OPEN ACCESS INTERNATIONAL JOURNAL OF SCIENCE & ENGINEERING

“Design and Simulation of a Boost Converter-Based Active Power Factor Correction System”

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Abstract: In the present study we used Matlab/Simulink for the simulation of the boost type power factor correction topology which we modeled simply for the current stage. Power factor is the ratio of real power (kilo Watt) which is the actual energy that the device uses, to apparent power (kilo Volt Ampere) which is what the network has to supply. Power Factor is a measure of how well your system uses what is put out by the grid. A system with a poor power factor draws more apparent power than real power. A low power factor is considered to be less than 0.9. Also, what we see is that certain types of loads like inductive and capacitive loads which bring down this factor.In many applications which include Interruptible Power Supplies (UPS) and inverters the performance of (Alternating Current-Direct Current) and Direct Current-Direct Current power converters is a function of power factor. We see that in the case of (Alternating Current-Direct Current) conversion rectifiers produce high harmonics, low power factor, poor efficiency, and large inductors and filters. It is the improvement in performance and efficiency of converters which is achieved through improved power factor and reduced line current distortion which we see is the issue at hand. To meet this need typically some form of PFC circuit is included for input phase current shaping.

In this paper the traditional AC-DC converter which we controlled via the MOSFET firing angle to in turn control the output voltage and current for a capacitive load. These converters do not do well with power factor. To improve the power factor, we developed PFC converters which we made to achieve a THD of around 94% via the use of PWM techniques. We did the simulation in the MATLAB Simulink environment .Keywords: Power Factor Correction (PFC), Buck-Boost, Pulse-Width Modulation (PWM) control, Particle Swarm Optimization (PSO) tuning, PID controller

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I. INTRODUCTION

There’s basic reason diode rectifiers tend to distort the input current and give a poor power factor: the diodes are reverse biased for much of the AC cycle. In practice this means the rectifier only draws current when the instantaneous input voltage exceeds the voltage on the output capacitor. The input current therefore appears as short pulses centered near the input voltage peaks, and those pulses are what recharge the capacitor. Because the rectifier’s output follows the input peak voltage, any disturbances on the AC supply show up at the DC output as well.

An effective way to reduce these problems is to add an active Power Factor Correction (PFC) stage after the diode bridge — typically a boost converter. PFC can also be built directly into the rectifier. The controller forces the inductor current to follow a sinusoidal reference so the input current is in phase with the input voltage, making the whole circuit behave like a resistor to the source. That also lets the rectifier’s output voltage be regulated independently of line voltage.

PFC is common in switch-mode power supplies (SMPS), such as computer PSU units, which operate from 50 or 60 Hz mains. Implementations vary with cost and application: low-cost consumer devices may only correct displacement power factor while still showing significant current distortion, whereas higher-end or sensitive equipment uses more sophisticated PFC to keep total harmonic distortion (THD) very low (often < 5%). Much research and many practical designs target the 50–60 Hz range, relatively low powers (under 1 kW), and are often implemented using analog control ICs. Equipment connected to the grid must also meet standards such as IEC 61000-3-2 in Europe and IEC 555-2/Energy Star rules in the US. As Nilsson explains, utilities push these regulations because they want to minimize reactive power drawn by appliances — reactive power isn’t billed to consumers, who only pay for active energy.

Aircraft AC/DC power supplies introduce additional challenges because their supply frequency can vary widely (commonly 360–800 Hz, called “wild frequency”) due to the generator being directly coupled to the engine. Airborne systems have strict harmonic limits to prevent interference with sensitive avionics, so controlling harmonics is critical. Modern airborne converters often use multi-phase transformer arrangements — for example converting three-phase to 21 phases or using a 42-pulse rectifier — which achieve very low THD. Implementing active PFC in three-phase aircraft systems can further reduce THD and improve power factor, and it also offers the practical benefit of smaller, lighter converters by eliminating large passive components.

II.LITERATURE REVIEW

Active power factor correction (PFC) is critical in enhancing the efficiency of power systems, particularly in single-phase applications. The proliferation of non-linear loads necessitates innovative solutions to mitigate adverse effects on power quality. This literature review synthesizes recent findings regarding active power factor correction utilizing boost converters, particularly focusing on the advancements in topology, control strategies, and efficiency improvements.

