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Design and Simulation of Power Factor Correction Boost Converter using Hysteresis Control

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ABSTRACT

Nowadays various power converters like AC-DC or DC-DC are widely used due to their flexible output voltage and high efficiency. But these converters take the current in the form of pulses from the utility grid so that the high Total Harmonic Distortion (THD) and poor Power Factor (PF) are the major disadvantages of these converters. Hence there is a continuous need for PF improvement and reduction of line current harmonics. The most popular topology for Active Power Factor Correction (APFC) is a boost converter as it draws continuous input current. This input current can be manipulated by Hysteresis control technique. The boost converter can perform this type of active power factor correction in many discontinuous and continuous modes. The design and simulation of boost converter with power factor correction in continuous conduction mode is represented by using MATLAB/SIMULINK software.

KEYWORDS: *APFC, Boost Converter, Hysteresis Control, PF, THD*

I. INTRODUCTION

Most electronic devices are supplied by 50 Hz or 60 Hz utility power supplies. Almost in all of the devices power is processed through some kinds of power converters such as AC-DC or DC-DC or DC-AC. Rectifiers i.e. AC to DC power converters are typically used in SMPSs (switch-mode power supplies), ASDs (adjustable-speed drives), UPSs (uninterrupted power supplies), power provisions for communication system devices, test devices etc [1].

An AC-DC converter consisting of line frequency diode bridge rectifier with a large filter capacitor is cheap and robust, but demands a harmonic rich AC line current. So the input power factor is poor [2].These converters rectify the input AC line voltage to obtain DC output voltage, but this DC voltage oscillates between zero to peak. The filter capacitor is used to reduce the ripple present in the output voltage but introduces distortion in the input current which results in poor PF and high THD [3]. So the conventional capacitor filter is replaced by boost converter which helps in making power factor unity [4].

If there is no power factor correction circuit in the input rectifier followed by a capacitive filter draws pulsating currents from the utility grid. So the power quality become poor and the higher harmonic contents in the power creates bad affect to the other users fed from same grid. Higher harmonics in the current affects the utility grid and other users appliances as well [5].

Various power Factor correction (PFC) techniques are employed to overcome these power quality problems out of which the boost converter topology has been extensively used in various AC-DC and DC-DC appliances [6].The boost topology is very simple and allow low-distorted input currents and almost unity power factor with different control techniques [7]. Boost converter topology in continuous conduction mode (CCM) is used in medium power AC-DC converter, as it gives near unity power factor at AC input [8].

A power factor correction circuit inserted between the line and nonlinear load can give both stable output DC voltage and input side high power factor [9]. PFC methods based on passive and active topologies are discussed and by using active PFC topology the source current is made sinusoidal with minimum THD and almost unity power factor (PF) [10].

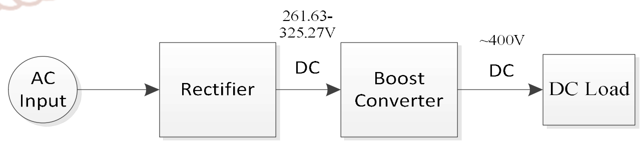

Fig.1, Block Diagram of Conventional AC-DC Boost Converter

II. COMPONENTS OF SYSTEM

A. Diode Bridge Rectifier

A diode bridge rectifier is an arrangement of four diodes in a bridge circuit configuration that provides the same polarity of output for either polarity of input. When used in its most common application, for conversion of alternating-current input into a direct-current output, it is known as diode bridge rectifier. The DC output voltage can be calculated by (1)

$$V_{dc} = \frac{2V_{max}}{\pi} \qquad (1)$$

$$V_{max} = \sqrt{2}V_{rms} \qquad (2)$$

Where, Vmax=maximum peak value
Vrms=root means square of voltage

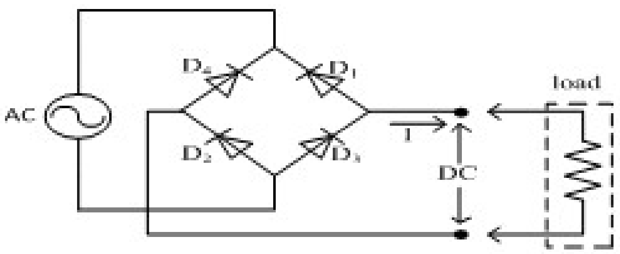

Fig. 2, Circuit diagram of the diode bridge rectifier

B. Smoothing Capacitor

A smoothing capacitor is used in conjunction with a rectifier circuit. It acts to smooth or even out fluctuations in a signal. It is placed across the output of the rectifier and in parallel with the load. Usually when choosing the smoothing capacitor, it is used from anywhere from 10µF to a few thousand µF. The greater the amplitude of the fluctuations and greater the waveform, the larger capacitor will be necessary.

