

# Active Power Factor Correction using Boost Converter With Fast Transient Response

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**Abstract**—The proposed system is an effort to explain active power factor correction using Pseudo Continuous Conduction (PCCM) boost converter and offers means to effectively avoid distortion of current waveform. Pseudo continuous conduction mode strategy with boost converter is proposed to realize output voltage regulation and wave shaping of current waveform achieve unity power factor.

Proposed system focuses on execution of PCCM mode by connecting a power switch in parallel with the inductor, which provides an additional degree of control freedom to realize PFC control introduced by inductor current freewheeling operation. Therefore, a simple and fast voltage control loop of the PCCM boost PFC converter can be designed to realize output-voltage regulation. Analysis, simulation, and a 400-W prototype of the PCCM boost PFC converter have been proposed for SMPS. The dynamic response of the PCCM boost PFC converter is significantly faster than the existing boost PFC converter.

**Keywords**-PCCM, dynamic response, power factor.

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## I INTRODUCTION

The number of electronic appliances is growing, an increasing amount of non-sinusoidal current is drawn from the distribution network (Mohan, et al.). Consequently, due to the increasing amount of harmonic currents drawn, the distribution network becomes more and more polluted. Most of the electrical and electronic appliances such as laptops, desktops, SMPS, UPS, and VFD work on D.C supply. Designing D.C power supplies for such applications is extremely demanded. AC to DC converter or rectifier is a device that converts ac to dc. This conversion is done by switching devices such as diodes, Thyristors, power MOSFET's, etc. AC to DC converter consisting of line frequency diode with a large output filter capacitor is cheap and robust but very inefficient. Due to the nonlinear behavior of the switches they tend to draw highly distorted input current in short bursts or spikes relative to the line voltage. As a result input power factor becomes very poor and also produces a large spectrum of harmonic signals that may interfere with other equipment. Low power factor results in poor output voltage regulation.

The number of switched mode power supplies (SMPS) and other power electronics appliances are increasing. SMPS are needed to convert electrical energy from AC to DC. SMPS are used as a replacement of the linear power supplies when higher efficiency, smaller size or lighter weight is required. Motors, electronic power supplies and fluorescent lighting consume the majority of power in the world and each of these would benefit from power factor correction.

In the proposed system for SMPS, the problem lies in the input rectification and filter network. The equipment connected to an electricity distribution network usually needs some kind of power conditioning, typically rectification. AC to DC rectifiers usually interfaced with the mains. These devices convert the

sinusoidal line voltage to a DC voltage. However, the rectification process produces a non-sinusoidal line current due to the nonlinear input characteristic. It is a well-known fact that the input current of an SMPS tends to have a non-sinusoidal, distorted waveform.

The distorted line current of a power converter is composed of the line frequency component and higher frequency harmonic components of the current. It should be noted that only the line frequency component of the current is carrying the power when voltage is sinusoidal.

The current drawn by simple SMPS is non-sinusoidal and not in phase with the supply voltage waveform so the most common rectifier and SMPS designs have a very low power factor of below than 0.60, and their use in personal computers and compact fluorescent lamps presents a growing problem for power distribution.

### A. Objective of Proposed system

The Active Power Factor Correction (APFC) is a method to improve the power factor near to unity, reduces harmonics distortion noticeably and automatically corrects the distorted line current of an SMPS and regulates DC output voltage. It will replace the Passive Power Factor Correction (PPFC) which has become a conventional method for the past 20 years. This system aims to implement the Unity Power Factor (UPF) for single-phase rectifier and regulated DC output which is used in designing the high-end SMPS by using APFC approach. This system involves the design of a 400W Unity Power Factor Rectifier. The converter operates at an input voltage of 220VAC and regulated output at 220VDC with improved power factor. Aim of the proposed active power factor correction system is -

- To simulate and analyze the typical power supplies.
- To investigate the effects of harmonics and low power factor to the power system.

- To simulate and analyze the methodology chosen for UPF.
- To determine the best control mode for UPF.
- To implement a single-phase UPF rectifier in designing the better SMPS.

## II. POWER FACTOR CORRECTION TOPOLOGY

In recent years, the demand for energy is increasing rapidly and with the rapid development of power electronics technologies, usage of power electronic system has been expanded to a wide range of applications that include residential, industrial, commercial, and aerospace and traction systems.

