SOFT SWITCHING CONTROL OF POWER FACTOR CORRECTION FOR DISTRIBUTION SYSTEM

A project report submitted in partial fulfillment of the requirements for the award of degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRICAL AND ELECTRONICS ENGINEERING

Submitted by

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I solemnly declare that this project report" "**SOFT SWITCHING CONTROL OF POWER FACTOR CORRECTION FOR DISTRIBUTION SYSTEM"** is the bonafide work done purely by me/us, carried out under the supervision of **Dr.D.RAVI KISHORE,** towards partial fulfillment of the requirements of the Degree of **ELECTRICAL & ELECTRONICS** in Engineering as administered under the Regulations of Godavari Institute of Engineering & Technology, Rajamahendravaram, AP, India and award of the Degree from Jawaharlal Nehru Technological University, Kakinada during the year 2020-2021.

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ABSTRACT

A boost Power Factor Correction (PFC) front end converter followed by a full bridge transformer-isolated dc/dc converter is popular in offline dc power supply. In this configuration switching losses are high and overall efficiency is reduced. For solving this problem individual soft-switching techniques are required for both the converters. A dc power supply system that uses a new Zero-Voltage Switching (ZVS) strategy to get ZVS function is proposed here. A soft-switching dc power supply system with high input power factor and stable dc output voltage is presented with simple and compact configuration. The proposed circuit is not only operated at constant frequency, but all semiconductor devices are operated at soft switching without additional voltage stress. A significant reduction in the conduction losses is achieved, since the circulating current for the soft switching flows only through the auxiliary circuit and a minimum number of switching devices are involved in the circulating current path, and the rectifier in the proposed converter uses a single converter instead of the conventional configuration composed of a four-diode front-end rectifier followed by a boost converter. An average-current-mode control is employed in proposed dc power supply system to synthesize a suitable low-harmonics sinusoidal waveform for the input current.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The use of rectifiers in industrial applications started at the era of mercury converters with the Electro mechanical contact converter. DC machines are common in day to day use. But the supply that we get from power companies is AC. To use those machines AC supply has to be turned into DC supply by the use of a rectifier. A rectifier is an electrical device that converts the incoming AC (alternating current) from a transformer or any other ac power source to pulsating DC (direct current). Rectifier may be made of diodes, solid states, vacuum tube, mercury arc valves and other components. All rectifier circuits may be classified into one of two categories, i) half wave rectifiers and ii) full wave rectifier. Rectifiers are also used for 3-phase inputs. Rectifiers can further be classified into two categories i. e. controlled and uncontrolled rectifier.

The dc output always remain constant if ac input voltage is constant in an uncontrolled rectifier whereas the output voltage can be controlled in a controlled rectifier. Rectifiers are widely used in nonlinear loads which are connected with distribution systems which plays an important role in power system network (ex: UPS, discharge lamp, television, computer, fax machines, ferromagnetic devices, arc furnaces, energy savers etc).

A further application of the rectifier is driving a DC motor. Speed control in DC motor is an important issue. With time the need of flexible speed control for motor is becoming essential . One way to control the speed of the motor is by varying its input voltage.

1.2 AC-DC Converters:

One of the first and most widely used application of power electronic devices have been in rectification. Rectification refers to the process of converting an ac voltage or current source to dc voltage and current. Rectifiers specially refer to power electronic converters where the electrical power flows from the ac side to the dc side. In many situations the same converter circuit may carry electrical power from the dc side to the ac side where upon they are referred to as inverters. In this lesson and subsequent ones the working principle and analysis of several commonly used rectifier circuits supplying different types of loads (resistive, inductive, capacitive, back emf type) will be presented.

- Waveforms and characteristic values (average, RMS etc) of the rectified voltage and current.
- Influence of the load type on the rectified voltage and current.
- Harmonic content in the output.
- Voltage and current ratings of the power electronic devices used in the rectifier circuit.
- Reaction of the rectifier circuit upon the ac network, reactive power requirement, power
- factor, harmonics etc.
- Rectifier control aspects (for controlled rectifiers only) In the analysis, following simplifying assumptions will be made.
- The internal impedance of the ac source is zero.
- Power electronic devices used in the rectifier are ideal switches.

The first assumption will be relaxed in a latter module. However, unless specified otherwise, the second assumption will remain in force. Rectifiers are used in a large variety of configurations and a method of classifying them into certain categories (based on common characteristics) will certainly help one to gain significant insight into their operation. Unfortunately, no consensus exists among experts regarding the criteria to be used for such classification.

1.3 Applications

With the wide spread of electronics and technology the necessary of DC power has increased as the used of DC electronics has increased over the decades. Here comes an AC-DC converter in play. With the wide spread of DC power needs, the application of AC-DC converter has overed a range from milli-watts to megawatts. Some applications of AC-DC converter is given below.

- Use in detection of amplitude modulated radio signal
- Use to supply polarized voltage for welding
- Use in Uninterruptible power supplies
- Use in Induction heating
- Use in HVDC power transmission

- Use in Variable-frequency drives
- Use in Electric vehicle drive Application
- Use in vacuum cleaners
- Use in Air conditioning
- Use in cordless telephone
- Use in DC motor control
- Use in rice cookers
- Use in electric carpets
- Use in washing basket
- Use in washing machine
- Use in air cleaner

1.4 Study of Rectifiers

Classification of Rectifiers

I) Single phase

a) Half-wave : i) Controlled ii) Uncontrolled

b) Full-wave : i) Controlled ii) Uncontrolled

II) Three Phase

a) Half-wave : i) Controlled ii) Uncontrolled

b) Full-wave : i) Controlled ii) Uncontrolled

1.5 Single phase rectifier

(a) Half-Wave Rectifier: In half-wave rectifier, half of the ac cycle (either positive or negative) pass, while during the other half cycle the diode blocks the current from flowing. Basic half-wave rectifier circuit may be constructed with a single diode in a one phase supply, or three diodes with a three-phase supply. Such circuits are known as half wave rectifier as they only work on half of the incoming ac wave.

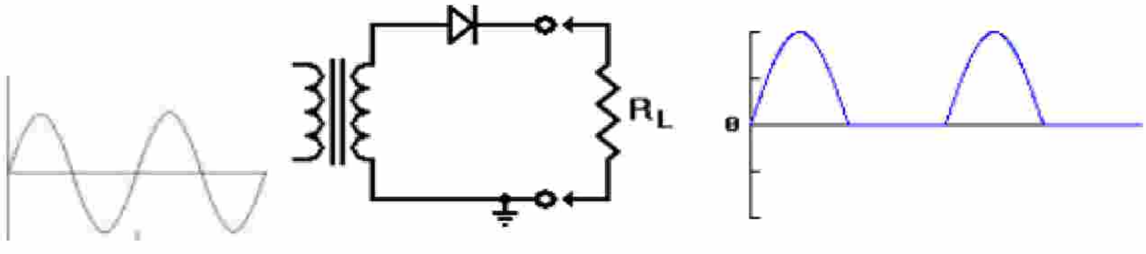


Fig. 1.1: Half Wave Rectifier

(b) Full-Wave Rectifier: A full-wave rectifier converts the whole incoming ac wave so that both halves are used to cause the output current to flow in same direction (either positive or negative). Full-wave rectification is more efficient because it converts both polarities of input waveform to DC. A full-wave rectifier circuit requires four diodes instead of one needed for half-wave rectification. For the arrangement of four diodes the circuit is called a diode bridge or bridge rectifier.

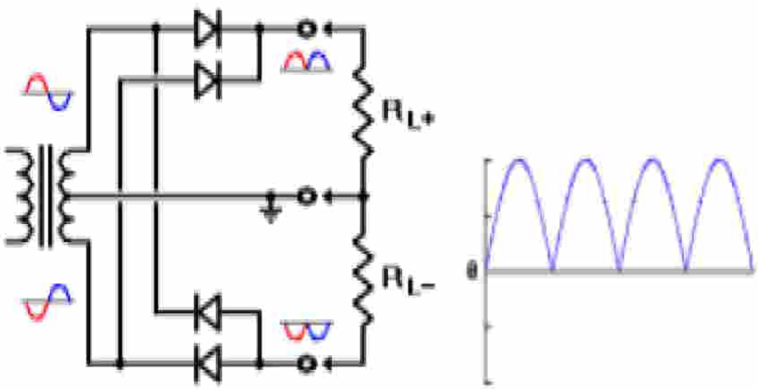


Fig. 1.2: Full Wave Rectifier

1.6 Three-phase half wave rectifier

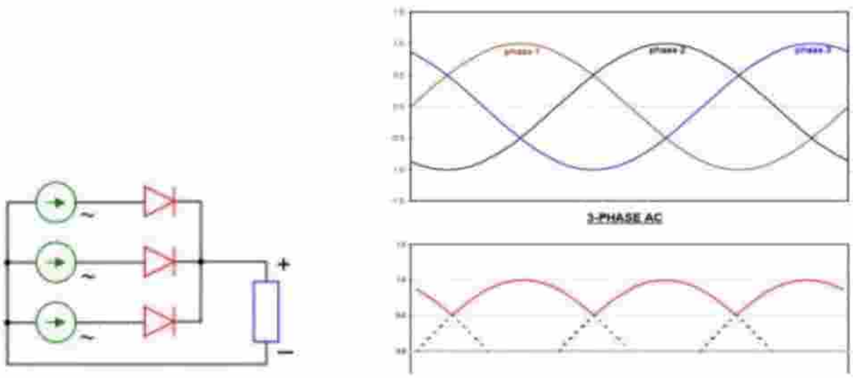


Fig. 1.3: phase half wave rectifier

The operation theory is like a single phase half wave rectifier. As each of the phases reach 0.7V the diode of the respective phase start conducting. The resultant current flows through the load.

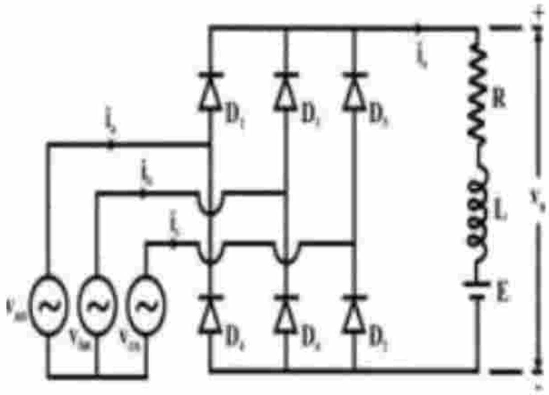


Fig. 1.4: 3-phase full wave rectifier

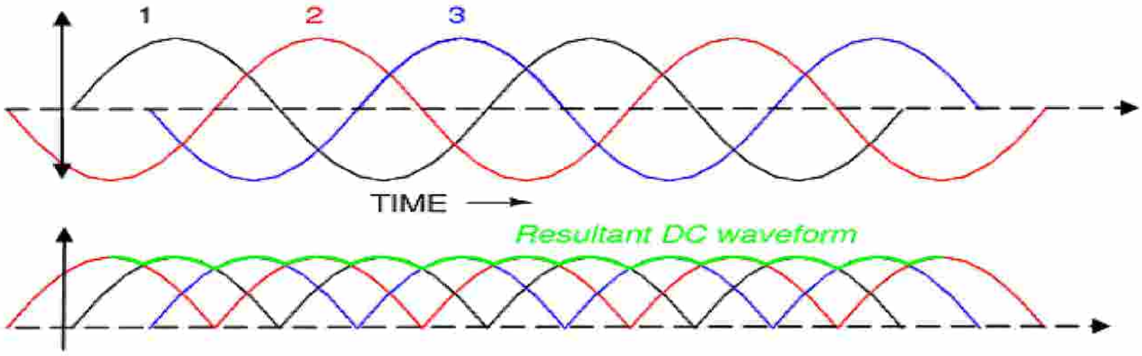


Fig. 1.5: Input and output voltage waveform for 3 phase full wave rectifier

1.7 Power Factor:

The power factor is defined as the ratio of the average power to the apparent power at an AC terminal. Assuming an ideal sinusoidal input voltage source, the power factor can be expressed as the product of two factors, the distortion factor and the displacement factor. The distortion factor kd is the ratio of the fundamental root-mean-square (RMS) current to the total RMS current. The displacement factor kq is the cosine of the displacement angle between the fundamental input current and the input voltage.

$$PF = K_d\ K_\theta$$

$$K_d = \frac{I_{rms(1)}}{I_{rms}}$$

$$K_\theta = \cos\theta$$

(1.1)

When a converter has less than unity power factor, it means that the converter absorbs apparent power higher than the real power it consumes. This implies that the power source should be rated with higher VA ratings than the load needs. In addition, the current harmonics the converter produces deteriorate the power source quality, which eventually affect the other equipment. The simple solution to improve the power factor is to add a passive filter, which is usually composed of a capacitor and an inductor. However, this passive filter is bulky and inefficient since it operates at the line frequency. Therefore, a power factor correction stage has to be inserted to the existing equipment to achieve a good power factor. Usually, two types of power factor correction methods are used: The VAR/harmonics compensation method employs a switch-mode power converter in parallel with the nonlinear load to supply a reactive power and/or line current harmonics to cancel the displacement and the line current harmonics created by the nonlinear load. This method cannot cancel all the line current harmonics, however, and this additional line current harmonics compensator cannot regulate the output to the load. The high frequency switch mode power factor correction converter called a PFC stage, is usually inserted in the equipment to shape the line input current into a sinusoidal waveform and its line current is in phase with the line voltage.

1.7.1 SOURCES OF POOR PF

- Poor power factor caused by reactive linear circuit elements results as the current either leads or lags the voltage, depending on whether the load looks capacitive or inductive.
- Less than acceptable power factor typically associated with electronic power conversion equipment is caused by nonlinear circuit elements.

In most off-line power supplies, the AC-DC front end consists of a bridge rectifier followed by a large filter capacitor.

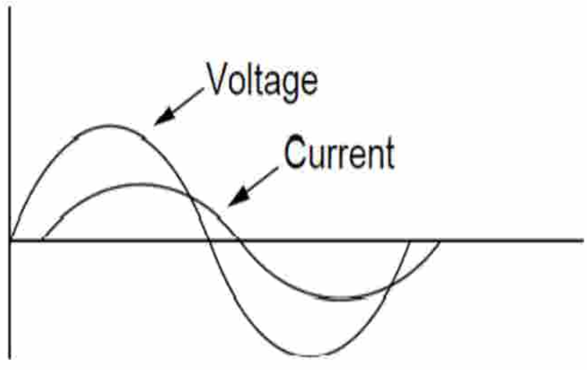


Fig.1.6 (a): Traditional poor power factor—the current either leads or lags the voltage

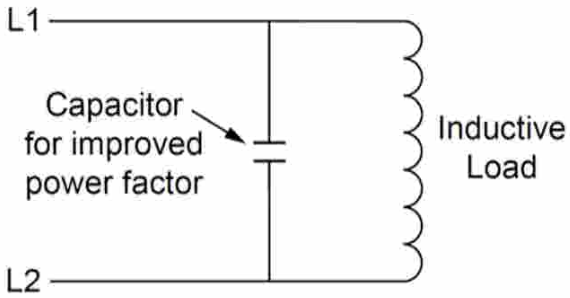


Fig. 1.6(b) : Improvement of power factor

In this circuit, current is drawn from the line only when the peak voltage on the line exceeds the voltage on the filter capacitor. Since the rate of rise and fall of current is greater than that of line voltage, and the current flows discontinuously, a series of predominantly odd harmonics are generated. It is these harmonics that cause problems with the power distribution system. The power factor of the system can be improved slightly by either adding series inductance with the line or decreasing the value of the holdup capacitor, which will lengthen the conduction angle. However, both these methods severely limit the amount of power that can be drawn from the line.

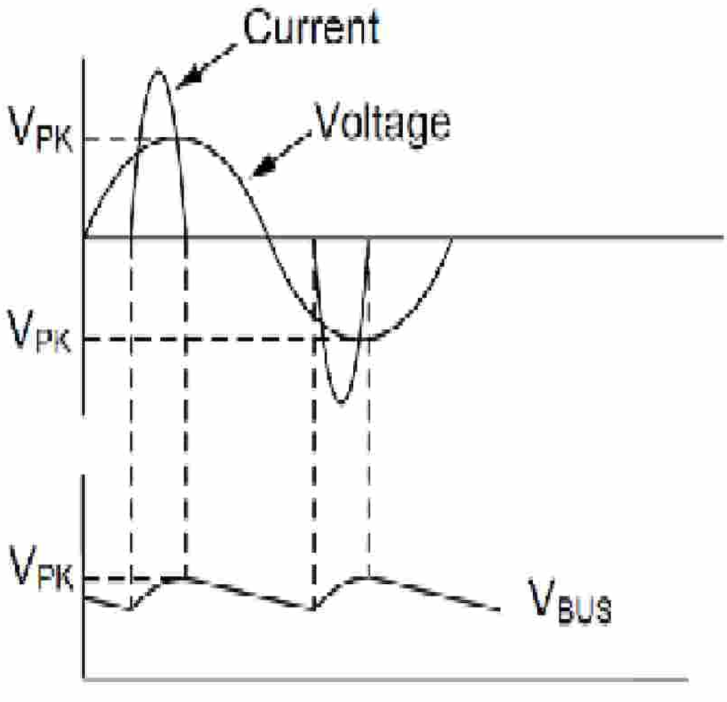


Fig. 1.7 Current drawn from the line only when line voltage exceeds the voltage across the capacitor

1.8. POWER FACTOR CORRECTION

1.8.1 Power Factor Correction (PFC)

Power factor correction is the method of improving the power factor of a system by using suitable devices. The objective of power factor correction circuits is to make the input to a power supply behave like purely resistive or a resistor. When the ratio between the voltage and current is a constant, then the input will be resistive hence the power factor will be 1.0. When the ratio between voltage and current is other than one due to the presence of non-linear loads, the input will contain phase displacement, harmonic distortion and thus, the power factor gets degraded.

1.8.2 Need of PFC

The rise in the industrial, commercial and residential applications of electronic equipments has resulted in a huge variety of electronic devices requiring mains supply. These devices have rectification circuits, which is the prominent reason of harmonic distortion. These devices convert AC to DC power supply which causes current pulses to be drawn from the ac network during each half cycle of the supply waveform. Even if a single device for example, a television may not draw a lot of reactive power nor it can generate enough harmonics to affect the supply system significantly, but within a particular phase connection, there may exist several such devices connected to the same supply phase resulting in production of a large amount of reactive power flow and harmonics in line current.

With improvement in the field of semiconductors, the size and weight of control circuits have drastically reduced. This has also affected their performance and thus power electronic converters have become increasingly popular in industrial, commercial and residential applications. However this mismatch between power supplied and power used cannot be detected by any kind of meter meant for charging the domestic consumers, and hence, results in direct loss of revenues.

Moreover, since different streets are supplied with different phases, a 3-phase unbalanced condition may also arise within a housing scheme. The unbalance current flows in the neutral line of a star connected network causing undesirable heating and burning of the conductor.

This pulsating current contains harmonics which results in additional losses and dielectric stresses in capacitors and cables, increasing currents in windings of rotating machinery (e.g., induction motors) and transformers and noise emissions in many equipments. The rectifier used in the AC input side is the prime source of this problem. Thus, in order to decrease the effect of this distortion, power factor correction circuits are added to the supply input side of equipments used in industries and domestic applications to increase the efficiency of power usage.

1.8.3 Types of Power Factor Correction (PFC)

Power Factor Correction can be classified as two types:

- Passive Power Factor Correction
- Active Power Factor Correction

1.8.3.1 Passive Power Factor Correction

In Passive PFC, in addition to the diode bridge rectifier, passive elements are introduced to improve the nature of the line current. By using this, power factor can be increased to a value of 0.7 to 0.8 approximately. As the voltage level of power supply increases, the sizes of PFC components increase. The idea of passive PFC is to filter out the harmonic currents by use of a low pass filter and only allow the 50 Hz power frequency wave to increase the power factor.

Advantages of Passive PFC :

- It has a simple structure.
- It is reliable and rugged.
- The cost is very low because only a filter is required.
- The high frequency switching losses are absent and it is not sensitive to noises and surges.
- The equipments used in this circuit don’t generate high frequency EMI.

