1}^{\infty}\dot{V}_{kn} \qquad k=(a,b,c) \tag{3}$$

$$\dot{I}_k=\sum_{n=1}^{\infty}I_{kn}\angle\phi_{kn}=\sum_{n=1}^{\infty}\dot{I}_{kn} \qquad k=(a,b,c) \tag{4}$$

With matrix showing for balanced parts in each order harmonic of three phases a, b, c, the results is told voltages and currents in forward, revert and zero order [2].

$$\begin{bmatrix}\dot{V}_{0n}\\ \dot{V}_{+n}\\ \dot{V}_{-n}\end{bmatrix}=\frac{1}{3}\begin{bmatrix}1 & 1 & 1\\ 1 & \alpha & \alpha^2\\ 1 & \alpha^2 & \alpha\end{bmatrix}\begin{bmatrix}\dot{V}_{an}\\ \dot{V}_{bn}\\ \dot{V}_{cn}\end{bmatrix} \tag{5}$$

In that matrix equation $\alpha=1\angle 120^0=e^{j(2\pi/3)}$

The revert matrix is given below (6)

$$\begin{bmatrix}\dot{V}_{an}\\ \dot{V}_{bn}\\ \dot{V}_{cn}\end{bmatrix}=\begin{bmatrix}1 & 1 & 1\\ 1 & \alpha^2 & \alpha\\ 1 & \alpha & \alpha^2\end{bmatrix}\begin{bmatrix}\dot{V}_{0n}\\ \dot{V}_{+n}\\ \dot{V}_{-n}\end{bmatrix} \tag{6}$$

Expanding the matrix above and get the details in (7)

$$\begin{aligned}
v_{an}(t)&=\sqrt{2}V_{0n}\sin(\omega_n t+\phi_{0n})+\sqrt{2}V_{+n}\sin(\omega_n t+\phi_{+n})+\\
&+\sqrt{2}V_{-n}\sin(\omega_n t+\phi_{-n})\\
v_{bn}(t)&=\sqrt{2}V_{0n}\sin(\omega_n t+\phi_{0n})+\sqrt{2}V_{+n}\sin(\omega_n t+\phi_{+n}-\frac{2\pi}{3})+\\
&+\sqrt{2}V_{-n}\sin(\omega_n t+\phi_{-n}+\frac{2\pi}{3})\\
v_{cn}(t)&=\sqrt{2}V_{0n}\sin(\omega_n t+\phi_{0n})+\sqrt{2}V_{+n}\sin(\omega_n t+\phi_{+n}+\frac{2\pi}{3})+\\
&+\sqrt{2}V_{-n}\sin(\omega_n t+\phi_{-n}-\frac{2\pi}{3})
\end{aligned} \tag{7}$$

The same respectively, three-phase currents can be taken below (8)

$$\begin{aligned}
i_{an}(t)&=\sqrt{2}I_{0n}\sin(\omega_n t+\delta_{0n})+\sqrt{2}I_{+n}\sin(\omega_n t+\delta_{+n})+\\
&\sqrt{2}I_{-n}\sin(\omega_n t+\delta_{-n})\\
i_{bn}(t)&=\sqrt{2}I_{0n}\sin(\omega_n t+\delta_{0n})+\sqrt{2}I_{+n}\sin(\omega_n t+\delta_{+n}-\frac{2\pi}{3})+\\
&\sqrt{2}I_{-n}\sin(\omega_n t+\delta_{-n}+\frac{2\pi}{3})\\
i_{cn}(t)&=\sqrt{2}I_{0n}\sin(\omega_n t+\delta_{0n})+\sqrt{2}I_{+n}\sin(\omega_n t+\delta_{+n}+\frac{2\pi}{3})+\\
&\sqrt{2}I_{-n}\sin(\omega_n t+\delta_{-n}-\frac{2\pi}{3})
\end{aligned} \tag{8}$$

With unbalance Loads in system, the source three-phase will be including the harmonic and caused low quality, these make damaged to the electric and electronic equipments.

2.2. Model of Loads

Model of Loads: there are three switchs in Loads block, the first, named No Load switch, for no loads or use load choosing. The second, named Load switch 1. And the last of three, named Load switch 2, for choosing RL load or Rectifier load. The type of current in *alfa-beta* or in *d-q*. RL_Load's model of phase a shown in Fig 2.