$$C_f = \frac{V_{max}}{2fRV_{r(pp)}} \qquad (3)$$

Assuming,
Vr(pp) = 5%of output voltage
(peak to peak ripple voltage, V)
f = line frequency (50 Hz)
R = load resistance (Ω)

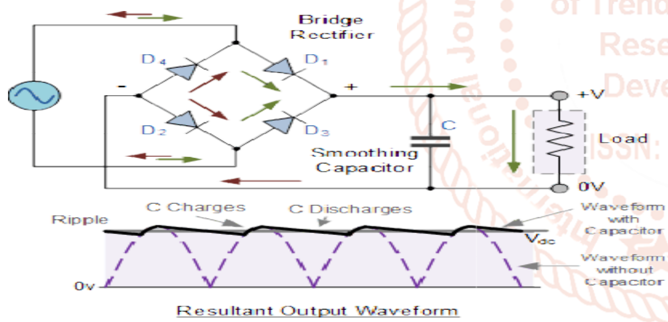

Fig. 3, Resultant output waveform with and without smoothing capacitor

C. DC-DC Boost Converter

Power of the boost converter can come from any suitable DC sources, such as DC generators, batteries, solar panels and rectifiers. The method that changes one DC voltage to a different DC voltage is called DC to DC conversion. Generally, a boost converter is a DC to DC converter with an output voltage greater than the source voltage. It is sometimes called a step-up converter since it "step-up" the source voltage. It is a class of switched-mode power supply (SMPS) consists of a power MOSFET, a diode, inductor and capacitor. This converter has the filter inductor on the input side, which provides a smooth continuous input current waveform. Capacitor is normally added to the output of the boost converter to reduce the output voltage ripple.

$$V_{out} = \frac{1}{1-D} V_{in} \qquad (4)$$

Here, D is the duty cycle. Vin is the rectified input voltage and Vout is the output voltage.

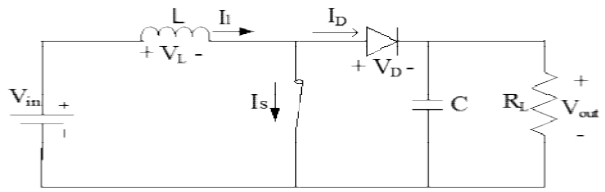

Fig. 4, Mode (1) Operation of DC-DC Boost Converter

When the switch is ON,

$$L\frac{di_L}{dt} = V_{in} \qquad (5)$$

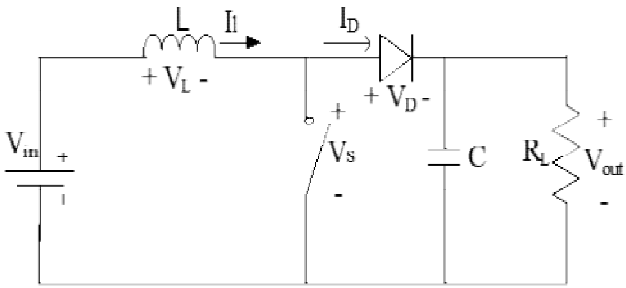

Fig. 5, Mode (2) Operation of DC-DC Boost Converter

When the switch is OFF,

$$L\frac{di_L}{dt} = V_{in} - V_{out} \qquad (6)$$

During mode (1) operation, energy is stored in the inductor. Load is supplied by capacitor current. During mode (2) operation, energy stored in the inductor is transferred to the load together with the input voltage. Energy is charged in the capacitor.

