METAPHORICAL STUDY ON THE PERFORMANCE OF CONTROLLERS IN MODELING, CONTROL AND SIMULATION OF RENEWABLE SOURCE BOOST CONVERTER USING MATLAB

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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. The DC-DC Boost Converter working is mainly based on the ON and OFF state of the switch. This process is known as the duty cycle. Pulse Width Modulation (PWM) is the technique used as the trigger to produce pulse input to the switch. In order to regulate the uncontrolled supply of voltage, a controller has to be designed and modeled to stabilize the output voltage. The controller is designed to control the duty cycle of the switch which in turn controls the switch ON and OFF state. Since the convectional controllers cannot work under dynamic operating conditions, advanced controllers are to be designed to overcome the problems. In this article, the performance of the convectional controllers and advanced controllers such as Model Predictive Control (MPC), NARMA-L2 Controller, Fuzzy Logic Controller (FLC) and Sliding Mode Controller (SMC) are implemented and their responses are compared using MATLAB. This Boost Converter is designed with the renewable source such as solar energy as the input. Solar energy is converted into electrical energy using the solar panels. It is used to control the speed of the universal motor connected to a pump which is used in application such as flow control in Plate Type Heat Exchangers.***

Key Words: *Converter, duty cycle, MATLAB, model, operating condition, renewable source*

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 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 comparison of the controllers such as PID, MPC, NARMA-L2, FLC and SMC using MATLAB [2] and the responses are presented.

2. DESIGN OF BOOST CONVERTER

The boost converter is a high efficiency step-up DC/DC switching converter. The converter uses a transistor switch, typically a MOSFET, to pulse width modulate the voltage into an inductor. 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 [3].

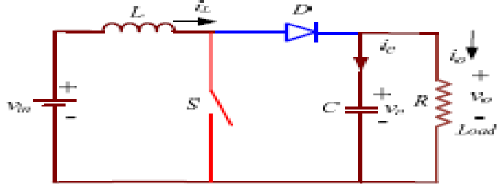

Fig -1: Boost Converter Circuit

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.

$$D = 1 - \frac{V_{in}}{V_o} \quad (1)$$

V_{in} = input voltage

V_o = desired output voltage

Load Resistance (R):

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

V_o = desired output voltage

I_o = desired output current

Inductance (L):

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

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

V_{in} = input voltage

V_o = desired output voltage

f_s = switching frequency

ΔIl = inductor ripple current

I_o = desired output current

Capacitance (C):

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

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

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.

Table -1: Design Specifications

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

3. MODELNG OF BOOST CONVERTER (STATE SPACE AVERAGING TECHNIQUE)

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 [4]:

3.1 Switch ON Equivalent Circuit

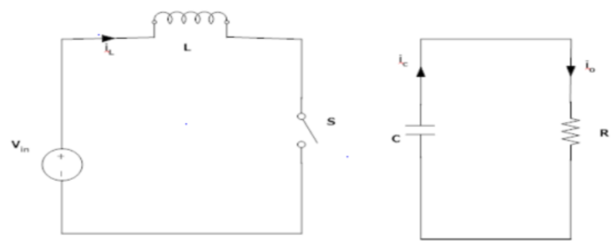

Fig -2: ON Mode Circuit

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

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

$$V_o = \begin{bmatrix}0 & \frac{R}{R+R_c}\end{bmatrix} * \begin{bmatrix}i_l\\ v_c\end{bmatrix} \quad (7)$$

3.2 Switch OFF Equivalent Circuit

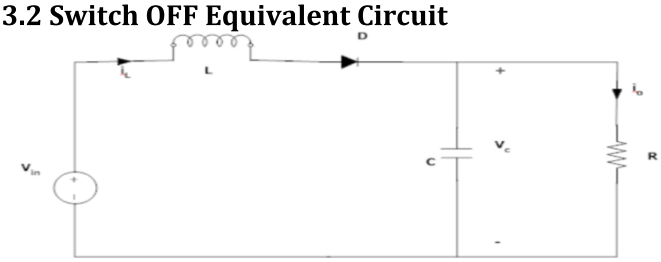

Fig -3: OFF Mode Circuit

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

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

4. IMPLEMENTATION OF CONTROLLERS FOR BOOST CONVERTER

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 real time PID controller is implemented to achieve a proper system performance [5]. 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, PID controller is implemented. Pulse Width Modulation (PWM) technique is the often used switching control method. Proportional-Integral-Derivative (PID) controllers are employed for PWM switching control mainly because of its simplicity. By small signal modeling technique, the control transfer function is determined.

