# Power Factor Correction Circuits: Active Filters

Vijaya Vachak[1], Anula Khare[1],Amit Shrivatava[1]

Electrical & Electronics Engineering Department

Oriental College of Technology, Bhopal, India

vijayavachak@gmail.com

***Abstract:*** **-**The increasing growth in the use of electronicequipment in recent years has resulted in a greater need toensure that the line current harmonic content of anyequipment connected to the ac mains is limited to meetregulatory standards. This requirement is usually satisfiedby incorporating some form of Power Factor Correction(PFC) circuits to shape the input phase currents, so thatthey are sinusoidal in nature and are in phase with theinput phase voltages. There are multiple solutions in whichline current is sinusoidal. This paper provides a concisereview of the most interesting passive and active circuits ofpower factor correction, for single phase and low powerapplications.The major advantages and disadvantages arehighlighted.

***Keywords****:* Converter, Power factor correction,active Power factor correction circuit, passive power factor correction circuit.

## INTRODUCTION

Power factor is defined as the cosine of the angle between voltage and current in an ac circuit. There is generally a phase difference Ø between voltage and current in an ac circuit. cos Ø is called the power factor of the circuit. If the circuit is inductive, the current lags behind the voltage and power factor is referred to as lagging. However, in a capacitive circuit, current leads the voltage and the power factor is said to be leading.

In a circuit, for an input voltage V and a line current I,

VIcos Ø –the active or real power in watts or kW.

VIsin Ø**-** the reactive power in VAR or kVAR.

VI**-** the apparent power in VA or kVA.

Power Factor gives a measure of how effective the real power utilization of the system is. It is a measure of distortion of the line voltage and the line current and the phase shift between them.

Power Factor=Real power(Average)/Apparent power

Where, the apparent power is defined as the product of rms value of voltage and current.

Improvements in power factor and total harmonic distortion can be achieved by modifying the input stage of the diode rectifier filter capacitor circuit. Passive solutions can be used to achieve this objective for low power applications. With a filter inductor connected in series with the input circuit, the current conduction angle of the single-phase full-wave rectifier is increased leading to a higher power factor and lower input current distortion. With smaller values of inductance, these achievements are degraded

However, the large size and weight of these elements, in addition to their inability to achieve unity power factor or lower current distortion significantly, make passive power factor correction more suitable at lower power levels. The power factor correction (PFC)technique has been gaining increasing attention in power electronics field in recent years. For the conventional single-phase diode rectifier, a large electrolytic capacitor filter is used to reduce dc voltage ripple. This capacitor draws pulsating current only when the input ac voltage is greater than the capacitor voltage, thus the THD is high and the power factor is poor. To reduce THD and improve power factor, passive filtering methods and active wave-shaping techniques have been explored. Reducing the input current harmonics to meet the agency standards implies improvement of power factor as well. Several techniques for power factor correction and harmonic reduction have been reported and a few of them have gained greater acceptance over the others. Commercial IC manufacturers have introduced control ICs in the market for the more popular techniques. In this paper, the developments in the field of single-phase PFC are reviewed. In this paper the hysteresis is control method and average current control method is analysed and simulated using MATLAB/ SIMULINK software and results are obtained near unity power factor.

**POWER FACTOR CORRECTION CIRCUITS**

The classification of single-phase PFC topologies is shown in Fig.The diode bridge rectifier has no sinusoidal line current. This is because most loads require a supply voltage $V_2$ with low ripple, which is obtained by using a correspondingly large capacitance of the output capacitor $C_f$. Consequently, the conduction intervals of the rectifier diodes are short and the line current consists of narrow pulses with an important harmonic contents.
There are several methods to reduce the harmonic contents of the line current in single-phase system.