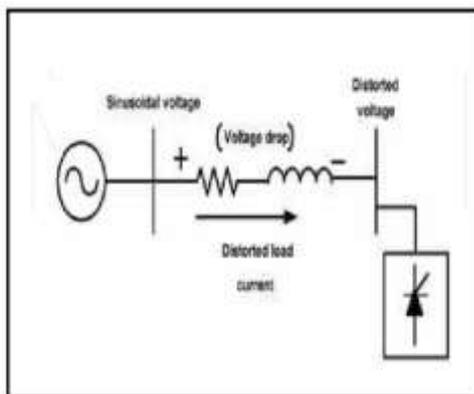


Fig.1. Distorted voltage at load bus caused by harmonic current flow through the system impedance

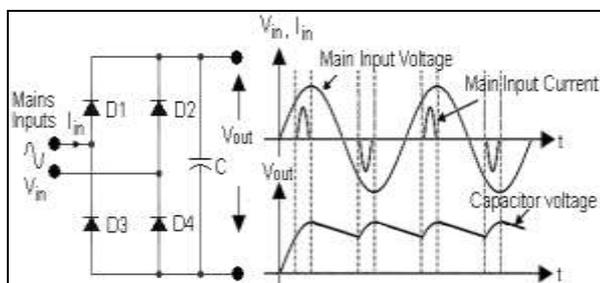


Fig 2. A typical power supply with filter capacitor and waveforms.

The DC output voltage of rectifier should be as ripple free as possible.

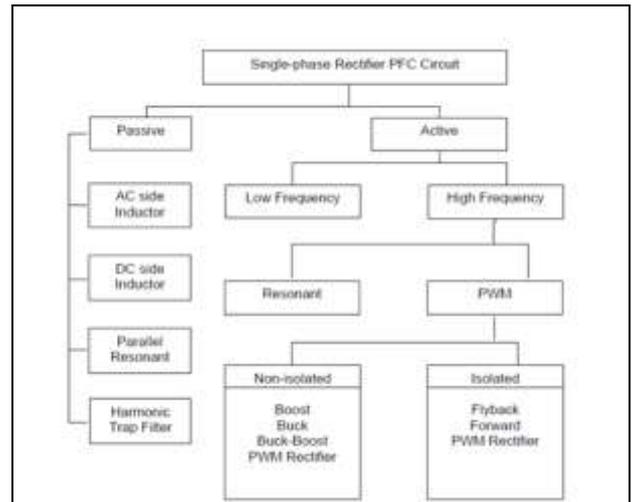
Therefore, a large capacitor is connected as a filter on the DC side. The capacitor will be charged during the peak of the AC input voltage and this will result in high peak input current. This rectifier draws highly distorted current from the utility.

### A. Different types of power correction topologies

PFC shaped the distorted input current waveform to approximate a sinusoidal current that is in phase with the input voltage.

There are basically two types of topology for power factor correction.

1. Active power factor control topology.
2. Passive power factor control topology.



### B. Passive PFC

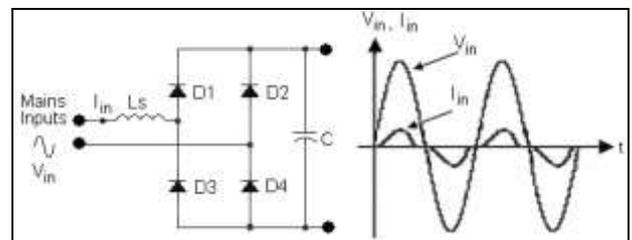


Fig 3. Passive APFC with AC inductor

Passive power factor correctors have certain advantages, such as Simplicity, reliability, ruggedness, Insensitive to noises and surges, no generation of high-frequency EMI, no high-frequency switching losses. Due to following drawbacks new technique such as active power factor correction is considered for project.

#### Shortfalls Of Passive PFC:

- Solutions based on filters are heavy and bulky, because line-frequency reactive components are used.
- They have poor dynamic response.
- Lack voltage regulation and the shape of their input current depend on the load.
- Even though line current harmonics are reduced, the fundamental component may show an excessive phase shift that reduces the power factor.
- Parallel resonance

### C. Active PFC

Better characteristics can be obtained by using “Active PFC”, which will be discussed. The boost PFC converter implements two control loops—a **voltage** loop and a **current** loop.

The objective of voltage loop is to regulate the output voltage of boost converter. In contrast, the objective of current loop is to make the supply current to follow the sinusoidal waveform of the supply voltage, providing high power factor (PF) and low total harmonic distortion (THD). Current control loop implements average, peak or hysteresis current control.