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

4.1 PID Tuning

The most widely used tuning method for PID controller is Zeigler-Nichols method. Zeigler-Nichols tuning method is applied to obtain the K_p, T_i and T_d values of the closed loop transfer function of the converter [6]. The proportional gain is slowly increased by giving small periodic disturbance to the process. At one point of time, closed loop response tends to produce sustained oscillations and Table -2 shows the tuning parameters. From the oscillations obtained, the ultimate gain (K_u) and the period of oscillation known as ultimate period (P_u) are calculated. Using the values of K_u and P_u, the K_p, T_i and T_d parameters are determined. Fig -4 shows the closed loop simulink model [7,8].

Table -2: Tuning Parameters

S.No	TYPE OF CONTROLLER	K_p	T_i	T_d
1.	P	0.4883	-	-
2.	I	-	1.0173	-
3.	D	-	-	0.05856

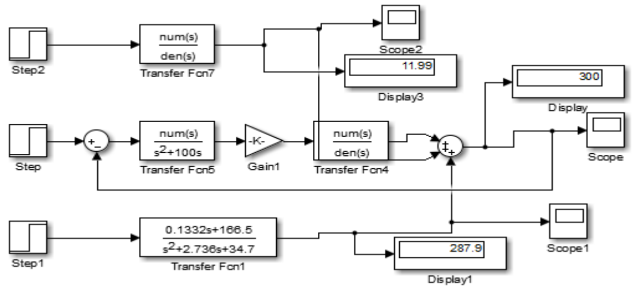

Fig -4: PID Simulink Model

The transfer function for the compensator is determined as

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

Therefore the overall control transfer function is

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

4.1 Model Predictive Control (MPC)

Model Predictive Controller is an advanced technique in process control which is used in process industries such as chemical plants and oil refineries. It is also used in power system models. MPC depends on dynamic models of the process. The advantageous factor is that it predicts the future output with respect to the output obtained from the model and the residues obtained between the plant and model output. Based on the future event, MPC takes the control action accordingly. In order to improvise the performance obtained from PID controller, the MPC is implemented and the output response is shown in the results and discussions. Fig -5 shows the simulink model of the Model Predictive Controller [9].

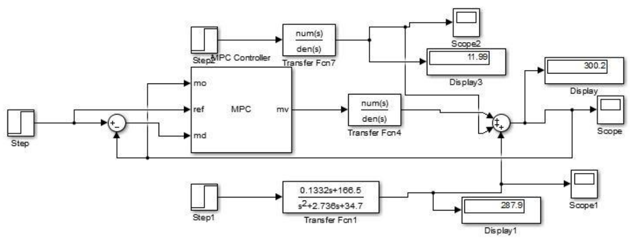

Fig -5: MPC Simulink Model

4.3 NARMA-L2 Controller

NARMA-L2 Controller is also called as Feedback Linearization Control. It is referred to as feedback linearization when the plant model has a particular form (companion form). It is referred to as NARMA-L2 control when the plant model can be approximated by the same form. The central idea of this type of control is to transform nonlinear system dynamics into linear dynamics by cancelling the nonlinearities. Fig -6 shows the simulink model of the NARMA-L2 controller [10].

Feedback linearization (or NARMA-L2) controller is used to identify the system to be controlled. Training a neural network represents the forward dynamics of the system. The first step is to choose a model structure to use. One standard model that is used to represent general discrete-time nonlinear systems is the nonlinear autoregressive-moving average (NARMA) model:

$$y(k+d) = N[\,y(k), y(k-1), , y(k-n+1), u(k), u(k-1), ,u(k-n+1)] \quad (14)$$

where u(k) is the system input, and y(k) is the system output. For the identification phase, you could train a neural network to approximate the nonlinear function N.

