Fuzzy Logic Control for Renewable Source DC-DC Boost Converter using MATLAB

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Abstract – DC- DC boost converters are switched power converters. In this article, the boost converter for 300V is designed. The main drawback of the power converter is the unlimited supply of voltage and current. In order to control the output voltage with variations in the input voltage, a Fuzzy Logic Controller (FLC) is designed. The output response of the open loop model of the converter and the FLC system is compared using the simulation results. This article also gives the overall design procedure for the boost converter and its controller transfer function.

Index Terms – Converter, FLC, Simulation, Voltage.

1. INTRODUCTION

DC-DC boost converters usually provide variations in output voltage with respect to input voltage. The free supply of voltage and current leads to malfunctioning of the boost converter. Control techniques such as analog and digital methods are used [1]. DC-DC converters are intrinsically non-linear circuits and it is difficult to obtain accurate models which influences dynamic behavior. The DC-DC converter inputs are generally unregulated DC voltage input and the required outputs should be a constant or fixed voltage. Application of a voltage regulator is that it should maintains a constant or fixed output voltage irrespective of variation in load current or input voltage. Boost converters are widely used for power monitoring of the renewable energy sources such as solar cell, wind mills, wind generators and fuel cell systems. Because of these advantages boost converters are more extensively used in industrial applications. In this article, the transient response of the converter system is improved FLC using MATLAB.

2. PROPOSED MODELING

The Boost converter is designed using the following procedure:

2.1. Design of Boost Converter

The necessary parameter for the design of boost converter is the input voltage, output voltage, output current and switching frequency. Figure 1 shows the basic circuit of boost converter [2].
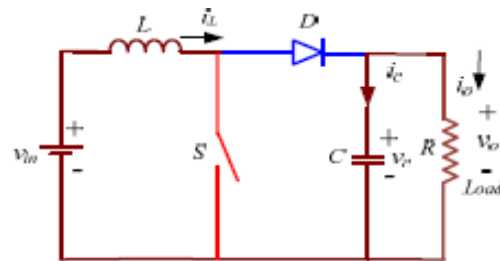

Figure 1 Ideal Boost Converter Circuit

Duty Cycle (D): to determine the duty cycle D, for the minimum input voltage. The minimum input voltage is used because it leads to the maximum switching current.

$$D = 1 - \frac{Vin}{Vo} \tag{1}$$

Vin = input voltage

Vo = desired output voltage (2)

Load Resistance (R):

$$R = \frac{Vo}{Io}$$

V_o = desired output voltage (3)

I_o = desired output current

Inductance (L):

$$L = \frac{Vin*(Vo-Vin)}{\Delta Il*fs*Vo}$$

$\Delta Il = 10\% \ of \ Io$

V_{in} = input voltage

V_o = desired output voltage

f_s = switching frequency

ΔIl = inductor ripple current

I_o = desired output current

Capacitance (C):

$$C = \frac{(Io*D)}{(fs*\Delta Vo)} \tag{4}$$

$$\Delta Vo = ESR\left(\frac{Io}{1-D} + \frac{\Delta ll}{2}\right) \tag{5}$$

I_o = desired output current

D = duty cycle

f_s = switching frequency

ΔVo = output ripple voltage

ΔIl = inductor ripple current

ESR = equivalent series resistance of the capacitor

Diode: In order to reduce losses, ultra-fast recovery diodes can be used. The forward current rating needed is equal to the maximum output current. From the above equations the design parameters are obtained as shown in Table 1.

S.NO	PARAMETERS	VALUES
1.	Input Voltage (V_{in})	60 V
2.	Input Current (I_{in})	5 A
3.	Output Voltage (V_o)	300 V
4.	Output Current (I_o)	1 A
5.	Duty Cycle (D)	0.8
6.	Load Resistance (R)	300 Ω
7.	Inductance (L)	240 mH
8.	Equivalent Series Resistance (ESL)	0.5 Ω
9.	Capacitance (C)	5000 μF
10.	Equivalent Series Resistance (ESR)	16 mΩ

*Units: V- volt, A- ampere, Ω- ohms, mH- milli Henry, μF- micro Farad

Table 1 Design Specifications

3. STATE SPACE MODELING

The modeling of DC-DC boost converter is carried out to determine the state space model. The output and the control transfer function of the system are obtained from the state space model using MATLAB. This method is known as state space averaging technique. The operation of the boost converter takes place in two modes [3]:

