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FUZZY LOGIC BASED INTERLEAVED BUCK CONVERTER

A.Antonamolopraveen [1] ,T.Ram Kumar [2],S.Archana[3]

P.G. Scholar[1] , Assistant Professor[2]
Department of Power Electronics and Drives
K.Ramakrishnan College of Technology, Samayapuram
Trichy-621112, Tamilnadu, India .

E-mail:*archanasangapillai@gmail.com*

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ABSTRACT

This project proposes a fuzzy logic controller based new Interleaved Buck Converter to reduce the ripple. Fuzzy logic controller is used to minimize the steady state error. A controller based on Fuzzy logic is implemented and its application to the regulation of power converter is examined. It has various conditions of operation with heavy computation and fast dynamic response. The topology is modeled by using MATLAB software and operated at finite higher switching frequency to evaluate its closed-loop performance This is suitable for the applications where the input voltage is high and the operating duty is below 50%. The proposed fuzzy logic controller based Interleaved Buck Converter shows its being free of complex equation and heavy computation and so it achieves fast dynamic response. In addition the proposed IBC has higher step down conversion ratio and a smaller output current ripple compared with a conventional IBC.This study is confirmed by the experimental results with the range of (36-48)V input and (12-20)V output.

Keywords-*Buck converter, interleaved,fuzzy logic.*

I INTRODUCTION

Power-electronic converter is the need of the day, may it be process control automation, energy conservation or medical instrumentation telecommunication, and it is imperative to design such converters capable of operating at higher frequency for achieving high power density. The converter must be made increasingly reliable and the output voltage regulation of such converter against load and supply voltage fluctuations is an important criterion in design .

Crucial to the performance of power converters is the choice of control methods. Frequency domain analog methods predominantly used are based on an equivalent linear small signal model of the converter and this model has restricted validity especially for systems with strong non-linearity. It also cannot meet the more stringent requirement of today's digital circuit because of inherent disadvantages such as low flexibility, low reliability, temperature drift of the components and susceptibility to electromagnetic interference. The complexity of the system with non-linearity, the practical converter operation because of problems associated with parasitic resistance, stray capacitance and leakage inductance of the components, and increasingly demanding closed loop system performance necessitates the use of more sophisticated controllers. With the aid of advanced digital control and microcomputer technology of power converter becomes feasible but such methods involve a lot of complex equations and calculations. The required processing time of the controller can be reduced and the sluggish response shall be improved, if the control method is based on an artificial intelligence instead of solving equations arithmetically.Design of fuzzy logic or rule based non-linear controller is easier since its control function is described by using fuzzy sets and if–then predefined rules rather than cumbersome mathematical equations or large look up–tables; it will greatly reduce the development cost and time and needs less data storage in the form of membership rules and function.It can exhibit increased reliability, saturation effects,robustness in the face of changing circuit parameters and external disturbances and so on.Fuzzy logic is a departure from classical Boolean or crisp logic as it relies on human capability to understand system's behaviour and it is adaptive in nature.

In application where step-down conversion ratio, nonisolation,and high output current with low ripple are required, an interleaved buck converter (IBC) has received a lot of attention due to its simple structure and low control complexity. However, all semiconductor devices suffer from the input voltage in the conventional IBC shown in Fig. 1, and hence, high-voltage devices rated above the input voltage is used. High-voltage-rated devices have poor characteristics such as high on-resistance, high cost, severe reverse recovery, high forward voltage drop, etc. In addition to it the converter operates under hard switching condition. Thus, the efficiency becomes poor and the cost becomes high. And, for higher power density and better dynamics, it is required that the converter operates at higher switching frequencies. However, higher switching frequencies increase the switching losses associated with reverse recovery, turn-on and turn-off. Consequently, the efficiency is further declined. It also experiences an extremely short duty cycle in the case of high-input and low-output voltage applications.

