

## Modeling, Control and Simulation of Renewable Source Boost Converter using MATLAB

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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 a convectional PID controller is designed to regulate the output voltage. The response is further improved using MPC and NARMA-L2 controller. The time domain specifications of the controllers are compared using the simulation results.

**Key words:** DC voltage, MPC, NARMA, 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, MPC and NARMA-L2 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].

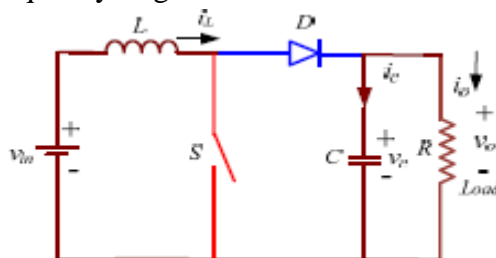


Fig 1: Ideal Boost Converter

### 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.

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

$V_{in}$  = input voltage

$V_o$  = desired output voltage

### Load Resistance (R):

$$R = \frac{V_o}{I_o} \quad (2)$$

$V_o$  = desired output voltage

$I_o$  = desired output current

### Inductance (L):

$$L = \frac{V_{in} * (V_o - V_{in})}{\Delta I_l * f_s * V_o} \quad (3)$$

$\Delta I_l$  = 10% of  $I_o$

$V_{in}$  = input voltage

$V_o$  = desired output voltage

$f_s$  = switching frequency

$\Delta I_l$  = inductor ripple current

$I_o$  = desired output current

### Capacitance (C):

$$C = \frac{(I_o * D)}{(f_s * \Delta V_o)} \quad (4)$$

$$\Delta V_o = ESR \left( \frac{I_o}{1-D} + \frac{\Delta I_l}{2} \right) \quad (5)$$

$I_o$  = desired output current

$D$  = duty cycle

$f_s$  = switching frequency

$\Delta V_o$  = output ripple voltage

$\Delta I_l$  = 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 $\Omega$
7.	Inductance ( $L$ )	240 mH
8.	Equivalent Series Resistance (ESL)	0.5 $\Omega$
9.	Capacitance ( $C$ )	5000 $\mu$ F
10.	Equivalent Series Resistance (ESR)	16 m $\Omega$

\*Units: V- volt, A- ampere,  $\Omega$ - ohms, mH- milli Henry,  $\mu$ F- micro Farad

### 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

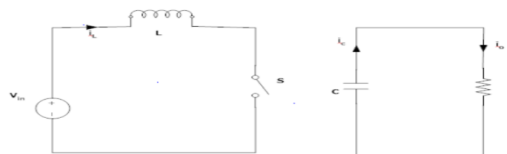


Fig 2: Boost converter- ON mode

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

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

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

**Switch OFF equivalent circuit**

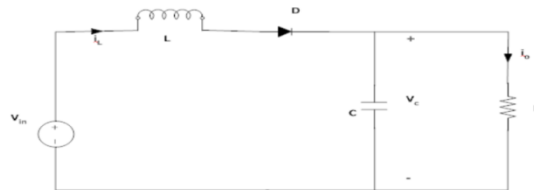


Fig 3: Boost converter- OFF mode

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

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

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

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 discussions.

**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.

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

### 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

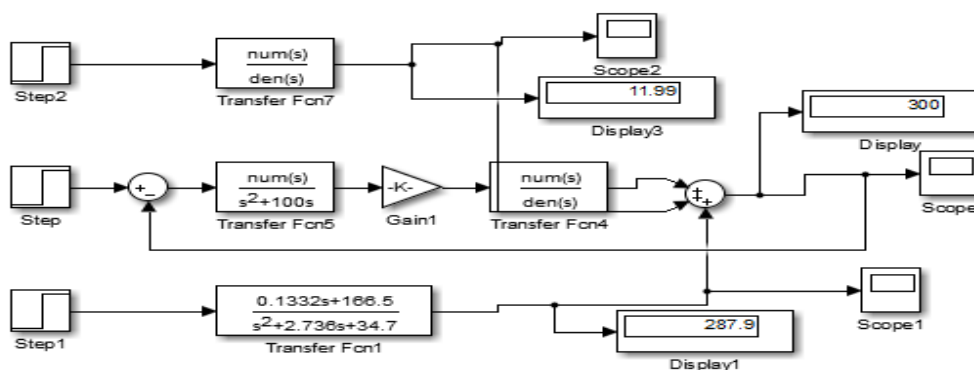


Fig 5: Closed loop simulink model

The transfer function for the compensator is determined as

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

Therefore the overall control transfer function is

$$\frac{-0.5083s^6 - 6327s^5 + (2.583 \times 10^5)s^4 + (3.906 \times 10^6)s^3 + (2.385 \times 10^7)s^2 + (1.308 \times 10^8)s + (1.75 \times 10^8)}{s^6 + 84.55s^5 + 1452s^4 + (1.744 \times 10^4)s^3 + (8.935 \times 10^4)s^2 + (4.40)8 \times 10^5s + (5.834 \times 10^5)} \quad (13)$$

### 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 improve 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].

