A NOVEL SOFT COMPUTING BASED ALGORITHM FOR THE CONTROL OF DYNAMIC UNCERTAIN SYSTEMS- AN APPLICATION TO DC-DC CONVERTERS

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Abstract

Both Soft computing based controllers and sliding mode controllers have been utilized to regulate the output voltage of dc-dc converters in response to changes in the load and the input voltage. Although both control techniques possess desirable characteristics, they have disadvantages which prevent them from being applied extensively. Many researchers have proposed the combination of sliding mode control and Soft computing based control to combine the advantages of both control techniques. In literature survey, it is found that the combination of the methods are proposed so that sliding mode algorithm is used in the design of Soft computing based controllers and the inputs to the controller are error and change in error and the inherent stability property of sliding mode controller is not utilized. This paper presents a novel soft computing based sliding mode controller in which inputs are switching function and change in switching function which combines the advantages of soft computing based controllers, sliding mode controllers and integral controllers. Since soft computing is used in the design of sliding mode controller, the stability of the proposed controller is assured. In addition, it is well suited for digital control design and implementation. The proposed controller has been designed for a buck converter and the controller is able to obtain the desired transient response without causing chattering and error under steady-state conditions. The proposed controller is able to give robust performance in terms of rejection to input voltage variations and load variations.

Keywords

Soft Computing, Fuzzy Logic Control, Sliding Mode Control, dc-dc Converters.

1. INTRODUCTION

Soft Computing is a branch of computing which can deal with imprecision, uncertainty, partial truth and approximation. The guiding principle of soft computing is to exploit the tolerance for imprecision, uncertainty, partial truth, and the approximation to achieve the tractability, the robustness, the low cost solution and the better rapport with reality. Soft computing consists of fuzzy logic, neural networks, evolutionary computation (Genetic algorithm, Particle Swarm Optimization algorithm, Ant Colony Optimization algorithm etc), and chaos theory. The application of soft computing techniques is a good alternative for controlling non-linear dynamical systems with uncertainties in real-world problems.

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DC-DC converters are power electronic systems that convert one level of DC voltage into other level using switching action. The DC–DC conversion technology has been developing very rapidly, and they have been widely used in industrial applications such as dc motor drives, computer systems, adapters and communication equipments. In addition to a controllable and theoretically lossless DC voltage transformation, DC-DC converter circuits may also provide voltage isolation through the incorporation of a small high frequency transformer. One of the main problems in Power Electronics is the adequate selection of the control scheme for switch mode DC-DC converters, because these systems are nonlinear and show complex behavior patterns. Crucial to the performance of power converters is the choice of control methods. Traditional frequency-domain analog methods are predominantly used in compensator design. However, there are several drawbacks that hinder the performance of analog controllers, such as temperature drift of the components, necessity for making adjustment to many physical parts, and susceptibility to electromagnetic interference (EMI). In order to overcome these limitations, four classes of non-linear controllers are to be used are Robust, adaptive, Fuzzy (FLC) and neural controller. Intelligent (Fuzzy Logic and Neural Network) control techniques are important alternative to linear controllers in the field of power electronics. After pioneer study of DC–DC converters, a great deal of effort has been directed in developing the modeling and control techniques of various DC–DC converters. Classic linear approach relies on the state averaging techniques to obtain the state-space averaged equations. From the state-space averaged model, possible perturbations are introduced into the state variables around the operating point and small-signal state-space equations are therefore derived. On the basis of the equations, linear transfer functions of the open-loop plant can be obtained. A linear controller is easy to be designed with these necessary transfer functions based on the small-signal state-space equations. The procedure is well known. However, these methods cannot ensure stability under large variations of state condition changes. Sliding mode control is a powerful method that can produce a very robust closed-loop system under plant uncertainties and external disturbances [1], because the sliding mode can be designed entirely independent of these effects. However several disadvantages exist for sliding mode control. First of all, an assumption for sliding mode control is that the control can be switched from one value to another infinitely fast. In practice, it is impossible to change the control infinitely fast because of the time delay for control computations and physical limitations of switching devices. As a result, chattering always occurs in steady state and appears as an oscillation that may excite unmodeled high-frequency dynamics in the system. The second disadvantage is that the sliding mode controller will generate an ON-OFF control for the buck converter that yields a non-constant switching frequency [10]. Hysteresis can be used to control the switching frequency, but a constant switching frequency can not be guaranteed. However, there is always chattering in the sliding mode when hysteresis is employed. The third disadvantage of sliding mode control is that, in a discrete-time implementation, the control action (in this case, ON or OFF of the switch) can only be activated once during each sampling period resulting in a constant control effort over that period. As a result, the system is able to approach the sliding mode but not able to stay on it. Fuzzy control has also been applied to control DC-Converters [5]-[7], [8]-[12]. Fuzzy controllers are well suited to nonlinear time-variant systems and do not need an exact mathematical model for the system being controlled. They are usually designed based on expert knowledge of the converters, and extensive tuning is required based on a trial and error method. This tuning can be quite time consuming. In addition, the response of system with a fuzzy controller is not easy to predict.