In this paper, a new IBC, which is suitable for the applications where the input voltage is high and the operating duty is below 50%, is proposed. It is similar to the conventional IBC, with two active switches are connected in series and a coupling capacitor is employed in the power path and the two active switches are driven with the phase shift angle of 180◦ and the output voltage is regulated by adjusting the duty cycle at a fixed switching frequency. The features of the proposed IBC are similar to those of the IBCin [14]. The current stress is low since the proposed IBC also operates at CCM. The voltage stress across all active switches before turn-on or after turn-off is half of the input voltage during the steady state,. Thus, switching losses and the capacitive discharging can be reduced considerably.

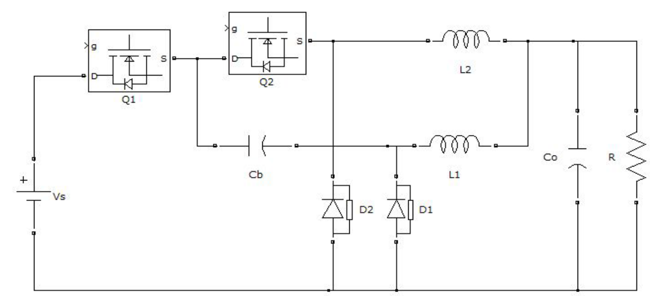

Fig.1 Conventional IBC

The voltage stress of the freewheeling diodes is also lower than that of the conventional IBC so that the reverse-recovery and conduction losses on the freewheeling diodes can be improved by employing schottky diodes that have generally low breakdown voltages, typically below 200V. The conversion ratio and output current ripple are lower than those of the conventional IBC. The circuit operations of the proposed IBC are described in Section II in detail. The performance of the proposed IBC is confirmed by the experimental results of prototype converters with 150– 200V input, 24 V/10A output.

II CIRCUIT OPERATIONS

Fig. 1 shows the circuit configuration of the conventional IBC. The structure is similar to a conventional IBC except two active switches in series and a coupling capacitor employed in the power path and show the key operating waveforms of the proposed IBC in the steady state. Referring to the figures, it can be seen that switches $Q1$ and $Q2$ are driven with the phase shift angle of 180◦. This is the same as that for a conventional IBC and each switching period is divided into four modes. In order to illustrate the operation of the proposed IBC and some assumptions are made as follows:

1) the output capacitor is large enough to be considered as a voltage source;

2) the two inductors have the same inductance L;

3) all power semiconductors are ideal;

4) the coupling capacitor is large enough to be considered as a voltage source.

A. Steady-State Operation when $D \leq 0.5$

Mode 1:

Mode 1 begins when $Q1$ is turned ON at $t0$. Then, the current of $L1$, $iL\,1\,(t)$, flows through $Q1$, CB , and $L1$ and the voltage of the coupling capacitor VCB is charged. The current of $L2$, $iL\,2\,(t)$, freewheels through $D2$. During this mode, the voltage across $L1$, $VL\,1\,(t)$, is the difference of the input voltage VS , the voltage of the coupling capacitor VCB, and the output voltage VO , and its level is positive. Hence, $iL\,1\,(t)$ increases linearly from the initial value. The voltage across $L2$, $VL\,2\,(t)$, is the negative output voltage, and so $iL\,2\,(t)$ decreases linearly from the initial value. The voltage across $Q2$, $VQ2\,(t)$, becomes the input voltage and the voltage across $D1$, $VD\,1\,(t)$, is equal to the difference of VS and VCB.

Mode 2:

Mode 2 begins when $Q1$ is turned OFF at $t1$. Then, $iL\,1\,(t)$ and $iL\,2\,(t)$ freewheel through $D1$ and $D2$, respectively. Both $VL\,1\,(t)$ and $VL\,2\,(t)$ become the negative VO , and hence, $iL\,1\,(t)$ and $iL\,2\,(t)$ decrease linearly. During mode 2, the voltage across $Q1$, $VQ1\,(t)$, is equal to the difference of VS and VCB and $VQ2\,(t)$ becomes VCB.

