

Power Factor Correction Circuits: Active Filters

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Abstract: -The increasing growth in the use of electronic equipment in recent years has resulted in a greater need to ensure that the line current harmonic content of any equipment connected to the ac mains is limited to meet regulatory standards. This requirement is usually satisfied by incorporating some form of Power Factor Correction (PFC) circuits to shape the input phase currents, so that they are sinusoidal in nature and are in phase with the input phase voltages. There are multiple solutions in which line current is sinusoidal. This paper provides a concise review of the most interesting passive and active circuits of power factor correction, for single phase and low power applications. The major advantages and disadvantages are highlighted.

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 ϕ between voltage and current in an ac circuit. $\cos \phi$ 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 ,

$VI \cos \phi$ – the active or real power in watts or kW.

$VI \sin \phi$ – 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 the 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 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.

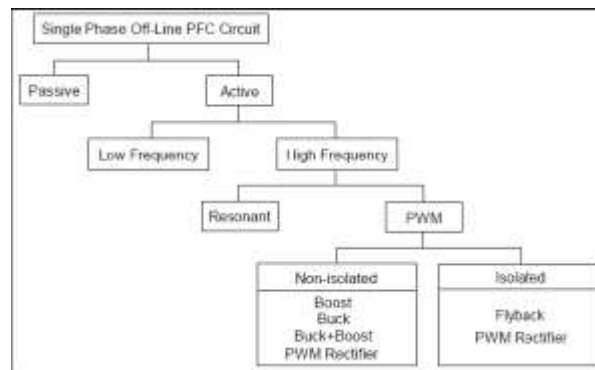


Figure 1 Classification of single-phase PFC topologies.

Active PFC

Active PFC circuits are based on switchmode converter techniques and are designed to compensate for distortion as well as displacement on the input current waveform. They tend to be significantly more complex than passive approaches, but this complexity is becoming more manageable with the availability of specialized control ICs for implementing active PFC. Active PFC operates at frequencies higher than the line frequency so that compensation of both distortion and displacement can occur within the timeframe of each line frequency cycle, resulting in corrected power factors of up to 0.99. Active approaches can be divided into two classes:

- Slow switching topologies
- High frequency topologies

Slow Switching Topologies

The slow switching approach can be thought of as a mix of passive and active techniques, both in complexity and performance. The most common implementation is shown in Figure and includes the line frequency inductor L . The inductor is switched during the operating cycle, so this is considered an active approach, even though it operates at a relatively low frequency - typically twice the line frequency. This is a boost circuit in the sense that the AC zero crossing is sensed and used to close the switch that places the inductor across the AC input.

Consequently, the inductor current ramps up during the initial portion of the AC cycle. At time T_1 , the switch is opened so that the energy stored in the inductor can freewheel through the diodes to charge the capacitor. This energy transfer occurs from T_1 to T_2 and the input current drops as a result. From T_2 to T_3 the input current rises again because the line voltage is larger than the bulk capacitor voltage. From T_3 to T_4 , the current reduces to zero. Consequently, the conduction angle as seen at the input is much longer than that of a non-compensated off-line rectifier, resulting in lower distortion and a power factor of up to 0.95.

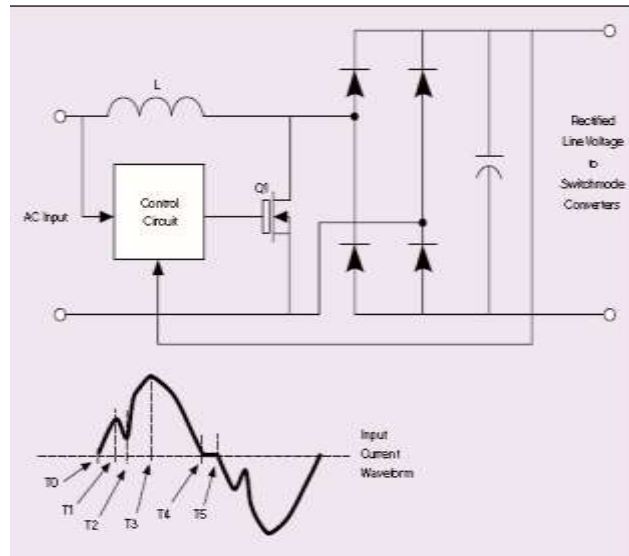


Figure 2 Slow Switching Active PFC Circuit

This circuit is much simpler than the high frequency circuit to be discussed next, but has a few shortcomings in addition to its limited maximum power factor. Since the switching activity is usually in the 100Hz to 500Hz range, there can be audible noise associated with its operation. Also, a large and heavy line frequency inductor is required.

