International Journal of Scientific Engineering and Research (IJSER)
www.ijser.in
ISSN (Online): 2347-3878
Volume 2 Issue 10, October 2014

# Design and Implementation of a New Three-Phase Two-Switch ZVS PFC DCM Boost Rectifier

**M. Krishna Kumar**[1], **S. Prakash**[2]

[1]Asst Professor, Bharath university, Selaiyur, Chennai - 600 073, India

[2]Asst Professor, Department of EEE, Bharath university, Selaiyur, Chennai - 600 073, India

**Abstract:** ***A new, three-phase, two-switch, power-factor correction (PFC) rectifier that can achieve less than 5% input current total harmonic distortion (THD) and features zero-voltage switching (ZVS) of all the switches over the entire input-voltage and load ranges is introduced. The proposed rectifier also offers automatic voltage balancing across the two output capacitors connected in series, which makes it possible to use downstream converters designed with lower voltage-rated component that offer better performance and are less expensive than their high-voltage-rated counterparts. In addition, the proposed rectifier also exhibits low common-mode EMI noise. The performance of the proposed rectifier was evaluated on prototype with a output that was designed to operate VL-L, RMS input-voltage range, and also simulation results are verified with the help of MATLAB/SIMULINK software.***

**Keywords:** ZVS, PFC, DCM, Boost Rectifier, MATLAB, SIMULINK

## 1. Introduction

Power factor correction is the growing issue of concern. Within power quality framework, one of the important aspects is reactive power control. Consumer load requires reactive power that varies incessantly and increases transmission losses while affecting voltage in the transmission network. To prevent unacceptably high voltage fluctuations or the power failures that can result, this reactive power must be compensated and kept in balance. This function has always been performed by passive elements such as reactors or capacitor, as well as combination of the two that supply inductive or capacitive reactive power. The more quickly and precisely the reactive power can be compensated, the more efficiently the various characteristics of transmissions can be controlled. The objective of the use of power factor correction circuits is to make input voltage and input current of a rectifier or a power consuming electrical device in phase so that the power factor of the device as seen by the ac power distribution network is unity or close to unity.

These types of rectifiers are called unity power factor rectifiers. The basic classification of the unity power factor rectifiers in this work is single phase or three phase unity power factor rectifiers on the basis of whether the rectifier is supplied from three phases or single phase mains supply. According to the relative magnitude of rectifier's input voltage and output voltage, there is the classification of buck, boost and buck-boost type of rectifier. Unity power factor rectifiers can also be classified as those using single switching transistor or more than one switching transistor.

As the use of energy is increasing, the requirements for the quality of the supplied electrical energy are more tighten. This means that power electronic converters must be used to convert the input voltage to a precisely regulated DC voltage to the load. Regulated DC power supplies are needed for most analog and digital electronic system. Most power supplies are designed to meet regulated output, isolation and multiple outputs. The aim of the thesis is to investigate unity power factor 3-phase rectifiers and looking for a new unity power factor 3-phase rectifiers topology with possible performance improvement. The unity power factor rectifier's output voltage is desired to be constant. For this purpose, first the literature is studied and some of the existing topologies are studied.

### 1.2 Problem Statements

AC-DC power converters (rectifiers) are used in industry to convert an AC input voltage into a DC voltage that is either fed into a load or into another power converter. Three-phase rectifiers are preferred in high power applications because they have lower switch stresses, lower output ripple, and better power factor than single-phase rectifiers. The AC source for almost all rectifiers is provided by the utility. There are stringent regulatory agency requirements on the harmonic content of the current that is drawn by power electronic converters to avoid the harmonic pollution of the utility voltage. These converters are therefore implemented with some sort of power factor correction (PFC) to make their input line currents more sinusoidal and in compliance with the standards. The term power factor or PF in the field of power supplies is slightly deviate from the traditional usage of the term, which applied to reactive AC loads, such as motors powered from the AC power line. Here, the current drawn by the motor would be displaced in phase with respect to the voltage. The resulting power being drawn would have a very large reactive component and little power is actually used for producing work.

Since the number of electronic appliances is growing, an increasing amount of non-sinusoidal current is drawn from the distribution network. Consequently, due to the increasing amount of harmonic currents drawn, the distribution network becomes more and more polluted. As a direct consequence, available power from the grid becomes less. This is because unnecessary current components, which contribute to the root mean square (RMS) value of the line current is drawn from the grid which produces unnecessary.

### 1.3 Research Objectives

The three phase rectifier with power factor correction is a method to improve the power factor near to unity, reduces harmonics distortion noticeably and automatically corrects the distorted line current. It will replace the Passive Power Factor Correction (PPFC) which has become a conventional method for the past 20 years. This research aims to implement the Unity Power Factor (UPF) for three phase rectifier which is used in designing the high-end SMPS by using APFC approach. For this purpose, a power electronic circuit is inserted between the bridge rectifier, the output filter capacitor and the load. This approach requires additional semiconductor switches and control electronics, but permits cheaper and smaller passive components. The goals of this research are:

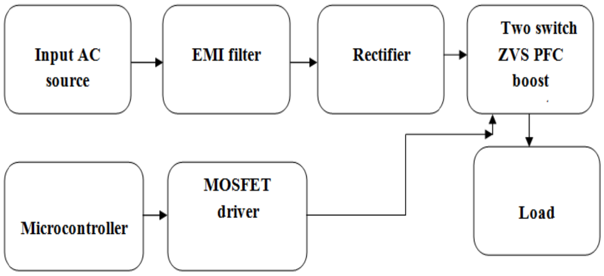
1. To simulate and analyze the typical power supplies.
2. To investigate the effects of low power factor to the power system.
3. To implement a three phase unity power factor rectifier.

In this, two types of converters are considered and they were designed in first stages converter. The first stage deals with a rectification process that is AC to DC conversion together with PFC circuit. The preferable type of PFC is Active Power Factor Correction (APFC) since it provides more efficient power frequency. An active PFC uses a circuit to correct power factor and able to generate a theoretical power factor near to unity. Active Power Factor Correction also markedly diminishes total harmonics, automatically corrects AC input voltage, and capable for a wide range of input voltage.

### 1.4 Research Methodology

The research was carried out in two stages via analysis and experimental. The analysis starts with a literature studies which are related to the thesis topic. A completed studies and investigations were carried out on the characteristic of nonlinear loads, voltage and current distortion, total harmonic distortion, power factor and active power. In the literature survey, various topologies have been evaluated which might be able to fulfill the design specifications. Based on the literature survey, several topologies were selected for further evaluation. In measuring power factor, harmonics in term of Total Harmonic Distortion (THD) and power ratings of different nonlinear loads, MATLAB software was used. After collecting the data and identifying the problems associated with SMPS, an active PFC circuit has been designed in order to achieve unity power factor. Finally the results were recorded and some evaluations were made. The design and analysis of the circuit is based on a pre-regulator circuit required for SMPS application. Most of computer SMPS now do not have an input pre-conditioner section which makes the SMPS meet the minimum requirements of power factor and total harmonic distortion.

