CHAPTER 5

COMPARISON OF CONVENTIONAL AND FUZZY BASED PI CONTROLLER FOR PHC METHOD OF REFERENCE CURRENT ESTIMATION TECHNIQUES

5.1 INTRODUCTION

The previous chapter analysed the PI controller based reference current estimation techniques namely, p-q, d-q, SDM and PHC. The PI controller requires precise linear mathematical models, which are difficult to obtain and may not give satisfactory performance under parameter variations, load disturbances, etc. Recently, Fuzzy Logic Controllers (FLCs) have been introduced in various applications and have been used in the power electronics field. The advantages of fuzzy logic controllers over conventional PI controllers are that they,

- Do not need an accurate mathematical model,
- Can work with imprecise inputs and
- Can handle non-linearities and are more robust than conventional PI controllers.

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis, from which decisions can be made. The process of fuzzy inference involves
membership functions, fuzzy logic operators and if-then rules. Two types of fuzzy inference systems that can be implemented in the Fuzzy Logic Toolbox are,

- Mamdani type and
- Sugeno type

The Mamdani type of fuzzy controller used for the control of APF gives better results compared with the PI controller, but it has the drawback of having larger number of fuzzy sets and rules. Further, all the coefficients have to be optimized to get better performance than the conventional PI controller. This increases the complexity of the controller; hence, this demands large computational time. As a result, it may not be useful for real time applications with small sampling time. On the other hand, the TS fuzzy controller may have an edge over the Mamdani type fuzzy controller in the following features:

- numbers of fuzzy sets used for input fuzzification,
- number of rules to be used,
- number of coefficients to be optimized and
- computation time.

The settling of dc capacitor voltage to its reference value is quite important in the context that at this condition, the real power balance between the source and load is realized. Therefore, apart from the reduction in Total Harmonic Distortion (THD), there is also a need to bring back the dc voltage as early as possible to its reference value. In this thesis, a TS type of fuzzy logic controller has been implemented for a three-phase shunt active filter with the objective
to reduce THD,
- Reactive power compensation and
- Power factor improvement.

The TS fuzzy controller can provide a wide range of control gain variation and it can use both linear and nonlinear rules in the consequent expression of the fuzzy rule base. In this thesis, through the simulation results, it is shown that the TS fuzzy controller has improved the dynamic response of the system.

5.2 BASIC FUZZY ALGORITHM

In a fuzzy controller as shown in Figure 5.1, the control action is determined from the evaluation of simple linguistic rules. The development of the rules requires a thorough understanding of the process to be controlled but it does not require a mathematical model of the system.

![Figure 5.1 Structure of Fuzzy Logic Controller](image-url)
A fuzzy controller consists of four stages, namely fuzzification, knowledge base, fuzzy inference mechanisms and defuzzification. The knowledge base is composed of a data base and a rule base, and is designed to obtain good dynamic responses under uncertainty in process parameters and external disturbances. The data base, consisting of input and output membership functions, provides information for appropriate fuzzification operations, the inference mechanism and defuzzification. The inference mechanism uses a collection of linguistic rules to convert the input conditions into a fuzzified output. Finally, defuzzification is used to convert the fuzzy outputs into control signals.

In order to implement the control algorithm of a VSI-SHAF using PHC technique in closed loop, the conventional PI controller is replaced by a fuzzy based PI controller wherein the optimum value of fuzzy gain (K) is calculated by a fuzzy inference system, which receives as inputs the slope of D.C. average bus voltage and D.C. voltage error (Rafiei et al 2001). Both quantities (error and slope of DC voltage) are normalized by suitable values. Thus, each range is from -1 to 1 and normalized to unity. The value of K is chosen to be near unity. To characterize this fuzzy controller, five sets each respective to the error and slope inputs are chosen. The output is defined by five sets. The linguistic rules for the fuzzy logic controller are chosen, in most cases, depending only of the D.C. voltage error. These fuzzy rules, used in the object to maintain the K gain not too far from unity, are shown in Table 5.1.