Advantages and Disadvantages of Slow Switching Active 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 - 95% Maximum Power Factor
3.	High Efficiency - 98% Typical	Audible Noise
4.	Low EMC due to Inductor	

High Frequency Topologies

Conceptually, any of the popular basic converter topologies, including the fly back and buck, could be used as a PFC stage. We will focus, however, on the boost topology since it is the most popular implementation. There are several possible control techniques that can be used to implement a boost PFC converter, but the version shown in Figure is a good general representation of the concept and will be used here for illustration.

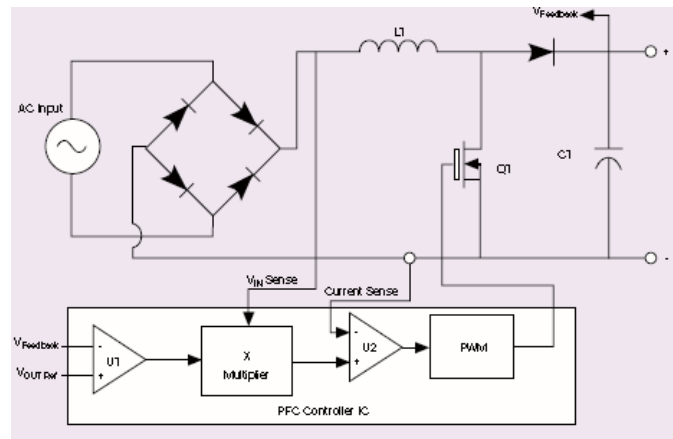


Figure 3 High Frequency Active PFC Circuit

Almost all present day boost PFC converters utilize a standard controller chip for the purposes of ease of design, reduced circuit complexity and cost savings. These ICs are available from many of the analog IC suppliers and greatly simplify the process of achieving a reliable high-performance circuit. In order for the converter to achieve power factor correction over the entire range of input line voltages, the converter (in the PFC circuit) must be designed so that the output voltage, V_{OUT} is greater than the peak of the input line voltage*. Assuming a maximum line voltage of 240Vrms and allowing for at least a 10% margin results in a nominal V_{OUT} in the vicinity of 380 Vdc. V_{OUT} is regulated via feedback to the operational amplifier U1. The sensed V_{IN} will be in the form of a rectified sine wave, which accurately reflects the instantaneous value of the input AC voltage. This signal is used as an input to the multiplier along with the V_{OUT} error voltage to formulate a voltage that is proportional to the desired current. This signal is then compared with the sensed actual converter current to form the error signal that drives the converter switch Q1. The result is that the input current waveform will track the AC input voltage waveform almost perfectly. By definition, this constitutes a power factor approaching unity. The active boost circuit will correct for deficiencies in both displacement and distortion.

During operation of the converter, the duty cycle will vary greatly during each half cycle of the input AC waveform. The duty cycle will be the longest when the instantaneous value of the AC is near zero and will be very short during the peaks of each half cycle. The voltage stress on the switch Q1 is equal to only V_{OUT} and the current levels are reasonable, resulting in an economical device selection. Since Q1 is referenced to ground, its control and driver circuits are relatively straightforward and easy to implement. The inductor L1 assists in reducing EMC from the converter and in suppressing some input transients from the power line. It is not large enough in value, however, to be considered as protection from start-up inrush current, which must be provided by other methods.

