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Study of Diode Bridge Boost PFC and Totem Pole PFC Converter

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ABSTRACT: The increasing demand for energy-efficient systems in power electronics has made Power Factor Correction (PFC) circuits integral to modern designs. Achieving a high power factor is crucial for minimizing energy losses, reducing harmonic distortion, and enhancing overall system performance in various applications. Various PFC topologies, such as boost, buck, and bridgeless configurations, are commonly employed to improve power factor. This work presents the study of Diode Bridge Boost PFC and Totem Pole PFC, along with a comparative analysis, performance, and the trade-offs involved in selecting the appropriate topology for specific applications. Additionally, Matlab simulations demonstrate the real-world use of these circuits to wave shape the input current and optimize energy efficiency.

KEYWORDS: Power Factor Corrector (PFC), Total Harmonic Distortion (THD).

I. INTRODUCTION

1. Introduction

Firstly we will see what is Power Factor (PF). So, if we want to define PF, we can say that it is the ratio between Active Power in Watts to Total Apparent Power in Volt-Amp which is circulating between input power source and Load.

$$\text{Apparent Power (VA)} = \text{Active Power (Watt)} + j \text{ Reactive Power (VAr)}$$

$$\text{Power Factor (PF)} = \frac{\text{Active Power (Watt)}}{\text{Apparent Power (VA)}}$$

If we have DC source available, then input voltage and Input Current are always in Phase and we can say:

$$\text{Apparent Power (VA)} = \text{Active Power (Watt)}$$

So, if you see the figure 1 where Input Current and Input Voltage are shown in same phase which means power Factor in this case is UNITY. But for most of the system Input Supply is coming from AC grid where input current naturally not follow the wave shape of input Voltage and hence power Factor is less than Unity.

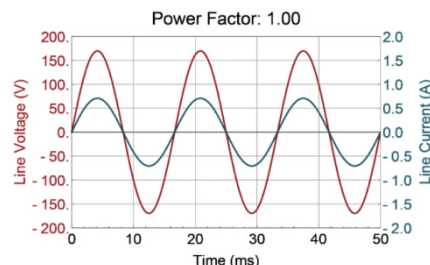


Figure 1 – At PF=1, Input Current & Input Voltage Wave Shape [15]

2. Importance of High Power Factor

To explain the importance of high power factor, consider a small example of AC/DC laptop adapter whose power requirement is 60 Watts.

CASE 1: If the Laptop adapter is capable of maintaining ideally PF=1, then naturally input current will follow the wave shape of input voltage shown in Fig 1. So in this case the RMS input current drawn from source is 521 mA.

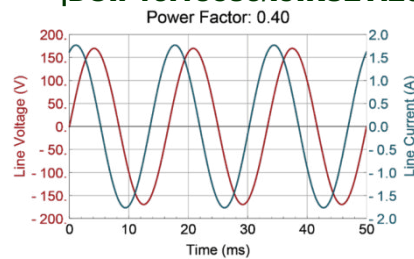


Figure 2 – At PF=0.4, Input Current and Input Voltage Wave shape with phase delay because of poor PF [15]

CASE 2: Now in practical case, PF is never be equal to Unity, it may be close to unity. So if we consider that the Power Factor is reduced and it's value is now 0.40, so input current wave shape will not follow input voltage wave shape because as the power factor reduces which is shown in Fig 2, the content of Harmonic in the current Increases. Now with this, if I want to supply the require input power of 60 Watts, the RMS value of current is now increase to 1.3 Amp.

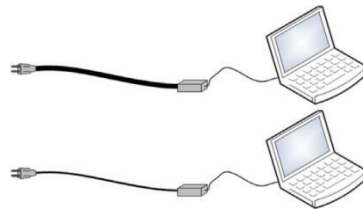


Figure 3 – Laptop cable comparison [15]

So what is happening, as the power factor reduces the RMS value of current increases and thereby losses also increase in system. Also to handle the higher amount of RMS current, more expensive cable is also require which is shown in Fig 3.

This increase from 521 mA to 1.3 A (700 mA) is seem insignificant considering a single Laptop adapter but if the same case we consider for larger scale this might be a very significant and cost us too much. And hence there is strict requirement for maintaining the Power Factor close to Unity. So if PF is Unity, whatever the power is generated by Utility is fully utilize by load connected in household application or Industrial application. And on the other hand, if power Factor is not close to Unity, most of the power circulates in system only instead of consume by the load.

