Closed Loop Controlled Boost Converter for Photo-Voltaic Applications

Jeneena Babu[1] Bobin K Mathew[2]
[1,2]Department of Electrical & Electronics Engineering
[1,2]Amal Jyothi College of Engineering, Kanjirapally, Kottayam, India

Abstract— The research on renewable energy, especially solar energy becomes more and more important. To achieve high step-up and high efficiency DC/DC converters is the major consideration in the renewable power applications due to the low voltage of Photo-Voltaic (PV) arrays. In DC-DC converters, the output voltage must be kept constant, regardless of changes in the effective load resistance. The closed loop boost converter is used to convert a low level dc input voltage from solar PV module to a high level dc voltage required for the load. To regulate the output voltage of the converter closed loop voltage feedback and inductor current feedback technique is used. Feedback loop is necessary to maintain output voltage constant which means some type of compensation is required to maintain the loop stability. PI controller is designed for a closed loop boost converter and stability is analysed.

Key words: Boost converter, Closed loop control, PI controller, Voltage control, Current control

I. INTRODUCTION

Renewable energy sources play an important role in electricity generation. The benefits of renewable energy system are more attractive than they ever had before. Specially, energy from the sun is the best option for electricity generation as it is available everywhere and is free to harness. The merits of solar PV system are cleanness, relative lack of noise or movement, as well as their ease of installation and integration when compared to others. Electricity from the sun can be generated through the solar photovoltaic modules (SPV). The SPV comes in various power output to meet the load [1]. However, the output power of a PV panel is largely determined by the solar irradiation and the temperature of the panel. At a certain weather condition, the output power of a PV panel depends on the terminal voltage of the system. To maximize the power output of the PV system, a high efficiency, low-cost DC/DC converter with a voltage and current feedback signal is employed to control the output voltage of the PV system at optimal values in various solar radiation conditions [2].

The DC/DC converters are non-linear dynamic systems. The primary reasons for the non-linearity are due to high frequency switching, power devices like Metal Oxide Semiconductor Field Effect Transistor (MOSFETs), diodes and passive components such as inductors and capacitors. Therefore, there is a need for an optimal control technique for these DC/DC converters which can deal with their intrinsic non-linearity and variations in the load ensures stability in any operating condition while taking care of obtaining the fast transient response.

II. STATE SPACE AVERAGE MODELLING AND CLOSED LOOP CONTROL OF BOOST CONVERTER

A DC - DC boost converter consists of an inductor, diode, MOSFET used as a switch, output filter capacitor and resistive load. When supply voltage is given, inductor current increases, when the switch is closed. When the switch is opened, both inductor voltage and supply voltage gets discharged through the load. Hence a higher voltage at the output is obtained than the given input voltage. Assumptions made are the components are ideal and lossless and converter is in continuous conduction mode. Fig.1 shows the boost converter.

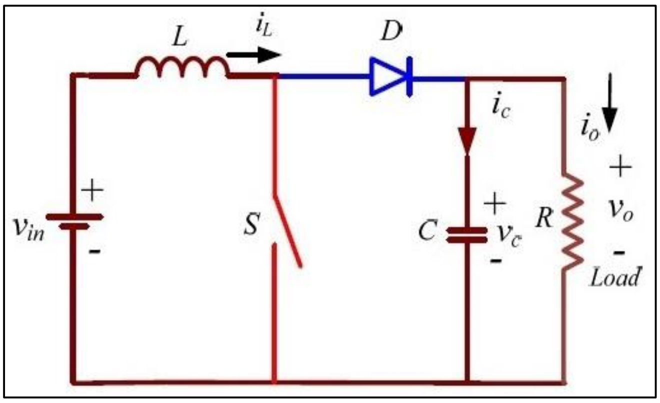

Fig. 1: Boost Converter

When the main switch is ON,

$$L\frac{di_L}{dt} = v_{in} \quad (1)$$
$$C\frac{dv_o}{dt} = -\frac{v_o}{R}$$

When the switch is OFF,

$$L\frac{di_L}{dt} = v_{in} - v_o \quad (2)$$
$$C\frac{dv_o}{dt} = i_L - \frac{v_o}{R}$$

Averaging the state equations over a switching cycle and introduce perturbation in state variables and take Laplace transforms, the control equations are obtained as Control to output transfer function.

$$\frac{\hat{v}_o(s)}{\hat{d}(s)} = \frac{(1-D)V_o - (LI_L)s}{(LC)s^2 + \frac{L}{R}s + (1-D)^2} \quad (3)$$

Control to input current transfer function

$$\frac{\hat{\imath}_L(s)}{\hat{d}(s)} = \frac{(CV_o)s + 2(1-D)I_L}{(LC)s^2 + \frac{L}{R}s + (1-D)^2} \quad (4)$$

Current to output transfer function

$$\frac{\hat{v}_o(s)}{\hat{\imath}_L(s)} = \frac{(1-D)V_o - (LI_L)s}{(CV_o)s + 2(1-D)I_L} \quad (5)$$

Two control loops an inner current control loop (fast loop) and outer voltage control loop (slow loop) are used to regulate the output voltage. Setting the outer voltage loop bandwidth (BW) lower than the inner current loop makes the design of controller easier. The average input current should be controlled to be dc, which requires that bandwidths of voltage and current loops are separated far apart with a slow voltage loop and a fast current loop.