Mode 3:

Mode 3 begins when $Q2$ is turned ON at$t2$. At the same time, $D2$ is turned OFF. Then, $iL\,1\,(t)$ freewheels through $D1$ and $iL\,2\,(t)$ flows through $D1$, CB , $Q2$, and $L2$. Thus, VCB is discharged. During this mode, $VL\,2\,(t)$ is equal to thedifference of VCB and VO and its level is positive. Hence, $iL\,2\,(t)$ increases linearly. $VL\,1\,(t)$ is the negative VO , and hence, $iL\,1\,(t)$ decreases linearly.

Mode 4:

Mode 4 begins when $Q2$ is turned OFF at $t3$, and its operation is the same with that of mode 2. The steady-state operation of the proposed IBC operating with the duty cycle of $D \leq 0.5$ has been described. From theoperation principles, it is known that the voltage stress of all semiconductor devices except $Q2$ is not the input voltage, but it is determined by the voltage of coupling capacitor VCB. The maximum voltage of $Q2$ is the input voltage, but voltage before turn-on or after turn-off is equal to VCB. As these results, capacitive discharging and switching losses on $Q1$ and $Q2$ can be reduced considerably. In addition, since diodes with good characteristics such as schottky can be used for $D1$ and $D2$, the reverse-recovery and conduction losses can be also improved.

B. Steady-State Operation When $D > 0.5$

Mode 1:

Mode 1 begins when $Q2$ is in on-state and $Q1$ is turned ON at $t0$. Then, $iL\,1\,(t)$ flows through $Q1$, CB , and $L1$ and $VCB(t)$ is charged. $iL\,2\,(t)$ flows through $Q1$, $Q2$, and $L2$. $VL\,1\,(t)$ is equal to the difference of VS , VCB, and VO and its level is positive and thus, $iL\,1\,(t)$ increases linearly from the initial value. $VL\,2\,(t)$ is equal to the difference of VS and VO and $iL\,2\,(t)$ also increases linearly from the initial value.

Mode 2:

Mode 2 begins when $Q2$ is turned OFF at $t1$. Then, $iL\ 1\ (t)$ flows through $Q1$, CB , and $L1$ and $iL\ 2\ (t)$ freewheels through $D2$. The operation during this mode is the same with mode 1 in the case of $D \leq 0.5$.

Mode 3:

Mode 3 begins when $Q2$ is turned ON at $t2$, and the operation is the same with mode 1.

Mode 4:

Mode 4 begins when $Q1$ is turned OFF at $t3$. Then, $iL\ 1\ (t)$ freewheels through $D1$ and $iL\ 2\ (t)$ flows through $D1$, CB , $Q2$, and $L2$. Thus, VCB is discharged and the operation during this mode is the same with mode 3 in the case of $D \leq 0.5$. The steady-state operation of the proposed IBC operating with $D > 0.5$ has been described.

III FUZZY CONTROLLER FOR QUASI RESONANT BUCK CONVERTER

A process control algorithm that is based on fuzzy logic is called Fuzzy control and it essentially embeds the intuition and experience of a human operator . The general structure of a fuzzy controller is represented in Figure.6 and the algorithm consists of a set of fuzzy rules which are related by the concepts of fuzzy implication and the compositional rule of inference .Its perfomance depends on rules size and tuning parameters .

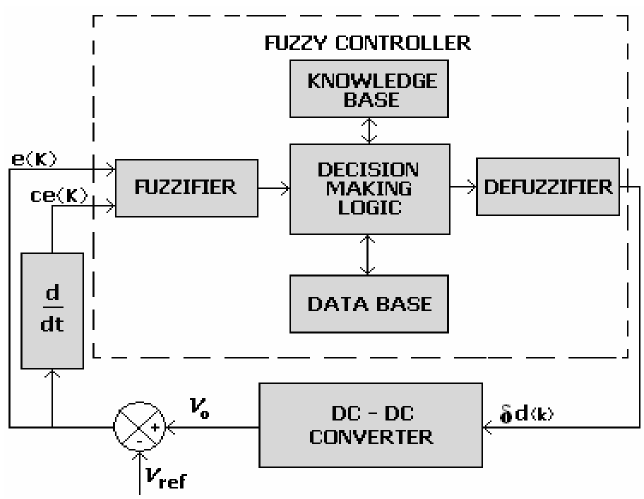

Fig.2 Configuration of closed loop fuzzy logic controller

The steps involved in the design in off-line implementation are:

i. To select control elements and parameters as scaling factors for input and output signals.

ii. To partition the universe of discourse of the interval spanned by each variable into a number of fuzzy subsets, and assigning each a linguistic label.

iii. To assign membership function for each fuzzy subset.

iv. To assign the fuzzy relational between the input and output fuzzy subsets and thus forming the rule base.

v. To choose appropriate scaling factors for the input and output variables in order to normalize the variables to [-1, 1] or [0,1] interval.

vi. To fuzzify the inputs or to classify the input data into suitable linguistic values or sets to the controller.

vii. To use fuzzy appropriate reasoning to infer the output contributed from each rule.

viii. To aggregate the fuzzy outputs recommended by each rule

ix. To apply defuzzification technique to form a crisp output.

x. To send the change of control action to control the plant.

Off-line implementation employs a look up table built according to the set off all possible combinations of input variables and can actually reduce the controller actuation time as the only effort is limited to consulting the table at each iteration.

A. Identification of inputs and output

The inputs of the fuzzy logic controller are the error e (k) and the change in error voltage Ce (k) which are defined as

$E(k) = V_0 - V_{ref}$ $\quad\quad$ $Ce(k) = e(k) - e(k-1)$

Where Vo is the sampled output voltage of the DC-DC converter, Vref is the reference output voltage and the symbol k denotes value at the beginning of the kth switching cycle. The output of fuzzy controller is the change in duty cycle and is defined as

$D(k) = d(k-1) + \eta.\delta d(k)$

Where $\delta d(k)$ is the inferred change in duty cycle by the fuzzy controller at the k^{th} sampling time and η is the gain factor of the fuzzy controller.

B. Membership functions

Three continuous Gaussian membership functions are chosen to the model, analyze and simulate the Fuzzy Controller. It has been defined by taking into account the conditions of normality and convexity of fuzzy sets; it embodies the mathematical representation of membership in a set and is required to have parameters,uniform shapes and functions for the sake of computational efficiency with efficient use of the computer memory and performance analysis. The membership functions for the input and output are shown in Figures 7, 8 and 9. Fuzzy logic is being developed as a discipline to meet two objectives.There are as a professional subject dedicated to the building of systems of high utility for example fuzzy control and as a theoretical subject fuzzy logic is symbolic logic with a comparative notion of truth developed fully in the spirit of classical logic and it is a branch of many-valued logic based on paradigm.

