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Design and Hardware Implementation of Closed Loop Buck Converter Using Fuzzy Logic Controller

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Abstract*—DC voltage is converted from one voltage level to another using a DC to DC converter. Applications of DC to DC converter includes self regulating power supplies, current sources to drive solid state lighting applications, advanced datacom and telecom systems, appliance control, DC motor drives, aircraft, etc. But controlling of this converter is vital task in conversion of power. Focus of this paper is to model a controlling system for buck converter which controls output of buck converter and keeps it constant instead of changing circuit parameters, load and input supply of the buck converter. The pulse width modulation (PWM), voltage mode control, PWM linear mode control with proportional controller (P), proportional integral controller (PI), and proportional integral derivative controller (PID) are some of the controlling methods fr used for dc-dc converters. But the performance of these methods are not satisfactory when there are large variations in parameters or load. This is why nonlinear controllers are used for controlling DC to DC converters. The nonlinear controller has the advantages that it reacts faster to a transient condition. Thus the Controlling method used to control buck converter in this paper is fuzzy control logic which is simulated in MATLAB/SIMULINK using fuzzy logic toolbox. The proposed strategy is then implemented on buck converter hardware setup such that for an input of 30 volts we get the desired output for variable references. Thus using Fuzzy controlling method less overshoots are obtained in the output of buck converter. This control system increases converter efficiency and power efficiency.

Keywords*— DC–DC converters, Fuzzy logic controller (FLC), Buck Converter, Pulse with Modulation (PWM), MATLAB (SIMULINK).

I. INTRODUCTION

Now a days the requirements for lower voltage but higher currents and vice versa are very common. This is a challenge for modern designer in addition to economic feasibility and reliability. Power converters can be classified as, ac-ac converters, ac-dc converters , dc-ac converters, dc-dc converters. linear system design techniques like PID, Sliding mode, dead beat controllers etc. are used to design DC-DC converter. But drawback of these methods is fixed set of parameters and noise sensitivity. Therefore digital control methods which are non linear are used so as to get large-signal stability. Fuzzy controllers are suitable for non-linear time variant systems because of its simplicity of design & implementation. Mathematical model is not required for fuzzy controllers. The design of buck converter with fuzzy logic is presented in this paper.

Methodology of proposed strategy is discussed in Section II. Section III gives fundamental analysis of fuzzy controller used for the simulation. Results of simulation are presented in section IV and section V discusses hardware details.

II. METHODOLOGY

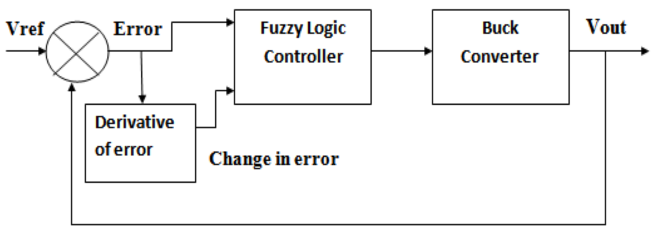

Fig.1 Block Diagram for Buck Converter Using Fuzzy Logic.

The goal of this system is to keep output voltage constant even if there are variations in the load and power supply. Here difference in the output voltage and desired voltage (Vref) is considered. This difference value is called error(e) and then along with change in error (ee) that is derivative of error will be applied to FLC through multiplexer. FLC gives variations in the values of duty cycle as the data changes. These values are compared and scaled using gain. This output is applied to the power switch of buck converter through PWM generator. Thus a desired output voltage will be obtained.

A. Algorithm:

Figure 2 shows the flowchart for algorithm. Using the research and observation (literature survey) as the guide for mathematical model of buck converter, a mathematical model is designed in order to verify whether appropriate output is achieved using MATLAB Simulink. Initially the performance of the system for different membership functions is evaluated in simulation. The most optimized membership function is then taken for the implementation.

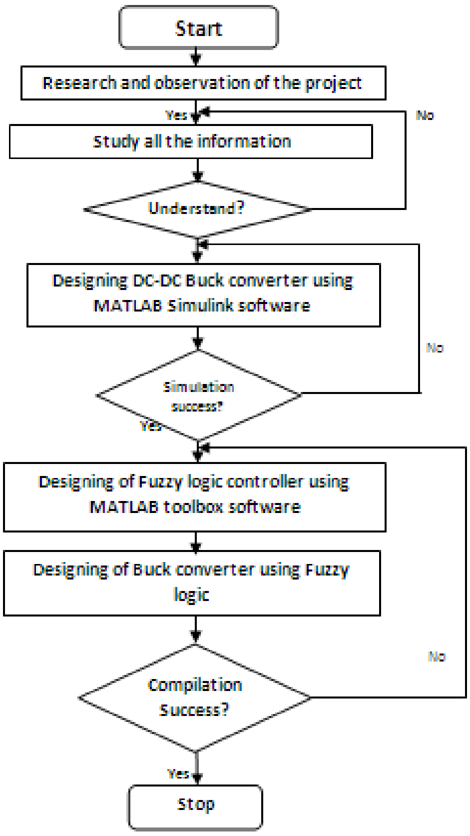

Fig.2 Flow chart of the project.