IEE Standard regarding THD : As the Load power rating is above 150W, according to IEEE 61000-3-2 it is required to maintain THD less than 15% or power factor more than 0.9.

Advantages of Unity PF

- ✓ First one is Active Power becomes Total Apparent Power ($\text{Watt} = \text{VA}$).
- ✓ Voltage fluctuation will reduced, resulting in to better Voltage profile of Distribution System.
- ✓ As $\text{Watt} = \text{VA}$, there is significant reduction in Line and Transformer Losses.
- ✓ Insulation requirement get significantly reduce.
- ✓ Power handling Capability of line get's increase.

KVAh Based Billing

If Power Factor is not maintain close to unity, there is significant penalty is there from government and now as per new rules, KVAh based billing is start in most of States so its now highly important to maintain PF close to Unity. As if we don't, we have to pay for whole KVAh as well as for Penalty.

So, because of all this reason it is very important in any application field to maintained the power factor close to Unity.

II. LITERATURE SURVEY

1. Review on PFC

The history of Power Factor Correction (PFC) circuits in power electronics dates back several decades, evolving in response to the growing demand for energy efficiency and improved power quality. Early power electronics systems

were primarily focused on rectification and basic AC-DC conversion without much attention to power factor. As a result, these systems often exhibited poor power factors, leading to inefficient energy use and increased strain on the electrical grid. In the 1950s and 60s, with the advent of industrial electrification, the importance of power factor became evident, particularly as larger machines and systems demanded more power.

Initially, passive PFC methods were developed, relying on simple components like inductors and capacitors to counteract the effects of reactive power. These early passive designs were effective in reducing some harmonics but were bulky, inefficient at lower loads, and had limited ability to adapt to varying conditions in modern systems. As technology progressed and the demand for compact, efficient systems grew, engineers began to search for more advanced solutions.

The 1970s and 80s saw the development of the first active PFC circuits. These circuits, unlike their passive predecessors, utilized switching devices such as transistors and diodes to dynamically adjust the input current waveform. The boost converter quickly emerged as the most common active PFC topology, as it allowed for continuous conduction mode (CCM) operation, achieving higher efficiency and better performance. This period marked a significant leap in PFC technology, as active designs could maintain a near-unity power factor across a wide range of operating conditions, making them ideal for consumer electronics, industrial applications, and power supplies.

In the 1990s, as switching technologies became more sophisticated with the introduction of MOSFETs and IGBTs, PFC circuits continued to evolve. Engineers focused on improving efficiency, reducing size, and minimizing electromagnetic interference (EMI). Bridgeless PFC topologies were introduced to eliminate losses associated with traditional rectifier bridges, leading to reduced power dissipation and higher overall efficiency. This era also saw the development of interleaved PFC designs, which used parallel converters to share the load, further reducing ripple currents and improving power density.

In recent years, attention has shifted towards cutting-edge PFC topologies to meet the increasing energy demands of high-power applications such as electric vehicle charging, data centers, and renewable energy systems. Among the most notable advancements is the Totem-Pole PFC topology, which has gained prominence for its ability to achieve very high efficiency, especially in wide-bandgap semiconductor applications. By eliminating the diode bridge and using fast-switching transistors like GaN (Gallium Nitride) or SiC (Silicon Carbide), Totem-Pole PFC offers ultra-low conduction losses, making it highly suitable for high-frequency, high-power environments.

Today, PFC circuits are essential in virtually all modern power electronics systems, from household electronics to industrial machinery. The evolution of PFC technologies over the years reflects the industry's relentless pursuit of greater efficiency, reduced size, and enhanced performance, making power electronics systems more reliable and sustainable.

2 Review of Various Power Factor Corrector Circuit

There are various topologies available for PFC circuit listed below:

- ✓ Boost PFC Converter
- ✓ Interleaved Boost PFC
- ✓ Different Bridgless PFC
- ✓ PWM PFC Converter / Totem Pole PFC
- ✓ Phase Shifted Boost PFC

Few of the commonly used topologies are discussed below:

A. Boost PFC Converter

Below Figure 4 shows the Conventional Diode Bridge Boost Power Factor Converter Circuit. This PFC configuration is most commonly use because of it's simple structure i.e. Diode Bridge Circuit followed by Boost Converter. AC supply from grid is given as input AC voltage to Diode Bridge circuit which rectifies the AC input in to DC voltage. During this conversion, current drawn by AC source is not in phase with the input Voltage and hence boost converter circuit is connected between Diode bridge circuit and Load with some control strategy implemented. The boost converter consist of two Switches or (One switch, one Diode), Inductor, Capacitor etc. This boost converter is used to maintained the desire output voltage across the load with minimum ripple in output voltage.