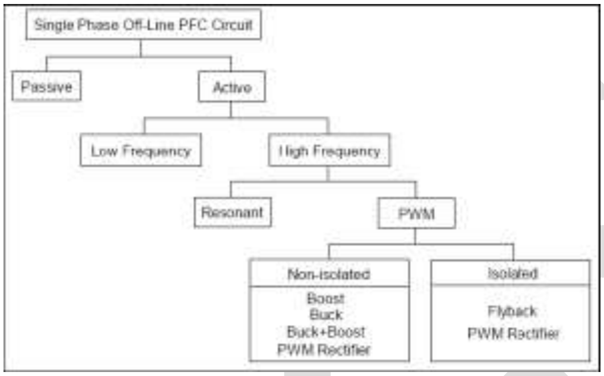



**Figure 1 Classification of single-phase PFC topologies.**

**Active PFC**

Active PFC circuits are based on switchmode convertertechniques and are designed to compensate fordistortion as well as displacement on the input currentwaveform. They tend to be significantly more complexthan passive approaches, but this complexity isbecoming more manageable with the availability ofspecialized control ICs for implementing active PFC.Active PFC operates at frequencies higher thanthe line frequency so that compensation of bothdistortion and displacement can occur within thetimeframe of each line frequency cycle, resultingin corrected power factors of up to 0.99. Activeapproaches can be divided into two classes:

- Slow switching topologies
- High frequency topologies

**Slow Switching Topologies**

The slow switchingapproach can be thought of as a mix of passiveand active techniques, both in complexity andperformance. The most commonimplementation is shown in Figure andincludes the line frequency inductor L. Theinductor is switched during the operatingcycle, so this is considered an activeapproach, even though it operates at arelatively low frequency - typically twice theline frequency. This is a boost circuit in thesense that the AC zero crossing is sensedand used to close the switch that placesthe inductor across the AC input.

Consequently, the inductor current rampsup during the initial portion of the AC cycle.At time T1, the switch is opened so that the energystored in the inductor can freewheel through the diodesto charge the capacitor. This energy transfer occurs fromT1 to T2 and the input current drops as a result. FromT2 to T3 the input current rises again because the linevoltage is larger than the bulk capacitor voltage. FromT3 to T4, the current reduces to zero. Consequently, theconduction angle as seen at the input is much longerthan that of a non-compensated off-line rectifier, resultingin lower distortion and a power factor of up to 0.95.

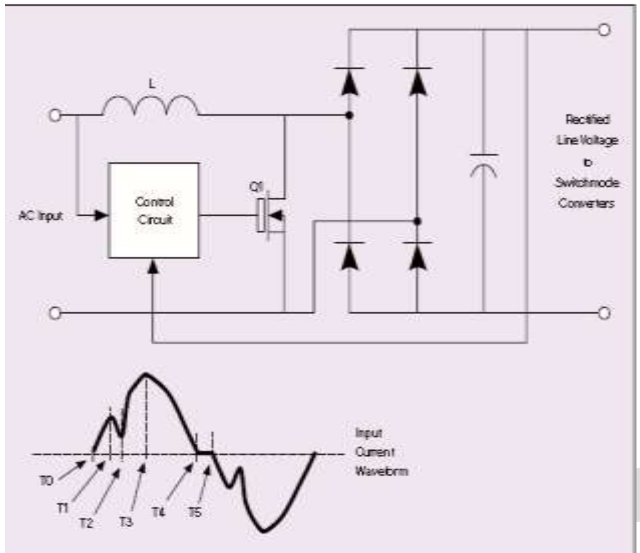



**Figure 2 Slow Switching Active PFC Circuit**

This circuit is much simpler than the high frequencycircuit to be discussed next, but has a few shortcomingsin addition to its limited maximum power factor. Sincethe switching activity is usually in the 100Hz to 500Hzrange, there can be audible noise associated with itsoperation. Also, a large and heavy line frequencyinductor is required.

