International Journal of Advanced Information Science and Technology (IJAIST) ISSN: 2319:2682
Vol.3, No.7, July 2014 DOI:10.15693/ijaist/2014.v3i7.68-73

Design of Fuzzy Logic Controller for Buck Converter to Improve Power Quality

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***Abstract*--In this paper,the design of a fuzzy logic controller for Buck converters is discussed.The design of fuzzy controllers does not require an exact mathematical model. Instead they are designed based on general knowledge of the plant. Fuzzy logic controller (FLC) is cheaper to develop, they cover a wider range of operating conditions. An explanation about fuzzy logic controller and its application to control algorithm is given. The algorithm of a fuzzy controller is designed to regulate Buck converter. Performance of the proposed buck converter is evaluated under varying loads and power quality indices such as THD (Total Harmonic Distortion), PF (Power Factor) are evaluated.**

***Keywords*—Fuzzy logic controller, Buck converter, THD, power quality**

I. INTRODUCTION

The way that people think is inherently fuzzy. The way that we perceive the world is continually changing and cannot always be defined in true or false statements. A fuzzy set allows for its members to have degrees of membership. If the value of 1 is assigned to objects entirely within the set and a 0 is assigned to objects outside of the set, then any object partially in the set will have a value between 0 and 1. The number assigned to the object is called its degree of membership in the set. Basically, it provides an effective means of capturing the approximate, inexact nature of the real world [2]. The essential part of the FLC is a set of linguistic control rules related by the dual concept of fuzzy implication and the compositional rule of inference. 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. The FLC appears very useful when the processes are too complex for analysis by conventional quantitative techniques [3].In [1-13] various methods are discussed and used.

Conventional control techniques used for dc-dc converters are PID controllers which tend to provide linear characteristics[1]. But dc-dc converters exhibit nonlinear characteristics. The causes of nonlinearity in the power converters include a variable structure within a single switching period, saturating inductances, voltage clamping, etc. So whenever there isany change in system, any parameter variations or even load disturbances PID controllers tend to be less [1-6]. To control non linear systems satisfactorily non linear controllers are often developed. It is always desirable for buck converters with constant output voltage that the output voltage remains unchanged in both steady and transient operations whenever

the supply voltage and/or load current is disturbed. The most commonly used method in converters is the direct duty ratio control. This method is too complex to be practically executed. Using human linguistic terms and common sense, several fuzzy logic based controllers have been developed.

In this paper we present a case of using fuzzy logic for the derivation of a practical control scheme for regulating Buck converters. We begin with a brief review of the concept of fuzzy logic and fuzzy sets. Then, we describe in detail the derivation of a fuzzy control scheme. Computer simulations are used initially to verify the feasibility of the proposed fuzzy control. synthesis of a new control system using a fuzzy inference is proposed. The operation of the proposed system is verified by MATLAB/SIMULINK simulation.

II. BASICS OF FUZZY LOGIC CONTROLLER

The basic fuzzy logic control system is composed of a set ofinput membership functions, a rule-based controller, and adefuzzification process. The fuzzy logic input uses memberfunctions to determine the fuzzy value of the input. There canbe any number of inputs to a fuzzy system and each one ofthese inputs can have several membership functions. The setof membership functions for each input can be manipulated toadd weight to different inputs. The output also has a set ofmembership functions. These membership functions definethe possible responses and outputs of the system [4].

The fuzzy inference engine is the heart of the fuzzy logiccontrol system. It is a rule based controller that uses If-Thenstatements to relate the input to the desired output [4]. Thefuzzy inputs arecombined based on these rules and the degreeof membership in each function set. The output membershipfunctions are then manipulated based on the controller for eachrule. Several different rules will usually beused since theinputs will usually be in more than one membership function.All of the output member functions are then combined into oneaggregate topology.

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For a system whose output is fuzzy, it is easier to take a crisp decision if output is represented as as a single scalar quantity. This conversion of a fuzzy set to single crisp value is called defuzzification and is reverse process of fuzzification. The defuzzification process then choosesthe desired finite output from this aggregate fuzzy set. Thereare several ways to do this such as weighted averages,centroids, or bisectors. This produces the desired result for theoutput.

