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A Comparative Study and Analysis of Power Factor Control Techniques

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Abstract: - Power factor correction (PFC) is the capacity of absorbing the reactive power produced by a load. The major industrial loads have an inductive power factor. The current tends to go beyond the power is usually used for the power conversion. This paper presents an active input power factor correction with single phase boost converter topology using various control techniques. A comparative study of several analog and digital power factor control techniques is studied. This investigation is to identify a low cost, efficient and reliable PF control technique. Digital implementation by using Microcontroller and DSP achieves more reliability. For Digital Signal Processor based PFC technique power factor is above 0.99 and very close to unity.

Keywords: Power Factor Correction, Digital Signal Processor, PF Control Technique,

1. Introduction

In recent years, the power quality of the AC system has become a great concern due to the rapidly increased numbers of electronic equipment, power electronics and high voltage power system. Now passive PFC schemes are implemented & used by customer for commercial & industrial applications.

Drawbacks of Passive PF Method:

- Large size of reactive elements.
- Power factor improvement for a narrow operating region.
- Large output dc voltage ripple.

Active high frequency power factor correction makes the load behave like a resistor, leading to near unity load power factor and the load generating negligible harmonics for variable loads.

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To compensate for the higher reactive power demand by the converters at high power transfer levels, power factor correction becomes mandatory. This is also consistent with the goals of switch mode conversion. A variety of topologies can be used including the boost converter and the buck converter. For reasons of relative simplicity and popularity, the boost converter is described here.

A diode rectifier effects the ac/dc conversion, while the controller operates the switch in such a way to properly shape the input current ig according to its reference shown in Fig.1. The output capacitor absorbs the input power pulsation, allowing a small ripple of the output voltage VL. The boost topology is very simple and allows low-distorted input currents and almost unity power factor with different control techniques. Moreover, the output capacitor is an efficient energy storage element due to the high output voltage value and the ground-connected switch simplifies the drive circuit [1-2].

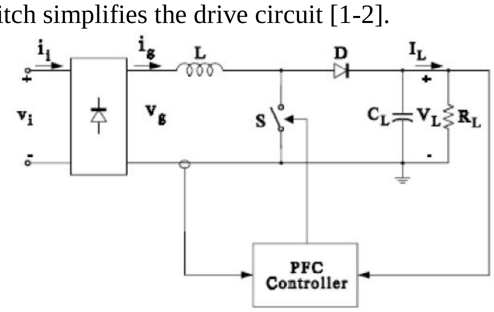

Fig.1 – Boost Converter with active PFC

The paper is organized as follows: Section II provides seven different PF control techniques. Section III describes the analysis of all the control techniques. Section IV presents some conclusion along with future issues that need to be addressed.

2. PF Control Techniques

A) Continuous Current Mode Control:

1. INDUCTOR CURRENT CONTROL

The switching pre-regulator circuit of Fig. 2 is a high frequency boost converter. The output voltage of the pre-regulator can be transformed via conventional switched-mode methods to generate low voltage dc outputs. There are twocontrollers in the pre-regulator circuit. These are the voltage and current-loop controllers. The voltage-loop controller regulates the output voltage around the desired nominal value while the current-loop controller shapes the inductor current into a rectified sinusoid in phase with the input ac voltage. Thus, near unity power factor can be achieved.

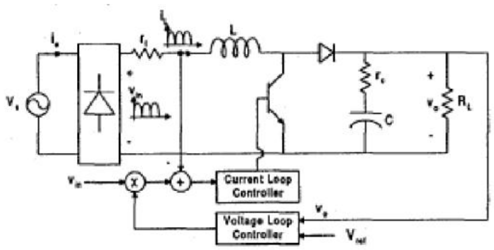

Fig.2 - Boost Converter with switching pre-regulator under current mode control technique.

The controller specifies a peak switch current in each cycle, or a peak inductor current, rather than the duty cycle. The switch is turned on at the beginning of the switching cycle, and is turned off when its current reaches a specified upper threshold value, im. This threshold value is the primary control variable and the duty ratio becomes an indirectly determined auxiliary variable. This method has lead to an inductor current that approximates a rectified sinusoid in phase with the input voltage. It can yield power factors in the range of 0.95 to 0.99, which reduces the total harmonic distortion of the source voltage amplitude, permits the use of a smaller capacitor.

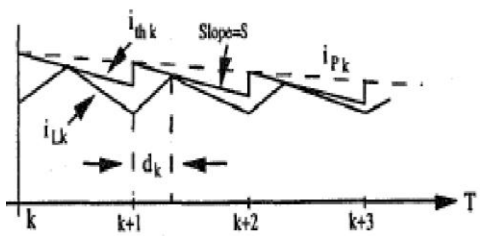

Fig. 3: Inductor current under CMC

Fig. 3 shows the relationship between the threshold current and the inductor current. The threshold current, ith, is determined from the sum of two signals: a slowly varying signal, ip, determined by the voltage controller on the basis of the discrepancy between the reference and output voltages, and a regular saw-tooth ramp of slope-S at the switching frequency.