Disadvantages of Passive PFC :

- For achieving better power factor the size of the filter increases.
- Due to the time lag associated with the passive elements it has a poor dynamic response.
- The voltage cannot be regulated and the efficiency is low.
- Due to presence of inductors and capacitors interaction may take place between the passive elements and the system resonance may occur at different frequencies.
- Although by filtering the harmonics can be filtered out, the fundamental component may get phase shifted thus reducing the power factor
- The shape of input current is dependent upon what kind of load is connected.

1.8.3.2 Active Power Factor Correction

An active PFC is a power electronic device designed to control the amount of power drawn by a load and obtains a power factor as close as possible to unity. Commonly any active PFC design functions by controlling the input current in order to make the current waveform follow the supply voltage waveform closely (i.e. a sine wave). A combination of the reactive elements and some active switches increase the effectiveness of the line current shaping and to obtain controllable output voltage.

The switching frequency differentiates the active PFC solutions into two classes.

- **Low frequency active PFC:**

Switching takes place at low-order harmonics of the line-frequency and it is synchronized with the line voltage.

- **High frequency active PFC:**

The switching frequency is much higher than the line frequency. The power factor value obtained through Active PFC technique can be more than 0.9. With a suitable design even a power factor of 0.99 can be achieved easily. Active PFC power supply can detect the input voltage automatically, supports 110V to 240V alternative current, its size and weight is smaller than passive PFC power supply.

Advantages of Active PFC :

- The weight of active PFC system is very less.
- The size is also smaller and a power factor value of over 0.95 can be obtained through this method.
- It reduces the harmonics present in the system.
- Automatic correction of the AC input voltage can be obtained.
- It is capable of operating in a full range of voltage

Disadvantages of Active PFC :

- The layout design is somewhat more complex than passive PFC.
- It is very expensive since it needs PFC control IC, high voltage MOSFET, high voltage ultra-fast choke and other circuits

1.9 Electromagnetic interference (EMI):

Electromagnetic interference (EMI), also called radio-frequency interference (RFI) when in the radio frequency spectrum, is a disturbance generated by an external source that affects an electrical circuit by electromagnetic induction, electrostatic coupling, or conduction. The disturbance may degrade the performance of the circuit or even stop it from functioning. In the case of a data path, these effects can range from an increase in error rate to a total loss of the data. Both man-made and natural sources generate changing electrical currents and voltages that can cause EMI: automobile ignition systems, cell phones, thunder storms, the Sun, and the Northern Lights. EMI frequently affects AM radios. It can also affect cell phones, FM radios, and televisions.

There are many forms of electromagnetic interference, EMI that can affect circuits and prevent them from working in the way that was intended. This EMI or radio frequency interference, RFI as it is sometimes called can arise in a number of ways, although in an ideal world it should not be present.

EMI - electromagnetic interference can arise from many sources, being either man made or natural. It can also have a variety of characteristics dependent upon its source and the nature of the mechanism giving rise to the interference.

By the very name of interference given to it, EMI is an unwanted signal at the signal receiver, and in general methods are sought to reduce the level of the interference.

1.10 Types of EMI - Electromagnetic Interference

EMI - Electromagnetic Interference can arise in many ways and from a number of sources. The different types of EMI can be categorised in a number of ways.

One way of categorising the type of EMI is by the way it was created:

- ***Man-made EMI:*** This type of EMI generally arises from other electronics circuits, although some EMI can arise from switching of large currents, etc.
- ***Naturally occurring EMI:*** This type of EMI can arise from many sources - cosmic noise as well as lightning and other atmospheric types of noise all contribute.

Another method of categorising the type of EMI is by its duration:

- ***Continuous interference:*** This type of EMI generally arises from a source such as a circuit that is emitting a continuous signal. However background noise, which is continuous may be created in a number of ways, either manmade or naturally occurring.

- ***Impulse noise:*** Again, this type of EMI may be man-made or naturally occurring. Lightning, ESD, and switching systems all contribute to impulse noise which is a form of EMI.

It is also possible to categorise the different types of EMI by their bandwidth.

- ***Narrowband:*** Typically this form of EMI is likely to be a single carrier source - possibly generated by an oscillator of some form. Another form of narrowband EMI is the spurious signals caused by inter modulation and other forms of distortion in a transmitter such as a mobile phone of Wi-Fi router. These spurious signals will appear at different points in the spectrum and may cause interference to another user of the radio spectrum. As such these spurious signals must be kept within tight limits.
- ***Broadband:*** There are many forms of broadband noise which can be experienced. It can arise from a great variety of sources. Man-made broadband interference can arise from sources such as arc welders where a spark is continuously generated. Naturally occurring broadband noise can be experienced from the Sun - it can cause sun-outs for satellite television systems when the Sun appears behind the satellite and noise can mask the wanted satellite signal. Fortunately these episodes only last for a few minutes.

1.11 EMI coupling mechanisms

There are many ways in which the electromagnetic interference can be coupled from the source to the receiver. Understanding which coupling method brings the interference to the receiver is key to being able to address the problem.

- ***Radiated:*** This type of EMI coupling is probably the most obvious. It is the type of EMI coupling that is normally experienced when the source and victim are separated by a large distance - typically more than a wavelength. The source radiates a signal which may be wanted or unwanted, and the victim receives it in a way that disrupts its performance.
- ***Conducted :*** Conducted emissions occur as the name implies when there is a conduction route along which the signals can travel. This may be along power cables or other interconnection cabling. The conduction may be in one of two modes:

- *Common mode:* This type of EMI coupling occurs when the noise appears in the same phase on the two conductors, e.g. out and return for signals, or +ve and -ve for power cables.
- *Differential mode:* This occurs when the noise is out of phase on the two conductors.

The filtering techniques required will vary according to the type of EMI coupling experienced. For common mode lines are filtered together. For differential mode they may be filtered together.

- ***Inductive coupling:*** What is normally termed inductive coupling can be one of two forms, namely capacitive coupling and magnetic induction.
- ***Capacitive coupling :*** This occurs when a changing voltage from the source capacitively transfers a charge to the victim circuitry.
- ***Magnetic coupling:*** This type of EMI coupling exists when a varying magnetic field exists between the source and victim - typically two conductors may run close together (less than λ apart). This induces a current in the victim circuitry, thereby transferring the signal from source to victim.

By determining the form of coupling that exists and the way in which it is reaching the victim, it may prove to be that the most effective method of reducing the EMI is by putting measures in place to reduce the coupling and reduce the level of interference to an acceptable level.

Electromagnetic interference, EMI is present in all areas of electronics. By understanding the source, the coupling methods and the susceptibility of the victim, the level of interference can be reduced to a level where the EMI causes no undue degradation in performance.

1.12 High frequency (HF)

High frequency (HF) is the ITU designation for the range of radio frequency electromagnetic waves (radio waves) between 3 and 30 MHz. It is also known as the decameter band or decameter wave as its wavelengths range from one to ten decameters (ten to one hundred metres). Frequencies immediately below HF are denoted medium frequency

(MF), while the next band of higher frequencies is known as the very high frequency (VHF) band. The HF band is a major part of the shortwave band of frequencies, so communication at these frequencies is often called shortwave radio. Because radio waves in this band can be reflected back to Earth by the ionosphere layer in the atmosphere – a method known as "skip" or "skywave" propagation – these frequencies are suitable for long-distance communication across intercontinental distances. The band is used by international shortwave broadcasting stations (2.310 - 25.820 MHz), aviation communication, government time stations, weather stations, amateur radio and citizens band services, among other uses.

1.13 Light-emitting diode

A light-emitting diode (LED) is a two-lead semiconductor light source. It is a p–n junction diode, which emits light when activated. When a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons. This effect is called electroluminescence, and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor.

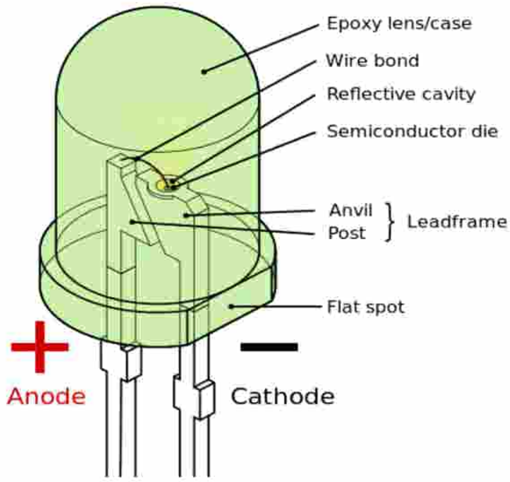
An LED is often small in area (less than 1 mm2) and integrated optical components may be used to shape its radiation pattern.

Appearing as practical electronic components in 1962, the earliest LEDs emitted low-intensity infrared light. Infrared LEDs are still frequently used as transmitting elements in remote-control circuits, such as those in remote controls for a wide variety of consumer electronics. The first visible-light LEDs were also of low intensity, and limited to red. Modern LEDs are available across the visible, ultraviolet, and infrared wavelengths, with very high brightness.

Early LEDs were often used as indicator lamps for electronic devices, replacing small incandescent bulbs. They were soon packaged into numeric readouts in the form of seven-segment displays, and were commonly seen in digital clocks.

Recent developments in LEDs permit them to be used in environmental and task lighting. LEDs have many advantages over incandescent light sources including lower energy consumption, longer lifetime, improved physical robustness, smaller size, and faster switching. Light-emitting diodes are now used in applications as diverse as aviation lighting, automotive headlamps, advertising, general lighting, traffic signals, camera flashes and lighted wallpaper. As of 2016, LEDs powerful enough for room lighting remain somewhat more expensive, and require more precise current and heat management, than compact fluorescent lamp sources of comparable output. They are, however, significantly more energy efficient and, arguably, have less environmental concerns linked to their disposal. The governments of some countries are promoting the domestic use of LED-based lighting, and in some cases providing LED-based lighting solutions to the public at subsidized rates.

LEDs have allowed new displays and sensors to be developed, while their high switching rates are also used in advanced communications technology.



1.8 Light Emitting Diode

To understand the working principle of light emitting diode, we first have to understand a basic of quantum theory. According to this theory, when an electron comes down from its higher energy level to lower energy level, it emits energy in form of a photon. The energy of this photon is equal to the energy gap between these two energy levels. When a pn junction diode is forward biased, current flows through the diode. Flow of current through the semiconductor is caused by both flow of free electrons in opposite direction of current and flow of holes in the direction of current. Hence during flow of these charge carriers, there will be recombinations. Recombination mean electrons in condition band jump down to the valence band. During this jump electron will emit electromagnetic energy in form of photons whose energy is equal to forbidden energy gap Eg. Again according to quantum theory, energy of a photon is the product of frequency of electromagnetic radiation and Planck constant.

$$E_g = hf \tag{1.1}$$

Where h is Planck constant. Again velocity of electromagnetic radiation is fixed and it is equal to the speed of light i.e. c. The frequency of radiation f is related to velocity of light as f = c / λ. Where λ is wavelength of the electromagnetic radiation. Hence from equation (1.1)

$$E_g = \frac{hc}{\lambda} \tag{1.2}$$

So we have seen that wavelength of electromagnetic radiation is inversely proportional to the forbidden energy gap. In normal silicon, germanium semiconductor this forbidden energy gaps between condition and valence band are such that entire radiation of electromagnetic wave during recombinations is in the form of inferred radiation. The wavelengths of the inferred are out of our visible range so we cannot see it. Inferred electromagnetic radiation is nothing but heat. This is because, silicon and germanium semiconductor are not direct gap semiconductor rather these are indirect gap semiconductor. In indirect gap semiconductor the maximum energy level of valence band and minimum energy level of conduction band do not occur at same momenta of electrons. Hence during recombinations of electrons and holes that is migration of electrons from conduction band to valence band the momentum of electrons would be changed.

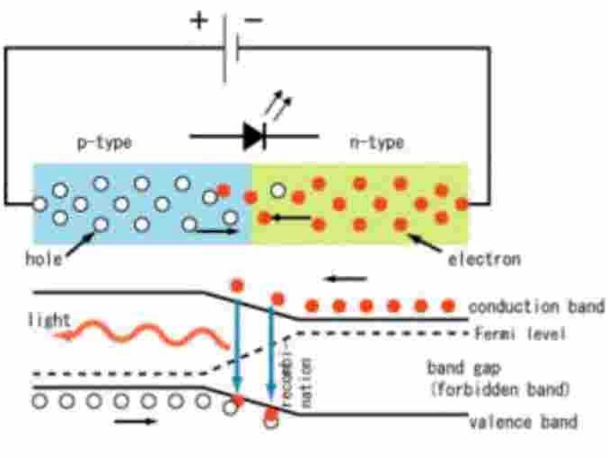


Fig.1.9 The LED electron momentum

The photons originated from these electrons will be mostly utilized for the electron momentum. In direct gap semiconductor the maximum of valence band and minimum of conduction band occur at same electron momenta. Hence, there will be no change of momentum of electrons during migration from conduction band to valence band so the photons originated due that migration have not to provide momentum to electrons. As a result, the photons are emitted from the surface of semiconductor crystal. There are some special type of specially alloyed direct energy gap semiconductors whose energy gap between condition and valence band are such that the electromagnetic radiation emitted during recombinations has wavelengths within our visible range. That means in these special semiconductors when recombinations between electrons and holes occur, there will be emissions of light. This is how a light emitting diode works.

1.14 Application of LED or Light Emitting Diode

Today almost everywhere LEDs lights are used and the application of LED is huge. First we are going to see through the list, then we will categorize the application of these.

- In motorcycle and bicycle lights.
- In traffic lights and signals.
- In message displaying boards.
- In light bulbs and many more.

Now, practically if we sit to list all the applications it will be a non-ending list. So, here we are classifying the use in to some parts.

Indicators and Signs:-

These are mainly used in traffic signals, exit signs, light weight message, displaying box etc

Lighting:-

Light Emitting Diode lamps have become highly popular and as the energy consumption is very low for them, they are also being made by LED s. In 2001, the Italian village Torraca was the first place to convert all its lighting to LED. In television and computer/laptop displaying, LEDs are used.

Non Visual Application:-

Communication, sensor are the main area of non visual application of LEDs.

1.15 Advantages of LED or Light Emitting Diode

If anybody compares LEDs to other illumination methods present in the market now days it will be found that LED lighting in by far the most saving solution. In modern era of technology, there is an up gradation from analog to digital. You can say LED is digital light which has huge advantages over conventional analog lights. The main advantages are briefly described below.

- **Size :-**

Sizes of Light Emitting Diodes are from 3 mm to 8 mm long. The small size allows them to be used in small spaces where tube lights cannot be used. Because of its small size, various designs can be made very simply.

- **Larger lifetime :-**

This is the number one benefit of LEDs lights. As an example a high power white LEDs life time is projected to be 35,000 to 50,000 hours. Where as an incandescent bulbs life time is 750 to 2,000 hours. For compact fluorescent bulbs, the life time is 8,000 to 10,000 hours. Actually unlike standard lighting LEDs do not burn out. They just gradually fade.

- **Lower Temperature :-**

LED's mechanism does not consists of any step to produce heat. In conventional lights, the production of heat are very common fact. They waste most of their energy as heat. They remain cool.

- **Energy Efficiency :-**

Light Emitting Diode is today's most energy efficient way of lighting its energy efficiency is nearly 80% to 90% whereas traditional lights have 20% energy efficiency, 80% is lost, as heat. More over the quality of lighting is very good.

- **Design Flexibility :-**

LEDs can be merged in any shape or combination. They can be used in singly as an irony. Single LED can be operated, resulting in a dynamic control of light. Superb lighting effects of differentcolors can be achieved by well designed LED illumination system.

- **Ecologically Friendly:-**

LED lights do not contain any toxic chemical. They do not leave any toxic material and 100% recyclable. Their illuminations are close to no UV emission. The solid package of it can be designed to focus its light also.

- **Color:-**

LEDs can be emit light of intended color this is done by charging the compositions of the solid state materials doping without using any color filter.

- **On/Off Time:-**

Light Emitting Diodes can be operated very quickly. They can be used in frequent on/off operation in communication devices.

1.16 Technology

1.16.1 Physics

The LED consists of a chip of semiconducting material doped with impurities to create a p-n junction. As in other diodes, current flows easily from the p-side, or anode, to the n-side, or cathode, but not in the reverse direction. Charge-carriers—electrons and holes—flow into the junction from electrodes with different voltages. When an electron meets a hole, it falls into a lower energy level and releases energy in the form of a photon.

The wavelength of the light emitted, and thus its color, depends on the band gap energy of the materials forming the p-n junction. In silicon or germanium diodes, the electrons and holes usually recombine by a non-radiative transition, which produces no optical emission, because these are indirect band gap materials. The materials used for the LED have a direct band gap with energies corresponding to near-infrared, visible, or near-ultraviolet light.

LED development began with infrared and red devices made with gallium arsenide. Advances in materials science have enabled making devices with ever-shorter wavelengths, emitting light in a variety of colours.

LEDs are usually built on an n-type substrate, with an electrode attached to the p-type layer deposited on its surface. P-type substrates, while less common, occur as well. Many commercial LEDs, especially GaN/InGaN, also use sapphire substrate.

1.16.2 Refractive index

Bare uncoated semiconductors such as silicon exhibit a very high refractive index relative to open air, which prevents passage of photons arriving at sharp angles relative to the air-contacting surface of the semiconductor due to total internal reflection. This property affects both the light-emission efficiency of LEDs as well as the light-absorption efficiency of photovoltaic cells. The refractive index of silicon is 3.96 (at 590 nm), while air is 1.0002926.

In general, a flat-surface uncoated LED semiconductor chip emits light only perpendicular to the semiconductor's surface, and a few degrees to the side, in a cone shape referred to as the *light cone*, *cone of light*, or the *escape cone*. The maximum angle of incidence is referred to as the critical angle. When this angle is exceeded, photons no longer escape the semiconductor but are instead reflected internally inside the semiconductor crystal as if it were a mirror.

Internal reflections can escape through other crystalline faces if the incidence angle is low enough and the crystal is sufficiently transparent to not re-absorb the photon emission. But for a simple square LED with 90-degree angled surfaces on all sides, the faces all act as equal angle mirrors. In this case, most of the light can not escape and is lost as waste heat in the crystal.[50]

A convoluted chip surface with angled facets similar to a jewel or fresnel lens can increase light output by distributing light perpendicular to the chip surface and far to the sides of the photon emission point.

The ideal shape of a semiconductor with maximum light output would be a microsphere with the photon emission occurring at the exact center, with electrodes penetrating to the center to contact at the emission point. All light rays emanating from the center would be perpendicular to the entire surface of the sphere, resulting in no internal reflections. A hemispherical semiconductor would also work, with the flat back-surface serving as a mirror to back-scattered photons.

1.16.3 Transition coatings

After the doping of the wafer, it is cut apart into individual dies. Each die is commonly called a chip.

Many LED semiconductor chips are encapsulated or potted in clear or colored molded plastic shells. The plastic shell has three purposes:

- Mounting the semiconductor chip in devices is easier to accomplish.
- The tiny fragile electrical wiring is physically supported and protected from damage.

The plastic acts as a refractive intermediary between the relatively high-index semiconductor and low-index open air.

The third feature helps to boost the light emission from the semiconductor by acting as a diffusing lens, emitting light at a much higher angle of incidence from the light cone than the bare chip would alone.

1.16.4 Efficiency and operational parameters

Typical indicator LEDs are designed to operate with no more than 30–60 milliwatts (mW) of electrical power. Around 1999, Philips Lumileds introduced power LEDs capable of continuous use at one watt. These LEDs used much larger semiconductor die sizes to handle the large power inputs. Also, the semiconductor dies were mounted onto metal slugs to allow for heat removal from the LED die.

One of the key advantages of LED-based lighting sources is high luminous efficacy. White LEDs quickly matched and overtook the efficacy of standard incandescent lighting systems. In 2002, Lumileds made five-watt LEDs available with luminous efficacy of 18–22 lumens per watt (lm/W). For comparison, a conventional incandescent light bulb of 60–100 watts emits around 15 lm/W, and standard fluorescent lights emit up to 100 lm/W.