In literature survey, it is found that the combination of the methods are proposed so that sliding mode algorithm is used in the design of Soft computing based controllers and the inputs to the controller are error and change in error and the inherent stability property of sliding mode controller is not utilized [4]-[12], [16], [17]. Presented in this paper is the application of fuzzy logic in the design of sliding mode controller to regulate the output voltage of a buck converter. The proposed controller combines the advantages of fuzzy logic, sliding mode and integral controllers and has its own unique advantages that facilitate its design and implementation. First of all, the proposed algorithm can be implemented like a regular fuzzy controller. The output from the proposed controller is the duty cycle directly; therefore, a constant switching frequency can be achieved. Secondly, because the proposed algorithm can be designed systematically based on the principles of sliding mode control, the amount of time needed for tuning is significantly reduced compared to a pure fuzzy controller. In addition, the system's response can be predicted. Oscillation in steady state is eliminated by incorporating a boundary layer into the rule base of the fuzzy controller. The parallel integrator eliminates steady state error as it increases the type of the system. The proposed algorithm presented in this paper can be implemented on a DSP. Computation power of DSPs allows digital implementation of more advanced control algorithms such as a sliding mode and fuzzy controller. An analog implementation of the controller would require a considerable amount of complex hardware.

2. DC-DC CONVERTERS

The dc-dc converters are widely used in regulated switch-mode power supplies and in dc motor drive application. The input to these converters is an unregulated dc voltage. Switch mode dc-dc converters are used to convert the unregulated dc input in to a controllable dc output at a desired voltage level.

3. FUZZY LOGIC CONTROLLERS

Though the fuzzy controllers are highly customizable and vary a great degree on various counts, it is often possible to describe certain basic components which inevitably find place in any fuzzy control scheme. The basic components of a generalized fuzzy logic controller for a buck converter are as shown in the Fig. 1.