MODELLING OF BUCK CONVERTER

Figure 3 shows a buck converter. Here the switch is controlled by duty cycle coming from the controller.

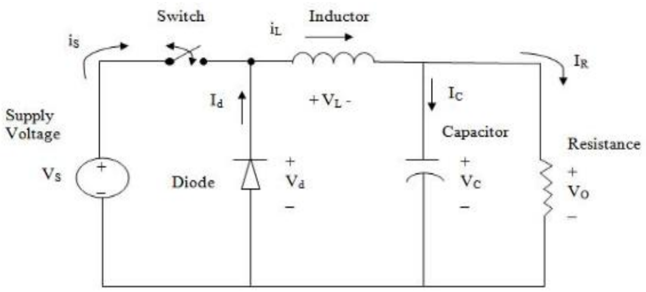

Fig.3 Circuit Diagram of Buck Converter [1].

Where V_S= Supply voltage, V_d =Voltage across diode, V_L= voltage across inductor, V_C= Voltage across capacitor, V_o= Output voltage of buck converter.

Two modes of operation of buck converter are discussed here.

Mode 1 (Switch Closed): Conduction does not take place as the diode gets reverse biased due to the closing of the switch. Voltage across inductor is $V_S - V_O$, the rising current in the inductor is according to the following equation$(V_S - V_O)/L$ [1].

Mode 2 (Switch Opened): In this mode the inductor polarity reverses but current still flows in same direction. As a result current still flows through the inductor and into the load. Diode gets forward biased due to the inductor's changed reversed polarity and the required output voltage and current through the inductor decreases with a slope equal to $-V_o/L$ [1].

III. FUZZY LOGIC CONTROLLER

Fuzzy logic is an computing logic based on "degree of truth" rather than the usual "true or false" . Fuzzy logic includes various states in between 0 and 1 instead of only 0 and 1 (i.e extreme cases of truth). Fuzzy logic aggregates data and form a number of partial truths which it aggregate further into higher truths which in turn, when certain thresholds are exceeded, cause certain further results [2]. Simplicity of control, low cost, design without mathematical model are few advantages of FLC over other controllers. Fuzzy logic is used in various industrial and household applications.

A. Fuzzy Logic Block Diagram

Figure 4 shows Fuzzy logic controller.

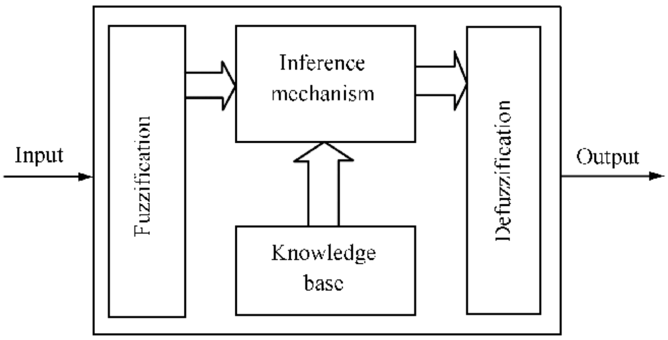

Fig.4 Fuzzy Logic Controller block Diagram.

Input: The inputs are crisp measured values.

Fuzzification: Each input data is mapped to the degree of membership function. This matching is done as per the conditions given by the rule base. For each linguistic term which applies to the input variable a degree of membership exists.

Rule base: Rule base is nothing but a set of rules. The rules used in fuzzy logic are generally "if and then" statements where the if stands for condition and then stands for conclusions. For the designed system depending on the measured inputs i.e.; error (e) and change in error (de) computer executes these rules and give a control signal. Even for an inexpert user it is easy to understand the implementation of rule base.

Inference mechanism: This mechanism decides the control rule that is suitable for the particular situation and respectively gives the input to the plant.

Defuzzification: The combination of all the decisions (that are been taken) into a single non fuzzy output signal is called defuzzification process. Various defuzzification methods are used for this purpose.