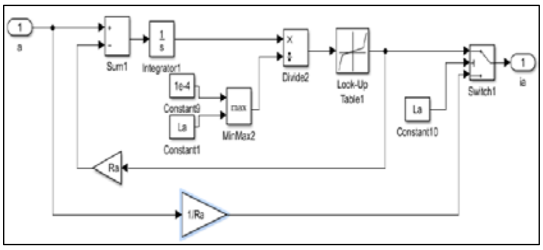

Fig 2. RL_Load's model of phase a in details.

The same model for phase b and phase c. Fig 3 is the cover of the three phase - *Rectifier*_Load's model and fig 4 is that load in top.

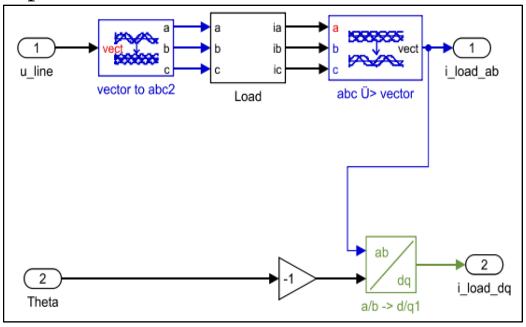

Fig 3. Three phase - Rectifier_Load's model.

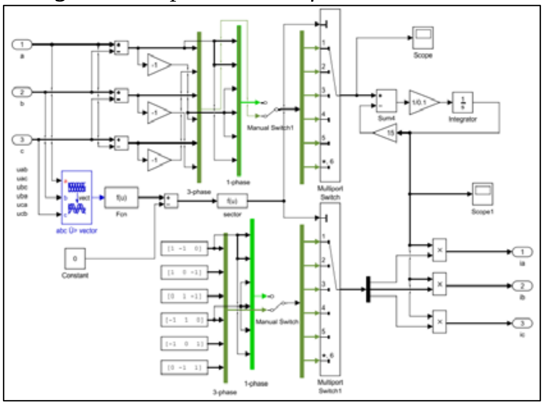

Fig 4. Main top of three phase - Rectifier_Load's model.

A non-ideal load is any of three phases load that consumes power with anything else than a symmetric three phase current at power factor of 1 (no phase lag between voltage and current) and fundamental frequency is non-ideal. A non-ideal load current contains at least one of the following components:

Reactive currents: Loads containing inductive or capacitive elements consume reactive current components.

Asymmetric currents: Consumed by three phase loads that are not equal in all three phases.

Harmonics: Consumed by non-linear loads, e.g. a diode rectifier, with the result that the current is not perfectly sinusoidal.

2.3. Model of Active Power Filters

A general control model based on d-q theory as Fig 5 [1]. Then fig 6 is the main top of the Active Filter Control.

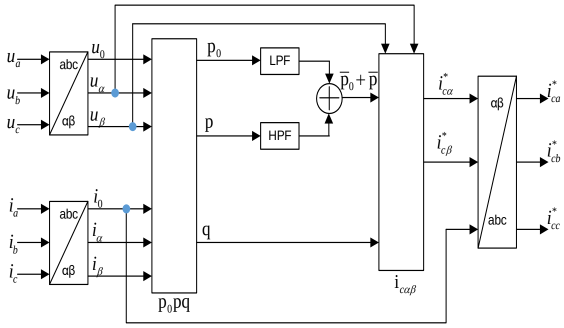

Fig 5. Scheme of Active Filter Controller.

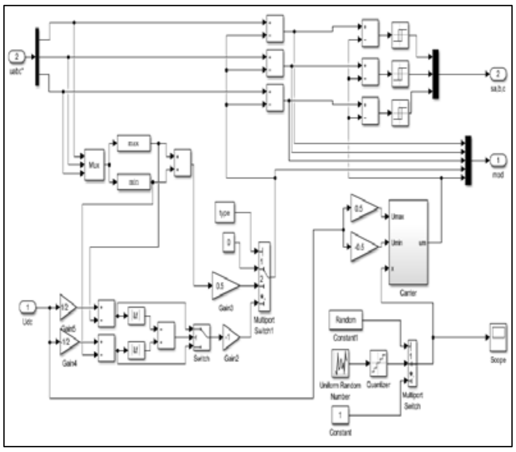

Fig 6. Main top of the Active Filter Control.

