Comparison of Power Factor Correction Controllers for CRM Boost Converters

KRISHNAPRIYA VINOD [1] *PG SCHOLAR*, ANNA BABY [2] *ASST.PROFESSOR*,

ELECTRICAL AND ELECTRONICS DEPT., ASIET, KALADY

E mail: [1]krishnapriyavinodt@gmail.com, [2]anna.eee@adishankara.ac.in

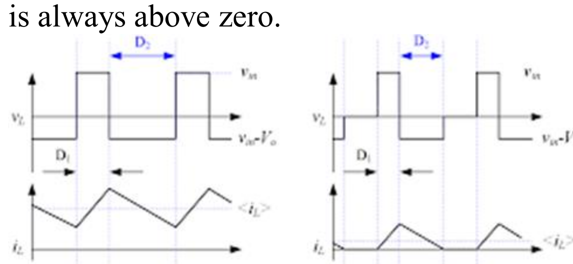
Abstract - This paper presents modified critical conduction mode (CRM) boost converter for low and high-power applications. The main aim is to improve the power factor (PF) reduce the total harmonic distortion (THD) of the CRM boost converter. The converter consists of EMI filter, bridge rectifier and a boost stage. The power factor correction (PFC) in ac-dc power conversions can improve PF and reduce THD. The CRM mode for this converter makes switches turn-on at zero current crossing and no reverse recovery losses for diodes. In this configuration the PI controller improves the PF and lowers THD value. The boost converter with variable on time (VOT) controller makes the circuit bulky and losses are more. In the proposed converter the PF and efficiency can be improved. Also, the controller reduces the size of the circuit and lower the THD. Hence CRM boost converter PFC controller based on PI controller is used to improve the above-mentioned parameters. Using MATLAB Simulink software, the existing and the modified controller is verified, and results proves the effectiveness of the controller for the CRM boost converter.

Keywords: Critical conduction mode, Power factor correction, Total harmonic distortion

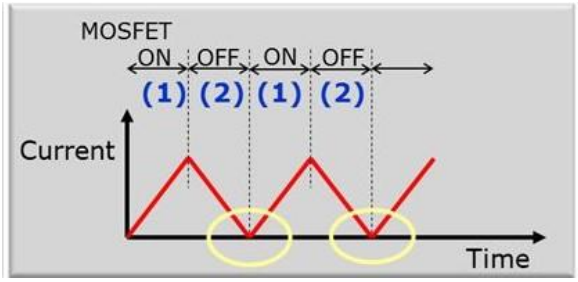
I. INTRODUCTION

In AC circuits PFC is necessary to improve the characteristics and working. The control algorithms are used to improve the PF and reduce the THD in ac-dc converters [2]. In commercial power supplies to correct the PF, mainly the boost converters are used due to its continuous current, low cost and high performance in terms of simplicity, PF and efficiency [1].

Based on inductor current, there are different modes of operation. There are three operation modes: continuous conduction mode (CCM), critical conduction mode (CRM) and discontinuous conduction mode (DCM). Both the CRM and CCM concern only with minimum of input inductor current [4]. In every switching cycle without maintenance the input inductor current touches zero in CRM. But in CCM the input inductor current is always above zero.



(a) (b)



(c)

Figure 1. (a) CCM, (b) DCM, (c) CRM Operation Modes

Fig 1. Shows the types of operation modes based on inductor current. Mainly the CRM PFC needs one compensator but CCM PFC needs two compensators [8]. Hence, in CCM complexity and cost is high. For low power applications CRM PFC is used since its peak inductor current is twice higher than average input current.

The different PFC methods are:
Passive PFC method, conventional two-stage method, single-stage PFC method etc. In passive method the inductor and capacitor filter low frequency current harmonics. Hence, the converter size is large. But it is one of the simple and efficient method. Two-stage topology is conventional method which has a PFC stage and a DC-DC regulation stage [7]. This makes the circuit more bulky, expensive, and less efficient. Now a days the single-stage converters are used. In this the PFC stage and DC-DC regulation stage are merged [3]. It is more efficient, simple, and classified based on number of switches.

