Performance Evaluation of Fuzzy and PI Controller for Boost Converter with Active PFC

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ABSTRACT

In this paper, the problem of controlling AC-DC full bridge converter is considered. The control objectives are two, one is guaranteeing a regulated voltage for the connected load and second one is enforcing power factor correction (PFC) with input current sinusoidal. Power factor correction of Boost converter is done by using fuzzy control technique. The inner loop has a current error amplifier which improves the power factor by properly shaping the input current in accordance with its reference. This reference signal is always synchronized and proportional to the line voltage hence the input current comes in phase with the input voltage. Thus by improving the power factor maximum active power can be delivered to the load. The voltage loop is being controlled by the fuzzy controller and the multiplier. Voltage regulation is done by the fuzzy controller and input distortion is minimized by the fuzzy controller. The desired features of an active PFC technique are close to Unity Power Factor operation, less than 10 % total harmonic distortion in line current and simple control strategy. The fuzzy control technique gives better performance during different line voltage and load. The results are verified through MATLAB/Simulink.

Keyword: AC-DC converter, DC-DC Converter, Fuzzy controller, Modelling of PFC Control, PI controller

1. INTRODUCTION

In the attempt to meet standard requirements (like IEC 555-2), many rectifier topologies and control techniques have been proposed, which provide almost unity power factor. In most solutions, however, the main effort is dedicated to improve the quality of the input current waveform, while dynamic response of the output voltage is sacrificed [3]. In fact, due to input power fluctuation, the output voltage contains a low-frequency ripple at twice the line frequency, which must be outside the voltage loop bandwidth in order to avoid input current distortion.

In the attempt to overcome this limitation, average current control, which allows improved response to the detriment of a higher input current distortion, was proposed in [4], while other techniques, aimed to remove the low-frequency ripple from the feedback signal, were analyzed in [5]. Also the Fuzzy Logic Control (FLC) seems very powerful for this purpose: in fact, fuzzy control rules can be written so as to allow low-distorted and m-phase line current during normal operation and fast dynamic response during transient conditions.

Since the fuzzy control rules derive from a heuristic knowledge of system's behaviour neither precise mathematical modelling nor complex computations are needed [6], [7] to design the fuzzy controller. In fact, design is simple, since it is based on linguistic rules of the type: "if the output voltage error is positive and their rates of change are negative then reduce slightly the duty-cycle", and so on. This approach relies on the basic physical properties of the system and it is potentially able to extend the control capability even to those operating conditions where linear control techniques fail, i.e. large-signal dynamic and large parameter
variations. Of course, fuzzy controllers cannot provide, in general, better small signal response than standard regulators. In fact the insight given by a detailed mathematical model of the system is superior to that given by a simple linguistic description of its behaviour.

In particular, in PFP’s application the fuzzy logic may overcome the voltage loop bandwidth limitation provided that some input current distortion is accepted (with the limits posed by the standards). From this point of view, fuzzy logic is a powerful tool because, by properly weighting the input current and the output voltage errors, it can provide an optimal trade-off between the needs for improving dynamic response and reducing input current distortion. Another advantage of the FLC approach is its generality, since almost the same control rules can be applied to several pre-regulator topologies; however, some scale factors must be tuned according to converter topology and parameters.

In the first section, the importance of power factor and the need of fuzzy logic controller are explained. In the second section, the proposed system configuration for PFC and the fuzzy control technique are discussed. Its operation, circuit description, designing of error amplifier and its control technique are analyzed in this chapter. In third section, simulation results of boost converter without control technique and both PI and Fuzzy control techniques are discussed. The performance of evaluation for both control techniques are studied for different input voltage.

2. Proposed System Configuration

Figure 1 shows the system configuration of fuzzy control based boost converter for active PFC. It consists of two loops first one is called fast loop and second one is called slow loop. Fast one is nothing but the inner current control loop and slow one is called fuzzy control loop. The fuzzy (or) feedback control loop is responsible for regulating the output voltage and the current (or) feed forward control loop is responsible for programming the input current, so that it follows the same sinusoidal waveform as the input voltage [2].

![Figure 1. Boost PFC converter with proposed control](image)

2.1. Fuzzy Control scheme

In order to implement the control algorithm of a shunt active power filter in closed loop, the DC side capacitor voltage is sensed and then compared with a reference value. The obtained error is given eqn (1)

\[ e(n) = V_{dc} \tag{1} \]

and

Change of error signal is given in eqn (2)
at the $n^{th}$ sampling instant are used as inputs for the fuzzy processing. The control scheme is shown in Figure 1. The output of the fuzzy controller after a limit is considered as the amplitude of the reference current $I_{max}$. This current takes care of the active power demand of load and the losses in the system.

2.2 Basic Fuzzy Algorithm

The internal structure of the fuzzy controller is shown in Figure 2. The error $e$ and change of error $ce$ are used numerical variables from the real system[1]. To convert these numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen as: NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big) as shown in Figure 2.

The fuzzy controller is characterized as follows:

(i) Seven fuzzy sets for each input and output.
(ii) Fuzzification using continuous universe of discourse.
(iii) Implication using Mamdani’s 'min' operator.
(iv) Defuzzification using the 'bisector' method.

2.3 Rule Base

The elements of this rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse input/output variables; in the steady state, small errors need fine control, which requires fine input/output variables. Based on this, the elements of the rule base table are obtained as shown in Table 1, with error and change in error as inputs [1].

