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Enhancement of Power Factor Correction Using Dual Boost Converter

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Abstract
This paper aims to develop a circuit for PFC using active filtering approach by implementing two boost converters arranged in parallel. It shall be based on an optimized power sharing strategy to improve the current quality and at the same time reduce the switching losses. The work involves simulation of basic power electronic circuits and the analysis of the current and voltage waveforms. It starts with simple circuits with a gradual increase in complexity by inclusion of new components and their subsequent effect on the current and voltage waveforms. Main objective is to improve the input current waveform i.e. making it sinusoidal by tuning the circuits. All the simulation work is done in MATLAB Simulink environment.
Keywords: Active filter, Boost converter, PFC, Simulink

I. INTRODUCTION

In the past, rectification used to be a much simpler task. But in recent times, rectifiers have become much more complicated systems rather than simple circuits. They include pulse-width modulated converters such as the boost converter with control systems that regulate the ac input current waveform. The reason for this change is the unwanted ac line current harmonics and low power factors of conventional rectifier circuits such as peak-detection and phase-controlled rectifiers. The adverse effects of power system harmonics are well recognized and include heating and reduction of transformers and induction motors life, degradation of system voltage waveforms, insecure currents in power-factor-correction capacitors and malfunctioning of certain power system protection elements.

In a true sense, conventional rectifiers are harmonic polluters of the ac power distribution system. With the extensive use of electronic equipment, rectifier harmonics have become a major problem. Therefore, there is a need for high-quality rectifiers that can operate with high power factor, high efficiency and reduce generation of harmonics. A number of international standards now exist that in particular limit the magnitude of harmonics currents, for both high-power equipment such as industrial motor drives, and low-power equipment such as electronic ballasts. Power Factor gives a measure of how effective the real power utilization of the system is. It is a figure of merit that measures how effectively power is transmitted between a source and load network.

Power Factor (pf) = Real power/Apparent power
Power factor (pf) = (average power) / (rms voltage) * (rms current)

In a linear system, the load draws purely sinusoidal current and voltage; hence the power factor is determined only by the phase difference between voltage and current. That is,
PF = cos θ, where cos θ is the displacement factor of the voltage and current.
When the load is nonlinear, the line current is non-sinusoidal for a sinusoidal voltage, and the power factor (pf) can be expressed as:

$$pf = \frac{V_{rms} I_{1rms}}{V_{rms} I_{rms}} \cos\phi = \frac{I_{1rms}}{I_{rms}} \cos\phi = K_p \cos\phi$$

where Kp describes the harmonic content of the current with respect to the fundamental and is referred to as purity factor or distortion factor. Another important parameter that measures the percentage of distortion is known as the current total harmonic distortion (THDi) and is defined as follows:
Hence the relation between Kp and THDi is

$$THDi = \frac{\sqrt{\sum_{n=2}^{\infty} I_{n,rms}^2}}{I_{1,\,rms}}$$

Hence the relation between Kp and THDi is

$$Kp = \frac{1}{\sqrt{1 + THDi^{\,2}}}$$

The harmonics can decline power quality and affect system performance in several ways.

II. POWER FACTOR CORRECTION

It is a technique of counteracting the undesirable effects of electric loads that create a power factor less than 1.When an electric load has a pf lower than 1, the apparent power delivered to the load is greater than the real power which the load consumes. Only the real power is capable of doing work, but the apparent power determines the amount of power that flows into the load, combining both active and reactive components. The purpose of the power factor correction circuit is to minimize the input current waveform distortion and make it in phase with the voltage one. Most of the research on PFC for nonlinear loads is actually related to the reduction of the harmonic content of the line current. There are several methodologies to achieve PFC but depending on whether active switches (controllable by an external control input) are used or not, they can be categorized as "Passive" or "Active".

Passive PFC

Harmonic current can be controlled in the simplest way by using a filter that passes current only at line frequency (50 or 60 Hz).Harmonic currents are suppressed and the non-linear device looks like a linear load. Power factor can be improved by using capacitors and inductors i.e. passive devices. Such filters with passive devices are called passive filters.

