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Power Factor Correction by Boost Converter

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Abstract: ***Conventionally the AC-DC conversion is done by making use of full wave bridge rectifier and a capacitor filter at the output to absorb the power pulsation there by reducing the ripple in the output voltage. But this conventional technique does not take account of the input power factor which must be high. Low power factor reduces the power available from the utility grid. An ideal power factor corrector must have a resistor on the supply side and at the same time it should maintain fairly regulated output voltage. The objective of the present paper is to design the proposed two switches Boost converter with high power factor and with the ability to set the output voltage arbitrarily. Firstly, this paper describes the modes of operations of the proposed convertor. Secondly, the average current control technique is applied to the Boost converter for power factor correction. Power Factor Correction (PFC) is generally used to compensate systems in which the source current and voltage wave forms are out of phase and distorted.***

Keywords: Power Factor Correction (PFC)

1. Introduction

The demand for power, which has been increased tremendously over the last few decades, has forced the power engineers to establish reliable network in order to supply the quality power to the consumer. Over the years lot of research has been carried out for the supply of quality power to the consumers. This research got a tremendous boost with the strides made in the miniaturization of the electrical industry. The power electronic devices are very versatile devices capable of delivering power as high as 10KW. These devices are capable of working at frequencies in the range of hundreds of KHz and at the same time the control being only at the gate terminal of the devices, which makes these devices easily controllable. Most of the equipment is supplied by 50/60 Hz utility power, and more than 50% of the power is processed through some kind of power convertors.

Conventionally, most of the power conversion equipments employ either diode rectifier or thyristor rectifier with bulk capacitor to convert AC voltage to DC voltage before processing it. Such rectifiers produce input current with rich harmonic content, which pollute the power system and the utility lines. Power quality is becoming a major concern for many electrical users. To measure the quality of input power of electrical equipment, power factor is a widely used term. The power factor of off-line equipment is defined as the product of two components the displacement between the voltage and current, but the input current distortion and current harmonics, since they pollute the power system and causes interference among off- line utilities. To limit the input current harmonics drawn by the off-line equipment, several international regulations such as the IEC 61000-3-2 and its corresponding Japanese regulation have been proposed, These specifications have prompted many power supply manufacturers to intensify their efforts towards finding simple and cost-effective solutions for complying with the specifications.

As a result, the techniques for reduction of input current harmonics have been intensively introduced and studied in recent years. Although the main objective is really Input-Current-Shaping (ICS), most people refer their work as power-factor-correction (PFC). Various types of single-phase PFC converter circuits have been developed and used to improve the AC current waveform. The PFC converter is constructed by use of a boost chopper circuit with a switching device in the DC side of the diode bridge rectifier circuit. A sinusoidal current waveform in phase with the AC line voltage and the constant DC voltage can be obtained from the PFC converter.

This paper describes the average current control technique applied to boost converter. In this technique there are two loops attached to the Boost converter. The inner loop is the current loop which has a current error amplifier. The current error amplifier will improve the power factor of the circuit by comparing the input current with sinusoidal current reference. The outer loop has two main functions to serve. Firstly, the voltage error amplifier of the outer loop will regulate the output voltage and secondly it minimizes the distortion. The proposed two switch converter together with the power factor correction circuit can be applied to a single phase power factor correction. The basic requirement of Boost converter is that the output voltage must be higher than the input voltage. This condition limits its application for wide range of output voltage.

2. Introduction to Non Linear Loads

In the last years the use of electronic equipment has been increasing rapidly. This equipment draws a different current from the AC mains when compared to traditional loads such as motors and resistive heating elements. The current drawn from the AC mains has harmonic components, which leads to low power factor, low efficiency, interference in some instruments and communication equipment. A classical solution is the use of passive filters to suppress harmonics in power systems. However, passive filters have many disadvantages, such as large size, resonance, and fixed compensation characteristics. Therefore, it does not provide a complete solution. Non-linear loads change the shape of the current waveform from a sine wave to some other form.

Non-linear loads create harmonic currents in addition to the original (fundamental frequency) AC current. Filters consisting of linear capacitors and inductors can prevent harmonic currents from entering the source system. In linear circuits having only sinusoidal currents and voltages of one frequency, the power factor arises only from the difference in phase between the current and voltage. This is of importance in practical power systems which contain non-linear loads, such as rectifiers, some forms of electric lighting, electric arc furnaces, welding equipment, switched-mode power supplies and other loads.