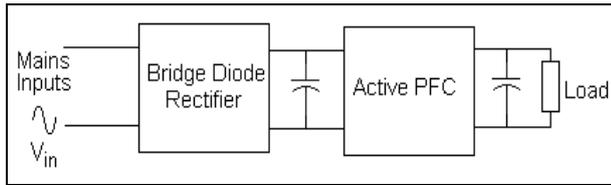


Fig 4. Block Diagram of rectifier with APFC

D. Design Methodology

Types of Converter

- Buck converter
- Boost Converter
- Buck boost converter

Modes of operation of converter

- Continuous Conduction Mode (CCM)-where the inductor current never reaches zero during one switching cycle
- Discontinuous Conduction Mode (DCM) -where the inductor current is zero during intervals of the switching cycle.
- Pseudo Continuous Conduction Mode (PCCM)-Fast dynamic response, low ripple, utilization of the freewheeling switch to provide an additional degree of control freedom,
- In DCM –Inductor current ramps up, down & maintains Zero
- In CCM –V & I loop are coupled. O/P of Voltage control loop is input of Current control loop
- In PCCM-output voltage control loop and the input-current control loop of the PCCM boost PFC converter can be designed independently

E. Converter Details :

Buck Converter-

The Buck converter has a lower output voltage than input voltage, and it has pulsating input current generating high harmonics into the power line. This circuit is not practical for low-line input because it does not draw the input current when input voltage is lower than the output voltage. The line current of a PFC based on a Buck converter has distortions and the input current of the converter is discontinuous as shown. Therefore, it has relatively low power factor.

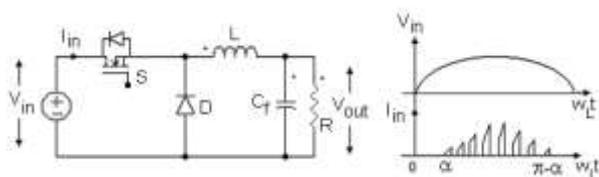


Fig 5. (a) Buck converter and Inputs waveforms

Boost Converter-

The Boost converter is shown, it has step-up conversion ratio. Therefore the output voltage is always higher than the input voltage. The converter will operate throughout the entire line cycle, so the input current does not have distortions and continuous as shown above. It has a smooth input current because an inductor is connected in series with the power source. In addition, the switch is source-grounded, therefore it is easy to drive. This topology is a universal solution for off-line power supplies and SMPS applications.

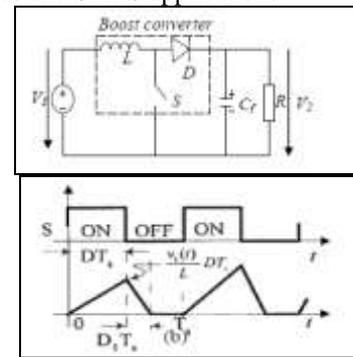


Fig 6. Boost Converter and waveforms

Buck-Boost converter

The Buck-Boost converter, shown in fig, can operate either as a step-down or a step-up converter.

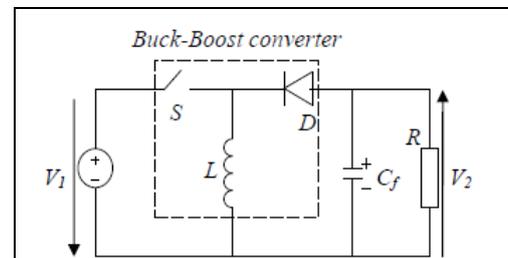


Fig 7. Buck-Boost converter and waveforms

F. Control Techniques

- Peak current control.
- Average current control.
- Hysteresis control.
- Borderline control.

Even though peak current control gives better characteristics, it has several drawbacks, such as: poor noise immunity, need of slope compensation, peak to average current error. These problems can be eliminated by average current control at the cost of increased circuit complexity. Hysteresis control and borderline control leads to variable frequency operation which may create sub-harmonic components. In borderline control, due to the presence of high current ripple it has high harmonic distortion. Hence the maximum power factor obtained will be limited to 0.87. Hence, peak and average current control techniques are the most preferable control techniques.

### III. PROPOSED SYSTEM FOR ACTIVE POWER FACTOR CORRECTION

#### A Mode of Operation and converter selection –

The pseudo continuous current mode (PCCM) operation of a boost converter is selected and it shows features as

- Intermediate between the continuous current mode (CCM) and discontinuous current mode (DCM) operation.
- Effective compromise to get advantages of both the modes.
- The control flexibility and stability in DCM operation of a boost converter can be attributed to the PCCM operation as far as the control design is concerned.
- Improve steady state and dynamic response
- Simple control design.
- Improved PF compared to DCM and reduced current ripple compared to CCM

