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Comparison of PID and Fuzzy Controlled DC to DC Converter with Inductor Resistance

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Abstract

The DC-DC boost converter reveals highly non-linear and non-minimum phase properties, is very difficult task to design a controller that is healthy against load variation. For this purpose a Fuzzy PID Controller is proposed to control DC-DC boost converter which has a practical inductor and a series resistance. A balancing Proportional-Integral-Differential (PID) controller to the parallel-damped passivity-based controller PD-PBC is also proposed for removing the steady state error even though the parasitic resistance. MATLAB simulations are performed under step changes and load perturbations to measure the improvement in performance of the proposed approach.

Keywords: Boost converter, load variation, parasitic resistance, passivity-based control, Fuzzy Logic Control (FLC).

Introduction

Because of the DC voltage generated by fuel cells or pv array systems varies broadly in magnitude and surprising transient states frequent result from uncertain load variations, a reliable DC-DC boost (step-up) conversion stage is essential to provide a highly regulated DC voltage. This prompts the growth of various control algorithms for dc to dc converters [1] – [5]. To improve the performance many control methods have been invented. A passivity-based controller (PBC) as one of the robust control algorithms has been applied to many practical control applications including DC-DC power converters.

PID stands for “proportional, integral, derivative.” These three terms describe the basic elements of a PID controller. Each of these elements performs a different task and has a different effect on the functioning of a system. In a typical PID controller these elements are driven by a combination of the system command and the feedback signal from the object that is being controlled (usually referred to as the “plant”). Their outputs are added together to form the system output [6].

In the proposed approach, the PID controller uses an additional system state variable instead of a constant reference value for generating an error signal. This is the main difference between the proposed controller and conventional PID controllers.

The term passivity-based control (PBC) to define a controller design methodology which achieves stabilization by passivation. More precisely, the control objective is to passives the system with a storage function which has a minimum at the desired equilibrium point. A second requirement that ensures asymptotic stability is detect ability of the passive output. The objective is to ensure passivity of the closed-loop system by changing the energy function and adding damping so as to achieve asymptotic stability of the system.

However, the nonlinear controller does not take into consideration the parasitic resistance such as the resistance in the inductor. Although the parasitic resistance is relatively very small, it cannot be ignored in the practical DC-DC boost converter because it increases the model uncertainty. Owing to the parasitic resistance, the PD-PBC cannot maintain robust performance under load variations.

The objective of this paper is to provide a robust output feedback controller for the DC-DC boost converter that has two parasitic resistors including the inductor resistance. Based on the fact that the PD-PBC exhibits robust performances for the ideal boost converter, this paper extends the application of the approach to the boost converter with a practical inductor.The main drawback of PBC is that the asymptotic stability of the resulting controller is not ensured. That is why another approach of PBC has been developed.

Fuzzy control is an intelligent control method which imitates logical thinking of human and is

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independent on an accurate mathematical model of the controlled object. What is more, it is insensitive to parameters variation, and has strong robustness. It is perfectly applied to overcome the effects of nonlinearity. To the problem that the steady-state error is hard to be eliminated with a fuzzy controller, a fuzzy-PID controller is proposed in this paper.

In fuzzy logic controller, the parameters are controlled using rule based system. Fuzzy logic is the simplest which does not require a detailed mathematical model and so it can be applied for non linearity problem. The FLC has multiple rules and membership function that lead to high computational burden.

DC-DC Boost Converter Model

A boost converter is a DC-to-DC power converter with an output voltage greater than its input voltage. It is also called as step up converter. It is a class of Switched-Mode Power Supply(SMPS) containing at least two semiconductor switches a diode and a transistor and at least one energy storage element, a capacitor, inductor, or the two in combination. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.

This paper deals with the output voltage regulation problem of the DC-DC boost converter shown in Fig. 1. We consider a practical inductor with a parasitic resistance R_1. This model also includes a resistor R_s to represent unavoidable voltage drops and a current-sensing resistor.