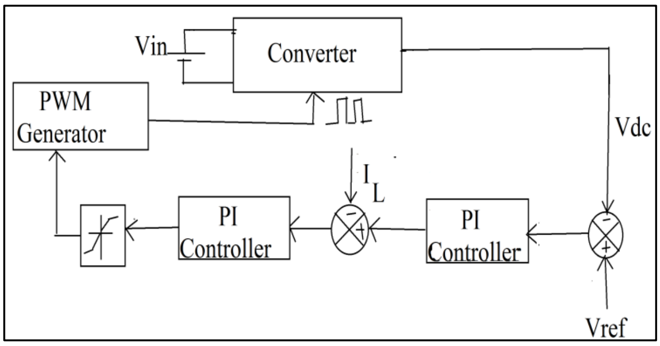

Fig. 2: Closed Loop Controlled Boost Converter

III. DESIGN CONSIDERATIONS

Boost converter is designed for feeding a 15W load and the input voltage of boost converter is 17V and the output voltage is 34V. The inductance and capacitance values are selected using design equations of boost converter. The parameters of components for PI controller which are used for control is also calculated using bode plots and gain, phase angle conditions.

For the inner current loop the gain condition is assumed that at crossover frequency the system gain is unity and phase angle condition is assumed that the phase angle of the loop is PM-180 at crossover frequency. The bode plot for inner current loop is shown in Fig.3. The K_p and K_i values for inner PI controller is obtained as 6.12 and 358645.93 at a phase margin of 60degree and crossover frequency of 15.92kHz.

Parameters	Specifications
Input Voltage	17V
Output Voltage	34V
Duty Ratio	50%
Switching Frequency	10kHz
Output Power	15W
Inductance	481uH
Capacitance	64.9uF
Load Resistance	77Ω

Table 1: Boost Converter Specifications

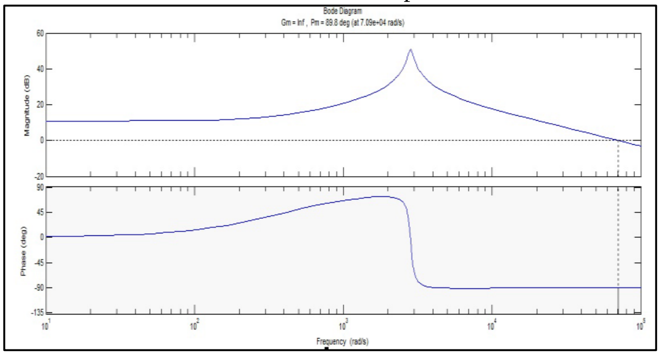

Fig. 3: Bode plot for open loop transfer function of current loop

Similar to inner current loop, the values for outer voltage control PI is calculated using bode plot and gain, phase angle conditions. The bode plot for open loop voltage transfer function is shown in Fig.4. The K_p and K_i values for outer PI controller is obtained as 0.2378 and 215.01 at a phase margin of 60degree and crossover frequency of 320Hz. The low frequency gain is improved.

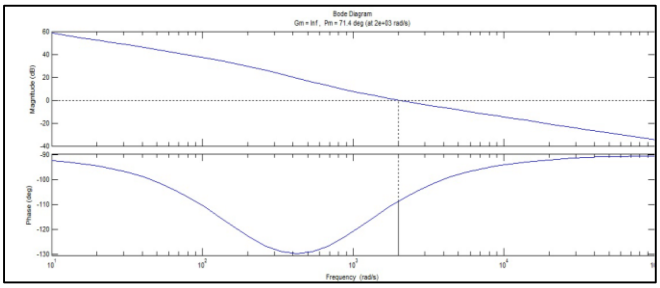

Fig.4 Bode plot for open loop transfer function of voltage loop

IV. SIMULATION RESULTS

Boost converter with closed loop control is designed in MATLAB/SIMULINK environment and the output voltage is maintained constant irrespective of changes in load. The open loop boost converter and closed loop control with voltage control, current control, both current and voltage control are compared in terms of efficiency, settling time, overshoot voltage etc. The Simulink model of open loop boost converter is shown in Fig.5 and output current and voltage waveform is shown in Fig.6. The Simulink model of closed loop boost converter with voltage and current control and the output current and voltage waveforms are shown in Fig.7 and Fig.8 respectively.