A significant contribution to single-phase power factor correction is the development of bridgeless converter topologies. Dixit et al. (2020) proposed a discontinuous current conduction mode (DCM) based bridgeless PFC converter specifically designed for electric vehicle (EV) charging applications. This design not only enhances power factor correction but also minimizes conduction losses associated with traditional bridge rectifiers. The bridgeless configuration is particularly pertinent in low-voltage applications ranging from 1.0 to 3.3 kW, addressing the growing demand for efficient power conversion in EV infrastructure.

Chen et al. (2020) extended this discussion by deriving and benchmarking 15 different bridgeless PFC topologies based on various DC-DC converter configurations. Their work systematically evaluates these topologies concerning power loss, size, and cost, thus providing valuable insights for engineers seeking to optimize designs for single-phase applications.

The exploration of single-stage and multi-stage converters has also gained momentum. Liu et al. (2022) introduced a single-phase bidirectional AC-DC wireless power transfer (WPT) converter with an integrated power factor correction stage. This innovation demonstrates a practical application of boost converters in achieving high efficiency and low electromagnetic interference, critical for power factor correction applications.

Moreover, an experimental evaluation of a 1-kW PFC boost converter prototype utilizing silicon carbide (SiC) devices revealed a peak efficiency of 97.2% at full-rated power, showcasing the potential of modern semiconductor technologies in enhancing converter performance (**Tiwari et al. **, 2019). The use of SiC devices is particularly advantageous due to their fast switching capabilities and reduced conduction losses, key factors for effective PFC.

A comprehensive review by Coman et al. (2020) categorized various single-phase AC/DC converters focusing on boost topology. This analysis included performance metrics such as power factor correction efficiency, Total Harmonic Distortion (THD), and operational characteristics of various converter types including bridge, semi-bridgeless, and bridgeless configurations. Such comparisons are crucial for guiding future research and development efforts in power factor correction technologies.

Challenges and Knowledge Gaps:

Despite significant advancements, knowledge gaps remain, particularly in the scalability and adaptability of these technologies for varying load conditions and grid configurations. Many studies, including those focusing on three-phase systems, do not adequately address the specific challenges associated with single-phase applications. Future research must investigate the integration of advanced control strategies that can dynamically adapt to changing load profiles while maintaining optimal power factor correction.

Additionally, while experimental validations have been conducted, there is a need for more extensive field trials to assess the long-term reliability and performance of these converters in real-world scenarios. Research should also explore the economic implications of implementing these technologies at a larger scale, particularly in residential and commercial settings.

Single Phase Power Factor Correction Topologies

While not a true "topology," you can improve a diode-bridge rectifier's power factor by adding passive components on the AC input, such as inductors and capacitors. An input inductor smooths the current waveform and improves power factor, though it won't produce a perfect result. Passive correction alone also leaves the DC output unregulated and tied to the input voltage. If you need to control the output voltage, you must add an active stage; the choice of topology depends on whether you need to step the voltage up or down.

The buck converter (Figure 1) reduces the output voltage relative to its input. Because it requires the input voltage to be higher than the desired output, a buck stage is a poor choice as a pre-regulator immediately after a rectifier: during much of the AC half-cycle the rectified voltage is below the required output, so the buck cannot operate throughout the waveform. However, a buck works well when placed after a boost pre-regulator (which raises and steadies the DC bus): in that arrangement the buck can trim a stable DC level down, provide precise output regulation, or implement current limiting.

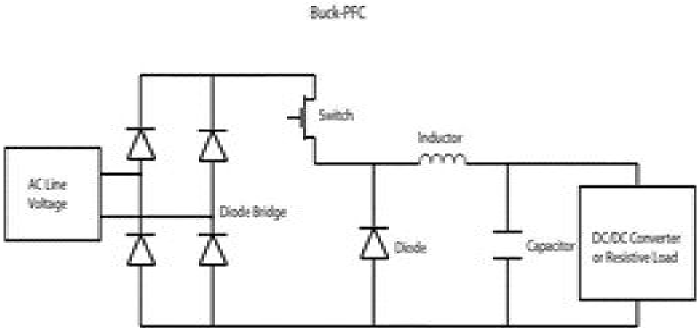


Figure 1 Buck PFC topology

The boost converter (Figure 2) raises the output voltage above the input voltage. Because of its ability to shape and control the input current, the Boost-PFC topology is the most commonly used choice for power-factor-correction circuits. For convenient operation, the boost converter's output must be higher than its input. If the output is set above the maximum input peak, the converter can regulate correctly over the whole AC cycle, from zero up to the peak.