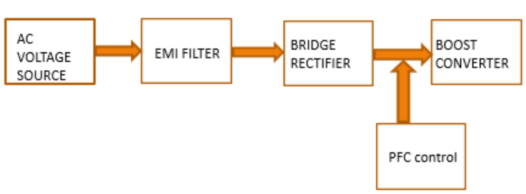


Figure 2. Block Diagram

Fig 2. Shows the block diagram of CRM boost converter with proposed PFC control strategy. CCM boost PFC converter can be used for high power applications to achieve unity power factor (UPF), low current ripple [5]. But it suffers from reverse recovery loss due to hard switching. DCM PFC used for low power applications and has no reverse recovery in diodes [6]. In low and medium applications, we can use CRM boost converters with existing control strategy based on variable turn-on (VOT) method.

The converter consists of an EMI filter, bridge rectifier and boost converter topology with CRM mode PFC control strategy. In this the control is PI based PFC control. Using this control, the PF is improved, and the converter can be used for both low and high-power applications. The control algorithm based on feedback linearization is used to achieve high power factor without additional PFC circuit. Thus, the converter with PI control can improve the PF even for higher input voltages. Therefore, the proposed converter is suitable for high power applications other than CCM. The paper is organized as follows: Section II explains the circuit description of the proposed charger, and Section III proposes control algorithm for PFC converter. Section IV shows the simulation results obtained for the proposed system.

II. PROPOSED SYSTEM

A. Circuit Description

This paper proposes CRM boost PFC converter with PI controller for high and low power applications. The Fig 3. Shows the proposed converter.

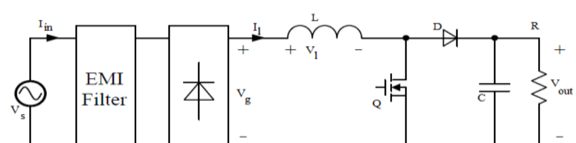


Figure 3. Proposed Converter

The converter consists of EMI filter that directly filters the ac supply. In this configuration the bridge circuit converts the ac to dc and fed to boost converter to provide a voltage gain. Frequency dithering is used for the converter with a fixed frequency control that can vary the switching frequency in a particular range. In the noise spectrum it can spread the noise energy and reduce the peak values.

B. Operation Principle

In the above converter configuration, there are assumptions to be followed when in ideal case:

- All elements including switch and diode are ideal.
- Considering that the grid voltage is constant.

The aim is to propose a control scheme of fixed switching frequency for a CRM Boost PFC converter for both low and high-power applications and to obtain UPF for all voltage levels. The control strategy used in this scheme provides high PF for different voltage range and reduce the THD value.

C. Design Equation

The proposed converter is a boost converter in CRM mode with PFC control. The input voltage, inductor current, as well as the input current, in a switching cycle are:

$$V_s = V_m \sin \omega t \tag{1}$$

$$I_{l\,pk} = \frac{V_m |\sin \omega t|}{L} t_{on} \tag{2}$$

where V_m and ω are the amplitude and angular frequency of the input voltage, t_{on} is the on-time of the switch, L is the Boost inductance.

The switching frequency F_s is given by:

$$F_s = \frac{{V_m}^2 (V_{out} - V_m |\sin \omega t|)}{4 L V_{out} P_o} \tag{3}$$

Where P_o is the rated power.

The inductance is obtained by selecting minimum switching frequency from (3):

$$L = \frac{{V_m}^2}{4 F_s P_o} \left(1 - \frac{V_m}{V_{out}}\right) \tag{4}$$

Consider the rated power P_o, the output voltage V_{out}, the switching frequency and the voltage ripple desired for the output ΔV_{out} to design the output capacitor C.

$$C > \frac{P_o}{\left(V_{out} \Delta V_{out} \pm \frac{1}{2} {\Delta V_{out}}^2\right) F_s} \tag{5}$$

III. CONTROL STRATEGY

The existing control system in fig 4. shows the VOT control which makes converter suitable for only low to medium power applications. Also, this makes the circuit more complex and THD value is more. So, to improve the range of PF and reduce THD we modified the converter with PI based controller.