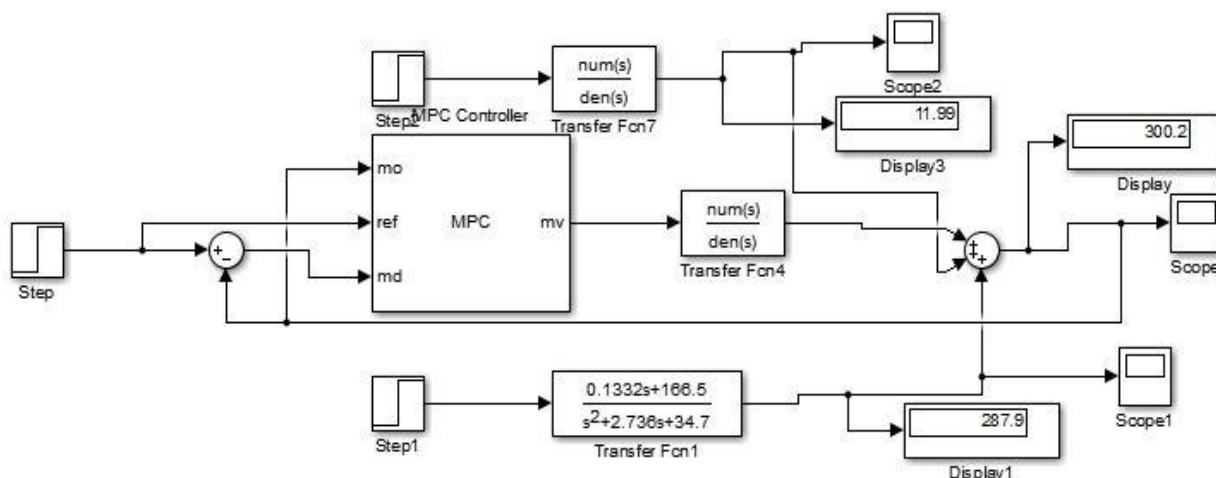


Fig 6: Simulink Model of MPC

### 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 7 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: (14)

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

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 (15)

$$y(k + d) = y_r(k + d),$$

The nonlinear controller of the model is of the form: (16)

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

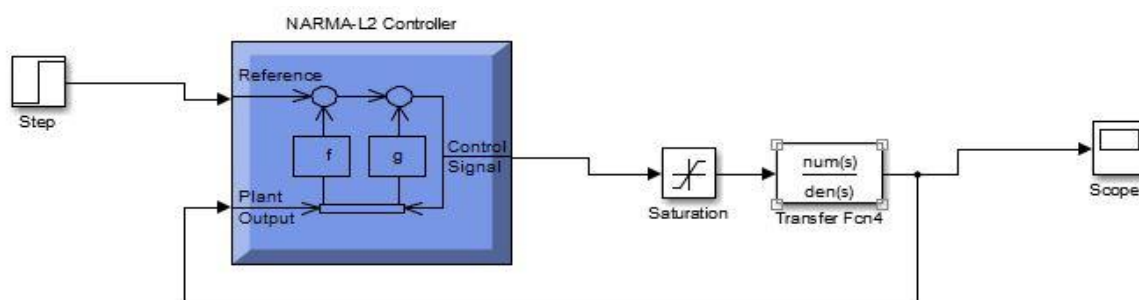


Fig 7: Simulink Model of NARMA-L2

## MODELING OF PV CELL

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. Fig 8 shows the simulink model of Photo-Voltaic (PV) cell.

Solar cells are described as being photovoltaic irrespective of whether the source is sunlight or an artificial light. They are used as a photo detector, detecting light or other electromagnetic radiation near the visible range, or measuring light intensity. The operation of a photovoltaic (PV) cell requires 3 basic attributes [11]:

- The absorption of light, generating either electron-hole pairs or excitons.
- The separation of charge carriers of opposite types.
- The separate extraction of those carriers to an external circuit.