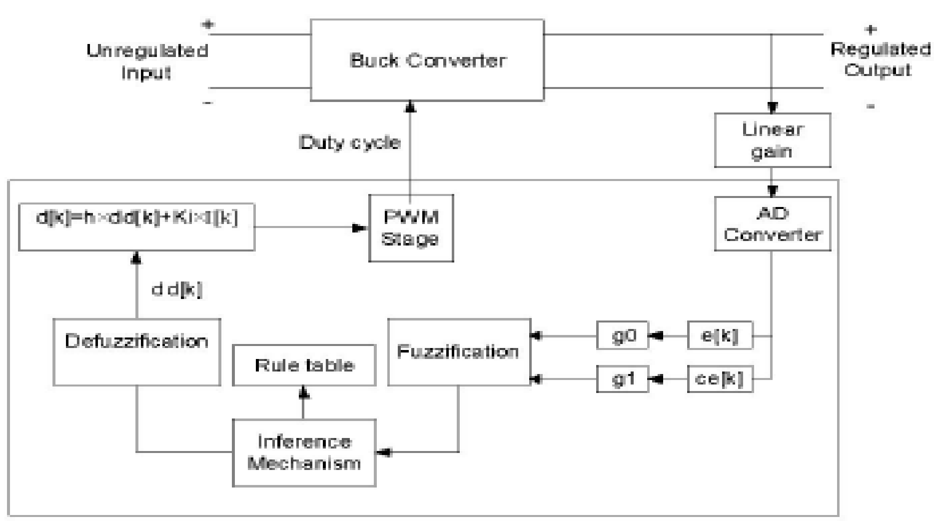

Fig 1. Basic Components of Fuzzy Inference System

4. A NOVEL FUZZY LOGIC BASED CONTROLLER FOR DC-DC CONVERTERS

One of the most important features of the sliding mode regime in the Variable Structure Systems is the ability to achieve response that is independent of the system parameters. From this point of view, the dc-dc converter is particularly suitable for the application of the SMC, because of its controllable state ‘‘the system is controllable if every state variable can be affected by an input signal’’. The output voltage and its derivative are both continuous and accessible for measurement. The main problem of this control method is that there is no direct way to measure the gain of linear part, which can be considered as a drawback. One possible way is to apply a step response and select a suitable gain to the specified application.

The proposed controller has a configuration as shown in Fig. 2. 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 [8]. The integrator in the output side eliminates steady-state error.

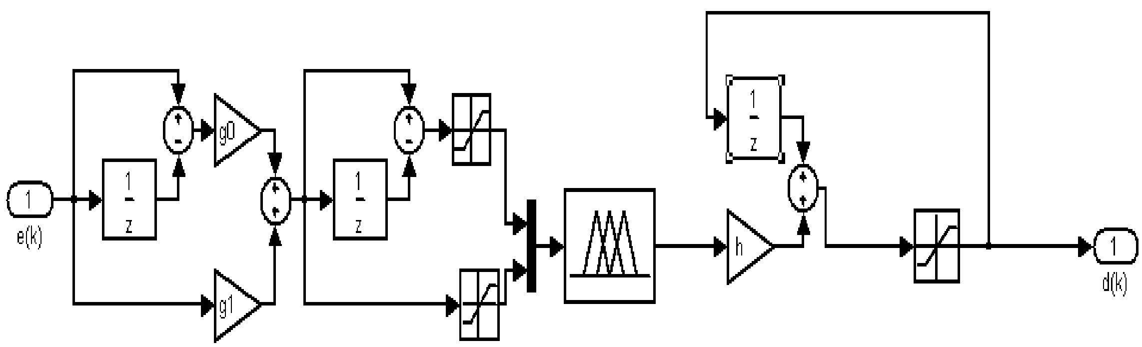

Fig 2. The Proposed controller

5. DESIGN PROCEDURE OF THE PROPOSED CONTROLLER

There are four steps involved in the design of a sliding mode fuzzy controller [9] (1) a switching function that represents the desired system dynamics is first designed; (2) from the switching function, inputs to the sliding mode fuzzy controller and their scaling factors can be determined; (3) a rule base is designed according to the switching function; and, (4) the other parts of the sliding mode fuzzy controller are designed, including the inference mechanism and the defuzzification method. The four steps will be followed to design a sliding mode fuzzy controller for a buck converter.

5.1. Switching function

A switching function is first designed to represent a desired interface system dynamics. It is often of lower order than the plant [10]. Since a buck converter's small signal model is second order, a first order switching function is designed, which is shown below.

$$S(x) = \dot{e} + \lambda e \qquad (\lambda > 0) \qquad \textbf{(1)}$$

In digital implementation

$$\dot{e} = \frac{e(k) - e(k-1)}{T} \qquad (2)$$

5.2. Inputs and their scaling factors

The proposed controller for the buck converter has two inputs. The first input is the switching function S[k] which is given by (1) and (2) and second is cSk] =e[k]-e[k-1]. The two scaling factors g0 and g1 are designed using sliding mode principle, and then fed into the fuzzy controller. Each universe of discourse is divided into fuzzy subsets using membership function.

5.3. Design of Input gains

The dynamics of S represent a stable first-order system with a pole at -λ. The time constant is 1/ λ seconds, and the settling time is 4/ λ seconds. λ is designed for the required settling time, go and g1 can be designed as follows
Assume go as 1
Then g1=1/(λT)
Where T is sampling period

5.4. Inference Mechanism

The results of the inference mechanism include the weighing factor w_i and the change in duty cycle c_i of the individual rule [4]. The weighing factor wi is obtained by Mamdani's min fuzzy implication of μS(S[k]) and μcS(cS[k]), where w_i = min{μS(S[k]), μcS(CS[k])} and μS(S[k]), μcS(cS[k]) are the membership degrees [10]. c_i is taken from the rule base. The change in duty cycle inferred by the ith rule z_i is

z_i = min{μS(S[k]), μcS(cS[k])c_i (3)