A passive PFC circuit requires only a few components to increase efficiency, but they are large due to operating at the line power frequency. A passive PFC circuit is shown below in Figure 1.

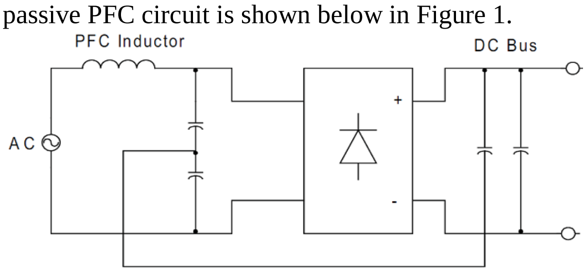


Fig 1. A Passive PFC circuit [1]

Active PFC

An active approach is the most effective way to correct power factor of electronic supplies. Here we place a boost converter between the bridge rectifier and the main input capacitors. The converter tries to maintain a constant DC output bus voltage and draws a current that is in phase with line voltage as well as at the same frequency. Figure 2 shows one such control circuit with boost converter.

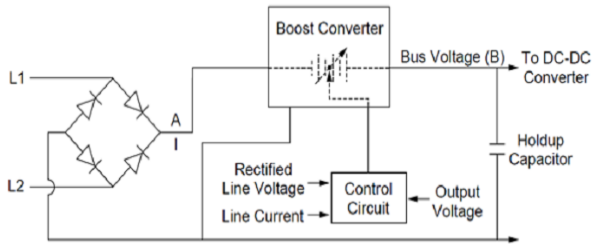


Fig 2. Control circuit with boost converter to maintain a sinusoidal input current [2]

III. CIRCUIT ANALYSIS OF ACTIVE POWER FACTOR CORRECTOR

Many circuits and control methods using switched-mode model have been developed to act in accordance with the standard. The active PFC's basic converter topologies are

1) Buck Converter
2) Boost Converter
3) Buck-Boost Converter
4) Cuk, Sepic and Zeta Converter

In this paper, we use the boost converter topology which is one of the most significant high power factor converters. The higher order harmonics are considerably reduced in the line current by using a boost converter. It is derived from a conventional non-controlled bridge rectifier, with the addition of transistor, diode and inductor [1] as shown in figure 3.

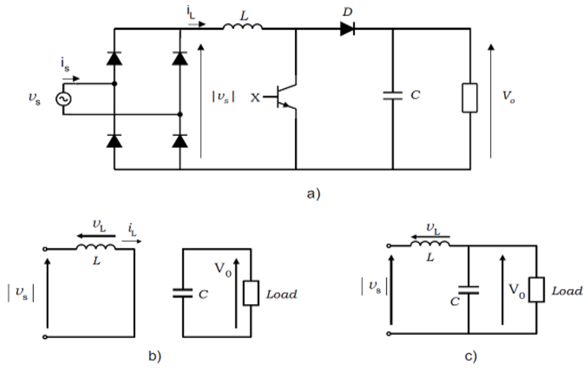
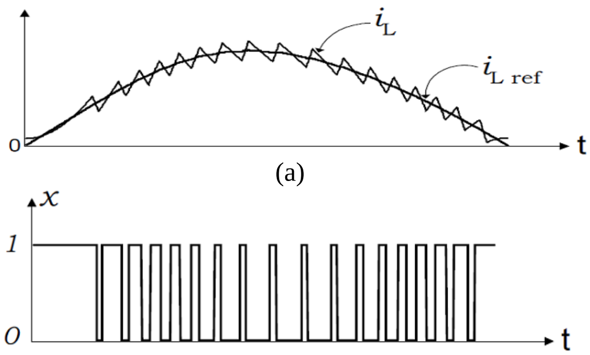


Fig 3. On and Off states of a boost rectifier [1]

The input current $i_s(t)$ is controlled by altering the conduction state of transistor. By switching the transistor with suitable firing pulse sequence, the waveform of the input current can be controlled to track a sinusoidal reference, as can be observed in the positive half wave in Figure 4. The figure shows the reference inductor current i_{Lref}, the inductor current i_L, and the gate drive signal x for transistor. Transistor is ON when x = 1 and it is OFF when x = 0. The ON and OFF states of the transistor cause an increase and decrease in the inductor current i_L respectively.