The model output to follow some reference trajectory

$$y(k+d) = y_r(k+d), \quad (15)$$

The nonlinear controller of the model is of the form:

$$u(k) = G[y(k), y(k-1), y(k-n+1), y_r(k+d), u(k-1), ,u(k-m+1)] \quad (16)$$

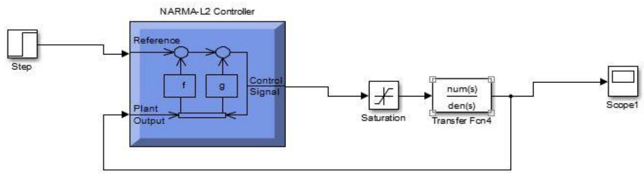

Fig -6: NARMA-L2 Simulink Model

4.4 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 [11]. 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 [12]. Fig -7 shows the simulink model of the FLC. Table -3 shows the rule-base for the boost converter.

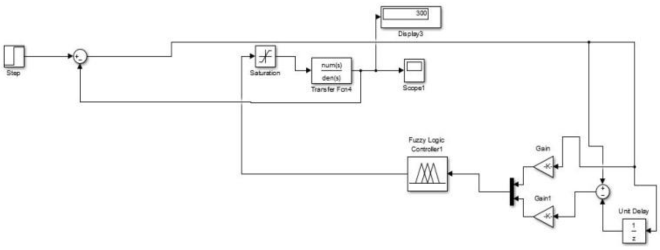

Fig -7: FLC Simulink Model

Table -3: Rule Base

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

4.5 Sliding Mode Controller (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 [13]. 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 [14]. Fig -8 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 [15].

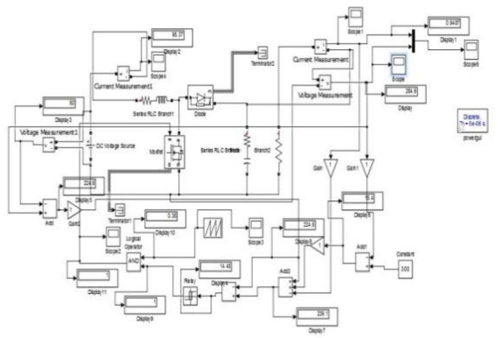

Fig -8: SMC Simulink Model

5. SOLAR CELL MODELLING

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 [16]. Fig -9 shows the simulink model of PV cell.

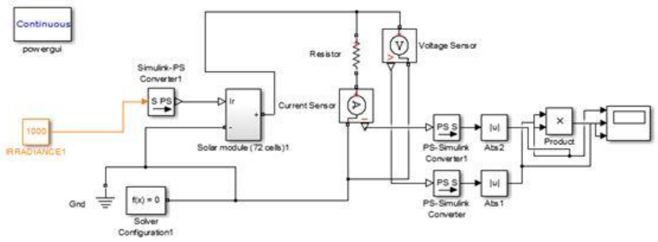

Fig -9: Simulink Model of PV Cell

6. RESULTS AND DISCUSSIONS

In this section, the output responses of the convectional and advanced controllers are compared and the response shows that the performance of the boost converter is improved. Fig -10, 11, 12, 13 and 14 shows the response of the controllers.