The value of Inductance for Diode Bridge Boost PFC is given by:

$$L = \frac{1}{\%del_I} * \frac{Vinmin^2}{Pin} * \left(1 - \frac{\text{sqrt}(2) * Vinmin}{Vout}\right) * \frac{1}{Fsw}$$

The value of Capacitance for Diode Bridge Boost PFC is given by:

$$C = \frac{2 * P_{out} * thold}{V_{out}^2 - V_{outmin}^2}$$

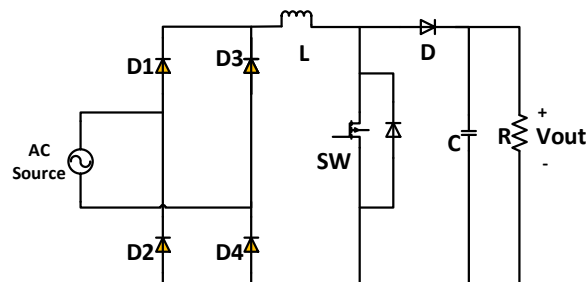


Figure 4 – Boost PFC Converter.

The problem associated with Diode Bridge Boost PFC is that with increase in power level, the losses in diode bridge is significant and thereby overall efficiency decreases. As more power loss is happening in the circuit, the more heat dissipation will happen. At particular power level, increase in value of L, limit the power level.

B. Interleaved Boost PFC Converter

Advance version of diode bridge boost PFC circuit is Interleaved boost PFC which is shown in below Figure 5. It uses the concept of phase shifting using paralleling the N inductor branches. If we are using N parallel branches of Inductor, the phase shifting of $3600/N$ can be achieved. By using 2 parallel branches, the phase shifting of 1800 can be achieved. By doing so, we can reduce the ripple in Current as well as reduce the effect of EMI.

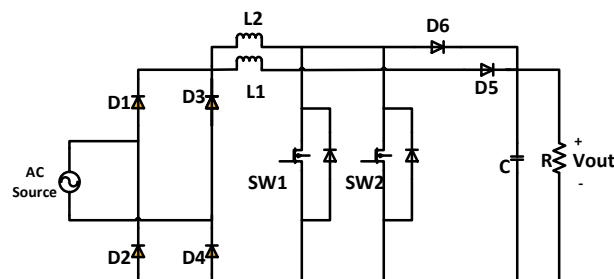


Figure 5 – Interleaved Boost PFC Converter.

When we do two branches in parallel, the phase shift of 1800 is achieved and hence ripple current in two branches cancelled out each other and significant reduction in Harmonic we can observe using this topology. Further, if we want to achieve to shift the Higher order Harmonics N times, we can use N parallel branches.

Again advantage is that, with paralleling the Inductor branches, size of inductor is significantly reduces and thereby converter power density gets improved. But the problem of more loss dissipated in diode bridge is still a problem.

C. PWM PFC converter

Below Figure 6 shows PWM PFC converter (Pulse Width Modulated PFC Converter), also known as Totem Pole PFC Converter. This topology was invented far back but because of losses in system, this topology is not of great interest for people. But with advancement in Wide band gap devices and advantages this devices offer, this topology is now gaining more popularity and been in interest of research.

SW1 and SW2 are the main Active switches and SW3, SW4 are low frequency switches. SW1 and SW2 are GaN/SiC devices are use and for SW3 and SW4 either Diode or MOSFET's are used. Using this, various configuration are possible.

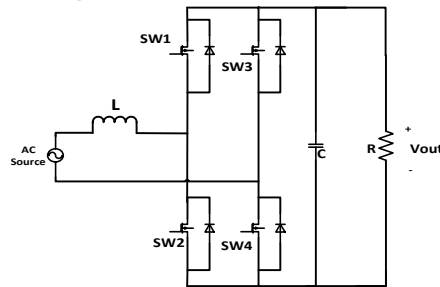


Figure 6 – PWM PFC Converter.

