Fuzzy Sliding Mode Control Method for DC/DC Buck Converter

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Abstract—This paper proposes a Fuzzy Sliding Mode Control (FSMC) as a control strategy for Buck DC-DC converter. The proposed controller uses a sliding mode control mechanism to improve the performance of a conventional buck converter. The performances of the proposed fuzzy sliding controller are compared to those obtained by a classical sliding mode controller. A simple sliding mode control (SMC) technique for the buck converter that has a fixed switching frequency and zero steady state error. The response of this controller is robust and can be defined directly in the time domain. In addition, fuzzy logic implementation of the proposed SMC is provided.

Keywords—DC/DC Buck converter; fuzzy logic controller; sliding mode control; fuzzy sliding Mode Control;

1. INTRODUCTION

DC-DC converters are nonlinear system in nature due to their switching property. Static and dynamic characteristics of these converters have been widely discussed in the literature. In many industrial applications there is a need for the transformation of a constant dc voltage source to a variable dc voltage source, and like a transformer, the converter can be employed for stepwise increase or reduction of dc source voltage. In this way Buck converter has a wide application in electrical industry and power systems and specifically it can supply the voltage for a direct current consumer. Buck is a one-input and multiple-output in structure with a non-linear property due to its switching behavior, but at the same time when the switch is on and off its behavior is linear. Therefore, by employing the averaging method, it is possible to exchange a non-linear system with a linear one. Many of the methods are centered on the isolation of the system variables and PI controller design [1]. Some control methods have defined the subject of control based on pole placement.

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This control scheme is developed for the buck converter topology and digital implementation of the controller is considered. It has been noted that fuzzy logic can give a sliding mode like response [3]. This paper also provides an explanation of how this is possible by implementing the proposed sliding mode like control in fuzzy logic.

2. THE DC–DC BUCK CONVERTER

The Buck converter circuit model is depicted in Fig.1.

Figure 1: Buck Converter

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The function of the circuit is divided into two parts. The first part starts when the switch is turned on at $t=0$. The input current which is rising passes through $L$ filter inductor, $C$ filter capacitor, and $RL$ load resistance. The second part starts when the switch is turned off at $t=t1$. Due to the presence of stored energy in the inductor, and the inductor current continues passing from $L$, $C$, load and $D$. The inductor current declines until the second switch switching in the next cycle. In this model, $Vo$ is the system output voltage and $Vref$ is the converter voltage.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_L$</td>
<td>0.7Ω</td>
</tr>
<tr>
<td>$r_d$</td>
<td>0.7Ω</td>
</tr>
<tr>
<td>$r_c$</td>
<td>1.18Ω</td>
</tr>
<tr>
<td>$r_t$</td>
<td>0.2Ω</td>
</tr>
<tr>
<td>$C$</td>
<td>1450μF</td>
</tr>
<tr>
<td>$L$</td>
<td>0.42mH</td>
</tr>
<tr>
<td>$R_L$</td>
<td>118Ω</td>
</tr>
<tr>
<td>$V_{dc}$</td>
<td>50 V</td>
</tr>
<tr>
<td>$d$</td>
<td>0.5</td>
</tr>
</tbody>
</table>

4. FUZZY LOGIC

In 1965, Zadeh proposed Fuzzy logic; it has been effectively utilized in many field of knowledge to solve such control and optimization problems [12]. Fuzzy logic has been available as a control methodology for over three decades and its application to engineering control systems is well proven. In a sense fuzzy logic is a logical system that is an extension of multi-valued logic although in character it is quite different. It has become popular due to the fact that human reasoning and thought formation is linked very strongly with the ways fuzzy logic is implemented. In power system area, it has been used to stability studies, load frequency control, unit commitment, and to reactive compensation in distribution network and other areas.

The most important specifications of fuzzy control method are their fuzzy logical ability in the quality perception of system dynamics and the application of these quality ideas simultaneously for power systems [11]. A simple block diagram of a fuzzy system is shown in Fig.4.
Four major units are fuzzification block, a fuzzy knowledge-base block, a fuzzy inference engine and a defuzzification block. The functions of the blocks and working principles of the fuzzy system are briefly summarized [14].

A. Fuzzification

The fuzzification block performs the following tasks:
- Measures the value of input variables.
- Performs a scale mapping that transfers the range of values of input variables into the corresponding universes of discourse.
- Performs the function of fuzzification, which converts input data into suitable linguistic values that may be viewed as labels of fuzzy sets.

The input signals to FLC are scaled using appropriate scaling factors. These scaled input data are then converted into linguistic variables, which may be viewed as labels of fuzzy sets. Fuzzy sets can be characterized by membership functions. There are many types of membership functions e.g., the bell-shaped, linear function, triangular function, trapezoidal function and exponential function.

B. Knowledge-base

The knowledge base is comprised of two components namely called fuzzy sets (data base) and fuzzy control rule base. The concepts associated with fuzzy sets are used to characterize fuzzy control rules and fuzzy data manipulation in an FLC. These concepts are subjectively defined and based on experience. So, it should be noted that the correct choice of the membership functions of a term set plays an essential role in the success of an application [14].

