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Design & Control of DC-DC Converter using Hybrid Fuzzy PI Controller

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Abstract

In order to prevent the overshoot and the variation in the output voltage of the buck converter, hybrid fuzzy controller plus PI are used in this paper. This design is then compared with hybrid fuzzy controller without using PI. The model of the power system is developed using SimPowerSystem toolbox and the control part is realized using Fuzzy Logic Toolbox in MATLAB.

Keywords: *Hybrid Fuzzy Logic Controller, Buck Converter, PI controller*

1. Introduction

Fuzzy logic is a form of knowledge representation suitable for notions that cannot be defined precisely but which depend upon their context based on a system of non-digital (continuous & fuzzy without crisp boundaries) set theory and rules. This was developed by Lotfi Zadeh in 1965.Its advantage is its ability to deal with vague systems and its use of linguistic variables. An accurate quantitative model is not required to control a plant or determine appropriate action. Leads to faster and simpler program development of system controllers. It can be a decision support system tool for managers

Fuzzy logic, which is the logic on which fuzzy control is based, is much closer in spirit to human thinking and natural language than the traditional logical systems. Basically, it provides an effective means of capturing the approximate, in exact nature of the real world. Viewed in this perspective, the essential part of the fuzzy logic controller (FLC) [1] is a set of linguistic control rules related by the dual concepts of fuzzy implication and the compositional rule of inference. In essence, then, the FLC provides an algorithm which can convert the linguistic control strategy based on expert knowledge into an automatic control strategy. Experience shows that the FLC yields results superior to those obtained by conventional control algorithms. In particular, the methodology of the FLC appears very useful when the processes are too complex for analysis by conventional quantitative techniques or when the available sources of information are interpreted qualitatively, inexactly, or uncertainly.

In this paper a fuzzy logic based hybrid approach is proposed for PI controllers. Classical control seeks to achieve a balanced tradeoff between multiple performance objectives using a single feedback function, whereas hybrid control seeks to achieve multiple performance objectives in a locally adaptive sense by switching between members of a priori specified family of feedback functions. Hybrid controllers can be used to obtain improved closed-loop performance, beyond what can be achieved by using either classical linear or smooth nonlinear controllers. A hybrid controller can exibit, to some extent, multiple performance properties associated with the closed-loop properties provided by each individual feedback function. In this the hybrid fuzzy logic controller can be used to avoid the variation in the output voltage.

In section 2 design of buck converter is presented. In section 3 the main purpose of the study is presented and in the last section simulation results of fuzzy logic, hybrid fuzzy logic is compared.

2. Modeling a Buck Converter

Fig 1 shows Buck-Boost converter [2] with a controller. The buck converter converts the unregulated source voltage Vin into a lower output voltage Vout. The NPN transistor shown in Figure 1 works as a switch. In order to control the output voltage of buck converter the change of duty cycle should be considered. So, the actual output voltage V_{out} is compared with the reference voltage V_{ref} to obtain error signal to determine the switching signal duty cycle. The switching signal is applied on the MOSFET used to reduce and enlarge output voltage on the circuit.[4]

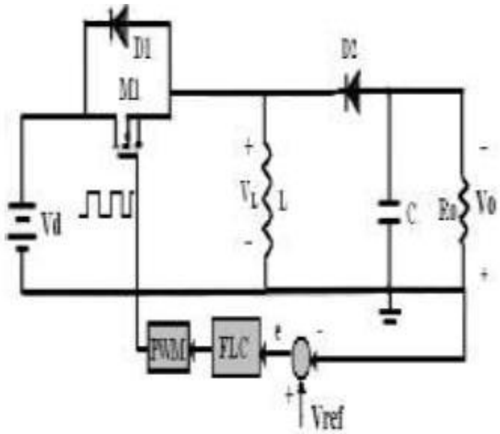

Fig 1 design of buck-boost converter using FLC

2.1Design of conventional PI controller

The proportional plus integral controller produces an output signal consisting of two terms one proportional to error signal and the other proportional to the integral of error signal.

In PI controller,

$$u(t) \propto [e(t) + \int e(t)dt] \quad (1)$$

$$u(t) = Kpe(t) + \frac{Kp}{Ti}\int e(t)dt \quad (2)$$

Where K_p is the proportional gain and T_i is the integral gain.