## 2. Block Diagram



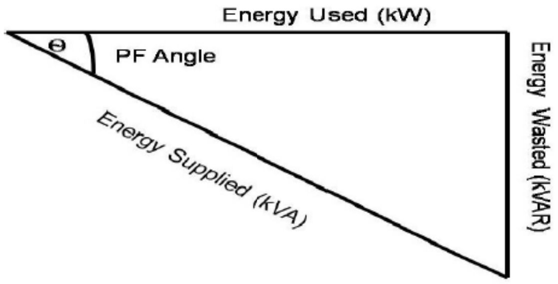
### 2.1 Power Factor

Power factor is defined as the cosine of the angle between voltage and current in an AC circuit. There is generally a phase difference θ between voltage and current in an AC circuit. cos θ is called the power factor of the circuit. It is a measure of how effectively the current is being converted into useful work output and a good indicator of the effect of the load current on the efficiency of the supply system. Poor power factor results in increase load current draw that causes additional losses in the supply and distribution systems. If the circuit is inductive, the current lags behind the voltage and power factor is referred to as lagging [Hong, Chen]. However, in a capacitive circuit, current leads the voltage and the power factor is said to be leading. - Power Factor Triangle.

In a circuit, for an input voltage V and a line current I,

- The active or real power in Watts (W)
- The reactive power in VAR
- The apparent power in VA

Power factor can determined as follows:



Power Factor gives a measure of how effective the real power utilization of the system is. It is a measure of distortion of the line voltage and the line current and the phase shift between them [Akagi Hirofumi]. Power factors range from zero (0) to unity (1) with a typical power factor being between 0.8 and 0.95. The power factor can also be leading or lagging depending on whether the load is predominantly capacitive or inductive in nature.

### 2.1.1 Benefits of Power Factor Correction (PFC)

Below are the advantages of using power factor correction circuit:

1. Electricity tariff savings.
2. Avoidance of Network Service Provider (NSP) penalties for low power factor, including restricted access to more suitable tariffs (minimum of 0.9 for large and high voltage supply establishments in most states).
3. Reduced losses.
4. Reduce power drawn from distribution systems, optimum sizing of electrical infrastructure.
5. Stabilized site voltage levels by reducing the inductive effect of the connected load.
6. The payback for PFC installations can be very reasonable and should not be over looked when considering PFC for existing installations.

Poor power factors are typically due to the effect of inductive or capacitive loads such as with a motor or with long cables providing capacitive coupling. Poor power factor due to distorted current waveforms such as with high harmonic content caused by electronic equipment cannot normally be corrected with PFC alone and will typically require complex or costly filtering [Cupertino, Marinelli].

### 2.1.2 Disadvantages of Low Power Factor

Since low PF increases the apparent current from the source, the amount of useful power that can be drawn from the circuit is lowered due to thermal limitation. Low PF also increases not only the apparent line current but also the additional current capacity cost money [Cupertino, Marinelli]. Below are other disadvantages of low power factor:

1. KVA rating of the electrical equipments increases due to low power factor as power factor is inversely proportional to the KVA rating of the equipment. This increases the size and cost of the equipment.
2. Conductor size increases. To transmit the same amount of power at low power factor at constant voltage needs to carry high current. So to keep the current density constant conductor area increases.
3. Copper loss of the equipment increases.
4. Voltage regulation becomes poor. Current at low lagging power factor causes greater voltage drop in alternators, transformers and transmission lines causing to have low power supply at the receiving end.
5. Handling capacity of the equipment decreases because the reactive component of current prevents the full utilization of the installed capacity.

## 2.2 Power Factor Correction

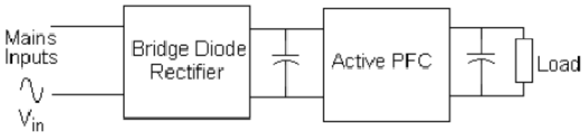
In view of low power factor drawbacks, some of alternatives for improving the input current waveforms are discussed along with their advantages and disadvantages. The technique used to improve the value of power factor is called Power Factor Correction (PFC) [Kneschke, T]. PFC shaped the distorted input current waveform to approximate a sinusoidal current that is in phase with the input voltage. There are several effective techniques for getting a sinusoidal input current waveform with low distortion. The objective of PFC is to make the input to a power supply looks like a simple resistor. Two typical techniques for PFC can be divided into Passive Power Factor Correction (PPFC) and Active Power Factor Correction (APFC). In this thesis, both the correction techniques are discussed for a single-phase circuitry. Regardless of the particular converter topology that is used, the output voltage carries a ripple at twice the line-frequency. This is because in a single-phase system the available instantaneous power varies from zero to a maximum, due to the sinusoidal variation of the line voltage.

### 2.2.1 Passive PFC

The most common type of PFC is passive PFC. PPFC methods use additional passive components (capacitor or inductor) in conjunction with the diode bridge rectifier to correct poor power factor. A PPFC is more reliable than an APFC because no active devices are utilized. Because it operates at line frequency of 50Hz, PPFC requires relatively large fixed value inductors and capacitors to reduce the low frequency harmonic currents [Wildi]. PPFC includes passive filters which can broadly be classified into series filters, shunt filters and a hybrid combination of the two. Series filters introduce impedances in series with the utility to reduce harmonic currents. Shunt filters provide a low impedance path for the harmonic currents generated by the rectifiers so that they are not reflected in the current drawn from the utility. These filters use resonant pass or resonant trap circuits sensitive to both frequency and load.

### 2.2.2 Active PFC

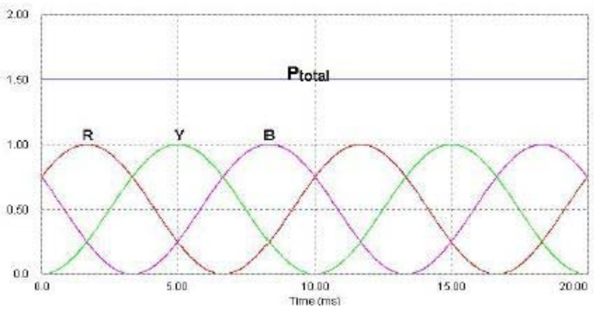
An active power factor correction (APFC) performs much better and is significantly smaller and lighter than the PPFC circuits. An APFC refers to the use of a power electronic converter, switching at higher frequency than line frequency, to shape the input current to be sinusoidal and in-phase with the input utility voltage [Hart]. Using APFC techniques, it is possible to achieve a power factor near unity and current THD less than 5%. Despite of active wave shaping, APFC includes feedback sensing of the source current for waveform control and feedback control to regulate the output voltage even when the input voltage varies over a wide range. Compared with passive solutions, they are less bulky and can easily meet the standards of harmonic distortion [Saadat]. Figure 2.2 shows the block diagram of an APFC circuit.