The fuzzy rule base consists of a set of linguistic control rules written in the form:

IF a set of conditions are satisfied (premise), THEN a set of consequences are inferred The collection of fuzzy control rules that are expressed as fuzzy conditional statements forms the rule base or the rule set of an FLC. In particular, the choice of linguistic variables and their membership function have a strong influence on the linguistic structure of an FLC. Typically, the linguistic variables in an FLC are the state, state error, state error derivative, state error integral, etc.

One of the key problems is to find the appropriate fuzzy control rules. In general, there are four models of derivation of fuzzy control rules [14].
- Using the experience and knowledge of an expert.
- Modeling the control actions of the operator.
- Using a fuzzy model of a process.
- Using self-organized fuzzy controllers.

C. Fuzzy inference engine

The fuzzy engine is the kernel of a fuzzy logic controller, which has capability of simulating human decision making based on fuzzy concepts and of inferring fuzzy control actions using fuzzy implication (fuzzy relation) and the rules of inference in fuzzy logic. This means that the fuzzy inference engine handles rule inference where human experience can easily be injected through linguistic rules.

D. Defuzzification

The defuzzification block performs the following functions:
- Scale mapping, which converts the range of values of output variables into corresponding universes of discourse.
- Transforms the fuzzy control actions to continuous (crisp) signals, which can be applied to the physical plant.

5. FUZZY SLIDING MODE CONTROL DESIGN

The proposed controller has a configuration as shown in Fig. 5. In an ordinary fuzzy controller, the input gains g0, gl, output gain h and the rule base are designed based on the in depth knowledge of the converter, and tuned using a trial and error method. In a fuzzy controller using sliding mode algorithm, the input gains g0, gl and the rule table are designed based on the principles of sliding mode control. The only variables that need to be tuned are the output gain h. Therefore, the time required for tuning is greatly reduced for a fuzzy controller using sliding mode algorithm [7]. The integrator in the output side eliminates steady-state error.

The combination of the sliding mode control with the fuzzy logic control aims to improve the robustness and the performances of the controlled nonlinear systems. The proposed fuzzy sliding mode controller forces the derivative of the Lyapunov function to be negative definite. So, the rule base table is established to satisfy the inequality Intuitively, suppose that $S > 0$ and $S' > 0$, the duty cycle must increase. Also, if $S < 0$ and $S' < 0$ the duty cycle must decrease. Thus, the surface $S$ and its variation $S'$ are the
inputs of the proposed controller. The output signal is the control increment $\Delta U(k)$ which is used to update the control law. The control signal is defined as follows:

$$U(k) = \Delta U(k) + \Delta U(k-1)$$

The proposed Fuzzy sliding mode controller is a zero order Sugeno fuzzy controller which is a special case of Mamdani fuzzy inference system. Only the antecedent part of the Sugeno controller has the "fuzzyness", the consequent part is a crisp function. In the Sugeno fuzzy controller, the output is obtained through weighted average of consequents [15]. Trapezoidal and triangular membership functions, denoted by N (Negative), Z (Zero) and P (Positive), were used for both the surface and the surface change.

### 5.1 Rule Table

Rule table is designed based on FSMC and is given in Table -2

<table>
<thead>
<tr>
<th>$\dot{S}/S$</th>
<th>NB</th>
<th>NM</th>
<th>NS</th>
<th>Z</th>
<th>PS</th>
<th>PM</th>
<th>PB</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>NVB</td>
<td>NVB</td>
<td>NVB</td>
<td>NB</td>
<td>NM</td>
<td>NS</td>
<td>Z</td>
</tr>
<tr>
<td>NM</td>
<td>NVB</td>
<td>NVB</td>
<td>NB</td>
<td>NM</td>
<td>NS</td>
<td>Z</td>
<td>PS</td>
</tr>
<tr>
<td>NS</td>
<td>NVB</td>
<td>NB</td>
<td>NM</td>
<td>NS</td>
<td>Z</td>
<td>PS</td>
<td>PM</td>
</tr>
<tr>
<td>Z</td>
<td>NB</td>
<td>NM</td>
<td>NS</td>
<td>Z</td>
<td>PS</td>
<td>PM</td>
<td>PB</td>
</tr>
<tr>
<td>PS</td>
<td>NM</td>
<td>NS</td>
<td>Z</td>
<td>PS</td>
<td>PM</td>
<td>PB</td>
<td>PVB</td>
</tr>
<tr>
<td>PM</td>
<td>NS</td>
<td>Z</td>
<td>PS</td>
<td>PM</td>
<td>PB</td>
<td>PVB</td>
<td>PVB</td>
</tr>
<tr>
<td>PB</td>
<td>Z</td>
<td>PS</td>
<td>PM</td>
<td>PB</td>
<td>PVB</td>
<td>PVB</td>
<td>PVB</td>
</tr>
</tbody>
</table>
5.2 TUNING OF OUTPUT GAIN
Using simulink based simulation h is designed using trial and error and $h = 1.5e^{-12}$

6. CONCLUSION
we propose a fuzzy sliding mode control for improving the robustness and the dynamical performances of a buck DC-DC. The proposed fuzzy controller design has as inputs the sliding surface and its variation. It defines the control signal to satisfy the stability and the attraction condition of the sliding surface. The simulation results show that the proposed controller this controller has been designed for a buck converter and the controller is able to overcomes the chattering problem. Moreover, it is proven that the proposed controller is robust for the case of the desired output currents variation and input voltage variations.

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REFERENCES


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