IMPROVING THE ADAPTIVE EFFECTING FOR ACTIVE POWER FILTER USING FUZZY CONTROL IN THE DC LINK VOLTAGE’S STABILITY CONTROLLER

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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. Fuzzy logic controller was used to control the capacitor’s DC voltage of the two level three phases inverter that was designed to work as an Active Filter. Modeling simulink schem shows the improving of the capacitor DC voltage responding as well as decreasing Total Harmonic Distortion of the line currents.

Key words: Nonlinear load, non – ideal load, unbalanced load, three-phase active filter, PI controller, Total Harmonic Distortion, Fuzzy logic controller (FLC), Active Power Filter (APF), Rectifier load, power quality.

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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 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 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.

As it was mentioned in [5], [6] and [7], the fuzzy logic control method pointed out the advantage and disadvantage for these applications. This paper, with SCC (Sample Current Control) method using Fuzzy logic control in DC-Voltage-Capacitor Unit of the three phase two level inverter modulation making a progress in DC-Voltage - Responding results and count down the THD index of the line currents. The improve were showed 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”.

![Figure 1. Active Filter with types of Load’s model](image-url)
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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:

<table>
<thead>
<tr>
<th>Signals</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>E_line</td>
<td>Source in Amplitude</td>
</tr>
<tr>
<td>Psi_line</td>
<td>Power invariant emf vector on alpha/beta frame</td>
</tr>
<tr>
<td>Theta_line</td>
<td>Source’s phase</td>
</tr>
<tr>
<td>In1</td>
<td>For E_line inside</td>
</tr>
<tr>
<td>In2</td>
<td>For Psi_line inside</td>
</tr>
<tr>
<td>In3</td>
<td>For Theta_line inside</td>
</tr>
<tr>
<td>Load current in ab</td>
<td>Signals for load currents</td>
</tr>
<tr>
<td>U_line</td>
<td>Signals for source’s Amplitude</td>
</tr>
<tr>
<td>Theta</td>
<td>Signals for source’s phases</td>
</tr>
</tbody>
</table>

2.1. Model of Source

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

\[
V_i(t) = \sum_{n=1}^{\infty} \sqrt{2}V_{in} \sin(\omega nt + \phi_{in}) \quad k = (a,b,c) \quad (1)
\]

\[
I_i(t) = \sum_{n=1}^{\infty} \sqrt{2}I_{in} \sin(\omega nt + \phi_{in}) \quad k = (a,b,c) \quad (2)
\]

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].

\[
V_k = \sum_{n=1}^{\infty} V_{in} \angle \phi_{kn} = \sum_{n=1}^{\infty} V_{in} \quad k = (a,b,c) \quad (3)
\]

\[
I_k = \sum_{n=1}^{\infty} I_{in} \angle \phi_{kn} = \sum_{n=1}^{\infty} I_{in} \quad k = (a,b,c) \quad (4)
\]

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

\[
\begin{bmatrix}
V_{oa} \\
V_{ra} \\
V_{pa}
\end{bmatrix} = \begin{bmatrix}
1 & 1 & 1 \\
\frac{1}{\alpha} & \frac{1}{\alpha^2} & 1 \\
\frac{1}{\alpha} & 1 & \frac{1}{\alpha^2}
\end{bmatrix} \begin{bmatrix}
V_{an} \\
V_{bn} \\
V_{cn}
\end{bmatrix}
\]

(5)

In that matrix equation \( \alpha = 120^\circ = e^{j2\pi/3} \).

The revert matrix is given below (6)

\[
\begin{bmatrix}
V_{oa} \\
V_{ra} \\
V_{pa}
\end{bmatrix} = \begin{bmatrix}
1 & 1 & 1 \\
\alpha & \alpha^2 & 1 \\
\alpha & 1 & \alpha^2
\end{bmatrix} \begin{bmatrix}
V_{an} \\
V_{bn} \\
V_{cn}
\end{bmatrix}
\]

(6)

