DESIGN AND SIMULATION OF THREE PHASE RECTIFIER WITH POWER FACTOR CORRECTION

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ABSTRACT

The Switch Mode Power Supplies (SMPS) are a multi-million dollar industry and continuously growing industry within the field of power electronics. SMPS is widely been used in communication, computers and industrial. The Unity Power Factor (UPF) rectifier has become an important design issue as a consequence of recent legislation. European legislation restricts the harmonic content of power supplies. The advantages of UPF are more than legislative compliance. The advantages include greater efficiency, larger power density and improved power quality result in economic benefits to the electricity service provider. The goal of this thesis is to develop a unity power factor rectifier. The motivation in developing this product was to develop a regulated power supply capable of producing power with low level of harmonic current distortion. This project observes the current, voltage waveform and also the harmonics component before and after the compensation to the nonlinear load. In this work MATLAB/SIMULINK power system toolbox is used to simulate the proposed system. Simulation results are presented and the improvement in the supply current will show in this work.

ABSTRAK

Bekalan Kuasa Mod Pensuisan merupakan industri yang menguntungkan dan berkembang pesat secara berterusan terutamanya dalam bidang elektronik kuasa. Ianya digunakan secara meluas dalam bidang perhubungan, komputer dan juga elektronik kuasa. Masalah yang dihadapi oleh pereka penerus adalah kesan perlaksanaan undang – undang terkini. Perundangan Eropah menghadkan kandungan harmonik pada bekalan kuasa. UPF mempunyai kelebihan dalam mematuhi undang – undang tersebut. UPF juga mempunyai kelebihan lain termasuk kecekapan, ketumpatan kuasa yang lebih besar dan meningkatkan kualiti kuasa yang akan memberi manfaat pada ekonomi terutama kepada pembekal perkhidmatan elektrik. Matlamat tesis ini adalah untuk membangunkan penerus berfaktor kuasa tinggi. Motivasi menghasilkan produk ini adalah untuk mmencipta bekalan kuasa terkawal yang mampu menghasilkan kuasa dengan tahap herotan harmonik yang rendah. Arus, gelombang voltan dan juga komponen harmonic sebelum dan selepas dibaiki akan diperhatikan dalam projek ini. Untuk kerja-kerja ini, program MATLAB / Simulink digunakan untuk mensimulasi sistem yang dicadangkan. Keputusan simulasi dan peningkatan arus bekalan akan dibentangkan dalam projek ini.

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LIST OF SYMBOLS

α	-	Alpha
β	-	Beta
$APLC$	-	Active Power Line Conditioner
APF	-	Active Power Filter
THD	-	Total Harmonic Distortion
p	-	Real Power
$\bar{p}$	-	Average Active Power
$\tilde{p}$	-	Instantaneous Active Power
P_{reg}	-	Regulated Power
q	-	Imaginary Power
$\bar{q}$	-	Average Reactive Power
$\tilde{q}$	-	Instantaneous Reactive Power
e_a, e_b, e_c	-	Instantaneous Voltages
i_a, i_b, i_c	-	Instantaneous Currents
PWM	-	Pulse Width Modulation
$icompA, B, C$	-	Reference currents
$icompA^*, B^*, C^*$	-	Compensation currents
VSI	-	Voltage Source Inverter
PI	-	Proportional Integral
LPF	-	Low-Pass-Fiter
C_1	-	DC-bus capacitor
$L_{f\,min}$	-	Minimum Interfacing Inductor

CHAPTER 1

INTRODUCTION

1.1 Background

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 thesis, 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.