1) Definition of Linear Loads

A device is considered non-linear load if it's impedance changes with the applied voltage. The changing impedance means that the current drawn by a non-liner load will not be sinusoidal. These non-sinusoidal currents contain harmonic currents that interact with the impedance of the power distribution system to create voltage distortion that can affect both the distribution system equipment and the loads connected to it. For **Linear load** voltage & currents are in phase with each shown in figure.

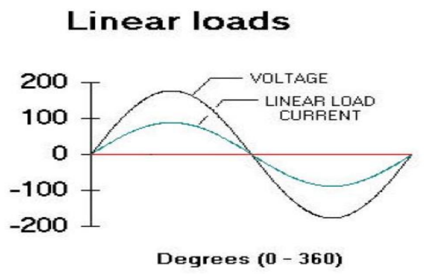

Figure 2.1: Typical voltage & current wave forms.

For Non-Linear loads voltage & currents are out of phase with each shown in figure.

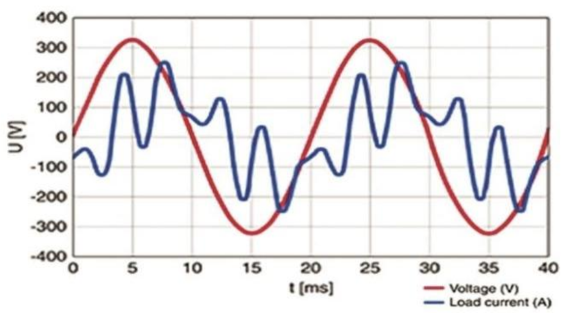

Figure 2.2: Typical voltage & current waveforms for Non-linear loads

2) Example for Non-linear Loads

The term non linear load is commonly used to describe the switch mode power supply found in personnel computers in fact this type of power supply is used commonly in a myriad of applications. Microwave ovens, laser printers, medical instruments, stereos and electronic lighting are 6- pulse phase angle controlled loads and 12-pulse rectified supplies variable speed drives commonly use 6-pulse rectified and phase angle controlled power supplies.

A typical switched-mode power supply first makes a DC bus, using a bridge rectifier or similar circuit. The output voltage is then derived from this DC bus. The problem with this is that the rectifier is a non-linear device, so the input current is highly non-linear. That means that the input current has energy at harmonics of the frequency of the voltage. This presents a particular problem for the power companies, because they cannot compensate for the harmonic current by adding simple capacitors or inductors, as they could for the reactive power drawn by linear device.
Many jurisdictions are beginning to legally require power factor correction for all power supplies above a certain power level. In the past, non-linear loads were primarily found in heavy industrial applications such as arc furnaces, large variable frequency drives (VFD), heavy rectifiers for electrolytic refining, etc. The harmonics they generated were typically localized and often addressed by knowledgeable experts. Non Linear devices are: computer, rectifiers, PLC etc.

3) Effects of Non-Linear Loads

Non-sinusoidal currents contain harmonic currents that interact with the impedance of the power distribution system to create voltage distortion that can affect both the distribution system equipment and the loads connected to it. The nature of non-linear devices is to generate harmonics in the current waveform. This distortion of the current waveform leads to distortion of the voltage waveform. Under these conditions, the voltage waveform is no longer proportional to the current.

4) Total Harmonic Distortion (THD)

Harmonic problems are almost always introduced by the consumer's equipment and installation practices. Harmonic distortion is caused by the high use of Non-Linear load equipment such as computer power supplies, electronic ballasts, compact fluorescent lamps and variable speed drives etc, which create high current flow with harmonic frequency components. The limiting rating for most electrical circuit elements is determined by the amount of heat that can be dissipated to avoid overheating of bus bars, circuit breakers, neutral conductors, transformer windings or generator alternators.

$$\text{Power Factor} = \frac{1}{\sqrt{1 + \text{THD}^2}}$$

Total Harmonic Distortion of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency.

5) Cost Effect Due to Harmonics

Harmonic currents add to the fundamental load current and can affect revenue billing by introducing errors into kilowatt hour metering systems, which will directly increase the net kilowatt demand and kilowatt hour consumption charges. The commercial effects of harmonic distortion to power quality are dramatically shorter equipment lifetimes, reduced energy efficiency. The cost of supply interruption is high, however caused, resulting in data corruption, disruption of process manufacturing and failure of telecommunications facilities etc.