This configuration allow bi-direction power flow which is advantageous in case some cases. The biggest advantage is that UNITY PF , Low distortion in Current, well regulated DC output voltage with very less ripple. The value of Inductance for this PFC configuration is given by:

$$L \geq \frac{V_{out} * T_{sw}}{12 * I_{ripple}}$$

The value of Capacitance for this PFC configuration is given by:

$$C \geq \frac{P_{out}/V_{out}}{4 * \pi * f_{line} * V_{ripple_max}}$$

3. Review of Various Control Scheme

There are various control schemes available for controlling PFC circuits listed out below:

- ✓ Peak Current Mode Control
- ✓ Valley Current Mode Control
- ✓ Average Current Mode Control
- ✓ Hysterisi Current Control
- ✓ Constant ON time Control
- ✓ Contant OFF time Control
- ✓ Sliding Mode Control
- ✓ Predictive Control

Few of the important control schemes are discussed below:

[I] Peak current control

Peak Current Mode Control (PCMC) is a popular control method used in switching converters like buck, boost, and flyback converters. PCMC employs two feedback loops – an outer voltage loop and an inner current loop. The outer loop regulates the output voltage, while the inner loop controls the peak inductor current. Since the current is directly controlled, PCMC offers faster transient response compared to voltage-mode control, making it suitable for dynamic load conditions. PCMC improves stability in the system by reducing the order of the control loop. The inner current loop effectively eliminates the need to compensate for the inductor in the outer loop, simplifying the design.

The peak current in the inductor is sensed and compared to a reference. When the peak current reaches the desired value, the switch is turned off, providing inherent overcurrent protection. In continuous conduction mode (CCM), PCMC can suffer from subharmonic oscillations. To counteract this, slope compensation is introduced to the current signal to stabilize the system. Peak current control provides inherent current limiting by directly controlling the maximum current that flows through the inductor.

PCMC can be more sensitive to noise, especially when sensing the current. A well-designed current-sensing circuit and filtering are necessary to avoid noise-related issues. The control method allows for cycle-by-cycle limiting of the inductor current, enhancing the protection of the power components.

[II] Average current mode control

ACMC controls the average inductor current rather than the peak current, providing more accurate current regulation over a switching cycle. Since ACMC works on the averaged value of the current rather than the peak, it is less sensitive to noise compared to Peak Current Mode Control (PCMC). Although ACMC is more stable, it tends to have a slower transient response compared to PCMC because it averages the current over time. Unlike PCMC, ACMC does not suffer from subharmonic oscillations in Continuous Conduction Mode (CCM), thus eliminating the need for slope compensation.

Similar to PCMC, ACMC also uses two loops: an outer voltage loop and an inner current loop, but the inner loop controls the average current instead of the peak. ACMC provides very precise control of the current, making it ideal for applications requiring strict current regulation.

The design and implementation of ACMC is more complex compared to PCMC, as it requires averaging circuits, which increases the complexity of the control system. By controlling the average current, ACMC can reduce current ripple in the system, resulting in better performance and less stress on components.

III] Hysteresis control

The current is maintained within an upper and lower limit (hysteresis band) around the reference current. The method offers a very fast response since the switches are turned on or off as soon as the current crosses the hysteresis band, without delay. Hysteresis current control is easy to implement, as it doesn't require complex compensators or PID controllers, making it attractive for various power converter applications. A key drawback is the variable switching frequency, which fluctuates based on the load conditions and the hysteresis band width, potentially complicating the design of filters and increasing electromagnetic interference (EMI).

