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DESIGN OF FUZZY LOGIC CONTROLLER FOR BUCK BOOST CONVERTER

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This Report Is Submitted In Partial Fulfillment Of Requirements Or The Degree Of Bachelor In Electrical Engineering (Power Industry)

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"I admit that this project is written by me and is my own effort and that no part has been plagiarized without citation."

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"For my beloved father and mother
Mr. Gabriel Enak Ak Sindang and Mrs. Lim Teng Hua
In appreciation for support and understanding during my project research"
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I would first like to thank my family for their warm support and patience during the research and writing of this thesis and throughout my career path. This includes all my friends and colleagues who encouraged my work and made valuable suggestions; their friendship is unforgettable.

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Last but not least, I would like to thank to all those who called for answers, came by for help, scanned, scratched, screamed and cried. I appreciate being able to share with you. It is what I envisioned and what I strive to achieve.
Conventional control of Buck Boost Converter utilising PI controller is requesting for converter modeling and application of linear control theory. One route to avoid by employing Fuzzy Logic controller where a set of linguistic rules will be used to produce an automatic control algorithm. In this project, the simulation of Buck Boost Controller circuit utilising both PI-based and fuzzy-based controller will be carried out using Simulink program (Matlab 6.5). The performance produced by both controllers which is based on step-response will be compared and analysis.
ABSTRAKS

# TABLE OF CONTENT

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>DESCRIPTION</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TITLE</td>
<td></td>
<td>i</td>
</tr>
<tr>
<td>ADMISSION</td>
<td></td>
<td>ii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td></td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td></td>
<td>iv</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td></td>
<td>v</td>
</tr>
<tr>
<td>TABLE OF CONTENT</td>
<td></td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF TABLE</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>LIST OF FIGURE</td>
<td></td>
<td>xi</td>
</tr>
<tr>
<td>1</td>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1</td>
<td>Background</td>
<td>1</td>
</tr>
<tr>
<td>1.2</td>
<td>Objective and Outline</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>LITERATURE REVIEW</td>
<td>4</td>
</tr>
<tr>
<td>2.1</td>
<td>Buck Boost Converter</td>
<td>4</td>
</tr>
<tr>
<td>2.1.1</td>
<td>The Main Idea of Buck Boost Converter Approach</td>
<td>5</td>
</tr>
<tr>
<td>2.1.2</td>
<td>Understanding Buck Boost Steady-States Continuous Conduction Mode Analysis.</td>
<td>5</td>
</tr>
<tr>
<td>2.1.3</td>
<td>State-space averaging and linearization technique to obtain the control-to-output transfer function of the Buck Boost converter.</td>
<td>8</td>
</tr>
<tr>
<td>2.1.3.1</td>
<td>State-space averaging the inductor waveforms</td>
<td>8</td>
</tr>
<tr>
<td>2.1.3.2</td>
<td>State-space averaging the capacitor waveforms</td>
<td>9</td>
</tr>
</tbody>
</table>
2.1.3.3 Linearization Technique 10
2.1.4 Buck Boost converter transfer function, Vo/d 13
2.2 Fuzzy Logic controller 16
   2.2.1 Fuzzy Logic controller modeling approach and design. 17
      2.2.1.1 Identification of input and output's parameter 17
      2.2.1.2 Membership functions for the parameter 18
      2.2.1.3 Fuzzification method 19
      2.2.1.4 Inference method 20
      2.2.1.5 Defuzzification method 20

2 FUZZY LOGIC CONTROLLER OF BUCK BOOST CONVERTER MODULES 23
3.1 Linear controller-design guidelines 23
   3.1.1 Deriving the small signal model of the buck boost converter 23
   3.1.2 Design of Fuzzy logic controller for buck boost converter 27
      3.1.2.1 Simulation based on Matlab simulink 27

4 FUZZY LOGIC CONTROLLER PERFORMANCE AND ANALYSIS 33
4.1 Step-response analysis for Fuzzy Logic controller simulation. 33
4.2 Step-response analysis when gain for G0 is change 34
4.3 Step-response analysis when gain for G1 is change 35
4.4 Step-response analysis when the gain for G2 is change 36
4.5 The effects of the choice of G0, G1 and G2 from simulation 37

