Design and Simulation of a Single-Phase Front-End Converter

P.N.Kapil [1], Parth Gandhi [2] and Utsav Gonawala[3]

Abstract—**This paper presents the design and simulation of a Single-Phase front-end converter in rectification mode for the power factor control and power quality improvement. Specifically this paper concentrates on the design aspects of the power components as well as the dc link voltage balancing and maintenance of near to unity power factor of the supply. This converter topology also ensures that the %THD of input current is well within the acceptable limits. The simulation of the proposed model has been carried out in PSIM.**

Index terms— **Front End Converters, Unity Power factor Controlling, Power quality improvement, THD.**

I. INTRODUCTION

DC CONVERTERS or Rectifiers are extensively used in various applications like power supplies, DC motor drives, front-end converters in variable speed drives, SMPS, HVDC transmission lines and more etc. Traditionally the converters have been dominated by the use of Diode Bridges or phase controlled rectifiers. These converters act as non-linear loads on the power system and draw input currents which are rich in harmonics and have poor supply power factor. Thus creating power quality problem for the power distribution networks and for the other important electrical systems in the vicinity of it. So as to get rid of these problems several regulatory norms have been instituted such as IEEE-519. IEC555 etc [1] [3]. and these standards or norms have been strictly enforced on the consumers and manufacturers. To meet these standards and achieve power quality improvement there has been extensive use of passive filters, active filters and Hybrid Filters, along with the conventional rectifiers in high power and already installed applications. In this respect new advancements have been initiated in the field of power quality improvement and they have become integral and inherent part of the electrical systems. More specifically to eliminate these problems the controlled rectifiers were conceptualized. Various topologies of power factor improvement have been developed like the buck, boost, buck-boost converters. The use of Front-End Converter topologies have also become extensive in the power quality improvement techniques because of their excellent performance like sinusoidal input currents with negligible THD, high supply power factor, regulated and near to ripple free dc output voltage, reduced voltage stresses, reduced dv/dt stresses and hence low EMI emissions [4] [5]. The sinusoidal supply currents at unity power factor are produced in the Front-End converters. The specific application of this topology of front-end converter is in the field of excitation for synchronous alternators.

In this paper a single-phase front-end converter is proposed to reduce the line-current harmonics, give nearly unity power factor, produce well- regulated dc output voltage with negligible ripples and provide dc bus voltage balance at load transition. The converter strategy helps in maintaining the regulatory norms such as IEEE-219 and IEC555. The proposed topology also nullifies the use of bulky passive and hybrid filters which were previously very much popular [2]. A PI controller is used to achieve the dc link voltage control, the dc link voltage balance and the input line side power factor control. To verify the validity of the proposed scheme the computer simulations using PSIM have been included in this paper.

II. SYSTEM DESCRIPTION

The adopted single-phase power factor correction converter topology is shown in the Figure.1 below. The input of the topology is the single-phase 50 Hz ac supply and line contains boosting inductor at the input side. Each power switch which is IGBT in this case blocks a voltage equal to the dc link voltage. The switches are commutated with a high switching frequency to generate the PWM signals for the gate pulse of the IGBT.

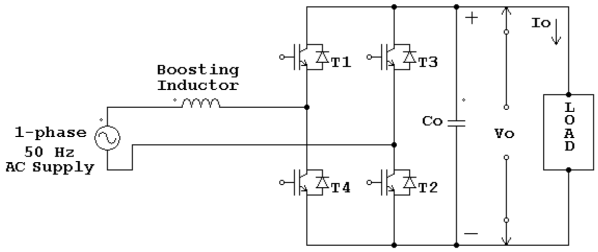

Figure. 1. Proposed Single-Phase Front-End Converter

The main requirement of the boosting inductor is to boost the dc link voltage from the rectified value of 325V to around 450V. Here the converter also works as a boost converter. The switching sequence of the devices is controlled by the PI controller. By controlling the PI value the power factor of the converter is to be maintained near to unity. Here the switches T1, T4 and T3, T2 for the complimentary pair of switches.

III. Block Diagram and Control Strategy

The main aspects for the control strategy for the proposed converter topology were as under.

1. Minimization of input current harmonics.
2. Maintaining near to unity power factor.
3. Regulating and controlling of the DC load voltage.
4. Maintaining DC link voltage balancing.

The proposed block diagram of the converter topology is shown in the Figure.2 below.