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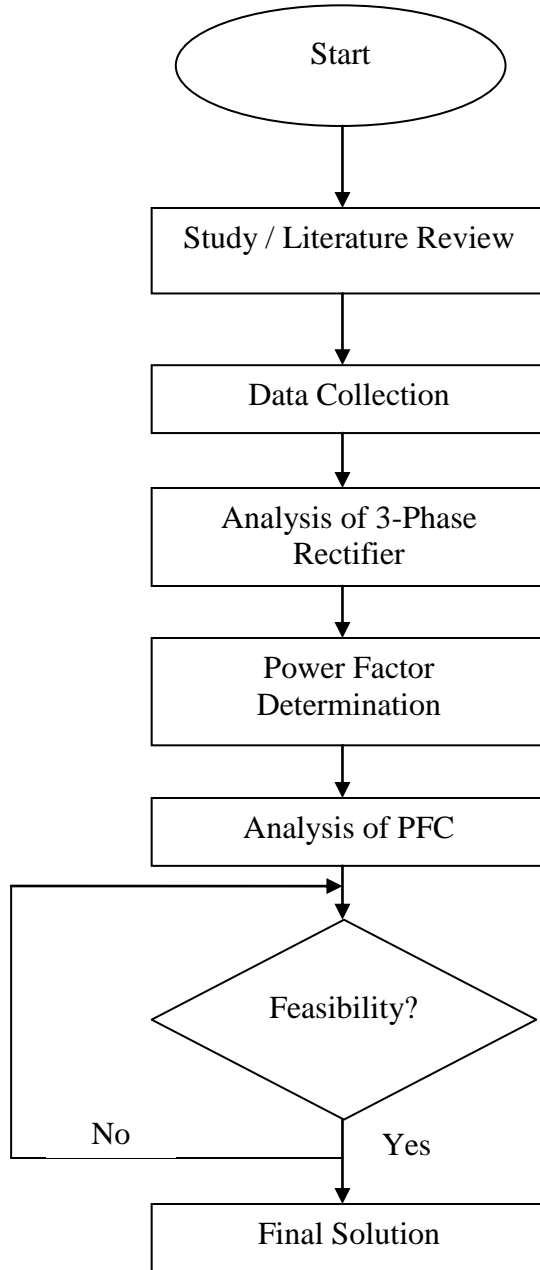
Figure 1. 1 – Workflow for the research

1.5   Thesis Outline

The thesis is organized into 5 chapters namely the introduction, literature reviews, methodology, simulations and results analysis, conclusion and recommendation.

Chapter 1 discuss the background and general idea of the proposed project. Besides that, the objective and scope of the project are stated too in this chapter.

Chapter 2 discuss the reviews of the literature which includes the principles of technique implemented in the design of proposed rectifier. The brief reviews of the control strategy used in the proposed active power filters are mentioned in this chapter too.

Chapter 3 shows the research methodology of each design stage. The details of the topology of the proposed are discussed in this chapter with the operations of the system.

Chapters 4 displays the simulation results and analyze the compensation performance of the three-phase rectifiers subject to a typical nonlinear load. The simulation design and the results of each stage will be observed

Chapter 5 presents conclusions and recommendations and future works and improvements that can be done for this system.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

The summary of results on previous research related to PFC techniques and input power factor corrected 3-phase rectifier systems are introduced in this chapter. Numerous 3-phase PFC topologies are classified and various PFC circuits for 3-phase rectifiers are reviewed. The study of PFC topologies is limited to single-phase systems since most SMPS are powered by a single-phase utility source.

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.

Energy Used (kW)

PF Angle

Energy Supplied (kVA)

Energy Wasted (kVAR)
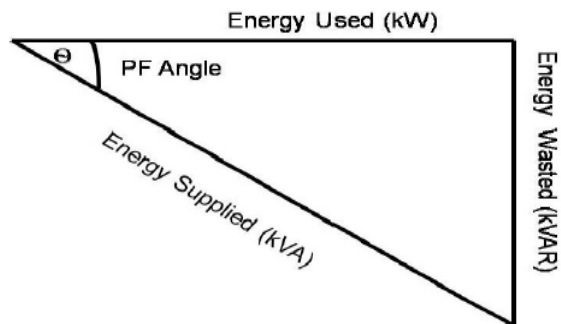
Figure 2. 1 - Power Factor Triangle

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

$VI \cos\theta$ – the active or real power in *Watts (W),*

$VI \sin\theta$ – the reactive power in *VAR* ,

VI – the apparent power in *VA*,

Power factor can determined as follows:

$$p.f \ (\cos\theta) = \frac{active \ power \ (W)}{apparent \ power \ (VA)}$$

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.

On the other hand, the load power is assumed to be constant. Every single-phase PFC converter requires energy-storage (bulk) capacitor to handle difference between instantaneous input power and average output power [Bosela].

There are several approaches that have been taken by power designers to improve the value of power factor when they are designing SMPS. Most of them make used of PPFC as a solution to improve the waveform of line current in order to reduce the harmonic contents generated by SMPS. These approaches can be described as follows.