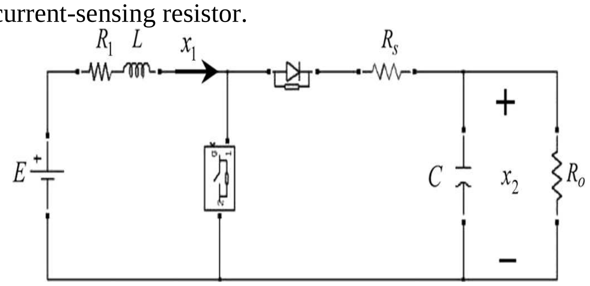

Fig.1. DC-DC boost converter having parasitic resistance.

By using an average switching method, the mathematical model of Fig.1 is described by,

$$\dot{x}_1 = -\frac{R_1}{L}x_1 - (1-d)\left(\left(\frac{R_s}{L}\right)x_1 + \frac{1}{L}x_2\right) + \frac{E}{L} \qquad (1)$$

$$\dot{x}_2 = (1-d)\frac{1}{c}x_1 - \frac{1}{R_0C}x_2 \qquad (2)$$

where,

x_1 - inductor current;
x_2 - output voltage;
E- DC source voltage;
d- Duty ratio ($0 \leq d \leq 1$);
L- Inductance;
C-Capacitance;
R_0-Load resistance

Power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is a DC to DC converter with an output voltage greater than the source voltage. A boost converter is sometimes called a step-up converter since it “steps up” the source voltage. Since power must be conserved, the output current is lower than the source current.

Passivity Based controller

Passivity is a fundamental property of many physical systems which may be roughly defined in terms of energy dissipation and transformation. It is an inherent Input-Output property in the sense that it quantifies and qualifies the energy balance of a system when stimulated by external inputs to generate some output. Passivity is therefore related to the property of stability in an input-output sense, that is, we say that the system is stable if bounded “input energy” supplied to the system, yields bounded output energy [7].

Passivity based control is a methodology which consists in controlling a system with the aim at making the closed loop system, passive. A passive system as a system which cannot store more energy than is supplied by some “source”, with the difference between stored energy and supplied energy, being the dissipated energy. Hence, it shall be clear that passivity is closely related to the stability of a system.

A fundamental property of passive systems is that, regarding a feedback interconnection of (other physical) passive systems, passivity is invariant under negative feedback interconnection.

Since DC to DC converters are absolutely non-linear systems, for better performance, adopting non linear control methods could be a good solution. The design process involves Energy shaping and damping injection. With energy shaping the potential energy function is modified in such way that a new point of equilibrium is obtained at a desired location [8].

The damping injection modifies the Rayleigh dissipation function so that the new point of equilibrium will be Globally Asymptotically Stable (GAS).The damping injection reinforces this property to output strict passivity.

PID controller

A PID controller attempts to correct the error between a measured process variable and a desired set point by calculating and then outputting a corrective action that can adjust the process accordingly. The PID controller calculation (algorithm) involves three separate parameters; the Proportional, the Integral and Derivative values. The Proportional value determines the reaction to

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the current error, the Integral determines the reaction based on the sum of recent errors and the Derivative determines the reaction to the rate at which the error has been changing. [9]

By "tuning" the three constants in the PID controller algorithm the PID can provide control action designed for specific process requirements. The proportional, integral, and derivative terms are summed to calculate the output of the PID controller mathematical description of PID controller is,

$$u(t) - K_p e(t) + K_i \int_0^t e(t)\, dt + K_d \frac{d}{dt} e(t) \quad (3)$$

Fuzzy PID Controller

Conventional PID controllers are the most common industrial controllers due to their simple structure and their robust performance. Because these PID controllers are linear controllers, they become less effective if the plant under control is nonlinear or comes with time–delay.

To overcome this problem, many researchers have suggested PID controllers using the fuzzy structure to increase the accuracy and convergence speed of the controllers, and to reduce their overshoot. Because fuzzy controllers can implement human experience in their structure, they have been applied to several plants for which mathematical models are difficult to derive but which human experts understand intuitively.