5 COMPARISON WITH PI CONTROLLER 38

6 CONCLUSION 41
## LIST OF TABLE

<table>
<thead>
<tr>
<th>NO</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 2.0</td>
<td>Inference for the chosen example</td>
<td>20</td>
</tr>
<tr>
<td>Table 3.0</td>
<td>Buck Boost converter specifications</td>
<td>26</td>
</tr>
<tr>
<td>Table 3.3</td>
<td>Membership function name and its parameter</td>
<td>30</td>
</tr>
<tr>
<td>Table 3.6</td>
<td>Rule table for implementing in Rule Editor</td>
<td>36</td>
</tr>
<tr>
<td>Table 4.1</td>
<td>Step response of buck boost converter with increasing and decreasing value for G0, G1 and G2.</td>
<td>37</td>
</tr>
</tbody>
</table>
### LIST OF FIGURE

<table>
<thead>
<tr>
<th>NO</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>Buck Boost converter</td>
<td>6</td>
</tr>
<tr>
<td>2.1</td>
<td>Buck Boost converter is switch to position 1</td>
<td>6</td>
</tr>
<tr>
<td>2.2</td>
<td>Buck Boost converter is switch to position 2</td>
<td>7</td>
</tr>
<tr>
<td>2.3</td>
<td>Buck Boost converter waveforms; (a) inductor voltage &amp; (b) inductor current</td>
<td>8</td>
</tr>
<tr>
<td>2.4</td>
<td>Buck Boost converter waveforms; (a) capacitor voltage &amp; (b) capacitor current</td>
<td>9</td>
</tr>
<tr>
<td>2.5</td>
<td>Buck Boost converter equivalent circuit</td>
<td>13</td>
</tr>
<tr>
<td>2.6</td>
<td>Manipulation of buck-boost equivalent circuit to find the control-to- output transfer function $Gvd(s)$: (a) set vg source to zero; (b) push inductor and voltage source through transformer</td>
<td>13</td>
</tr>
<tr>
<td>2.7</td>
<td>Solution of the model by superposition: (a) current source set to zero; (b) voltage source set to zero</td>
<td>14</td>
</tr>
<tr>
<td>2.8</td>
<td>Block diagram of Fuzzy Logic controller scheme for Buck Boost converter</td>
<td>17</td>
</tr>
<tr>
<td>2.9</td>
<td>Membership for $e_1$ &amp; $e_2$.</td>
<td>18</td>
</tr>
<tr>
<td>2.10</td>
<td>Fuzzification for $e_n = +1.8$ and $\Delta e_n = -1.3$</td>
<td>19</td>
</tr>
<tr>
<td>2.11</td>
<td>Modeling and Control approach</td>
<td>22</td>
</tr>
<tr>
<td>3.1</td>
<td>FIS Editor</td>
<td>28</td>
</tr>
<tr>
<td>3.2</td>
<td>Membership Function Editor</td>
<td>29</td>
</tr>
<tr>
<td>3.4</td>
<td>Membership Function editor for duty cycle output variable</td>
<td>31</td>
</tr>
<tr>
<td>3.5</td>
<td>Rule Editor</td>
<td>29</td>
</tr>
<tr>
<td>3.6</td>
<td>Buck Boost converter controller circuit</td>
<td>32</td>
</tr>
<tr>
<td>Figure 4.0</td>
<td>The step-response for fuzzy logic controller</td>
<td>31</td>
</tr>
<tr>
<td>Figure 4.1</td>
<td>Step-response analysis for different value of G0</td>
<td>34</td>
</tr>
<tr>
<td>Figure 4.2</td>
<td>Step-response analysis for different value of G1</td>
<td>35</td>
</tr>
<tr>
<td>Figure 4.3</td>
<td>Step-response analysis for different value of G2</td>
<td>36</td>
</tr>
<tr>
<td>Figure 5.0</td>
<td>Step-response comparison analyses between Fuzzy Logic and PI controller</td>
<td>38</td>
</tr>
<tr>
<td>Figure 5.1</td>
<td>PI controller for Buck Boost converter.</td>
<td>39</td>
</tr>
<tr>
<td>Figure 5.2</td>
<td>Bode plot analysis for open-loop PI controller of Buck Boost converter.</td>
<td>39</td>
</tr>
<tr>
<td>Figure 5.3</td>
<td>Open loop circuit analysis for PI controller.</td>
<td>40</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

1.1 Background

Buck Boost converter is an intriguing subject from the control point of view, due to its intrinsic non-linearity. Common control approaches like Voltage Control and Current Injected Control, require a good knowledge of the system and accurate tuning in order to obtain desired performances.