3. Boost Convertor

There are various types of converters which can be applied to power factor correction such as canonical switching cell (CSC), CUK converter, and Zeta converter. The CSC converter is the main block for all high frequency switching converters. It is found that the CSC converter has minimum components and it is reasonable. The CSC converter is suitable for single phase rectifier circuit with power factor correction.

It is shown that CSC converter is suitable for this application because of its high input impedance and low output impedance .For large capacity applications ZETA converters are used. However, these converters do not take in to account the output voltage regulation, component stresses, second harmonics of line frequency which leads to distortion of output voltage and the interference due to commutation noises. Average current control technique method simplifies the closed loop output and input impedance of the converters.

1) Boost Convertor

A boost converter (step-up converter) is a power converter with an output DC voltage greater than its input DC voltage. It is a class of Switched Mode Power Supply (SMPS) containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element.

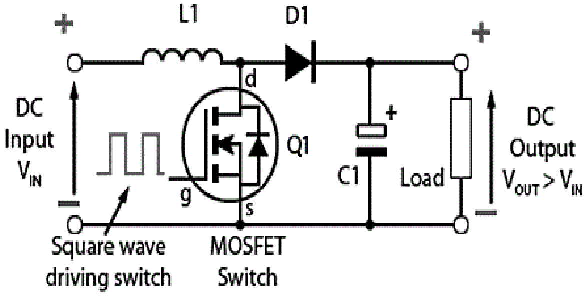

Figure 3.1: Boost Converter

2) Boost Mode of Operation

Fig: 3.2 (a), 3.2 (b) shows the sequence 1 and 2 of Boost mode. In **Sequence1** switch Q_1 is **ON** and in **Sequence 2** switch Q_1 is **OFF.**

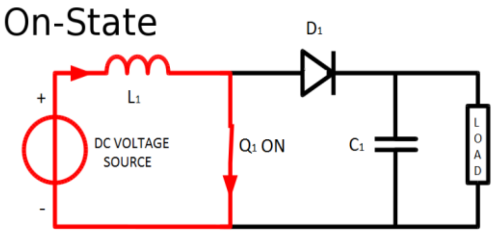

Figure 3.2: (a) Sequence 1, Switch Q_1 is ON

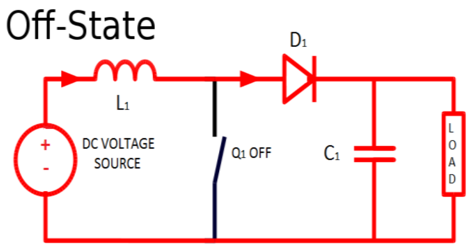

Figure 3.2: (b) Sequence 2, Switch Q_2 is OFF

3) Proposed Block Diagram

The proposed Block Diagram of Power Factor Correction by Boost Convertor is shown as follows

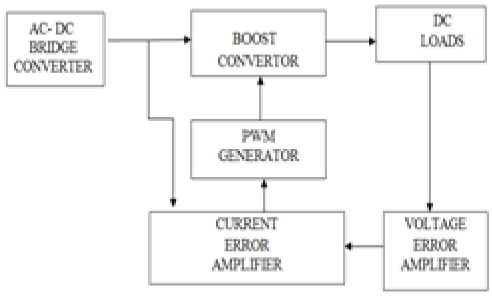

Figure 3.3: Proposed Block Diagram of Boost Convertor

The power factor of a boost converter is with power factor correction technique which is average current control technique. In this technique a PWM generator, current error amplifier & voltage error amplifier are used in a feedback circuit to improve the power factor at input side and voltage regulation in output side. DC load used in this is resistive. The proposed power factor correction circuit with PWM Generator is having input, output and feedback path as shown in fig.3.3.

4) Switching Agent (MOSFET)

Modern Power Electronics makes generous use of MOSFETS and IGBTS in most applications and, if the present trend is any indication, the future will see more and more applications making use of MOSFETS and IGBTS. Although sufficient literature is available on characteristics of MOSFETS and IGBTS, practical aspects of driving them in specific circuit configurations at different power levels and at different frequencies require that design engineers pay attention to a number of aspects. An attempt is made here to review this subject with some illustrative examples with a view to assist both experienced Design Engineers.

Due to the absence of minority carrier transport, **MOSFETS** can be switched at much higher frequencies, the limit on this is imposed by two factors: transit time of electrons across the drift region and the time required to charge and discharge the input Gate and '**Miller**' capacitances.