(b)

Fig 4. Behaviour of inductor current (a) Waveform (b) Transistor gate driving signal [1]

Conventionally, boost converter are used as active Power factor correctors. However, a recent novel approach for PFC is to use dual boost converter i.e. two boost converters connected in parallel for improving power processing capability, reliability and flexibility. However, being a non-linear system, a parallel-connected system of converters can perform in many ways that are not predictable by the conventional linear design and analysis method.

The main design issue in paralleling converters is the control of current sharing among the constituent converters. It is theoretically impossible to put two voltage sources in parallel unless a suitable control method is used to ensure proper current sharing. Over the past decade, many effective control schemes have been proposed. One common approach is to use an active-control scheme to force the current in one converter to follow that of the other. Circuit diagram of Dual boost PFC is shown in figure 5.

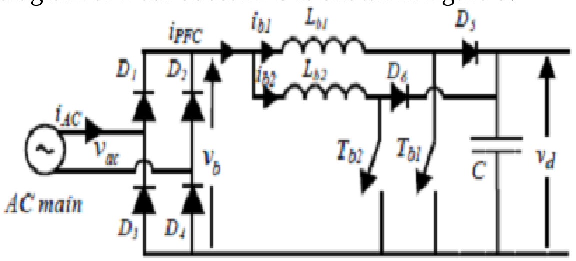


Fig. 5. Dual boost PFC circuit [3]

Here, we use a parallel scheme, where choke L_{b1} and switch T_{b1} are for main PFC while L_{b2} and T_{b2} are for active filtering. The filtering circuit serves two purposes; it improves the quality of line current, and reduces the PFC total switching loss. The reduction in switching losses occurs due to different values of switching frequency and current amplitude for the two switches. The parallel connection of switch mode converter is a well known strategy. It involves phase shifting of two or more boost converters connected in parallel and operating at the same switching frequency [3].

IV. DUAL PFC MODELLING AND CONTROLLING

With reference to Fig. 5 considering working in the continuous conduction mode, we obtain the following voltage equations:

$$\begin{cases} v_b = L_{b1}\dfrac{d}{dt}t_{b1} + R_{b1}i_{b1} + f_{b1}v_d \\ v_b = L_{b2}\dfrac{d}{dt}t_{b2} + R_{b2}i_{b2} + f_{b2}v_d \\ t_{PFC} = f_{b1} + f_{b2} \end{cases}$$

where

$$vb(t) = |vb(t)\sin(\omega t)|$$

$$f_{b1} = \begin{cases} 0 if T_{b1} = 1(switchon) \\ 1 if T_{b1} = 0(switchoff) \end{cases}$$

$$f_{b2} = \begin{cases} 0 if T_{b2} = 1(switchon) \\ 1 if T_{b2} = 0(switchoff) \end{cases}$$

The above set of equations can also be written as:

$$f_{b1} = 0 \rightarrow \frac{di_{b1}(t)}{dt} = \frac{v_b(t)}{L_{b1}}$$

$$f_{b1} = 1 \rightarrow \frac{di_{b1}(t)}{dt} = \frac{v_b(t) - v_d(t)}{L_{b1}}$$

$$f_{b2} = 0 \rightarrow \frac{di_{b2}(t)}{dt} = \frac{v_b(t)}{L_{b2}}$$

$$f_{b2} = 1 \rightarrow \frac{di_{b2}(t)}{dt} = \frac{v_b(t) - v_d(t)}{L_{b2}}$$

where

$$i_{b1} \geq 0, i_{b2} \geq 0$$

PFC currents i_{b1} and i_{b2} can be achieved if the following condition occurs:

Vd(t) > vb(t)

If the above condition is satisfied, it is possible to control the derivative of the total PFC current i_{PFC} [3].

$$\frac{di_{PFC}}{dt} = \frac{di_{b1}}{dt} + \frac{di_{b2}}{dt}$$

The input current waveform of two interleaved PFC under ideal and actual working condition is shown in figure 6 and 7.