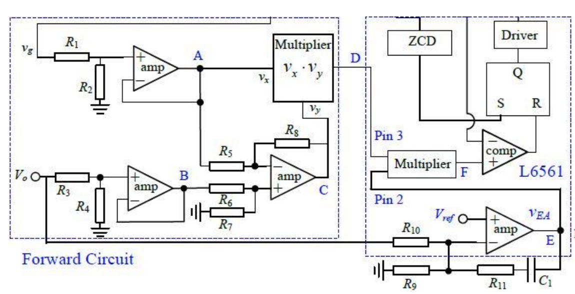


Figure 4. Existing Control System

The control strategy in Fig 5 provided is to improve the PF. Hence the PI controller controls the switching and the duty ratio is maintained to improve the PF. The PI controller is a voltage controller.

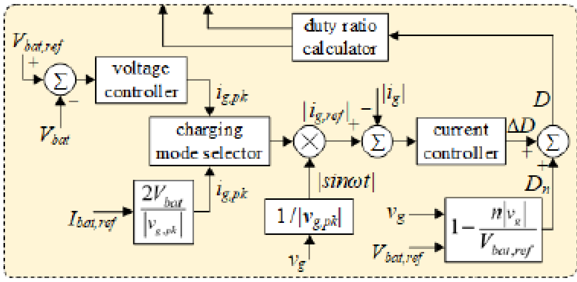


Figure 5. Proposed Control System

The input reference voltage is compared with the output voltage which is taken as the feedback and its error is given to voltage controller. Output from voltage controller and peak input current is given to a charge mode selector. The current corresponding to input voltage is compared with output of selector and reference input current is obtained. The reference and actual input current compared and given to a current controller. The current controller produces an error duty cycle ΔD. Then using eq.6 we get the nominal duty cycle Dn. Summing up both the duty cycle we get the correct duty cycle D.

$$D_n = 1 - \frac{n|V_g|}{2V_{o,ref}} \qquad (6)$$

$$\Delta D = \frac{nL_1}{2V_{o,ref}T_s}\Delta I_g \qquad (7)$$

Then by adding Eq. 6 and Eq. 7, we get the required duty ratio D.

$$D = 1 - \frac{n|V_g|}{2V_{o,ref}} + \frac{nL_1}{2V_{o,ref}T_s}\Delta I_g \qquad (8)$$

In this control the switching is controlled by controlling duty cycle. Hence in this way the PF is corrected and made near to UPF. Here voltage and current controller used are PI controllers. Then summing up the nominal and error value of duty cycle, corrected duty cycle is obtained and given to PWM generator. The generated signal controls the switching and PF is corrected.

IV. SIMULATION RESULTS

The CRM boost converter with PI control is simulated and the predicted results are obtained. Fig 6 shows the input ac grid voltage V_s. After conversion to dc in boost side the output voltage is 55V is shown in Fig 7.

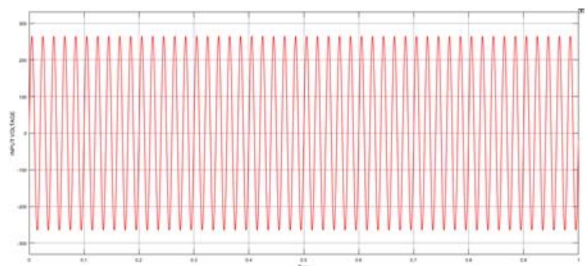


Figure 6. Input Voltage

Under a high input voltage there will large variation in switching frequency for converter which results in greater turn-off loss of the switch.

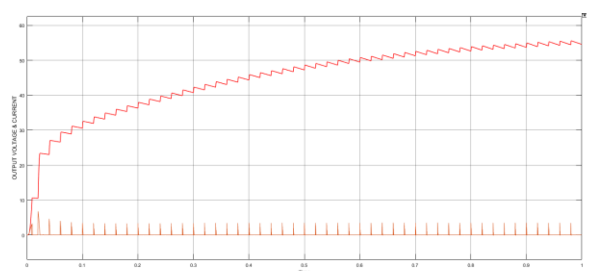


Figure 7. Output Voltage & current

Fig 7. Shows graphs for output voltage and current for CRM boost converter. In the graph the PF range is almost the same and different voltages. From Fig. 9 (e) to (h) the input voltage range given is 180 V – 260 V. For this range of input voltage, the PF is 0.992 - 0.9. Fig (a) to (d) shows the PF for 120 V – 85 V input ad it ranges from 0.999 – 0.96. Hence using this converter, the PF is improved for higher voltage levels also. Before, using the VOT control the PF was 0.9 for low voltage levels from 85 V to 120 V. Now using this PFC control the PF range has increased to UPF for low voltages. Also, the PF is 0.9 for even higher voltage range. The boost converter is working in CRM; hence the mode is shown in Fig 8. Based on the shape of the inductor current.