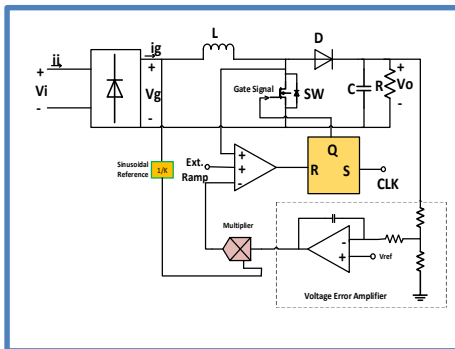


Figure 7 – Block Diagram of Peak Current Control Method

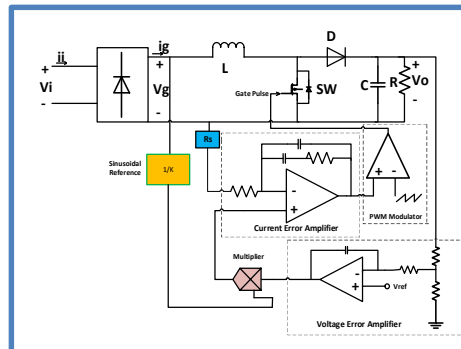


Figure 8 – Block Diagram of Average Current Control Method

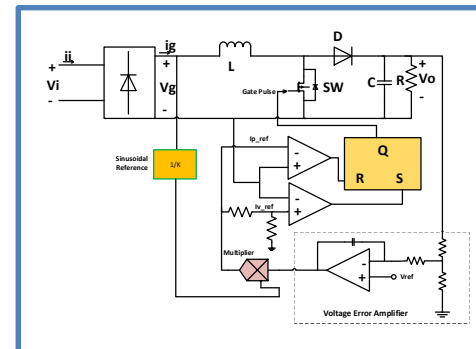


Figure 9 – Block Diagram of Hysteresis Control Method

III. COMPARATIVE STUDY

To compare the two topologies (Boost PFC and Totem Pole PFC), the following comparative table is provided:

ASPECT	DIODE BRIDGE BOOST PFC	TOTEM POLE PFC
Topology	Diode bridge rectifier + Boost converter	Active switches replace the diode bridge
Efficiency	Moderate efficiency due to diode conduction losses	Very high efficiency due to reduced conduction losses
Complexity	Simple and easy to implement	Complex design with advanced control algorithms
Switching Devices	Single MOSFET/IGBT for boost stage	Four MOSFETs or GaN FETs for rectification and boost
Control	Simpler control techniques (CCM, DCM)	Advanced digital control needed for zero crossing
Power Handling	Suitable for low to medium power levels	Ideal for medium to high power applications
Switching Frequency	Low-cost components	Higher cost due to advanced switches (GaN MOSFETs)

Thermal Management	Requires larger heat sinks due to diode losses	Reduced heat generation, smaller thermal management
Application	Low to medium power AC-DC converters, industrial equipment	High-efficiency applications, EV chargers, data centers

The choice between Diode Bridge Boost PFC and Totem Pole PFC depends largely on the application requirements. For low to medium power systems where cost is a concern, the Diode Bridge Boost PFC is often sufficient, offering simplicity and reliability. However, in high-power or high-efficiency applications, the Totem Pole PFC stands out for its reduced losses and ability to operate at higher switching frequencies, making it ideal for cutting-edge applications like electric vehicle chargers, data centers, and other high-efficiency power systems. This comparative study highlights the trade-offs in complexity, efficiency, and cost, guiding designers in selecting the appropriate topology based on their specific needs.

IV. MATLAB SIMULATION & RESULTS

1. Diode Bridge Boost PFC Converter

Control block diagram for this is shown below:

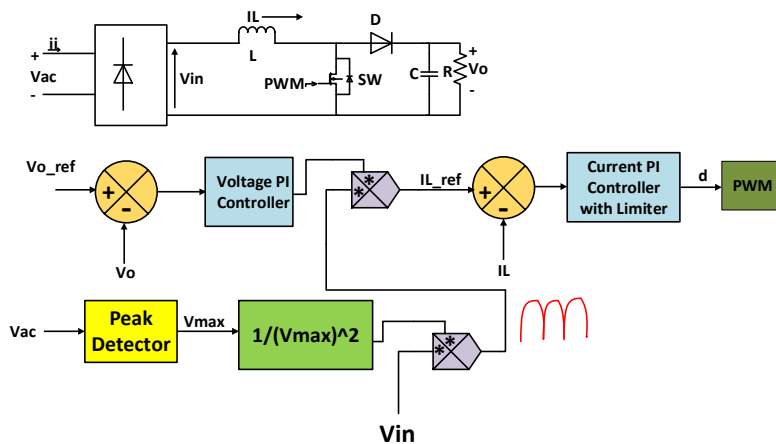


Figure 10 – Control Block diagram for Boost PFC Converter

For tuning the Voltage PI Controller by Bode Plot Approach, the following transfer function is require:

$$\frac{\hat{v}_o(s)}{\hat{d}(s)} = \frac{V_g}{(1-D)^2} \left[\frac{1 - s \frac{L}{R(1-D)^2}}{1 + s \frac{L}{R(1-D)^2} + s^2 \frac{LC}{(1-D)^2}} \right]$$

