



Modified Bi-directional AC/DC Power Converter with Power Factor Correction

M. Sasikumar ^{a,*}, S. Chenthur Pandian^b

^a Electrical & Electronics Engineering Department, Jeppiaar Engineering College, Chennai, P.O. Box 600119, India

^b Principal, Dr.Mahalingam College of Engineering & Technology, Pollachi, P.O. Box 642003, India

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ABSTRACT

Most existing power converters and industrial motor drive systems draw non-sinusoidal currents from the supply. Non-sinusoidal currents contained harm harmonics disturb the power supply which it causes serious concern for reliability. Other equipments that use the same power supply are adversely affected. This paper suggests the operation and performance of a new modified AC/DC converter that allows bi-directional power flow. It also provides improved power factor and reduces harmonic magnitude and disturbance to the supply by system. The bi-directional feature allows recovery of regenerative energy of loads, back to the power supply and the converters. The proposed converter has high potential for industrial applications, such as electronically controlled traction system, lifts and generally industrial motor drive systems which can increase overall efficiency and reliability.

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1. INTRODUCTION

In recent years, development of sophisticated static conversion techniques has gained increasing attention from many researchers because of the growing demand for industrial motor drives with power conditioning and power factor management. Many existing power converter and motor drives system draw the non-sinusoidal input current from the mains. The classical AC/DC rectification approach of using a full wave bridge followed by a bulk capacitor is not suitable due to the undesirable input current harmonics [1- 4]. These harmonics need to be controlled using passive filtering or active filtering with power factor correction. A common problem associated in drive system with frequent regeneration is the size of the dc link capacitor is often very large to limit the link voltage. Normally, a large capacitor bank of thousands of microfarad is required. The large value of capacitor not only increases the size and weight of converter equipment, but also equipment cost. In order to reduce the link capacitor, a bi-directional converter can be used so that regenerative energy can be fed to the supply instead of being stored in large capacitor. This project presents a modified

thyristor based AC/DC power converter circuit with reduced harmonics and improved power factor. The inductor average current control method of the converter provides improved power factor in both power flow direction. The input current is sinusoid ally shaped to follow the input voltage either in phase with the input voltage in motoring mode or 180 degree out of phase with the input voltage in the regenerating mode. Thus, the power factor approaches unity reduces harmonics and disturbance on the power supply. The design and performance of the converters is validated through the computer simulation using MAT-LAB SIMULINK. The design and performance analysis of the proposed converters are validated through the computer simulation using MAT-LAB /SIMULINK.

2. SYSTEM CONFIGURATION

Figure 1 shows the circuit configuration of the proposed bi-directional AC/DC power converter. It consists of three main components. They are the power conversion stage, inductor average current controller and synchronization circuit for triggering the thyristors. The power conversion stage consists of four low cost, highly robust thyristors (T1-T4 uses TYN 616), two high frequency

*Corresponding Author Email: pmsasi77@gmail.com (M. Sasikumar)

switches (S1 and S2 uses IRF 460), two diodes (D1 and D2 uses MUR 8100), one inductor, one capacitor. The operation of the bi-directional AC/DC power converter consists of two modes, one is motoring mode and another one is regenerating mode. The operating mode of the converter either in motoring mode or in regenerating mode is controlled by conduction state of S2, which is determined by sensing the dc link voltage. In motoring mode a.c voltage is applied to the thyristor based full converter. Now the thyristor T1 and T3 is fired at an angle 5 degree in the +ve half cycle of V_s and T2 and T4 are fired at an angle 165 degree, which gives an input voltage for the chopper circuit, similar to that the diode rectifier. S2 is turned off for the entire motoring mode period and the chopper circuit acts as a boost converter and a boost converter is formed by L, S1, D1 and C and diode D2 is forward biased.