1.16.5 Efficiency droop

Efficiency droop is the decrease in luminous efficiency of LEDs as the electric current increases above tens of milliamperes.

This effect was initially theorized to be related to elevated temperatures. Scientists proved the opposite is true: though the life of an LED would be shortened, the efficiency droop is less severe at elevated temperatures. The mechanism causing efficiency droop was identified in 2007 as Auger recombination, which was taken with mixed reaction. In 2013, a study confirmed Auger recombination as the cause of efficiency droop.

In addition to being less efficient, operating LEDs at higher electric currents creates higher heat levels, which compromise LED lifetime. Because of this increased heat at higher currents, high-brightness LEDs have an industry standard of operating at only 350 mA, which is a compromise between light output, efficiency, and longevity.

1.16.6 Possible solutions

Instead of increasing current levels, luminance is usually increased by combining multiple LEDs in one bulb. Solving the problem of efficiency droop would mean that household LED light bulbs would need fewer LEDs, which would significantly reduce costs.

Researchers at the U.S. Naval Research Laboratory have found a way to lessen the efficiency droop. They found that the droop arises from non-radiative Auger recombination of the injected carriers. They created quantum wells with a soft confinement potential to lessen the non-radiative Auger processes.

Researchers at Taiwan National Central University and Epistar Corp are developing a way to lessen the efficiency droop by using ceramic aluminium nitride (AlN) substrates, which are more thermally conductive than the commercially used sapphire. The higher thermal conductivity reduces self-heating effects.

1.16.7 Lifetime and failure

Solid-state devices such as LEDs are subject to very limited wear and tear if operated at low currents and at low temperatures. Typical lifetimes quoted are 25,000 to 100,000 hours, but heat and current settings can extend or shorten this time significantly.

The most common symptom of LED (and diode laser) failure is the gradual lowering of light output and loss of efficiency. Sudden failures, although rare, can also occur. Early red LEDs were notable for their short service life. With the development of high-power LEDs, the devices are subjected to higher junction temperatures and higher current densities than traditional devices. This causes stress on the material and may cause early light-output degradation. To quantify useful lifetime in a standardized manner, some suggest using L70 or L50, which are runtimes (typically in thousands of hours) at which a given LED reaches 70% and 50% of initial light output, respectively.

Whereas in most previous sources of light (incandescent lamps, discharge lamps, and those that burn combustible fuel, e.g. candles and oil lamps) the light results from heat, LEDs only operate if they are kept cool enough. The manufacturer commonly specifies a maximum junction temperature of 125 or 150 °C, and lower temperatures are advisable in the interests of long life. At these temperatures, relatively little heat is lost by radiation, which means that the light beam generated by an LED is cool.

The waste heat in a high-power LED (which as of 2015 can be less than half the power that it consumes) is conveyed by conduction through the substrate and package of the LED to a heat sink, which gives up the heat to the ambient air by convection. Careful thermal design is, therefore, essential, taking into account the thermal resistances of the LED's package, the heat sink and the interface between the two. Medium-power LEDs are often designed to solder directly to a printed circuit board that contains a thermally conductive metal layer. High-power LEDs are packaged in large-area ceramic packages that attach to a metal heat sink—the interface being a material with high thermal conductivity (thermal grease, phase-change material, thermally conductive pad, or thermal adhesive).

If an LED-based lamp is installed in an unventilated luminaire, or a luminaire is located in an environment that does not have free air circulation, the LED is likely to overheat, resulting in reduced life or early catastrophic failure. Thermal design is often based on an ambient temperature of 25 °C (77 °F). LEDs used in outdoor applications, such as traffic signals or in-pavement signal lights, and in climates where the temperature within the light fixture gets very high, could experience reduced output or even failure.

Since LED efficacy is higher at low temperatures, LED technology is well suited for supermarket freezer lighting. Because LEDs produce less waste heat than incandescent lamps, their use in freezers can save on refrigeration costs as well. However, they may be more susceptible to frost and snow buildup than incandescent lamps, so some LED lighting systems have been designed with an added heating circuit. Additionally, research has developed heat sink technologies that transfer heat produced within the junction to appropriate areas of the light fixture.

1.17 DC-DC CONVERTER:

DC-DC converters are electronic devices used whenever we want to change DC electrical power efficiently from one voltage level to another. They are needed because unlike AC, DC cannot simply be stepped up or down using a transformer. In many ways, a DC-DC converter is the equivalent of a transformer.

The dc-dc converters can be viewed as dc transformer that delivers a dc voltage or current at a different level than the input source. Electronic switching performs this dc transformation as in conventional transformers and not by electromagnetic means. The dc-dc converters find wide applications in regulated switch-mode dc power supplies and in dc motor drive applications.

DC-DC converters are non-linear in nature. The design of high performance control for them is a challenge for both the control engineering engineers and power electronics engineers. In general, a good control for dc-dc converter always ensures stability in arbitrary operating condition. Moreover, good response in terms of rejection of load variations, input voltage changes and even parameter uncertainties is also required for a typical control scheme.

After pioneer study of dc-dc converters, a great deal of efforts has been directed in developing the modeling and control techniques of various dc-dc converters. Classic linear approach relies on the state averaging techniques to obtain the state-space averaged equations. From the state-space averaged model, possible perturbations are introduced into the state variables around the operating point. On the basis of the equations, transfer functions of the open-loop plant can be obtained. A linear controller is easy to be designed with these necessary transfer functions based on the transfer function.

DC to DC converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits, each with its own voltage level requirement different than that supplied by the battery or an external supply (sometimes higher or lower than the supply voltage, and possibly even negative voltage). Additionally, the battery voltage declines as its stored power is drained. Switched DC to DC converters offer a method to increase voltage from a partially lowered battery voltage thereby saving space instead of using multiple batteries to accomplish the same thing.

DC-DC converters are electronic devices that are used whenever we want to change DC electrical power efficiently from one voltage level to another. In the previous chapter we mentioned the drawbacks of doing this with a linear regulator and presented the case for SMPS. Generically speaking the use of a switch or switches for the purpose of power conversion can be regarded as a SMPS. From now onwards whenever we mention DC-DC Converters we shall address them with respect to SMPS.

DC-DC Converters are needed because unlike AC, DC can't simply be stepped up or down using a transformer. In many ways, a DC-DC converter is the DC equivalent of a transformer. They essentially just change the input energy into a different impedance level. So whatever the output voltage level, the output power all comes from the input; there's no energy manufactured inside the converter. Quite the contrary, in fact some is inevitably used up by the converter circuitry and components, in doing their job.

1.18 Types of dc-dc converters

There are many different types of DC-DC converters, each of which tends to be more suitable for some type of applications than for others. For convenience they can be classified into various groups, however. For example some converters are only suitable for stepping down the voltage, while others are only suitable for stepping it up a third group can be used for either. In this we are going to main types of DC-DC converters.

Currently DC-DC converters can be divided into two types

- Non-isolated dc-dc converters
- Isolated dc-dc converters

1.18.1 Non-isolated DC-DC Converters

The non-isolated converter usually employs an inductor, and there is no dc voltage isolation between the input and the output. The vast majority of applications do not require dc isolation between its input and output voltages. The non-isolated dc-dc converter has a dc path between its input and output. Battery-based systems that don't use the ac power line represent a major application for non-isolated dc-dc converters. Point-of-load dc-dc converters that draw input power from an isolated dc-dc converter, such as a bus converter, represent another widely used non-isolated application.

Most of these dc-dc converter ICs use either an internal or external synchronous rectifier. Their only magnetic component is usually an output inductor and thus less susceptible to generating electromagnetic interference. For the same power and voltage levels, it usually has lower cost and fewer components while requiring less pc-board area than an isolated dc-dc converter. For lower voltages non-isolated buck converters can be used.

There are five main types of converter in this non-isolating group they are

- Buck Converter
- Boost Converter
- Buck-Boost Converter
- Cuk Converter
- Charge-pump Converter

The Buck converter is used for voltage step-down reduction, while the Boost converter is used for voltage step-up. The Buck-Boost and Cuk converters can be used for either step-down or step-up, but are essentially voltage polarity reversers or 'inverters'. The Charge-pump converter is used for either voltage step-up or voltage inversion, but only in relatively low power applications.

1.18.2 Isolated DC-DC Converters

For safety considerations, there must be isolation between an electronic system's ac input and dc output. Isolation requirements cover all systems operating from the ac power line, which can include followed by an isolated "brick" dc-dc converter, followed by a non-isolated point -of-load converter. Typical isolation voltages for ac-dc and dc-dc converter employs a transformer to provide dc isolation between the input and output voltage which eliminates the dc path between the two.

Isolated dc-dc converters use a switching transformer whose secondary is either diode-or synchronous-rectified to produce a dc output voltage using an inductor capacitor output filter. This configuration has the advantage of producing multiple output voltages by adding secondary transformer windings. For higher input voltages transformer isolated converters are more variable.

There are two main types of isolating inverter in common use they are

- Fly back converter
- Forward type converter

1.19 Step-Down (Buck) Converter

The buck converter circuit can be seen in Fig 1.10. Output waveforms of the converter can be seen in Fig.1.11. Here it has been assumed that the inductor current is always positive.

If switch is turned on, the diode becomes reverse biased(no current).When switch is turned off, the diode becomes forward biased and conducts, thus providing uninterrupted current in the inductor.

As per to Faraday's law, voltage time product of inductor in steady-state is zero. In case of the buck converter

$$(Vs-Vo)DT=-Vo(1-D)T$$

DC Voltage transfer function, Mv=Vo/Vs=D

Filter inductance at the boundary of DCM (discontinuous conduction mode) and CCM(continuous conduction mode) is given by

$$Lb=(1-D)R/2f$$

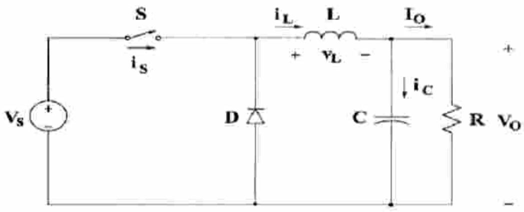


Fig.1.10: Buck Converter circuit

For Inductor value less than above, the converter goes to CCM mode In CCM mode the inductor current includes a dc current and a triangular ac component superimposed to it.Most of this ac component flows through the filter capacitor as ac current, which produces a voltage ripple in the output load voltage. To reduce the ripple voltage value below a required value called ripple voltage, the filter capacitance C should be more than the below mentioned value.

$$Cmin=(1-D)Vo/8VrLf^2$$

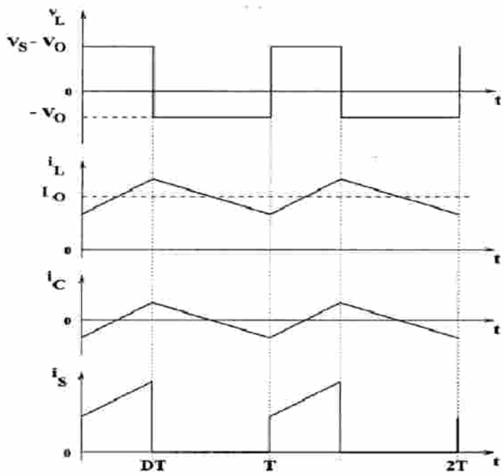


Fig.1.11: Output waveforms for the buck converter circuit

1.20 Step-Up (Boost) Converter

A boost converter (step-up converter)is a DC-to-DC power converter with an output voltage greater than its input voltage. It is a class of switched- mode power supply (SMPS) containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element, a capacitor, inductor, or the two in combination. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.

Fig.1.14 shows a PWM controlled boost converter (step up). It includes a dc input voltage, filter inductor, controlled switch, filter capacitor, diode and load resistance. When the switch is turned on, the diode is reverse biased and the current in the inductor increases linearly.If the switch is off, the energy is extracted from the inductor and transferred via the diode to the output RC circuit. According to Faraday's law, for inductor in boost mode

$$VsDT=(Vo-Vs)(1-D)T$$

DC Voltage transfer function Mv=Vo/Vs=1/(1-D)

Thus the output voltage is higher than the input voltage (boost operation) all the time. The boundary value of inductor is given by

$$Lb=(1-D)^2DR/2f$$

The converter works in CCM mode if inductor value is less than above value. The current in the output RC circuit is not continuous in this case. Thus, a large filter capacitor is needed here as compared to that of buck converters in order to limit the output voltage ripple.

When diode is reversed biased, the filter capacitor must discharge through the load resistor. The filter capacitance has the lowest value resulting in voltage ripple Vr which is given by

$$C_{min}=DV_o/V_rR_f$$

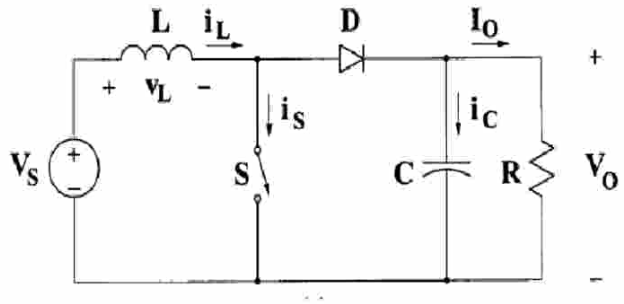


Fig.1.12: Boost Converter circuit

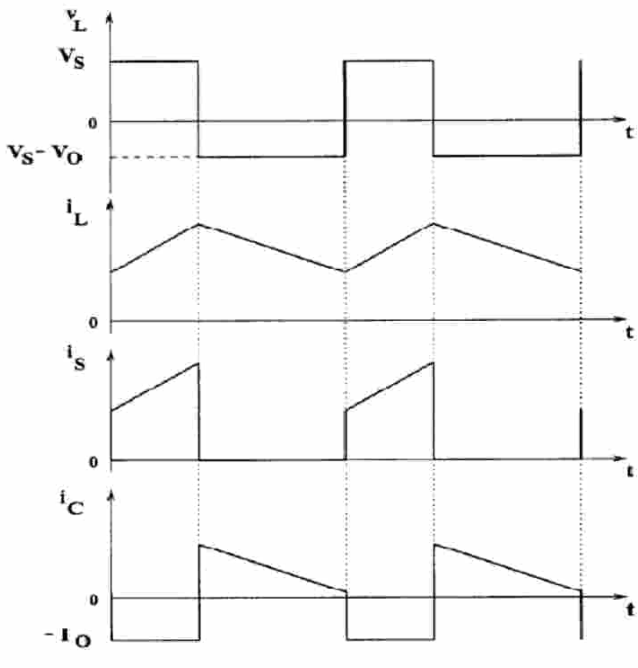


Fig.1.13: Output waveforms for the boost converter circuit

1.21 Non Isolated Buck Boost Converter

A non isolated or no transformer topology of a dc dc converter can be seen in Fig.1.16.If switch is turned on, current in inductor rises and the diode becomes reverse biased. If the switch is off, the diode becomes forward biased and conducts and inductor current flows. The waveforms for buck-boost converter are shown in Fig.1.17 The steady state zero voltage second product for the inductor is given by

$$V_sDT=-V_o(1-D)T$$

Transfer function for DC voltage, $M_v=V_o/V_s=-D/(1-D)$

Here with respect to the ground, the output voltage is negative. The converter works in buck mode when Duty Cycle of the PWM applied to switch is less than 50% and works in boost mode when Duty Cycle is greater than 50%.

The inductor value at the boundary in between the CCM and DCM is

$$L_b=(1-D)^2R/2f$$

Filter Capacitor for Ripple Voltage Vr is given by,

$$C_{min}=DV_o/V_rRf$$

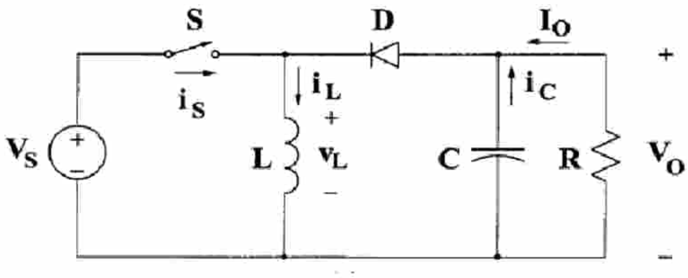


Fig.1.14: Buck Boost Converter circuit

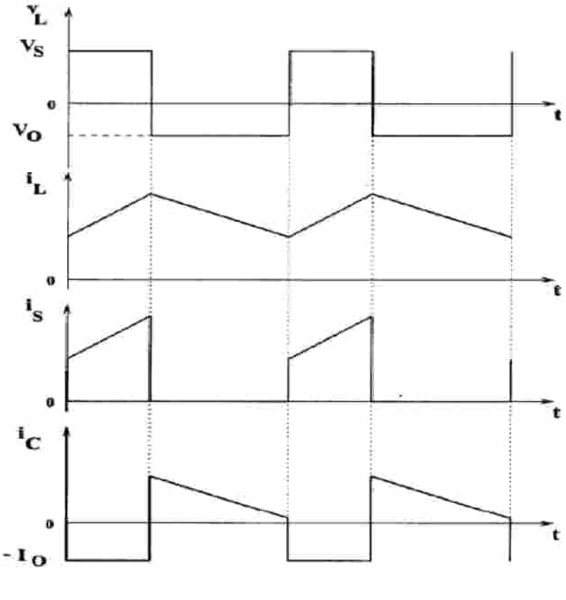


Fig.1.15: Output waveforms for the buck boost converter circuit

CHAPTER 2

LITERATURE SURVEY

2.1 Single Phase Power Factor Correction: A Survey [1]

Power supplies connected to ac mains introduce harmonic currents in the utility. It is very well known that these harmonic currents cause several problems such as voltage distortion, heating, noise and reduce the capability of the line to provide energy. This fact and the need to comply with "standards" or "recommendations" have forced to use power factor correction in power supplies.

Unity power factor and tight output voltage regulation are achieved with the very well known two stage approach, shown in Fig.2.1. Since the power stage is composed by two converters, size, cost and efficiency are penalized, mainly in low power applications. However, this is probably the best option for ac-dc converters due to the following reasons.

1) Sinusoidal line current guarantees the compliance of any Regulation.

2) It gives good performance under universal line voltage.

3) It offers many possibilities to implement both the isolation between line and load, and the hold-up time.

4) The penalty on the efficiency due to the double energy processing is partially compensated by the fact that the voltage on the storage capacitor is controlled. The fact of having a constant input voltage allows a good design of the second stage.

Although unity power factor is the ideal objective, it is not necessary for meeting the Regulations. For example, both IEEE519 and IEC 1000-3-2, allow the presence of harmonics in the line current [1]. This fact has lead to the publication of a great number of papers in the last years, proposing solutions that obtain some advantages over the two stage approach. Some of these circuits are practical but others are too complex to be worth changing.

The purpose of this paper is to classify and compare several converters proposed for the ac–dc conversion with power factor correction, having the two stage approach as a reference and focusing the study in the low power range.