For tuning the Current PI Controller, the following transfer function is require:

$$\frac{\hat{i}(s)}{\hat{d}(s)} = \frac{V_g}{R(1-D)^3} \left[\frac{(2 + sCR)}{1 + s \frac{L}{R(1-D)^2} + s^2 \frac{LC}{(1-D)^2}} \right]$$

Parameter Set

Parameter	Value
Vac	230 Volt RMS
Pout	2.5e3 Watt
Fsupply	50 Hz
Vout	400 Volt
Fsw	40e3 Hz
Iout	Pout/Vout
R	Vout/Iout = 64 ohm
L	1.1 mH
C	1.9 mF
D	0.4821

Simulation Result

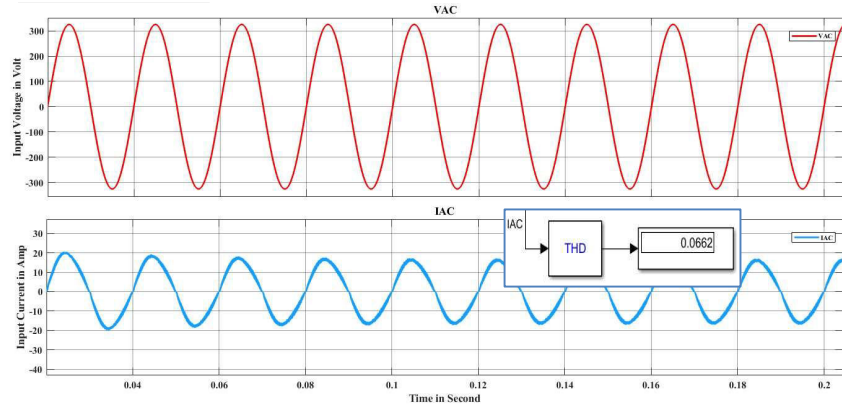


Figure 11 – Input Voltage & Input Current wave shape of Boost PFC Converter

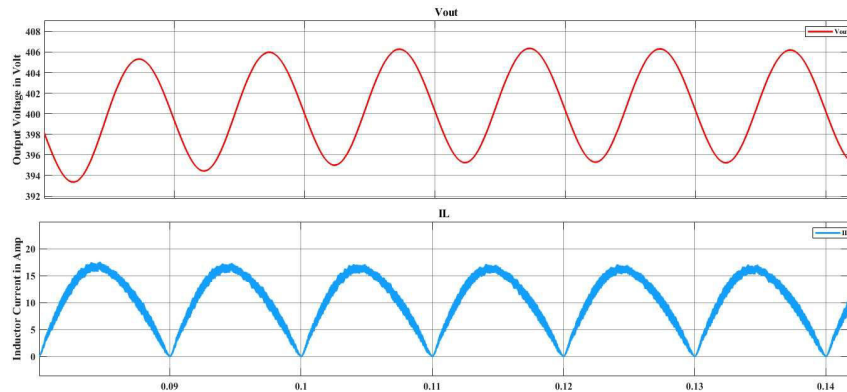


Figure 12 – Output Voltage & Inductor Current wave shape of Boost PFC Converter

2. Totem Pole PFC Converter

Control block diagram for this is shown below:

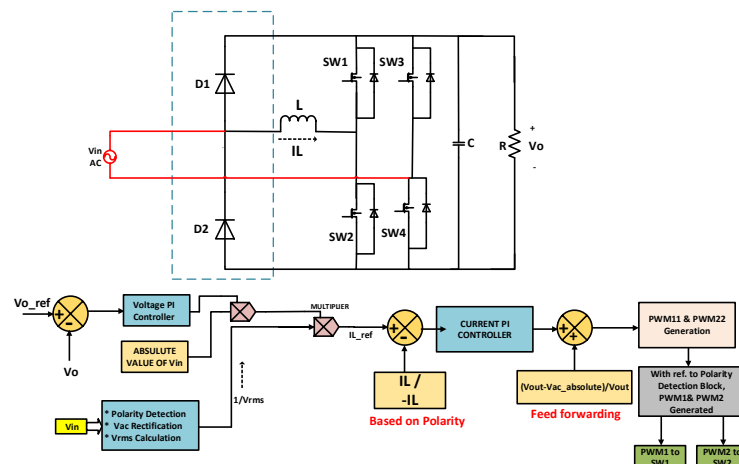


Figure 13 – Control Block Diagram for Totem Pole PFC

For tuning the Voltage PI Controller by Bode Plot Approach, the following transfer function is require:

$$G_{vi}(s) = \frac{R_L(1-D)^2 - sL}{(1-D)(R_LCs + 2)}$$

For tuning the Current PI Controller, the following transfer function is require:

$$G_{id}(s) = \frac{V_o(sC + \frac{2}{R_L})}{LCs^2 + \frac{L}{R_L}s + (1-D)^2}$$

Parameter Set

Parameter	Value
Vac	120 Volt RMS
Pout	1000 Watt
Fsupply	50 Hz
Vout	400 Volt
Fsw	100e3 Hz
Iout	Pout/Vout
R	Vout/Iout = 160 ohm
L	0.00056 H
C	0.000741 F

