The Closed Loop Control of Soft Switching DC-DC Boost Converter with Fuzzy Logic Controller

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Abstract : The power converters are widely used in many applications to reduce the switching losses and to increase the efficiency the soft switching technique are used. The close loop control of soft switching DC-DC Boost converter consists of development of fuzzy logic controller for generating control PWM pulses of required duty cycle for MOSFET of the converter to maintain the constant output voltage. Duty cycle of the converter is adjusted continuously to obtain required output voltage for variable input voltage. This paper describes the design of fuzzy logic controller using output voltage of the converter as feedback for significantly improving the dynamic performance of soft switching DC-DC boost converter by using MATLAB/Simulink.

Keywords- **DC-DC Converter, Boost Converter, Soft-switching techniques, Fuzzy logic controller, MATLAB/Simulink**

I. INTRODUCTION

In Military affairs ,aerospace, winches, renewable energy sources and motor speed control for many applications the dc/dc converters are used. These converters are capable of converting a variable dc voltage input to the fixed dc voltage output based on the load requirement [1].the boost converter is dc-dc converter with a output voltage higher than the source voltage. But switching transition in DC-DC converter have more losses because of the voltage and current stress across the switching elements.so it is very important to design converter which reduces switching losses.

The only way to reduce the switching losses is possible by including different switching techniques. The method used for soft switching is zero voltage switching which is more suitable for the MOSFET [2].For ZVS soft switching uses resonant circuit which consists of the inductor and the capacitor. Since the main switch turn on with soft switching ZVS the switching loss of the converter is very much reduced. This further increases the efficiency of the converter. Usually the soft switching condition is achieved by the addition of the auxiliary element consists of switches, diodes, inductor and capacitor. The addition of the auxiliary elements reduces the current stress, in turn it reduces the elements sizes present in the converter.

Many researchers reported successfully adopted fuzzy logic controller (FLC) recently. FLC become one of the intelligent controller to their appliances.[3] It improve the performance of the soft switching boost converter. The duty cycle of the boost converter is controlled by FLC. The fuzzy logic controller offer a completely different approach which is FLC[5] does not require a precise mathematical modeling of the system. this control technique based on the human capability to understand the system behavior and is based on qualitative control linguistic IF-THEN rules. The successfully implementation of the close loop using fuzzy logic controller with feedback by output voltage to give appropriate measure on steady state signal[12].

II. THE SOFT SWITCHING DC-DC BOOST CONVERTER WITH FUZZY LOGIC CONTROLLER

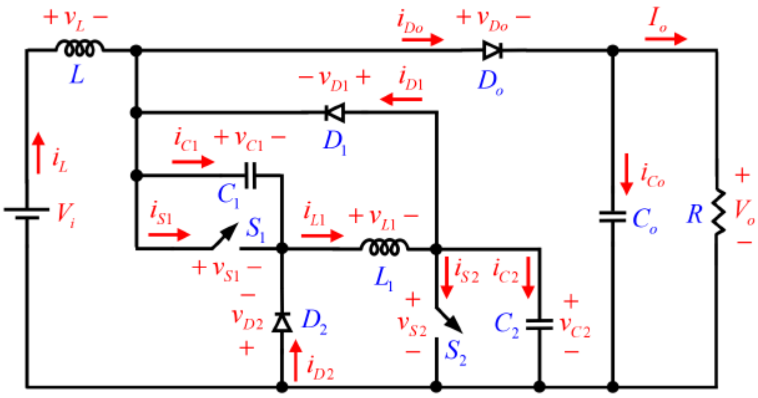

Figure1.Equivalent Circuit diagram of Soft Switching DC-DC boost Converter

The Equivalent circuit diagram of soft switching dc-dc boost converter shown in figure 1. The Vi is input voltage, S1 is the auxiliary switch, C1 is parallel capacitor of S1, D1 and D2 are auxiliary elements for resonant circuit, L1 is resonant inductor, S2 is the main switch, C2 is the parallel capacitor of S2, Do is the output diode, L is the filter inductor, Co is the filter capacitor, and R is the load resistance.