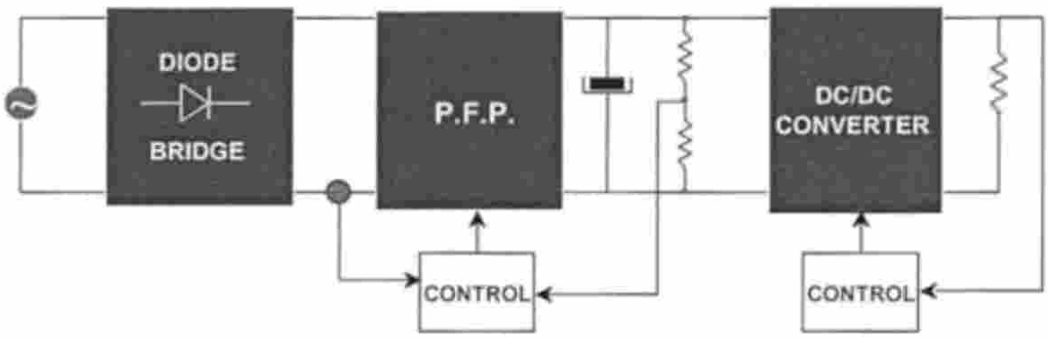


Fig.2.1. Two stage ac-dc PFC converter

2.2 A Review of Single-Phase Improved Power Quality AC–DC Converters [3]

Solid-state ac–dc conversion of electric power is widely used in adjustable-speed drives (ASDs), switch-mode power supplies (SMPSs), uninterrupted power supplies (UPSs), and utility interface with nonconventional energy sources such as solar PV, etc., battery energy storage systems (BESSs), in process technology such as electroplating, welding units, etc., battery charging for electric vehicles, and power supplies for telecommunication systems, measurement and test equipments [3]. Conventionally, ac–dc converters, which are also called rectifiers, are developed using diodes and thyristors to provide controlled and uncontrolled dc power with unidirectional and bidirectional power flow. They have the demerits of poor power quality in terms of injected current harmonics ,caused voltage distortion and poor power factor at input ac mains and slow varying rippled dc output at load end, low efficiency and large size of ac and dc filters. In light of their increased applications, a new breed of rectifiers has been developed using new solid state self commutating devices such as MOSFETs, insulated gate bipolar transistors (IGBTs),gate turn-off thyristors (GTO), etc., even some of which have either not been thought or not possible to be developed earlier using diodes and thyristors. Such pieces of equipment are generally known as converters, but specifically named as switch-mode rectifiers (SMRs), power-factor correctors (PFCs), pulse width-modulation (PWM) rectifiers, multilevel rectifiers, etc. Because of strict requirement of power quality at input ac mains several standards [3] have been developed and are being enforced on the consumers. Because of severity of power quality problems some other options such as passive filters, active filters (AFs), and hybrid filters along with conventional rectifiers, have been extensively developed especially in high power rating and already existing installations. However, these filters are quite costly, heavy, and bulky and have reasonable losses which reduce overall efficiency of the complete system. Even in some cases the rating of converter used in AF is almost close to the rating of the load. Under these observations, it is considered better option to include such converters as an inherent part of the system of ac–dc conversion, which provides reduced size, higher efficiency, and well controlled and regulated dc to provide comfortable and flexible operation of the system. Moreover, these new types of ac–dc converters are being included in the new text books and several comparative topologies are reported in recent publications. Therefore, it is considered atimely attempt to present a broad perspective on the status of ac–dc converters technology for the engineers working on them dealing with power quality issues.

2.3 Opportunities and Challenges in Very High Frequency Power Conversion [6]

The need for power electronics having greater compactness, better manufacturability, and higher performance motivates pursuit of dramatic increases in switching frequencies. Increases in switching frequency directly reduce the energy storage requirements of power converters, improving achievable transient performance and — in principle — enabling miniaturization and better integration of the passive components. Realizing these advantages, however, requires devices, passive components, and circuit designs that can operate efficiently at the necessary frequencies [6].

To achieve dramatic increases in switching frequency, it is typically necessary to mitigate frequency-dependent device loss mechanisms including switching loss and gating loss. Zero-voltage switching can be used to reduce capacitive discharge loss and voltage/current overlap losses at the switching transitions. Likewise, resonant gating can diminish losses resulting from charging and discharging device gates, provided that the gate time constants are short compared to the desired switching transition times. In this paper, we will focus on designs compatible with zero-voltage switching and resonant gating such that they can be scaled with good efficiency to very high switching frequencies.

2.4 A Technology Overview of the Power Chip Development Program [7]

Power electronics is a key technology for improving functionality and performance and reducing energy consumption in many kinds of systems. However, the size, cost, and performance constraints of conventional power electronics currently limit their applications and ability to realize this potential This is especially true in relatively high-voltage, low-power applications (e.g., voltages of up to a few hundred volts and power levels of up to tens of watts), such as offline power supplies, light-emitting diode (LED) drivers, converters and inverters for photovoltaic panels, and battery interface converters, among myriad other applications. Advances in miniaturization and integration of energy-conversion circuitry in this voltage and power range would have tremendous impact on many such applications and are the topic of the work described here [7].

2.5 Two-Stage Power Conversion Architecture Suitable for Wide Range Input Voltage [8]

The performance and size of power converters are important for many applications. Achieving small size and high performance is particularly challenging in high-voltage and low-power applications (e.g., voltages up to a few hundred volts and powers up to several tens of watts). In this paper, we explore improved design in this voltage and power range, with a focus on LED driver circuits as an important application in this space. Light emitting diode devices promise unprecedented reductions in energy consumption in comparison to incandescent and fluorescent lights, but come with an as-yet unmet demand for high power density, high efficiency, and high-power-factor LED driver circuitry [8].

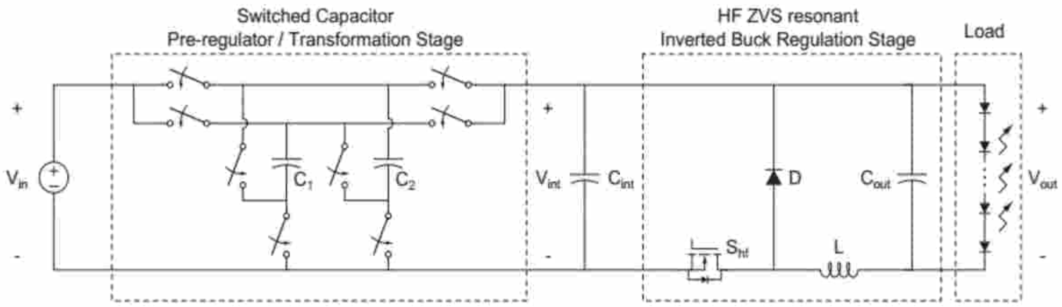


Fig.2.2. A merged two-stage conversion architecture includes a switched capacitor first stage that provides voltage pre-regulation and transformation, and a high-frequency magnetic stage that provides fine regulation of the output. Converters having this architecture may be realized for operation either from wide-range (e.g., 25–200 V) dc voltage or from a rectified 120 Vrms ac voltage.

Recently published academic designs are harder to fully evaluate and compare because of large variation on LED output configurations (e.g., separate into multiple LED loads or diverse LED voltage specifications),but appear to provide generally similar performance with moderate improvements in individual aspects [8]. Overall, the volume of the converters was uniformly dominated by magnetic components, and in each case the driver circuit represented a major contribution to the LED system size. These examinations indicate that power electronics continues to be a significant limitation in solid-state lighting and that there is a need for major improvements in miniaturization and performance in this voltage and power range.

Miniaturization of power electronics requires reductions in magnetic components, which can be realized through increases in the switching frequency. Recent work has shown the potential of high-frequency (or very-high-frequency) operation in systems operating at tens of watts and tens of volts, and there has been preliminary work at hundreds of watts and volts. Other switched-capacitor (SC)based design efforts has shown the advantages of merged operation of a switched capacitor (SC) transformation circuit and a high-frequency inductor based regulation circuit, but has only been studied for low-voltage and low power levels (i.e., under 2 watts and ten volts). Thus, achieving the necessary frequency increases at high voltages and modest powers (e.g., at up to hundreds of volts and tens of watts) and realizing the desired miniaturization and performance still remains a major challenge.

CHAPTER 3

PFC WITH INDUCTOR LEAKAGE CURRENT

3.1 INTRODUCTION

THE widespread use of electronic devices from single-phase ac supplies necessitates the increasing use of power factor corrected (PFC) power supplies in many applications including electronic equipment, computer servers, and consumer products. PFC power supplies provide low total harmonic distortion (THD) in the current drawn from the line and this is an increasingly important requirement. Power factor correction techniques have been researched widely in the literature [1], [2] and an active PFC using high frequency switching techniques [3] are now commonly used.

The overarching principle involves controlling the input current drawn from the mains input to achieve the required current shape for low THD and high power factor. The power supply must provide a regulated dc output voltage and for many applications, galvanic isolation is also required. The basic boost or step-up converter [4] forms the core of most architectures as it has an input inductor that allows input current control to be readily achieved. The well-known fly back converter can be derived from the buck-boost converter, but with a transformer for output voltage isolation [4].

Traditionally for PFC supplies, fly back converters have been used for lower power levels (≤100 W). For higher power levels(≥500 W), a separate boost converter for PFC and separate dc to dc converter with transformer isolation for output dc voltage regulation is used.

3.1.1. Brief Review of Published Isolated PFC Converters

For lower power levels, fly back type architectures, often using a single switching element can provide PFC functionality, and use an output bulk capacitor for energy storage. A range of fly back-based PFC power supplies have been developed and are described in the literature. Yan et al. [5] describe a 60 W fly back PFC supply to achieve IEC61000 THD requirements. A10–30 W LED lighting supply is described in [6] and another60 W supply described in [7]. A 72 W fly back design is shown in [8] and a 100 W fly back PFC design is described in [9].

In these architectures, the fly back transformer initially stores energy from the input source and then releases it to the output bulk capacitor. The transformer thus provides the PFC input current control and galvanic isolation. However, the need to store all the energy in the fly back transformer, the unidirectional core excitation [4], high voltage stresses in the switching device, and difficulties with the transformer leakage inductance, limit the usage of such power supplies to lower power levels.

At higher power levels, two-stage supplies with a separate boost PFC stage and isolated dc to dc stage are widespread. They typically consist of a power factor correction stage, based around a boost converter with large bulk storage capacitor to control the input line current, followed by an inverter driving a high-frequency isolation transformer and finally an output stage with at least some filtering components. Such designs work well, especially when there is a need to supply a number of different voltage rails and a long holdup time is required.

Most of these architectures use one (or more) boost inductors in the active PFC stage [3], and such inductors need to handle the full supply power levels resulting in a significantly sized component. The design of such front end PFC converters is a trade offs between boost inductor size and high-frequency losses[10]. Also, cascading multiple power stages leads to reduced overall efficiencies. The front end boost PFC stage typically has . high inrush current on start-up, or needs additional components to limit the inrush current [11], [12].

Therefore, there has been considerable research published on other architectures that attempt to eliminate or mitigate some of the disadvantages of both the fly back and two-stage PFC ac/dc power supplies.

A quasi-active PFC converter in [14] delivers 100 W using a combined PFC cell with two transformers, one operating as a fly back converter and another operating as a forward converter.

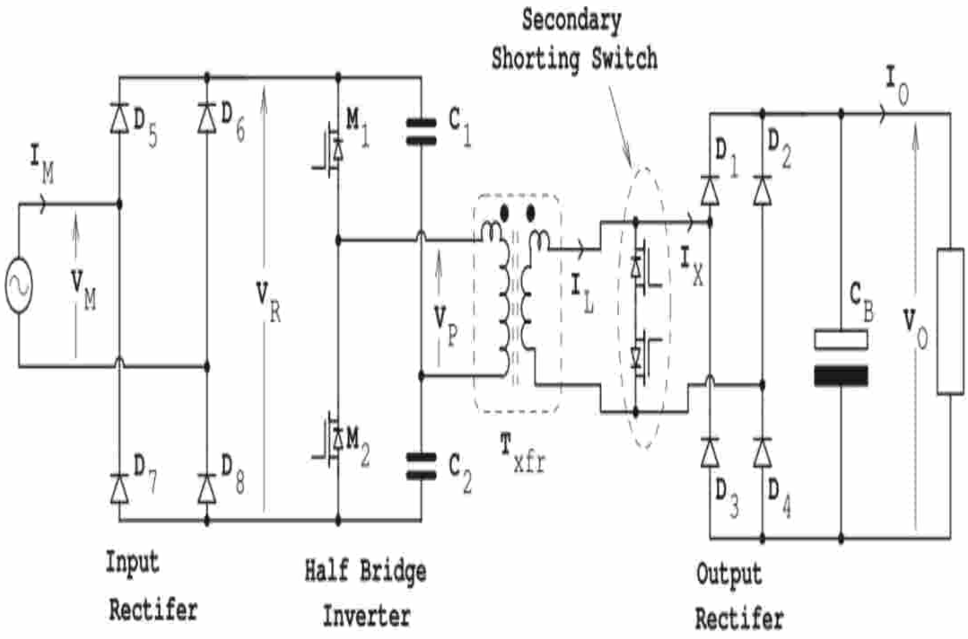


Fig. 1.Circuit diagram of the proposed power supply architecture.

This allows parallel power transfer and avoids lossy snubber networks, all with a single controlled switch, but at the expense of a number of magnetic cores and inductor elements.

A combination of a separate boost stage cascaded with a lossless snubber network is presented in [15], delivering 96 W. Again only a single controlled switch is used, but a number of separate magnetic cores and inductor elements are required. For higher power levels, modified two-stage structures have been proposed. An architecture to improve on the existing two stage PFC is described in [10], which moves the boost inductor and bulk capacitor to the isolated side of a resonant LLC converter with the effect of improving the voltage stresses on the switching devices and providing an output power of 250 W.

A two-stage structure proposed in [16] uses a boost converter PFC with a resonant LLC converter. The design uses transformer coupled power transfer from the boost inductor to the output. Using two transformers (one providing the boost inductor functionality), a power output of 480 W is provided.

3.1.2. Proposed PFC Architecture

In this paper, an active PFC power supply is described, whereby the leakage inductance of the high-frequency isolation transformer is used to provide the functionality of the boost inductor. Minimization of the leakage inductance in high frequency isolation transformers is normally desirable in most dc to dc converters, although resonant and soft switching architectures do use a controlled amount of leakage inductance [17]for the purpose of reducing switching losses.

The use of a controlled amount of leakage inductance is proposed in this paper to eliminate the need for two separate magnetic components in the two-stage PFC converter and instead uses one magnetic component to achieve both the power factor correction and galvanic isolation. Inrush current on start up can also be controlled by implementing a soft start strategy whereby the large bulk capacitor is initially charged up in a controlled manner.

Bidirectional core excitation is used, with part of the energy transferred via transformer action, and part stored in the transformer leakage inductance. The described architecture provides a useful technique at power levels above those suitable for single-stage flyback type converters.

The technique lends itself to the adoption of wide band gap semiconductor devices [18] with hard switching [19], [20]. Typically applications might include LED lighting, electronic equipment, server power supplies, and on-board chargers for electric vehicles.

3.2 Proposed Architecture

The circuit diagram of the proposed power supply is shown in Fig. 3.1. A conventional four diode full wave rectifier rectifies the input ac source voltage producing a voltage VR. This voltage is inverted to the high frequency fs with a half-bridge inverter before being applied to a high-frequency transformer Txfr. The half-bridge inverter consists of the two switches M1 and M2operated out of phase with a 50% duty cycle at the switching frequency fs and the capacitive divider formed by C1 and C2.

The capacitors C1 and C2 prevent dc current flowing through the transformer primary and causing saturation problems. The values of C1 and C2 are chosen sufficiently small, such that at the mains frequency fAC and low power level, they allow the rectifier output voltage VR to follow the input mains wave form envelope. However, at the switching frequency, their values are sufficiently large to act as fixed voltage sources and not resonate with the transformer inductances or load. For the circuit of Fig. 1. The mains input voltage is VM (t) $=\sqrt{2}$VAC sin(2πfACt), with VAC being the rms input voltage and VR(t) being the input voltage fully rectified. The transformer primary voltage VP (t) switches at the high frequency rate fs, but with an amplitude of half VR(t), due to the half-bridge configuration.

The symbol for the transformer in Fig. 3.1 is drawn to emphasize that the transformer leakage inductance is used in the circuit rather than the usual case whereby leakage inductance is minimized as much as possible. The key to the operation of the circuit is the bidirectional secondary shorting switch shown in Fig. 3.1 [21].

3.3 THEORY OF OPERATION

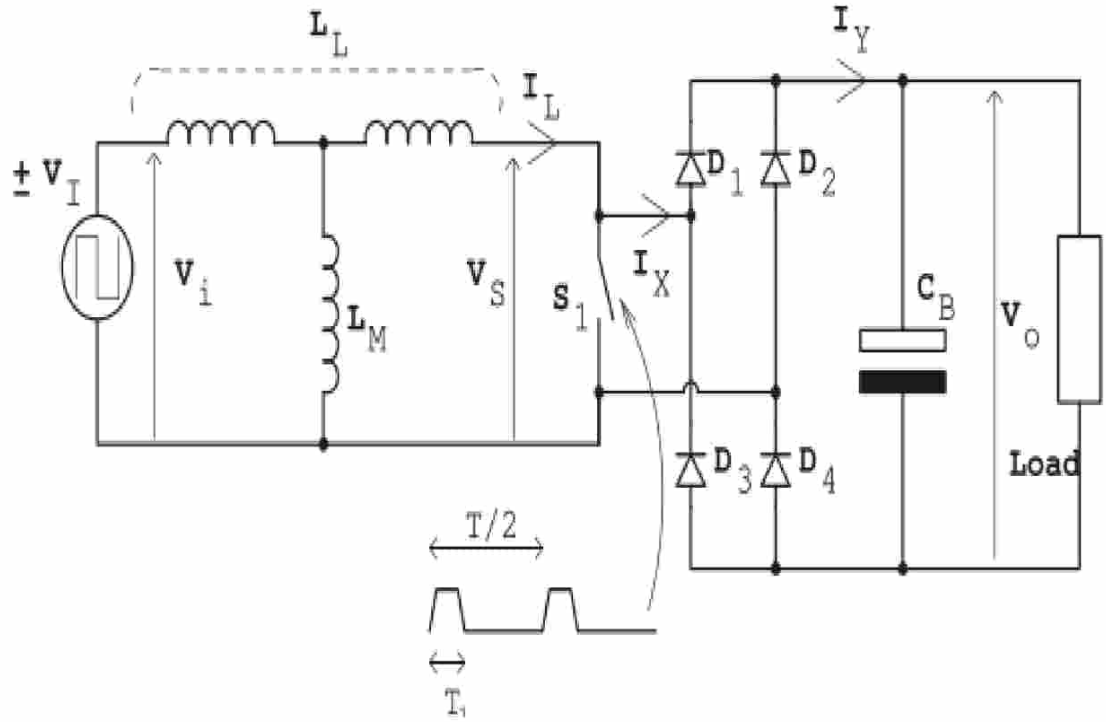


Fig. 3.2.Simplified circuit model for the proposed power supply.

Fig. 3.2 shows a simplified circuit model for the proposed power supply. Assuming the switching frequency of the converter is very high compared to the ac source frequency, the input to the transformer can be considered to be essentially a 50% duty cycle square wave with period T and peak amplitude ±VI . The model in Fig. 3.2 is referenced to the secondary side of the transformer and the voltage amplitude into the transformer model is the primary voltage VP (t) multiplied by the turns ratio of the transformer, or at time t = kT .

$$V_I[kT] = \left| V_P(kT)\frac{N_s}{N_p} \right| \tag{3.1}$$

The operation of the circuit is based on the assumption that the transformer magnetizing inductance LM has little effect on the operation of the circuit other than to add a magnetizing current to the input source. Simulations show that magnetizing currents significantly less (a factor of 1 5 × or less), than the currents being transferred, have little impact on the circuit overall functionality. The total leakage inductance of the transformer is denoted as LL and the current flowing out of the transformer secondary winding is denoted as IL(t).

The operation of the system is essentially that of a step up or boost converter and is based around the timing of shorting switch S1 in Fig. 3.2. At the beginning of a switching cycle, the input voltage switches to +VI (dropping the [kT] for notation for clarity) and simultaneously the shorting switch S1 is turned ON. The current IL(t) in the leakage inductance LL rises linearly while the switch S1 is ON. When the switch S1 is turned OFF, the current in the leakage inductance is forced through the rectifier diode bridge formed by D1, D2, D3, and D4, and into the capacitor CB and system load, and the current in the leakage inductance falls. After a period of T2 , the input voltage changes sign to −VI and the same operation occurs, except for a change in the sign of the inductor current. Two distinct operation modes of the circuit can be identified depending on whether the leakage inductance current starts at zero and returns to zero before timeT2, denoted as the discontinuous conduction mode (DCM), or when the leakage inductance current starts the cycle with a nonzero (negative) value, retains a nonzero (positive) value at time T2 and returns to a nonzero (negative) value at the end of the cycle (time T), denoted as the continuous conduction mode(CCM).

To achieve unity power factor, the circuit needs to be operated in such a manner as to control the input current drawn from the supply. The two operating modes are now discussed in detail to relate the input current drawn to the timing period T1.