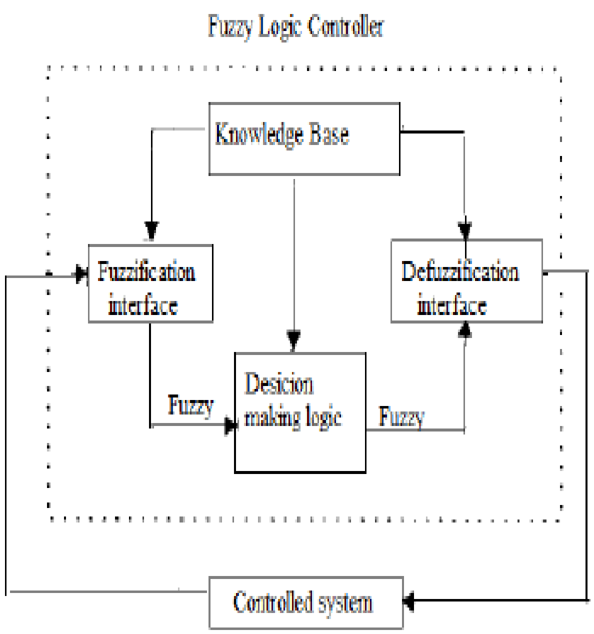

Fig. 1. Basic of Fuzzy logic controller

III. SYSTEM CONFIGURATION

The overall system configuration of the buck converter with a full bridge dc-dc converter system is shown in Fig. 2. The ac supply is given to a diode bridgerectifier to obtain an unregulated dc output. This is processedby two series connected buck converters which is further linkedto a full bridge buck converter. Each of the buck converter ishaving one inductor, one switch and a capacitor. Filter capacitor C3 and inductor L3 are connected at the output of the buck converter. A zig zagtransformer is connected at the utility interface for ripple injection. The output of buck converter issensed and compared with a reference voltage and the error is used in Fuzzy logic controller.Fuzzy logic controller is used to generate the switching pattern for the switches ofthe buck converter. The frequency of the buck converter can beeasily controlled through the constant of integrator. Switches Sw3, Sw4, Sw5 and Sw6 of the full bridge dc-dcconverter are connected at the primary side of the HFT(High Frequency Transformer). This HFT is used for steppingdown the voltage and also for providing isolation. The HFT hasNp turns in the primary and Ns_1 and Ns_2 turns in the secondarywindings. Secondary windings of the HFT are connected incenter-tapped fashion to reduce the conduction losses in thediodes. High frequency Diodes D9 and D10 are connected at thesecondary winding of HFT, and a capacitor Co is alsoconnected at the output side which works as a filter. The outputof the full bridge converter is sensed and compared with thereference voltage to regulate the output voltage and generatethe PWM pulses for the switches of the full bridge converter asshown in Fig.3

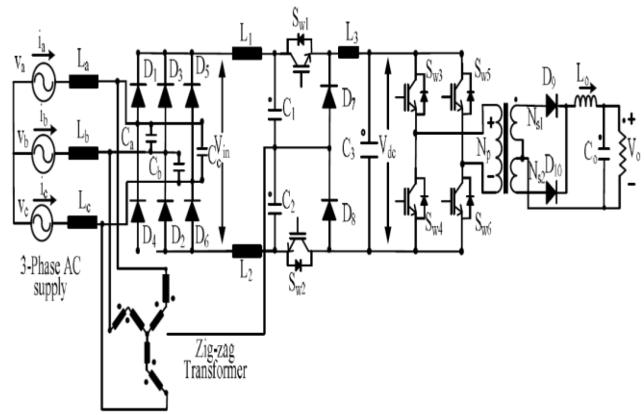

Fig. 2.System configuration

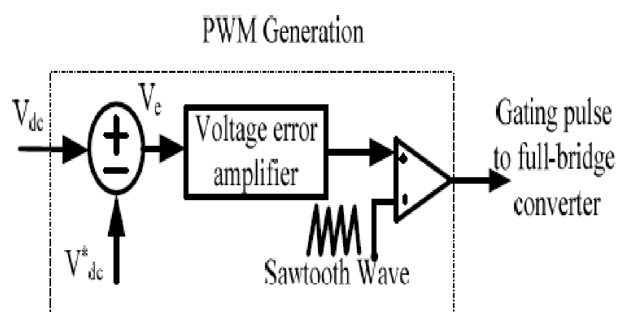

Fig. 3.Control of full bridge buck dc-dc converter to generate switching signal

IV. DESIGN AND ANALYSIS

A. Design of fuzzy logic controller

The fuzzy controller is divided into five modules: fuzzifier, data base, rule base, decision maker, and de-fuzzifier. The inputs of the fuzzy controller are the error e and the change of error c_e, which are defined as