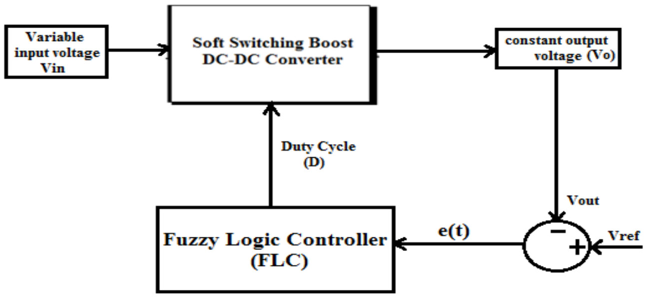

Figure 2. Block diagram of the fuzzy logic controller for soft switching dc-dc boost converter

The fuzzy set theory is widely used in control area with some application to dc-dc converter system. Based on the human knowledge of system a simple fuzzy logic control is build up by the group of rules. The MATLAB/SIMULINK simulation model is made to study the dynamic behavior of soft switching dc-dc boost converter and performance of proposed converter. the design of fuzzy logic controller can provide desirable both small signal and large signal dynamic[4] performance at the same time, which is not possible with linear control technique. Thus fuzzy logic controller is ability to improve the robustness of the proposed converter. The basic fuzzy logic controller consists of four main components such as fuzzification, process converts input crisp value into linguistic fuzzy value; a fuzzy rule are in "If-Then" format map input truth value to desirable output truth value. a fuzzy inference is a system which simulates the decision making process using fuzzy rules which are written in the fuzzy inference. And last Defuzzification process of converting the fuzzy output into the crisp value. As shown in figure 2 block diagram of the fuzzy logic controller for soft switching dc-dc boost converter which is consist of the variable input voltage (Vin),soft switching boost dc-dc converter, constant output voltage(Vo),error signal and fuzzy logic controller. here the main aim is to obtain the constant output voltage for variable input voltage. this can be achieved by altering the duty cycle of the main switch(s2) and auxiliary switch(s1) by fuzzy logic controller. The output of the soft switching boost converter is compared with the set reference voltage (Vref) and error is fed to the fuzzy control unit to get the desire steady state response. Based on evaluating fuzzy rules output of the fuzzy is given to the both switches S1 and S2 to control PWM as shown in figure 3.The close loop circuit diagram of the soft switching boost converter with fuzzy logic controller.

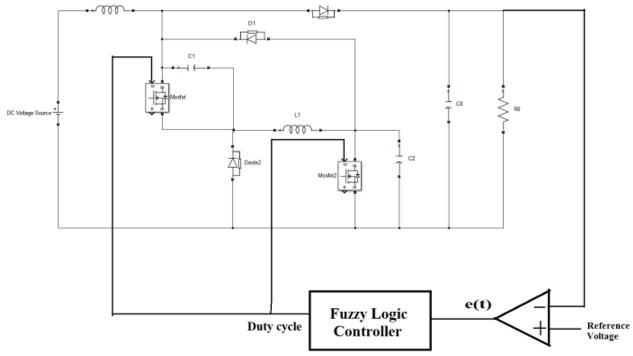

Figure 3.The close loop circuit diagram of the soft switching boost converter with fuzzy logic controller.

The main principle involved in working of this converter is to generate a square pulse to control the switching of the MOSFET. This square pulse is called duty cycle and this duty cycle control the output voltage. For generating pulses for switches here the constant reference signal is compared with carrier signal(in this paper a sawtooth wave is taken as carrier signal),which produces a square pulses. then again the square pulses are compared with the signal from the fuzzy controller. This can generate the required duty cycle for the switching of MOSFET of the converter thereby regulate the constant output voltage. The output voltage (Vo) of the soft switching boost converter is compared with set reference voltage (Vref) and error is fed to the fuzzy control to get desire steady state response. The one input linguistic variable i.e, voltage error(E) is expressed in (2.1) below.

$$E(n) = V_O - V_{ref} \qquad (2.1)$$

Where n is the sample time and duty cycle (D) is defined as the one output variable for fuzzy controller. Mainly fuzzy controller is constructed in four parts which have been discussed in following sections.