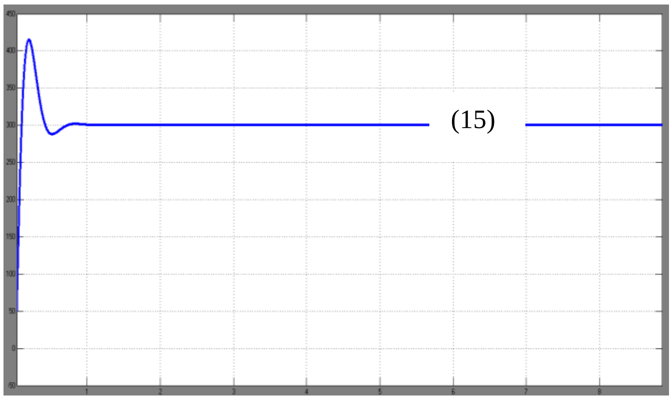

Fig -10: Response of PID

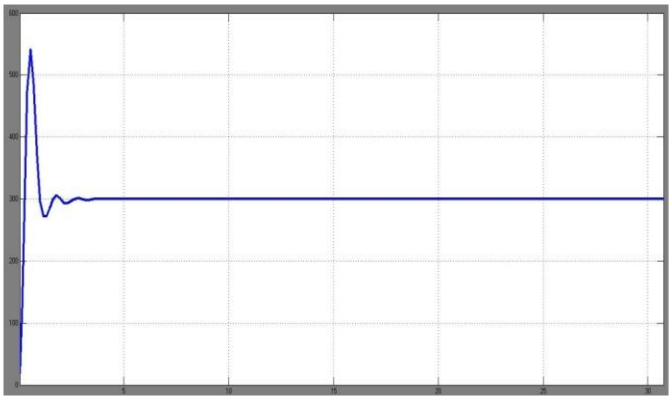

Fig -11: Response of MPC

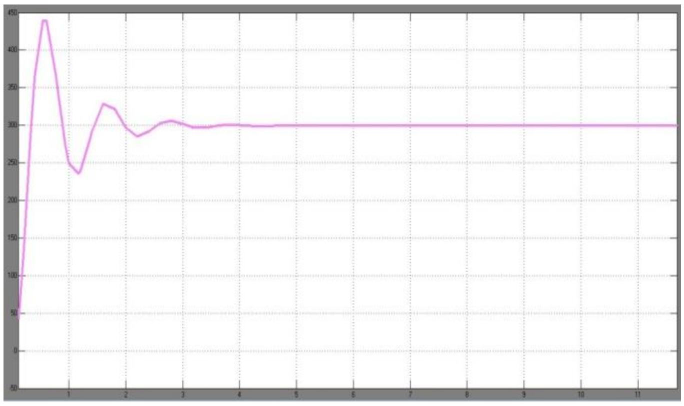

Fig -12: Response of NARMA-L2

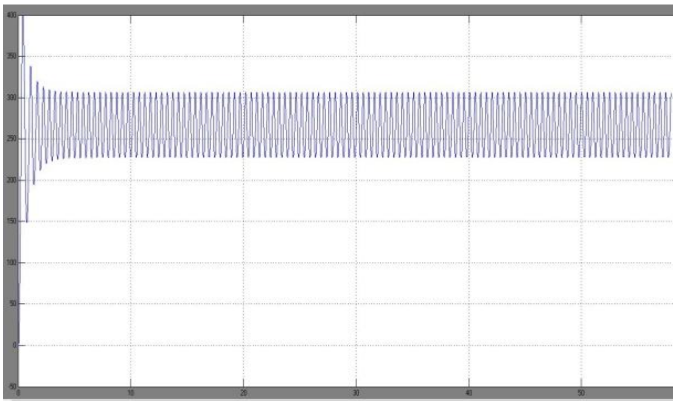

Fig -13: Response of FLC

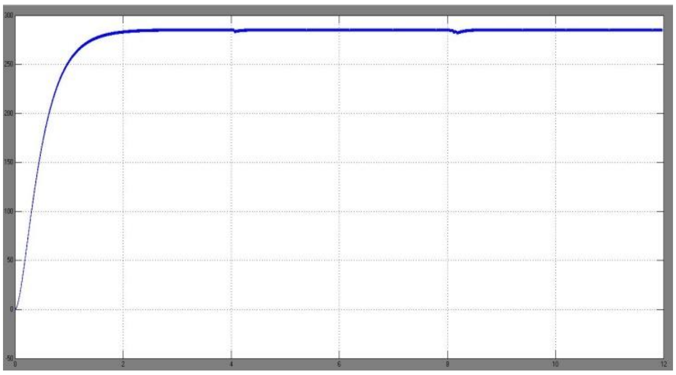

Fig -14: Response of SMC

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