For single phase PFC, a DC-DC converter is placed in between the input voltage and the load. In principle, any DC-DC converter can be used for this purpose, if a suitable control method is used to shape its input current or if it has inherent PFC properties. These converters may operate in Continuous Conduction Mode (CCM), where the inductor current never reaches zero during one switching cycle or Discontinuous Conduction Mode (DCM), where the inductor current is zero during intervals of the switching cycle. The result is a large current ripple in DCM and a smaller current ripple in CCM [Chapman]. The choice of CCM or DCM depends on which SMPS is used and the necessary current and power rating required. DCM is often implemented in low power design where the current ripple is lower. CCM is often preferred at high power levels.

### 2.3 Existing Three Phase Power Converter Topologies

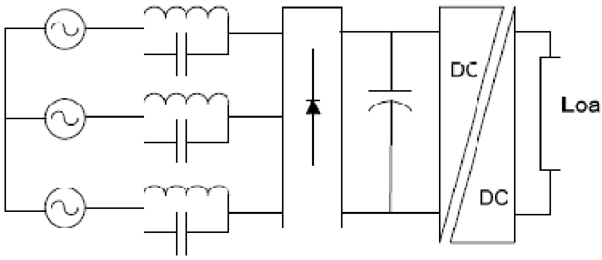
A three-phase system has certain inherent advantages over a single-phase system, with the most obvious being the constant flow of power available; hence, energy storage is no longer required. A three-phase system, from a pragmatic point of view, offers more supply integrity over a single phase system. A single-phase system requires additional phase-neutral protection and is more susceptible to imbalances and harmonics [Bhavaraju, V.B]. Also, the availability of a neutral is known to be an issue in many installations. In an ideal three-phase system, there is a continuous energy transfer from source to load, and the total power transferred is the sum of the power from the three individual phases. In a three-phase system with resistive phase loads, the power drawn by each phase is given by the following formula: Where Vp= peak input voltage and θ = phase angle. Assuming that the voltage is unchanging; It can be seen that the power drawn per phase by a three-phase system has a sin2 θ wave profile with the power in each phase summing together resulting in the total power being constant and equal to 1½ times the peak input power per phase as illustrated in Figure 2.3.



A number of common three-phase topologies exist that could be realized as power converter systems. Among those are the power converters that use passive input filtering in order to comply with the standard, however these do have size and weight issues making them not a very popular choice [Akagi Hirofumi]. Boost derived topologies are traditionally the topology of choice due to good current symmetry with numerous designs proposed by various authors.

### 2.3.1 Rectifier Topology using Passive Input Filter

A technique that uses passive input filters is described in, the aim being to reduce the large 5th and 7th harmonic current components; this is shown in Figure 2.4. The passive elements decrease the total harmonic distortion by filtering out the low frequency harmonics, thus, improving the current waveforms drawn from the supply [Kanazawa &Nabae]. The storage capacitor is not required for energy storage, but for ripple reduction and, hence, has a reduced size compared with the single-phase passive approach. This technique has several disadvantages; one being the size and weight requirements of the filter elements; the second, being the difficulty in tuning the filter if the AC line and source impedances are unknown; and the third, is the difficulty in designing the appropriate components so that the desired PFC occurs for wide variations in input AC voltage [Salmeron]. In using this approach, it is possible to comply with the IEC1000-3-2 standard. However, a DC-DC converter stage is still needed to provide isolation, voltage transformation and ripple reduction and, hence, compliance with the psophometric standard [Grady].

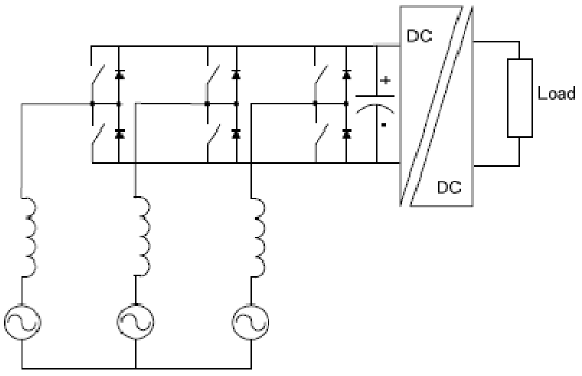


### 2.4 Boost Derived Power Converter Topologies

Three-phase boost PFC power converters have traditionally been the preferred topology for high power applications due to their symmetric current drawing characteristics. A disadvantage to any boost derived topology is the inability to control startup inrush currents and output short circuit conditions, unless bi-directional power flow is possible [Grantham, Colin]. The following subsections describe various boost derived topologies.

### 2.4.1 Six Switches Boost Power Converter

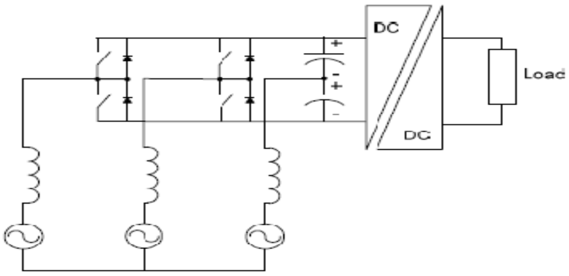
A common six switch boost converter topology has the ability to operate as a rectifier as well as an inverter due to the bidirectional power flowing capabilities. It also has good current quality and low EMI emissions [Tan, P.C]. The use of bidirectional switches also results in the ability to control the output voltage down to zero, thus, eliminating the problem that boost topologies have with regard to startup inrush currents and output short circuit protection.



### 2.4.2 Four Switches Boost Power Converter

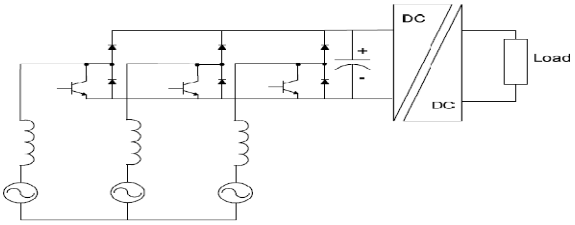
The boost derived converter shown in Figure 2.6. It has three boost inductors in the AC lines, four active switches and two series connected capacitors. The boost derived converter is capable of bi-directional power flow and, thus, is able to control the output voltage down to zero.