Boost converters are well suited to higher-power applications and often use current-mode control to force the input current to follow a half-sine reference, which helps achieve a near-unity power factor. When the converter runs in Continuous Conduction Mode (CCM), the inductor and input currents never drop to zero, which further reduces input current harmonics.

It's common to pair a boost with a buck stage downstream when lower output voltages are needed—this lets the boost establish a stable DC bus and the buck trim it down, rather than relying on a buck alone at the rectifier output.

A key limitation of the boost topology is that it has no switching element in series with the input, so it cannot directly limit input current. That makes inrush or overload current difficult to control. Also, if the instantaneous input voltage exceeds the regulated output, the rectifier diode conducts and the boost can no longer control the input current.

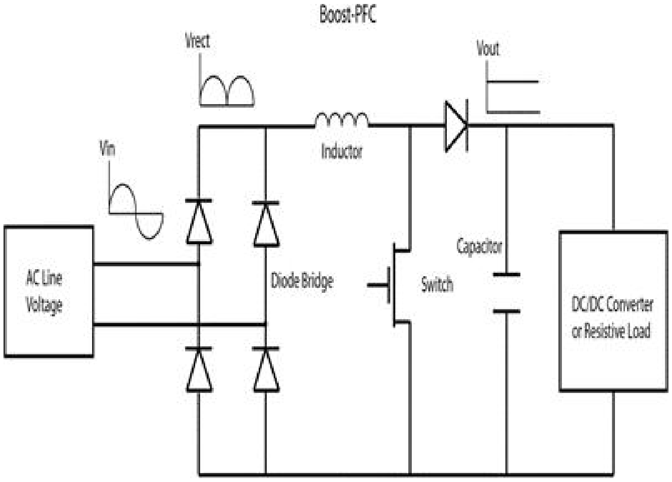


Figure 2 Boost PFC circuit

Sometimes a circuit needs to both step a voltage up and down without using two separate converters. Two common single-stage solutions are the buck-boost converter and the flyback converter. Both can produce an output higher or lower than the input, which makes them attractive compared with using only a buck or only a boost. Their basic operating principles are similar, but their implementations differ (see simple schematics in Figures 3 and 4).

There are many variants of these topologies. Buck-boost converters can be built with one or two switches, and some designs include magnetic (galvanic) isolation between input and output. Flyback converters naturally provide galvanic isolation and are relatively low cost. They can regulate the output both up and down, so they're often chosen for flexible power-electronics designs. Flyback converters are efficient at low to medium power levels (typically under about 500 W). For higher power you usually need to parallel multiple devices, which requires careful current sharing and more advanced control.

Digital signal processors (DSPs) are commonly used in those cases to implement the required control and coordination algorithms.

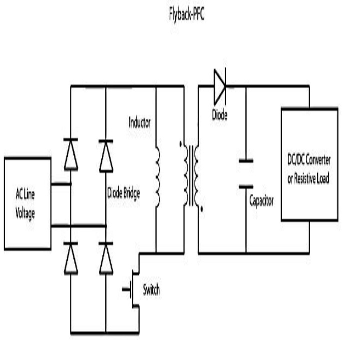


Figure 3 Flyback PFC converter

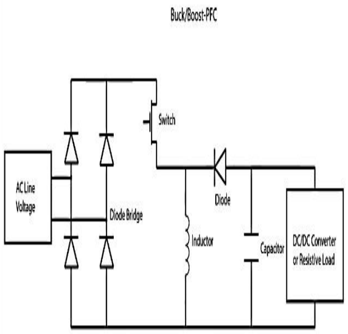


Figure 4 Buck/Boost PFC

The Buck-, Buck/Boost- and Flyback-topologies have discontinuous input current due to the fact that there are switches in series with the line for these topologies. However, the input current of Boost-topology can have an input current in both CCM and DCM. The ability to operate in CCM makes the Boost-topology the most viable option of the mentioned topologies for high performance power factor correction circuits.

