

Average Current Mode Controlled Power Factor Correction Converter

Sachin K. Kupati*, Mukul Chavan, Sunil Bhattad and N. Arun

School of Electrical Engineering, VIT University, Vellore-632014, Tamil Nadu, India;
 Sachink.kupati2013@vit.ac.in, narun@vit.ac.in

Abstract

This paper explains the simulation of Boost Power Factor Correction (PFC) Converter. The DC-DC boost converter circuit is analyzed, designed with feedback controller. The closed loop operation of boost converter is made to work in average current mode. Design is such a way that unity power factor is achieved. Design equations are derived and it is modeled in MATLAB. Extensive simulation is carried out and results are compared.

Keywords: Power Factor, Boost Converter, Controller, Average Current Mode

1. Introduction

In this era, power electronics is modernizing the electrical systems by controlling the power flow, improving the quality of power, saving energy etc. On the other hand making use of these power electronic converters typically rectifiers, are polluting the power quality by introducing harmonic distortions.⁵ In convention in order to reduce the distortions the capacitor filter is used at the output side. But use of capacitor makes the power quality sluggish. It makes the source current peaky in nature, which in turn deteriorate the voltage.

This paper mainly focus on the improving the power quality. The conventional capacitor filter is replaced by boost converter which helps in making power factor unity. The necessary modeling and analysis is done using MATLAB and results are discussed as shown below.

2. Modeling of Boost Converter

In order to achieve closed loop operation of boost converter, mathematical modeling is to be done such a way that it includes the dynamic behavior.² This can be achieved by state space analysis. The state space analysis of boost converter is as follows.

The analysis includes certain assumptions. It is assumed that ideal and lossless boost converter is considered for the analysis. And also it is assumed that boost converter is working in continuous conduction mode.¹

Let us consider the input voltage as V_g is fed to boost converter to obtain the desired output voltage V_o with duty cycle of D . I_L is the inductor current. Using the state space analysis on considering the circuit averaging method the following equations (1) and (2) are obtained.⁴ The inductor current I_L and voltage across the capacitor V_C are considered as state variables.

$$\begin{bmatrix} \dot{\check{i}}_L \\ \dot{\check{v}}_x \end{bmatrix} = \begin{bmatrix} 0 & -(1-D) \\ \frac{(1-D)}{C} & \frac{-1}{RC} \end{bmatrix} \begin{bmatrix} \check{i}_L \\ \check{v}_x \end{bmatrix} + \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & \frac{-1}{C} \end{bmatrix} \begin{bmatrix} V_C \\ d \end{bmatrix} \begin{bmatrix} \check{v}_g \\ \check{i}_g \\ \check{v}_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} \check{v}_g \\ \check{i}_g \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} \check{i}_L \\ \check{v}_c \end{bmatrix} \quad (2)$$

The circuit averaging method is used to obtain the small signal model. Using this small signal model controller design is obtained.

*Author for correspondence

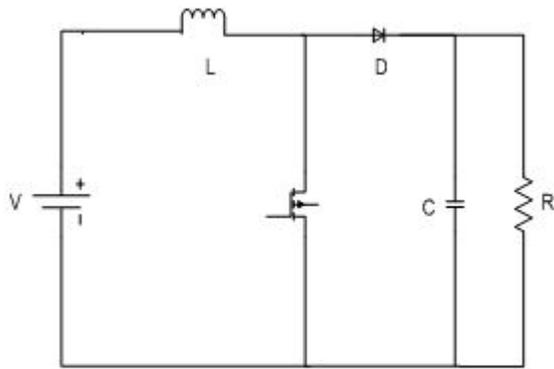


Figure 1. Open loop boost converter.