The converter performs PFC by taking advantage of the fact that if two of the three line currents in a balanced three-phase system are controlled, the third is automatically constrained. This removes the need for a third converter leg. A disadvantage is that even with a slight imbalance in the supply system, the converter performance may deteriorate considerably [Aresdes]. In using this approach, it is possible to comply with the IEC1000-3-2 standard



### 2.4.3 Three Switches Boost Power Converter

The three switches boost derived converter proposed in works on the principle of current control. When two switches are conducting, the phase with the larger supply voltage is connected to the positive rail, while the phase with the smaller supply voltage is connected to the negative rail. As a result, the phase shift angle between the modulation references and supply voltages can be at most 30o. Accordingly, this topology cannot be used for bi-directional power flow. As a result, this topology suffers from startup inrush currents and, also, uncontrolled negative half cycles on all phases and fluctuations in the DC bus voltage. In using this topology, it is possible to comply with the IEC1000-3-2 standard.



## A New ZVS-PWM Full-Bridge Boost Converter

### 2.1. Introduction

A new ZVS-PWM isolated full-bridge boost converter is proposed in this chapter. The new converter achieves ZVS operation using a simple auxiliary circuit that consists of an active switch and a few passive components. It does not have the disadvantages that other previously proposed converters of the same type have such as the circulating current found in resonant type converters or the hard auxiliary switch turn-off found in converters with auxiliary circuits. In this chapter, the new converter is presented, its basic operation is explained, and its advantageous features are stated.

### 2.2. Proposed Converter

The proposed ZVS-PWM isolated full-bridge boost converter is shown in Fig. 2.1. It is like a conventional PWM isolated boost converter (Fig. 1.5), but with an auxiliary circuit that consists of an auxiliary switch Saux, capacitor Cr, inductor Lr, and diodes D1 and D2. The basic operating principle of the converter is as follows: The main full-bridge switches operate in the same way as the switches of a conventional PWM isolated boost converter. As described in Section 1.3, the gating signal of these switches is such that converter states or modes when a pair of diagonally opposed switches is on (power transfer mode) are always followed by the turning on of all the four full-bridge switches (boosting mode). The auxiliary circuit is activated just before a full-bridge is about to be turned on. By doing so, the output capacitances of each switch and capacitor Cr are fully discharged so that the switches can be turned on with ZVS.

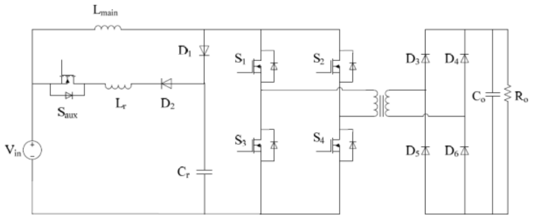


Fig. 2.1. Proposed current-fed full-bridge boost converter

### 2.3. Converter operation

In this section, the steady-state operation of the proposed converter is explained in detail in terms of the different states or modes that the converter goes through over a steady state switching cycle. These modes are distinct from each other in terms of the voltage across and the current flowing through different circuit components. When the converter is in steady-state operation, the final voltage and current of each converter component are identical to its initial values for every switching cycle. The proposed boost converter goes through ten different modes of operation over half of a steady-state switching cycle; the other half cycle is identical to the first half. Typical converter voltage and current waveforms are shown in Fig. 2.2 and equivalent circuit diagrams for each mode of converter operation are shown in Fig. 2.3. What should be especially noted about these diagrams and waveforms is how the main full-bridge switches turn on and off with ZVS and how the auxiliary switch turns on and off softly as well. The converter's modes of operation during a half switching cycle are as follows:

Mode 0 (t < t0) (Fig.2.3(a)): In this mode, only switches S1 and S4 are on and the converter is in an energy transfer mode as energy is transferred from the input to theoutput through diodes D3 and D6. The current through L main is falling throughout this mode.

Mode 1 (t0 < t < t1) (Fig.2.3(b)): This mode begins when switch Saux is turned on in anticipation of the DC bus being shorted and the converter entering a boosting mode.

Since the snubber capacitor voltage VCr is greater than the input voltage, current will start flowing through Saux. Saux turns on softly as inductor Lr is in series with this switch and limits the rise in current through it. Cr discharges into the auxiliary inductor during this mode. Since voltage VCr is higher than the bridge voltage, diode D1 is reversed biased and does not conduct. This mode ends when Cr voltage reaches the voltage across off-state bridge switches which is ◎◎◎ .22

Mode 2 (t1 < t < t2) (Fig.2.3(c)): This mode begins when diode D1 becomes forward biased and starts to conduct. The voltage across the bridge switches therefore follows capacitor voltage VCr which is decreasing. This voltage is also equal to the voltage across the transformer. Ideally, if the voltage across the transformer is less than ◎◎ , the output diodes become reversed biased and power is not transferred to the output, but this power transfer does not in fact stop immediately because of the presence of leakage inductance in the transformer. The transformer current reaches zero at the end of this mode.

Mode 3 (t2 < t < t3) (Fig.2.3(d)): The output capacitances of switches S2 and S3 and capacitor Cr keep discharging during this mode. The current in the auxiliary circuit branch is equal to the sum of the current from the full-bridge caused by the discharging of the switch output capacitances and Cr, and the input current that flows through Lmain. Mode 4 (t3 < t < t4) (Fig.2.3(e)): At the beginning of this mode, the DC bus voltage is zero and is clamped to zero as the body-diodes of the converter switches are forward biased and start to conduct. Switches S2 and S3 can be turned on with ZVS sometime during this mode while current is flowing through their body-diodes. Also during this mode, the current that flows through the auxiliary circuit (and thus the current through the full-bridge) begins to decrease because the voltage across the auxiliary inductor is negative as the input voltage is at one end of the circuit and the DC bus voltage is zero. The auxiliary circuit current is equal to the current through Lmain at the end of this mode, which makes the current flowing through the full-bridge to be zero.

Mode 5 (t4 < t < t5) (Fig.2.3(f)): At t = t4, the current that was flowing through the full-bridge reverses direction and flows through the switches. The current in the auxiliary circuit continues to decrease as the input current is gradually transferred to the full-bridge. The auxiliary circuit current is zero by the end of this mode and Saux can be turned off softly at any time afterwards until a diagonally pair of switches is turned off and the DC bus is no longer shorted.

Mode 6 (t5 < t < t6) (Fig.2.3(g)):

The converter is in a boosting mode during this mode. It operates like a standard PWM boost converter as the DC bus is shorted, the current through Lmain rises, and the auxiliary circuit is inactive.

Mode 7 (t6< t < t7) (Fig.2.3(h)):

At t = t6, switches S1 and S4 are turned off. Due to the presence of their output capacitances (not shown in the figure) and Cr, these switches can be turned off with ZVS. Main switch output capacitances and Cr start charging and at the end of this mode their voltage reaches.