The error ‘e’ and the change of error ‘ce’ are used as numerical variables from the real system. To convert these numerical variables into linguistic variables, the following five fuzzy sets are used: NB (negative big), NS (negative small), ZE (zero), PS (positive small) and PB (positive big).
The fuzzy controller is characterized as follows:

Five fuzzy sets for each input and output are of,

- Triangular membership functions for simplicity,
- Fuzzification using continuous universe of discourse,
- Implication using Sugeno type inference system and
- Defuzzification using the weighted average method.

5.3 DESIGN OF CONTROL RULES

The fuzzy control rule design involves defining rules that relate the input variables to the output model properties as the FLC is independent of the system model. The design is mainly based on the intuitive feeling and experience of the process.

The control rules are formed by using Table 5.1. The elements of the Table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse input / output, small errors need fine control, which requires fine input / output variables. Based on this, the elements of the rule table are obtained from an understanding of the filter behavior and modified by the simulation performance.

Table 5.1 Fuzzy Rules for D.C. voltage control

<table>
<thead>
<tr>
<th>DC Voltage Slope</th>
<th>DC Voltage error</th>
<th>NB</th>
<th>NS</th>
<th>ZE</th>
<th>PS</th>
<th>PB</th>
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<tbody>
<tr>
<td>NB</td>
<td>NB</td>
<td>NS</td>
<td>Z</td>
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<tr>
<td>ZE</td>
<td>ZE</td>
<td></td>
<td>Z</td>
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<td>PB</td>
<td></td>
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</tr>
</tbody>
</table>
5.4 FUZZY GUI TOOLS

There are five primary GUI tools for building, editing and observing fuzzy inference systems in the Fuzzy Logic Toolbox namely,

- the Fuzzy Inference Systems or FIS Editor,
- the membership Function Editor,
- the Rule Editor,
- the Rule Viewer and
- the Surface Viewer.

5.4.1 FIS Editor

The FIS Editor displays general information about a fuzzy inference system as shown in Figure 5.2. The FIS Editor handles the high level issues for the system, how many input and output variables are used in the system and their names. The Fuzzy Logic Toolbox does not limit the number of inputs. If the number of inputs is too large or the number of membership functions is too big, then it may also be difficult to analyze the FIS using the other GUI tools.

![Figure 5.2 FIS Editor](image)
5.4.2  Membership Function Editor

The Membership Function Editor tool is used to edit all of the membership functions associated with all of the input and output variables for the entire fuzzy inference system as in Figure 5.3.

![Membership Function Editor](image)

**Figure 5.3 Membership Function Editor**

5.4.3  Rule Editor

Based on the descriptions of the input and output variables defined with the FIS Editor, the Rule Editor allows to construct the rule statements automatically, by clicking on and selecting one item in each input variable box, one item in each output box and one connection item as in Figure 5.4. Choosing none as one of the variable qualities will exclude that variable from a given rule. Choosing not under any variable name will negate the associated quality. Rules may be changed, deleted or added by clicking on the appropriate button.
5.4.4 Rule Viewer

The Rule Viewer displays a road map of the whole fuzzy inference process as in Figure 5.5. The three small plots across the top of the figure represent the antecedent and consequent of the first rule. Each rule is a row of plots and each column is a variable. The first two columns of the plots show the membership functions referenced by the antecedent, or the if-part of each rule. The third column of plots shows the membership functions referenced by the consequent, or the then-part of each rule.

The Rule Viewer allows interpreting the entire fuzzy inference process at once. The Rule Viewer also shows how the shape of certain membership functions influences the overall result.
5.4.5 Surface Viewer

The Surface Viewer has a special capability that is very helpful in cases with two (or more) inputs and one output. It is used to get a different 3-D view on the data as in Figure 5.6.
5.5 SIMULATION RESULTS FOR PI AND FUZZY CONTROLLER BASED PHC METHOD OF REFERENCE CURRENT ESTIMATION TECHNIQUE

The simulation results for fuzzy based PHC method of reference current estimation techniques are given below for R-load and DC Motor load:

Based on the Fuzzy rules shown in table 5.1, the simulation model for VSI-SHAF using fuzzy based PHC technique is shown in Figure 5.7 for R-load.