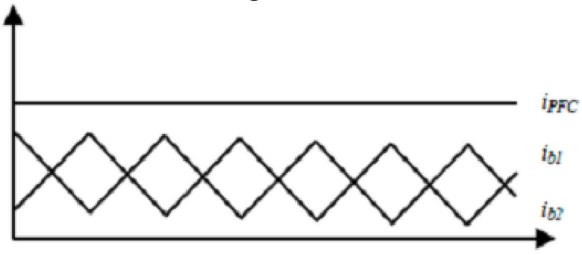


Fig. 6. Input current waveform of two interleaved PFC under ideal working condition [3]

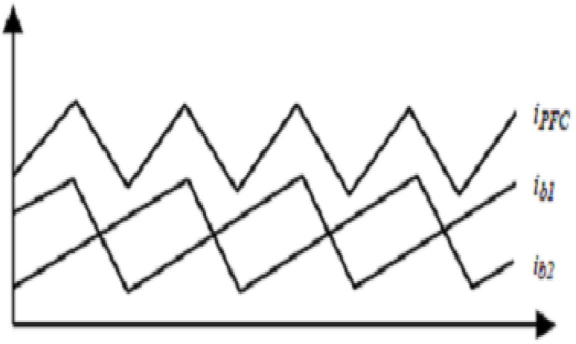


Fig.7. Input currents waveform of two interleaved PFC under actual working condition [3]