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

\[
v_{an}(t) = \sqrt{2}V_{0n}\sin(\omega_{n}t + \phi_{0n}) + \sqrt{2}V_{+n}\sin(\omega_{n}t + \phi_{+n}) + \sqrt{2}V_{-n}\sin(\omega_{n}t + \phi_{-n})
\]

\[
v_{bn}(t) = \sqrt{2}V_{0n}\sin(\omega_{n}t + \phi_{0n}) + \sqrt{2}V_{+n}\sin(\omega_{n}t + \phi_{+n} - \frac{2\pi}{3}) + \sqrt{2}V_{-n}\sin(\omega_{n}t + \phi_{-n} + \frac{2\pi}{3});
\]

\[
v_{cn}(t) = \sqrt{2}V_{0n}\sin(\omega_{n}t + \phi_{0n}) + \sqrt{2}V_{+n}\sin(\omega_{n}t + \phi_{+n} + \frac{2\pi}{3}) + \sqrt{2}V_{-n}\sin(\omega_{n}t + \phi_{-n} - \frac{2\pi}{3})
\]

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

\[
i_{an}(t) = \sqrt{2}I_{0n}\sin(\omega_{n}t + \delta_{0n}) + \sqrt{2}I_{+n}\sin(\omega_{n}t + \delta_{+n}) + \sqrt{2}I_{-n}\sin(\omega_{n}t + \delta_{-n})
\]

\[
i_{bn}(t) = \sqrt{2}I_{0n}\sin(\omega_{n}t + \delta_{0n}) + \sqrt{2}I_{+n}\sin(\omega_{n}t + \delta_{+n} - \frac{2\pi}{3}) + \sqrt{2}I_{-n}\sin(\omega_{n}t + \delta_{-n} + \frac{2\pi}{3});
\]

\[
i_{cn}(t) = \sqrt{2}I_{0n}\sin(\omega_{n}t + \delta_{0n}) + \sqrt{2}I_{+n}\sin(\omega_{n}t + \delta_{+n} + \frac{2\pi}{3}) + \sqrt{2}I_{-n}\sin(\omega_{n}t + \delta_{-n} - \frac{2\pi}{3})
\]

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 switches 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 \(alpha-beta\) or in \(d-q\).

RL_Load’s model of phase a shown in Fig 2.

Figure 2. RL_Load’s model of phase a in details
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**Figure 3.** Main top of three phase - Rectifier_Load’s model

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

**Figure 4.** 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 current:** Loads containing inductive or capacitive elements consume reactive current components.

**Asymmetric current:** 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.

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):
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\[
\begin{bmatrix}
    v_0 \\
v_a \\
v_b \\
v_c
\end{bmatrix} = \frac{2}{\sqrt{3}} \begin{bmatrix}
    \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\
    1 & -\frac{1}{2} & -\frac{1}{2} \\
    0 & \sqrt{3}/2 & -\sqrt{3}/2
\end{bmatrix} \begin{bmatrix}
v_a \\
v_b \\
v_c
\end{bmatrix}
\]

(9)

The \(\alpha\beta\) load current ingredients:

\[
\begin{bmatrix}
i_0 \\
i_\alpha \\
i_\beta
\end{bmatrix} = \frac{2}{\sqrt{3}} \begin{bmatrix}
    \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\
    1 & -\frac{1}{2} & -\frac{1}{2} \\
    0 & \sqrt{3}/2 & -\sqrt{3}/2
\end{bmatrix} \begin{bmatrix}
i_a \\
i_b \\
i_c
\end{bmatrix}
\]

(10)

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

\[
\begin{bmatrix}
p \\
q \\
0
\end{bmatrix} = \begin{bmatrix}
v_0 & 0 & 0 \\
0 & v_a & v_b \\
0 & -v_b & v_a
\end{bmatrix} \begin{bmatrix}
i_0 \\
i_\alpha \\
i_\beta
\end{bmatrix}
\]

(11)

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

\[
\begin{bmatrix}
i_{\alpha a}^- \\
i_{\beta a}^- \\
i_{\alpha b}^+
\end{bmatrix} = \frac{1}{v_a^2 + v_b^2} \begin{bmatrix}
v_a & -v_b \\
v_b & v_a
\end{bmatrix} \begin{bmatrix}
-p + p_{\text{Loss}} + \Delta p \\
-q
\end{bmatrix}
\]

(12)