Fuzzy logic provides an effective means of dealing with the approximate and inexact nature of the real world. Fuzzy logic controller has proven effective for complex and non linear processes. It converts a linguistic control strategy into automatic control strategy. [10]

Fuzzy control system block diagram is shown in fig 2. FLC consists of three components namely fuzzification, inference (knowledge base and decision making) and defuzzification. In general a fuzzy set is used to express a fuzzy variable which is defined by a membership function. The values of membership function vary between 0 and 1. At the heart of the fuzzy rule base are the IF-THEN rules.

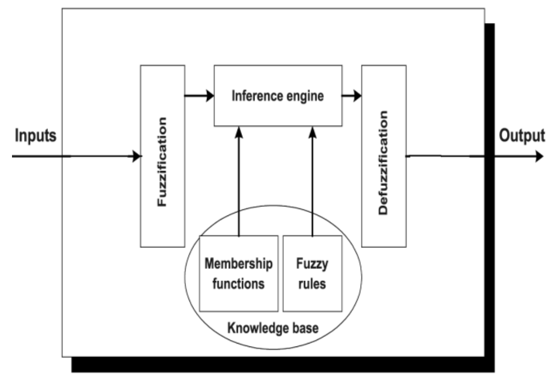

Fig: 2 Block diagram of Fuzzy Control system

Fuzzy Membership Functions

The fuzzy set is defined by a function that maps objects in a domain of concern to their membership value in the set. Such a function is called membership function and is usually denoted by Greek symbol „μ". Figure 3, shows the selection of number of inputs and outputs in the form of membership functions in order to design FIS. So, it resembles the selection of two inputs - error, error change, and one output - control signal.

Figure 4, shows the Fuzzy Membership function editor, where the number of membership functions, and type of membership function is chose, such as trapezoidal, triangular, and Gaussian according to the process parameter. The fuzzy logical operation is Fuzzification. Fuzzification involves the process of converting the input data into suitable linguistic values.

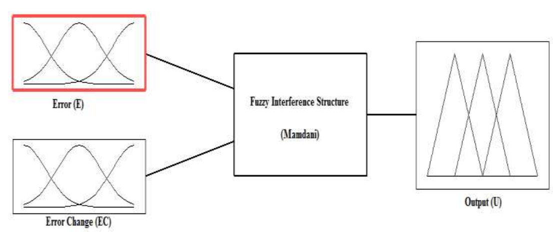

Fig: 3. Selection of number of inputs/outputs for designing Fuzzy Inference Structure (FIS) for Fuzzy Logic controller.

There are basically two Fuzzification methods namely, Mamdani and Sugeno, and generally used Defuzzification methods are Adaptive integration, Center of area, Center of gravity, Fuzzy clustering Defuzzification, First of maximum, Last of maximum, Mean of maxima, Semi-linear Defuzzification, Quality method, Middle of maximum. The maxima methods are good candidates for fuzzy reasoning systems. The distribution methods and the area methods exhibit the property of continuity that makes them suitable for fuzzy controllers.

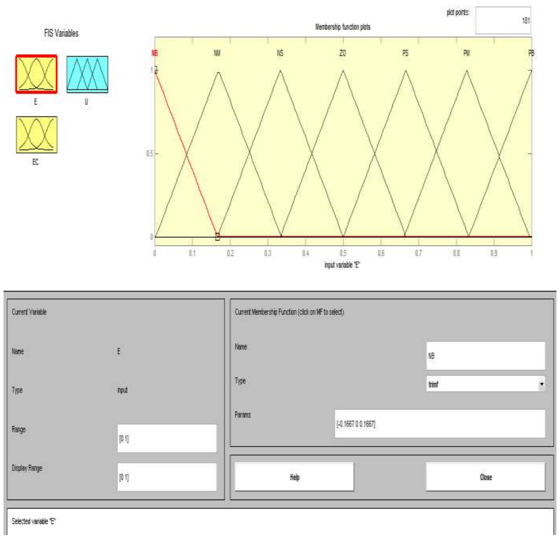

Fig: 4 Membership function editor for Fuzzy controller.