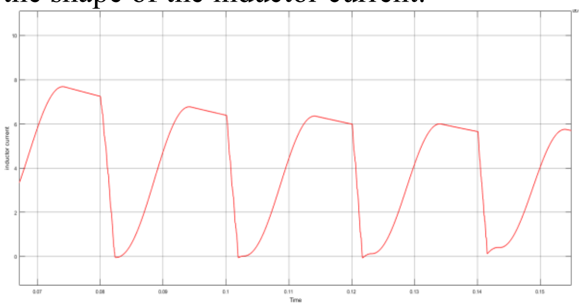
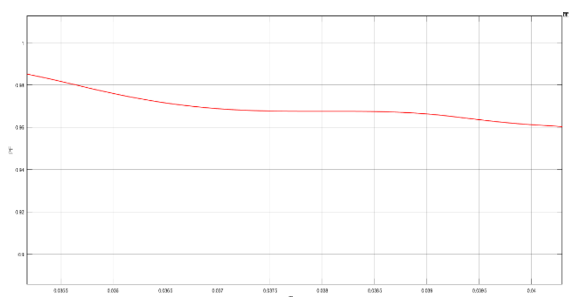
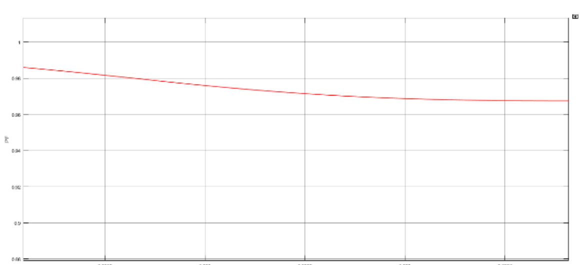


Figure 8. Inductor Current

Fig 9. Shows graphs for PF for different range of input voltage from 85V to 260 V, range. From this experiment it can be observed that PF range is almost better for both the high and low voltage ranges. So, using this control the PF is closer to UPF for low voltage. Also, this can be used for both low and high voltage applications.

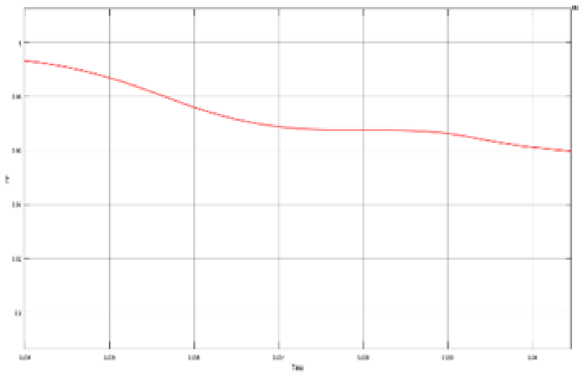


(a) PF curve for $V_{s} = 85V$

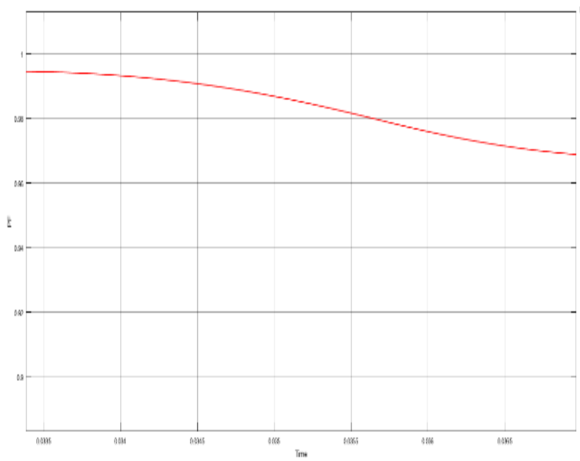


(b) PF curve for $V_{s} = 90V$

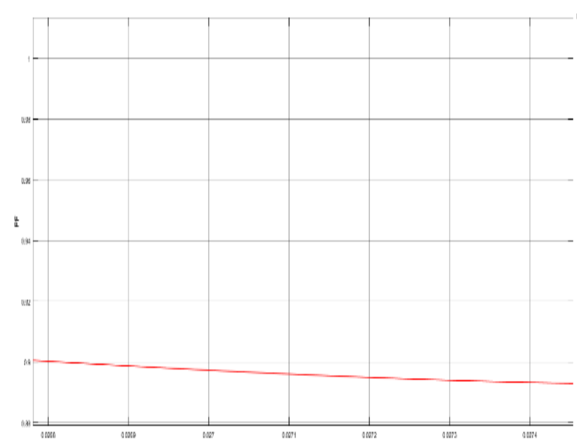
Hence this controller is best compared to the existing one because it can make use the converter both in lower and higher voltage ranges.