On taking laplace transform of equation (2) with zero initial conditions.

Equation (4) gives the output of the PI controller for the input E(s) and equation (3) is the transfer function of the PI controller.

$$\frac{U(s)}{E(s)} = Kp\left[1 + \frac{1}{Ti\,s}\right] \quad (3)$$

Where $1/T_i = K_i$
K_i is the integral gain

2.2 Design of Fuzzy Logic Controller

$$U(s) = KpE(s) + \frac{Kp}{Ti}\frac{E(s)}{s} \quad (4)$$

2.3 Method for Computing Duty Cycle

Fig 2 shows block diagram of FLC for buck converter. Fuzzy Logic Controller (FLC) is constitutes a way of converting linguistic control strategy into an automatic by generating a rule base which controls the behaviour of the system. Fuzzy control is control method based on fuzzy logic. Fuzzy provides a remarkably simple way to draw definite conclusions from vague ambiguous or imprecise information.FLC has 4 major components.1) Fuzzification interface that converts crisp value to fuzzy value. The output from the process will always be crisp: 2) the rule base It is a collection of rules referring to a particular system; 3) the inference mechanism compares the output from the fuzzification module and that from fuzzy rule base generating an inference output based on the type of condition selected; and 4) the defuzzification interface converts the obtained fuzzy value from the inference engine to crisp value.

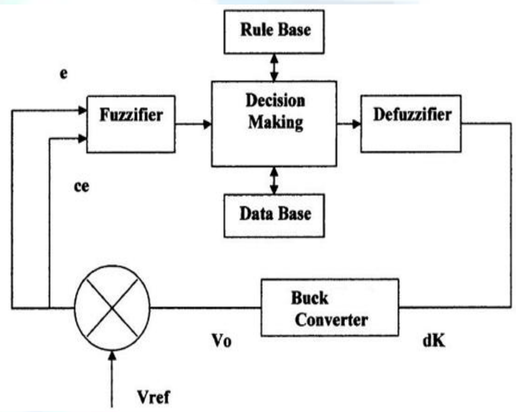

Fig 2 Block Diagram of FLC for Buck converter

The 2 inputs to the fuzzy controller are

1) the voltage error (e) (reference voltage subtracted from actual voltage)

2) the change in voltage error (ce) (previous error subtracted from current error) over one sample period)

$$e(k)=V_{ref} - V_0 \quad (5)$$

$$ce(k)=e(k)-e(k-1) \quad (6)$$

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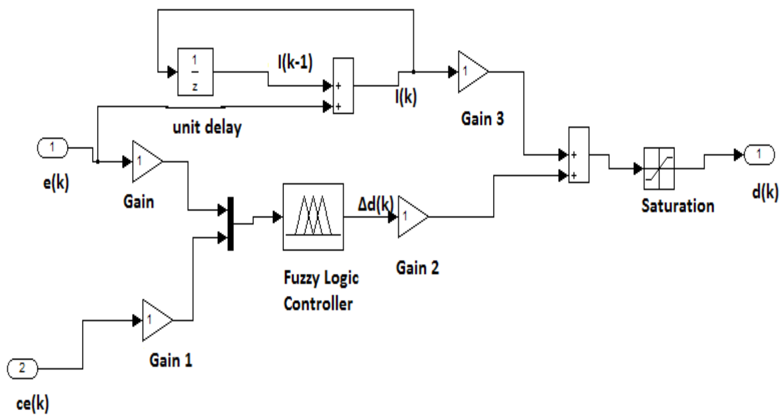

Fig 3 Duty Cycle Generartion

Fig 3 shows a method for duty cycle generation. The fuzzy controller's output is scaled by a factor h and then added to the output of parallel integrator

Where,

$$d(k) = K_i I(k) + h\Delta d(k) \quad (7)$$

Here, I[k] is the output of the discrete time integration of the error e[k], and K_i is the gain of the integrator. The integrator is used to eliminate steady-state error. The change of duty cycle is not accumulated every sampling period, so the output gain h can be increased to reduce transient response time. This is a combination of linear and nonlinear controllers. This method is applied to the buck converter to obtain satisfactory response. This structure is applied during startup transient to obtain fast transient response.