Simulation Result

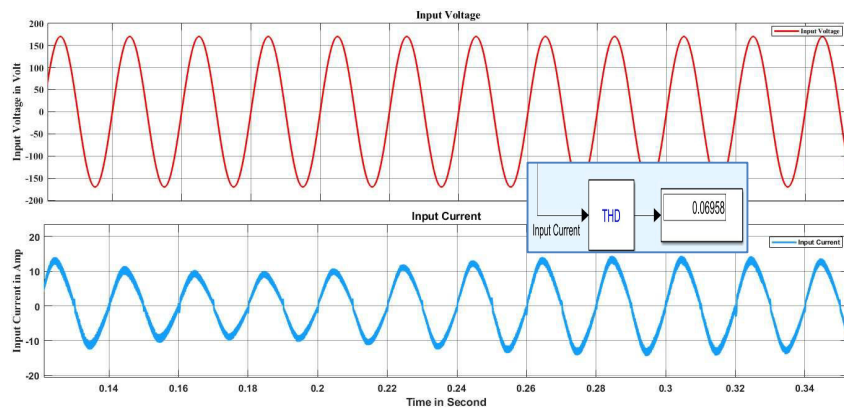


Figure 14 – Input Voltage & Input Current wave shape of Totem Pole PFC Converter

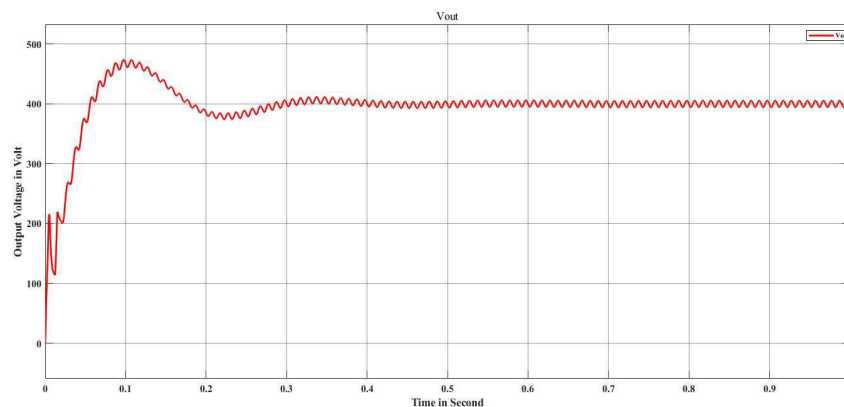


Figure 15 – Output Voltage wave shape of Totem Pole PFC Converter

V. CONCLUSION

In this paper, I have explored two prominent Power Factor Correction (PFC) topologies: Diode Bridge Boost PFC and Totem Pole PFC. After discussing various topologies and control schemes available for PFC, a detailed comparative study between these two topologies was presented, highlighting their strengths and limitations. The comparative analysis, along with the efficiency data in the provided table, offers a clear understanding of the trade-offs involved in selecting each topology.

The simulation results demonstrate that both the Diode Bridge Boost PFC and Totem Pole PFC topologies are effective in shaping the input current to improve the power factor. However, the choice between the two depends on the specific application requirements.

- ✓ Diode Bridge Boost PFC is well-suited for low to medium power applications where simplicity, cost-effectiveness, and reliable operation are prioritized, even though it has slightly lower efficiency.
- ✓ Totem Pole PFC, with its significantly higher efficiency, especially when using GaN transistors, is ideal for high-power, high-efficiency applications like electric vehicle chargers and data centers, but it comes with increased complexity and cost.

In conclusion, for low-cost, medium-power designs, Diode Bridge Boost PFC remains a practical choice, while Totem Pole PFC should be favored in cutting-edge, high-performance applications that demand maximum efficiency and reduced component losses.

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