Introduction to PSO

Particle Swarm Optimization (PSO) is a population-based optimization method inspired by the social behavior of animals like birds and fish. In PSO, each candidate solution is called a particle, and a group of particles forms a swarm. The swarm is usually initialized with random solutions, and each particle moves through a multi-dimensional search space, updating its position based on its own experience and the experience of its neighbors.

Each particle has a position (a possible set of unknown parameters to optimize) and a velocity. Particles evaluate how good their current positions are using an objective function, commonly called the fitness function. Each particle remembers the best position it has visited so far (pbest), and the swarm also tracks the best position found by any particle (gbest). During the search, a particle adjusts its velocity and position using a combination of: its own past best, the swarm best, and some random variation. This lets particles explore and exploit the search space adaptively.

The goal is for the particles to converge on an optimal or near-optimal solution. As the swarm iterates, individual particles tend to improve and the overall fitness values typically decrease (for minimization problems) or increase (for maximization). PSO's performance depends on the fitness function used and how well the problem is modeled.

In this work, PSO is applied to tune the parameters of a PID controller for a two-tank process. The swarm is initialized with random candidate PID settings and random initial velocities. The fitness function measures controller performance (for example, rise time, overshoot, and steady-state error), and PSO uses information exchange among particles to find the best parameter set. Here, D denotes the dimensionality of the search space (the number of parameters being optimized).

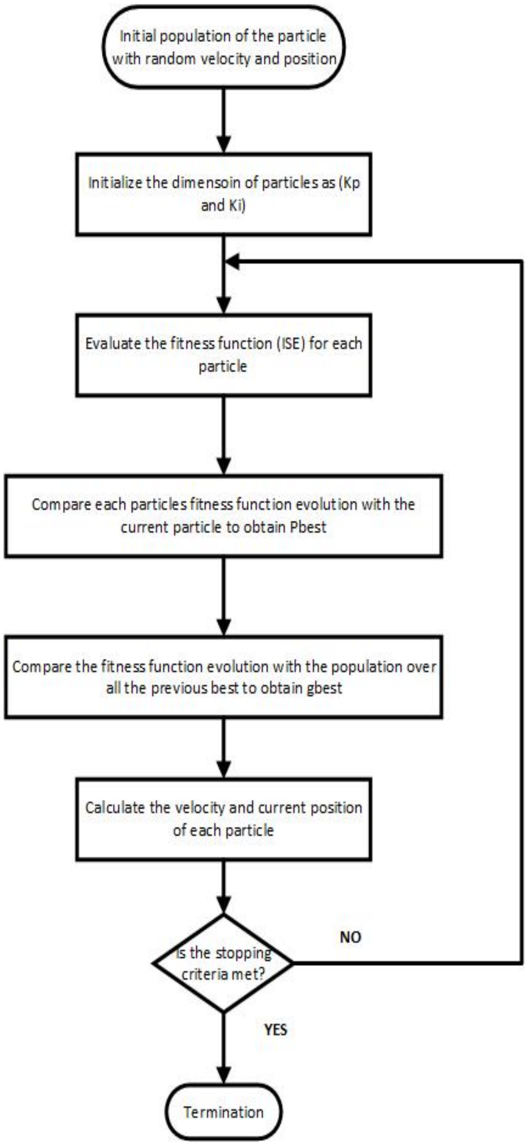


Figure. 5 PSO flow chart

A basic PSO run has two main phases: exploration and exploitation. During exploration, particles spread out and probe promising regions of the search space. During exploitation, particles move toward the best-known positions to refine solutions.

Each particle keeps track of its own best position so far (pbest) and shares that information with neighbors; the swarm also tracks the global best position (gbest). Particles update their velocities and positions using their pbest and gbest values, so the overall best solution gradually attracts the rest of the swarm. The algorithm's effectiveness depends on how you choose the update strategy and parameter values for each iteration.

The basic PSO loop has three steps:

initialize a population of particles with random positions (xi_k) and velocities (vi_k) within the allowed bounds;

update each particle's velocity based on its current velocity, the distance to p_{best}, and the distance to g_{best};update each particle's position using its new velocity. PSO is initialized with the group of random particle positions (x_i^k) and velocities (v_i^k) between upper and lower bound of design variable values as expressed in following equations

$$x_i^k = x_{min} + rand(N,d).*\ (x_{max} - x_{min}) \qquad (1)$$

And

$$= v_{min} + rand(N,d).*\ (v_{max} - v_{min}) \qquad (2)$$

Where, *N*: number of population.

d: number of parameters to optimize.

k: current iteration count.

x_{min} and x_{max}: minimum and maximum value of particles in search space.

v_{min} and v_{max}: minimum and maximum value of the position of particles to move in search space.