3.3.1 Discontinuous Conduction Mode

Fig. 3.3(a) shows the input voltage Vi(t), the secondary voltage VS (t), the leakage inductor current IL(t), and the current into and out of the output rectifier IX (t) and IY (t) as well as the switch current IS 1(t), for the circuit operating in DCM. With the shorting switch S1 closed, the leakage inductor current IL(t)rises from zero to the value +IP over the set period T1, thus

$$I_P = V_I T_1 / L_L . \tag{3.2}$$

When the shorting switch S1 opens, the inductor current falls back to zero over a period T2 with the relationship

$$I_P = (V_O - V_I)T_2/L_L. \tag{3.3}$$

The sum of the periods must be less than the half period T/2to ensure operation in the DCM or

$$T_1 + T_2 \leq \frac{T}{2}. \tag{3.4}$$

The average input current to the transformer model (ignoring the magnetizing inductance) over the period T/2 can then be calculated as follows:

$$I_L^* = \frac{1}{2} I_P \frac{T_1 + T_2}{\frac{T}{2}} \tag{3.5}$$

And combining with (2) and (3), the average input current is

$$I_L^* = \frac{T_1^2}{TL_L}\left(\frac{V_I V_O}{V_O - V_I}\right). \tag{3.6}$$

The actual input current from the ac source is a scaled version of this current and is

$$I_M = \frac{1}{2}\frac{N_s}{N_p} I_L^* \tag{3.7}$$

With any contribution from the magnetizing inductance averaging to zero over each T period.

It is apparent by considering (1) and (7), that achieving unity power factor in the input source is equivalent to controlling the current value I∗L to be directly proportional to VI . Denoting the constant of proportionality as GM , or IL∗ = GM VI , then substituting in (6) and rearranging yields the equation

$$T_1 = \sqrt{G_M T L_L \left(\frac{V_O - V_I}{V_O}\right)}. \tag{3.8}$$

The equation shows that given a constant of proportionality as GM , the required time period T1 can be calculated by knowledge of the system parameters LL and T , measurement of the output voltage VO and calculating VI by measurement of the rectified input source voltage and scaling by a factor of 1 2 NN sp

3.3.2 Continuous Conduction Mode

Fig. 3.3(b) shows the input voltage Vi(t), the secondary voltage VS (t), the leakage inductor current IL(t), and the current into and out of the output rectifier IX (t) and IY (t) as well as the switch current IS 1(t), for the circuit operating in CCM. With the shorting switch S1 closed, the leakage inductor current IL(t)rises from the value −IE to the value +IP over the set periodT1, thus

$$I_P + I_E = V_I T_1 / L_L . \tag{3.9}$$

When the shorting switch S1 opens, the inductor current falls back to +IE over a period T2 = T/2 − T1 with the relationship

$$I_P - I_E = (V_O - V_I) T_2 / L_L . \tag{3.10}$$

The average input current to the transformer model (ignoring the magnetizing inductance) over the period T/2 can then be calculated as follows:

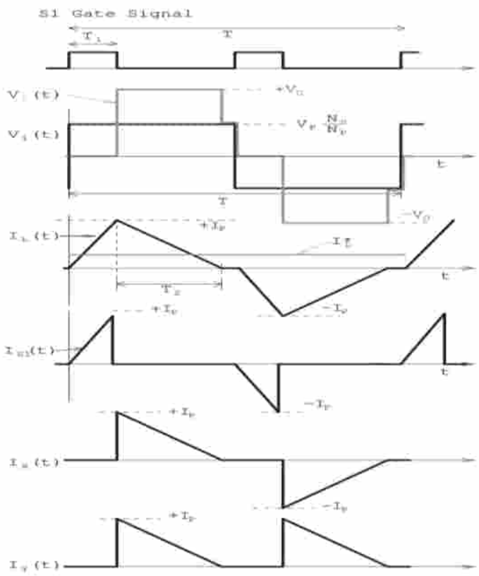
$$I_L^* = \frac{\frac{1}{2}(I_P - I_E)T_1 + \frac{1}{2}(I_P + I_E)T_2}{\frac{T}{2}} \tag{3.11}$$

And combining with (9) and (10), the average input current can be shown as

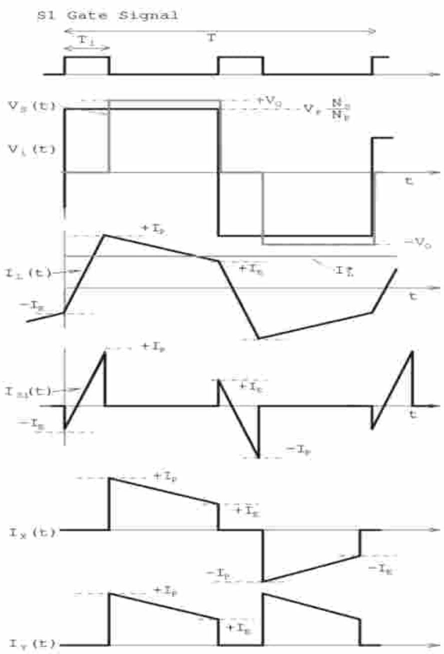
$$I_L^* = \left(T_1 \frac{T}{2} - T_1^2 \right) \frac{V_O}{T L_L} . \tag{3.12}$$

With I∗L = GM VI , then substituting in (12) and rearranging yields the equation

$$T_1 = \frac{T}{4}\left(1 - \sqrt{1 - \frac{16 G_M L_L V_I}{T V_O}}\right). \tag{3.13}$$



(a) Discontinuous conduction mode.



(b) Continuous conduction mode.

Fig. 3.3 Idealized waveforms. (a) Discontinuous conduction mode. (b) Continuous conduction mode.

3.3.3 Power Handling Capability

The power capability of converter is determined by the maximum value of GM supported, which is limited by the requirement for (13) to result in a real number. This requires the argument under the square root to be non-negative, and hence

$$\frac{16G_{M\max}L_L V_I}{TV_O} \leq 1$$

$$P_{\max} = \tfrac{1}{2}G_{M\max}V_{I\max}^2 \text{ of}$$

$$P_{\max} \leq \frac{V_{\text{AC}}\frac{N_s}{N_p}V_O}{32\sqrt{2}f_s L_L}. \tag{3.14}$$

This equation can be used as a basis for converter design as demonstrated by the prototype example in Section V. The maximum peak current in the leakage inductor during the CCM can be calculated as follows:

$$I_{P\max} = \frac{V_O T}{8L_L} \tag{3.15}$$

And the transformer must be designed to handle this peak current without saturation.

3.4. POWER SUPPLY CONTROL

The control objective for the power supply is to provide a constant output voltage and unity input power factor. This requires measurement of the output voltage and adjustment of the input current through the GM factor defined in Section III-A. However, calculating the time parameter T1 in Section III-A and III-B also requires knowledge of the parameter LL, the leakage

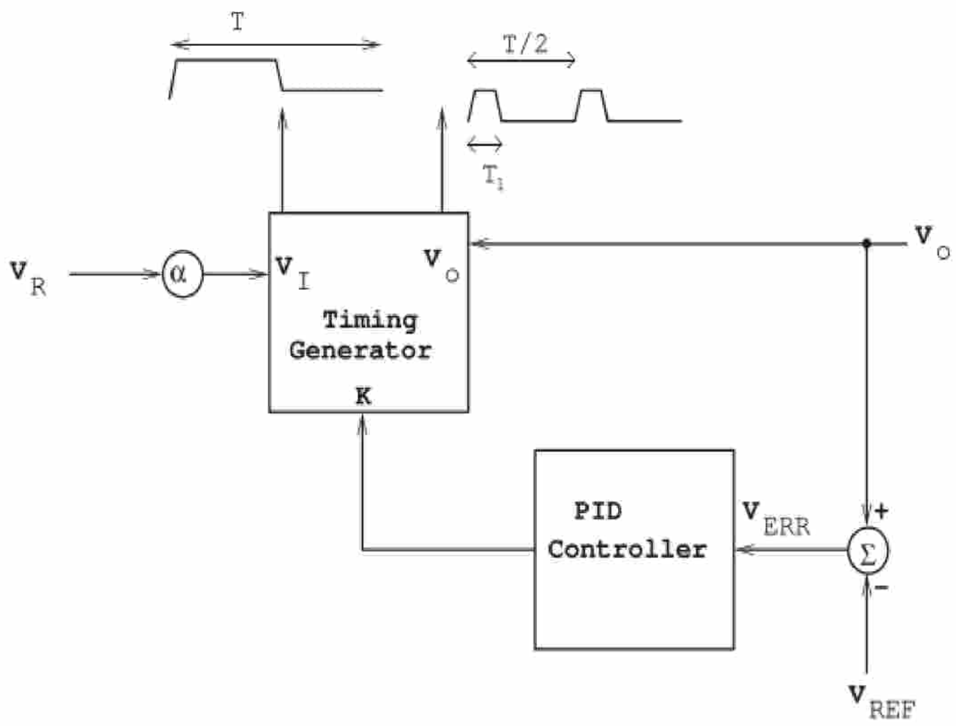


Fig. 3.4 Feedback control for the power supply.

Inductance, which may not be accurately known. Therefore anew control parameter K is defined as follows:

$$K = \frac{G_M L_L}{T} \tag{3.16}$$

And K is used for control rather than GM . Substituting into (8)and (13) results in the required calculations for DCM as

$$T_1 = T\sqrt{K\left(\frac{V_O - V_I}{V_O}\right)} \tag{3.17}$$

And CCM as

$$T_1 = \frac{T}{4}\left(1 - \sqrt{1 - \frac{16KV_I}{V_O}}\right). \tag{3.18}$$

It can further be shown that the boundary condition of (4) canbe written as follows:

$$V_O(1 - 4K) \geq V_I. \tag{3.19}$$

The feedback loop of Fig. 3.4 can then be used to control the power supply. In Fig. 3.4, the power supply output voltage VO is measured and compared to a reference voltage VREF to produce an output voltage error VERR = VO − VREF. This error voltage is used by a PID controller with dynamics below the input ac frequency fAC to adjust the variable K to control the output voltage VO .

The variable K, is used in the timing generator to generate the inverter timing and the secondary shorting period T1 twice per sample period T. The timing generator uses the measured power supply output voltage VO , and a scaled version of the input rectifier voltage VR as VI = 1 2 NN sp VR. Using K, VI , and VO , the timing generator evaluates the condition in (3.19) and if the result is true, the DCM is selected and (3.17) is used to calculate the time period T1. Otherwise, the CCM is selected and (3.18) is used to calculate the time period T1.

CHAPTER 4

SOFT SWITCHING CONTROL SATRATEGY FOR PFC WITH BOOST CONVERTER

4.1 Introduction

The main function of power electronics devices is to condition electrical power taken from a power source to the form suitable for user loads. Hence, power electronics converters serve as interface between user loads and the source. The converters are classified into acac, ac-dc, dc-ac and dc-dc converters. The classification is based on nature of the input source and output load. For instance, a dc-dc converter is used to connect a dc input source to a dc load.

Power electronic converter circuits are generally composed of energy storing components such as capacitors and inductors, control devices and semiconductor elements like diodes and transistors. The semiconductor devices such as Bipolar Junctions Transistors (BJTs), Insulated Gate Bipolar Transistors (IGBTs) and Metal Oxide Silicon Field Effect Transistors (MOSFETs) are used as switches (Mousavi, 2013).

DC-DC converter, converts DC voltage from one level to another. The most common topologies are the buck, boost, buck-boost and Sepic converters. A buck converter steps down a voltage, producing a voltage lower than the input voltage. On the hand, boost converter steps up a voltage, producing a voltage higher than the input voltage. A buck-boost converter steps a voltage up or down, producing a voltage equal to or higher or lower than the input voltage. A Sepic converter is used for similar applications as the buck-boost, but provides some advantages in some applications (Maker.io, 2016).

Many electronic equipment such as, servo-motor drives, computer periphery power supplies, high-intensity-discharge (HID) lamps for automobile headlamps X-ray power generators, the dc back-up energy system for an uninterruptible power supply (UPS), and fuel cells required dc–dc converters with a high step-up voltage ratio (Zhao & Lee, 2003).

4.2 Hard Switching

Energy losses are in evitable in real semiconductor devices and therefore the switches used in converters produces power losses. These losses include switching losses and conduction losses. In practical converters, during switching (turn-off and turn-on) the switch current and voltage do not go to zero immediately. The current through the switch and the voltage become high simultaneously for some time within the switching process (turn-off and turn-on). This result in a power loss which is equivalent to overlapping area of the switch current and voltage waveforms at the time of turn-off or turn-on. Switching the power electronic converters with these power losses is referred to as “hard switching”. Fig. 4.1 demonstrate the graph of switch gate, voltage and current within a switching cycle.

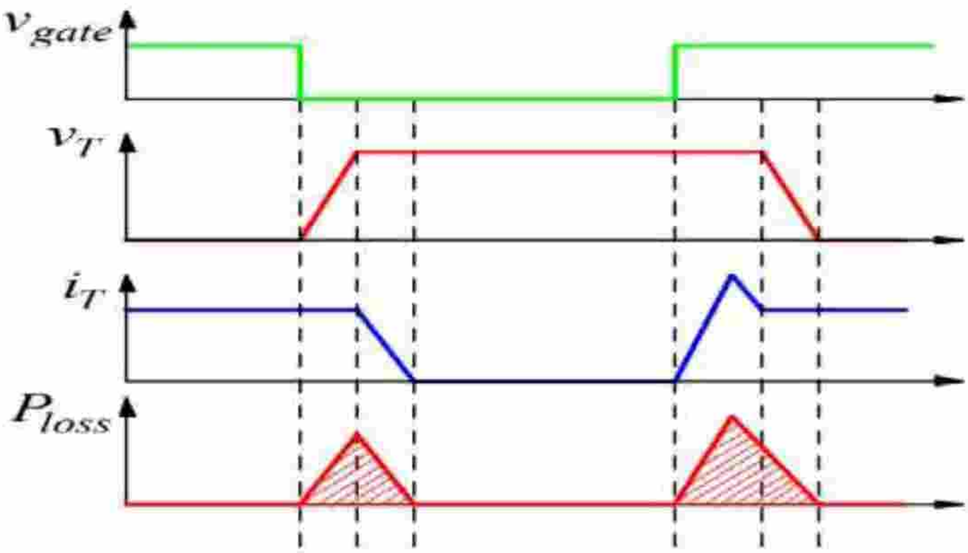


Figure 4.1: Loss of Power during hard switching

4.3 Soft-switching

By using soft switching techniques, the issues of switching losses due to hard-switching in classical converter operation can be solved. In power electronics soft-switching is considered as set of techniques by which switching processes are controlled and made to be gradual so that either the current or voltage are zero during the switching. This means that switching transitions take place when the device current or voltage is zero in soft- switching There are two types of soft-switching: zero current switching (ZCS) and zero voltage switching (ZVS). In zero voltage switching, the switch voltage is forced to zero before applying the gate voltage during turn-on. Whereas, in zero current switching, the switch current is forced to zero during turn-off before removing the gate voltage. By proper use of soft-switching, switching losses, switch stress, and electromagnetic interference (EMI) are significantly reduced (Al-Saffar, Ismail, & Sabzali, 2013). Electromagnetic interference is decreased by soft-switching since the sudden switching transitions (from off-to-on and onto-off) are avoided, the transitions are made gradually. On the other hand, switching losses and stress are decreased because the power loss during the switching transition is proportional to the overlap between the current passing through the switch and the voltage across it. In soft-switching, transitions take place when the device current or voltage is zero, hence, the overlap between current and voltage is eliminated and therefore, no switching losses.

4.3.1 Zero-current Switching

Zero current switching (ZCS) can be explain by using the waveforms in figure 4.2. MOSFET switch is used, however the same explanation holds for IGBTs. As can be seen from the figure, an inductor is connected in series with the switching device in order to make the drain-voltage zero before the device current rises at turn on. As the result the switching loss is kept minimum at turn on. Furthermore, at the time of turn off, voltage across the drain/source is reversed and brought to zero using additional circuitry (such as resonant circuit). At the time of current reversal, the switch gate is turn-off in order to make sure that the device is off at the time the voltage is re-applied. In this way the switch off losses are eliminated [1,2]. For practical applications:

To avoid re-triggering in case of GTO and minimize electro-magnetic interference (EMI), the rate at which the voltage(dv ⁄dt)is applied has to be limited. ii. The time interval for which the diode current is reversed should be enough to permit the recombination of the device charges is case of BJTs.

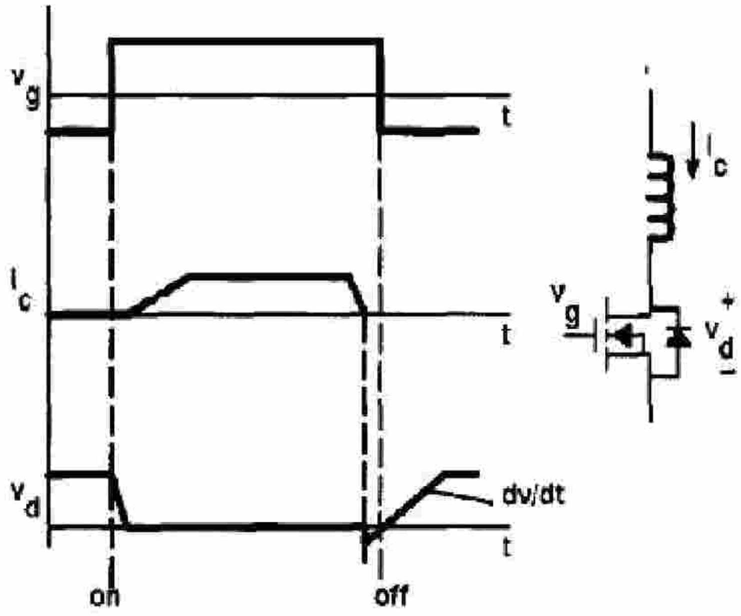


Figure 4.2: Zero-current Switching

4.3.2 Zero-voltage Switching (ZVS)

To explain the zero-voltage-switching (ZVS) condition we use figure 4.3. As can be seen from the figure, a capacitor is used in parallel with the switching device in order to make sure the turn on losses are kept minimum. Both ZVS and ZCS may be used in applications with low switching frequency and high- power. However, for applications where the switching rate is high ZVS based converters are preferred. Furthermore, ZVS based dc/dc converters are easier to control compared to ZCS based. Classical dc/dc converter topologies can be operated with ZVS by incorporating very few elements. The selection of the soft switching technique (ZVS or ZCS) is done by considering the type of switch in the circuit, required size, switching-frequency and complexity of the control technique.

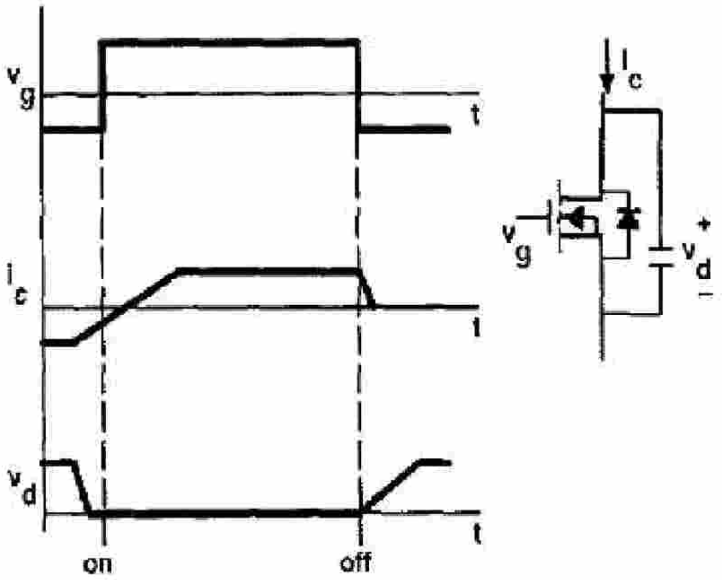


Figure 4.3: Zero-voltage switching

4.4 Power Factor Correction

To address the challenges of both phase delay as well as current distortion, a power factor correction stage can be introduced between the diode bridge and the DC/DC converter, as shown in Figure 4.4. It is possible to reduce this harmonic current content due to the relationship between power factor and harmonic distortion.