2.1.Fuzzy Membership Function

Fuzzy logic provides the solution for controlling nonlinear function like boost d c-dc converter because of the small signal model. Fuzzy controller does not require an exact mathematical model, it can be designed based on general knowledge of open loop behavior of the system. Fuzzification is a process of crisp data inputs to suitable linguistic membership function. The fuzzy sets must be defined for each input and output variable. The Error of the output voltage will the input of fuzzy logic controller. This input is plotted seven fuzzy subsets; NB: Negative Big, NM: Negative medium, NS: Negative Small, ZE: Zero Error, PS: Positive Small, PM: Positive Medium, PB: Positive Big. To control the pulses of the both switches S1 as auxiliary switch and S2 as main switch. The output of the fuzzy controller is taken as Duty cycle for switch S1 and switch S2. This output is plotted seven fuzzy subsets for both switches. For switch S1 can be labeled as D1 to D7 and for switch S2 can be labeled as D1* to D7*. For both input and output the Triangular Shape has been adopted for membership function, the value of each input and output variable is normalized.

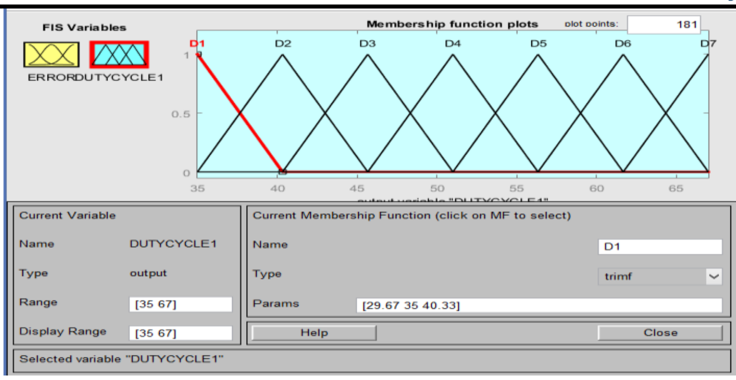

Figure 4. The Membership Function plots of error

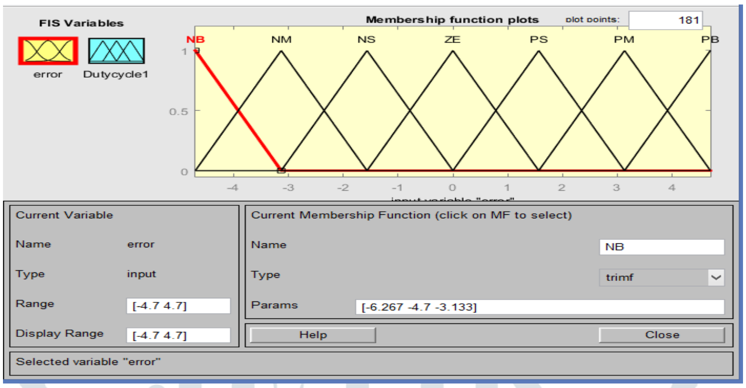

Figure5. The Membership Function plots of Duty cycle for switch S1

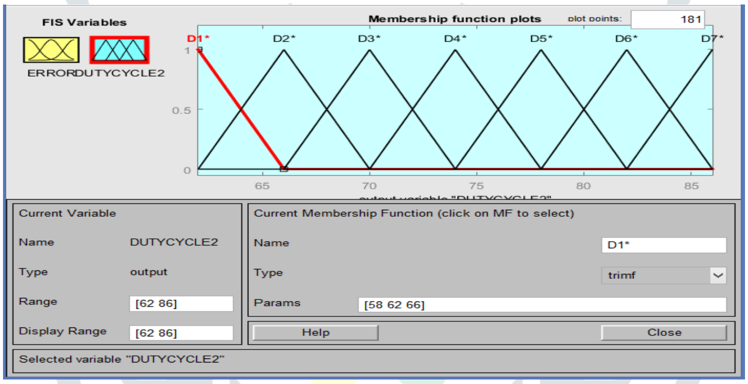

Figure 6. The Membership Function plots of Duty cycle for switch S2

2.2. Fuzzy Rules

The Fuzzy Rules describes the nonlinear control strategy of the Soft Switching DC-DC boost converter and decided according to their input-output combination, based on experience of system response. Fuzzy controller rule which are play a very important role for controller simulation are obtained from the analysis of the system behavior. Here Two Fuzzy Rules are made based on input error and output duty cycle of switch S1 as shown in figure 7 and input error and output duty cycle of switch S2 as shown in figure 8. Fuzzy rules are written in an IF-THEN format so for switch S1 seven rules and For Switch S2 seven rules are made.