V. SIMULATION RESULT

A. Model and simulation results for a rectifier circuit without PFC circuit

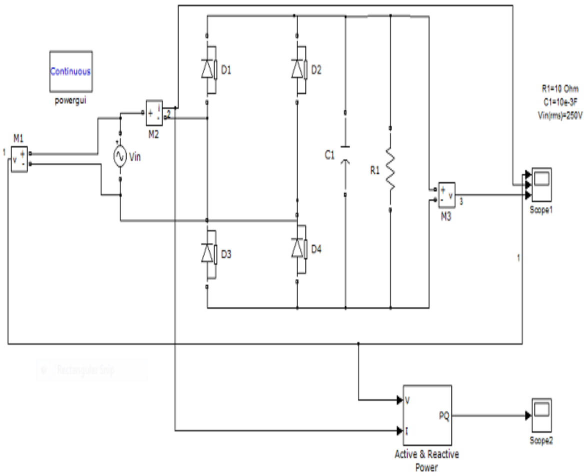


Fig 8 (a) Model

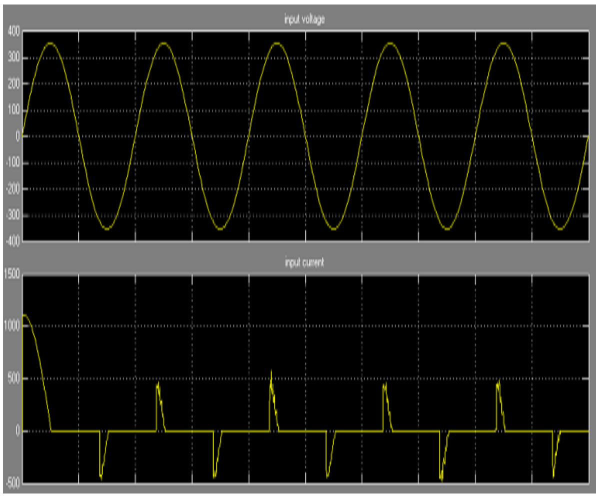


Fig 8 (b) Input voltage and input current

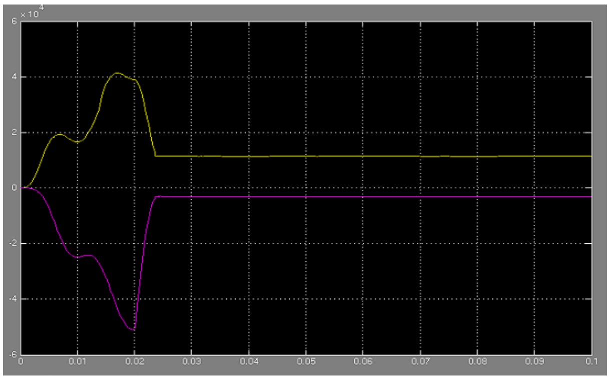


Fig 8 (c) Active and reactive power

B. Model and simulation results for PFC circuit having a boost converter

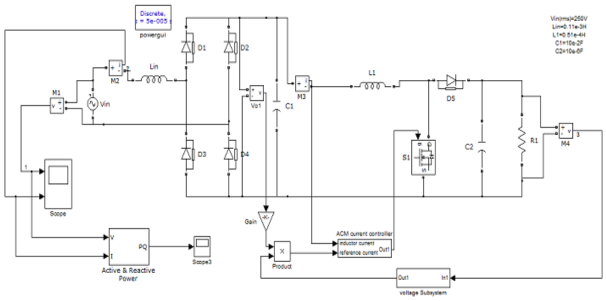


Fig 9 (a) Model

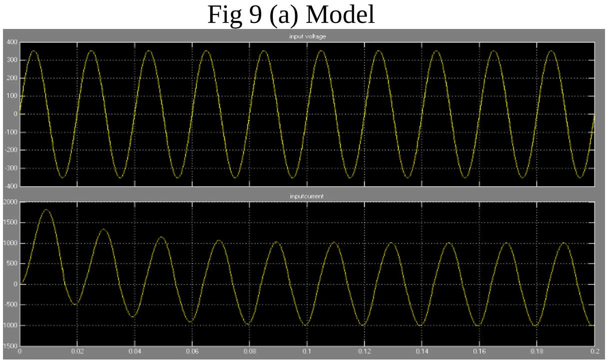


Fig 9 (b) Input voltage and input current

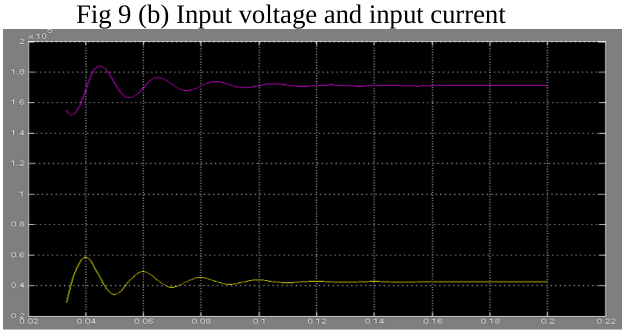


Fig 9 (c) Active and reactive power

C. Model and simulation results for a PFC circuit with a parallel boost converter

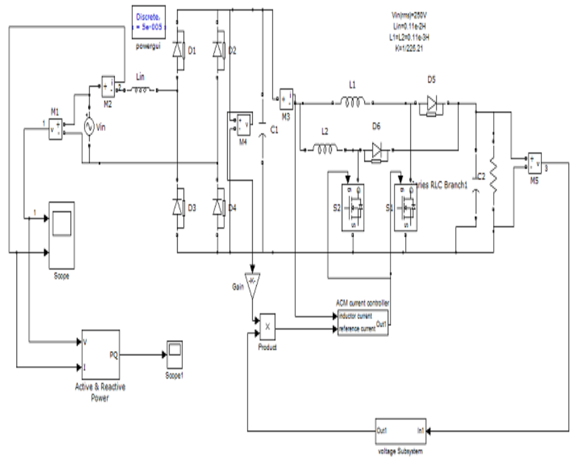


Fig 10 (a) Model

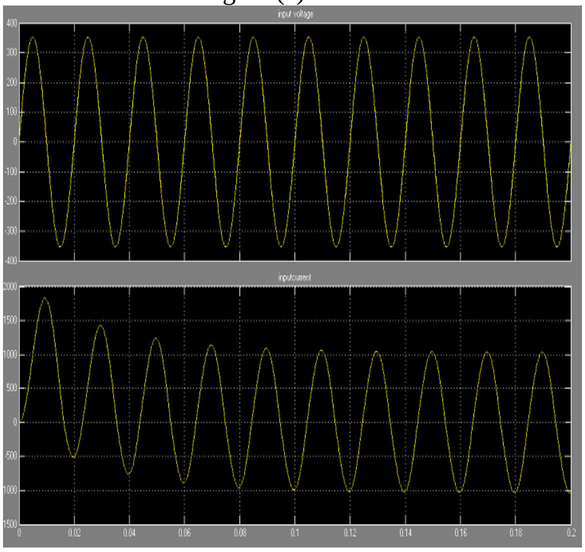


Fig 10 (b) Input voltage and input current

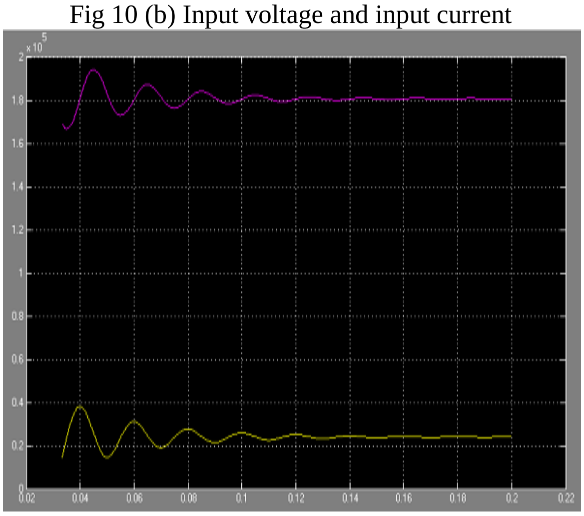


Fig 10 (c) Active and reactive power

Table. 1 Comparison of various circuits

Circuit	Active Power (P)	Reactive Power (Q)	Power Factor (PF)	THD
Without any PFC	11 KW	3.0 KVAR	96%	1.032
With Boost Converter	170 KW	42.5 KVAR	97%	0.125
With Dual Boost converter	180 KW	24.0 KVAR	99%	0.124

VI. CONCLUSION

As can be seen from the above table, the power factor has improved from 96 % in a rectifier circuit without any PFC to 99% in a circuit employing a parallel boost converter for Power Factor Correction. As far as the reduction of harmonics is concerned, it was observed that an inductor placed on the input side acts as a filter and reduces the higher order harmonics considerably. Introduction of a source side inductor reduced the THD from 1.032 to 0.124 which is indeed a considerable reduction.

