Modeling and Control of Renewable Source Boost Converter using Model Predictive Controller

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ABSTRACT

DC-DC converters are switched power converters. They are used to convert one DC voltage to another DC voltage. It is inordinately used in industry as well as in research. The model of converter system varies from the ON state to the OFF state. The major drawback of the boost converter is the uncontrolled supply of voltage and current. So initially convectional PID controller is designed to regulate the output voltage and shows improved performance of the converter when compared to open loop circuit. The performance of the PID controller is further improvised using the Model Predictive Controller (MPC) and the corresponding responses are compared from the simulation results.

Key words: DC voltage, MPC, PID controller, performance, power converters, simulation.

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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. Generally, DC-DC boost converters consist of power electronic circuits and semiconductor devices which act as the switch control for the system. In this article, the comparison of PID controller and MPC controller responses are determined using MATLAB [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.

Basic Configuration of Boost converter

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].

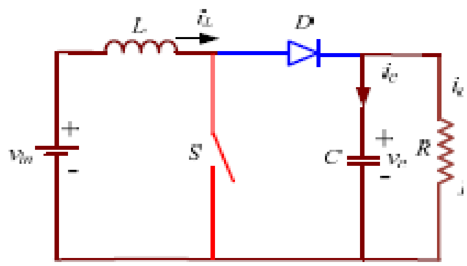

Fig 1: Ideal Boost Converter

Design Calculation

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

Load Resistance (R):

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

V_o = desired output voltage

I_o = desired output current

Inductance (L):

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

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

V_{in} = input voltage

V_o = desired output voltage

f_s = switching frequency

ΔIl = inductor ripple current

I_o = desired output current

Capacitance (C):

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

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

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

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

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 [4]:

Switch ON equivalent circuit

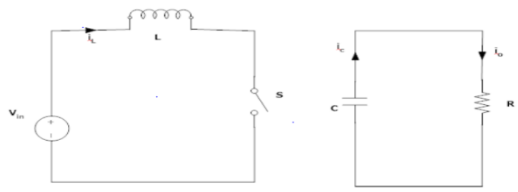

Fig 2: Boost converter- ON mode

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

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

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

Switch OFF equivalent circuit

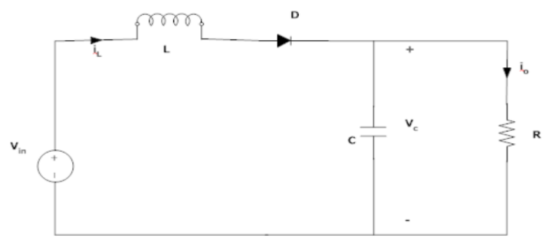

Fig 3: Boost converter- OFF mode

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

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

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

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

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

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

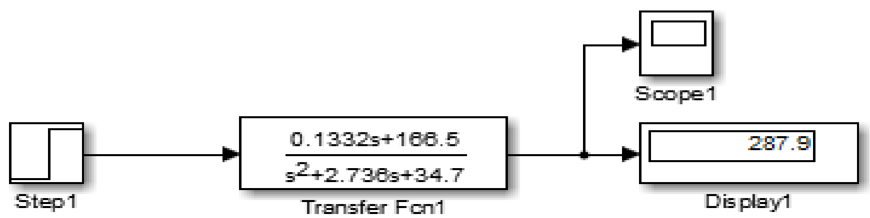

Fig 4: Open loop simulink model

CONTROLLER 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.

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

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 5 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

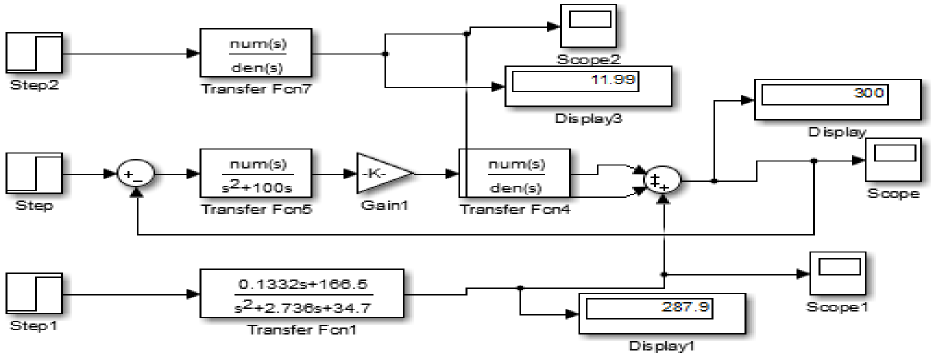

Fig 5: Closed loop simulink model

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

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

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 6 shows the simulink model of the Model Predictive Controller [9].