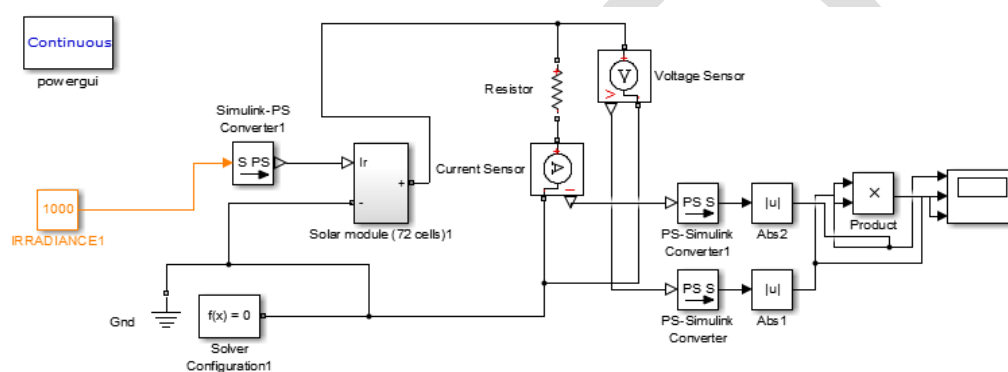


Fig 8: Simulink model of PV Cell

## RESULTS AND DISCUSSIONS

Thus the responses of PID, MPC and NARMA-L2 controllers are obtained as shown in Fig 9, Fig 10 and Fig.11. The time domain specifications of the responses are tabulated in table 3.

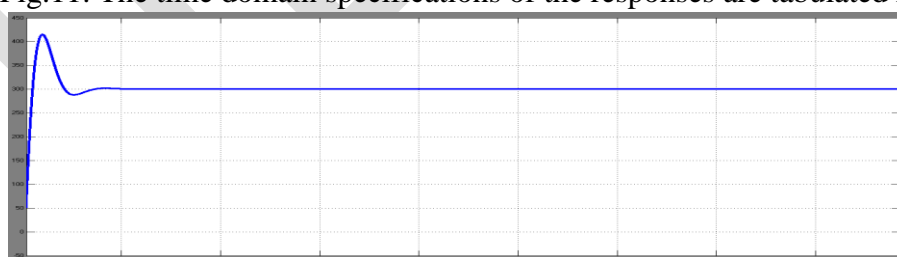


Fig 9: Response of PID

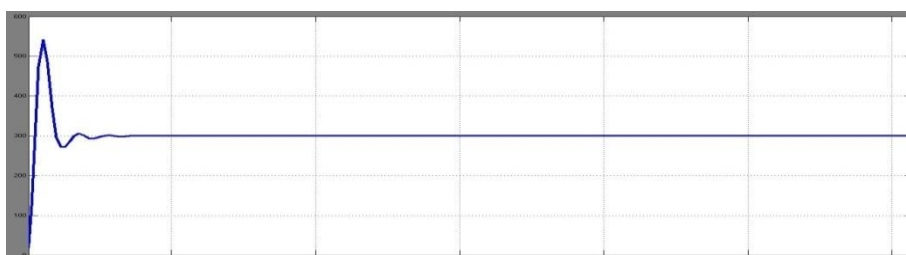


Fig 10: Response of MPC

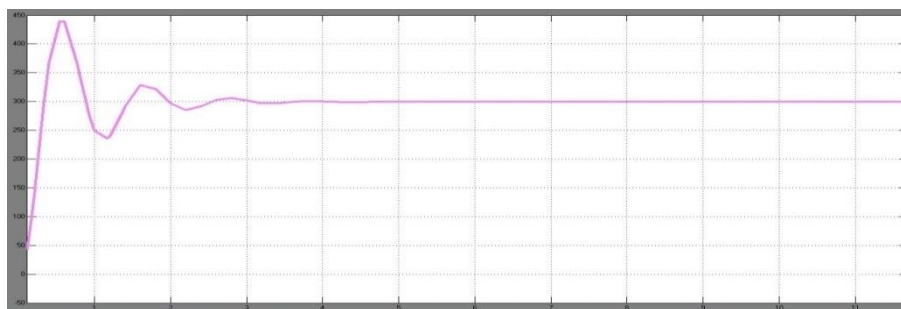


Fig 11: Response of NARMA-L2

Table 3. Time Domain Specifications

S.NO	PARAMETERS	PID	MPC	NARMA-L2
1.	Rise time ( $t_r$ )	0.064 sec	0.335sec	0.2sec
2.	Peak time ( $t_p$ )	0.21 sec	0.54sec	0.53 sec
3.	Maximum overshoot ( $M_p$ )	35.9%	47.23%	47.202 %
4.	Settling time ( $t_s$ )	2.84 sec	3.6sec	3 sec
5.	Peak Amplitude (A)	424 V	520 V	425 V

\*Units: sec-seconds, V- volt, %- percentage

## CONCLUSION

In this article, the desired specification of the boost converter is obtained. The output voltage is controlled using PID controller and the response is further improved using MPC and NARMA-L2 controller. The advanced controllers help the converter system to be operated in transient conditions. To improve the system, knowledge-based systems, genetic algorithms, neuro-fuzzy systems can be implemented.

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