B. The Fuzzy Algorithm for Buck Converter

Using fuzzy toolbox in SIMULINK two inputs and one output to and from fuzzy controller tool box are mapped in universe (-1 to 1) and *.fis* file in MATLAB SIMULINK is obtained.

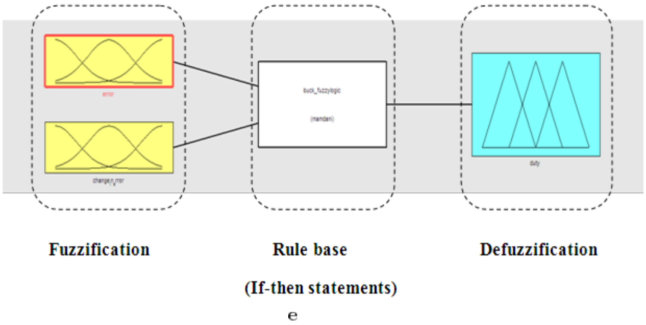

Fig.5 *.fis* File of MATLAB.

The basic fuzzy algorithm below is represented for buck converter. Fuzzy Logic Control configuration for buck converter is shown in figure 1 and same method is used in implementation.

Figure 5 shows three sections of fuzzy control algorithm

Fuzzification:

Here the two inputs which are to be converted into fuzzy values are error (e) and change in error (ee). The error voltage is calculated by taking the difference between reference voltage (V_{ref}) and the actual voltage (V_o) whereas the change in error is calculated by taking difference between obtained error (e) and the previous error (E previous) [5].

The error and change in error are given by[5]:

$$e = V_{ref} - V_o \qquad (1)$$

$$ee = e - E_{previous} \qquad (2)$$

Rule Base:

The rules for fuzzy control are based on common knowledge about the system. That is what decision should be taken if system output increases or decreases. This decision is based on the following conditions.

- Duty cycle should decrease when the output voltage of converter is higher than the reference voltage.
- Duty cycle should increase when the output voltage of converter is lower than theVref.

The logical operator used for Rule base is AND operator. Following are the six linguistic variables used for error and change in error.

- NB (Negatively Big)
- NM (Negatively Medium)
- NS (Negatively Small)
- Z (Zero), PB (Positively Big)
- PM (Positively Medium)
- PS (Positively Small)

TABLE I: RULE BASE FOR BUCK CONVERTER USING FUZZY LOGIC.

(e) / (ee)	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

A single level is given to each input and output. That is each input and output is given a membership grade to every fuzzy set [2]. To reduce the complexity in calculations, triangular and Trapezoidal type of membership functions are used. Figure 6 to 8 shows normalized values of error and change in error.

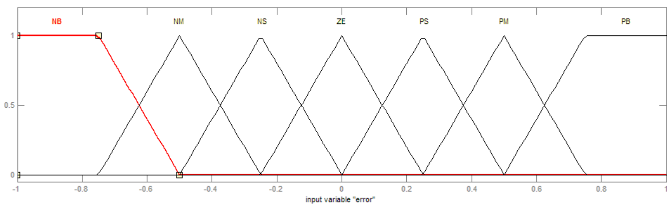

Fig.6 Membership Function for Input error.

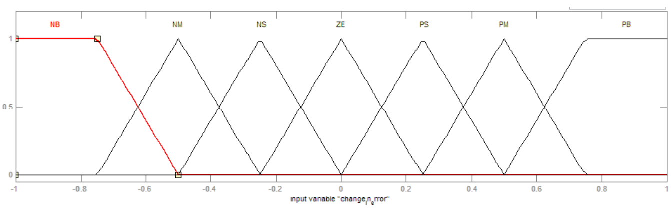

Fig.7 Membership Function for Input change in error.

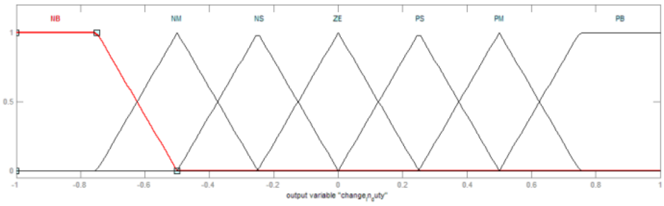

Fig.8 Membership Function for Output Change in Duty Cycle.

