Close Loop Control of Solar Powered Boost Converter with PID Controller

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Abstract - The power converter is a critical component of distributed generation system, particularly for renewable energy system based distributed generators. This paper presents a Sub System feeding power directly to the boost converter. The proper designed methodology is developed. Both the sub system and boost converter are modelled in Matlab .The close loop analysis of the system is done using PID controller and the PID is tuned is done using Ziegler Nikolas Method.

***Key Words*: Design, PID tuning ,Ziegler Nikolas, closed loop**

1.INTRODUCTION

In the current scenario where in the world the pollution level is increasing in alarming rates, it's a high time for the man kind to shift to a renewable energy resources. In India about 65 per of the energy produced is from Thermal power plants which produces huge pollution , So to overcome this problem we need to shift to renewable energy. But is the shift that much easy? Normally when we talk about renewable energy we talk mostly of wind energy and solar energy. Let us discuss each in detail, when we talk about wind mill we know that speed of wind is different in different times of the day so the rotation of turbine will produce variable voltage [1], but we need a constant voltage and frequency isn't it? So we need to do something so that we can get a constant voltage. Similarly when we talk about the Solar panel we see that irradiation is different for different times of the day, so photo voltaic cell produces different voltage so regulate this voltage to a constant we need to produce a circuit which can with stand the constant voltage even if there is regulation in input Voltage. [9]

Normally in system like electric vehicle, ups, photo voltaic system where the low dc voltage must be converted to high dc voltage so boost converters is used to cater this need

.But the open loop boost would give high ripple and it is very difficult to produce a system which produce a constant dc voltage with minimum transient so that our purpose is fulfilled. So we have to design a close loop system for this purpose state space averaging model is developed [3]. And suitable controller should be developed, that is done using Ziegler Nickolas Method [2].

1.1 DESIGN OF BOOST CONVERTER

The circuit diagram of boost converter is shown in Fig.1. The basic operation of the converter under steady state consist of two models. The Voltage conversion ratio of the converter is derived based on the volt-sec balance across the inductor over a switching period(Ts).

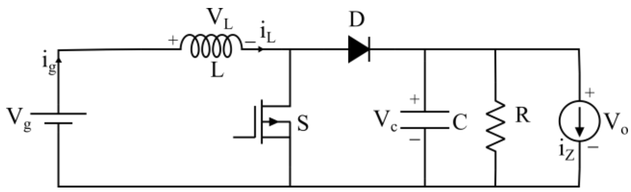

Fig. 1. Circuit Diagram of Boost Converter

Where $V_o = V_c$ and $i_g = i_L$

d is duty cycle .

There are two modes:

Mode 1: When The Switch is on ($0<t<dTs$)
$V_L = Vg$

Mode 2:When switch is off ($dTs<t<Ts$)
$V_L = Vg - V_0$

Applying Voltage - Sec balance across Inducrtor:
$V_0=V_g/(1-D)$

A. 1.2 *SPECIFICATIONS*

The PV array produces a Voltage fluctuation between 13.6 V to 16.6 V with change in Irradiation. The desired output Voltage is 50 For the design purpose the Voltage ripple across capacitor is considered as 1% and the inductor current ripple is 5%.Switching frequency 20000 Hz and the load resistance is 200Ω.

2. DESIGN CALCULATIONS

We have to design the circuit for worst condition so that the circuit can handle the maximum current stress though inductor, and maximum voltage stress through capacitor. This will happen because the circuit input voltage is a variable quantity.

We will use this following formulas

$V_o = \frac{1}{1-d} V_{in}, \Delta i_L = \frac{d(1-d)V_o}{f_s L}$ and $\Delta V_c = \frac{dI_o}{f_s C}$

We will calculate $I_o = \frac{50}{200} = 0.25A$

$$50 = \frac{1}{1-d} 15 d = 0.7$$

Average inductor current $(i_L) = \frac{1}{1-d} I_o = 3.33 I_o = 0.833$

So $2\Delta i_L << 005 \times 0.833 = 0.04165A$.

Calculate of d_{min} and d_{max}

$$d = 1 - \frac{V_{in}}{V_o} d_{max} = 1 - \frac{12.6}{50} = 0.728$$

$$d_{min} = 1 - \frac{16.6}{50} = 0.668$$

As the d_{min} and d_{max} is greater than 0.5 so we use d_{min} for calculation so theat we can design the circuit for maximum

inductor current. $0.4165 \geq \frac{d(1-d)V_o}{f_s L}$

$$0.4165 \geq \frac{0.668(1-0.668)50}{25000L}$$

$$L \geq 10.65mH$$

Peak to peak ripple voltage=1% of 50V

$$\Delta V_c = \frac{dI_o}{f_s C} = 0.01 \times 50 = 0.5V$$

$$0.5 \geq \frac{0.7287 \times 0.25}{25000 \times C} C \geq 14.56 \times 10^{-6} F$$

So C required is less than 20μF so we can use AC capacitor in our design.