Mode 8 (t7< t < t8) (Fig.2.3(i)):

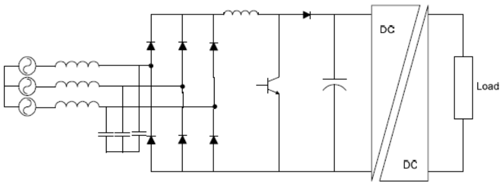
At the beginning of this mode, as the DC bus voltage is rising, the transformer primary side voltage reaches a certain level that results in the output diodes becoming forward biased and thus conducting current. The main inductor current transfer from snubber capacitor Cr to the transformer primary winding is gradual and takes some time because of the leakage inductance of the transformer. During this time, the current flowing through Cr results in the capacitor being charged over and above the DC bus voltage, which results in voltage overshoots in the voltage across the main full-bridge switches that are off. At the end of this mode, the voltage across Cr reaches its maximum value and is clamped at this value as there is no current path for it to discharge. In the meantime, the main switch output capacitances and capacitor Cr start to resonate with the transformer leakage inductance at the start of this mode.

Mode 9 (t > t8) (Fig.2.3(j)):

After t = t8, the converter is in an energy-transfer mode as switches S2 and S3 are conducting current, power is transferred from the input to the output, and the current in Lmain falls. The transformer leakage inductance continues to resonate with the output capacitors of the main switches at the beginning of this mode, but this resonance eventually dies down due to parasitic resistances.

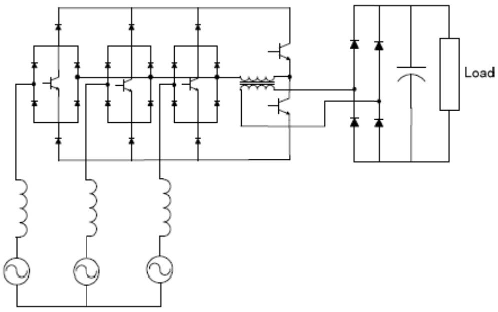
### 2.4.4 Single Switch Boost Power Converter

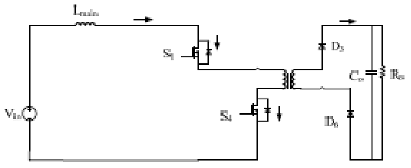
The single switch boost converter topology proposed in has an LC type input filter and, with the boost switch turned on at a constant frequency, the duty cycle is controlled such that the input current is always discontinuous. During the on-period of the boost switch, all three input phases become shorted through the input inductors, the six rectifier diodes and the boost switch [Sekaran]. The three input currents begin simultaneously to increase at a rate proportional to the instantaneous values of their respective phase voltages. The specific peak current values during each on-interval are proportional to the average values of their input phase voltages during the same on-interval. The result is that each AC line current is a discontinuous waveform made up of a train of triangular pulses bounded by a sinusoidal envelope [Moleykutty]. In using this topology it is possible to comply with the IEC1000-3-2 standard. However, a DC-DC converter is needed for isolation, voltage transformation and ripple reduction.



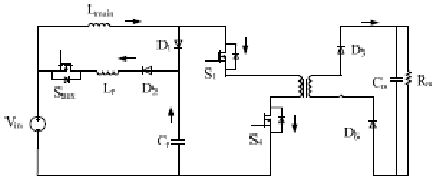
### 2.5 Vienna Rectifier

Another three-switch boost derived converter, also called the Vienna rectifier, is a unidirectional three-level PWM converter (Figure 2.9) and, as a result, suffers from start-up inrush currents. The input stage creates a DC voltage across the two switches connected to the transformer primary. These two switches, in turn, regulate the voltage being applied to the primary of the transformer. Accordingly, they are able to control the output voltage generated. The Vienna rectifier has a complex control system and requires special semiconductor module fabrication. It is possible to comply with the industrial standards using this topology with no additional second stage needed.

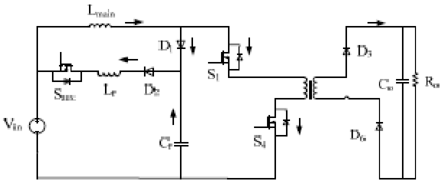




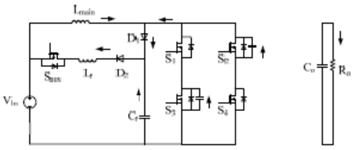
(a) Mode 0



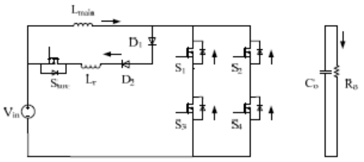
(b) Mode 1



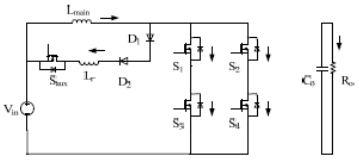
(c) Mode 2



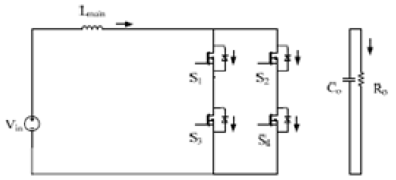
(d) Mode 3



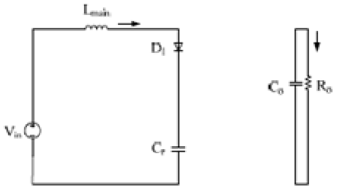
(e) Mode 4



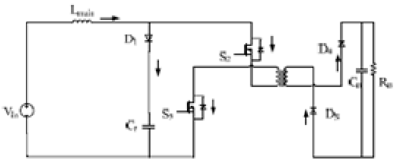
(f) Mode 5



(g) Mode 6



(h) Mode 7



(i) Mode 8

The proposed converter has the following features:

i. All four main switches can turn on and off with ZVS. The auxiliary circuit operates when the switches are about to turn on and discharges the switch parallel capacitances to have zero voltage turn-on. Switches also turn off softly due to the auxiliary capacitor in parallel with them.
ii. The auxiliary switch turns on and off softly. As it can be seen in Fig. 2.2, due to the series inductor with auxiliary switch, the current rise in the switch is gradual ("soft") and it does not have overlap with voltage across it. The turn-off of the switch occurs after the resonant interaction of Lr and Cr forces the switch current to zero, and diode D2 keeps current from flowing through the body-diode of Saux.
iii. The auxiliary circuit is very simple as it consists of a switch, an inductor, a capacitor, and two diodes.
iv. The timing of the turning off of the auxiliary switch is very flexible as it can be done at any time while the DC bus is shorted. This is contrast to other ZVS converters where the auxiliary switch (if it actually can be turned off softly) must do so within a narrow window of time. This feature simplifies the design of the auxiliary circuit considerably.
v. Due to the blocking diode D1, the auxiliary circuit does not pump additional current into the full-bridge switches so that their rms current and peak current ratings are the same as the switches of the conventional PWM converter shown in Fig. 1.5.
vi. One of the drawbacks of a conventional current-fed full-bridge converter is that there is no bus capacitor across the bridge. The lack of this capacitor may lead to excessive voltage spikes on the switches due to the resonance between their parasitic capacitances and transformer leakage inductance. The presence of a capacitor at the DC bus of the proposed converter prevents excessive voltage spikes from appearing across the full-bridge switches.
vii. The auxiliary circuit does not have any unnecessary circulating current. Whatever current flows in the

auxiliary circuit flows out of the circuit instead of being trapped inside, where it can contribute to conduction losses.

viii. The converter's ZVS operation is load independent as it can ensure that its switches can turn on with ZVS from full-load to no-load. Since the operation of auxiliary circuit is dependent on the bus voltage and the bus voltage is constant from full-load to no-load, by activation of auxiliary circuit, Cr discharges and soft switching is performed at any load.