$$e = V0 - Vref \quad (1)$$

$$c_e = ek - ek{-}1 \quad (2)$$

where V_0 is the present output voltage, is the reference output voltage, and subscript k denotes values taken at the beginning of the k^{th} switching cycle. The output of the fuzzy controller is the duty cycle and is defined as

$$dk=dk-1+n.\ \delta dk \qquad (3)$$

where δ d_k is the inferred change of duty cycle by the fuzzy controller at the k^{th} sampling time, and n is the gainfactor of the fuzzy controller. Adjusting n can change the effective gain of the controller. For ease of computation, the fuzzy variables e and c_e are described by fuzzy singletons, meaning that the measured values of these variables are used in the inference process without being fuzzified. Specifically the fuzzy rules are in the formR;: IF e is A; and c_e is B;, THEN d_k 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 shape of the membership function are shown in above figure. The values of e and c_e are normalized. The triangular shape of the membership function of this arrangement presumes that for any particular input there is only one dominant fuzzy subset. also for any combination of e and c_e, a maximum of four rules are adopted. The computation time can thus be further reduced. For instance, if e is 0.1 and c_e is -0.7, only (ZE, NS), (ZE, NB), (PS, NS), and (PS, NB) are ineffect. The inferred grades of membership of the rest of the rules are zero.
Fig membership function

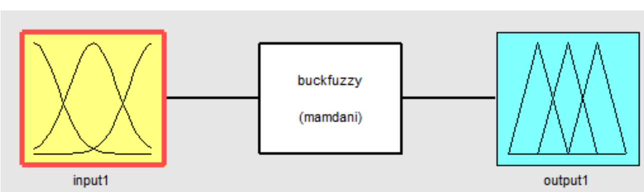

Fig. 4. Membership function of FLC

Table 1
Rule Table of fuzzy logic controller

	NB	NS	ZE	PS	PB
PB	-0.30	-0.35	-0.45	-0.65	-1.00
PS	0.00	-0.10	-0.20	-0.35	-0.50
ZE	0.20	0.10	0.00	-0.10	-0.20
NS	0.50	0.35	0.20	0.10	0.00
NB	1.00	0.65	0.45	0.35	0.30

The derivation of the fuzzy control rules is heuristic in nature and 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 pointand 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 i s 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 thechange of duty cycle must be negative, and vice versa.
According to these criteria, a rule table is derived and shown in Table. The entries of the table are the normalized singleton values of the change of duty cycle. If the magnitude of the inferred change of duty cycle is 1, the duty cycle will be changed in full strength, which is limited by n.

B. Design of Buck converter

Figure axis labels are often a source of confusion. Try to use A buck converter has output dc voltage less than its input dc voltage. For the analysis of the buck converter, it is considered that all switches are ideal and the output filter capacitor C_o is infinite to keep the output voltage constant with the current through the inductor L_1 being linear and continuous in each switching period. When the switch is on, the inductor L_1 charges and the increase of i_{L1} is therefore:

$$(\Delta i_{L1})_{ON} = (V_{in} - V_{dc})DT/L_1 \qquad (4)$$

Where V_{in} is the input voltage to buck converter, V_{dc} is the output voltage of the buck converter, D is the duty cycle of the buck converter and T is the switching period of the of the buck converter.
When the switch S_w is turned OFF, the inductor current flows through the load. The change in inductor current is as,

$$(\Delta i_{L1})_{OFF} = -V_{dc}(1-D)T/L_1 \qquad (5)$$

The integral of voltage across the inductors over one PWM period is zero. Therefore it is expressed as,

$$(V_{in}-V_{dc})\ DT/\ L_1-V_{dc}(1-D)T/L_1=0 \qquad (6)$$

Simplifying eqn. (6) results in

$$V_{dc}/V_{in}=D \qquad (7)$$

From eqn. (7), it is clear that the ratio of output voltage to the input voltage depends upon the duty cycle D.
The inductor value L_1 is calculated from eqn. (4) as,