![Internal Structure of Fuzzy controller](image)

Table 1. control rule base

<table>
<thead>
<tr>
<th>$ce$</th>
<th>NB</th>
<th>NM</th>
<th>NS</th>
<th>ZE</th>
<th>PS</th>
<th>PM</th>
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2.4 Inner current loop

In the current loop, the sensed inductor current is compared with the reference current profile using a current error amplifier. In the fuzzy controller loop the controller generate a reference current profile and the reference current profile is employed by the inner current loop for input current shaping. In the inner current loop the current error amplifier generate a error signal is then fed into the PWM modulator, where the logical gate drive signal is produced by comparing the current error with a fixed frequency saw tooth [2]. In this way the inductor current is programmed by the current loop to follow the sinusoidal envelope of the input voltage and a near unity power factor to achieve output voltage regulation.

3. RESULT AND DISCUSSION

To show the effectiveness of fuzzy control based power factor correction boost converter, mathematical simulation has been carried out by using MATLAB/Simulink. The simulation parameters and specifications of boost converter used in this paper are given in Appendix. For the simulation, the reference output voltage is taken as 400V.
Figure 4 shows the simulated waveform for input voltage in phase with line current. Figure 4 (a) shows the response of open loop PFC boost converter input voltage in phase with line current. Figure 4 (b) shows the response of PI controller PFC boost converter input voltage in phase with line current. Figure 4 (c) shows the response of fuzzy controller PFC boost converter input voltage in phase with line current. Comparing all the three techniques, the fuzzy control PFC boost converter is the optimum one and the power factor of the boost converter is improved to near unity (0.999).

Figure 5 shows the response of open loop PFC boost converter output voltage; figure 5 (b) shows the response of PI control PFC boost converter output voltage and figure 5 (c) shows the response of fuzzy control PFC boost converter output voltage. Comparing all the three techniques, fuzzy control PFC boost converter is optimum one, the output voltage is regulated and settling time of the output voltage improved (0.065ms) in fuzzy control technique.
Figure 5. Simulated waveform for Output voltage (a) Without control technique (b) PI controller (c) fuzzy controller at line voltage is 90V.
Figure 6. Simulated waveform for THD (%) (a) Without control technique (b) PI controller (c) fuzzy controller at line voltage is 90V.

Figure 6 (a) shows the response of open loop PFC boost converter THD (%), figure 6 (b) shows the response of PI control PFC boost converter THD (%) and figure 6. (c) Shows the response of fuzzy control PFC boost converter THD (%). Comparing all the three techniques fuzzy control PFC boost converter is optimum one and the THD (%) of the fuzzy controller is improved to 3.90%.

Figure 7. Simulated waveforms of Output voltage for different control techniques at line voltage is 90V

Figure 7. Shows the simulated response of output voltage for different control techniques, among all the three techniques fuzzy control technique has better performance and the settling time of the fuzzy control is improved that is 0.065ms.

Figure 8. Waveforms for variation of input voltage versus power factor for different control techniques

Figure 8 shows the analysis of the variation of input voltage versus power factor for PI controller and Fuzzy controller. In this figure shows the input voltage increases and the power factor decreases. In these waveforms fuzzy control technique improves the power factor near unity (0.999).
Figure 9. Waveforms for variation of input voltage versus THD (%) for different control techniques

Figure 9. Shows the analysis of the variation of input voltage vs input current THD (%) for PI controller and Fuzzy controller. In this figure shows the input voltage increases and the power factor decreases. In this waveform fuzzy control technique improves the input current THD (%) that is 3.90% as shown in the Table 2.

Table 2. Summary of PI and Fuzzy controller settling time

<table>
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<tr>
<th>SI.No</th>
<th>Type of Controller</th>
<th>Setting Time (ms)</th>
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<tr>
<td>01</td>
<td>PI</td>
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<tr>
<td>02</td>
<td>Fuzzy</td>
<td>0.068</td>
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</table>

Table 3. Comparison of %THDs and power factor with different line voltage

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Current THD (%)</th>
<th>Fuzzy Voltage</th>
<th>Current THD (%)</th>
<th>Fuzzy Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>5.57</td>
<td>5.91</td>
<td>11.84</td>
<td>11.99</td>
</tr>
<tr>
<td>150</td>
<td>5.50</td>
<td>5.82</td>
<td>10.92</td>
<td>10.90</td>
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<td>110</td>
<td>4.85</td>
<td>4.34</td>
<td>10.13</td>
<td>10.03</td>
</tr>
<tr>
<td>90</td>
<td>4.57</td>
<td>4.70</td>
<td>9.61</td>
<td>9.68</td>
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</tbody>
</table>

4. CONCLUSION

The performance of a fuzzy logic controller and PI controller for boost converter with active power factor correction has been studied. It can be concluded that fuzzy controller has a better transient response compared to a conventional PI controller, and the steady state performance of the fuzzy controller is comparable to the PI controller. The performance of the different control techniques compares, the fuzzy control is better to compare with PI controller and the settling time of the fuzzy controller is 0.065ms and PI controller is 0.22ms. With reference to Table 3, it can be concluded that the dynamic performance of the fuzzy controller is also better than PI controller. Superior performance of the system with fuzzy controller has been observed, which is able to reduce the harmonics below 10% in all cases studied, the harmonic limit imposed by the IEEE-519 standard.

REFERENCES