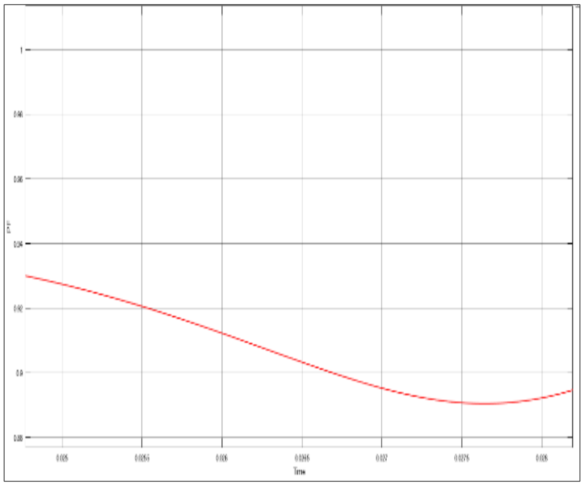
(c) PF curve for $V_{s} = 100V$



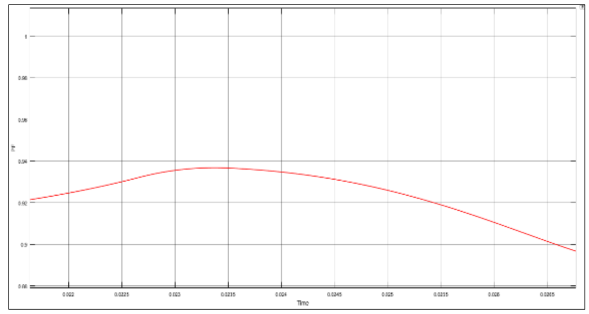
(d) PF curve for $V_{s} = 120V$



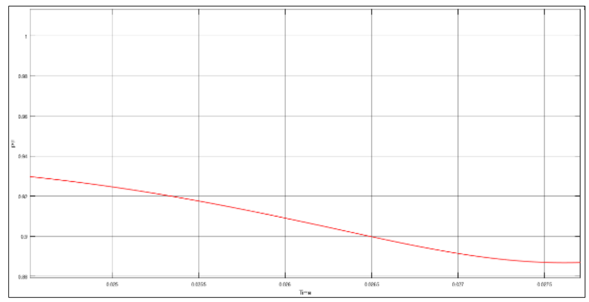
(e) PF curve for $V_{s} = 180V$



(f) PF curve for $V_{s} = 200V$



(g) PF curve for $V_{s} = 230V$



(h) PF curve for $V_{s} = 260V$

Figure 9. PF Curve for different Input Voltages

INPUT VOLATGE (V)	PF	INPUT CURRENT (A)
260	0.92 – 0.9	10
230	0.92 – 0.9	9
200	0.92 – 0.9	7
180	0.94 – 0.8	6
120	0.999 – 0.97	3.9
100	0.998 – 0.959	3.8
90	0.997 – 0.96	3
85	0.997 – 0.96	3.8

Figure 10. PF range for Input Voltages

The above table shows the range of PF and input current for different input voltage.

V. CONCLUSION

The CRM boost PFC converter is designed with the PI controller for the EMI filter design. Feedforward circuit is added to the existing control system with the implementation circuit. The variable ON time is derived for the proposed circuit. The PF for the first converter control scheme is around 0.99 and is apt for low power applications. Also, the MATLAB simulation is done with a PI controller for PFC. The THD value is reduced and PF is improved with the proposed controller. Here we compared both the PF controllers for the boost converter. Using the fixed switching frequency control, the PF is near to UPF only for low voltages, but PF can be made unity for both low and high voltages using PI controller. Hence this makes the converter suitable for both low and high voltage applications.

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