d(k) is sent to the PWM generator. PWM generator generates the necessary switching signal for the gate of the MOSFET in the converter. For ease of computation, the fuzzy variables e and ce are described by fuzzy singletons, meaning that the measured values of these variables are used in the inference process without being fuzzified. Fuzzy rules are in the "If Then" format and formally the If side is called the conditions and the Then side is called the conclusion. Specifically the fuzzy rules are in the form

R_i: If e is A_i and Δe is B_i, then Δu is C_i

where A; and B; are fuzzy subsets in their universes of discourse, and C; is a fuzzy singleton. Each universe of discourse is divided into five fuzzy subsets: PB (Positive Big), PS (Positive Small), ZE (Zero), NS (Negative Small), and NB (Negative Big).

The partition of fuzzy subsets and the structure of membership function is shown in figure 1.4 and 1.5.

For simpler design, universe ranges for inputs and outputs are normalized in [-1, 1].

The derivation of the fuzzy control rules are based on the following criteria:
1) When the output of the converter is far from the set point, the change of duty cycle must be large so as to bring the output to the set point quickly.

2) When the output of the converter is approaching the set point, a small change of duty cycle is necessary.

3) When the output of the converter is near the set point and is approaching it rapidly, the duty cycle must be kept constant so as to prevent overshoot.

4) When the set point is reached and the output is still changing, the duty cycle must be changed a little bit to prevent the output from moving away.

5) When the set point is reached and the output is steady, the duty cycle remains unchanged.

6) When the output is above the set point, the sign of the change of duty cycle must be negative, and vice versa.

In these 5 membership function are used so there are 25 rules according to these benchmarks. They are shown in table 1. A maximum of four rules are obtained for each combination of e and Δe.

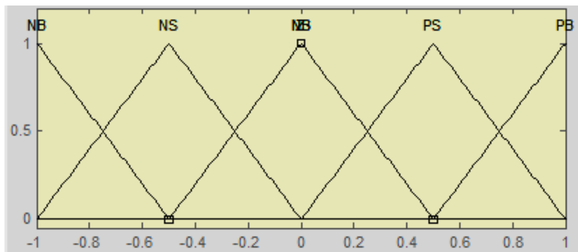

Fig 4 Inputs membership functions of fuzzy PI controller (error and the change of error)

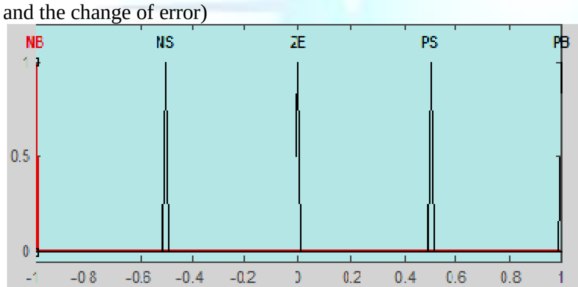

Fig.5 Output membership functions of fuzzy PI controller

The change of error (ce) / Error (e)

	NB	NS	Z	PS	PB
NB	NB	NB	NB	NS	Z
NS	NB	NB	NS	Z	PS
Z	NB	NS	Z	PS	PB
PS	NS	Z	PS	PB	PB
PB	Z	PS	PB	PB	PB

Table 1 Fuzzy control rules

Finally the resultant united fuzzy subset representing the controller output is converted into crisp values. The inference result of each rule consists of two parts, the compatibility (weighting factor), wi of the individual rule, and the degree of change of duty cycle, Ci according to the rule.