Exampe:1) IF error is NB then Duty cycle of switch S1 is D1

2) IF error is NB then Duty cycle of switch S2 is D1*

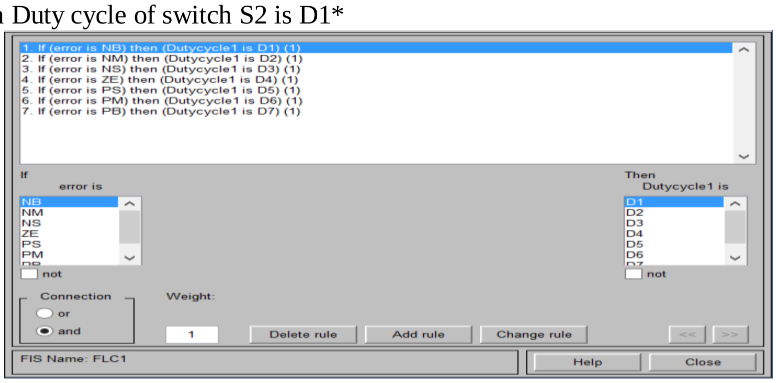

Figure 7. Fuzzy Rules for input error and duty cycle of switch S1

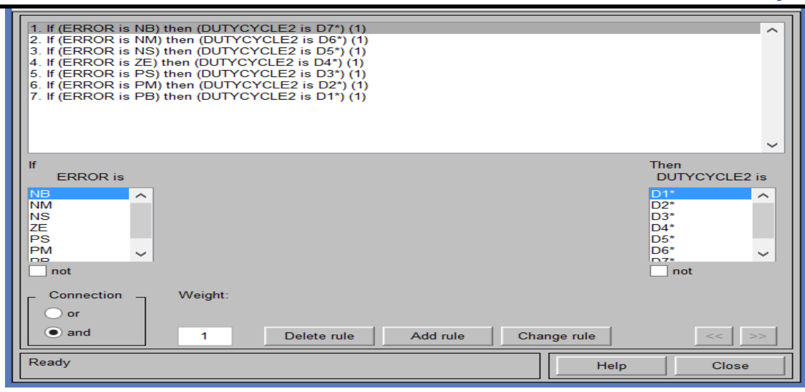

Figure 8. Fuzzy Rules for input error and duty cycle of switch S2

2-D surface view of the fuzzy rules for switches S1 and S2 as shown in figure 9 and 10 respectively. X axis represents Error and Y axis represents Duty cycle for switch S1 and S2.