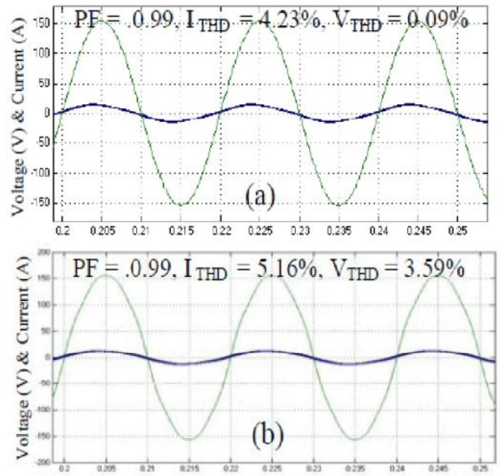

Fig.4 - Simulation Results; Performance of Boost converter using CMC

2. PEAK CURRENT CONTROL

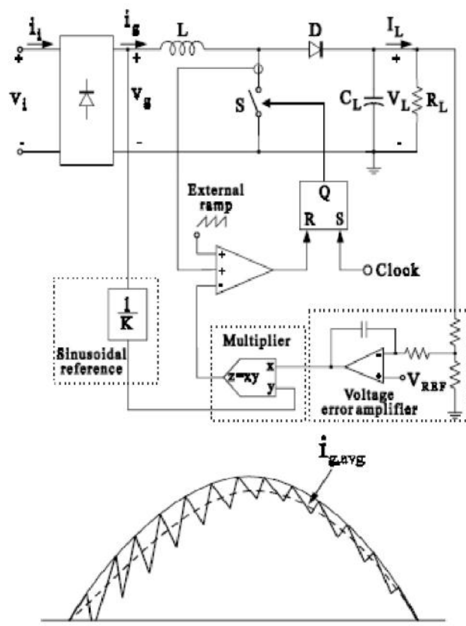

Fig.5 - Peak current control technique

The switch is turned on at constant frequency by a clock signal, and is turned off when the sum of the positive ramp of the inductor current or switch current and a compensating ramp reaches the sinusoidal current reference. This reference is usually obtained by multiplying a scaled replica of the rectified line voltage vg times the output of the voltage error amplifier, which sets the current reference amplitude. In this way, the reference signal is naturally synchronized and always proportional to the line voltage, which is the condition to obtain unity power factor. As Fig.5 reveals, the converter operates in Continuous

Inductor Current Mode (CICM); this means that devices current stress as well as input filter requirements are reduced. Moreover, with continuous input current, the diodes of the bridge can be slow devices (they operate at line frequency). On the other hand, the hard turn-off of the freewheeling diode increases losses and switching noise, calling for a fast device [3].

***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. AVERAGE CURRENT CONTROL

It allows a better input current waveform, is the average current control represented in Fig.6. 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 ig 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 [4].

***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 into account the different converter operating points during the line cycle.

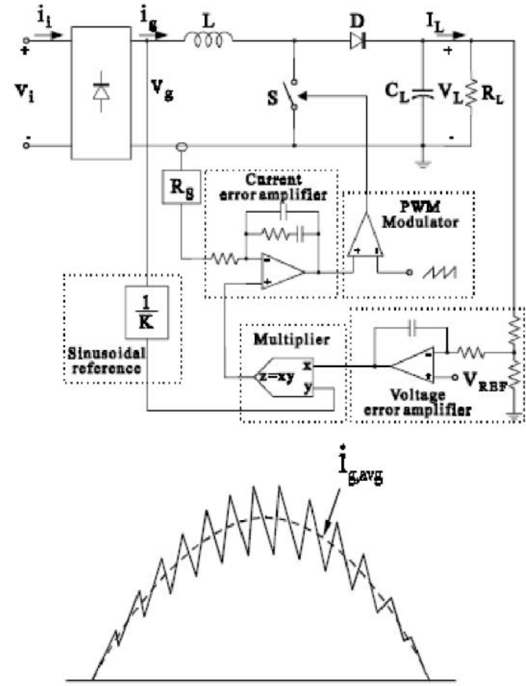

Fig.6 - Average current control technique

B) 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 .As shown in Fig.7, with the converter working in discontinuous conduction mode (DCM), this control technique allows unity power factor when used with converter topologies like flyback, Cuk and Sepic. Instead, with the boost PFC this technique causes some harmonic distortion in the line current.

***Advantages*:**
- Constant switching frequency;
- No need of current sensing;
- Simple PWM control;

***Disadvantages*:**
- Higher devices current stress than for borderline control;
- Input current distortion with boost topology.