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. It is difficult to achieve unity power factor with PPFC. Also, very large currents may circulate in the filter. However, the passive is an effective PFC solution in cases where the line frequency, line voltage and load are relatively constant [Talukdarl]. The various types of PPFC and the waveforms of input voltage and input current are discussed below and their associated waveforms are taken from the simulation results.

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.
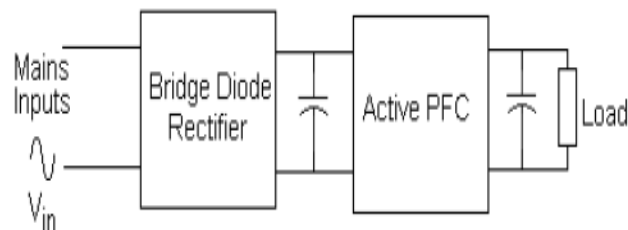

Figure 2. 2 – Block Diagram of An APFC Circuit

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:

$$P = \frac{V_{p^2} \sin \theta}{R}$$

Where V_p = 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 $sin^2\ \theta$ 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.
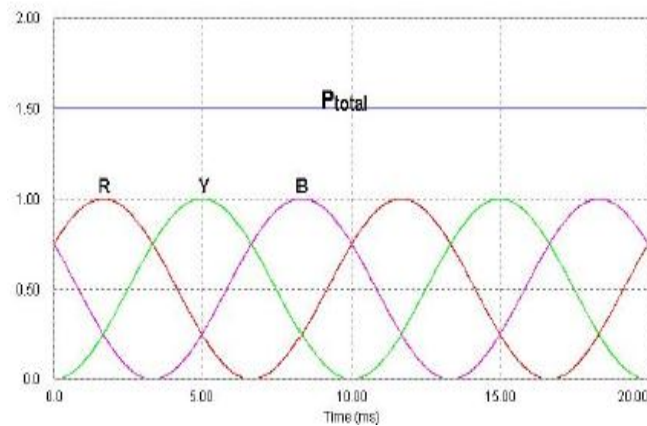
Figure 2. 3 – Three Phase Energy Transfer Model

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. A disadvantage with a boost derived topology is that unless bi-directional power flow is possible the circuit suffers from inrush currents during startup conditions.

Several buck derived topologies have been proposed which offer some attractive features compared to the boost topology, such as inherent short circuit protection, easy inrush current control, and low output voltage. The use of modular topologies is gaining in popularity as they offer a natural redundancy and independent control of modules can ensure power supply continuity during non-ideal mains conditions. The buck boost topology is another choice where inrush current control can be achieved, however this topology has efficiency penalties due to having at least two power semiconductors in the input current path as well as having poor silicon utilization factor [Kim, S., Yoo, G & Song, J]. These mentioned topologies are discussed in more detail further with the

emphasis on the suitability and realization effort of each topology, with regard to usage in the power converter market.

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].
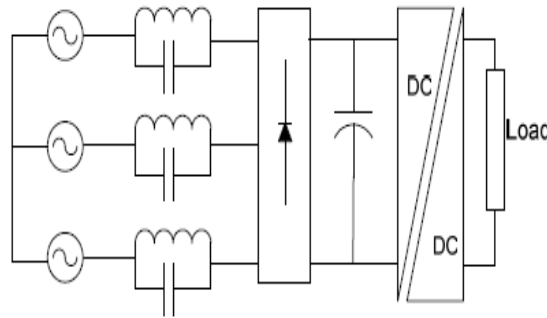
Figure 2. 4 - Rectifier Topology using Passive Input Filter

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.