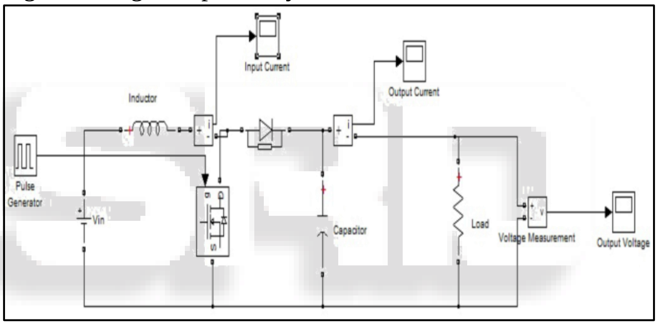

Fig. 5: Simulink model of open loop boost converter

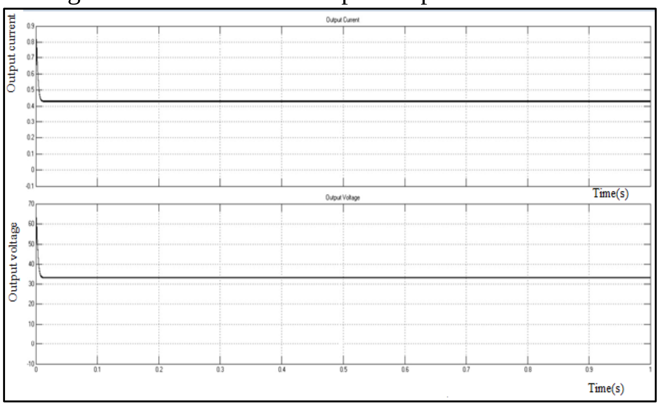

Fig. 6: Output waveforms of open loop boost converter

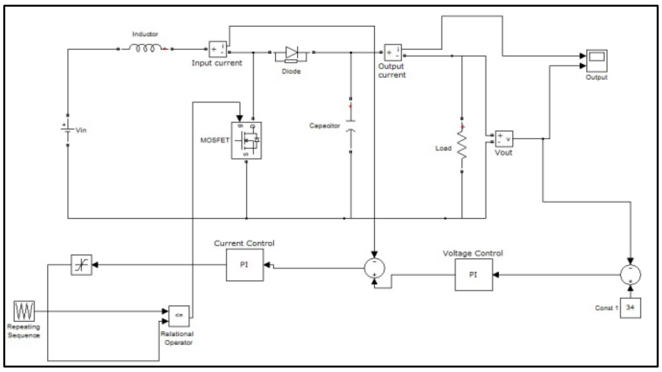

Fig. 7: Simulink model of closed loop boost converter with voltage and current control

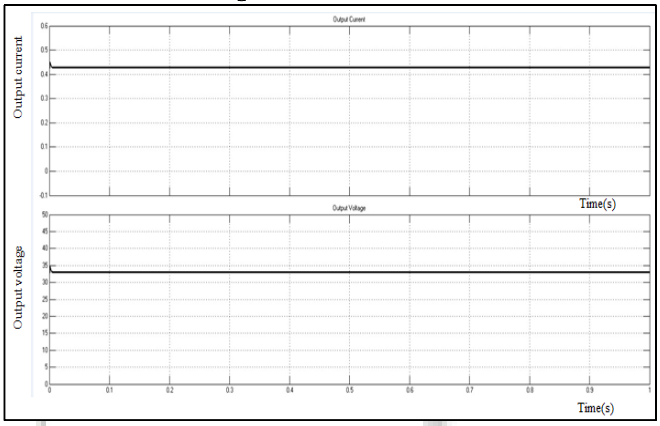

Fig. 8: Output waveforms of closed loop boost converter with voltage and current control

Different control schemes	V_o(V)	I_o(I)	Output voltage ripple	Output Current ripple	Settling Time(s)	Overshoot voltage(V)	Efficiency
Open Loop	33.1	0.43	0.2	0.005	0.008	62	93%
Closed loop with voltage control	33.9	0.44	0.2	0.0025	0.1	41	97%
Closed loop with current control	33.21	0.43	0.15	0.002	0.001	34	97%
Closed loop with voltage and current control	33.22	0.43	0.15	0.002	0.001	35	98%

Table 2: Simulation Results

Load Resistance	Closed Loop With Voltage And Current Control		
	Output Voltage	Output Current	Settling Time
80	33.28	0.416	0.001
100	34	0.34	0.001
200	34	0.17	0.001
500	34	0.068	0.001
1000	34	0.034	0.001
1500	34	0.0225	0.001

Table 3: Simulation Results with Varying Load Resistance for Voltage and Current Control

Table II shows the output voltage, current, output voltage ripple, output current ripple, settling time, overshoot voltage and efficiency of boost converter with and without control. The boost converter with voltage and current control has higher efficiency and more stable compared to others. Table III shows constant output voltage with varying load resistance.

V. Conclusions

Closed loop controlled boost converter with two PI controllers has been designed. A faster inner current loop and slower outer voltage loop is used to maintain the output voltage constant, irrespective of changes in the load. The results show that the closed loop system having two loops is more stable than the system having voltage control only. The efficiency of closed loop system increases compared to open loop system. The output is maintained a constant value with the variation in load using suitable proportional integral control techniques

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