$$Z_i = \min\{\mu_{Ai}(e), \mu_{Bi}(\Delta e)\}.C_i = W_i\, C_i \qquad (8)$$

The center of gravity (centroid) method is preferred in this study. According to this method,

$$coa = \frac{\sum_{i=1}^{4} w_i C_i}{\sum_{i=1}^{4} w_i} \qquad (9)$$

3.Hybrid Fuzzy Logic Controller

Fuzzy Logic control technique is generally opted when intelligence and fast dynamic response are among the prime requirements. The major disadvantage in this type of control logic is the presence of steady state speed error on load. To eliminate this disadvantage it is necessary to combine Fuzzy Logic control with another suitable control technique, which is capable of removing the disadvantage existing in Fuzzy Logic control. Therefore, a PI controller is used in combination with Fuzzy Logic such that at operating point the PI controller takes over eliminating the disadvantage of Fuzzy Logic controller. Similarly, when away from the operating point Fuzzy Logic controller dominates and eliminates the error due to PI controller such as occurrence of overshoot and undershoots in drive response. Such a speed controller where weighted combination of two controller outputs contributes to the net output is called hybrid controller. Fig 6 shows the general schematic block diagram of a Hybrid Fuzzy Speed Controller.

It comprises of a simple PI controller connected in series with a fuzzy logic controller. Due to simple structure and ease of application, the PI controller is generally used in implementation. To make the same control robust in nature so that it becomes independent of parameter variations as well as the problems of undershoot and overshoot occurrence.

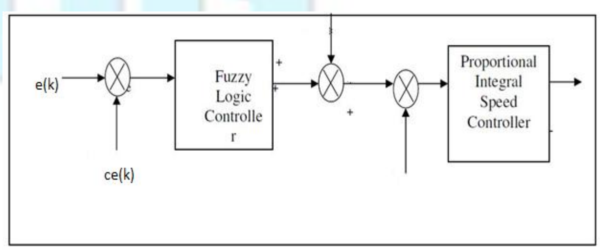

Fig 6 Block Diagram Of Hybrid Fuzzy Logic Controller

The processing occurs as the error and change in error is given as the input to the FLC.The output of the FLC is algebrically added with a reference signal so as to generate a modified reference signal. This modified speed signal is used by the remaining PI control strategy. Such a phenomenon eliminates the possible disadvantages in the normal PI controller and introduces robustness to the control system. Hybrid controllers provide a generalization of classical feedback controllers for linear and nonlinear systems.

3.1 Design of 2 Level Hybrid Fuzzy Logic Controller

Fig 7 shows the structure of hybrid fuzzy logic controller [6].Ther are 2 levels inthis structure.First level consists of 2 controllers which can be either PI controller or PD controller. PD controller for fastest response and PI controller for the elimination of the steady-state error. In the second level switching logic is present. At first, switching logic switches to the fuzzy PD (FPD) so as to increase the settling time, then controller switch to the fuzzy PI (FPI) in order to minimize steady state error. The PI portion activates only when the PD portion reduces the error and change in error to where both are in the zero fuzzy subset range. Therefore, at any instant, calculation of the control action involves only four control rules. The output of this controller is one of the inputs of switching logic. The inputs of FPD controller are error and the change of error which are given by (5), (6). [3]Inputs membership functions are as figure 4 and output membership functions are as figure 5. FPI controller part is fuzzifier, rule base, defuzzifier, interface engine. The input to the switching logic is output of PD controller, output of the PI controller, error and change in error. The switching logic switches to PI when the output is shown by Pi and when switch to PD, the output is shown by Pd. Fuzzy rules are derived according to these criteria: Fuzzy rules are in form: Ri: If e is Ai and Δe is Bi, then $zi = fi(x, y)$ When zi is the fuzzy output. The partition of inputs fuzzy subsets (PI and PD) are shown in figure 1.8. The partition of error and the change of error fuzzy subsets are shown in figure.4.

The logic switches to the PI portion when both change of error and error are in the zero range. The PD portion must not be re-enabled until the error variable moves out of the zero range, regardless of the change in error variable. The PI portion in the process of reaching steady-state obviously creates a change in error that might be out of the PD's zero range and thus reactivate the PD portion.