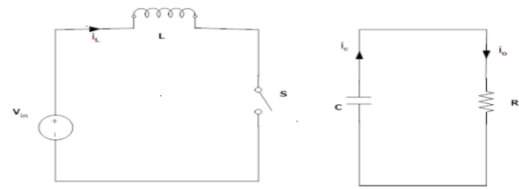### 3.1. Switch ON Equivalent Circuit

Figure 2 Boost converter- ON mode

During ON mode as shown in Figure 2, the state equation matrices are given by-

$$\begin{bmatrix} \frac{di_l}{dt} \\ \frac{dv_c}{dt} \end{bmatrix} = \begin{bmatrix} \frac{-R_l}{L} & 0 \\ 0 & \frac{-1}{C*(R+R_c)} \end{bmatrix} * \begin{bmatrix} i_l \\ V_c \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} * V_{in} \tag{6}$$

$$V_o = [0 \quad \frac{R}{R+R_c}] * \begin{bmatrix} i_l \\ V_c \end{bmatrix} \tag{7}$$

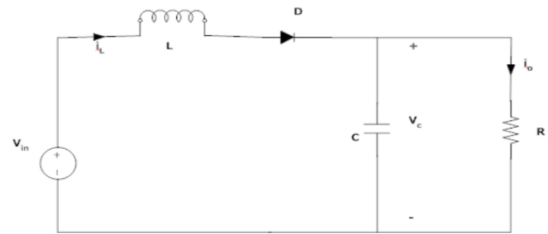### 3.2. Switch OFF Equivalent Circuit

Figure 3 Boost converter- OFF mode

During OFF mode as shown in Fig 3, the state equation matrices are given by-

$$\begin{bmatrix} \frac{di_l}{dt} \\ \frac{dv_c}{dt} \end{bmatrix} = \begin{bmatrix} \frac{-R_l+(R\|R_c)}{L} & \frac{-R}{L(R+R_c)} \\ \frac{R}{C(R+R_c)} & \frac{-1}{(R+R_c)} \end{bmatrix} * \begin{bmatrix} i_l \\ V_c \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} * V_{in} \tag{8}$$

$$V_o = [(R\|R_c) \quad \frac{R}{(R+R_c)}] * \begin{bmatrix} i_l \\ V_c \end{bmatrix} \tag{9}$$

The state space parameters A, B, C and D matrices for the above equations are obtained for ON and OFF states. By averaging techniques the determined matrices are:

$$A_{avg} = \begin{bmatrix} -2.06972 & -0.8332 \\ 39.996 & -0.666 \end{bmatrix}$$

$$B_{avg} = \begin{bmatrix} 4.166 \\ 0 \end{bmatrix}$$

$$C_{avg} = [0.003198 \quad 0.999]$$

$$D_{avg} = [0]$$

Using MATLAB, the output transfer function obtained is

$$\frac{V_o}{V_{in}} = \frac{0.0133s+166.5}{s^2+2.753s+34.72} \qquad (10)$$

The response of the output transfer function is shown in results and discussion. Figure 4 shows the open loop simulink model.
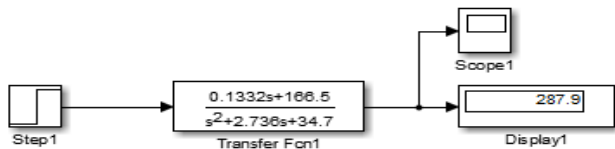

Figure 4 Open loop simulink model

4. MODELING OF CONTROLLER

The boost converter should always maintain constant voltage with variations in the input parameters. In order to maintain a stable output in the converter, an appropriate control signal should be applied. In practice the switching network is highly non-linear. An accurate mathematical modeling of the switching network is very difficult to obtain. In addition there are also reported problems of the supply voltage and load current fluctuating over a wide range. A controller is designed and modeled which yields the control transfer function and the controller transfer function. Therefore a Fuzzy Logic controller is implemented to achieve a proper system performance [4]. The occurrence of oscillatory behaviour of the boost converter is mainly caused by the switching operation of the semiconductor device. In order to stabilize the transient response of the system, FLC controller is implemented. By small signal modeling technique, the control transfer function is determined.

$$\frac{V_o}{d} = \frac{-0.7999s^2-996s+49500}{s^2+2.753s+34.72} \qquad (11)$$

4.1. Fuzzy Logic Controller (FLC)

PID controller are most widely used controllers and they are widely used in most power electronic closed loop appliances, But in the recent years, the Fuzzy Logic Controller (FLC) are considered to be one of intelligent controllers. This paper is using fuzzy logic controller with feedback of voltage output respectively. The voltage output in the circuit will be fed to fuzzy controller to give appropriate measure on steady state signal [5]. FLC offers an important concept of soft computing with words. It provides technique which deals with imprecision. The fuzzy theory provides mechanism for representation of linguistic terms such as "many," "low," "medium," "often," "few." In general, the fuzzy logic provide an inference structure that enable appropriate human reasoning capabilities. Fuzzy logic systems are suitable for approximate reasoning. Fuzzy logic systems have faster and smoother