These controllers are simple to implement and easy to design but their performance generally depend on the working point, so that the presence of parasitic elements, time-varying loads and variables supply voltages can make difficult selection of the control parameters which ensure a proper behavior in any operating conditions. Achieving large-signal stability often calls for a reduction of the useful bandwidth, so affecting converter performances [1].

Crucial to the performance of Buck Boost converter is the choice of control methods. One route to escape is to employ heuristic reasoning based on human experience of the plant [2],[3]. In this case, no modeling is at all required and the whole business of controller design reduces to the conversion of a set of linguistic rules into an automatic control algorithm.

Here, fuzzy logic comes into play as it provides the essential machinery for performing the said conversion.
1.2 Objective and Outline

Modern control of switching power converters is an interesting and challenging research topic. As mentioned above, the improved large signal performance and stability of power electronics systems has always been a main concern. Most times designers analyze in linear, small signal formalism, each circuit individually in order to tune and than prescribe a scheme to accommodate a designated set of transients. The scope of this work is motivated by a need of new tools and techniques in order to explore and determine how one might do better.

The main objective of the research in this thesis is to introduce, conduct analysis and develop design methodologies for using emerging fuzzy logic control for improved large signal performance of Buck Boost converter. In particular, this study develops is to implement nonlinear fuzzy logic control algorithms that provide satisfactory global behavior while maintaining good step-response.

Chapter 2 will introduce the main review of the existing project for design of fuzzy logic controller on buck boost converter. The first step of design the fuzzy logic is to understand the behavior and the steady-states continuous conduction mode of the buck boost converter. Then, state-space averaging and linearization techniques must be determined to get the linear model. Fuzzy logic controller design consist of determine the input and output parameter, define for membership function for the parameter, fuzzification, inference method and defuzzification.

In Chapter 3, calculation is done for getting the buck boost converter specification. This parameter specification will be use in getting the control-to-output transfer function. Then the simulation based on simulink is carrying out to verify the performance for fuzzy logic controller.

For Chapter 4, the performance based on step response for the fuzzy logic controller will be analyzed. Selected gains will be determined for getting the good step-response.
A comparison between PI and fuzzy logic controller will be analyzed where the analysis for both performances in step-response is carrying out in chapter 5.
CHAPTER 2

LITERATURE REVIEW

Basically, this chapter will review existing project created to get an idea on the project design of fuzzy logic controller for buck boost converter by following conception, specification and any information that related to improve the project. Later of this chapter, some review about design fuzzy logic controller of buck boost converter that proposed to fulfill this project will be reported.

2.1 Buck Boost converter

The conventional Buck Boost converter is some of the simplest power electronic circuit. It is widely used in the power supply equipment for most electronic instruments and also in specialized high-power applications such as battery charging, platting and welding.

Inverting Buck Boost converter is capable of converting supply voltages to both higher and lower voltages which mean either step up or step down voltages. The polarity of the Buck Boost converter output voltage is opposite to the supply voltage. The ability to work over a wide range of input voltage to generate both higher and lower voltages while supplying high current makes this topology an attractive choice. [4]
2.1.1 The Main Idea of Buck Boost Converter Approach

The basic Buck Boost converter power conversion function of switching converters is achieved by repetitive switching between two linear networks consisting of storage elements, inductors and capacitors. As known, state space averaging and linearization are analytical approximation techniques that allow switching regulators to be represented as linear systems.

The averaging allows the switched, discontinuous; system to be approximated as a continuous, nonlinear, large signal model and then linearization around the DC steady state operating point is applied in order to obtain a small signal, linear model. [5]. Thus, in the small signal analysis, all the results of the linear control systems can be applied, provided that the perturbation in the system is small enough.

2.1.2 Understanding Buck Boost Steady-States Continuous Conduction Mode Analysis

The following is a description of steady-state operation in continuous conduction mode. The main goal of this section is to provide a derivation of the voltage conversion relationship for the continuous conduction mode buck-boost power stage. This is important because it shows how the output voltage depends on duty cycle and input voltage or conversely, how the duty cycle can be calculated based on input voltage and output voltage. Steady-state implies that the input voltage, output voltage, output load current, and duty-cycle are fixed and not varying.
The Basic ac modeling approach for Buck Boost converter

![Buck Boost converter diagram](image)

Figure 2.0 Buck Boost converter

Switch in position 1:

![Buck Boost converter with switch in position 1](image)