Unidirectional switches can be used for simplicity at the expense of current control capabilities. The converter is controlled by an output voltage loop for output regulation,

and inner current loops which shape the input currents according to their sinusoidal references. The input inductors form part of the boost topology and, as such, work at the switching frequency [Granaghan]. As a result, input inductors operating at switching frequencies are smaller in size compared with line frequency input inductors.
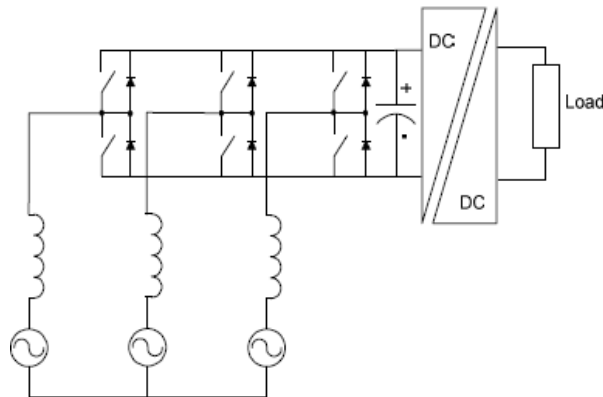

Figure 2. 5 - Six Switches Boost Power Converter

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. However, a DC-DC converter stage is still needed to provide isolation, voltage transformation and ripple reduction.
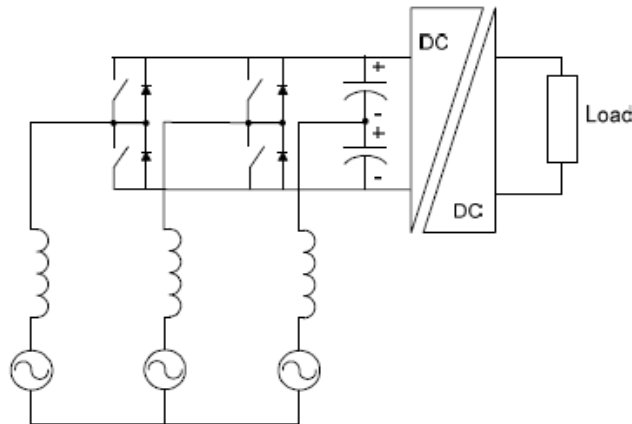

Figure 2. 6 - Four Switches Boost Power Converter

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 30°. 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. However, a DC-DC converter stage is still needed to provide isolation, voltage transformation and ripple reduction [Pinto].
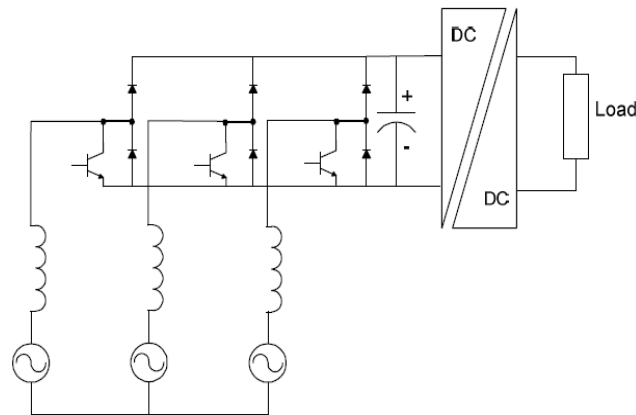
Figure 2. 7 - Three Switches Boost Power Converter

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.
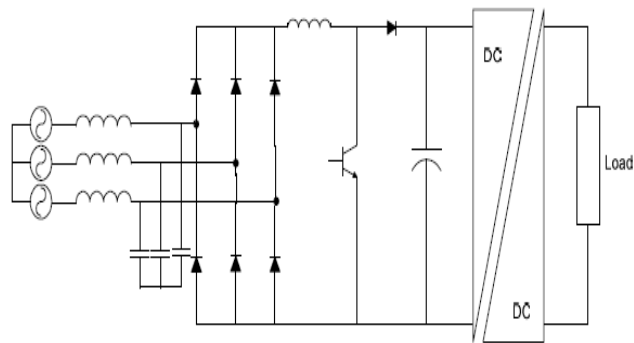
Figure 2. 8 - Single Switch Boost Power Converter

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 startup 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 [Arrillaga].
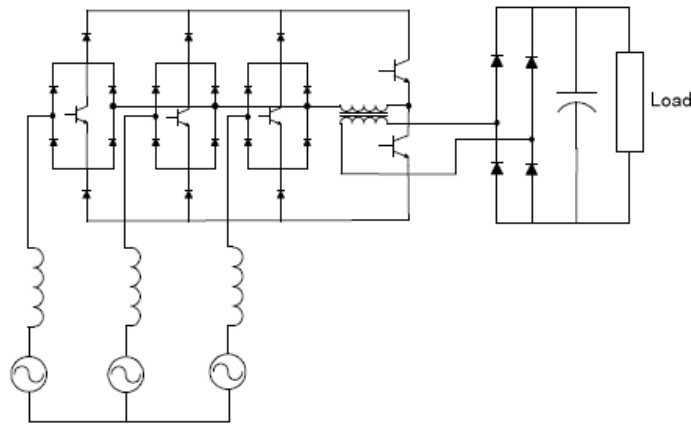
Figure 2. 9 - Vienna Rectifier