3. STATE SPACE AVERAGING AND SMALL SIGNAL ANALYSIS

The Fig:1 shows a boost converter the boost converter has two mode of operation. Mode 1 when the switch is on and mode 2 when the switch is off.

Mode 1:$(\boldsymbol{0 < t < dT_s})$

$$\begin{bmatrix} \dot{i}_L \\ \dot{V}_c \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & -\frac{1}{RC} \end{bmatrix} \times \begin{bmatrix} i_L \\ V_c \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} \times [V_g] + \begin{bmatrix} 0 \\ -\frac{1}{C} \end{bmatrix} \times [i_Z]$$

$\begin{bmatrix} V_o \\ i_g \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \times \begin{bmatrix} i_L \\ V_c \end{bmatrix}$ For the corresponding equations let the matrices be A_1, B_1, C_1, D_1

Mode 2:$(\boldsymbol{dT_s < t < T_s})$

$$\begin{bmatrix} \dot{i}_L \\ \dot{V}_c \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{1}{RC} \end{bmatrix} \times \begin{bmatrix} i_L \\ V_c \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} \times [V_g] + \begin{bmatrix} 0 \\ -\frac{1}{C} \end{bmatrix} \times [i_Z]$$

$$\begin{bmatrix} V_o \\ i_g \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \times \begin{bmatrix} i_L \\ V_c \end{bmatrix}$$

The corresponding equations are A_2, B_2, C_2 ,D_2.

3.1 AVERAGE LARGE SIGNAL MODEL.

A = A1d + A2(1 − d)

B = B1d + B2(1 − d)

C = C1d + C2(1 − d)

D = D1d + D2(1 − d)

Applying all the above equations [10] we get

$$\begin{bmatrix} \dot{i}_L \\ \dot{V}_c \end{bmatrix} = \begin{bmatrix} 0 & -\frac{(1-d)}{L} \\ \frac{1-d}{C} & -\frac{1}{RC} \end{bmatrix} \times \begin{bmatrix} i_L \\ V_c \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} \times [V_g] + \begin{bmatrix} 0 \\ -\frac{1}{C} \end{bmatrix} \times [i_Z]$$

$$\begin{bmatrix} V_o \\ i_g \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \times \begin{bmatrix} i_L \\ V_c \end{bmatrix}$$

3.2 STEADY STATE MODEL

At steady state condition d=D;vg = Vg;ig = Ig and for all x˙=0. [3].

$$\begin{bmatrix} 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 0 & -\frac{(1-d)}{L} \\ \frac{1-d}{C} & -\frac{1}{RC} \end{bmatrix} \times \begin{bmatrix} i_L \\ V_c \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} \times [V_g] + \begin{bmatrix} 0 \\ -\frac{1}{C} \end{bmatrix} \times [i_Z]$$

$$\begin{bmatrix} V_o \\ i_g \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \times \begin{bmatrix} i_L \\ V_c \end{bmatrix}$$

3.3 SMALL SIGNAL MODEL

Applying small perturbations the variables becomes [3]

d = D + d^ , Vo = Vo + Vo^ ,Vg = Vg + Vg^

iz = Iz + izˆ, iL = IL + iˆL

$$\begin{bmatrix} i_L + \hat{i}_L \\ \dot{V}_c + \hat{V}_c \end{bmatrix} = \begin{bmatrix} 0 & -\frac{(1-d)}{L} \\ \frac{1-d}{C} & -\frac{1}{RC} \end{bmatrix} \times \begin{bmatrix} i_L \\ V_c \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} \times [V_g] + \begin{bmatrix} 0 \\ -\frac{1}{C} \end{bmatrix} \times [i_z]$$

$$\begin{bmatrix} V_o \\ i_g \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \times \begin{bmatrix} i_L \\ V_c \end{bmatrix}$$

Simplifying the above equation, considering all steady state $\dot{x} = 0$ and all $\hat{a} \times \hat{b} = 0$ where $\hat{a}$ *and* $\hat{b}$ can be $\hat{d}, \hat{V}_o, \hat{V}_g$ *and* $\hat{\imath}_z$.