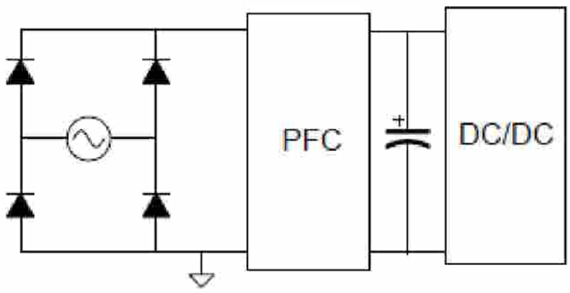


Figure 4.4– Introduction of power factor correction stage.

This PFC function can be achieved through either passive or active means. Passive PFC can be implemented by placing inductance inbetween the diode bridge and the input capacitor to the isolated DC/DC stage. While this approach has minimal complexity and low cost, its effectiveness is limited and can be difficult to maintain good power factor correction performance over extended operating ranges, such as a universal AC input from 85 VRMS to 265 VRMS. An active power factor correction approach entails the use of a full power converter stage in between the diode bridge and the isolated DC/DC converter. While this approach is more complex, an active PFC offers superior power factor performance with little degradation over a wide operating range. While numerous converter topologies have been utilized over the years, each with their own advantages and disadvantages, the most common topology choice in use today for active power factor correction is the boost converter. One of the primary reasons the boost converter has become the dominant PFC topology in use today is because the boost inductor is on the input side of the converter. This is advantageous because it means the input current does not experience high dI/dt, making the topology better equipped to achieve low input current distortion. The current paths of the boost converter are show in Figure 4.5, while Figure 4.6 shows noteworthy waveforms in the boost power stage. voltage is applied across the inductor and current in the inductor increases at a linear rate equal to VIN/L. During the MOSFET on-time, charge that is stored in the output capacitance supplies current to the load.

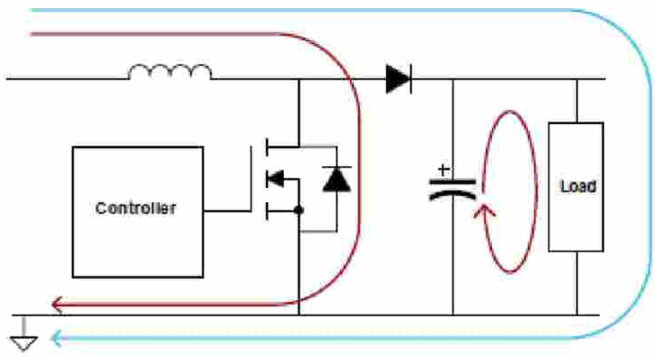


Figure 4.5 – Boost converter power paths.

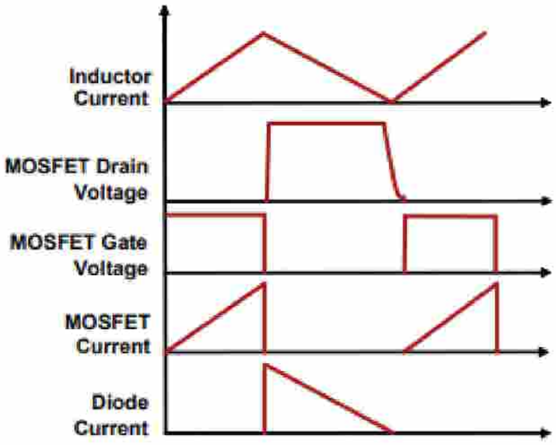


Figure 4.6 – Boost converter waveforms.

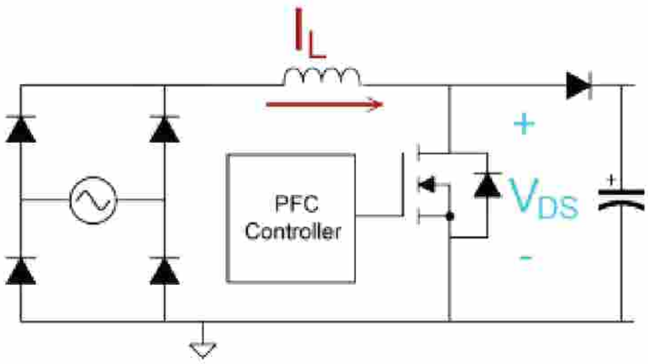


Figure 4.7 – Simplified boost PFC schematic.

Figure 4.7 shows the simplified boost PFC converter while Figure 4.8 illustrates what the cycle by cycle behavior looks like over a narrow time span relative to the line frequency.

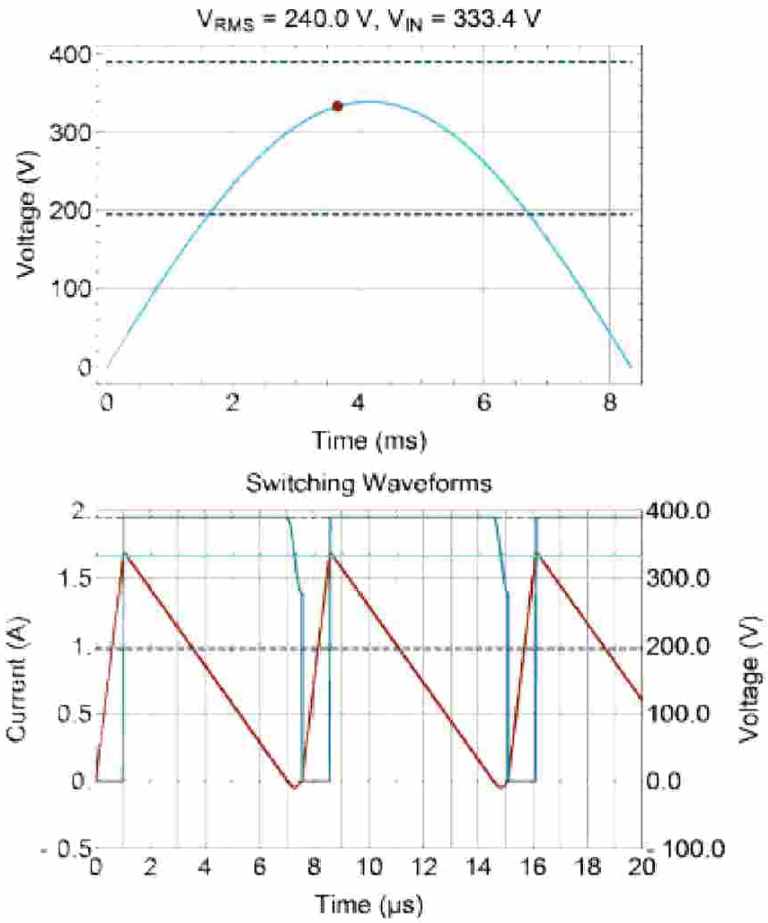


Figure 4.8 – CrCM near peak of AC line.

The top plot of Figure 4.8 shows the instantaneous variation of the line voltage over one half of the AC line cycle. The bottom plot shows the inductor current (red), the switch node voltage (solid blue), input voltage (solid blue flat line), output voltage (top dashed line) and 1/2 the output voltage (lower dashed line).

In this case there are a few things worth noting. First, the drain voltage of the MOSFET does not reach zero before the switch turns on. Second, the switch did not turn on the first time the inductor current reaches 0 A. Instead, the MOSFET turned on the second time after the inductor current momentarily becomes negative. While the inductor current is negative, notice that the MOSFET drain voltage begins to “ring” downward. By turning on the MOSFET at the second zero crossing, this has the advantage of turning on the MOSFET when the drain voltage is at its lowest point, minimizing turn-on loss. It can be shown that the conditions under which the drain will actually ring all the way to 0 V are as shown in Equation

$$V_{IN} < \frac{1}{2} V_{OUT}$$

Any time this inequality is met, zero voltage switching can result if turn-on is properly timed. If the inequality is not met, the MOSFET is valley switched. As the inductor current drops to 0 A before the MOSFET is turned back on, the boost diode is zero current switched and will not experience reverse recovery, enabling the use of lower cost ultra-fast diodes. For CrCM, the inductor current ripple is always 200% of the average inductor current. For higher output power designs, this large ripple current would be challenging to design due to the high peak currents in the power stage. Near the AC line zero crossing, the inductor does not have sufficient energy to turn on the output diode, resulting in no useful energy transfer. In addition, the cycle by cycle average current in the inductor is zero resulting in no current flow at the AC line zero crossings. This will result in significant distortion from the idealized equations. While it is true the CrCM PFC does need to turn on when the inductor current hits zero, there are some practical reasons why this might not be ideal. As already discussed, there is a benefit to waiting for the valley of the drain voltage resonant ring to achieve a slightly softer switching event and minimize switching loss. Figure 14 illustrates three possible times to initiate the MOSFET switch turn-on.

CHAPTER 5

MATLAB AND SIMULATION RESULTS

5.1 INTRODUCTION TO MATLAB:

The name MATLAB stands for MATrix LABoratory. MATLAB was written originally to provide easy access to matrix software developed by the LINPACK (linear system package) and EISPACK (Eigen system package) projects.

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming environment. Furthermore, MATLAB is a modern programming language environment: it has sophisticated data structures, contains built-in editing and debugging tools, and supports object-oriented programming. These factors make MATLAB an excellent tool for teaching and research.

MATLAB has many advantages compared to conventional computer languages (e.g., C, FORTRAN) for solving technical problems. MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. The software package has been commercially available since 1984 and is now considered as a standard tool at most universities and industries worldwide.

It has powerful built-in routines that enable a very wide variety of computations. It also has easy to use graphics commands that make the visualization of results immediately available. Specific applications are collected in packages referred to as toolbox. There are toolboxes for signal processing, symbolic computation, control theory, simulation, optimization, and several other fields of applied science and engineering.

5.2 SIMULATION RESULTS:

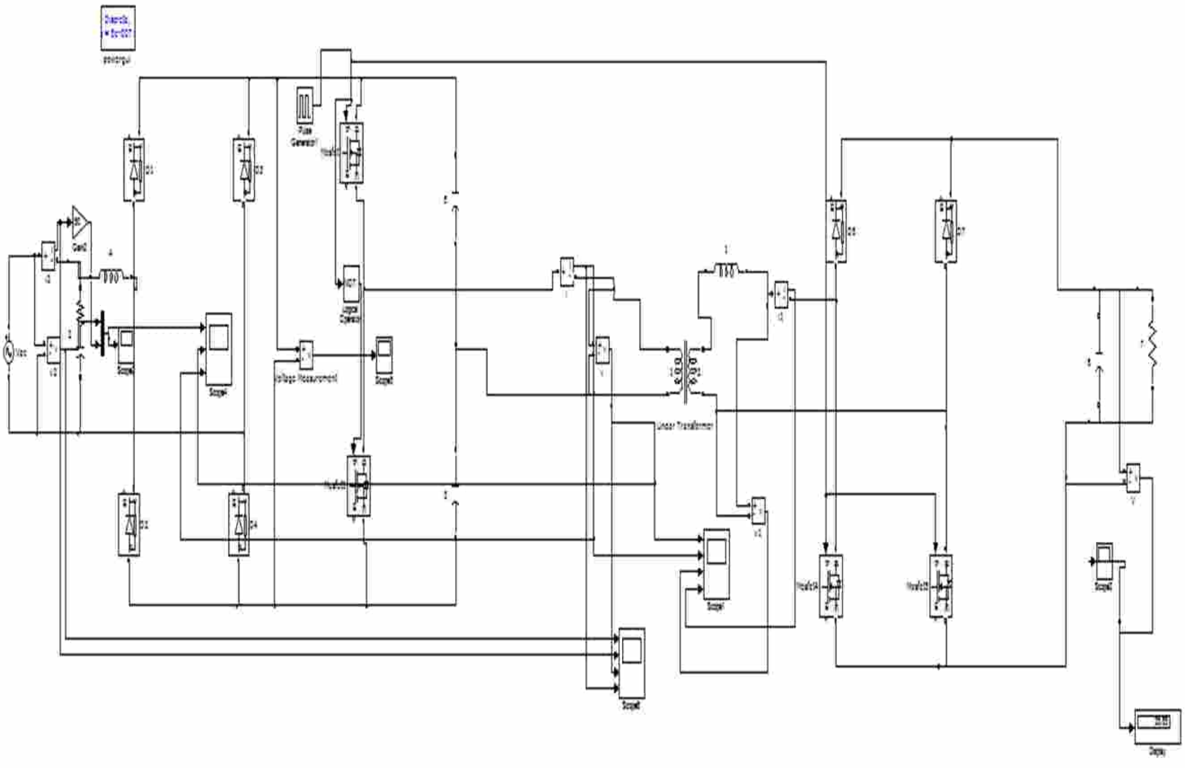


Fig 5.1 Simulink diagram of Power Factor Corrected AC–DC power conversion

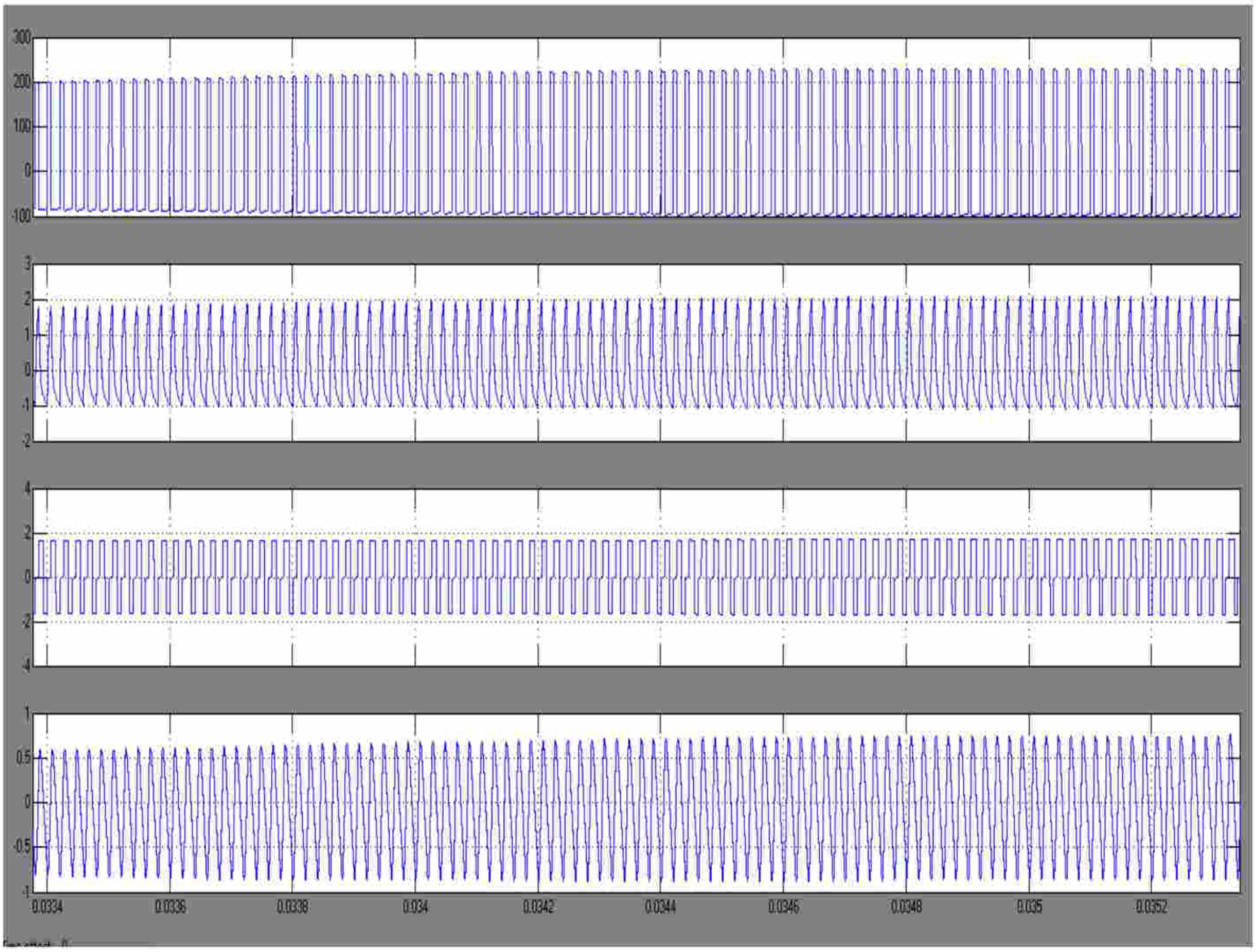


Fig. 5.2.Simulation waveforms at 300 W operation over a complete line cycle,input ac voltage (VAC) and current (IAC) and transformer primary voltage (VP) and current (IP)

Measured waveforms of the line input voltage and current and transformer primary voltage and current are shown in Fig. 5.2 over a full line cycle. Zoomed in waveforms of the transformer primary voltage and current and secondary voltage and current are shown in Fig. 5.3 (DCM) and Fig. 5.4 (CCM)and confirm the desired operation. The effect of finite values ofbus capacitors C1 and C2 can be seen in the primary voltage waveform of Fig. 5.4 as a drop in the voltage rather than an ideal square wave.

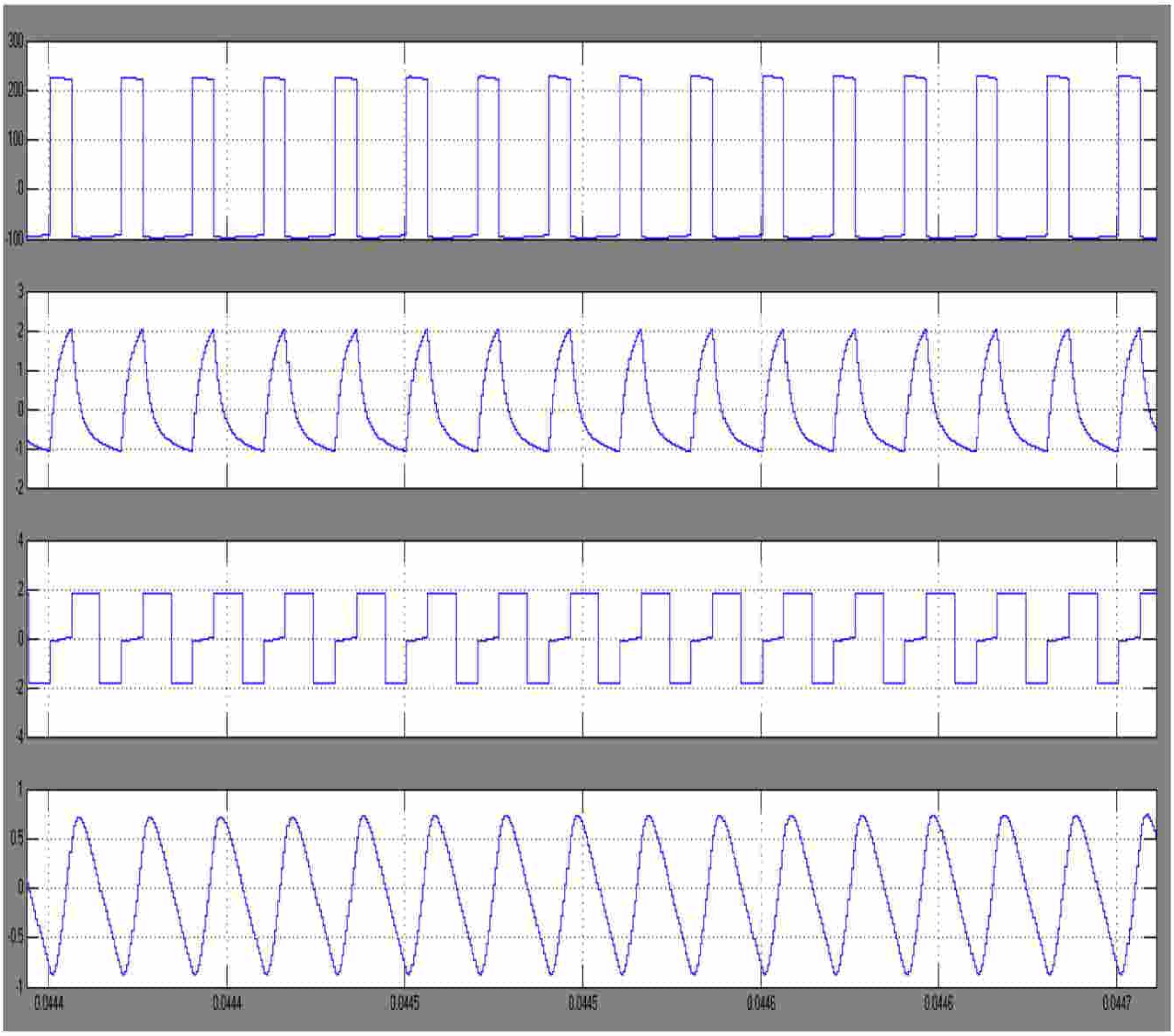


Fig. 5.3. Measured waveforms at 300 W operation, 1.5 ms from zero crossing and operating in DCM mode. Transformer primary voltage (VP) and current (IP) and secondary voltage and current (IS).