**Advantages and Disadvantages of Slow Switching Active PFC**

| S.No. | Advantages | Disadvantages |
|---|---|---|
| 1. | Simple | Line Frequency Components are Largeand Heavy |
| 2. | Cost Effective at Low Power | Cannot Completely Correct NonlinearLoads - 95% Maximum Power Factor |
| 3. | High Efficiency - 98% Typical | Audible Noise |
| 4. | Low EMC due to Inductor | |

**High Frequency Topologies**

Conceptually, any of thepopular basic converter topologies, including the fly backand buck, could be used as a PFC stage. We will focus,however, on the boost topology since it is the mostpopular implementation. There are several possiblecontrol techniques that can be used to implement aboost PFC converter, but the version shown in Figureis a good general representation of the concept andwill be used here for illustration.

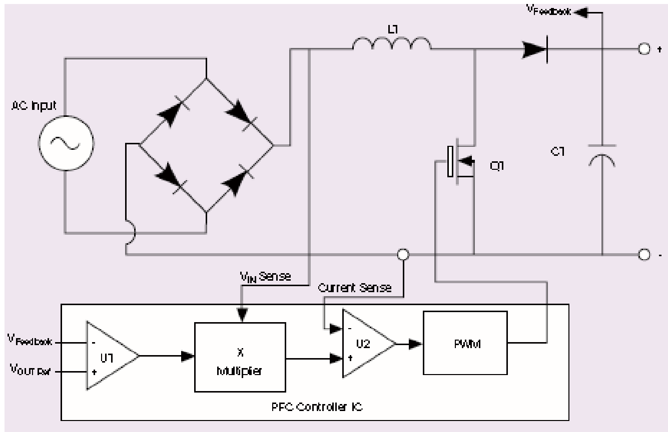



**Figure 3 High Frequency Active PFC Circuit**

Almost all present day boost PFC converters utilize astandard controller chip for the purposes of ease ofdesign, reduced circuit complexity and cost savings.These ICs are available from many of the analog ICsuppliers and greatly simplify the process of achieving areliable high-performance circuit. In order for theconverter to achieve power factor correction over theentire range of input line voltages, the converter (in thePFC circuit) must be designed so that the output voltage,VOUT is greater than the peak of the input line voltage*.Assuming a maximum line voltage of 240Vrms andallowing for at least a 10% margin results in a nominalVOUT in the vicinity of 380 Vdc. VOUT is regulated viafeedback to the operational amplifier U1. The sensedVIN will be in the form of a rectified sine wave, whichaccurately reflects the instantaneous value of the inputAC voltage. This signal is used as in input to themultiplier along with the VOUT error voltage to formulate avoltage that is proportional to the desired current. Thissignal is then compared with the sensed actual convertercurrent to form the error signal that drives the converterswitch Q1. The result is that the input current waveformwill track the AC input voltage waveform almost perfectly.By definition, this constitutes a power factor approaching unity. The active boost circuit will correct for deficienciesin both displacement and distortion.

During operation of the converter, the duty cycle will varygreatly during each half cycle of the input AC waveform.The duty cycle will be the longest when theinstantaneous value of the AC is near zero and will bevery short during the peaks of each half cycle. Thevoltage stress on the switch Q1 is equal to only VOUT andthe current levels are reasonable, resulting in aneconomical device selection. Since Q1 is referenced toground, its control and driver circuits are relativelystraightforward and easy to implement. The inductor L1assists in reducing EMC from the converter and insuppressing some input transients from the power line. Itis not large enough in value, however, to be consideredas protection from start-up inrush current, which must beprovided by other methods.

This circuit, of course, is much morecomplex than the other PFC techniques wehave considered. However, there are someadditional benefits to be derived from itsuse. The topology allows for inclusion ofautomatic range switching on the AC inputat essentially no extra cost. Since thisuniversal input function is now arequirement on the majority of powerconverters to allow for operation in allcountries without any manual settings, thisfeature helps offset the cost of theadditional componentry for the PFC function. Becausethe circuit operates at high frequencies, typically over100 kHz, the components, including the inductor L1, tendto be small and light and much more conducive toautomated manufacturing. The relatively high output voltage is actually an advantage for the down-converterfollowing the boost stage. The current levels in thesilicon and transformer of the down-converter are modest, resulting in lower cost devices. The efficiency ofthe active boost circuit is very high, approaching 95%.However, it will constitute a second conversion stage insome applications and can somewhat degrade theoverall power conversion efficiency compared to asolution without PFC.Considering all the tradeoffs, the active boost is a verygood solution for many applications, especially where thepower level is high enough so that the cost of the extracomponents is not a big percentage of the total cost.