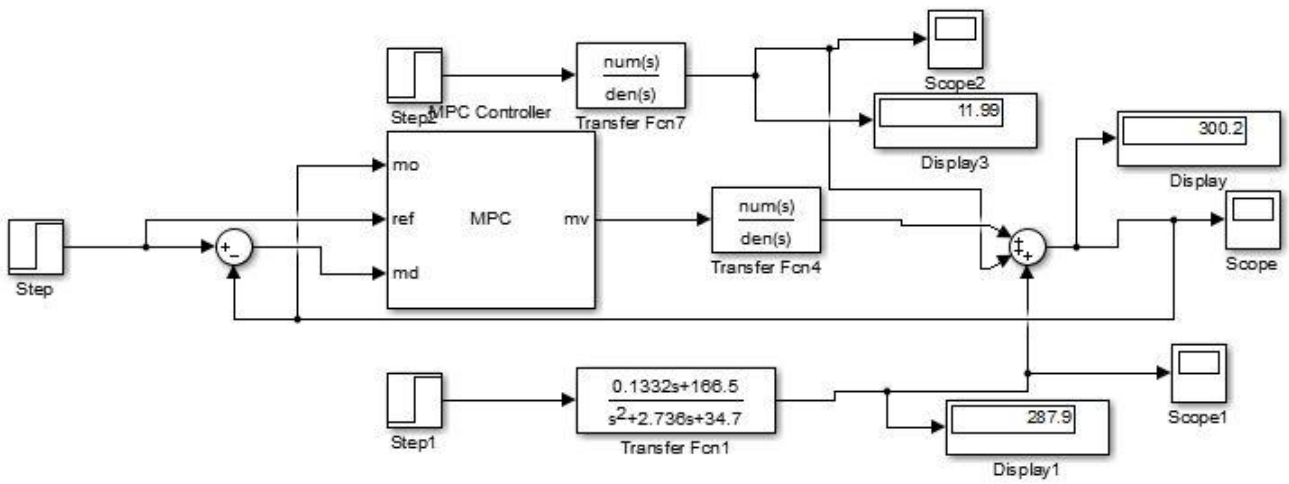

Fig 6: Simulink Model of MPC

SOLAR ENERGY SOURCE

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 [10]. Fig 7 shows the simulink model of PV cell.

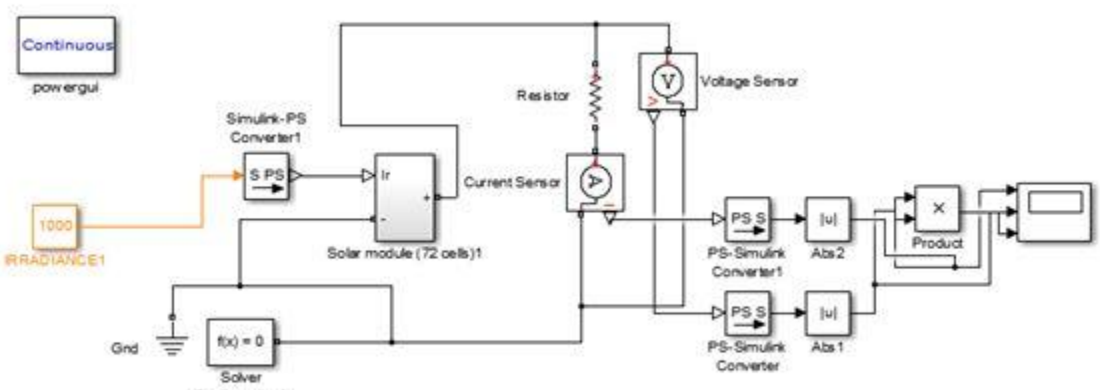

Fig 7: Simulink model of Solar cell

RESULTS AND DISCUSSIONS

In this section, the output response of the PID controller and Model Predictive Controller (MPC) are compared and the response shows that the performance of the boost converter is improved using MPC. Fig 8 and 9 shows the response of the PID and MPC.