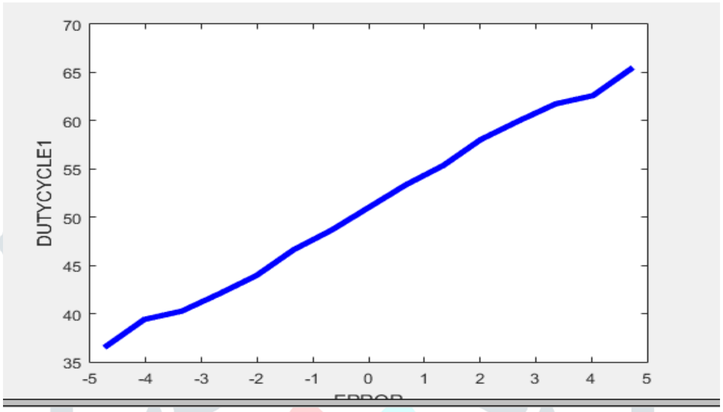

Figure 9. 2-D surface view of fuzzy rule for switch S1

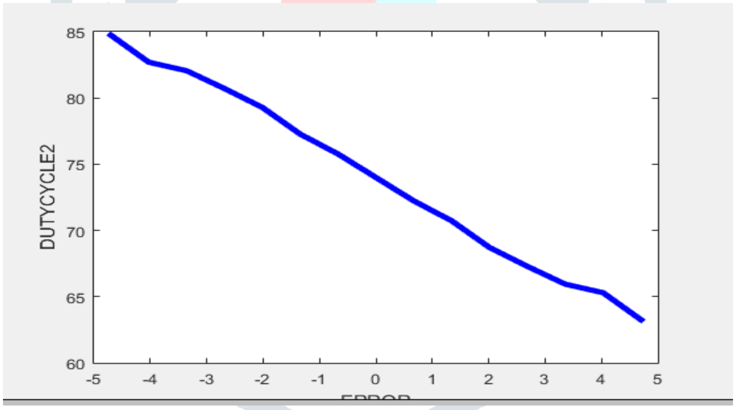

Figure 10. 2-D surface view of fuzzy rule for switch S2

2.3. Fuzzy Inference

Fuzzy inference is a system which simulates the decision making process using fuzzy rules which are written in the fuzzy interference engine. The mapping of fuzzy or crisp input to an output fuzzy set this methodology is called fuzzy inference. Basically Fuzzy inference are classified into two methods are Mamdani and Takagi-Sugeno. Mamdani method is commonly used method which is MAX-MIN method for AND-OR operation. All fuzzy consequents are combined to obtain a final fuzzy output after the aggregation process in nonlinear variable. Mamdani has more preferred than sugeno method.

2.4. Defuzzification

Defuzzification is a process of transformation of fuzzy output into the crisp value. The linguistic variables are converted in to a numerical variable. Centroid method is more common way to defuzzy the fuzzy quantities. It is stated as center of mass method. The output of the defuzzification using the centroid method is expressed in

$$Z^* = \frac{\int \mu_A(z).zdz}{\int \mu_A(z).dz} \qquad (2.2)$$

Where, μ_A(z) is the membership function of the linguistic variable duty ratio and Z is the numerical value of D corresponding to the designed FLC action.

III. Simulation Model And Results

The simulation model of close loop controlled soft switching dc-dc Boost converter using fuzzy logic controller is designed in MATLAB/Simulink as shown in figure 11. The open loop and close loop soft switching boost converter parameters are shown in table I. The main aim of implementing fuzzy controller for soft switching boost converter is to maintain the constant output voltage of 18Volts for a variable input voltage from 9Volts to 15Volts as shown in figure 12. By using soft switching technique, The switch S1 and S2 turn ON with ZVS condition. That is when the gate pulse is applied to make it turn on, voltage across the switch is zero. Hence voltage and current stresses are reduced as shown in figure 15. And similar results for variable input voltage which is mention in table II are shown in figure 13 and 14. For closed loop fuzzy control strategy, the reference voltage is set to 18V to track the output voltage. In presented model, error is taken as input to the fuzzy and Duty cycle is given as output of the fuzzy given to the both switches S1 and S2.The major advantage of the application of fuzzy logic in the system is to control the behavior of the system with rule sentences rather than particular maths equations of the system.

