Correlative Study on The Modeling and Control of Boost Converter using Advanced Controllers

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Abstract— DC-DC converters are switched power converters. The converters are most widely used in research and industrial applications. The DC-DC Boost Converters are used to step-up the supply voltage given to the plant model. The main advantage of using the Boost Converters is that it works in the low voltage according to the design specifications. In order to regulate the uncontrolled supply of voltage, a controller has to be designed and modeled to stabilize the output voltage. Since the convectional controllers cannot work under dynamic operating conditions, advanced controllers are to be designed to overcome the problems. In this article, the advanced controllers such as NARMA-L2, Fuzzy Logic (FLC) and Sliding Mode Controllers (SMC) are implemented and their responses are compared using MATLAB.

Key words: FLC, Duty Cycle (D), Design of Sliding Mode Control (SMC)

I. 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 behaviour. 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 by NARMA-L2, FLC and SMC using MATLAB and the responses are compared.

II. MODELING OF BOOST CONVERTER

The Boost converter is designed using the following procedure:

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

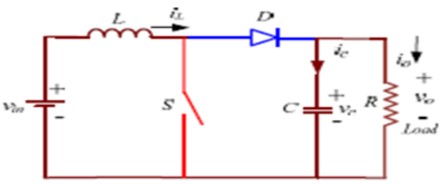

Fig. 1: Boost Converter Circuit.

A. *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.

$$D = 1-\frac{Vin}{Vo} \qquad (1)$$

Vin = input voltage

Vo = desired output voltage

1) *Load Resistance (R):*

$$R=\frac{Vo}{Io} \qquad (2)$$

V_o = desired output voltage

I_o = desired output current

2) *Inductance (L):*

$$L=\frac{Vin*(Vo-Vin)}{\Delta Il*fs*Vo} \qquad (3)$$

ΔIl = 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

3) Capacitance (C):

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

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

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

4) *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 I.

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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.	Switching frequency (f_s)	2 KHz
7.	Load Resistance (R)	300 Ω
8.	Inductance (L)	240 mH
9.	Equivalent Series Resistance	0.5Ω
10.	(ESL)	5000 µF

11.	Capacitance (C) Equivalent Series Resistance (ESR)	16 mΩ

Table I: Design Specifications

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

III. 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]:

A. *Switch On Equivalent Circuit*

Fig. 2: ON Mode Circuit

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

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

$$V_o = \begin{bmatrix} (R\|R_c) & \frac{R}{(R+R_c)} \end{bmatrix} * \begin{bmatrix} i_l \\ V_c \end{bmatrix} \quad (7)$$

B. *Switch Off Equivalent Circuit*

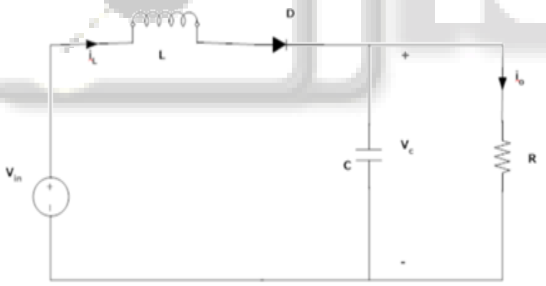

Fig. 3: OFF Mode Circuit

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

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

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

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

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

IV. MODELING & IMPLEMENTATION 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 NARMA-L2 Controller, Fuzzy Logic controller and Sliding Mode Control are 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, NARMA-L2, FLC and SMC are implemented. By small signal modeling technique, the control transfer function is determined.

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

A. *Design Of NARMA-L2 Control*

NARMA-L2 Controller is also called as Feedback Linearization Control (FLiC). If the model is inn companion form, then it is called as FLiC. When the converter model is approximated in the same form, it is called as NARMA-L2 Control. The design of NARMA-L2 Control aims at transforming the non-linear dynamics into linear dynamics by nullifying the non-linear behaviour of the model [5]. Fig. 4 shows the simulink model of the NARMA-L2 Controller.