response than conventional systems and control complexity is less. The fuzzy inference system combines fuzzy IF–THEN rules for mapping from fuzzy sets in the input space X to the output space Y based on fuzzy logic principle. In fuzzy logic, knowledge representation, fuzzy IF–THEN rule is a technique for capturing knowledge that involve imprecision. The main feature of reasoning using fuzzy rules is its partial matching capability, an inference to be made from fuzzy rule even when the rule's conditions are partially satisfied [6]. Figure 5 shows the simulink model of the FLC. Table 2 shows the rule-base for the boost converter. The transfer function for the compensator is determined as

$$\frac{6.3443s^2+49.8473s+101.73}{s^2+100s} \qquad (12)$$

Therefore the overall control transfer function is

$$\frac{-0.5083s^6-6327s^5+(2.583*10^5)s^4+(3.906*10^6)s^3+(2.385*10^7)S^2+(1.308*10^8)s+(1.75*10^8)}{s^6+84.55s^5+1452s^4+(1.744*10^4)s^3+(8.935*10^4)s^2+(4.408*10^5)s+(5.834*10^5)}$$
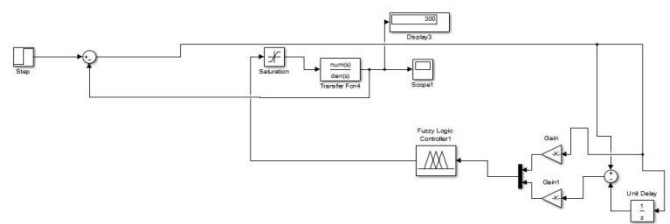
$$(13)$$

Figure 5 Simulink model of FLC

| e\ce	MN	NB	N	Z	P	PB	MP
MN	MN	MN	MN	MN	NB	N	Z
NB	MN	NB	NB	NB	N	Z	P
N	MN	NB	N	N	Z	P	PB
Z	MN	NB	N	Z	P	PB	MP
P	NB	N	Z	P	P	PB	MP
PB	N	Z	P	PB	PB	PB	MP
MP	Z	P	PB	MP	MP	MP	MP

*ce- change of error, e- error

Table 2 Rule-Base

5. PV CELL MODELING

A solar cell is an electrical device which converts the sunlight directly into electric signals. Solar cells are also called as

photovoltaic cells. A couple of these cells together is commonly called as solar panels or photovoltaic panels. The modeling of the solar panel is done to obtain a DC voltage source of 60V using MATLAB [7]. Figure 6 shows the simulink model of PV cell.
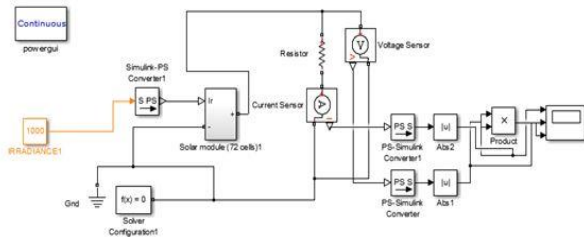
6. RESULTS AND DISCUSSIONS

In this section, the output responses of the open loop model and FLC are compared. Figure 7 and 8 shows the responses of open loop and FLC.
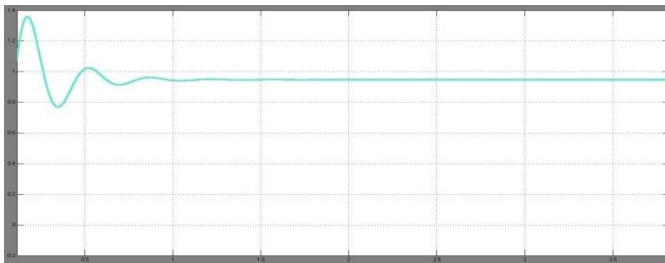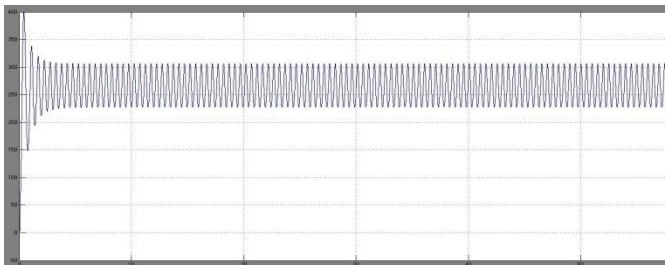

Figure 7 Response of Open loop model

Figure 8 Response of FLC

7. CONCLUSION

In this article, the output voltage is controlled using FLC with the variations in the input supply of voltage to the boost converter. The output voltage of Boost converter can be stabilized using variable duty cycle generated by the fuzzy logic controller. Boost converter with closed loop FLC precisely improved the dynamic response of the converter system. The circuit is simpler and much cheaper compared to other control mechanisms where large numbers of components are needed.

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