3. Design of Boost Converter

The important parameters are inductor, capacitor and respective internal resistances. These values can be calculated using the following equations.²

The inductance value is given by

$$L_{\min} \geq \frac{D(1-D)^2}{2 * f} * R_{load} \quad (3)$$

For the practical design purpose we consider L as 1.25 times the L_{\min} . The inductor current is given by the relation

$$I_L = \frac{V_s}{R * (1-D)^2} \quad (4)$$

The capacitor value is obtained by

$$C \geq \frac{D}{R * f * V_r} \quad (5)$$

Current ripple

$$\Delta I_L = \frac{V_s * D}{L * f} \quad (6)$$

$$I_{L\min} = I_L = \frac{\Delta I_L}{2} \quad (7)$$

$$I_{L\max} = I_L = \frac{\Delta I_L}{2} \quad (8)$$

Capacitance equivalence series resistance (ESR) can be found

$$r_C = \frac{V_{0ESR}}{I_{L\max}} \quad (9)$$

Inductance resistance is given by solving following equation.

$$V_0 = \frac{V_s}{1-D} * \frac{1}{1 + \frac{r_L}{(R_{load} * [1-D])^2}} \quad (10)$$

By using $V_{in} = 20$ v, $P_0 = 200$ w, $V_0 = 100$ v, $R = 50$

We get $L = 100$ uh, $C = 10$ uf, $I_1 = 10$ A, $D = 0.8$, $F_s = 25$ hz

4. Methodology Applied

To obtain desired output voltage, it is necessary to adjust Duty Cycle using Pulse Width Modulation. There are two control methods for the closed loop operation of boost converter: Voltage Mode Control (VMC) and Current Mode Control (CMC).³

Current-mode control is also called as current programmed mode or current-injected control. There are two loops in this current control mode, an inner current loop and an outer voltage loop. Here we are sensing and controlling inductor current directly, whereas the output voltage is indirectly controlled by the current loop. For stable and continuous operation of converter, the inner current loop should be faster than outer voltage loop. In order to obtain this specification the bandwidth of voltage loop is slower than that of current loop.

4.1 Current Loop

This loop is consisting of controller, modulator, and current loop transfer function with unity feedback. The controller will help to attain desired phase margin (PM) and bandwidth (BW) or crossover frequency (f_c). The bandwidth of this loop is faster than outer loop, so that inductor current can change quickly than output voltage.

Current loop transfer function:

$$\frac{\check{i}_L(s)}{d(s)} = \frac{(CV_0)s + 2(1-D)I_L}{(LC)s^2 + \frac{L}{C}s + (1-D)^2} \quad (11)$$

4.1.1 Modulator Design

In modulator, the carrier waveform which may be saw tooth wave or triangular wave is compared with the sensed inductor current. The output of this is nothing but the pulses of the switch in boost converter. The sensed current i.e. inductor current is passed through controller,

saturator and then compared with the carrier wave. The frequency of carrier wave should be same as that of switching frequency.

4.1.2 Feedback Design

Assuming 100% efficiency, the inductor current is equal to the reference inductor current, so that unity feedback is designed.

$$V_{m,p-p} = \frac{V_0 - V_{in}}{L} * \frac{T_s}{2} * K \quad (12)$$

$$T_m = \frac{1}{V_{m,p-p}} \quad (13)$$

4.1.3 Controller Design

Here controller is used in order to obtain required phase margin (PM) & crossover frequency. The design of controller i.e. Kp & Ki value can be done using gain condition and phase condition.

4.2 Voltage Loop Design

This loop is consisting of controller, limiter, and feedback loop. This loop is slower than current loop i.e. the bandwidth of this loop is lower. The reference voltage is compared with the output voltage, the error will generate that should be given to the controller. The value of

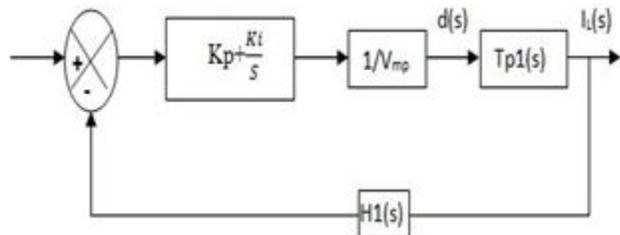


Figure 2. Current loop design.