The design calculation of the boost converter can be calculated by the following equations. The single-phase rectified line voltage Vin can be calculated by

$$V_{in} = \sqrt{2}V_{rms} \qquad (7)$$

Maximum and minimum value of DC voltage Transfer function is given by (8)

$$M_{VDC(max,min)} = \frac{V_{out}}{V_{in(min,max)}} \qquad (8)$$

Maximum and minimum load resistance is given by the relation

$$R_{L(max,\ min)} = \frac{V_{out}}{I_{o(min,\ max)}} \qquad (9)$$

Maximum and minimum value of duty cycle can be calculated from equation

$$D_{(max,\ min)} = 1 - \frac{\eta}{M_{VDC(max,\ min)}} \qquad (10)$$

Assuming the switching frequency, fs =100 kHz and minimum inductance value can be calculated by

$$L_{min} = \frac{R_{lmax}D_{min}(1-D_{min})^2}{2f_s} \qquad (11)$$

And also minimum capacitance value is obtained by

$$C_{min} = \frac{D_{max}V_{out}}{f_s R_{lmin} V_{cpp}} \qquad (12)$$

III. CONTROL SCHEME OF POWER FACTOR CORRECTION BOOST CONVERTER

When a converter has less than unity power factor, it means that the converter absorbs apparent power higher than active power. So the harmonic currents are generated by the converter. Higher harmonics in the current affects the utility grid and other appliances as well. So the power factor correction is needed.

A. Active Power Factor Correction

An active power factor correction approach is the most effective way to correct power factor of electronic supplies. The active PFC techniques can be classified as: (1) PWM PFC techniques, (2) Resonant PFC techniques, (3) Soft switching PFC techniques and so on. In PWM PFC approach, the power switching device operates at pulse-width modulation mode. Switching frequency of active power switch is constant, but turned-on and turned-off mode is variable. Here a boost converter is placed between the bridge rectifier and the load. The converter tries to maintain a constant DC output bus voltage and draws a current that is in phase with and at the same frequency as the line voltage.

Advantages of boost APFC are as follows:

- Active wave shaping of input current
- Filtering of the high frequency switching
- Feedback sensing of the source current for waveform control
- Feedback control to regulate output voltage

There are various types of control techniques present for improvement of power factor with tight output voltage regulation. They are:

- Peak current control
- Average current control method
- Borderline control method
- Discontinuous current PWM control method
- Hysteresis control method

There are different current mode control techniques to manipulate continuous input current obtained from the boost converter. Among them, Hysteresis Control Method is used because of many advantages over other methods. Hysteresis control method has the constant on-time and the constant off-time control, in which only one current command is used to limit either the minimum input current or the maximum input current. Hysteresis comparators are used to impose hysteresis band around the reference current. The hysteresis control scheme provides excellent dynamic performance because it acts quickly. Also, an inherent peak current limiting capability is provided. This type of control in which two sinusoidal current references IP,ref, IV,ref are generated, one for the peak and the other for the valley of the inductor current. According to this control method, the switch is turned on when the inductor current goes below the lower reference IV,ref and is turned off when the inductor current goes above the upper reference IP,ref, giving rise to a variable frequency control. The block diagram of the hysteresis controller is shown in Figure 6.

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

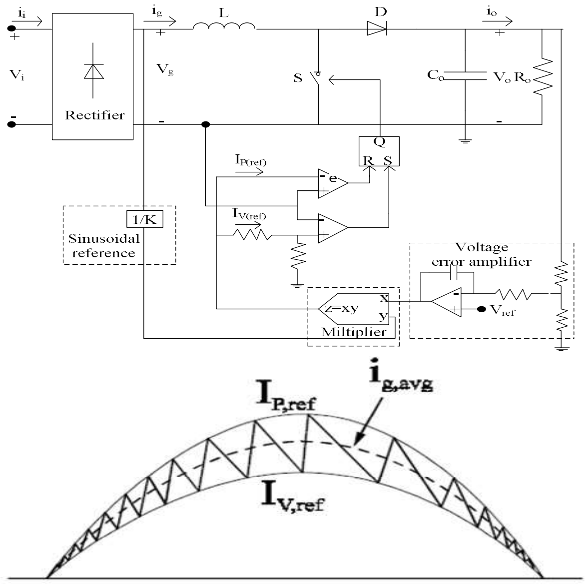

Fig. 6, Hysteresis control scheme

IV. DESIGN AND MODELLING FOR PFC BOOST CONVERTER

In this paper, design calculation and modelling is executed for conversion of 230 V single phase AC input voltage to 400 V DC at 3.4 kW output power. For this conversion, Hysteresis Controlled Mode based PFC boost converter is used. The specifications for the system are as follow:

AC input Voltage = 230 V
DC output voltage = 400 V
Converter Rated Power = 3.4 kW

By using equations described in section II, the calculated results for PFC boost converter are shown in TABLE I.