Figure 2.1: Buck Boost converter is switch to position 1

In this case, inductor voltage and capacitor current are:

\[ V_L(t) = L \frac{di(t)}{dt} = V_g(t) \quad (2.0) \]

\[ i_C(t) = C \frac{dv(t)}{dt} = -\frac{v(t)}{R} \quad (2.1) \]

Small ripple approximation: replace waveforms with their low-frequency averaged values:

\[ V_L(t) = L \frac{di(t)}{dt} \approx \langle V_g(t) \rangle_{rd} \quad (2.2) \]

\[ i_C(t) = C \frac{dv(t)}{dt} \approx -\frac{\langle v(t) \rangle_{rd}}{R} \quad (2.3) \]
Switch in position 2:

![Diagram of Buck Boost converter with switch in position 2](image)

Figure 2.2: Buck Boost converter is switch to position 2

In this case, inductor voltage and capacitor current are:

$$V_L(t) = L \frac{di(t)}{dt} = V_g(t) \quad (2.4)$$

$$I_c(t) = C \frac{dv(t)}{dt} = -i(t) - \frac{v(t)}{R} \quad (2.5)$$

Small ripple approximation: replace waveforms with their low-frequency averaged values:

$$V_L(t) = L \frac{di(t)}{dt} \approx \langle V_g(t) \rangle_{ta} \quad (2.6)$$

$$i_c(t) = C \frac{dv(t)}{dt} \approx -\langle i(t) \rangle_{ta} - \frac{\langle v(t) \rangle_{ta}}{R} \quad (2.7)$$
2.1.3 State-space averaging and linearization technique to obtain the control-to-output transfer function of the Buck Boost converter.

2.1.3.1 State-space averaging the inductor waveforms.

![Diagram of inductor voltage and current waveforms](image)

Figure 2.3: Buck Boost converter waveforms; (a) inductor voltage & (b) inductor current.

The inductor voltage and current waveforms are sketched in Figure 2.3. The low-frequency average of the inductor voltage is found by evaluation of Eq.2.8 where the inductor voltage during the first and second subintervals, given by Eq.2.2 and 2.6, are averaged in Eq 2.9:

\[
\langle X L(t) \rangle_{T_S} = \frac{1}{T_S} \int_{t}^{t+T_S} X(\tau) d\tau
\]  \hspace{1cm} (2.8)

\[
\langle V L(t) \rangle_{T_S} = \frac{1}{T_S} \int_{t}^{t+T_S} V L(\tau) d\tau \approx d(t) \approx \langle V_{g}(t) \rangle_{T_S} + d'(t) \langle V(t) \rangle_{T_S}
\]  \hspace{1cm} (2.9)

The right-hand side of Eq.2.9 contains no switching harmonics, and models only the low-frequency components of the inductor voltage waveform. Insertion of this equation into Eq.2.10 leads to:

\[
L \frac{d\langle i_L(t) \rangle_{T_S}}{dt} = \langle V_L(t) \rangle_{T_S}
\]

\[
C \frac{d\langle V_C(t) \rangle_{T_S}}{dt} = \langle i_C(t) \rangle_{T_S}
\]  \hspace{1cm} (2.10)
\[ L \frac{d\langle i(t) \rangle_{T_s}}{dt} = d(t)\langle V_g(t) \rangle_{T_s} + d'(t)\langle V(t) \rangle_{T_s} \quad (2.11) \]

2.1.3.2 State-space averaging the capacitor waveforms.

\[ L \frac{d\langle i(t) \rangle_{T_s}}{dt} = d(t)\langle V_g(t) \rangle_{T_s} + d'(t)\langle V(t) \rangle_{T_s} \]

![Figure 2.4: Buck Boost converter waveforms; (a) capacitor voltage & (b) capacitor current](image)

A similar procedure leads to the capacitor dynamic equation. The capacitor voltage and current waveforms are sketched in Figure 2.4. The average capacitor current can be found by averaging Eqs 2.3 and 2.7; the result is:

\[ \langle i_c(t) \rangle_{T_s} = d(t)\left(-\frac{\langle V(t) \rangle_{T_s}}{R}\right) + d'(t)\left(-\langle i(t) \rangle_{T_s} - \frac{\langle V(t) \rangle_{T_s}}{R}\right) \quad (2.12) \]

Upon inserting this equation into Eq.2.10 and collecting terms, one obtains

\[ C \frac{d\langle V(t) \rangle_{T_s}}{dt} = -d'(t)\langle i(t) \rangle_{T_s} - \frac{\langle V(t) \rangle_{T_s}}{R} \quad (2.13) \]
2.1.3.3 Linearization Technique