**Advantages and Disadvantages ofHigh Frequency Active PFC**

| S.No. | Advantages | Disadvantages |
|---|---|---|
| 1. | High Power Factor ≈ 0.99 | Complexity |
| 2. | Corrects both Distortion and DisplacementAuto ranging | VOUT has to be > Peak V IN ≈ 380 Vdc |
| 3. | Circuit includes Input Voltage | Cost for Low Power applications |

| | | |
|---|---|---|
| 4. | Regulated VOUT | Adds 2nd conversion Stage in somecases and Decreases efficiency |
| 5. | Small and Light Components | No Inrush Current Limiting |
| 6. | Good EMC Characteristics | |
| 7. | Absorbs Some Line Transients | |
| 8. | Design Supported by Standard Controller ICs | |
| 9. | Low Stresses on Switching Devices | |

**SINGLE PHASE BOOST CONVERTER TOPOLOGY:**

Design of input filters for power factor improvement in buck converters istherefore complex and provides only limited improvement in input current quality. Onthe other hand the boost type converter generate dc voltage, which is higher than theinput ac voltage. However, the input current in these converters flows through theinductor and therefore can easily be actively wave-shaped with appropriate current modecontrol. Moreover, boost converters provide regulated dc output voltage at unity inputpower factor and reduced THD of input ac current. These converters have foundwidespread use in various applications due to the advantages of high efficiency, highpower density and inherent power quality improvement at ac input and dc output.The preferred power circuit configuration of single-phase boost converter5-18 isthe most popular and economical PFC converter consisting of diode bridge rectifier withstep-up chopper. The single phase boost converter with unidirectional power flow shownin Figure 1 is realized by cascading single-phase diode bridge rectifier with boostchopper topology.

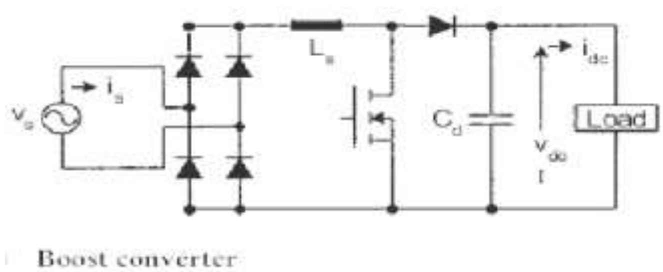
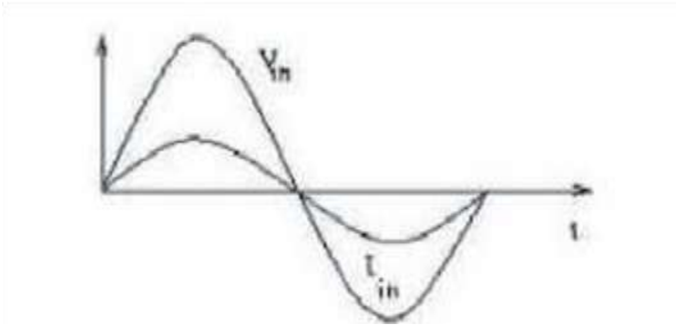