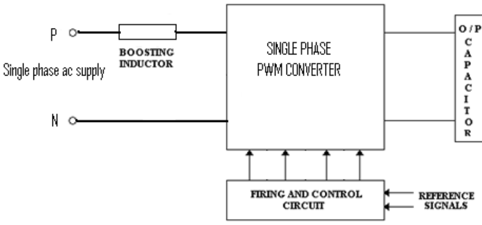

Figure. 2 Block Diagram Proposed Converter

The control strategy of the converter is achieved using the PI controller. The control strategy of the converter is as shown below in Figure.3.

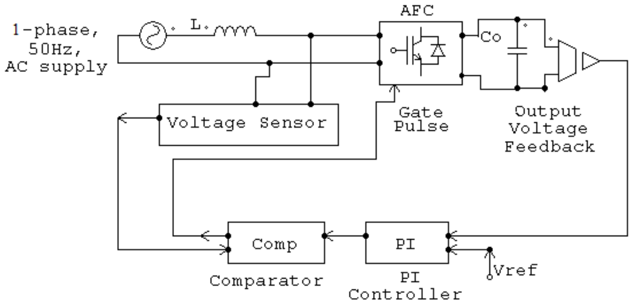

Figure. 3. Control Strategy of the Proposed Converter

In the proposed control strategy PI controller is used for the controlling of the firing pulses of the IGBTs of the converter. The reference signal is set at the required value and the feedback of the output voltages at the capacitor is taken out and compared and corrected using the PI then this is compared with the input side line voltages and a carrier signal which in all decides the switching pattern of the power switches. The output of the PI controller and the voltage sensor at the line side when multiplied an AC quantity with an offset which when compared with the triangular waveform decides the on time and off time of the IGBT.

As can be seen from the Figure.3 the output voltages and the input line side voltage are sensed using the voltage sensors. The compared output of the voltages and the PI controller output serve as the firing sequence of the converter switches to make it to work as a rectifier and in turn also control the power factor of the line side by optimizing the switching sequence. The firing is in the form of PWMs obtained from the controller.

IV. Design of Power Components

In the design of power components primarily the design and selection of line inductor and dc link capacitor is done. The selection of these components is very critical for the proper working, operation and optimization of the proposed converter. The value of inductor connected in line is calculated according to the voltage drop in the line due to the inductive reactance. This voltage drop is normally taken to be 3% of the line voltage. Similarly the value of capacitance to be connected in dc link is governed by not only the maximum tolerable voltage but also the maximum ripple current at switching frequency and operating temperature of the converter.

The relations useful for calculating the values of inductance are as under:

$$\therefore X_L = \frac{0.03 \times V_{phase}}{\sqrt{3} \times I_{ph}} \tag{1}$$

$$I_{peak} = I_{ph} \times \sqrt{2} \times 2 \tag{2}$$

$$\therefore 2\pi fL = \frac{0.03 \times V_{phase}^2}{P} \tag{3}$$

Where V_{phase} is input phase voltage, I_{ph} is phase current, I_{peak} is the peak current flowing in the inductor through the line, L is is the inductance, f is the frequency of the ac supply and P is the power rating of the converter.

On the same lines the relations useful for calculating the values of capacitance are as under:

$$C_{\min} = \frac{0.2 \times I_{peak}}{\Delta V_{p-p} \times f_s} \tag{4}$$

$$I_{ripple} = \frac{0.46 \times I_{peak}}{\eta} \tag{5}$$

Where C_{min} is the minimum capacitance value for sustaining the voltage ripple, I_{peak} is peak current flowing through the line, I_{ripple} is the ripple current to be sustained by the capacitor, ΔV_{p-p} is the peak to peak dc voltage ripple , f_s is the switching frequency of the IGBTs and η is the compensating factor to be found out form the datasheet of the capacitor which depends on the value of switching frequency & operating temperature.

For the purpose of simulation the parameters of the converter were taken as 1500 W output power, input phase voltage 230 V, supply voltage 50 Hz, switching frequency 5000 Hz, peak input current 18.5 A, peak to peak dc voltage ripple as 30 V and the compensating factor as 1.5. The values of inductance, capacitance and ripple current obtained were 3.36 mH at 18.5 A, 680 µF at 450 V and 5.65 A.