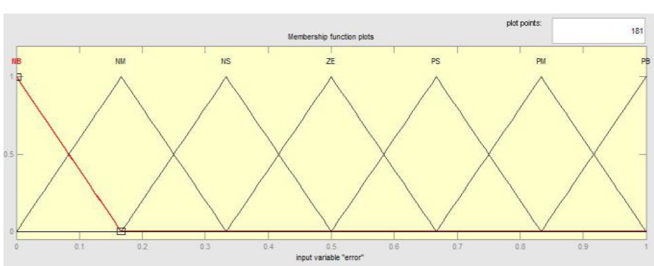

Fig.3 Member function for error signal

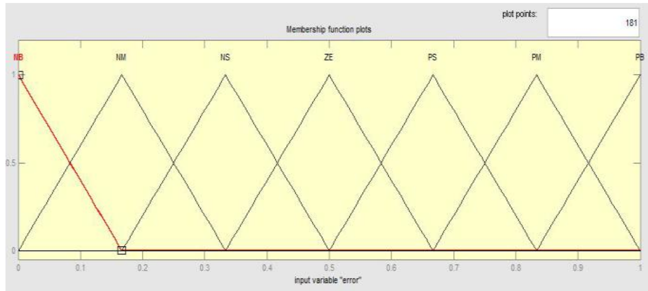

Fig.4 Member function for change in error signal

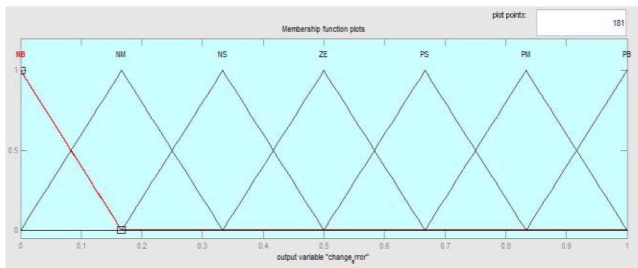

Fig.5 Member function for control signal

C. *Fuzzification*

Fuzzification matches the input data with the conditions of the rules to determine how well the condition of each rule matches that particular input instance. It provides a mathematical way to represent vagueness in humanistic systems and is defined for each input and output variables in natural language. For ease of computation, seven fuzzy subsets [20] are defined by the library of fuzzy set values for the error and change in error and they are NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big).

D. Development of rule base

The collection of rules is called a rule base and it expresses input-output relationship in linguistic terms. There is no design procedure in fuzzy control such as root-locus design, frequency response design, stability margins because the rules are often non-linear and are heuristic in nature; they are typically written as antecedent – consequent pairs of IF THEN structure and the inputs are combined by AND operator. The antecedent (condition part) and consequent (operation part) are the description of process state and control output respectively in terms of a logical combination of fuzzy propositions. Generic linguistic control rule has the form as If x is A AND y is B THEN z is C where x,y are the input linguistic variables and z is the output linguistic variable.49 rules as shown in Table are formed depending on the number of membership functions to play a key role in the improvement of system performance.

E. De-fuzzification

Conservation of the fuzzy to crisp or non-fuzzy output is defined as De-fuzzification. Mean of Maxima (MOM) method was implemented, where only the highest membership function component in the output is considered. This method disregards the shape of the fuzzy set but the computational complexity is relatively good. The rule table must now be created to determine which output ranges are used.The table is an intersection of the two inputs.The collection of rules is called a rule base and it expresses input-output relationship in linguistic terms.

e \ ce	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NM	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

Table Rules for control signal

IV SIMULATION RESULTS

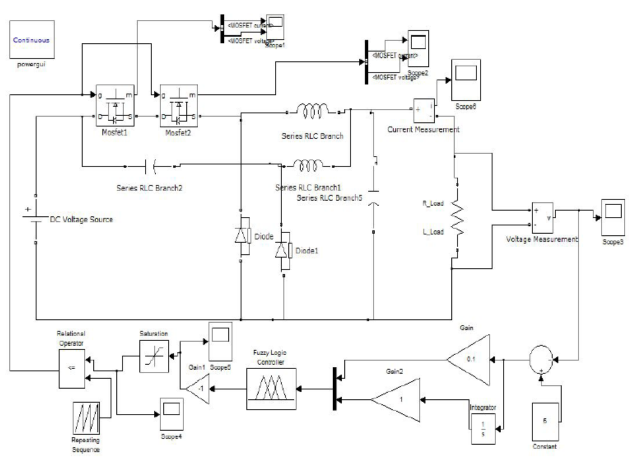

Fig.6 Simulation diagram for fuzzy logic controller based interleaved buck converter