FLiC is used for identification of the system that is to be controlled. Training of the ANN depicts the forward dynamics of the converter model. Initially, the dynamics of the converter model that is to be controlled should be chosen. The standard model of NARMA-L2 control is

x(a+ b) = P[x(a), x(a- 1), x(a - t +1),m(a),m(a -1), m(a - t +1)] [12]

where m(a) is the system input, and x(a) is the system output. Identification of the model can be done by training the ANN to approximate the nonlinear function P.

The model output is given as

$x(a + b) = x_r(a + b)$ [13]

The controller of the model is given as

$m(a) = Q[x(a), x(a -1), x(a - t +1), x_r(a + b), x(a -1), x(a -t +1)]$ [14]

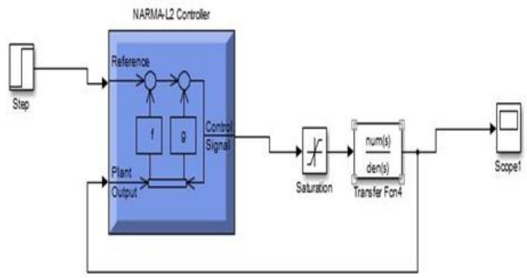

Fig. 4: Simulink Model of NARMA-L2 Controller

B. Design Of Fuzzy Logic Controller (FLC)

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 [6]. 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 [7]. Fig. 5 shows the simulink model of the FLC. Table 2 shows the rule-base for the boost converter.

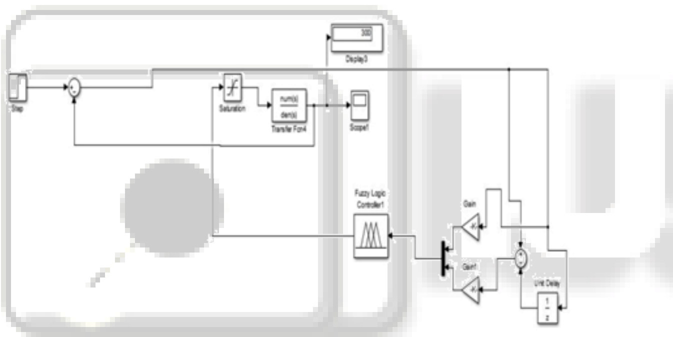

Fig. 5: Simulink Model of FLC

ce \ e	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

Table II: Rule Base

*ce- change of error, e- error

C. Design Of Sliding Mode Control (SMC)

SM controller is a type of non-linear controller. It is employed and adopted for controlling variable structured systems (VSSs). It is very easy to implement as compared to other types of nonlinear and classical controllers [8]. Two important steps in SM control is to design a sliding surface in state space and then prepared a control law to direct the system state trajectory starting from any arbitrary initial state to reach the sliding surface in finite time, and at the end it should arrive to a point where the system equilibrium state exists that is in the origin point of the phase plane. There are three important factors responsible for the stability of SM controllers, existence, stability, and hitting condition. The sliding line divides the phase plane into two main regions. Each region is represent by a switching state and when the trajectory comes at the system equilibrium point, in this case the system is considered as stable system [9].

Fig. 6 shows simulink model of the sliding mode control technique that operates at infinite switching frequency. But practical SM controllers are operated at finite switching frequencies represent a quasi-sliding mode [10]. The transfer function for the compensator is determined as

$$\frac{6.3443s^2 + 49.8473s + 101.73}{s^2 + 100s} \tag{15}$$

Therefore the overall control transfer function is

$$\frac{-0.5083s^6 - 6327s^5 + (2.583*10^5)s^4 + (3.906*10^6)s^3 + (2.385*10^7)S^2 + (1.308*10^8)s + (1.75*10^8)}{s^6 + 84.55s^5 + 1452s^4 + (1.744*10^4)s^3 + (8.935*10^4)s^2 + (4.408*10^5)s + (5.834*10^5)} \tag{16}$$