**Figure 4 Boost converter with load**

**POWER FACTOR CORRECTION TECHNIQUES**

In recent years, single-phase switch-mode AC/DC power converters have beenincreasingly used in the industrial, commercial, residential, aerospace, and militaryenvironment due to advantages of high efficiency, smaller size and weight. However, theproliferation of the power converters draw pulsating input current from the utility line,this not only reduce the input power factor of the converters but also injects a significantamount of harmonic current into the utility line . To improve the power quality, variousPFC schemes have been proposed. There are harmonic norms such as IEC 1000-3-2introduced for improving power quality. By the introduction of harmonic norms nowpower supply manufacturers have to follow these norms strictly for the remedy of signalinterference problem.The various methods of power factor correction can be classified as:(1) Passive power factor correction techniques(2) Active power factor correction techniquesIn passive power factor correction techniques, an LC filter is inserted between theAC mains line and the input port of the diode rectifier of AC/DC converter as shown in Figure . This technique is simple and rugged but it has bulky size and heavy weight andthe power factor cannot be very high [1]. Therefore it is now not applicable for the
35current trends of harmonic norms. Basically it is applicable for power rating of lowerthan25W. For higher power rating it will be bulky.In active power factor correction techniques approach, switched mode powersupply (SMPS) technique is used to shape the input current in phase with the inputvoltage. Thus, the power factor can reach up to unity. Figure shows the circuit diagramof basic active power correction technique. By the introduction of regulation norms IEC1000-3-2 active power factor correction technique is used now a day.



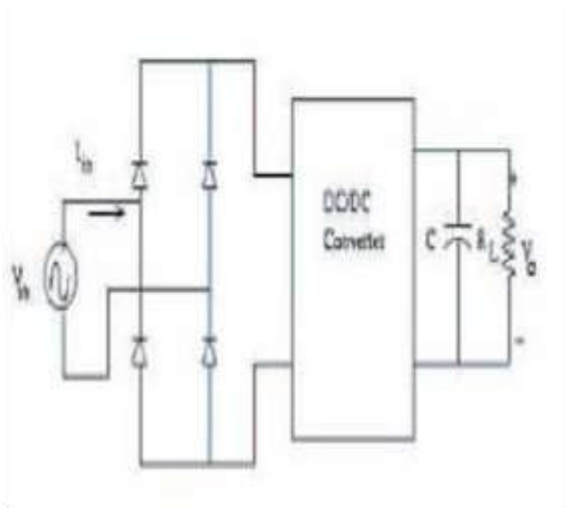




**Figure 5 Circuit diagram of active filter**

The active PFC techniques can be classified as:

(1) PWM power factor correction techniques
(2) Resonant power factor correction techniques
(3) Soft switching powerfactor correction techniques.

In PWM power factor correction approach, the power switching device operatesat pulse-width-modulation mode. Basically in this technique switching frequency of active power switch is constant, but turn-on and turnoff mode is variable.

Differenttopologies of PWM techniques are as follows:

(1) Buck type
(2) Fly back type
(3) Boost type
(4) Cuk' type

**Passive PFC**

Although most switchmode power converters now useactive PFC techniques, we will give a couple of examplesof using the simpler passive approach.

Figure shows the input circuitry of the power supply passive PFC. Note the line- voltage range switch connected to the center tap of the PFC inductor. In the 230-V position (switch open) both halves of the inductor winding are used and the rectifier function as a full wave bridge. In the 115V(switch closed) position only the left half of the inductor and the half of the rectifier bridge are used, placing the circuit in the half wave double mode. As in the case of the full wave rectifier with 230V ac input, this produces 325 at the out put of the rectifier. This 325 $V_{dc}$ bus is, of course, unregulated and moves up down with the input line voltage.

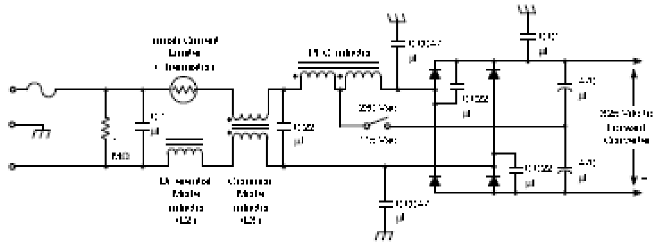


**Figure 6 Passive PFC in a 250 W PC Power Supply**

**Advantages and Disadvantages of Passive PFC**

| S.No. | Advantages | Disadvantages |
|---|---|---|
| 1. | Simple | Line Frequency Components are Large and Heavy |
| 2. | Cost Effective at Low Power | Cannot Completely Correct Nonlinear Loads |
| 3. | Reliable and Rugged | AC Range Switching Required |
| 4. | Not a Source of EMC | Needs to be Re-Designed as Load Characteristics Change |
| 5. | Can Assist with EMC Filtering | Magnetics needed if Load is Capacitive |
| 6. | Unity Power Factor for Linear Loads | |