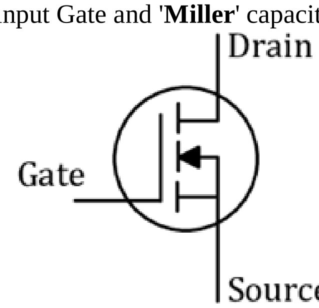

Figure 3.4: Symbol of N-Channel MOSFET

The MOSFET switch topology as in the proposed converter offers higher efficiency, reduced component stresses and ability to arbitrarily choose the DC output voltage. Moreover, the proposed converter will have lower voltage stresses on the components as compared to conventional single switch Boost.

5) PWM Techniques

Because of advances in solid state power devices and microprocessors, switching power converters are used in more and more modern motor drives to convert and deliver the required energy to the motor. The energy that a switching power converter delivers to a load is controlled by Pulse Width Modulated (PWM) signals applied to the gates of the power transistors. PWM signals are pulse trains with fixed frequency and magnitude and variable pulse width.

There is one pulse of fixed magnitude in every PWM period. However, the width of the pulses changes from pulse to pulse according to a modulating signal. When a PWM signal is applied to the Base of a power transistor, it causes the turn on and turns off intervals of the transistor lo change from one PWM period to another PWM period according to the same modulating signal. The frequency of a PWM signal must be much higher than that of the modulating signal, the fundamental frequency, such that the energy delivered to the motor and its load depends mostly on the modulation.

Advantages of PWM

The advantage of PWM based switching power converter over linear power amplifier is:

- Easy to implement and control.
- No temperature variation-and ageing-caused drifting.
- Degradation in linearity.
- Compatible with today's digital micro processors.
- Lower power dissipation.
- It allows linear amplitude control of the output Voltage/Current from previously.

Disadvantages of PWM

- Attenuation of the wanted fundamental component of the PWM wave form, in this case from 1.1-0.866 PU.
- Generation of high-frequency harmonic components.

4. Power Factor Correction Techniques

The attention devoted to the quality of the currents absorbed from the utility by electronic equipment is increasing due to several reasons. In fact, a low power factor reduces the power available from the utility grid; while a high harmonic distortion of the line current causes EMI problems and cross-interferences, through the line impedance, between different systems connected to the same grid. From this point of view, the standard rectifier employing a diode bridge followed by a filter capacitor gives unacceptable performances. Thus, many efforts are being done to develop interface systems which improve the power factor of standard electronic loads.

An ideal power factor corrector (PFC) should emulate a resistor on the supply side while maintaining a fairly regulated output voltage. In the case of sinusoidal line voltage, this means that the converter must draw a sinusoidal current from the utility; in order to do that, a suitable sinusoidal reference is generally needed and the control objective is to force the input current to follow, as close as possible, this current reference. The most popular topology in PFC applications is certainly the boost topology, together with a generic controller.

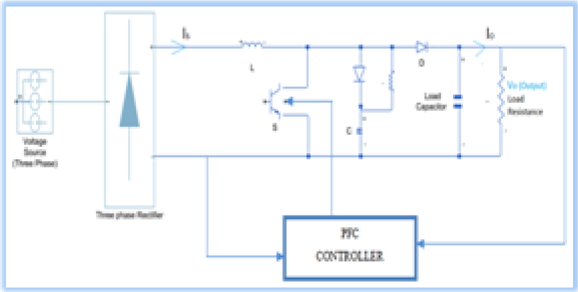

Figure 4.1: Principle scheme of a boost PFC

In the proposed technique, the converter works in continuous inductor current mode (CICM) which will reduce the input filter requirements. Average current control technique offers certain advantages such as, constant switching frequency; control is less sensitive to commutation noises due to current filtering. Above all the overall circuit is simple and cost effective.

PFC Control Techniques

1) Average Current Control
2) Peak Current Control
3) Hysteresis Control
4) Borderline Control
5) Discontinuous Current PWM Control

Each one can be explained as follows

1) Average Current Control

A better input current waveform is obtained in average current control technique. Here the inductor current is sensed and filtered by a current error amplifier whose output drives a PWM modulator. In this way the inner current loop tends to minimize the error between the average input current I_g, and its reference. This latter is obtained in the same way as in the peak current control. The converter works in CICM, so the same considerations done with regard to the peak current control can be applied.