#### B Block Diagram

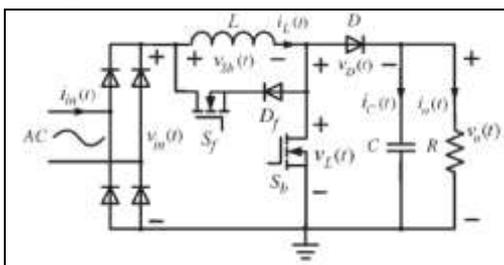
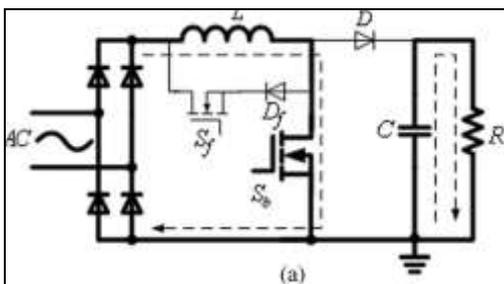


Fig 8. Block diagram of Active power factor correction using PCCM boost converter

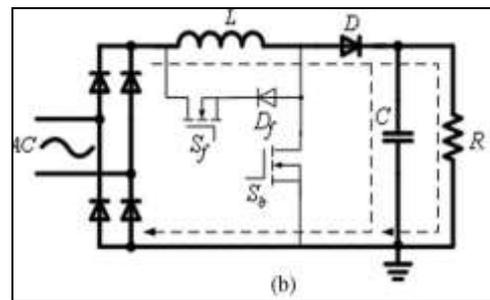
#### Operation of PCCM boost converter

- Boost Interval



In the “Boost” interval ( $dbT$ ), the boost switch  $S_b$  is on, freewheeling switch  $S_f$  is off. Inductor current  $i_L(t)$  ramps up, the diode  $D$  is reverse biased, and capacitor  $C$  is discharged to supply power to the load.

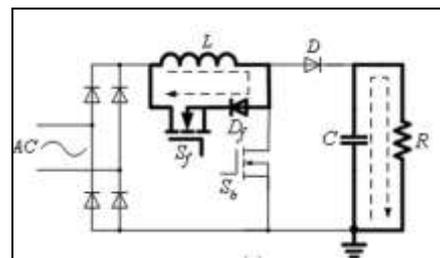
- “Capacitor-charging” Interval (Both the switches are off)



In the “Capacitor-charging” interval ( $dcT$ ), both  $S_b$  and  $S_f$  are off, diode  $D$  is forward biased.

Inductor current  $i_L(t)$  ramps down to supply power to the load, and the capacitor  $C$  is charged.

- Freewheeling Interval



(c)

In the “Freewheeling” interval ( $dfT$ ), the switch  $S_b$  is off, and  $S_f$  is on; the inductor current is in the freewheeling mode. In this operation mode, the diode  $D$  is reverse biased, and capacitor  $C$  is discharged again to supply power to the load. It should be noted that

$$db + dc + df = 1.$$

From above equation it can be seen that any two time intervals of the three time intervals during one switching cycle can be controlled independently, provided that the third time interval, the Freewheeling interval ( $df$ ), does not vanish to zero. Thus, compared with conventional CCM and DCM boost PFC converter, PCCM boost PFC converter introduces one more degree of control freedom provided by the freewheeling interval of the inductor current.

IV. CIRCUIT DIAGRAM OF PROPOSED SYSTEM

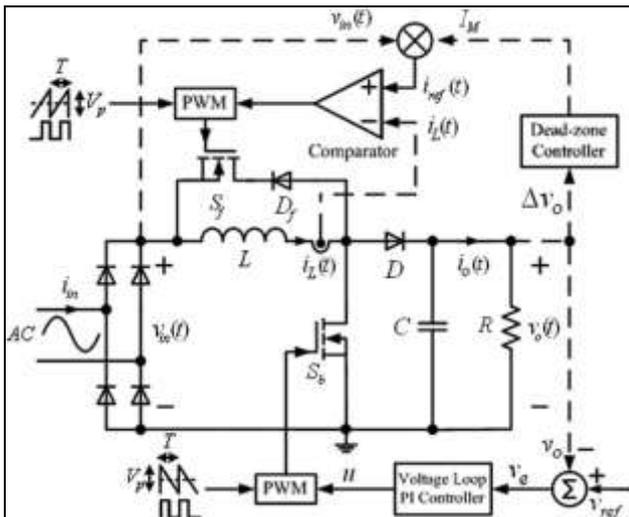


Fig 9. Circuit Diagram of Proposed System of APFC boost converter

A..Operation & Performance Analysis

Connecting a power switch in parallel with the inductor makes the boost converter operate in PCCM, which provides an additional degree of control freedom to realize PFC control. Simple and fast voltage control loop of the PCCM boost PFC Converter can be designed to realize output-voltage regulation. The additional degree of control freedom introduced by inductor current freewheeling operation of the PCCM boost PFC converter has been exploited through the dead-zone control technique, which can be dynamically adjusted in accordance with the output voltage ripple. Compared with continuous conduction mode(CCM) boost PFC converter, the controller of the proposed PCCM boost PFC converter is much simpler.