Defuzzification method:

Defuzzification is the last step of fuzzy inference process. Single scalar quantity is obtained at the output from aggregation process. This method does the opposite of fuzzification and gives a accurate quantity out of the range of fuzzy sets. The different fuzzification methods are Smallest of Max, Largest of Max, Centroid of Max, Bisector of Max, Mean of Max as shown in the fig. below. Amongst these defuzzification methods, the *Centroid Method* for defuzzification process is implemented.[4]

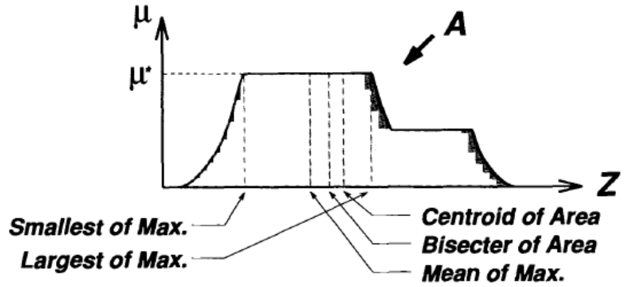

Fig. 9 Centroid Defuzzification Method.

The de-fuzzified output of the Fuzzy control algorithm is change in duty cycle which is scaled and compared to de-normalize. This calculated value will be of duty cycle which is forwarded to the PWM generator. PWM generator gives the switching pattern to control the switch in the buck converter.

IV. Simulation Results

Implementation of proposed strategy is done in MATLAB environment. The parameters for simulation were varied and corresponding changes were observed. The tables below show the results. Fig. 10 shows the MATLAB simulation structure and Fig. 11. Shows architecture of fuzzy control for simulation

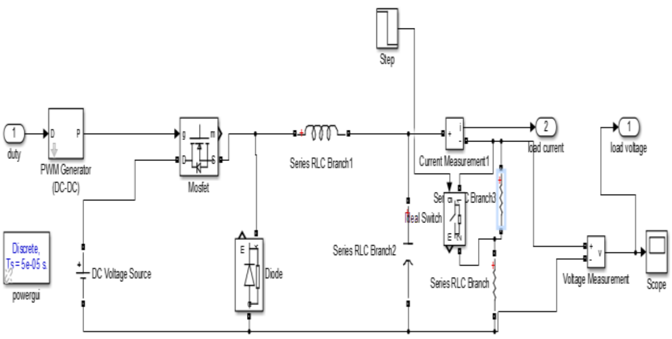

Fig.10 Simulation circuit diagram for Buck Converter.

TABLE II: BUCK CONVERTER PARAMETERS.

Parameter	Value
Inductor	3mH
Capacitor	2000uF
PWM Frequency	15KHz
Input Voltage	30 Volts
Output Voltage	15 Volts

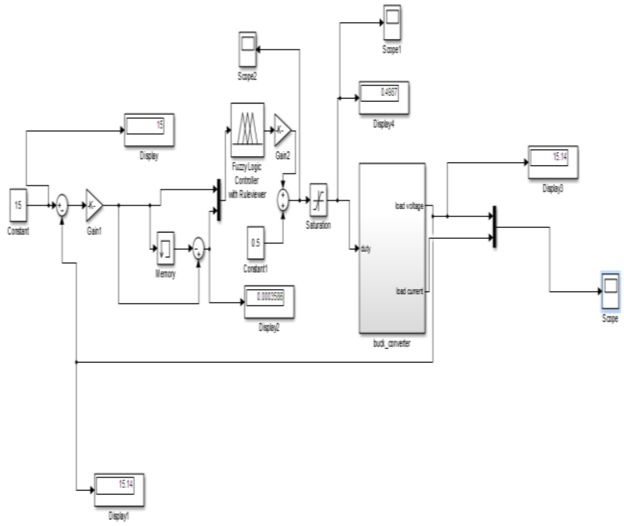

Fig.11 Simulation circuit diagram for Buck Converter using Fuzzy Logic.

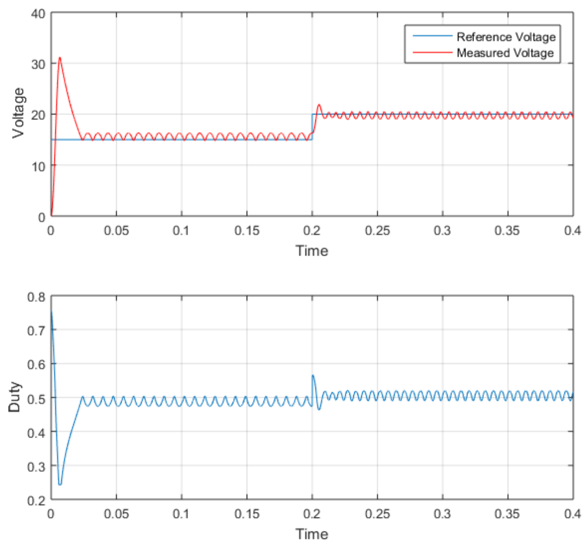

Fig.12 Simulation ouput for Buck Converter using Fuzzy logic for 15V and 18V reference input voltage.