The second step is to update velocities of all particle positions for next (k+1) iteration using the particles fitness values which is function of particle positions. These fitness function value determines which particle has a global best ($gbest_k$) value in the current swarm (iteration) and also determine the best position ($pbest^i$) of each particle.

After finding the two best values, the particles update its velocity and positions of each (i^{th}) particle using following equation:

$$v_i^{k+1} = wv_i^k + c_1 r_1 \left(pbest_i^k - x_i^k\right) + c_2 r_2 \left(gbest^k - x_i^k\right) \qquad (3)$$

Where, r_1 and r_2 are the two distinct random values between 0 and 1. c_1 and c_2 are acceleration constant which are set at 2. These constants help to move particles towards the best possible value ($gbest^k$) and '*w*' is the inertia weight used to balance between previous and current best value. Inertia weight change in succeeding iteration as:

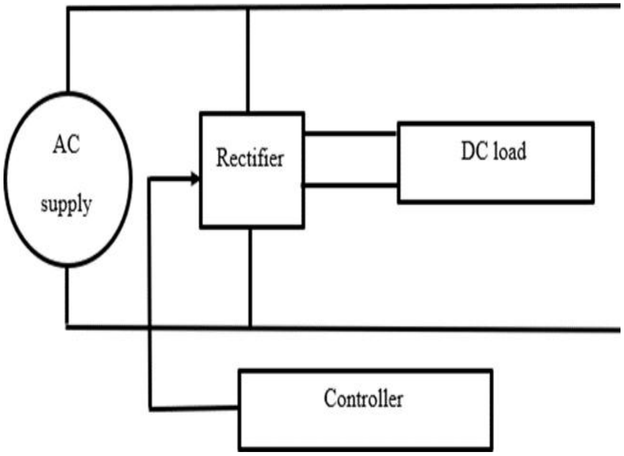
$$w = w_{max} - \frac{(w_{max} - w_{min\boxed{f0}})}{itermax} *\ iter \qquad (4)$$

Where, $i_{ter}max$ is the maximum number of iterations. w_{max} and w_{min}, the upper and lower limit of inertia weights which are 0.9 and 0.4 respectively. Now positions of particles are updated using following equation:

$$x_i^{k+1} = x_i^k + v_i^{k+1} \qquad (5)$$

III. RESLT AND DISCUSSION

The following block diagram illustrates the basic model proposed in this project for achieving power factor as high as possible



(a)

Fig. 6 Illustrate block diagram for the model

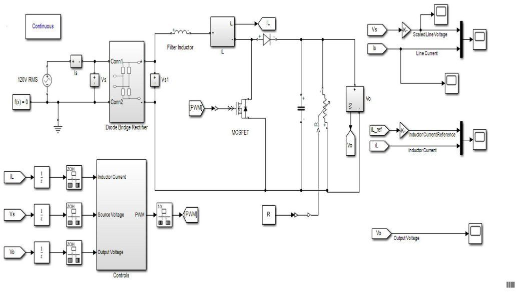


Figure 7 Represents MATLAB model for PFC circuit

An AC voltage source supplies the load. The rectifier sits in series with the DC load, which we model as a resistor, and its job is to convert the AC into DC. The rectifier uses controlled MOSFETs: each MOSFET is turned on by a pulse from a pulse generator and then turned off naturally at the end of that half-cycle (natural commutation). The pulse generator delays the turn-on within each half cycle — this delay is called the firing angle.

Changing the firing angle shifts the phase of the rectifier's fundamental current relative to the voltage, typically causing the current to lag the voltage. From the source's point of view, this creates phase shifts that can be either leading or lagging depending on the firing angle and operating conditions. The source sees the combined effect of the rectifier branch current and any other currents, so adjusting the rectifier's firing angle changes the overall source current waveform. By choosing the firing angle appropriately, the rectifier can improve the power factor seen by the source.