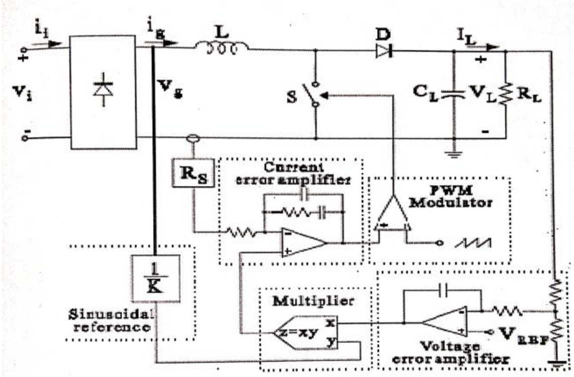

Figure 4.2: Average Current Control Scheme

Advantages

- Constant switching frequency;
- No need of compensation ramp;
- Control is less sensitive to commutation noises, due to current filtering;
- Better input current waveforms than for the peak current control since, near the zero crossing of the line voltage, the duty cycle is close to one, so reducing the dead angle in the input current.

Disadvantages

- Inductor current must be sensed;
- A current error amplifier is needed and its compensation network design must take in to account the different converter operating points during the line cycle.

2) Peak Current Control

In the peak current control the sum of the inductor current (i.e., the switch current) and an external ramp (compensating ramp) reaches the sinusoidal current reference. The reference signal is naturally synchronized and always proportional to the line voltage, which is the condition to obtain unity power factor.

Advantages

- Constant switching frequency.
- Only the switch current must be sensed and this can be accomplished by a current transformer, thus avoiding the losses due to the sensing resistor.
- No need of current error amplifier and its compensation network.
- Possibility of a true switch current limiting.

Disadvantages

- Presence of sub harmonic oscillations at duty cycles greater than 50%, so a compensation ramp is needed;
- Input current distortion which increases at high line voltages and light load and is worsened by the presence of the compensation ramp;
- Control more sensitive to commutation noises.

3) Hysteresis Control

In this control in which two sinusoidal current reference I_p, I_v are generated, one for the peak another for valley of the inductor current.

Advantages:

- No need of compensation ramp;
- Low distorted input current waveforms.

Disadvantages:

- Variable switching frequency;
- Inductor current must be sensed;
- Control sensitive to commutation noises.

4) Border Line Control

In this control approach the switch on-time is held constant during the line cycle and the switch is turned on when the inductor current falls to zero, so that the converter operates at the boundary between continuous and discontinuous current mode (CICM-DICM).

Advantages:

- No need of a compensation ramp;
- No need of a current error amplifier;
- For controllers using switch current sensing, switch current limitation can be introduced.

Disadvantages:

- Variable switching frequency;
- Inductor voltage must be sensed in order to detect the zeroing of the inductor current;
- For controllers in which the switch current is sensed, control is sensitive to commutation noises.

5) Discontinuous Current PWM Control

With this approach, the internal current loop is completely eliminated, so that the switch is operated at constant on-time and frequency. With the converter working in discontinuous conduction mode (DCM), this control technique allows unity power factor.

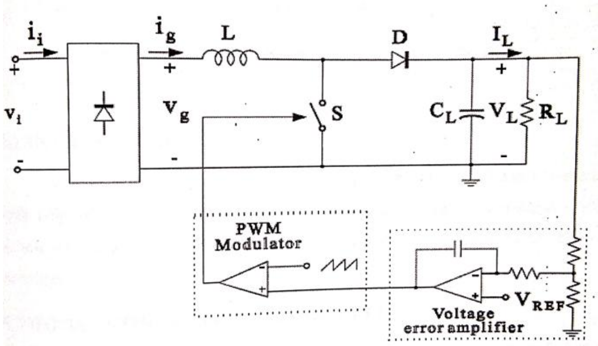

Figure 4.3: Discontinuous Current PWM Control Scheme

Advantages

- Constant switching frequency;
- No need of current sensing;
- Simple PWM control.

Disadvantages

- Higher devices current stress than for border line control;
- Input current distortion with boost topology.

5. Conclusion

Power factor correction of Boost converter is done by using average current control and discontinuous current control. The inner loop has a current error amplifier which improves the power factor by properly shaping the input current in accordance with its reference. This reference signal is always synchronized and proportional to line voltage hence the input current comes in phase with the input voltage. Thus but improving the power factor maximum active power can be delivered to the load. The voltage loop is being controlled by the voltage error amplifier and the multiplier.

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