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

\[
\begin{bmatrix}
i_{\alpha a}^- \\
i_{\beta a}^- \\
i_{\alpha b}^+
\end{bmatrix} = \frac{2}{\sqrt{3}} \begin{bmatrix}
    \frac{1}{\sqrt{2}} & 1 & 0 \\
    \frac{1}{\sqrt{2}} & -1/2 & \sqrt{3}/2 \\
    1/2 & -1/2 & -\sqrt{3}/2
\end{bmatrix} \begin{bmatrix}
i_{\alpha a}^* \\
i_{\alpha b}^* \\
i_{\beta a}^*
\end{bmatrix}
\]

(13)

In order to make sine for the source currents, the required currents \(i_{\alpha a}^*, i_{\beta a}^*, i_{\alpha b}^*\) 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 [9], [15] 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 Controller.

<table>
<thead>
<tr>
<th>$F_{fuzzy}(t)$</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NB</td>
</tr>
<tr>
<td>$e(t)$</td>
<td>PB</td>
</tr>
<tr>
<td>PM</td>
<td>NS</td>
</tr>
<tr>
<td>PS</td>
<td>N</td>
</tr>
<tr>
<td>ZE</td>
<td>NB</td>
</tr>
<tr>
<td>NS</td>
<td>NB</td>
</tr>
<tr>
<td>NM</td>
<td>NB</td>
</tr>
<tr>
<td>NB</td>
<td>NB</td>
</tr>
</tbody>
</table>

\[ 1 + \left( k_p + \frac{k_i}{s} \right) \frac{3[V_s + L \frac{I_{ic}}{s} - 2I_{ic}R_s]}{C_{dc}V_{dc}^2} = 0 \]  \( \text{Formula (14)} \)

Table 4: Effect of increasing the gain parameters of PI controller

<table>
<thead>
<tr>
<th>Gain</th>
<th>Increasing time</th>
<th>The overshoot</th>
<th>Steadability time</th>
<th>Steadability Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kp</td>
<td>Decrease</td>
<td>Increase</td>
<td>Nealy Steability</td>
<td>Decrease</td>
</tr>
<tr>
<td>Ki</td>
<td>Decrease</td>
<td>Increase</td>
<td>Increase</td>
<td>Destructively</td>
</tr>
</tbody>
</table>

Therefore, the wrong tests on the simulation selected the optimal constants as the parameters follows table 3.
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Table 3. System’s parameters.

<table>
<thead>
<tr>
<th>Index</th>
<th>Parameters</th>
<th>Value</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vₛ (Vol)</td>
<td>66.5</td>
<td>Source voltage</td>
</tr>
<tr>
<td>2</td>
<td>Uₛ (Vol)</td>
<td>250</td>
<td>DC Capacitor Voltage</td>
</tr>
<tr>
<td>3</td>
<td>Cₑ (uF)</td>
<td>0.00011</td>
<td>DC Capacitor</td>
</tr>
<tr>
<td>4</td>
<td>Iₑ (Ampe)</td>
<td>7.25</td>
<td>DC output Current</td>
</tr>
<tr>
<td>5</td>
<td>Lₑ (H)</td>
<td>0.003</td>
<td>Coil value</td>
</tr>
<tr>
<td>6</td>
<td>Rₑ (Ω)</td>
<td>0.4</td>
<td>Resistance value</td>
</tr>
</tbody>
</table>

Figure 9. Diagram of simulate dc capacitor control

4. SIMULINK RESULTS
Modeling and Monitoring for three kinds of load:

4.1. 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 certainly noise for the line current. dc link voltage has been kept in 250v position.

Figure 7. No load monitor for load current and filter current.
4.2. 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 the load current was sine form, so APF made the same form for line current, the signal showed the sign in phase c.

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

**Figure 9.** RL_load monitor for load current and filter current.
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4.3. Rectifier_load simulating

No load switch at load position “2”, load switch 1 and load switch 2 at rectifier_load position “2”.

Figure 10. Monitor the signal for phase a case RL_load

Figure 11. RL_ load monitor for load current and active filter current
The effect of load on three-phase power system using active filter will be declared in simulink results. The loads will lead 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.
REFERENCES