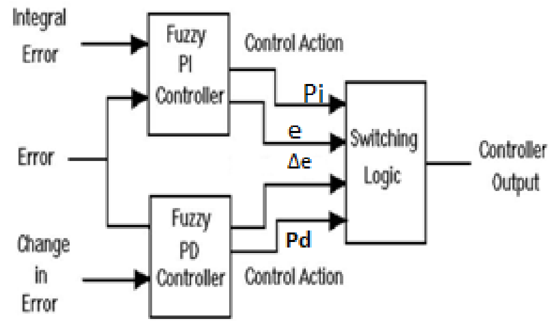

Fig 7 Design Of 2 level Hybrid Fuzzy Logic Controller

According to this 4 rules are derived

1- If e is ZE & Δe is ZE then U is P_i
2- If e is not ZE & Δe is ZE then U is P_d
3- If e is ZE & Δe is not ZE then U is P_d
4- If e is not ZE & Δe is not ZE then U is P_d

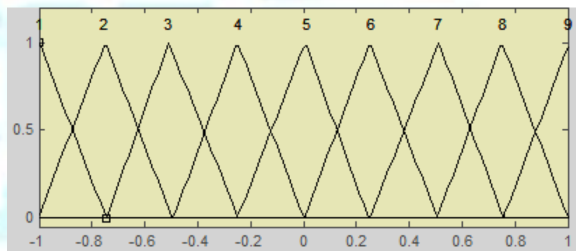

Fig 8 Input membership functions of switching logic controller(PI and PD)

4. Simulation results

This model is developed in Simulink / Matlab. The simulation results of fuzzy logic controller and hybrid fuzzy logic controller is compared. Table 2 shows the simulation parameters.

DC Input voltage	12V
Reference output voltage	5V
Switching frequency	1khz
Filter capacitance	10mH
Filter inductance	30mF
Output resistance	5Ohm

Table 2 : Simulation parameters

There is only a little variation in the output voltage while using a hybrid fuzzy PI controller as shown in fig 9.

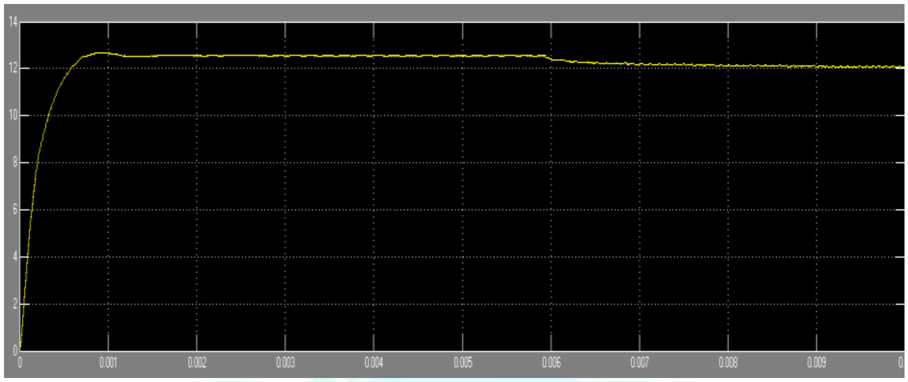

Fig 9 simulation result while using hybrid fuzzy logic controller

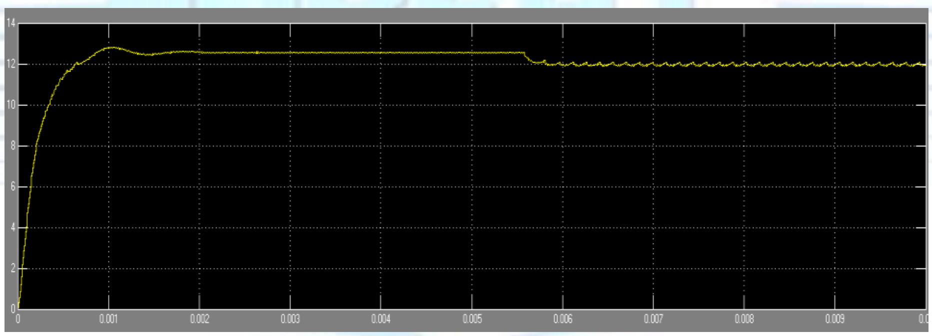

Fig 10 Simulation Result With Fuzzy Logic Controller

This is compared with a fuzzy logic controller which has got high variation in the output voltage compared to that of hybrid fuzzy logic controller as shown in fig 10

5. CONCLUSION

In this paper a hybrid fuzzy PI controller is presented and is compared with fuzzy logic controller. This is implemented in Matlab/Simulink. The simulation results are obtained

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