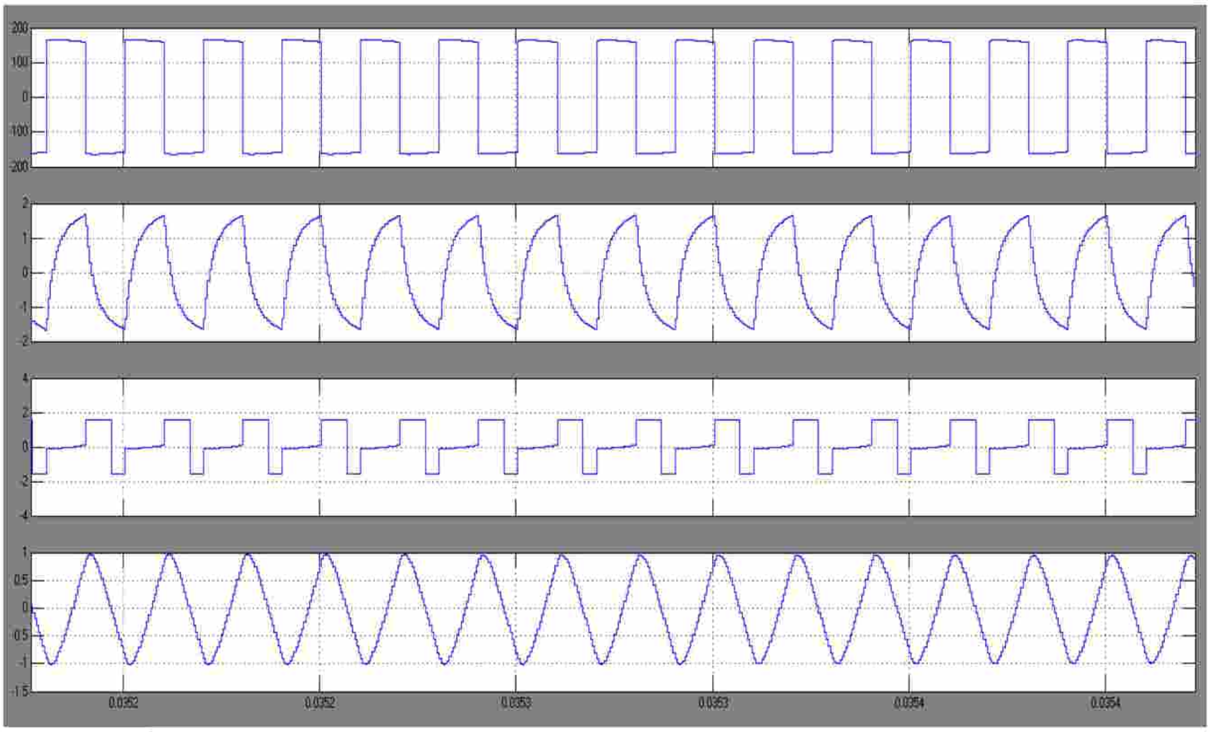


Fig. 5.4.Simulation waveforms at 300 W operation, 5 ms from zero crossing and operating in CCM mode. Transformer primary voltage (VP) and current (IP) and secondary voltage (VS) and current (IS).

5.3 PROPOSED SIMULATION CIRCUIT:

This project presents a new single-phase soft-switching parallel boost power factor correction (PFC) converter with a active snubber cell. In which to diminish the switching losses, for the main switches turn ON by ZVT and turn OFF with ZCT perfectly together, and for the secondary switch, turn ON with ZCS and also turn OFF with ZCS is achieved, with no important add to the cost and difficulty of the converter for the switches. A switch mode converter with parallel connection is a eminent approach. Phase changing of two or extra boost converters attached in parallel is involved and functioning at the identical switching frequency. Advantages of this approach include, overall efficiency is high, reduction of the development cost due to the modular design, reduction of conduction losses . All of the simulation employment is achieved in MATLAB – Simulink.

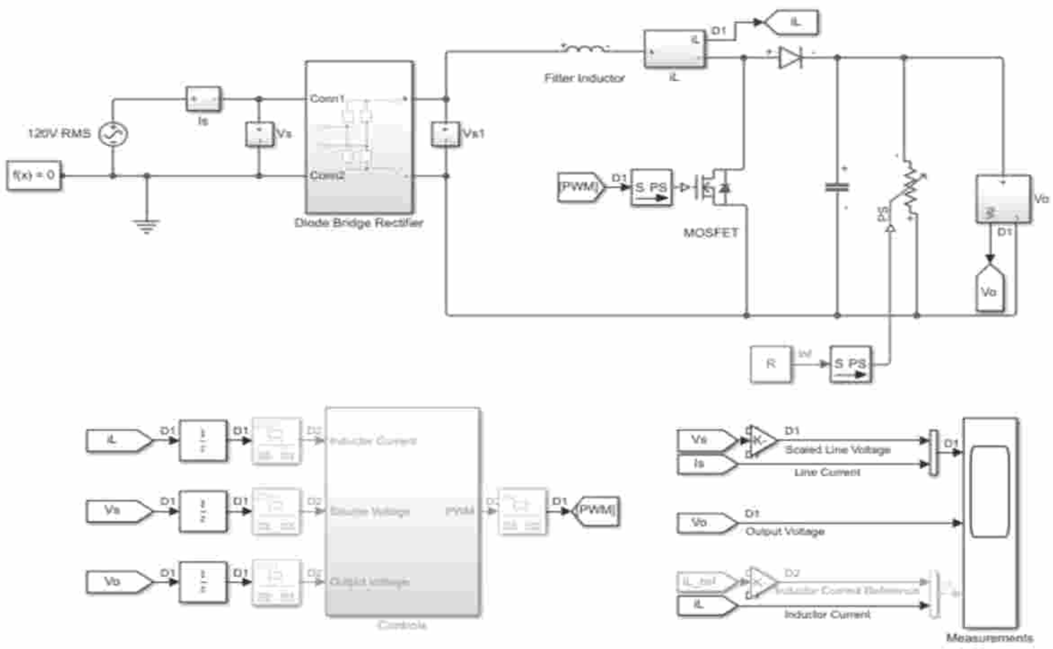


Fig 5.5: Simulation Circuit of Proposed Power Factor Correction for Continuous conduction

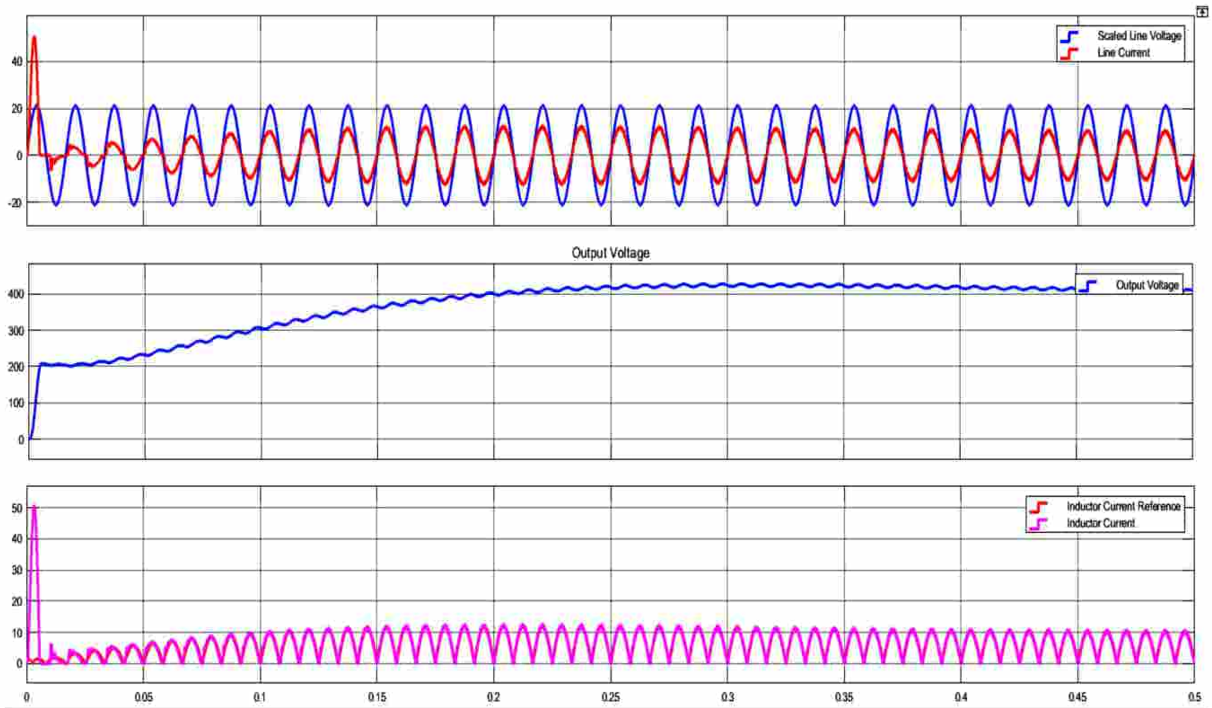


Fig 5.6: Simulation Results (a) line voltage and current (b) output voltage and (c) Inductor reference and actual current mode

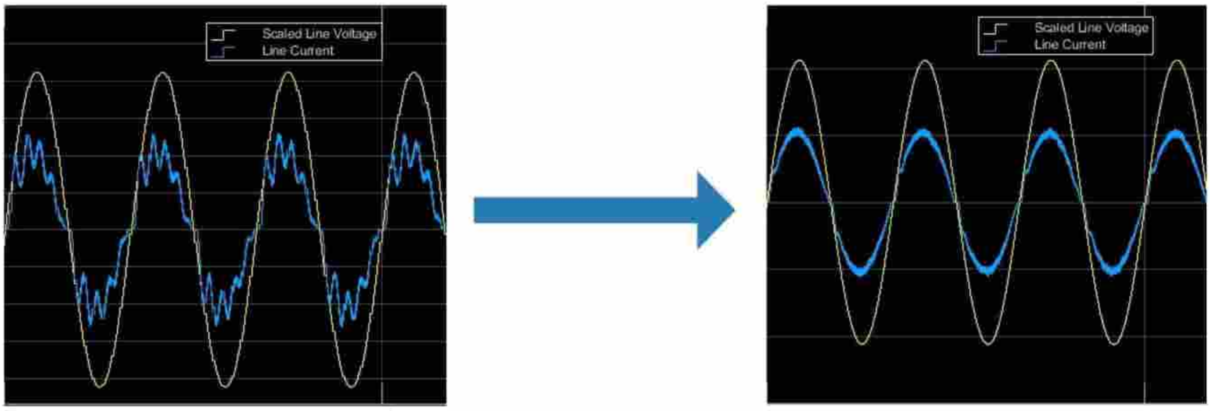


Fig 5.7 : Harmonic distortion in line current (blue) and after power factor correction (yellow).

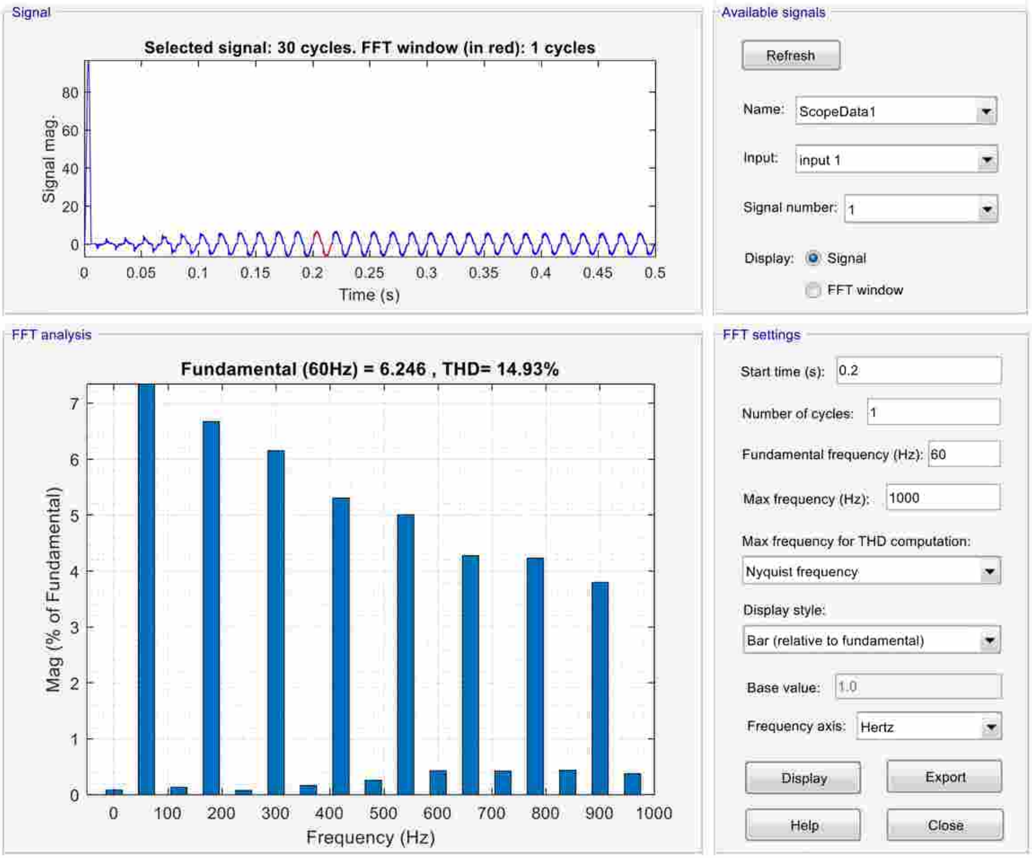


Fig:5.8 Source THD Value (14.93)

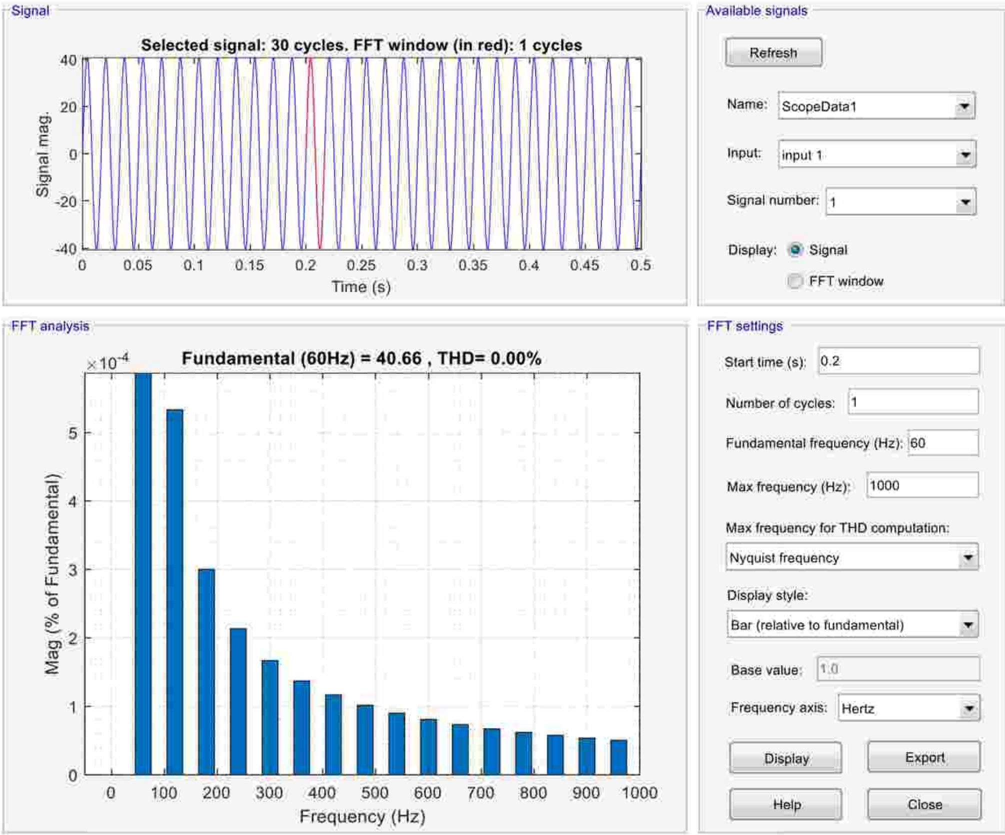


Fig:5.9 Source THD Value

5.4 Comparison between Existing and Proposed Topology:

Power Factor Correction circuits are implemented in 2 different ways.

First one is the PFC with controlling the inductor. In this converter improves the PF of the source by controlling the inductor current flowing through the transformer. This converter requires input diode rectifier and output diode rectifier and a half bridge inverter which operates at high switching frequency. A HF transformer is also required to improve the PF of the source.

Second methodology is PFC with boost converter. In this methodology requires only the input diode rectifier and a boost converter which can design with very low cost. The power losses in the converter are also reduced by implementing the soft switching topologies. The power quality of the source is improved very much when compared with first methodology. The components used in this methodology is also very less when compared with first methodology.

CHAPTER-6

CONCLUSION

The main objective throughout the project is to improve the Power Factor with active snubber circuit for the parallel boost converter. Simulations were initially done for conventional boost converter with snubber circuit. The changes in the input current waveform were saw and calculated. A PFC circuit having a parallel boost converter i.e. dual boost converters arranged in parallel was designed with soft switching which is provided by the active snubber circuit. For this idea, only one auxiliary switch and one resonant circuit is operated. The main switches and all the other semiconductors are switched by ZVT and ZCT techniques. The active snubber circuit is applied to the parallel boost converter, which is fed by rectified universal input ac line. This latest PFC converter is achieved with 200 V ac input mains. The diode is added in order to the auxiliary switch path to avoid the incoming current stresses as of the resonant circuit to the main switch. It is noticed that the Power Factor and the efficiency is better for Dual Boost Converter Circuit. Finally, 98% efficiency at full load is achieved and the power factor is reached to 99.97% for the proposed converter. Due to the main and the auxiliary switches have a common ground, the converter can easily control. The proposed new active snubber circuit can be simply functional to the further basic PWM converters and to all switching converters. The proposed converter does not need any further passive snubber circuits.

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Soft Switching Control of Power Factor Correction for Distribution System

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Abstract: A boost Power Factor Correction (PFC) front end converter followed by a full bridge transformer-isolated dc/dc converter is popular in offline dc power supply. In this configuration switching losses are high and overall efficiency is reduced. For solving this problem individual soft-switching techniques are required for both the converters. A dc power supply system that uses a new Zero-Voltage Switching (ZVS) strategy to get ZVS function is proposed here. A soft-switching dc power supply system with high input power factor and stable dc output voltage is presented with simple and compact configuration. The proposed circuit is not only operated at constant frequency, but all semiconductor devices are operated at soft switching without additional voltage stress. A significant reduction in the conduction losses is achieved, since the circulating current for the soft switching flows only through the auxiliary circuit and a minimum number of switching devices are involved in the circulating current path, and the rectifier in the proposed converter uses a single converter instead of the conventional configuration composed of a four-diode front-end rectifier followed by a boost converter. An average-current-mode control is employed in proposed dc power supply system to synthesize a suitable low-harmonics sinusoidal waveform for the input current.