$$\begin{bmatrix} \dot{\hat{i}}_L \\ \dot{\hat{V}}_c \end{bmatrix} = \begin{bmatrix} 0 & -\frac{(1-D)}{L} \\ \frac{1-D}{C} & -\frac{1}{RC} \end{bmatrix} \times \begin{bmatrix} \hat{i}_L \\ \hat{V}_c \end{bmatrix} + \begin{bmatrix} \frac{1}{L} & 0 & \frac{V_o}{L} \\ 0 & \frac{-1}{C} & \frac{-I_g}{C} \end{bmatrix} \times \begin{bmatrix} \hat{V}_g \\ \hat{\imath}_z \\ \hat{d} \end{bmatrix}$$

$$\begin{bmatrix} \hat{V}_o \\ \hat{\imath}_g \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \times \begin{bmatrix} \hat{i}_L \\ \hat{V}_c \end{bmatrix}$$

3.4 TRANSFER FUNCTION OF BOOST CONVERTER

For our analysis close loop system we require to control only the voltage so the plant transfer function we require is $\frac{V_o(s)}{d(s)}$.

So the transfer equation will be

$$\frac{V_o(s)}{d(s)} = C(sI - A)^{-1}B \quad (\hat{V}_g = 0 \text{ and } \hat{\imath}_z = 0)$$

$$\frac{V_o(s)}{d(s)} = \frac{-41667(s-900}{s^2+250s+2.25\times10^5}$$

We can see that there is a open loop zero on right half of s-plane

3.5 ROOT LOCUS OF BOOST CONVERTER

So we can see that root locus of the boost converter is moving in right half of the s plane means there is close loop pole on right half s plane ,so we can infer that that the system is unstable system. So now we need to design a suitable controller and compensator to get desired output.

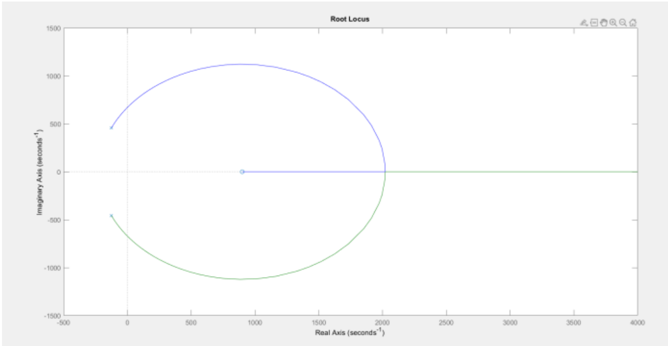

Fig. 2. Root Locus of Boost Converter

4. ZIEGLER NIKOLAS METHOD OF PID TUNING

There are 2 Algorithms [1][2]of tuning of PID by Ziegler Nikolas method

- One is for a system that is stable.
- Other is the for system with sustained oscillation with K_p.

4.1 STEPS FOR ZIEGLER NIKOLAS METHODS

1) Reduce Ki and Kp to 0

2) Increase Kp from 0 to critical value (Kcr) at which

Sustained oscillation occur.

3) Note value of Kcr and period Pcr at sustained oscillation.

Type of PID	K_p	K_i	K_d
P	$0.5K_{cr}$	∞	0
PI	$0.45K_{cr}$	$0.833P_{cr}$	0
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

Table 1: PID tuning by Ziegler Nikolas Method

4.2 CALCULATIONS

g=$\frac{V_o(s)}{d(s)} = \frac{-(41667(s-900))}{s^2+250s+2.25\times10^5}$=open loop gain of the plant

Considering proportional controller of gain K is attached to the plant.

So the characteristic equations will be

$$1 + KGH = 0$$

Where H is the feedback path gain which can be taken as unity.So our characteristic equation becomes

$$s^2 + (250 - 41667K)s + (225000 + 372250K) = 0$$

Doing the Routh-Hurwitz Criterion

s^2	1	(225000+372250K)
s^1	(250-41667K)	0
s^0	(225000+372250K)	0

Table 2: Routh-Hurwitz Criterion

So for the system to be stable all the elements of first row must be positive so there are two conditions.

- $K \geq -\frac{225000}{372250}$
- $K \leq \frac{250}{41667}$

$K = K_{cr} = \frac{250}{41667} = 0.0059$

Roots of Auxiliary Equations:

$s^2 + (225000 + 372250K) = 0$

$= \pm j476.651 = j\omega$

So the $P_{cr} = (2\pi/\omega) = 13.239 \times 10^{-3}$

$K_p = .6 \times 0.0059 = 3.54 \times 10^{-3}$

$T_i = 0.5 \times P_{cr} = 6.6195 \times 10^{-3}$

$T_d = 0.125 \times 13.23 \times 10^{-3} = 1.65375 \times 10^{-3}$

$K_d = K_p \times T_d = 5.854 \times 10^{-6}$

$K_i = (K_p/T_i) = 0.534$

There the final PID parameter values are given in the below table.