**Rectifier:**

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which is in only one direction, a process known as rectification. Rectifiers have many uses including as components of power supplies and as detectors of radio signals. Rectifiers may be made of solid state diodes, vacuum tube diodes, mercury arc valves, and other components.

A device which performs the opposite function (converting DC to AC) is known as an inverter. When only one diode is used to rectify AC (by blocking the negative or positive portion of the waveform), the difference between the term diode and the term rectifier is merely one of usage, i.e., the term rectifier describes a diode that is being used to convert AC to DC. Almost all rectifiers comprise a number of diodes in a specific arrangement for more efficiently converting AC to DC than is possible with only one diode. Before the development of silicon semiconductor rectifiers, vacuum tube diodes and copper oxide or selenium rectifier stacks were used. Early radio receivers, called crystal radios, used a "cat's whisker" of fine wire pressing on a crystal of galena (lead sulfide) to serve as a point-contact rectifier or "crystal detector". Rectification may occasionally serve in roles other than to generate direct current per se. For example, in gas heating systems flame rectification is used to detect presence of flame. Two metal electrodes in the outer layer of the flame provide a current path, and rectification of an applied alternating voltage will happen in the plasma, but only while the flame is present to generate it.

**Synchronous Rectifier:**

To convert AC currents into DC current in electric locomotives, a synchronous rectifier may be used. It consists of a synchronous motor driving a set of heavy-duty electrical contacts. The motor spins in time with the AC frequency and periodically reverses the connections to the load just when the sinusoidal current goes through a zero-crossing. The contacts do not have to switch a large current, but they need to be able to carry a large current to supply the locomotive's DC traction motors.

**Electrolytic:**

The electrolytic rectifier was an early device from the 1900s that is no longer used. When two different metals are suspended in an electrolyte solution, it can be found that direct current flowing one way through the metals has less resistance than the other direction. These most commonly used an aluminum anode, and a lead or steel cathode, suspended in a solution of tri-ammonium ortho-phosphate. The rectification action is due to a thin coating of aluminum hydroxide on the aluminum electrode, formed by first applying a strong current to the cell to build up the coating. The rectification process is temperature sensitive, and for best efficiency should not operate above 86 °F (30 °C).

**Mercury Arc**

A rectifier used in high-voltage direct current power transmission systems and industrial processing between 1909 and 1975 is a mercury arc rectifier or mercury arc valve. The device is enclosed in a bulbous glass vessel or large metal tub. One electrode, the cathode, is submerged in a pool of liquid mercury at the bottom of the vessel and one or more high purity graphite electrodes, called anodes, are suspended above the pool. There may be several auxiliary electrodes to aid in starting and maintaining the arc. When an electric arc is established between the cathode pool and suspended anodes, a stream of electrons flows from the cathode to the anodes through the ionized mercury. In principle, this is a higher-power counterpart to flame rectification, which uses the same one-way current transmission properties of the plasma naturally present in a flame.

**Argon Gas Electron Tube**

The General Electric Tungar rectifier was an argon gas-filled electron tube device with a tungsten filament cathode and a carbon button anode. It was useful for battery chargers and similar applications from the 1920s until low-cost solid-state rectifiers (the metal rectifiers at first) supplanted it. These were made up to a few hundred volts and a few amperes rating, and in some sizes strongly resembled an incandescent lamp with an additional electrode The 0Z4 was a gas-filled rectifier tube commonly used in vacuum tube car radios in the 1940s and 1950s. It was a conventional full wave rectifier tube with two anodes and one cathode, but was unique in that it had no filament (thus the "0" in its type number). The electrodes were shaped such that the reverse breakdown voltage was much higher than the forward breakdown voltage. Once the breakdown voltage was exceeded, the 0Z4 switched to a low-resistance state with a forward voltage drop of about 24 volts.

**Recent developments:**

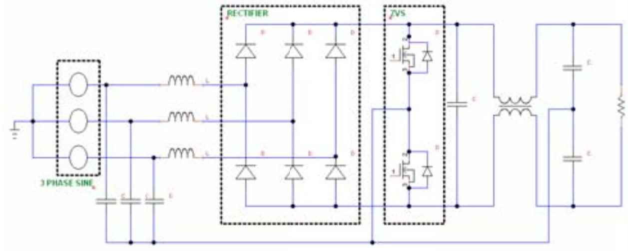
**High-Speed Rectifiers**

Researchers at Idaho National Laboratory (INL) have proposed high-speed rectifiers that would sit at the center of spiral nano antennas and convert infrared frequency electricity from AC to DC. Infrared frequencies range from 0.3 to 400 terahertz.

### Uni Molecular Rectifiers

A Uni molecular rectifier is a single organic molecule which functions as a rectifier. The technology is still in the experimental stage.

### Circuit Diagram



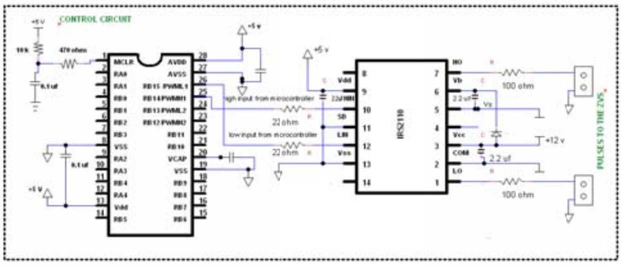
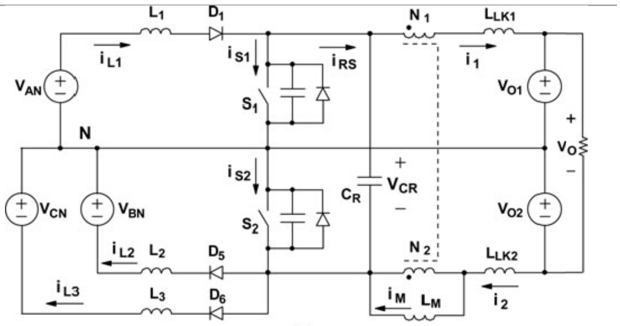
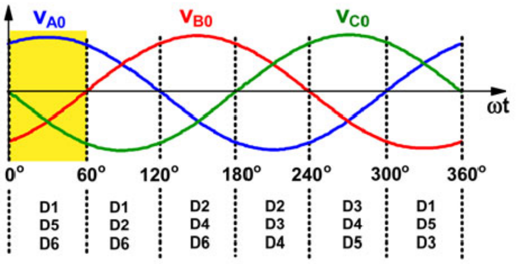