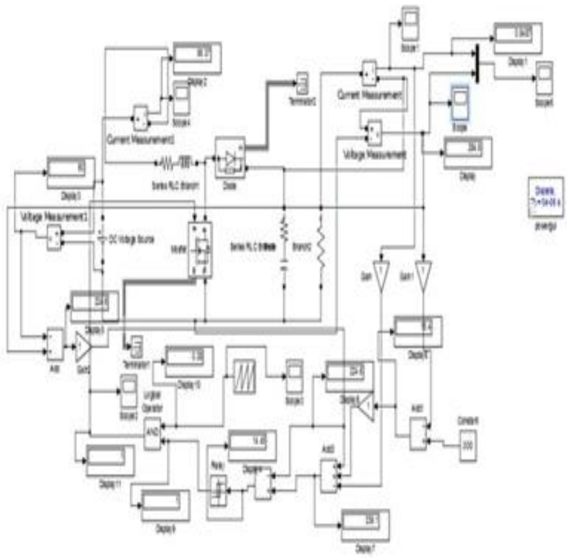

Fig. 6: Simulink Model of SMC

V. RESULTS AND DISCUSSIONS

In this section, the output response of the NARMA-L2, FLC and SMC controllers are compared and the response shows that the performance of the boost converter is improved. Fig. 7, 8 and 9 shows the response of the advanced controllers.

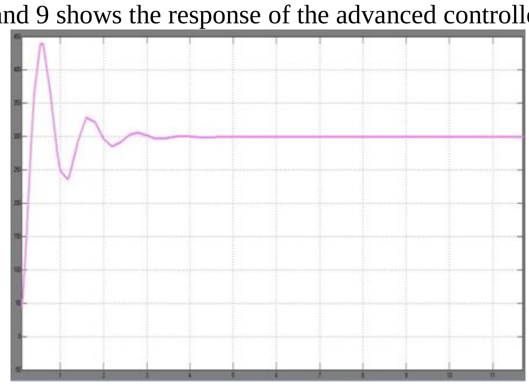

Fig. 7: Response of NARMA-L2 Controller

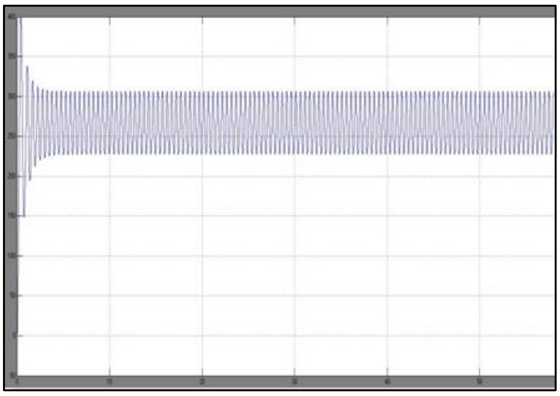

Fig. 8: Response of FLC

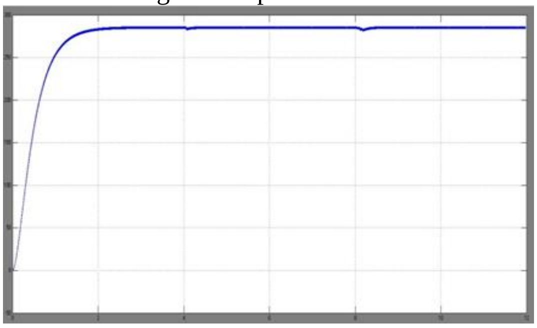

Fig. 9: Response of SMC

VI. CONCLUSION

In this article, the boost converter for the desired specification was obtained. The advanced controllers such as NARMA-L2 Control, FLC and SMC are modeled and designed. In this, the SMC have produced an improved output response using MATLAB. Since the advanced controllers are used, the Boost Converter operates in the dynamic operating conditions. Further this work can be developed into hardware using the required components and arduino boards.

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