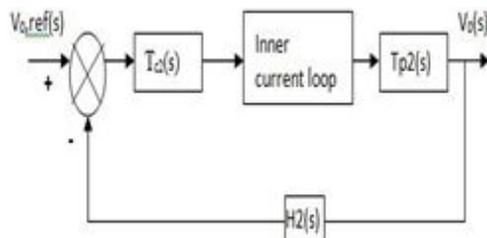


Figure 3. Voltage loop design.

controller is designed using gain and phase condition. The fast current loop can correct for the current errors quickly and the power stage transfer function for the voltage loop experiences the reference generated by voltage loop. In voltage loop design, inner current loop dynamics are neglected,³ hence duty cycle 'd' replaced by steady state equivalent 'D'. Hence d(s) = 0 in transfer function we get here feedback gain is same as the gain at the input side of reference voltage.

$$\frac{\check{v}_0(s)}{\check{d}(s)} = \frac{(1-D)V_0 - (LI_L)s}{(LS)^2 + \frac{L}{R}s + (1-D)^2} \quad (14)$$

$$\frac{\check{v}_0(s)}{\check{i}_L(s)} = \frac{(1-D)V_0 - (LI_L)s}{(CV_0)s + 2(1-D)I_L} \quad (15)$$

5. Boost Converter with Rectifier

Our main aim is to improve the power factor of diode rectifier so in order to improve this we will be connecting the boost converter to diode rectifier using closed loop. Following Figure shows the boost converter with diode rectifier in closed loop.

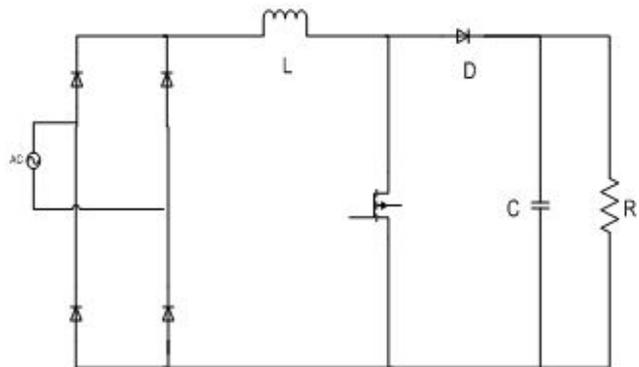


Figure 4. Boost with rectifier circuit.

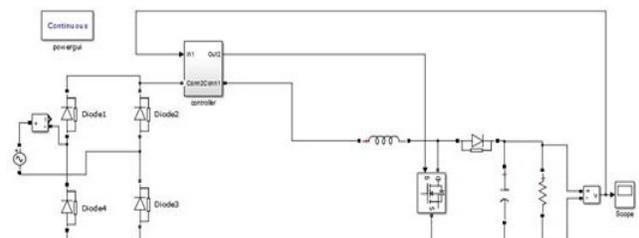


Figure 5. Closed loop boost converter.

6. Simulation Results

The boost converter with diode rectifier is simulated & we obtain the results. From results we can observe that the power factor has been improved & the THD is reduced to 4.98%.

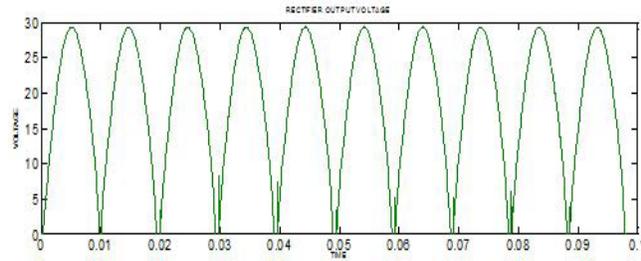


Figure 6. Rectified output voltage in closed loop.

7. Waveforms

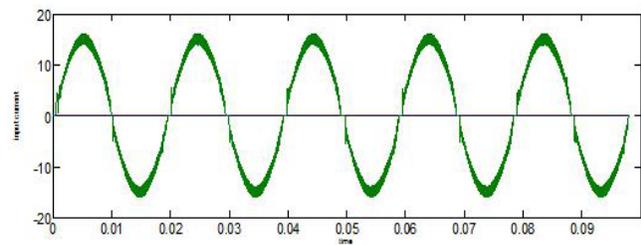


Figure 7. Input current of rectifier in closed loop.