This circuit, of course, is much more complex than the other PFC techniques we have considered. However, there are some additional benefits to be derived from its use. The topology allows for inclusion of automatic range switching on the AC input at essentially no extra cost. Since this universal input function is now a requirement on the majority of power converters to allow for operation in all countries without any manual settings, this feature helps offset the cost of the additional componentry for the PFC function. Because the circuit operates at high frequencies, typically over 100 kHz, the components, including the inductor L1, tend to be small and light and much more conducive to automated manufacturing. The relatively high output voltage is actually an advantage for the down-converter following the boost stage. The current levels in the silicon and transformer of the down-converter are modest, resulting in lower cost devices. The efficiency of the active boost circuit is very high, approaching 95%. However, it will constitute a second conversion stage in some applications and can somewhat degrade the overall power conversion efficiency compared to a solution without PFC. Considering all the tradeoffs, the active boost is a very good solution for many applications, especially where the power level is high enough so that the cost of the extra components is not a big percentage of the total cost.

Advantages and Disadvantages of High Frequency Active PFC

S.No.	Advantages	Disadvantages
1.	High Power Factor ≈ 0.99	Complexity
2.	Corrects both Distortion and Displacement Auto ranging	V_{OUT} has to be $>$ Peak $V_{IN} \approx 380$ 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 is therefore complex and provides only limited improvement in input current quality. On the other hand the boost type converter generate dc voltage, which is higher than the input ac voltage. However, the input current in these converters flows through the inductor and therefore can easily be actively wave-shaped with appropriate current mode control. Moreover, boost converters provide regulated dc output voltage at unity input power factor and reduced THD of input ac current. These converters have found widespread use in various applications due to the advantages of high efficiency, high power density and inherent power quality improvement at ac input and dc output. The preferred power circuit configuration of single-phase boost converter is the most popular and economical PFC converter consisting of diode bridge rectifier with step-up chopper. The single phase boost converter with unidirectional power flow shown in Figure 1 is realized by cascading single-phase diode bridge rectifier with boost chopper topology.

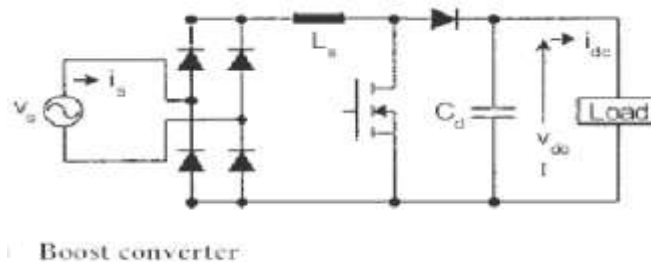


Figure 4 Boost converter with load

POWER FACTOR CORRECTION TECHNIQUES

In recent years, single-phase switch-mode AC/DC power converters have been increasingly used in the industrial, commercial, residential, aerospace, and military environment due to advantages of high efficiency, smaller size and weight. However, the proliferation 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 significant amount of harmonic current into the utility line. To improve the power quality, various PFC schemes have been proposed. There are harmonic norms such as IEC 1000-3-2 introduced for improving power quality. By the introduction of harmonic norms now power supply manufacturers have to follow these norms strictly for the remedy of signal interference problem. The various methods of power factor correction can be classified as: (1) Passive power factor correction techniques (2) Active power factor correction techniques. In passive power factor correction techniques, an LC filter is inserted between the AC 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 and the power factor cannot be very high [1]. Therefore it is now not applicable for the current trends of harmonic norms. Basically it is applicable for power rating of lower than 25W. For higher power rating it will be bulky. In active power factor correction techniques approach, switched mode power supply (SMPS) technique is used to shape the input current in phase with the input voltage. Thus, the power factor can reach up to unity. Figure shows the circuit diagram of basic active power correction technique. By the introduction of regulation norms IEC 1000-3-2 active power factor correction technique is used now a day.