TABLE I. THE CALCULATED RESULTS OF SYSTEM DESIGN PARAMETERS

Parameters	Symbols	Ratings
Maximum and minimum value of single-phase rectified line voltage	$V_{in\ max}$ $V_{in\ min}$	325.27V 261.63V
Maximum and minimum value of DC voltage transfer function	$M_{VDC\ max}$ $M_{VDC\ min}$	1.53 1.23
Maximum and minimum duty cycle	D_{max} D_{min}	0.419 0.268
Maximum and minimum load resistance	$R_{l\ max}$ $R_{l\ min}$	941.18 Ω 47.06 Ω
Minimum inductance	L_{min}	0.692 mH
Minimum capacitance	C_{min}	17 μF
Smoothing capacitor	C_f	180 μF

For the modelling of PFC boosted converter, MATLAB/SIMULINK software is applied. The model mainly consists of DC-DC boost converter and PFC control circuit. The Simulink models for designed system without PFC control and with PFC control methods are shown in figure 7 and figure 8.

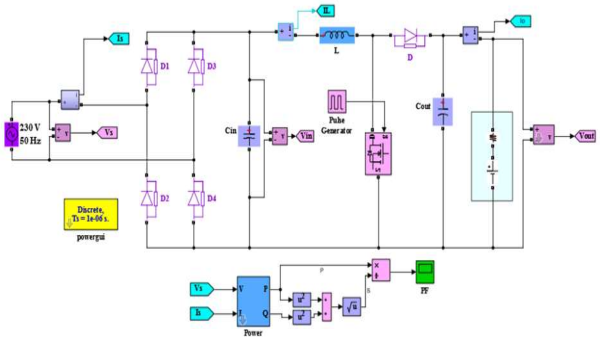

Fig. 7, DC-DC boost converter without PFC control method

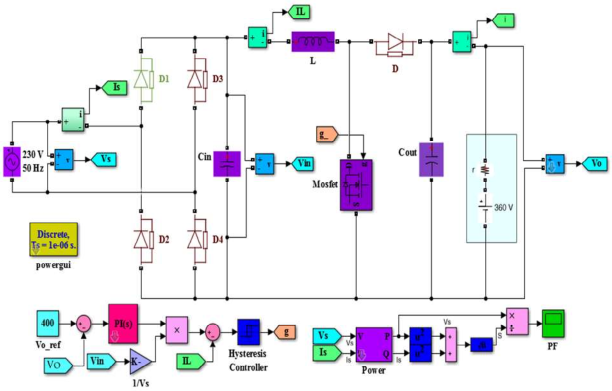

Fig. 8, DC-DC boost converter with Hysteresis Control based PFC Control Method

V. SIMULATION RESULTS FOR PFC BOOST CONVERTER WITH HYSTEERESIS CONTROL METHOD

To evaluate the performance of hysteresis control method based PFC boost converter, the simulations are carried out for DC-DC converter without PFC control and with PFC control method. In both case, simulation time is set as 0.5 second and sampling time is 1 µsec. The main measurements are carried out for output DC voltage, input current, power factor and total harmonic distortion of input current. The simulation results are shown in following Figures.