V. Simulation and Results

The performance of the proposed control strategy and the single-phase front-end converter topology has been verified by the simulation results obtained with the help of PSIM software. The mains phase voltage is taken as 230V rms with a supply frequency of 50Hz. The capacitance of the DC link capacitor is taken as 680μF each and the boost inductance connected in line is taken as 3.36 mH. A switching frequency of 5 kHz is chosen. A passive switching load of 500 Ω and other load of 1000 Ω are taken. The two loads here show the full-load and no-load conditions for the converter. The desired DC link is set at 450V which is appearing across the capacitor. The simulated waveforms for the phase voltages and the line currents of the converter in the rectification mode are shown in Figure.4. The harmonic spectrum of the input line current is shown in the Figure.5. It has a THD of only 2.48 % which is within prescribed harmonic standards. This is a highly desirable feature of a high power factor converter. Figure.6 depicts the waveforms of the load voltage and the load current in the rectification mode. The converter now undergoes the sudden change of full-load to no-load and the change in the dc output waveform and the line currents is shown in the Figure.7. The converter still retains the same desired DC output and the current THD becomes 3% as shown in Figure.8. The DC output ripple in any case of loading remains within the limit of ± 30V. The input power factor during both the cases remains close to unity which is shown in the Figure.9. During both the cases the DC link across the capacitor remains balanced which is shown in Figure.10, the DC link is maintained at 450 V. Thus the proposed control strategy of the converter maintains the DC bus capacitor voltages under all the conditions of load and also improves the power quality.

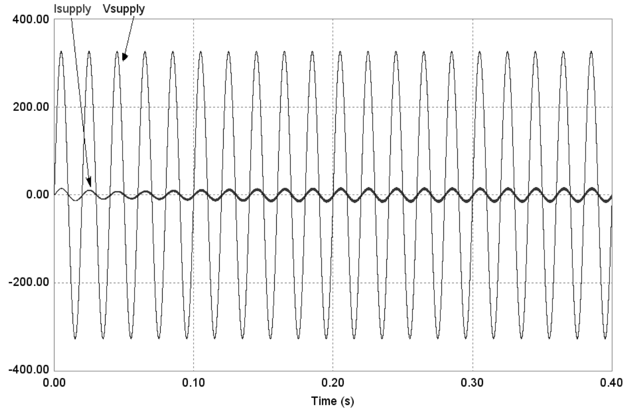

Figure. 4. Waveforms of Phase voltage and line current during rectification

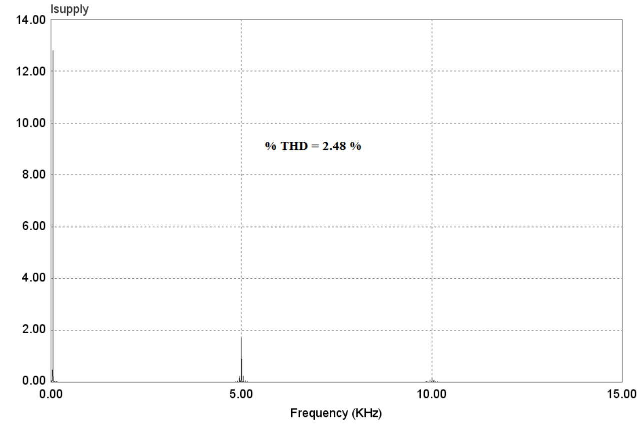

Figure. 5. Harmonic Spectrum of Line current.

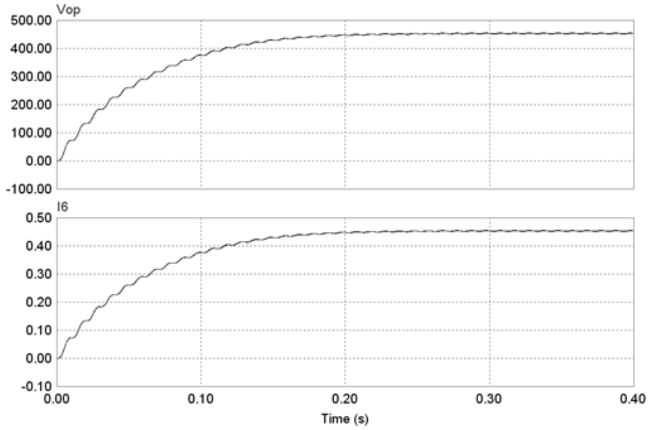

Figure. 6. Load Voltage and Load Current in rectification mode

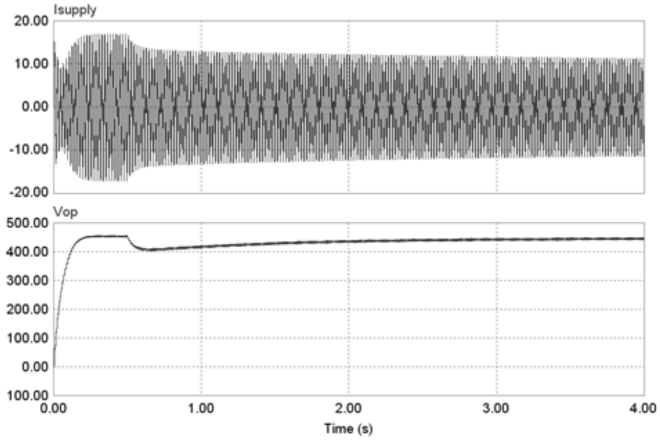

Figure. 7. Waveforms of Line current and DC output at load change (After 0.5 sec load changes)