TABLE III: MATLAB SIMULATION RESULT OF FUZZY CONTROLLED BUCK CONVERTER FOR 10 OHM LOAD AND REFERENCE INPUT VOLTAGE VARIANT CONDITION

Reference Input Voltage (Volt)	Output Voltage (Volt)
18V	18.45
20V	19.66
25V	22.13

It can be observed from Fig.12 that the system is tracking the change in set point by linearly changing the output with respect to the change in set point. The reference voltage for system is varied and the output voltage of converter obtained is tabulated in Table III.

TABLE IV: MATLAB SIMULATION RESULT OF FUZZY CONTROLLED BUCK CONVERTER FOR SUPPLY VOLTAGE 30V AND LOAD VARIANT CONDITION

Load Resistance (Ohm)	Output Voltage (Volt)
10	15.05
50	15.09
100	15.18

When the resistance value is increased the overshoot remains as it is but the ripple increases as well as the sudden overshoot (observed in the ripple) also increases. The result for variation in load is tabulated in Table IV.

TABLE V: MATLAB SIMULATION RESULT OF FUZZY CONTROLLED BUCK CONVERTER FOR 10 OHM LOAD AND INPUT SUPPLY VARIANT CONDITION

Input Supply Voltage (Volt)	Output Voltage (Volt)
20V	14.69
25V	15.06
35V	17.02

Overshoot increases and decreases when the voltage is increased and decreased respectively (i.e. a linear relationship between the overshoot and the voltage is exhibited). The result for change in supply voltage upon performance of fuzzy control is given in Table V.

TABLE VI: MATLAB SIMULATION RESULT OF FUZZY CONTROLLED BUCK CONVERTER FOR CAPACITOR VARIANT CONDITION

Capacitor (Farad)	Output Voltage (Volt)
1000uF	15.18
1200uF	15.15
3200uF	15.21
4200uF	15.13

When the capacitance value is reduced the output voltage increases more than 15V. Ripples are more if the value is reduced and almost becomes negligible when the value is increased.

TABLE VII: MATLAB SIMULATION RESULT OF FUZZY CONTROLLED BUCK CONVERTER FOR INDUCTOR VARIANT CONDITION

Inductor Value (Henry)	Output Voltage (Volt)
1mH	15.61
2mH	15.89
6mH	15.03
9mH	15.27

When the value of inductor is reduced output voltage increases (i.e.is more than 15, which is not the required output).The overshoot and ripples are reduced if the value of the inductor is increased.

V. HARDWARE IMPLEMENTATION

The Fig.13 depicts the hardware implementation setup of Buck converter using Arduino. A PWM signal is generated using an Arduino for triggering the MOSFET. The frequency of PWM signal is same as that of simulation value. The controller takes voltage as feedback and calculates error and change of error. The fuzzy logic is coded in embedded controller such that it follows the rule base designed in the simulation.

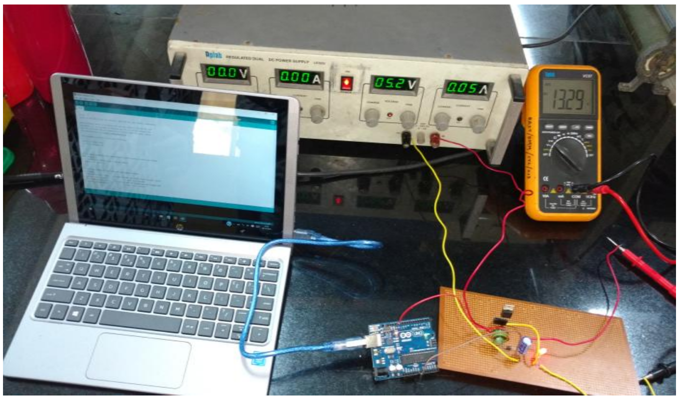

Fig.13 Hardware implementation of Buck Converter using Arduino.

VI. CONCLUSION AND FUTURE IMPROVEMENT

In this paper the simulation and hardware model of fuzzy logic based controller for buck converter has been developed. The results justify that to get a constant voltage at the output of buck converter for change in load and change in supply voltages the fuzzy controlling method is an adaptive controlling method.

The linear controllers are based on the precise system equations and are generally unable to cope up with the non linearities and disturbances present in the system. Whereas on the other hand Fuzzy controllers (which are non-linear controllers) are able to handle these effects and non-linearities in the system efficiently and thereby improving the performance of the system and saves development time and costs[8].

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