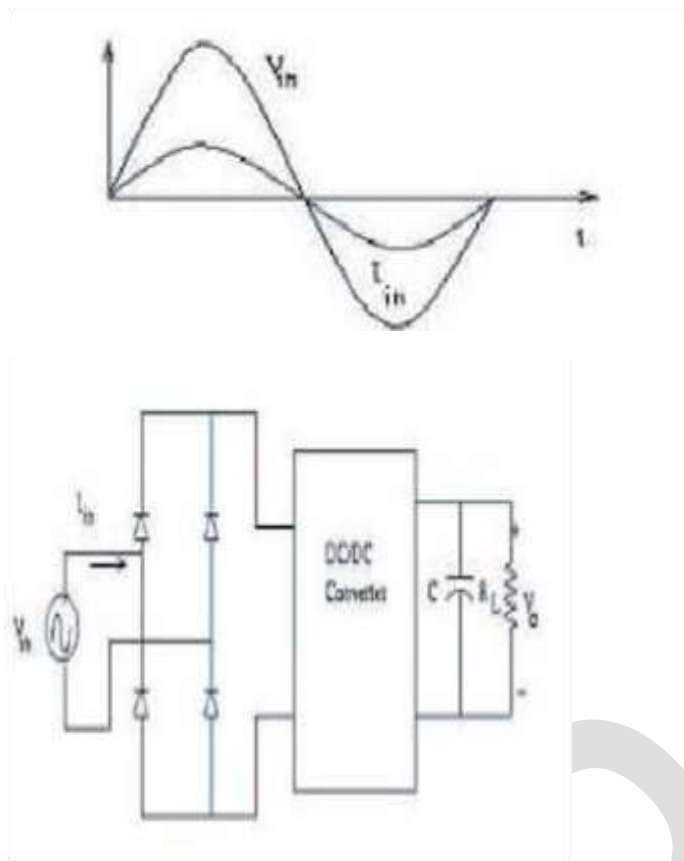


Figure 5 Circuit diagram of active filter

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 operates at pulse-width-modulation mode. Basically in this technique switching frequency of active power switch is constant, but turn-on and turnoff mode is variable.

Different topologies 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 use active PFC techniques, we will give a couple of examples of 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 output of the rectifier. This 325 V_{dc} bus is, of course, unregulated and moves up down with the input line voltage.

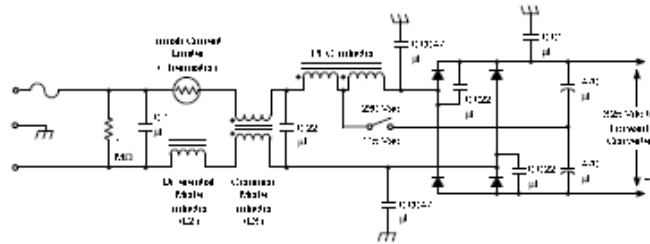


Figure 6 Passive PFC in a 250 W PC Power Supply

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) Discontinuous current 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 v_g times the output of the voltage error amplifier, which sets the current reference amplitude. In this way, the 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.

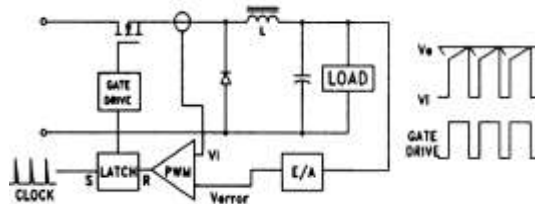


Figure 7 Peak current mode control circuit and its waveforms

2: Average Current Control Method

Here the inductor current is sensed and filtered by a current error amplifier whose output drives a PWM modulator. In this way the inner current loop tends to minimize the error between the average input current and its reference. This latter is obtained in the same way as in the peak current control. The converter works in CICM, so the same consideration 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 cycle and the switch is turned on when the inductor current falls to zero, so that the converter operates 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 the switch is operated at constant on-time and frequency. With the converter working in discontinuous conduction mode (DCM), this control technique allows unity power factor when used with converter topologies like fly back, Cuk. Instead, with the boost PFC 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 in detail. It shows that a high power factor has been obtained. Compared with the traditional PFC, the proposed PFC has the following advantages: 1) lower device rating, which reduces cost, EMI, and switching losses, 2) no additional inductor is required, the line impedance is enough for most cases, and 3) the proposed double hysteresis control reduces the switching frequency significantly, which leads to higher efficiency.

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