These equations are nonlinear because they involve the multiplication of time-varying quantities. So we need to linearize Eqs 2.11, 2.13 and 2.14 by constructing a small-signal model.

\[ \langle i_g(t) \rangle_{T_s} = d(t) \langle i(t) \rangle_{T_s} \quad (2.14) \]

\[ V = -\frac{D}{D^r} V_g \quad (2.15) \]

\[ I = -\frac{V}{D^r R} \quad (2.16) \]

\[ I_g = DI \quad (2.17) \]

Equations 2.15, 2.16 and 2.17 are derived as usual via the principles of inductor volt second and capacitor charge balance. They could also be derived from Eqs 2.11, 2.13 and 2.14 by noting that, in steady-state, the derivatives must equal zero.

To construct a small-signal ac model at a quiescent operating point \((I, V)\), one assumes that the input voltage \(v_g(t)\) and the duty cycle \(d(t)\) are equal to some given quiescent values \(V_g\) and \(D\), plus some superimposed small ac variations \(v_g(t)\) and \(d(t)\).

Hence, we have:

\[ V_g(t) = V_g + \bar{V}_g(t) \quad (2.18) \]

\[ d(t) = D + \bar{d}(t) \quad (2.19) \]

In response to these inputs, and after any transients have subsided, the averaged inductor current \(\langle i(t) \rangle_{T_s}\), the averaged capacitor voltage \(\langle v(t) \rangle_{T_s}\), and the averaged input current \(\langle i_g(t) \rangle_{T_s}\) waveforms will be equal to the corresponding quiescent values \(I, V, \) and \(I_g\), plus some superimposed small ac variations \(\bar{i}(t), \bar{v}(t), \) and \(\bar{i}_g(t)\):

\[ \langle i(t) \rangle_{T_s} = I + \bar{i}(t) \quad (2.20) \]
\[ (v(t))_r = V + \bar{v}(t) \]  \hspace{1cm} (2.21)

\[ (i_s(t))_r = I_s + \bar{i}_s(t) \]  \hspace{1cm} (2.22)

Then nonlinear equations 2.11, 2.13 and 2.14 can be linearized. This is done by inserting Eqs. 2.18, 2.19, 2.20, 2.21 and 2.22 into Eqs. 2.11, 2.13 and 2.14. For the inductor equation, one obtains:

\[ L \frac{d(I + \bar{i}(t))}{dt} = (D + \bar{d}(t))(V_s + \bar{v}(t)) + (D' - d'(t))(V + \bar{v}(t)) \]  \hspace{1cm} (2.23)

By multiplying out Eq.2.23 and collecting terms, one obtains:

\[ L \left( \frac{dI_0}{dt} + \frac{\bar{d}(t)}{dt} \right) = \left( D V_s + D'V \right) + \left( D \bar{v}_g(t) + D' \bar{v}(t) + (V_s - V) \bar{a}(t) \right) + \bar{d}(t)(\bar{v}_g(t) - \bar{v}(t)) \]  \hspace{1cm} (2.24)

We are left with the first-order ac terms on both sides of the equation. Hence,

\[ L \frac{d\bar{i}(t)}{dt} = D \bar{v}_g(t) + D' \bar{v}(t) + (V_s - V) \bar{a}(t) \]  \hspace{1cm} (2.25)

This is the desired result: the small-signal linearized equation which describes variations in the inductor current.

The capacitor equation can be linearized in a similar manner. Insertion of Eqs. 2.18, 2.19, 2.20, 2.21 and 2.22 into the capacitor equation of Eq.2.11, 2.13 and 2.14 yields:

\[ C \frac{d(V + \bar{v}(t))}{dt} = -\left( D' - \bar{d}(t) \right)(I + \bar{i}(t)) \frac{(V + \bar{v}(t))}{R} \]  \hspace{1cm} (2.26)

Upon multiplying out Eq.2.26 and collecting terms, one obtains:

\[ C \left( \frac{dV_0}{dt} + \frac{\bar{v}(t)}{dt} \right) = \left( -D'I - \frac{V}{R} \right) + \left( -D'\bar{i}(t) - \frac{\bar{v}(t)}{R} + \bar{a}(t) \right) + \bar{d}(t)\bar{i}(t) \]  \hspace{1cm} (2.27)