The signals i_a, i_b, i_c were defined as the load - currents, v_a, v_b, v_c for voltage – load – signals. Then the formatted converting to $\alpha\beta$ reference will be as shown in (9) and (10):

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (9)$$

The $\alpha\beta$ load current ingredients:

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (10)$$

For that, the load power was defined by (11):

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \cdot \begin{bmatrix} v_0 & 0 & 0 \\ 0 & v_\alpha & v_\beta \\ 0 & -v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \quad (11)$$

Leading the required currents were calculated as (12) [2]:

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} -\tilde{p} + p_{Loss} + \overline{\Delta p} \\ -q \end{bmatrix} \quad (12)$$

Then they were formatted back to the real frame as (13) [2]:

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} -i_0 \\ i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} \quad (13)$$

In order to make sine for the source currents, the required currents $i_{ca}{}^*$, $i_{ca}{}^*$, $i_{ca}{}^*$ and the feedback currents for the Active Filter must be processed by the PI controller. The required control voltages will be compared with the triangle high-frequency carry voltage to form the converter's pulse control voltages.

3. fuzzy control

Based on expert knowledge, the dynamic behavior of FLC is characterized by a set of linguistic If-Then rules [13, 14]. The input variables are error *e(t)* and error rate *de(t)/dt* and the output is *f*. Thus, fuzzy relations between *e*, *de* and *f* are figured out. Then *f* can be changed on line according the rules, current error and error rate.

The Inputs/Output of fuzzification interface is showed in fig. 2 [10]. In this paper, the Mandani's MIN–MAX inference engine type and center of area method (COA) defuzzification are employed. Since its combination yields the basic implementation parameters of the fuzzy control algorithm, the seven linguistic triangular membership functions assigned for input and output variables are: negative big (NB), negative medium (NM), negative small (NS), zero (ZE), positive small (PS), positive medium (PM) and positive big (PB). The fuzzy controller rule table is explained in table 2.

Table 2. *Rule table of Fuzzy Logic Controllers.*

	$e_{\text{Fuzzy}}(t)$					
		NP	NS	ZE	PS	PB
	PB	ZE	PM	PB	PB	PB
	PS	NM	ZE	PS	PN	PB
e(t)	ZE	NB	NS	ZE	PS	PB
	NS	NB	NM	NS	ZE	PM
	NP	NB	NB	NP	NM	ZE

4. Simulink results

Modeling and Monitoring for three kinds of load:

- *No load:* choosing No load switch at no load position and the screenshots of Load current in (alfa, beta) and Load current in (d/q) will be shown as fig 7.

In fig 7, the load current equals zero, filter current has the amplitude of noise, and certaintly noise for the line current. DC link voltage has been kept in 250V position.

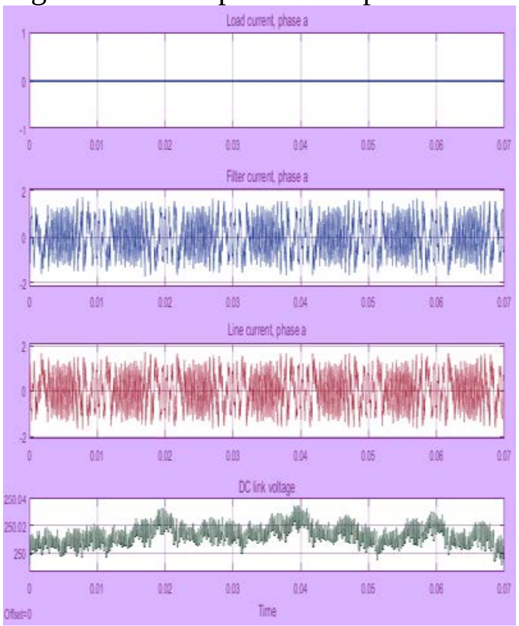

Fig 7. *No load monitor for Load current and filter current.*

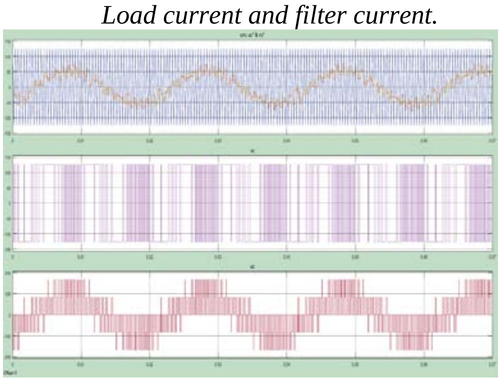

Fig 8. *Monitor for the voltage signal of phase c case no load.*

- RL_Load simulating: No Load Switch at Load position "2", Load Switch 1 and Load Switch 2 at RL_Load position "1", in fig 1.