When the switch S1 is conducting, the current flowing in the inductor will rise. Once the switch is turned off, the current in the inductor will start fall as the diode D1 conducts and the energy will transferred to the output load. In order to maintain the control of the dc link voltage, it must always be higher than the input voltage. The output voltage from the converter is compared with V_{ref} . Whenever the output voltage varies due to input voltage and load, the error voltage is obtained. This error voltage is fed to the LPF and PI controller. The PI controller produces the control signal is multiplied with diode rectifier output signal. Now the multiplier output is summed with ramp function to form the reference current. This reference current is compared with feedback current, which gives PWM pulse to drive switch S1. In motoring mode, supply voltage and supply current are in phase. During the regenerating mode, S2 is turned on and D2 is reverse biased. In this mode, T1-T4 are operated in anti-phase with the operation in motoring mode, which gives the reverse input voltage. The converter now acts as a buck converter with voltage across the bulk capacitor as the input voltage. In regenerating mode when the switch S1 is closed, the inductor current will rise and the current will flow from the load to supply through the thyristor. When the switch is open, the inductor current will fall as the current flows through diode D1; so that power can fed back to the ac power supply. In regenerating mode supply voltage is 180° out of phase with supply current. The pulse generated by current mode controller to drive the switch S1. In both mode switch S1 is ON and OFF because the inductor is same for both mode [5-8].

2. 1. Design Value of Inductance (L) The selection of inductance value for bi-directional AC to DC power converter circuit is based on the following criteria:

*Current ripple

*Maximum current in the inductor

The peak to peak value i_{ripple} is given as

$$i_{ripple} = \frac{V_s d T_s}{L} = \frac{V_m T_s}{L} |\sin \alpha| \left(1 - \frac{1}{M_1} |\sin \alpha|\right) \quad (1)$$

Differentiating i_{ripple} with respect to $\sin \omega t$ and equating the expression to zero gives

$$1 - \frac{2}{M_1} |\sin \alpha| = 0 \quad (2)$$

For maximum value of i_{ripple} . The minimum value of L that limits the maximum ripple current to a value $i_{ripple, max}$ is,

$$i_{ripple} = \frac{V_m M_1 T_s}{4L_{min}} \quad (3)$$

$$L_{min} = V_m M_1 T_s / 4i_{ripple}$$

where, V_m is input voltage and T_s is switching period,

$$M_1 = V_{out} / V_s = 67.40 / 50 = 1.285$$

Assume i_{ripple} is 5% of supply current

$L_{min} = 70 * 1.285 * 25e-6 / 4 * 0.05 = 180 * 2 / 70 = 1.7 \text{mHA}$
1.7mH inductor can be used in the circuit. In these above mentioned mathematical derivations, the voltage is assumed to be constant.

2. 2. Design of Output Capacitor (C) The value of C is determined by considering the maximum ripple voltage on the V_{dc} is the equivalent circuit in motoring mode

$$i_c(t) = i_s(t) - I_{dc}$$

$$i_s = I_m \sin \omega t \quad (4)$$

where, I_m is the peak input current, ω is the angular frequency of the ac main, and I_{dc} is the DC link current. In steady state, the average value of i_s equals I_{dc} . Thus,

$$C \geq \frac{I_{dc}}{\omega \Delta V_{dc, max}} (\pi \cos \theta - \pi + 2\theta)$$