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INTRODUCTION

Isolated AC/DC converters are frequently employed in service interfaced systems such as power supplies in telecommunication and data centers, plug-in hybrid electrical vehicles (PHEVs) and battery electric vehicles (BEVs)[1]. A low-cost and stout ac to dc converter consisting of a line frequency diode bridge rectifier with a large output filter capacitor requires a harmonic affluent ac line current. As a consequence, the input power factor is derived [2]. The converters with high power factor are highly required in industries. Most of the Power Electronic (PE) systems which get connected to AC efficiency mains use diode rectifiers at the input. The nonlinear nature of diode rectifiers causes considerable line current harmonic production; thus, they corrupt power quality, enlarges losses, collapse of some crucial medical equipment, etc[3].

The flaccid filter method to PFC is restricted to applications where the size and weight of the converter are not main concerns. For overcoming this problem, a boost PFC front-end converter followed by a transformer isolated dc–dc converter is the most extensively employed in offline power supplies, and full-bridge transformer-isolated dc/dc converter is the most extensively applied in medium-to-high power dc/dc power conversion[4]. Operating from a high input voltage needs a soft transition topology to diminish the switching losses and decrease the high frequency electro magnetic interference (EMI) caused by a high voltage changes [5]. Soft switching techniques are used for overcoming the hard switching problem [12]. To diminish switching stresses, losses, and electromagnetic interference (EMI), soft-switching techniques have been building up for power converters since the 1970s. There are several topologies, they use soft-switching for inverters [7].

As the frequency of switching raises thus do the switching losses and electromagnetic interference (EMI) noises. Switching losses and EMI noises of PWM converters are primarily generated during turn-on and turn-off transients. Resonant converters commutate with both zerovoltage- switching (ZVS) and zero-current-switching (ZCS) to decrease switching losses and

EMI noises [6]. Switch-mode power supplies has become lesser and lighter, because the switching frequency has enlarged. However, as the switching frequency has increased, the intervallic losses at turn-on/off have also increased. As a consequence, this loss carries increasing loss of complete system. Thus, to decrease these switching losses, a soft switching technique is proposed, which engages an extra auxiliary circuit[8].

Higher switching frequency causes lots of periodic losses at turn ON and turn OFF, ensuring in growing losses of the entire system. Hence, various converters have been given that employs resonance to reduce switching losses. Many researches with resonance have offered a zero-voltage and zero-current switching (ZVZCS) converter that do zero-voltage switching (ZVS) and zero-current switching (ZCS) concomitantly [4]. Soft-switching methods/ topologies are favored in each conversion phase as they facilitate extra decline of the losses and the amount of the system [1]. Though, all existing soft-switching inverters utilize extra active devices to attain soft-lively devices to attain soft-switching, thus growing costs and control complexity and reducing reliability. These soft-switching technologies are prior to, the Resistor, Capacitor, Diode snubber circuit had been broadly used in PWM inverters to reduce switching stresses and EMI. The conventional RCD snubber is lossy and massive, and it is hard to pertain to highfrequency switching PWM inverters since the losses in the snubber raises proportionally with the switching frequency [7].

Two techniques which incorporate a soft switching function are Zero voltage transition and Zero current transition. Furthermore ZVT methods can eliminate the turn on capacitive losses and thus MOSFETs are favored [12]. The Zero-Voltage-Transition (ZVT) and Zero-Current-Transition (ZCT) methods in which auxiliary circuits are used to aid the switches to function under soft switching condition are most motivating method [9]. Throughout this circuit, all of the switching devices attain soft-switching under zero-voltage and zero-current settings.

Thus, the periodic losses produced at turn-on and turn-off can be declined [8]. By means of soft switching techniques clarify the presentations of the dc to dc power converters in various classifications and the items where to boost up the circuit efficiency of the power converters by virtue of which circuit complicacy and excess cost contribution arise chaotically, supporting switch, additional control element, inactive elements are implemented. Still various papers reveal up to 96% efficiency without including switching losses of secondary switch and related other passive components [13].

PFC control methods for single phase boost converter may be categorized as current control and voltage control. Current control is the most common control approach since the main purpose of PFC is to oblige the input current to outline the shape of line voltage. Because of the requisite, the PFC current control methods acquire their rapid growth to meet the European standards fulfillment for the low frequency current harmonics directive [14]. Power factor correction (PFC) circuits are integrated in PE systems. Previously, to diminish rectifier-generated harmonics, exclusive and massive filter inductors and capacitors were installed, but they effectively abolish only definite harmonics .The active power line conditioners are usually hard switched; therefore, the components are subjected to high-voltage pressure which boosts additionally with raise in the switching frequency. Also, hard switching consequences in minute efficiency, bulky EMI, etc.,[3].

Passive power factor correction technique: Among the diode rectifier input port and the AC mains line of AC/DC converter in passive PFC techniques, an LC filter is included. Active power factor correction techniques: To form the input current in this approach of active PFC techniques in phase by means of the input voltage. Switched Mode Power Supply (SMPS) system is utilized. Hence, unity power factor can be achieved. The Active PFC techniques can be classified as follows 1) PWM PF correction, 2) Resonant power factor correction, 3) Soft Switching Power Factor Correction[4].

Between the input port and the AC mains line of the diode rectifier of AC/DC converter an LC filter is inserted. Active power factor correction techniques: In active PFC methods, to figure the input current in phase with the input voltage we apply a Switched Mode Power Supply method. Hence, the power factor can achieve up to unity. The Active PFC techniques can be defined as shown 1) PWM power factor correction, 2) Resonant power factor correction, 3) Soft Switching Power Factor Correction[4].

This paper presents a new single-phase soft-switching parallel boost power factor correction (PFC) converter with a active snubber cell. In which to diminish the switching losses, for the main switches turn ON by ZVT and turn OFF with ZCT perfectly together, and for the secondary switch, turn ON with ZCS and also turn OFF with ZCS is achieved, with no important add to the cost and difficulty of the converter for the switches. A switch mode converter with parallel connection is a eminent approach. Phase changing of two or extra boost converters attached in parallel is involved and functioning at the identical switching frequency. Advantages of this approach include, overall efficiency is high, reduction of the development cost due to the modular design, reduction of conduction losses . All of the simulation employment is achieved in MATLAB – Simulink.

POWER FACTOR CORRECTION

The cosine of the angle between voltage and current in an Ac circuit is stated as the Power factor. There is normally a phase difference Ø among the voltage and current in an Ac circuit. If the circuit is inductive, the current lags after the voltage and power factor is denoted as lagging. Where leading is stated as, the current leads the voltage and the power factor in the capacitive circuit.The ratio of real power to apparent power is the standard definition of power factor. With the cosine angle between them the real or average power is calculated as the product of the voltage and current magnitudes multiplied, whereas the product of the root mean square values for the apparent power.

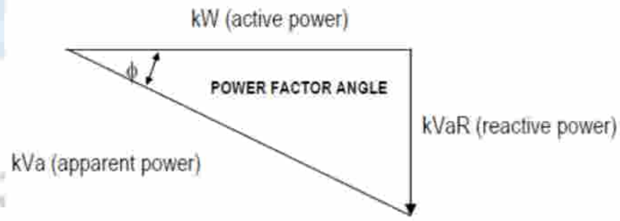

Fig 1: Power Triangle

Power Factor is usually specified as a number between 0 and 1, and is equal to the ratio of reactive power to active power, or Cosine ϕ, as presented above. The increase in power factor number makes the system more efficient. Thus, a system with a Power Factor of 0.9 is much more efficient than the power factor with 0.6.

$$\text{Power Factor} = \frac{Real\ Power}{Apparent\ Power}$$

A high power factor is generally required in a transmission system to decrease transmission losses and to improve voltage regulation at the load. To regulate the system power factor to close to 1.0 is often needed. The load produces purely sinusoidal current and voltage in a linear system. By only the phase difference between voltage and current the power factor is found out. When two sinusoidal signals are considered with the same frequency, power factor can be clear in terms of the phase angle between them, i.e.,

$$Power\ Factor = \cos \emptyset$$

The phase angle representation alone is not valid, because of the non linear performance of the active switching of power devices in non linear systems similar to power electronic systems. Typical biased line current draws a non linear load from the line. The *PF* for sinusoidal voltage and non-sinusoidal current can be said as

$$\text{Power Factor} = \frac{V_{rms}\, I_{1rms}}{\mathrm{V_{rms}\, I_{rms}}} \cos \emptyset$$

$$\text{Power Factor} = \frac{I_{1rms}}{\mathrm{I_{rms}}} \cos \emptyset$$

$$\text{Power Factor} = \mathrm{K_f} \cos \emptyset$$

Where, K_f is given as the purity factor or the distortion factor

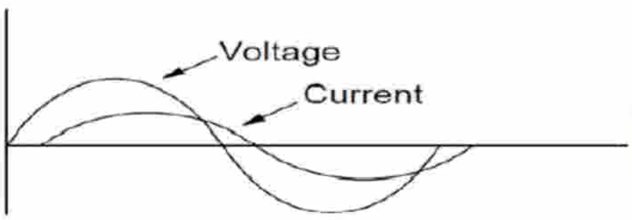

Fig 2: Traditional poor power factor (the current either leads or lags the voltage)

Poor Power Factor should be modified as it considerably raises costs. The purpose of a power factor correction circuit is to power the converter to look alike a resistive load to the line. A resistive load has zero degree phase displacement amongst its current and voltage waveforms (and no added harmonics).

RECTIFIER AND BOOST CONVERTER

The circuit scheme of the proposed power factor correction converter consists of an full wave bridge AC-DC rectifier and a modified boost converter. From a sinusoidal ac input waveform a rectified ac output generated is the purpose of the full wave rectifiers. It ensures this by means of the nonlinear conductivity characteristics of diodes to direct the path of the current.

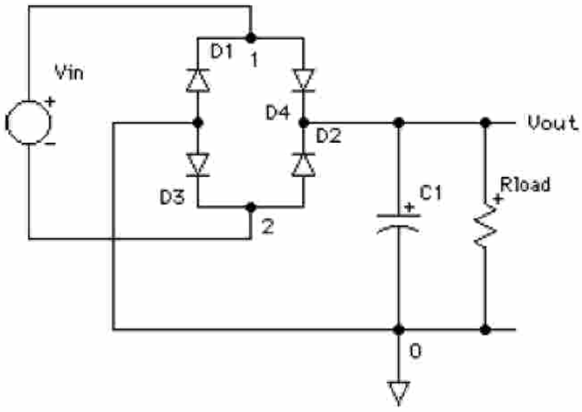

Figure 3. Filtered full wave rectifier

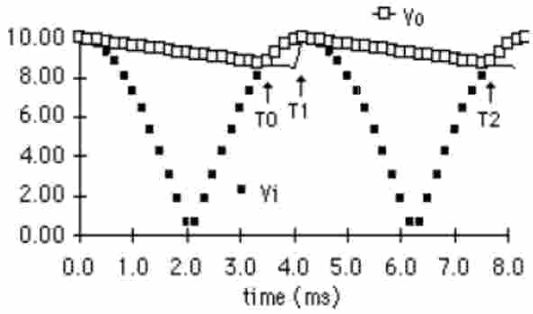

Figure 4. Output (Vi) and input (Vo) of a filtered full wave rectifier

The filtered full wave rectifier is obtained from the FWR by calculating a capacitor during the output. The FWR output is the outcome of the addition of a capacitor. The output is presently a pulsating dc, during a peak to peak variation is recognized as ripple. The input voltage magnitude and frequency be obtained during the magnitude relies of the ripple, through the filter capacitance, as well as the load resistance.

For the duration of the time period since T0 to T1, the diode D1 (or D3, based on the segment of the signal) is forward biased then Vi > VC1 (inexact the forward biased diode as a short circuit). When the capacitor C1 get charged due to the voltage across the load R increases. Starting from] T1 to T2, the D1 and D2 diodes are biased reversely (open circuit) as Vcap>Vi, and then the capacitor get discharge over the load R during a time constant of RC seconds. Along a capacitor discharge arc the voltages among times t1 and t2 set. Through which the output voltage is,

$$V_{Out}(t) = V_{mx} e^{\frac{-t+t1}{RC}}$$

The peak to peak (pp) ripple is indicating as the voltage difference between Vmax and Vmin

$$V_{Ripp}(pp) = V_{out}(t1) - V_{out}(t2) = V_{mx} - V_{mn}$$

$$= V_{mx}\left[1 - e^{\frac{-t2+t1}{RC}}\right]$$

If C is huge, such that RC >> T2 - T1,
we can estimate the exponential

$$1 - e^{\frac{-t2+t1}{RC}} \text{ as } 1 + \frac{-t2+t1}{RC}.$$

Then t2 - t1 ~ t/2, somewhere t is the period of the sine wave, now

$$V_{Ripp}(pp) = V_{mx}\frac{t}{2RC} = \frac{V_{mx}}{2fRC}$$

After the rectification of dc voltage is deposit to the boost converter using snubber circuit. A boost converter is just like a particular kind of power converter, here the output DC voltage is greater than that of the input DC voltage. This kind of circuit is used to 'step-up' a source voltage is greater than that the regulated voltage, leasing one power supply to offer different driving voltages. It is a part of switching-mode power supply, its including as a minimum two semiconductor switches (a diode and a transistor) and least one energy storage factor. After the transistor is conducted , the conventional boost converter current is being drawn in excess over the inductor and at the present, the energy is being stored in the inductor. When the transmission of current through the inductor cannot change immediately when transistor stops conducting the inductor voltage flies back or reversed.

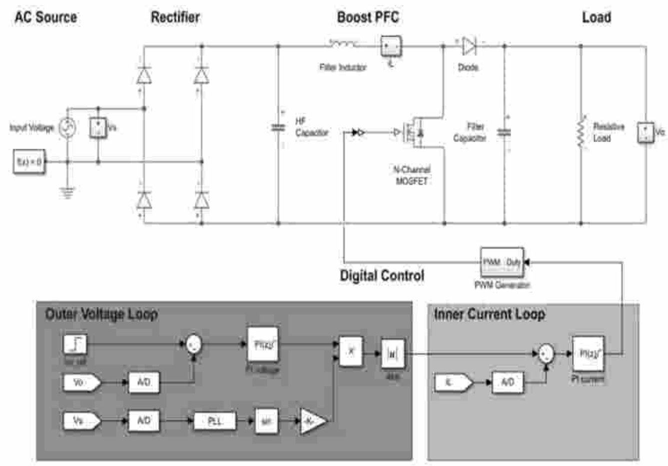

Fig 5: Simulink model of digitally controlled boost power factor correction.

SIMULATION DIAGRAM:

The proposed simulation circuit shows how to correct the power factor using a PFC pre-converter. This technique is useful when non-linear impedances, such as Switch Mode Power Supplies, are connected to an AC grid. As the current flowing through the inductor is never zero during the switching cycle, the boost converter operates in Continuous Conduction Mode (CCM). The inductor current and the output voltage profiles are controlled using simple integral control. During start up, the reference output voltage is ramped up to the desired voltage.

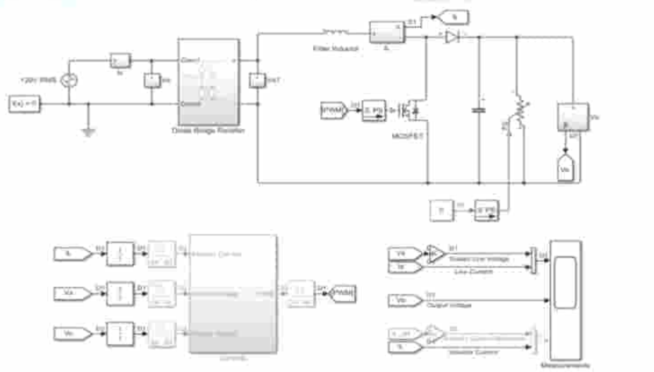

Fig 6: Simulation Circuit for Power Factor Correction for Continuous conduction mode

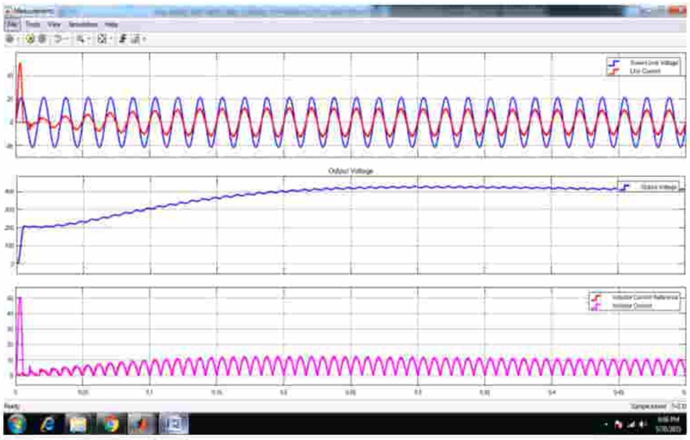

Fig 7: Simulation Results (a)line voltage and current (b)output voltage and (c) Inductor reference and actual current

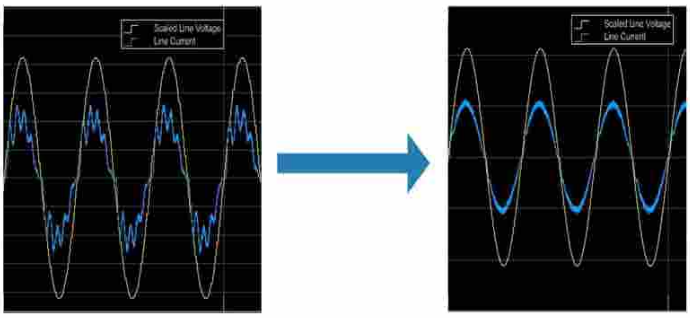

Fig 8 : Harmonic distortion in line current (blue) and after power factor correction (yellow).

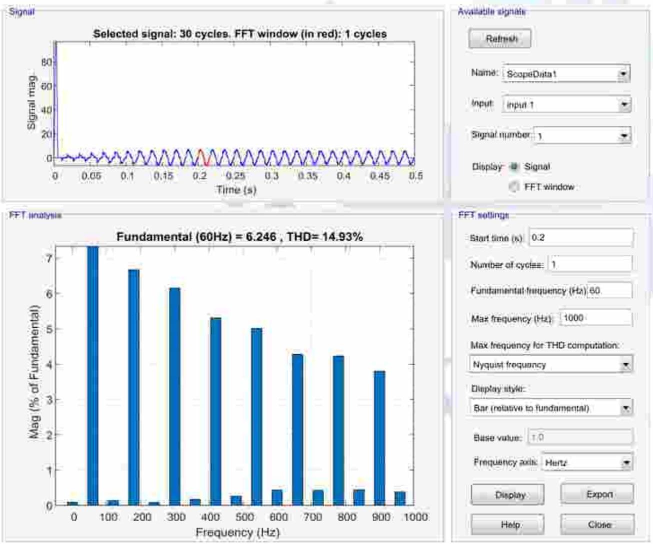

Fig: 9 Current THD

Fig: 10 Voltage THD

CONCLUSION

The main objective throughout the project is to improve the Power Factor with active snubber circuit for the parallel boost converter. Simulations were initially done for conventional boost converter with snubber circuit. The changes in the input current waveform were saw and calculated. A PFC circuit having a parallel boost converter i.e. dual boost converters arranged in parallel was designed with soft switching which is provided by the active snubber circuit. For this idea, only one auxiliary switch and one resonant circuit is operated. The main switches and all the other semiconductors are switched by ZVT and ZCT techniques. The active snubber circuit is applied to the parallel boost converter, which is fed by rectified universal input ac line. This latest PFC converter is achieved with 200 V ac input mains. The diode is added in order to the auxiliary switch path to avoid the incoming current stresses as of the resonant circuit to the main switch. It is noticed that the Power Factor and the efficiency is better for Dual Boost Converter Circuit. Finally, 98% efficiency at full load is achieved and the power factor is reached to 99.97% for the proposed converter. Due to the main and the auxiliary switches have a common ground, the converter can easily control. The proposed new active snubber circuit can be simply functional to the further basic PWM converters and to all switching converters. The proposed converter does not need any further passive snubber circuits.

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