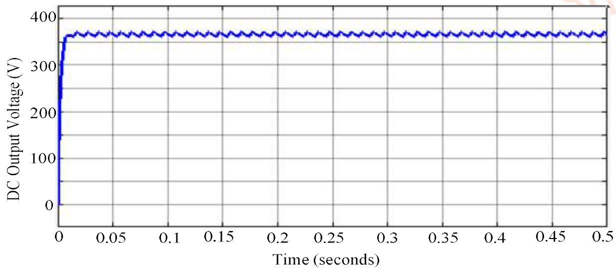

Fig. 9, DC Output Voltage of boost converter without control

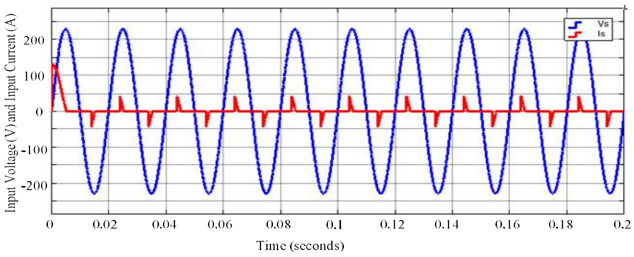

Fig. 10, PF without PFC boost converter

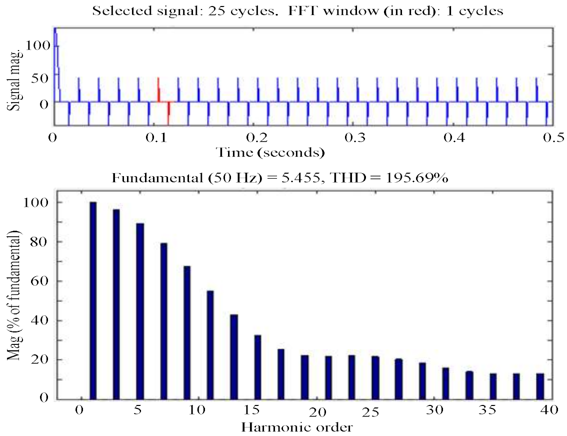

Fig. 11, Input supply current waveform and FFT analysis without PFC boost converter

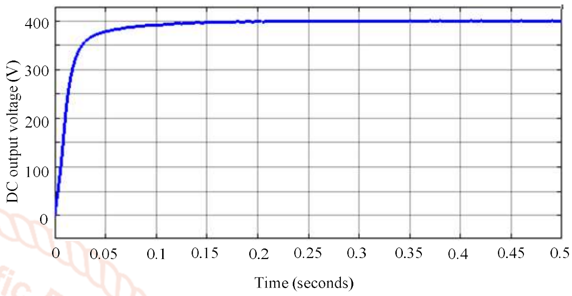

Fig. 12, DC Output Voltage of boost converter with hysteresis control

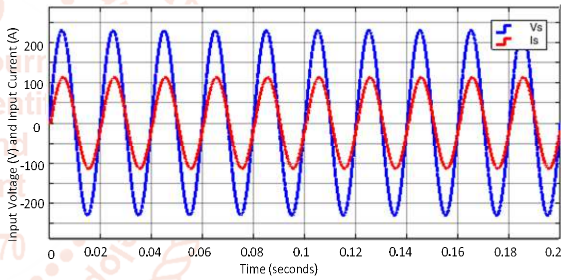

Fig. 13, Input Voltage and Input current of the rectifier with hysteresis control

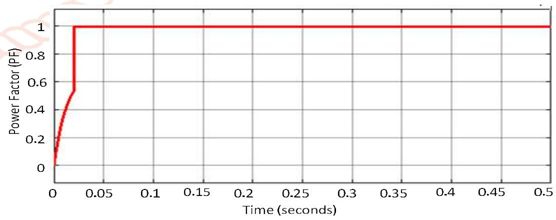

Fig. 14, PF with hysteresis control

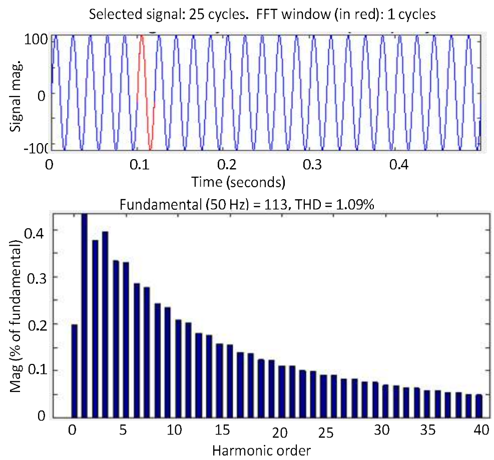

Fig. 15, Input supply current waveform and FFT analysis with hysteresis control

Comparative results of performance parameters for boost converter without and with control method incorporated from below TABLE II.

TABLE II COMPARATIVE RESULTS OF PERFORMANCE PARAMETERS OF BOOST CONVERTER WITH VARIOUS METHODS

Topology	THD (%)	Power Factor (PF)
Boost Converter (without control method)	195.69%	0.8326
Hysteresis Control	1.09%	0.9968

VI. CONCLUSION

Design calculations of rectifier and boost converter and simulation of PFC boost converter with hysteresis control method by using MATLAB/SIMULINK are presented in this paper. Various measurements consisting of THD and PF are executed. The analysis of circuit with and without PFC boost converter topology is shown. Without PFC boost converter topology, there is a phase difference between input voltage and current and moreover THD is very high. With PFC boost topology, the harmonics distortion in the input current can be removed; hence we can achieve the improvement of PF and reduction of THD. The simulation results show that hysteresis control offers power factor very closely to unity and supply current THD is 1.09%.

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