5.5. Defuzzification

The center of average method can be used to obtain the fuzzy controller's output, which is given below

$$\delta d[k] = \frac{\sum_{i=1}^{N} w_i \times c_i}{\sum_{i=1}^{N} w_i} \qquad (4)$$

6. DESIGN OF THE PROPOSED CONTROLLER FOR A DC-DC BUCK CONVERTER

The proposed controller for a dc-dc buck converter can be designed using the following steps

6.1. *Switching function*

The buck converter is a second order system; the switching function given in (1) can be selected.
Assume that required settling time is 1ms

λ=4/settling time
λ =4/6.67e-6
λ =4000

6.2. Inputs and their scaling factors

The input to the sliding mode fuzzy controller with parallel integrator are S(k) and cS(k). The scaling factor g0 is chosen as 1 so that scaling factor g1 can be obtained from the above equation of e(k) T=6.67e-6
g1=1/(4000*T) = 37.5

6.3. Fuzzification

Sliding mode fuzzy controller has to satisfy two properties
Property 1: Each rule gives the controller output when the inputs to the controller have full membership to the fuzzy sets in the antecedent of that rule. The controller output in this case is equal to the consequent of the rule. If the input-output relationship of the controller is visualized **as** a control surface, this means that each rule will define a specific point on the control surface.
Property **2:** If the consequent of each of the four active rules lie in a plane on the control surface, then all points calculated by the fuzzy controller using these rules will lie in that plane.
The necessary constraints on the fuzzy controller to realize these properties are as follows. The input membership functions are triangular except for the left most and right most membership function. Furthermore, the sum of the membership for all active fuzzy sets on each input is exactly one. The membership functions are arranged so that at most two have non-zero membership (are active) for any value of the input. The input and output memberships are selected as shown in Fig. 3, Fig. 4, Fig. 5.

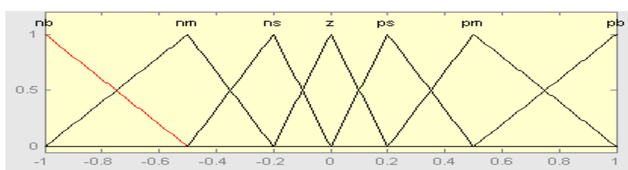

Fig 3. Membership functions of input S

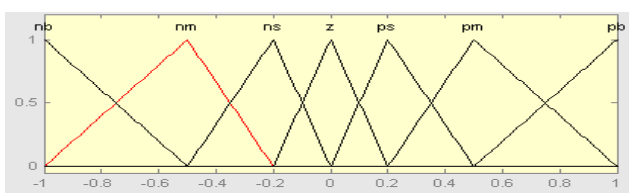

Fig 4. Membership functions of input cS

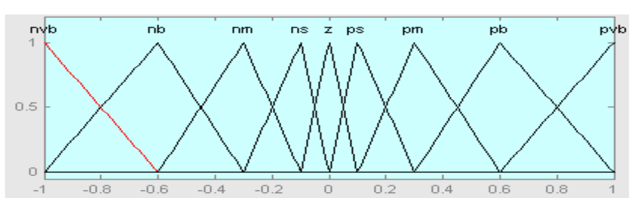

Fig 5. Membership functions of output Cd

6.4. Tuning of Output gain h

Using simulink based simulation, h is designed using trial and error and h=0.06135.

6.5. Rule Table

Rule table is designed based on Sliding mode principle and is given in Table1.

S/cS	NB	NM	NS	Z	PS	PM	PB
NB	NVB	NVB	NVB	NB	NM	NS	Z
NM	NVB	NVB	NB	NM	NS	Z	PS
NS	NVB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PVB
PM	NS	Z	PS	PM	PB	PVB	PVB
PB	Z	PS	PM	PB	PVB	PVB	PVB

Table 1. Rule Table

6.6. Inference Mechanism and De-Fuzzification

Mamdani's Inference given in equation (3) and centre of average defuzzification given in equation (4) can be used.