![Figure 5.7 Simulation model for VSI-SHAF using fuzzy based PHC technique](image)

Figures 5.8 and 5.9 give the simulation diagram of the pulse generator circuit and fuzzy gain control for DC bus voltage control.
Figures 5.10 to 5.11 give the source voltage, source current and load current waveforms and phase displacement between source voltage and source current for R-load.
Figure 5.10  Source voltage, source current and load current waveforms for VSI-SHAF based PHC technique for R-Load

Figure 5.11  Phase displacement between source voltage and source current of Fuzzy based VSI-SHAF for PHC technique for R-load

Figures 5.12 and 5.13 give the dc capacitor link voltage and %THD for VSI-SHAF based Fuzzy-PHC technique for R-load
The simulation results of VSI-SHAF based FuzzyPHC for DC motor load are shown in figures 5.14 to 5.17.
Figure 5.14  Source voltage, source current and load current waveforms for VSI-SHAF based FuzzyPHC technique for DC Motor Load

Figure 5.15 Phase displacement between source voltage and source current for VSI-SHAF based FuzzyPHC technique for DC Motor Load
Figure 5.16 DC link capacitor voltage for VSI-SHAF based FuzzyPHC technique for DC Motor load

Figure 5.17 %THD for VSI-SHAF based Fuzzy PHC technique for DC Motor Load
Table 5.2  Overall comparative results for various closed loop reference current estimation techniques and FuzzyPHC showing the variation of real and reactive powers, power factor and %THD for Resistive load

<table>
<thead>
<tr>
<th>Parameters</th>
<th>R-load</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without filter</td>
</tr>
<tr>
<td>Real Power(P)</td>
<td>2.18e5</td>
</tr>
<tr>
<td>Reactive Power (Q)</td>
<td>4.45e4</td>
</tr>
<tr>
<td>Power factor (pf)</td>
<td>0.92</td>
</tr>
<tr>
<td>% THD</td>
<td>13.15</td>
</tr>
</tbody>
</table>

Tables 5.2 and 5.3 show the overall comparative results for various closed loop reference current estimation techniques (PQ, DQ, SDM, PHC and FuzzyPHC) showing the variation of real and reactive powers, power factor and %THD for Resistive load and DC Motor load.

Table 5.3  Overall comparative results for various closed loop reference current estimation techniques and FuzzyPHC showing the variations of real and reactive powers, power factor and %THD for DC Motor load

<table>
<thead>
<tr>
<th>Parameters</th>
<th>DC Motor load</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without filter</td>
</tr>
<tr>
<td>Real Power(P)</td>
<td>8.099e4</td>
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<tr>
<td>Reactive Power (Q)</td>
<td>7.841e4</td>
</tr>
<tr>
<td>Power factor (pf)</td>
<td>0.65</td>
</tr>
<tr>
<td>% THD</td>
<td>95.89</td>
</tr>
</tbody>
</table>

Figures 5.18 to 5.21 show the graphical representation of comparative analysis of various closed loop current estimation techniques based on % THD and real and reactive power variation for Resistive load and DC Motor load.
Figure 5.18 Graphical representation of % THD for closed loop reference current estimation techniques for R-load

Figure 5.19 Graphical representation of % THD for closed loop reference current estimation techniques for DC Motor load
Figure 5.20 Graphical representations of Real and Reactive power variation for closed loop reference current estimation techniques for R-load

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Figure 5.21 Graphical representations of Real and Reactive powers for closed loop reference current estimation techniques for DC Motor load
5.6 CONCLUSION

The results for close loop reference current estimation techniques using conventional PI controller (taken from previous chapter) and fuzzy based PI controller for R-load and DC Motor load using PHC technique found in this chapter are compared and shown in Tables 5.2 and 5.3.

Among the various closed loop reference current estimation techniques, namely p-q, d-q, SDM, PHC and FuzzyPHC, %THD for fuzzy controller based PHC is the lowest (2.29% for R-load and 3.84% for DC Motor load). Also, in fuzzy based PHC there is considerable improvement in load balancing, least %THD, least reactive power and hence improved power factor.