Fig 9 shows the signals of phase c, in that

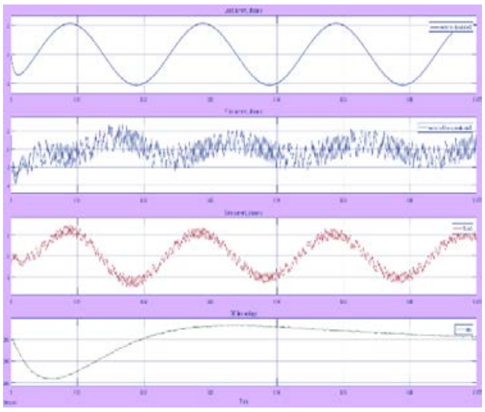

Fig 9. *RL_ load monitor for Load current and filter current.*

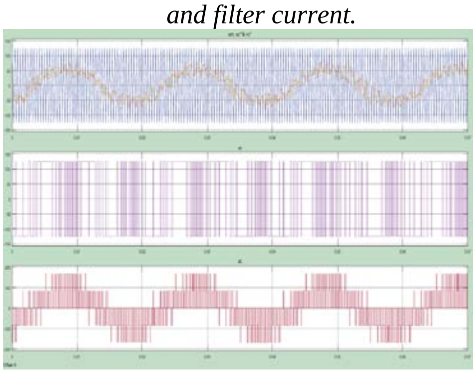

Fig 10. *Monitor the signal for phase a case RL_Load.*

- Rectifier_Load simulating: No Load Switch at Load position "2", Load Switch 1 and Load Switch 2 at Rectifier_Load position "2".

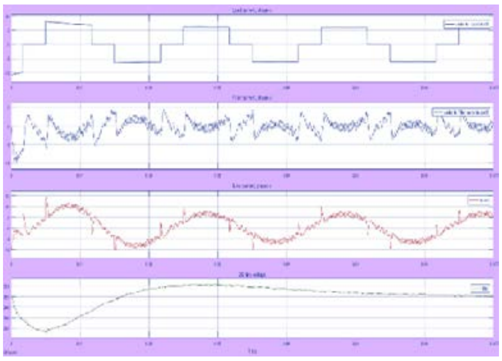

Fig 11. *RL_ load monitor for Load current and Active filter current.*

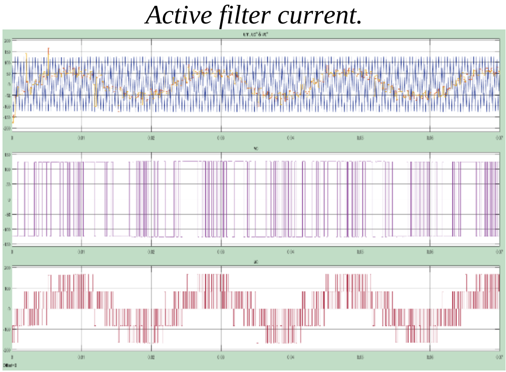

Fig 12. *Monitor the signal for phase a case Rectifier_Load*

The effect of load on three-phase power system using active filter will be declared in Simulink results. The loads will leaded the formed source changing. First, the no load case showing the pure forms of source current and Active Filter's current. Then, with the load's characteristics made these signals influenced. The paper is not to say about how to eliminate the harmonic caused by non-linear load to improve the source quality but the effecting of the kinds of load in the three-phase power system that using Active Filter. The validity of the Fuzzy control method has been verified by simulation results.

5. Conclusions

The show in figure 13 to speak to the efficiency of the control method and the adaptive of APF with others kinds of loads. Harmonics were eliminated from the line currents. The simulation results worth the students and researchers in studying power quality have more ideas about designing the controller of Active Filter❑

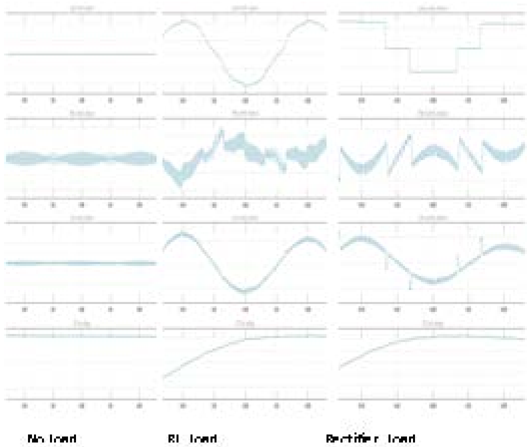

Fig 13. *The source currents with Active Filter.*

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