REFERENCES

[1] Rashid M., Power Electronics: Circuits, Devices and Applications, Pearson Education India, Third edition, 2004.

[2] Active PFC for power electronic supplies, Application Note VICOR.

[3] Parillo,F.;Dual Boost High performances Power Factor Correction Systems(PFC)

[4] Sun, J.;Bass, R.M.;, Adv.Technol. Center, Rockwell Collins, Inc., Cedar Rapids, IN, Modelling and practical design issues for average current control, Applied Power Electronics Conference and Exposition,1999.APEC'99.14th Annual

[5] Orabi,M.; Ninomiya,T;Dept. of Electr. & Electron. Syst. Eng., Kyushu Univ., Fukuoka, Japan, Stability Performancs of two-stage PFC converters, Industrial Electronics IEEE,Volume-50,Issue-6

[6] Attaianese, C.; Nardi, V.; Parillo, F.; Tomasso, G.; "Predictive Control of Parallel Boost Converters" in Industrial Electronics, 2008, IECON 2008, 34th Annual Conference of IEEE.

[7] Wu, M. K. W., et el. "A review of EMI problems in switch mode power supply design." Journal of Electrical and Electronics Engineering, Australia. vol. 16, nos. 3&4, (1996): pp. 193-204.

[8] Redl, Richard, "Power electronics and electromagnetic compatibility." Proc. of IEEE Power Electronics Specialists Conference, PESC'96. (1996): pp. 15-21.
[9] Vlatkovic, V., et el. "Input filter design for power factor correction circuits." IEEE Transactions on Power Electronics. vol. 11, no. 1, (Jan. 1996): pp. 199-205.
[10] Jang, Y., "Physical origins of input filter oscillations in current programmed converters." IEEE Transactions on Power Electronics. vol. 7, no. 4, (Oct. 1992): pp. 725-733