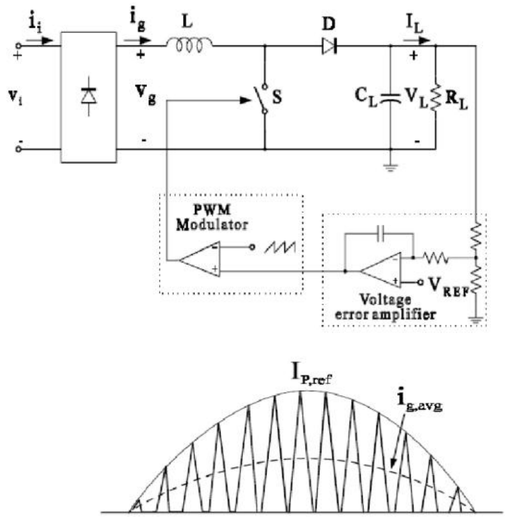

Fig.7 - Discontinuous current PWM control technique

C) Digital Signal Processor Control

DSP controllers provide many distinctive advantages over Traditional analog control, viz:

1. Standard control hardware design for multiple platforms.
2. Less susceptibility to aging and environmental variations.
3. Better noise immunity.
4. Ease of implementation of sophisticated control algorithms.
5. Flexible design modifications to meet a specific customer need.

Fig. 8 shows circuit diagram of PFC using digital technique a typical power-factor-corrected rectifier based on a boost converter. Current loop is designed so that the converter input current follows the waveform of the input voltage. In the ideal case these two waveforms have the same wave shape and are in phase, thus the rectifier presents a resistive load to the system. The outer loop regulates the voltage across the energy-storage capacitor. This voltage always has ripple at twice the line frequency 2 L. To maintain low input current harmonics output of the voltage regulator u(t) must not have significant line frequency harmonics. Consequently, to avoid distortion of the ac line current through feedback, the capacitor voltage ripple in conventional designs the bandwidth of the voltage loop is limited to frequencies significantly lower than the line frequency (typically 10- 20Hz).

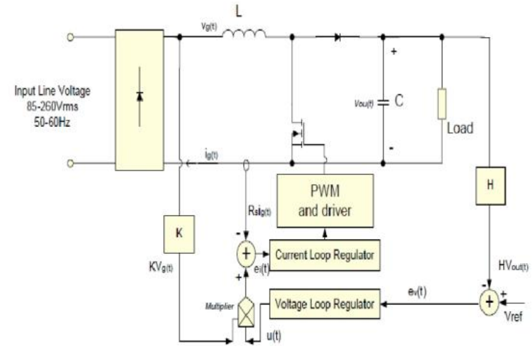

Fig.8 - Digital Signal Processor Control technique

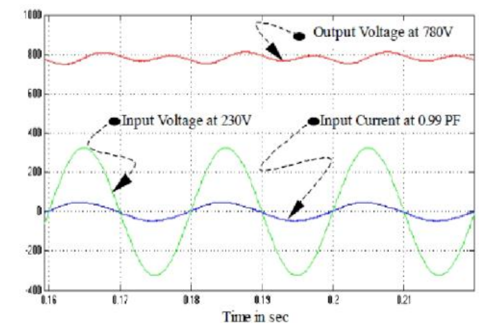

Fig.9 - Simulation Results; Performance of Boost converter using DSP Control

To increase systems reliability, it is proposed to implement converter controls in digital domain. Digital implementation also enhances systems programmability and reliability by removing few drawbacks of analog implementation such as parts count, ageing and environment effects and limited flexibility [5-6].The recently available high-speed digital signal processor executes controller algorithm faster and enhances converter-switching frequency to 20 kHz and higher. The control algorithm written in high-level language provides ease and flexibility. The digital implementation reduces number of components, increases reliability and hence attractive for UPS application.

3. Comparative Analysis

Table: 1 shows comparison of analog and digital control techniques. Simulation results of current mode and DSP control techniques are shown in Fig. 4 and Fig. 9.

Table: 1 Comparison of analog and digital control techniques for PFC.

Control Techniques	Features	Power Factor
Continuous current	**Inductor/Peak current control used**	**0.95-0.99**
Discontinuous current	**Simple PWM control**	**PF close to unity**
Digital Signal Processor	**Flexible design modification and easy implementation**	**above 0.99 to very close to unity**

4. Result and Conclusion

In this paper a comprehensive summary of several control techniques are studied and analyzed for PFC boost converter. The analog and digital control techniques are compared for variable load. Current mode controls have presence of sub harmonic oscillations and more sensitive to commutation noises. A DSP based control technique also enhances systems programmability and reliability and it is most suitable latest technique for achieve very close unity power factor than others.

Three phase boost converter PFC is one of the important future issue for various load demand for industrial applications.

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