7. RESPONSE OF THE BUCK CONVERTER USING THE PROPOSED CONTROLLER

The response of Buck converter using the proposed controller is given in Fig 6.

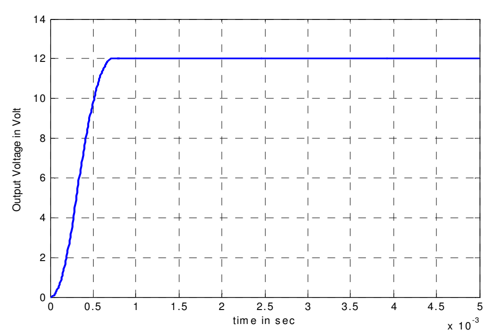

Fig 6. The response of Buck converter using the proposed controller

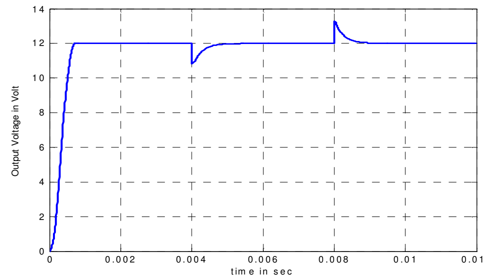

Fig 7. Response of Buck Converter using the proposed controller to input voltage variation from 20V to 18V to 20V

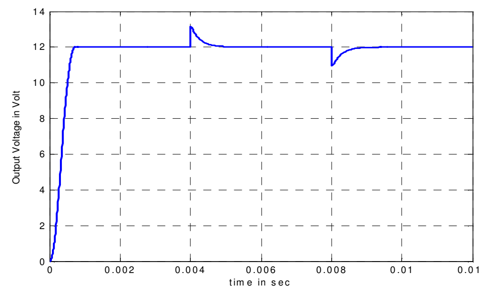

Fig 8. Response of Buck Converter using the proposed controller to input voltage variation from 20V to 22V to 20V

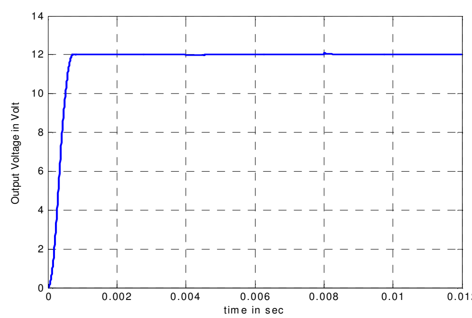

Fig 9. Response of Buck Converter using the proposed controller to load variation from 10Ω to 5Ω to 10Ω

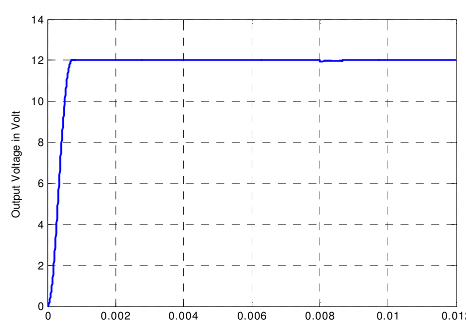

Fig.10 Response of Buck Converter using the proposed controller to load variation from 10Ω to 20Ω to 10Ω

8. CONCLUSION

A Soft Computing based controller using sliding mode algorithm with a parallel Integrator combines the advantages of soft computing based controllers, sliding mode controllers and integral controllers. The proposed algorithm can be implemented like a regular fuzzy controller. Since the algorithm can be designed systematically based on the principles of sliding mode control, the amount of time needed for tuning is significantly reduced compared to a pure fuzzy controller. In addition, the system's response can be predicted and is inherently stable. Oscillation in steady state is eliminated by incorporating a boundary layer into the rule base of the fuzzy controller. The parallel integrator eliminates steady state error as it increases the type of the system. The proposed algorithm presented in this paper can be implemented on a DSP. Computation power of DSPs allows digital implementation of more advanced control algorithms such as a sliding mode and fuzzy controller. An analog implementation of the proposed controller would require a considerable amount of complex hardware. The Soft computing based controller using sliding mode algorithm has been designed for a buck converter. The simulation results show that the proposed controller is able to obtain the desired transient response without causing chattering and error under steady-state conditions. The proposed controller is able to give robust performance in terms of rejection to input voltage variations and load variations.

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