$$L_1=DT(V_{in}-V_{dc})/(\Delta i_{L1})_{ON} \qquad (8)$$

Similarly the inductor L_2 value is calculated as,

$$L_2=DT(V_{in}-V_{dc})/(\Delta i_{L2})_{ON} \qquad (9)$$

C. Design of Full Bridge Buck DC-DCconverter

In one PWM cycle, first S_{W3} and S_{W6} are on, then all switches are off, followed by S_{W4} and S_{W5} are turned on and then all switches are off. When the switches (S_{W3} and S_{w6}) are on, the change in inductor current is,

$$(\Delta i_{Lo})_{on} = (nV_{dc}-V_o)D_bT_s/L_o \qquad (10)$$

where, V_{dc} is the output voltage of buck converter, and V_o is the output dc voltage, D_b is the duty cycle, n is the turns ratio and T_s is the switching period of the of the full bridge buck dcdc converter.
The change in inductor current

$$(\Delta i_{Lo})_{off} = -(0.5-D_b)T_sV_o/L_o \qquad (11)$$

The total change in the inductor current is zero over a half period under steady state condition. So,

$$(nV_{dc}-V_o)D_bT_s/L_o+\{-(0.5-D_b)T_sV_o\}/L_o=0 \quad (12)$$

So the output voltage is as,

$$V_o = 2nV_{dc}D_b \quad (13)$$

The output voltage of the full bridge buck dc-dc converter depends upon the duty cycle D_b, input voltage V_{dc}, turns ratio n and a multiplication factor 2.

The inductor value (L_o) can be calculated for a given value of its ripple current from eqn. (11) as,

$$L_o = V_o(0.5-D)T/(\Delta i_{Lo}) \quad (14)$$

V. Results

The performance of Buck converter with fuzzy logic controller is presented in this section. A 270 V output of the buckconverter is given to a full bridge dc-dc converter to generate60V/90A. Fig. 6 and 8 shows the input supply currentwaveform along with its harmonic spectrum under full-loadcondition. The currentTHD is 5.99% which is well within the limit and a proof of the elimination of harmonics in theinput supply current. The PF at full load is 0.998 which isclosed to unity. Fig. 6 shows the supply voltage Vabc, supplycurrent Iin, the output voltage of the buck converter Vdc, thecapacitor voltages of buck converter, output voltage andcurrent of full bridge buck converter. THD of supply current is always less than 10%.Moreover, there is an improvement in the dc link voltageregulation.