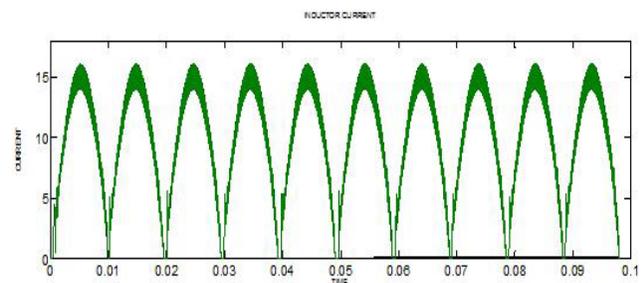


Figure 8. Inductor current.

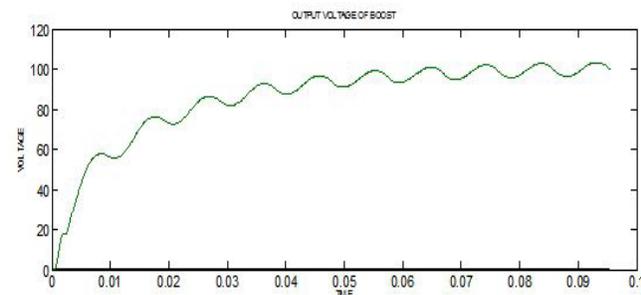


Figure 9. Output voltage of boost converter in closed loop.

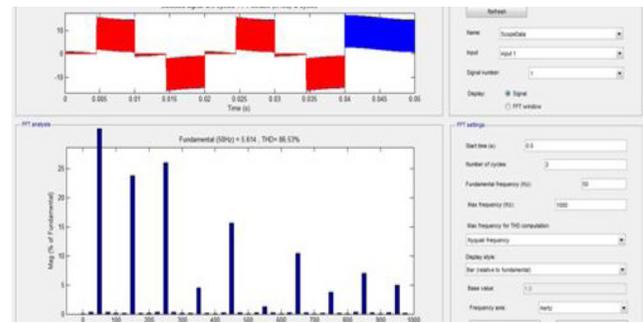


Figure 10. THD of source current (Rectifier in open loop with capacitive load).

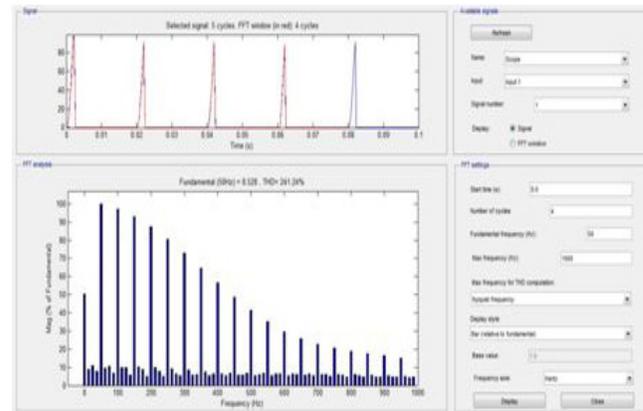


Figure 11. THD of source current (Open loop rectifier with boost converter).

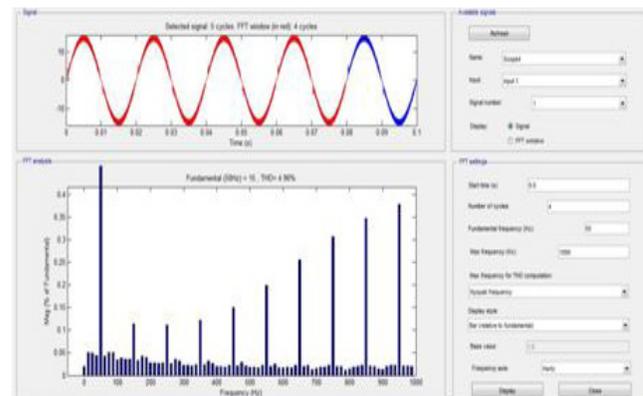


Figure 12. THD of source current (Closed loop rectifier).

8. Conclusion

This paper has explained the technique for the correction of power factor using current control method. The THD of rectifier circuit is 85% without boost converter & load as capacitive, current control loop after applying the explained methodology THD reduces to 4% & the

source current of the rectifier is maintained as sinusoidal. So there is no peak in source current as it was appeared with capacitor at the output side of rectifier. The circuit is implemented in MATLAB and corresponding results also obtained.

9. References

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