Parameter	Value
K_p	3.54×10^{-3}
K_d	5.854×10^{-6}
K_i	0.534

Table 3: Value of PID parameter.

5. SIMULATION RESULTS

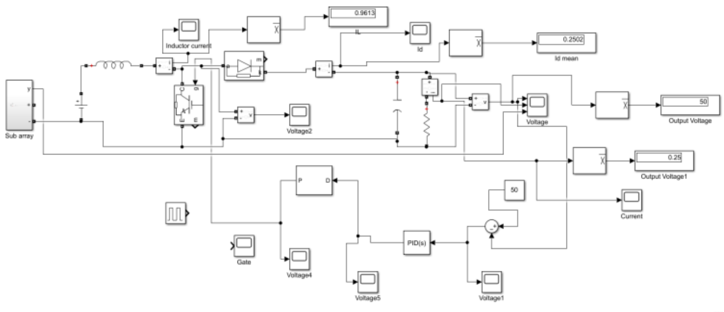

Fig. 3. Schematic Diagram of Closed Loop Control in Simulink

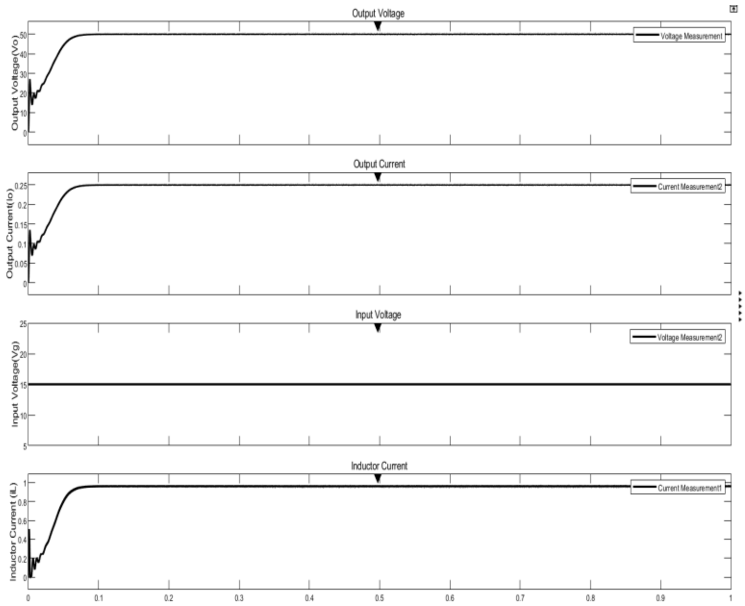

Fig. 4. Output Current , Inductor Current and Output Voltage Waveforms with Vg = 15V.

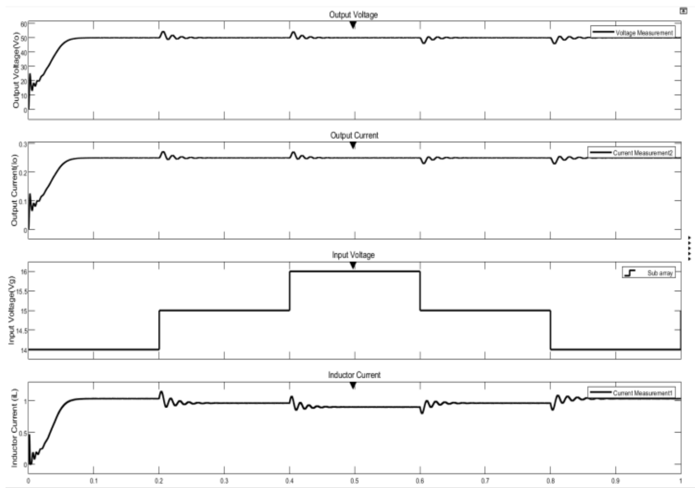

Fig. 5. Output Current and Voltage Waveforms with Subsystem input producing variable input voltage with change in Irradiation.

6. CONCLUSIONS

In this analysis we were successful to get a constant voltage on the output even if there is a change in voltage in the input. A small switching ripples were present. The performance of the system can be improved if we have considered the electrolytic capacitor, as the esr value of the capacitor helps in damping the oscillation in output voltage. This stabilized output can be used for external power supply for Multi-level inverter , drive application ,electronic load etc

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