B. Proposed Decoupling Controller- Independent Design of Voltage & Current loop

The voltage control loop is used to regulate the output voltage of the PFC converter.

The current control loop is used to control the Freewheeling inductor current to make it in the same wave shape to and in phase with the input voltage, to achieve unity power factor.

Design Steps

- Step1**-Design key specifications.(i/p, o/p Voltage ,Power ,Efficiency, Vripple, switching frequency etc)
- Step 2**- Design boost inductor
- Step 3**- Design Power stage components. (Diode, Switch)
- Step 4**- Output capacitor design.
- Step 5**-Set OVP,UVP levels, feedback divider values, controllers.
- Step 6**-Current sensing, Voltage sensing circuit.

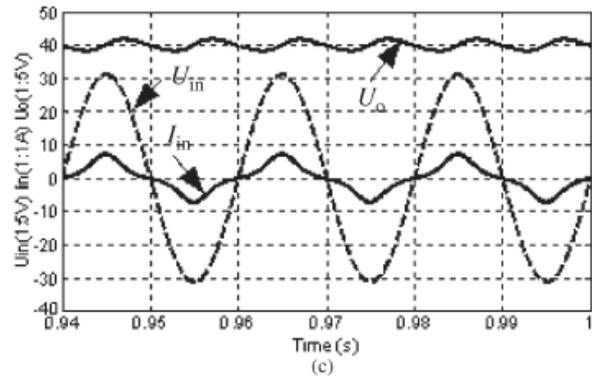


Fig 10.Steady State Input voltage, current and Output voltage Waveform

C. Transient Response

- 1.Load decreased form 400W to 200 W
- 2.Load increased form 200W to 400 W

From the figures, it can be seen that the PCCM boost PFC converter has the best transient performance, with the fastest transient responses and the smallest output-voltage drop and overshoot.

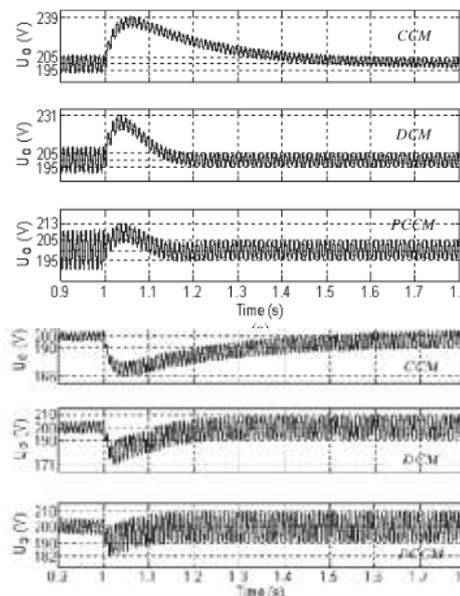
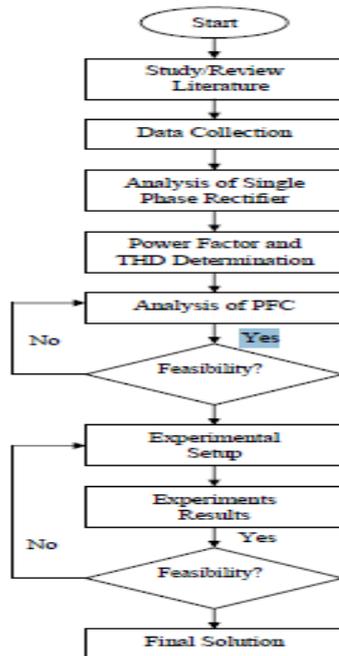


Fig 12. Load increased form 200W to 400 W

D.Flowchart



CONCLUSION

The additional degree of control freedom introduced by a freewheeling interval has been exploited through the decoupling controller. It shows fast transient response and increases current stress by reducing inductor-current ripple and increases the current-handling capability at heavy loads. Boost PFC converter is much simpler and has better dynamic performance of the PCCM boost PFC converter against load disturbance while maintaining low input-current distortion. Better design gives power range, improved power factor, and low line-current THD. The proposed converter can be used in applications wherever fast-response boost PFC action or wide ranges of load variation are needed.

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