Fuzzy Inference Structure (FIS) Working

The algorithm of fuzzy rule-based inference consists of four basic steps given as follows.

- **(i) Fuzzy Matching:** Calculate the degree to which the input data match the condition of the fuzzy rules.
- **(ii) Inference:** Calculate the rule's conclusion based on its matching degree.
- **(iii) Combination:** Combine the conclusion inferred by all fuzzy rules into a final conclusion.
- **(iv) Defuzzification**: For applications that need a crisp output (e.g., in control systems), this step is used to convert a fuzzy conclusion into a crisp one.

Fuzzy Rules for Developing FIS

Human beings make decisions based on rules. Although, we may not be aware of it, all the decisions we make are all based on computer like if-then statements. Rule associate ideas and relate one event to another.

Proposed Scheme

The proposed block diagram is shown in fig.5. It consists of boost converter and fuzzy-PID controller. Difference between the measured voltage from the boost converter and reference voltage is taken as the error value. This error value is given to the fuzzy PID controller. The fuzzy-PID controller is composed of a PID controller and a fuzzy parameter self-tuning controller (FPTC).

When it works, the fuzzy parameter self-tuning controller change the values of three parameters dynamically according to the values of ***e*** and e_c, then the values of parameters are sent to the PID controller. Consequently, the parameter self-tuning is achieved and the values are fuzzified. After optimization the outputs are defuzzified and are given to the switch.

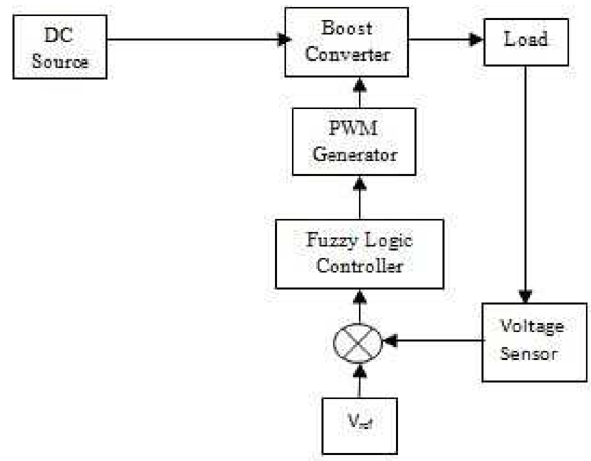

Fig: 5 Block diagram of proposed system.

Simulation Results

The proposed fuzzy PID controller with boost converter has been verified with simulated results are shown in fig: 6. Using Fuzzy Logic Controller technique increases the operating range with reduce the steady-state error. The performance of the boost converter is improved.

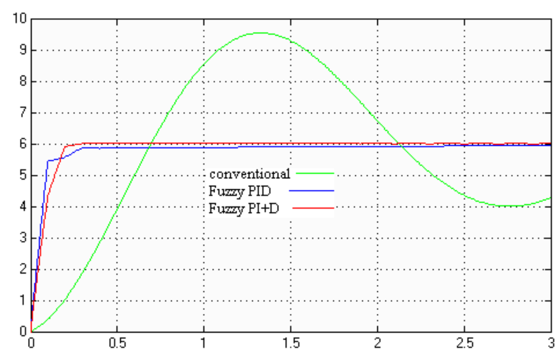

Fig.6. Output voltage of boost converter

Conclusion

In this paper, voltage regulation of boost converter has been proposed. The output feedback control problem of the DC-DC boost converter with an inductor parasitic resistance was studied. Because the simplified PD-PBC has successfully achieved the control objective for the converter with an ideal inductor, this paper has tested a modification of the previous controller to check whether it can be to maintain the performance with reduce the steady-state error. In order to reduce the steady state error owing to the parasitic resistance, this paper designs fuzzy logic controller and complementary PID controller to the PD-PBC. The proposed approach resulted in a dynamic output feedback controller using only the output voltage measurement. Through computer simulations, the proposed controller has been shown to have an improved performance and a robust stability.

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