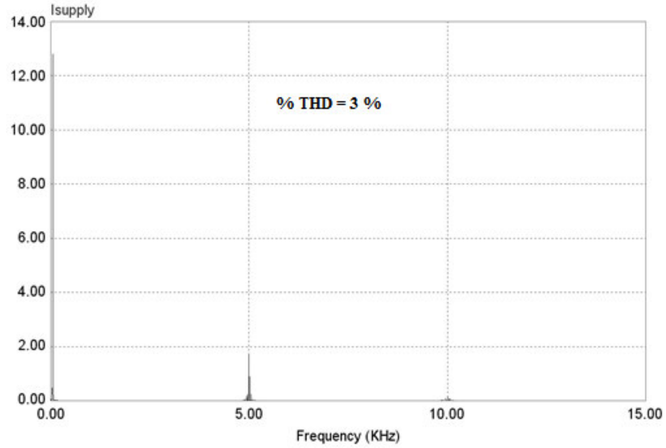

Figure. 8. Harmonic spectrum of Line current at load change

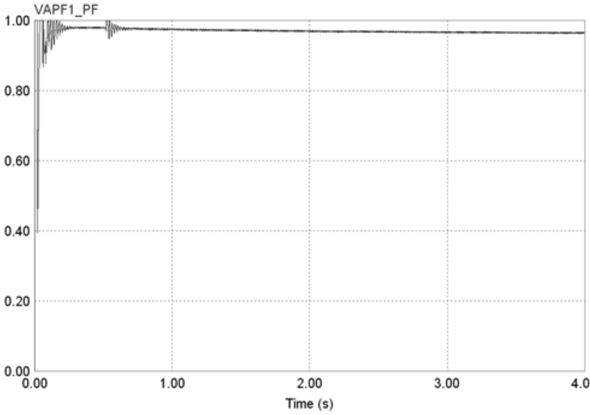

Figure. 9. Waveform of Line Power factor during load change (After 1 sec load changes)

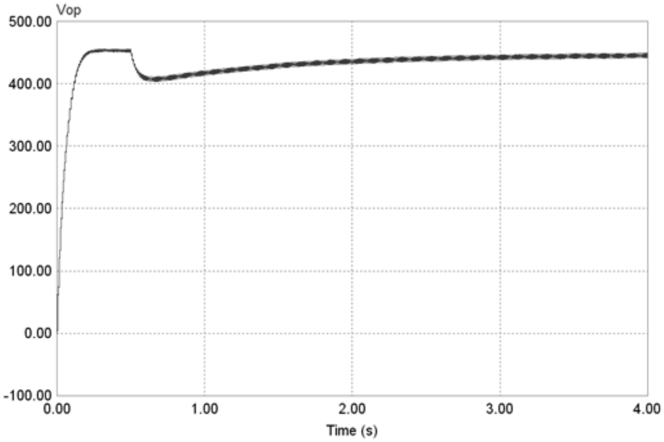

Figure. 10. Waveform of DC link voltage during load change (After 1 sec load changes)

VI. CONCLUSION

A single-phase front-end converter is proposed to achieve sinusoidal supply currents with nearly unity input line power factor, well regulated and balanced DC link voltage at the output with capacitor voltage balancing. The proposed control strategy was based on sinusoidal pulse width modulation technique for switching and in turn also maintaining near to unity power factor. The main objective fulfilled from the results is that by achieving near to unity power factor which gives it an edge over the conventional rectifiers. The converter is highly suitable for medium voltage and medium power industrial applications. The converter does not allow the harmonics and reactive power to flow in the system. The target application of the converter can be as a front end rectifier in inverters for ac drives and mainly as excitation systems for synchronous alternators which are primarily SCR based. Thus the proposed converter is a useful power quality improvement converter suitable for various types of applications including domestic, commercial and industrial applications.

VII. REFERENCES

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