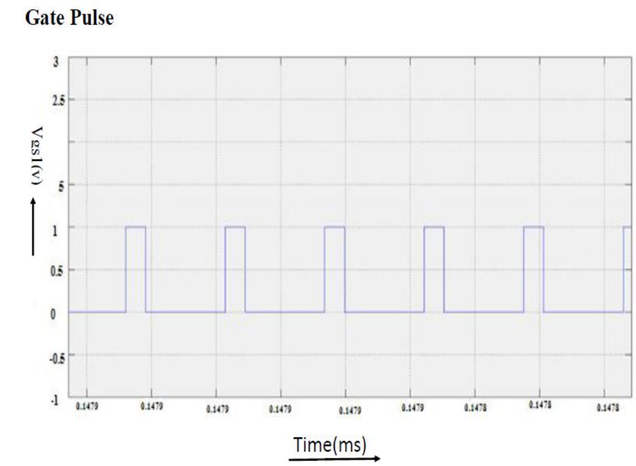

Fig.7 Pulse for MOSFET switch

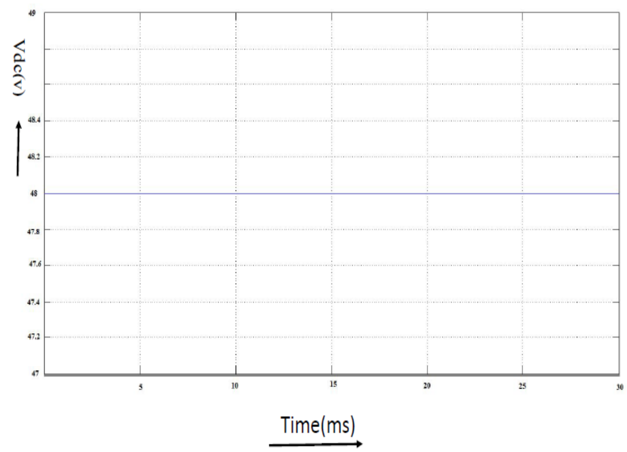

Fig.8 Input voltage for interleaved buck converter

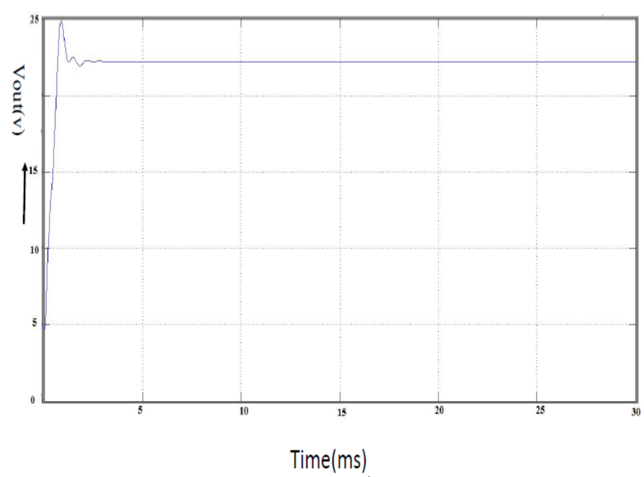

Fig.9 Output voltage for fuzzy logic controller based interleaved buck converter

V.CONCLUSION

Thus a Fuzzy control scheme is implemented to improve the dynamic performance of Interleaved Buck Converter .The converter is simulated by MATLAB SOFTWARE to show its feasibility and its transient characteristics compared with conventional IBC. Fuzzy Controller is able to regulate the output voltage to a desired value effectively The main advantage of the proposed IBC is that since the voltage stress across active switches is half of the input voltage before turn-on or after turn-off when the operating duty is below 50%, the capacitive discharging can be reduced considerably. Since the voltage stress of the freewheeling diodes is half of the input voltage in the steady state and can be quickly reduced below the input voltage during the cold startup, the use of lower voltage-rated diodes is allowed. From these results, the efficiency of the proposed IBC is higher than that of the conventional IBC and the improvement gets larger as the Switching frequency increases. Moreover, it is confirmed that the proposed IBC has a higher stepdown conversion ratio and a smaller inductor current ripple than the conventional IBC. Hence, the proposed IBC becomes attractive in application mainly in personal computer industry.

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