2.6   Buck Derived Power Converter Topologies

A buck derived topology has some attractive features compared to the boost topology, such as inherent short circuit protection, easy inrush current control, and low output voltage. In addition, its input currents can be controlled in open loop, and much wider voltage loop bandwidth can be achieved. Several three-phase buck derived topologies are discussed in the following subsections.

2.6.1   Six Switches Single-Stage Buck Power Converter

A basic six-switch isolated buck converter is shown in Figure 2.10. This type of converter directly converts the three-phase AC to DC in a single isolated buck-derived stage by splitting the conversion process into a three-phase cyclo-converter section. This is then used to synthesize the high frequency AC voltage from the three-phase input voltages [Madrigal]. The secondary AC signal is rectified and filtered to obtain the desired output DC voltage. The switching sequence of this type of converter can be implemented by either a look-up table or by an analogue derived PWM circuit with

distribution logic. This type of converter can be implemented as a hard switched or soft switched type. This topology can meet with all the telecommunication standards. However, it has the disadvantage of requiring AC switches and a complex control system.
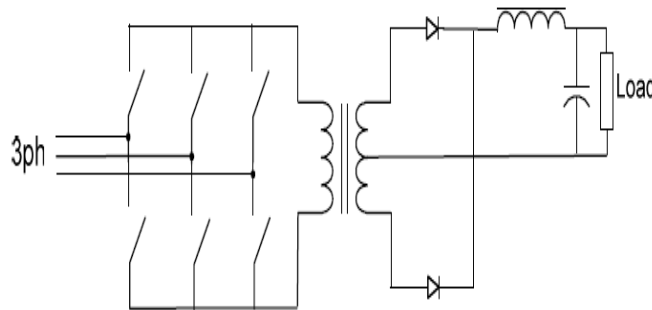

Figure 2. 10 - Six Switches Single-Stage Buck Power Converter

2.6.2   Six Switches Two-Stage Buck Power Converter

A six switch buck derived converter proposed in consists of IGBT switching devices connected in series with an ultra fast recovery diode, resulting in reverse voltage blocking capability and unidirectional current flow. The converter works on the principle of current control, and uses a direct phase control scheme based on a modulated space vector PWM method [Miller]. This topology is able to meet all the industrial standards with a second stage needed only for isolation and voltage transformation.
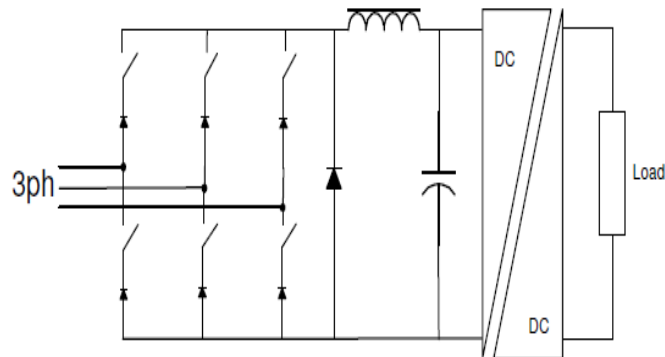
Figure 2. 11- Six Switches Two-Stage Buck Power Converter

2.6.3   Single Switch Buck Power Converter

The single switch buck converter, as seen in Figure 2.12, operates by having the voltages across the input capacitors discontinuous, resulting in high voltage peaks across the switch. An improved topology is introduced, which reduces the voltage stress across the switch. Using both topologies, 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 [Couto].

Both the single switch boost and buck topologies are limited in power because of the high stresses the switches must take. This is especially true of the buck converter, if the output voltage is low (i.e. 48V). In this case, the switch must remain open for a long time during the switching cycle. Accordingly, this results in the continual charging of the input capacitors, leading to high peak voltages across the switch.

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