Fig. shows the proposed three-phase two-switch ZVS PFC DCM boost rectifier. In the proposed circuit, the three Y-connected capacitors, C1 , C2 , and C3 , are used to create virtual neutral N, i.e., a node with the same potential as power source neutral 0 that is not physically available or connected in three-wire power systems. Since the virtual neutral is connected to the midpoint between two switches S1 and S2 and also to the midpoint of two output capacitors CO1 and CO2 , the potentials of these two midpoints are the same as the potential of neutral 0 of the balanced three-phase power source. In addition, by connecting virtual neutral N directly to the midpoint between switches S1 and S2, decoupling of the three input currents is achieved. In such a decoupled circuit, the current in each of the three inductors is dependent only on the corresponding phase voltage, which reduces the THD and increases the PF, [12].



(a)



(b)

To simplify the analysis of operation, it is assumed that ripple voltages of the input and output filter capacitors shown in Fig. 1 are negligible so that their voltages can be represented by constant-voltage source VAN, VBN, VCN, VO1 , and VO2 as shown in Fig. 2. Also, it is assumed that in the ON state, semiconductors exhibit zero resistance, i.e., they are short circuits. However, the output capacitances of the switches are not neglected in this analysis. Coupled inductor LC in Fig. 1 is modelled as a two winding ideal transformer with magnetizing inductance LM and leakage inductances LLK1 and LLK2. It should be noted that the average voltage across capacitor CR is equal to output voltage VO = VO1 + VO2. Since in a properly designed rectifier the ripple voltage of capacitor CR is much smaller than output voltage VO , voltage VCR across capacitor CR can be considered constant and equal to VO.

By recognizing that rectifiers D1, D2 , and D3 conduct only when their corresponding phase voltage is positive and rectifiers D4, D5 , and D6 conduct only when their corresponding voltage is negative, the simplified circuit diagram of the rectifier along with the reference directions of currents and voltages is shown in Fig. 2(a). It should be noted that the input model in Fig. 2(a) is only valid in the 60◦ segment of the line cycle where VA0 >0, VB0 <0, and VC0 <0, as shown in Fig. 2(b). However, the same model is applicable to any other 60◦ segment during which the phase voltages do not change polarity.

## 3. Simulation

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include

- Math and computation.
- Algorithm development.
- Data acquisition.
- Modelling, simulation, and prototyping.

- Data analysis, exploration, and visualization.
- Scientific and engineering graphics.
- Application development, including graphical user interface building.

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar non interactive language such as C or FORTRAN.

The name MATLAB stands for matrix laboratory. MATLAB was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects. Today, MATLAB engines incorporate the LAPACK and BLAS libraries, embedding the state of the art in software for matrix computation.

MATLAB has evolved over a period of years with input from many users. In university environments, it is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science. In industry, MATLAB is the tool of choice for high-productivity research, development, and analysis.

MATLAB features a family of add-on application-specific solutions called toolboxes .Very important to most users of MATLAB, toolboxes allow you to learn and apply specialized technology. Toolboxes are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control Systems, neural networks, fuzzy logic, wavelets, simulation, and many others.

### Simpower Systems

Sim Power Systems and other products of the Physical Modeling product family work together with Simulink to model electrical, mechanical, and control systems. Sim Power Systems operates in the Simulink environment. Therefore, before starting this user's guide, you should be familiar with Simulink.

## 4. The Role of Simulation in Design

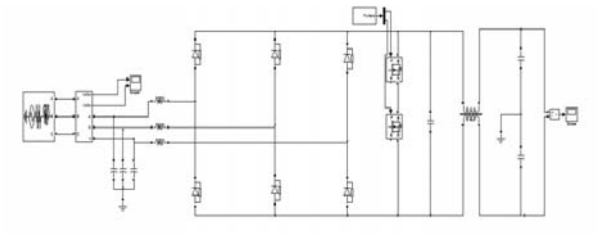
Electrical power systems are combinations of electrical circuits and electromechanical devices like motors and generators. Engineers working in this discipline are constantly improving the performance of the systems. Requirements for drastically increased efficiency have forced power system designers to use power electronic devices and sophisticated control system concepts that tax traditional analysis tools and techniques. Further complicating the analyst's role is the fact that the system is often so nonlinear that the only way to understand it is through simulation .Land-based power generation from hydroelectric, steam, or other devices is not the only use of power systems. A common attribute of these systems is their use of power electronics and control systems to achieve their performance.

Sim Power Systems is a modern design tool that allows scientists and engineers to rapidly and easily build models that simulate power systems. Sim Power Systems uses the Simulink environment, allowing you to build a model using simple click and drag procedures. Not only can you draw the circuit topology rapidly, but your analysis of the circuit can include its interactions with mechanical, thermal, control, and other disciplines. This is possible because all the electrical parts of the simulation interact with the extensive Simulink modeling library. Since Simulink uses MATLAB® as its computational engine, designers can also use MATLAB toolboxes and Simulink block sets.

### Simpower Systems Libraries

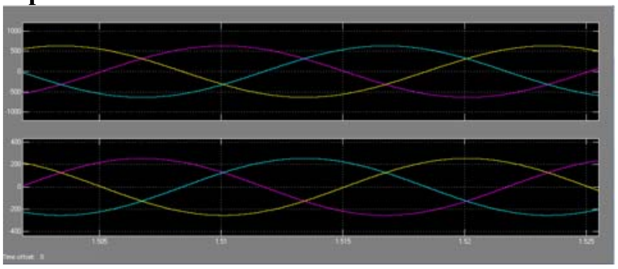
The libraries contain models of typical power equipment such as transformers, lines, machines, and power electronics. The capabilities of Sim Power Systems for modeling a typical electrical system are illustrated in demonstration files. And for users who want to refresh their knowledge of power system theory, there are also self-learning case studies. The Sim Power Systems main library, power lib, organizes its blocks into libraries according to their behavior. The power library window displays the block library icons and names. Double-click a library icon to open the library and access the blocks. The main Sim Power Systems power library window also contains the Powergui block that opens a graphical user interface for the steady-state analysis of electrical circuits. This is possible because all the electrical parts of the simulation interact with the extensive Simulink modeling library. Since Simulink uses MATLAB as its computational engine, designers can also use MATLAB toolboxes and Simulink block sets. Sim Power Systems and Sim Mechanics share a special Physical Modeling block and connection line interface.