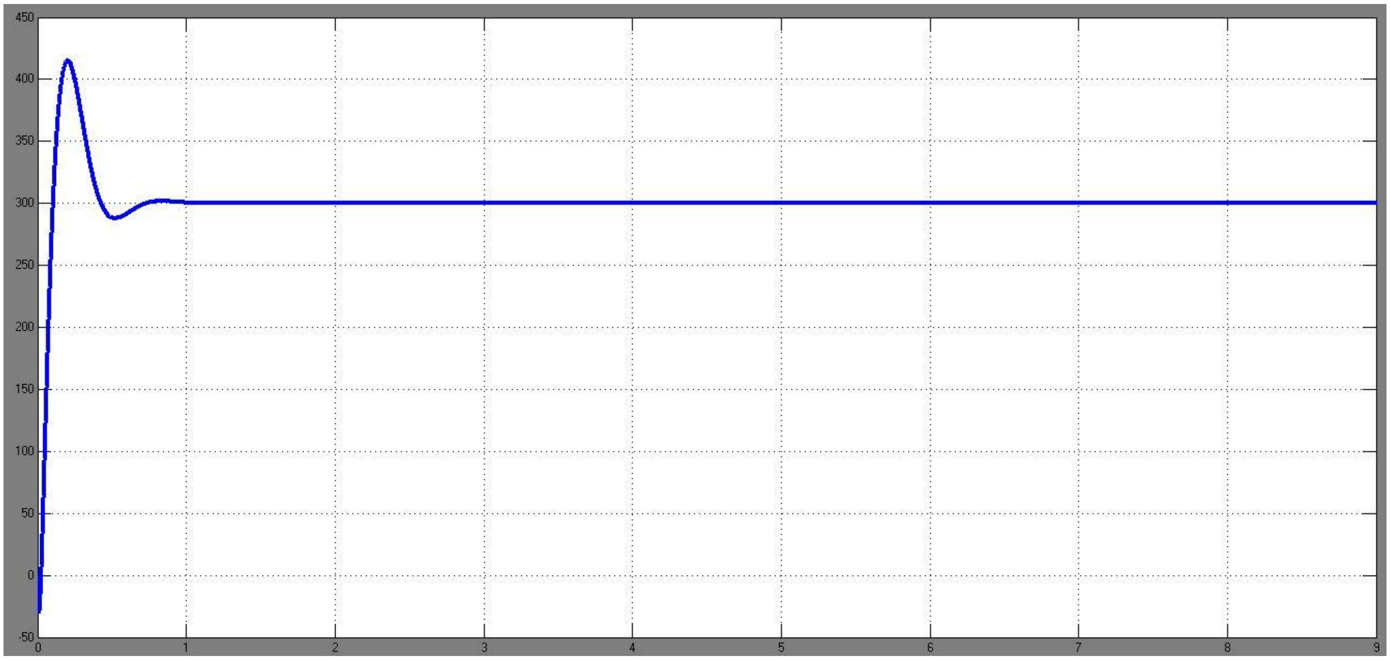

Fig 8: Closed Loop response of PID Controller

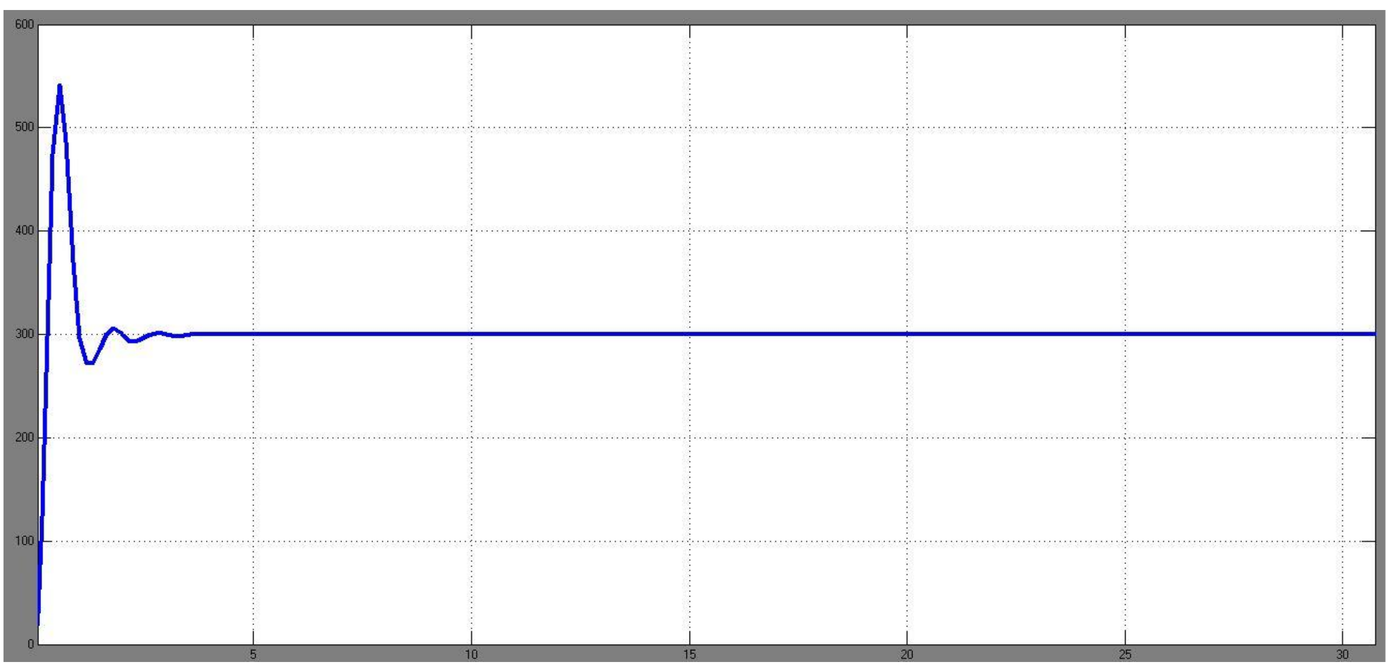

Fig 9: Closed Loop response of MPC Controller

CONCLUSION

In this article, the response of PID and MPC controllers are compared and the simulation results shows that the rise time of the Boost converter with MPC is minimized when compared to that of the PID controller. The converter model with MPC can withstand the variations in the input voltage with different operating conditions. Further the dynamic response of the highly non-linear models can be improved using Artificial Neural Networks (ANN), Fuzzy Logic Controllers (FLC) and Neuro-fuzzy systems (ANFIS).

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