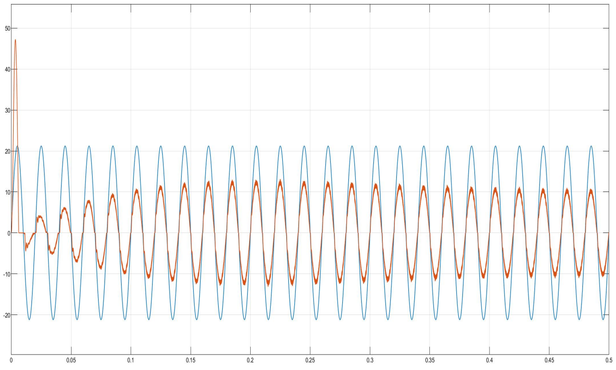


Fig 8 Line current across load

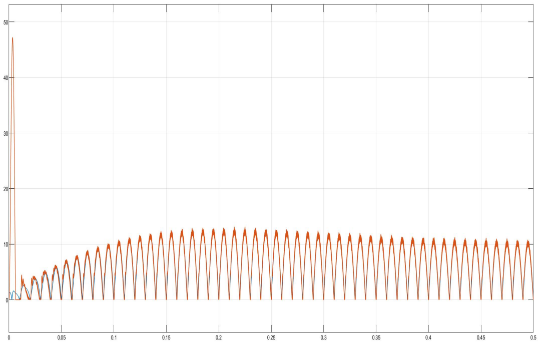


Fig 9 Inductor current across load

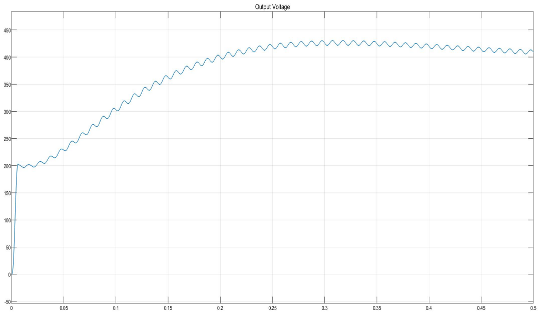
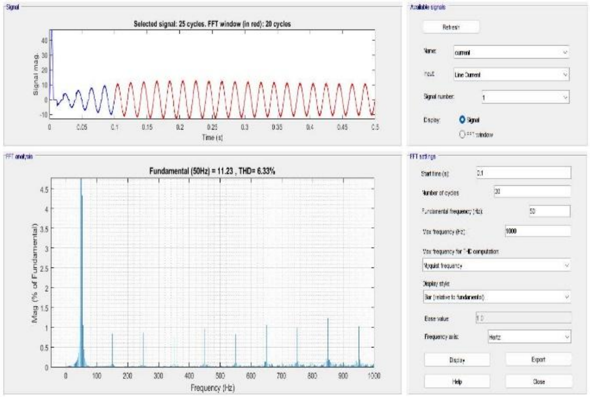


Fig 10 Output voltage across load



Selected signal: 25 cycles. FFT window (in red): 20 cycles

Fundamental (50Hz) = 11.23 , THD= 6.33%

Name: current
Input: Line Current
Signal number: 1
Display: ● Signal ○ FFT window

Start time (s): 0.1
Number of cycles: 20
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Fig 11 THD of model designed

Change in firing angle changes the power factor. when firing angle increases the phase difference between fundamental voltage and current increases and the power factor continue to increase until a certain point where the current is small compared to the total current so the effect of the correction current will be small making the AC effect more obvious to the source.

IV.CONCLUSION

The main goal of a Power Factor Correction (PFC) circuit is to make the input current follow the shape of the input voltage so the power supply looks like a pure resistor to the source. That improves the power factor, reduces energy losses, and helps prevent unnecessary stress or damage to equipment.

AC loads alone often have poor power factor. Adding a DC load can raise the apparent power factor because the DC current component changes how the overall waveform looks, but converters still introduce distortions. In controlled converters, changing the firing angle alters the phase relationship between the fundamental voltage and current: increasing the firing angle increases the phase shift, which generally lowers the power factor. In short, firing angle and power factor are inversely related.

Even when the DC-side power factor is already high, a PFC unit can still make improvements. Modern PWM-based PFC systems can automatically shape the input current to approach unity power factor and can eliminate the need for capacitor banks when the system would otherwise be leading. This makes PWM PFC a practical, cost-effective, and reliable solution for industrial installations and multi-storey buildings.

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