### Simulation Diagram

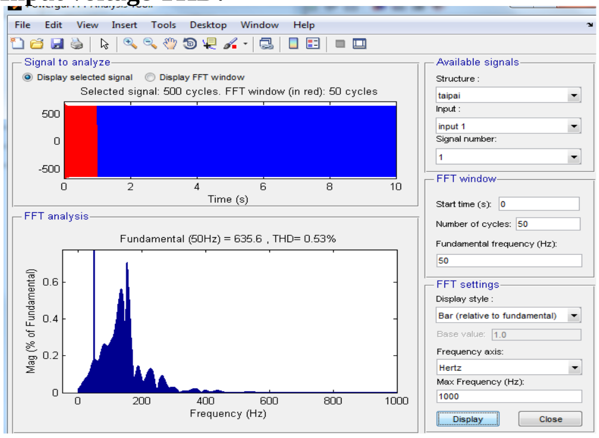


## 5. Simulation Result

### Input:



**Input voltage THD:**

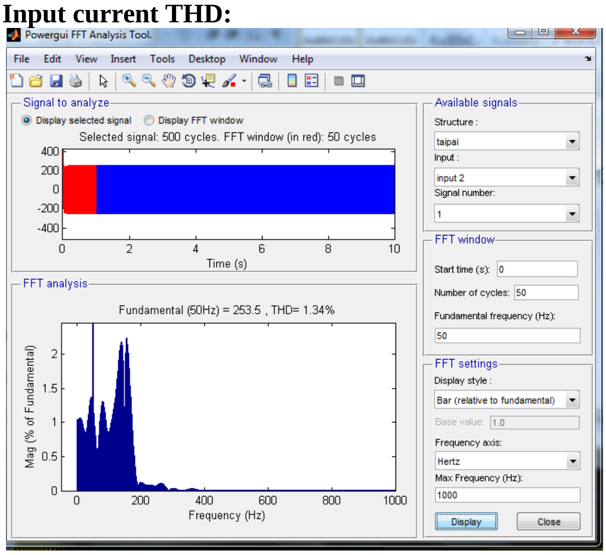


Selected signal: 500 cycles. FFT window (in red): 50 cycles

Fundamental (50Hz) = 635.6 , THD= 0.53%

Structure : taipai
Input : input 1
Signal number: 1
Start time (s): 0
Number of cycles: 50
Fundamental frequency (Hz): 50
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

**Input current THD:**

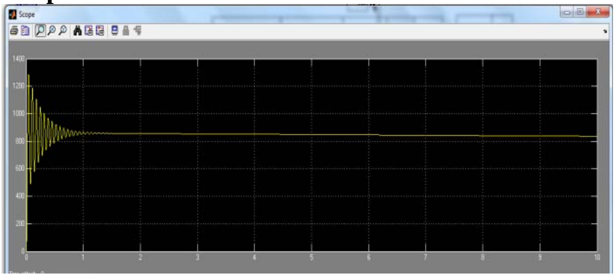


Selected signal: 500 cycles. FFT window (in red): 50 cycles

Fundamental (50Hz) = 253.5 , THD= 1.34%

Structure : taipai
Input : input 2
Signal number: 1
Start time (s): 0
Number of cycles: 50
Fundamental frequency (Hz): 50
Display style : Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz
Max Frequency (Hz): 1000

**Output:**



## 6. Conclusion

In this paper, a new three-phase two-switch ZVS PFC DCM boost rectifier has been introduced. The proposed rectifier achieves less than 5% input-current THD over the entire input Range and above 25% load and features complete ZVS of the switches. In addition, the proposed rectifier has automatic voltage balancing across the two split output capacitors, which simplify the implementation of downstream power processing with low-rated-voltage, low-cost, and high-performance converters connected across the split capacitors. The performance evaluation was performed on a three-phase prototype operating in the line voltage range of VL-L,RMS. The measured input-current THD at, RMS were 1.4% and 2.8%, respectively. The measured full-load efficiency was in the 97.6–98.2% range.

## References

[1] A. R. Prasad, P. D. Ziogas, and S. Manias, “An active power factor correction technique for three-phase diode rectifiers,” in Proc. IEEE Power Electron. Specialist’ Conf. (PESC) Rec., Jun. 1989, vol. 1, pp. 58–66.

[2] E. H. Ismail and R.W. Erickson, “A single transistor three phase resonant switch for high quality rectification,” in Proc. IEEE Power Electron. Spec. Conf. (PESC) Rec., Jun./Jul. 1992, vol. 2, pp. 1341–1351.

[3] J.W.Kolar, H. Ertl, and F.C. Zach, “Space vector-based analytical analysis of the input current distortion of a three-phase discontinuous-mode boost rectifier system,” in Proc. IEEE Power Electron. Specialists’ Conf. (PESC) Rec., Jun. 1993, pp. 696–703.

[4] Y. Jang and R. W. Erickson, “New single-switch three-phase high power factor rectifiers using multi-resonant zero current switching,” IEEE Trans. Power Electron., vol. 13, no. 1, pp. 194–201, Jan. 1998.

[5] Q. Huang and F. C. Lee, “Harmonic reduction in a single-switch, three phase boost rectifier with high order harmonic injected PWM,” in Proc. IEEE Power Electron. Specialists’ Conf. (PESC) Rec., Jun. 1996, vol. 2, pp. 1266–1271.

[6] J. Sun, N. Fr¨ohleke, and H. Grotstollen, “Harmonic reduction techniques for single-switch three-phase boost rectifiers,” in Proc. IEEE IAS Annu. Meet. Rec., Oct. 1996, vol. 2, pp. 1225–1232.

[7] Y. Jang and M.M. Jovanovi´c, “A novel, robust, harmonic injection method for single-switch, three-phase, discontinuous-conduction-mode boost rectifiers,” IEEE Trans. Power Electron., vol. 13, no. 5, pp. 824–834, Sep. 1998.

[8] D. S. L. Simonetti, J. L. F. Vieira, and G. C. D. Sousa, “Modeling of the high-power-factor discontinuous boost rectifiers,” IEEE Trans. Ind. Electron., vol. 46, no. 4, pp. 788–795, Aug. 1999.

[9] P. Barbosa, F. Canales, and F. C. Lee, “Analysis and evaluation of the two-switch three-level boost rectifier,” in Proc. IEEE Power Electron. Specialists’ Conf. (PESC) Record, 2001, vol. 3, pp. 1659–1664.

[10] J. W. Kolar and T. Friedli, “The essence of three-phase PFC rectifier systems,” in Proc. IEEE Int. Telecommun. Energy Conf. Rec., 2011, Plenary Session 2, Paper 12.1