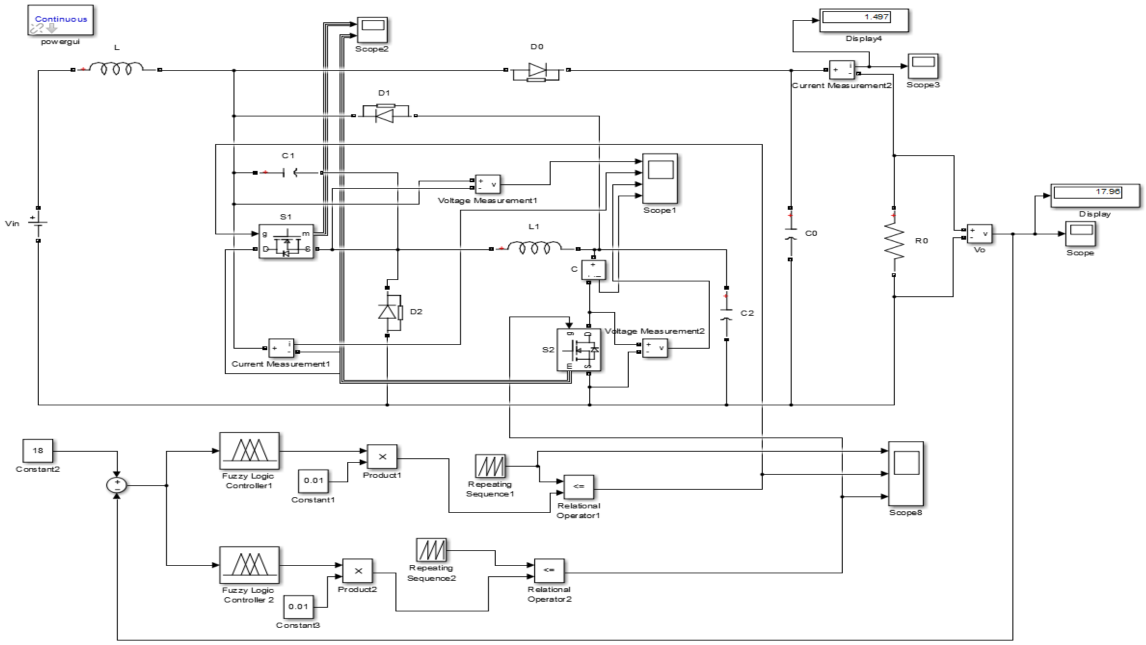

Figure11. MATLAB/Simulation model of soft switching dc-dc boost converter in close loop method with fuzzy logic controller