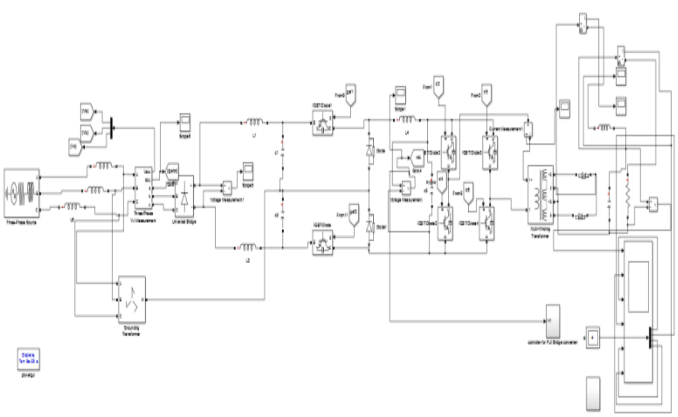

Fig. 5.Simulink of Buck converter with FLC

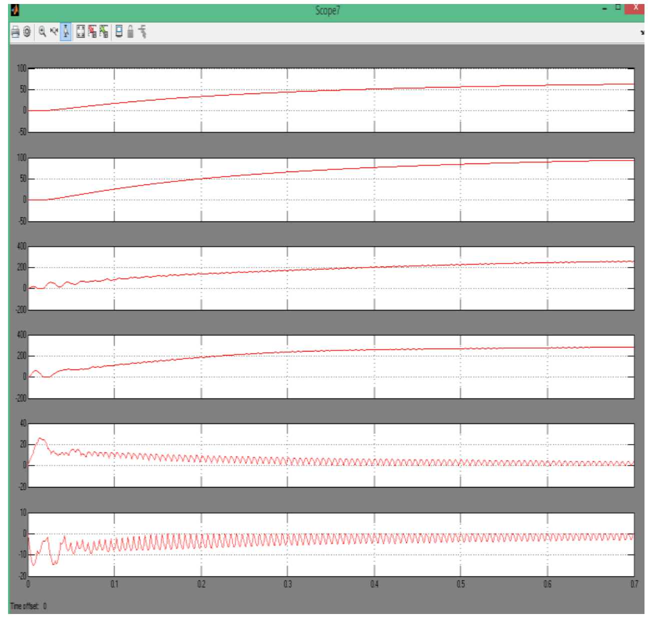

Fig 6. Wave forms of the output voltage and current and Inductive currents and voltage across capacitors

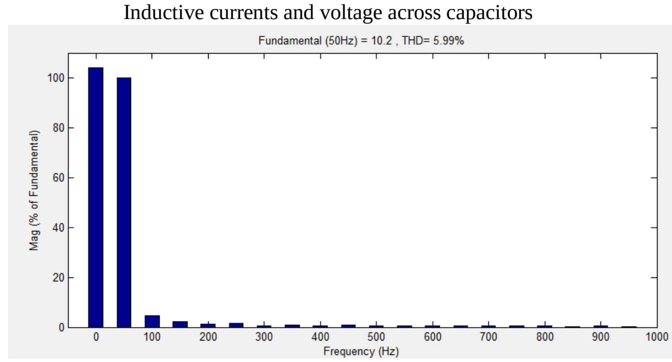

Fig. 7. THD calculation graph

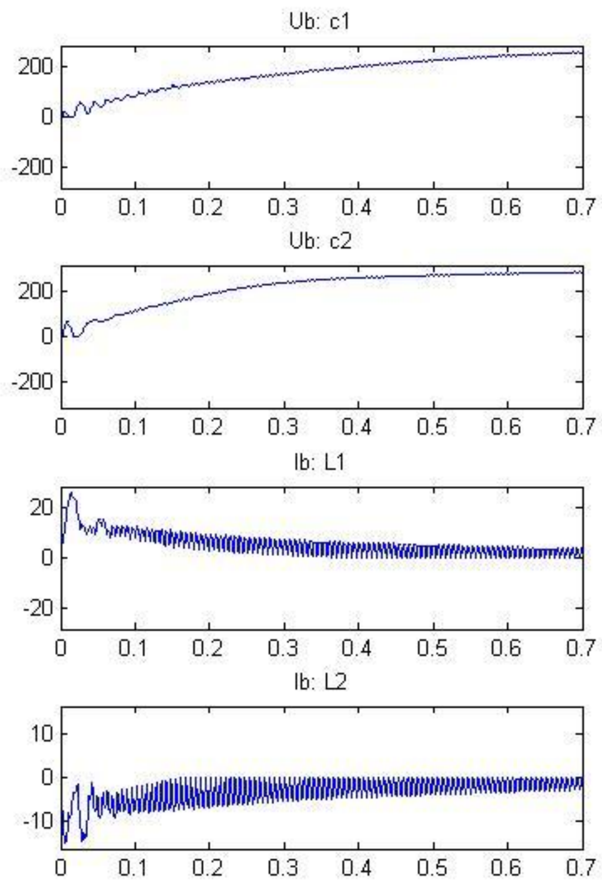

Fig. 8. Wave forms of the voltage and currents across capacitors and inductors

VI. CONCLUSION

The simulation model of the supply systemhas been developed in MATLAB based simulation platform.The input ac mains current THD has been found to be less than5% at full load, with a power factor close to unity. Fuzzy controllers were designed the buck and boost converters. The fuzzy controllers weredesigned based on the in-depth knowledge of the plant, simulation by Simulink and experimentalresults. The fuzzy controller for the boost converter uses two different controller configurations forthe start up transient and for steady state to obtain a fast and stable response, while only oneconfiguration is used for the buck converter. Fuzzy logic appears to be a valid element forgeneralization to many control applications. Since both buck and boost converters are controlled using the same fuzzy control algorithm.

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