**DIFFERENT CONTROL TECHNIQUES**

There are various types of control schemes present for improvement of powerfactor with tight output voltage regulation .viz.

(a) Peak current control method
(b)Average current control method
(c) Borderline current control method
(d) Discontinuouscurrent PWM control method
(e) Hysteresis control method

**1: Peak Current Control Method**

Switch is turned on at constant frequency by a clock signal, and is turned off when the sum of the positive ramp of the inductor current (i.e. the switch current) and an external ramp (compensating ramp) reach the sinusoidal current reference. This reference is usually obtained by multiplying a scaled replica of the rectified line voltage vg times the output of the voltage error amplifier, which sets the current reference amplitude. In this way, there reference signal is naturally synchronized and always proportional to the line voltage, which is the condition to obtain unity power factor the converter operates in normal condition.

The objective of the inner loop is to control the state-space averaged inductor current, but in practice the instantaneous peak inductor current is the basis for control. The switch current during the ON time is equal to the inductor current. If the inductor ripple current is small, peak current control is nearly equivalent to the average inductor current control. In a conventional switching power supply employing a buck derived topology, the inductor current is in the output.

Current mode control is then the output current control. On the other hand, in a high power factor pre-regulator using the boost topology, the inductor is in the input. Current mode control then controls the input current, allowing it to be easily conformed to the desired sinusoidal wave shape.

The peak method of inductor current control functions by comparing the upslope of inductor current (or switch current) to a current program level set by the outer loop. The comparator turns the power switch off when the instantaneous current reaches the desired level.

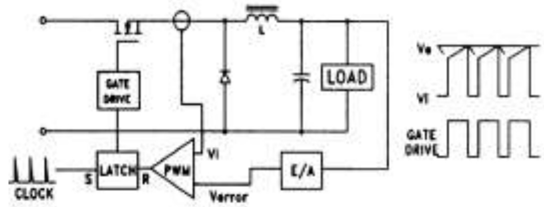



**Figure 7 Peak current mode control circuit and its waveforms**

### 2: Average Current Control Method

Here the inductor current is sensed and filtered by a current error amplifier whoseoutput drives a PWM modulator. In this way the inner current loop tends to minimize theerror between the average input current and its reference. This latter is obtained in thesame way as in the peak current control. The converter works in CICM, so the sameconsideration done with regard to the peak current control can be applied.

### 3. Borderline Control Method

In this control approach the switch on-time is held constant during the line cycleand the switch is turned on when the inductor current falls to zero, so that the converteroperates at the boundary between Continuous and Discontinuous Inductor Current Mode(CICM-DICM).

### 4. Discontinuous Current PWM Control Method

With this approach, the internal current loop is completely eliminated, so that theswitch is operated at constant on-time and frequency. With the converter working indiscontinuous conduction mode (DCM), this control technique allows unity power factorwhen used with converter topologies like fly back, Cuk. Instead, with the boostPFC this technique causes some harmonic distortion in the line current.

## Conclusion

In this paper, both PFC techniques have been presented. The operation principle has been discussed indetail. It shows that a high power factor has beenobtained. Compared with the traditional PFC, the proposed PFChas the following advantages: 1) lower devices rating, which reducescost, EMI, and switching losses, 2) no additional inductoris required, the line impedance is enough for most cases, and3) the proposed double hysteresis control reduces the switchingfrequency significantly, which leads to higher efficiency.

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