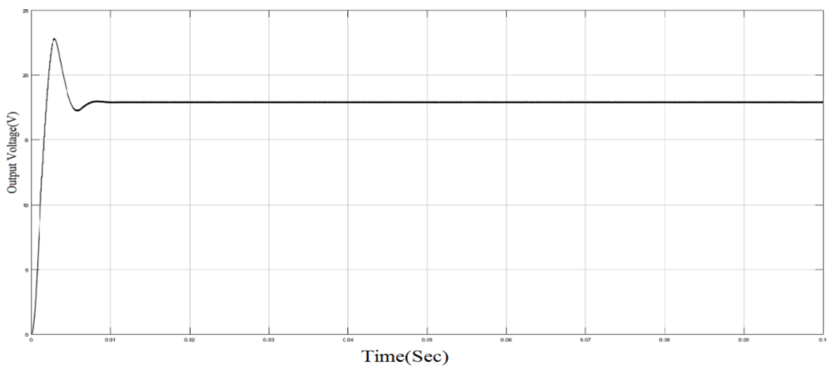

Figure 12. Waveform of output volatge of Vin=12V with fuzzy logic controller

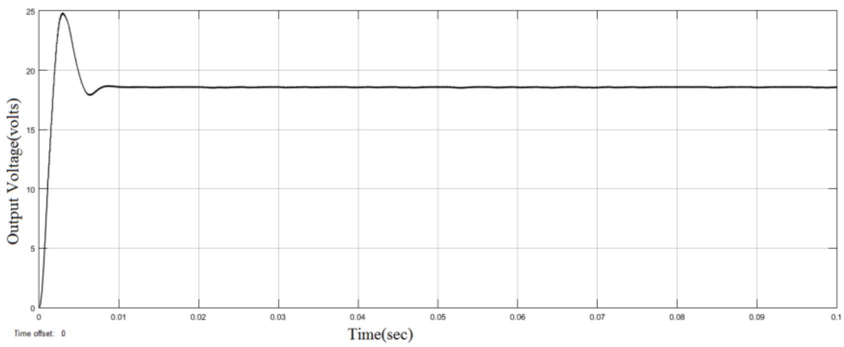

Figure 13. Waveform of Output voltage of Vin=13V with fuzzy logic controller

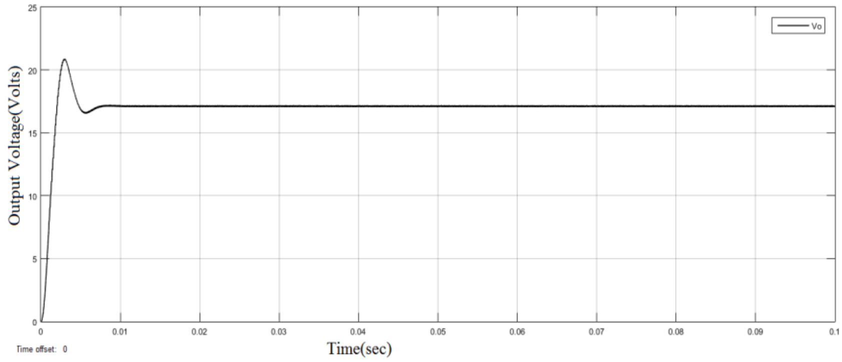

Figure 14. Waveform of Output Voltage of Vin=11V with fuzzy logic controller

Table 1.Circuit Parameters Used For Simulation Purpose

Indicator	Parameter	Value
Vi	Input Voltage	12V
Vo	Output Voltage	18V
fs	Switching Frequency	10kHz
L	Filter inductor	1mH
Co	Filter capacitor	500μF
L1	Resonant inductor	0.1mH
C1	Resonant capacitor	0.4μF
C2	Resonant capacitor	0.4μF
R	Load resistance	12Ω
D1	Duty cycle for switch S1	0.54
D2	Duty cycle for switch S2	0.76

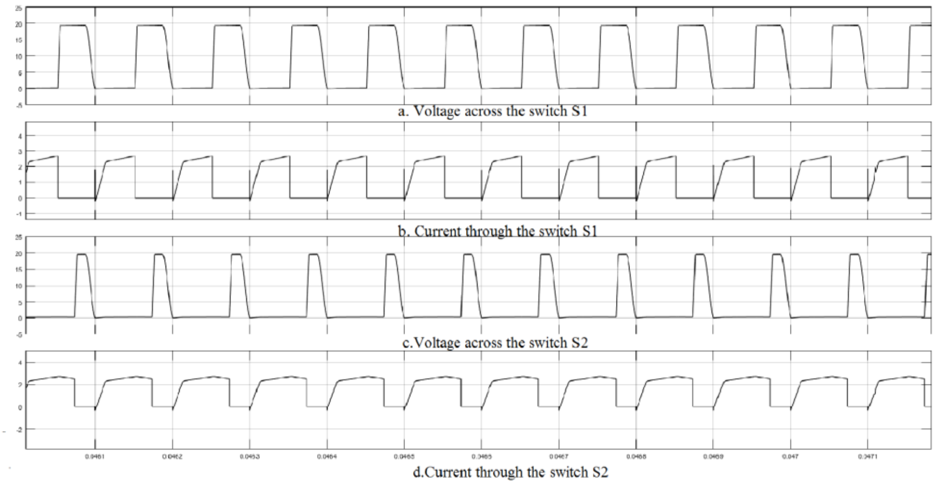

Figure 15. The waveform of soft switching condition in close loop operation a)Voltage across the switch S1 b)Current through switch s1 c)Voltage across switch S2 d)Current through switch s2

Table II. Simulation Results For Different Input Voltage

Input Voltage (Vin) in Volts	Duty Cycle (D1)	Duty Cycle (D2)	Output Voltage (Vout) in Volts
11	53.77	71.93	17.18
12	51.61	73.99	18
13	48.68	75.74	18.62

IV. CONCLUSION

In this paper, The Control of soft switching DC-DC boost converter with a fuzzy logic controller using MATLAB Simulink has been proposed. The main aim of this paper is to maintain the output voltage constant for the variable input voltage and to implement the FLC technique in an easy way to control the duty cycle of the soft switching boost converter directly. Based on the simulation results, it illustrates from the response the close loop controlled system using FLC gives the small overshot, settling time will be very less and zero steady state error. this is possible since fuzzy rules can be assigned separately for the various regions of operation, resulting in effective small signal and large signal operation. Simulation results are obtained using MATLAB/Simulink.

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