$$\theta = \sin^{-1} \frac{2}{\pi}$$

$$I_m = \frac{\pi}{2} I_{dc} \quad (5)$$

and

$$C \frac{dV_{dc}}{dt} = i_c(t) \quad (6)$$

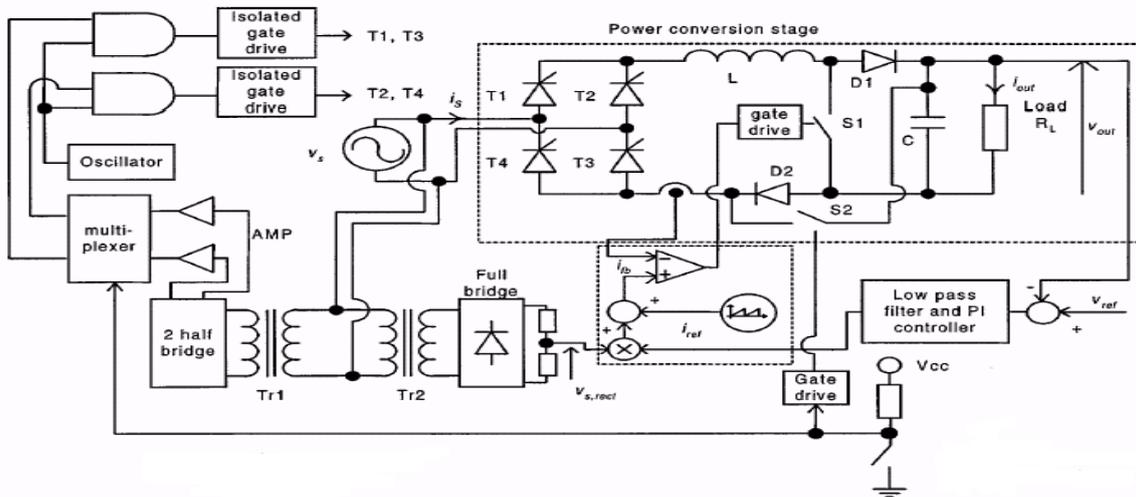


Figure 1. Proposed bi-directional AC/DC power converter

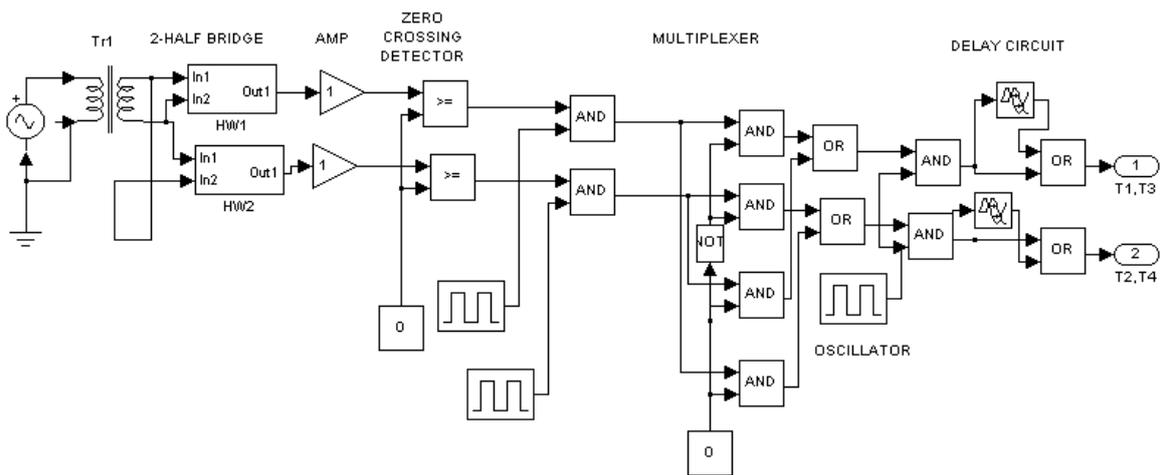


Figure 2. Synchronization network for triggering circuit

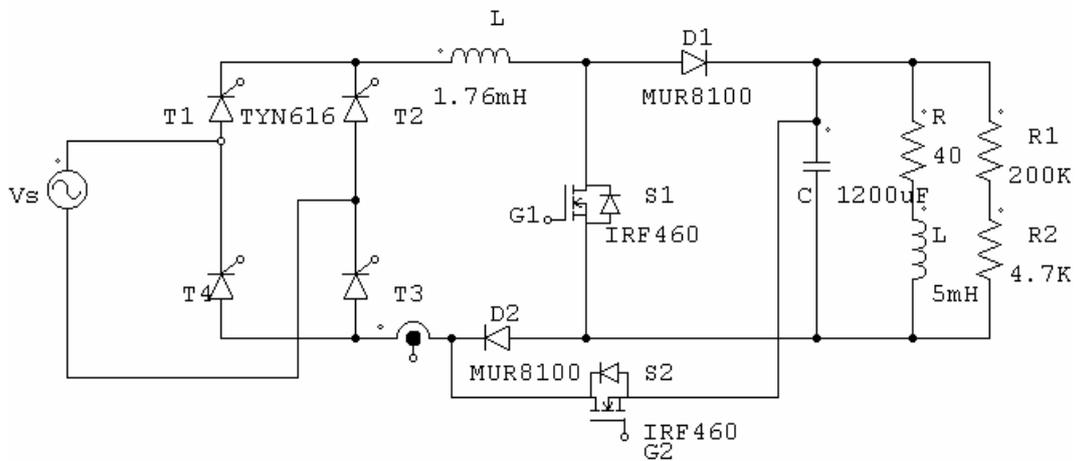


Figure 3. Implementation of power conversion stage

3. SYNCHRONIZATION NETWORK FOR TRIGGERING CIRCUIT

As in Figure 2, switch on the ac supply to the circuit. Now, 50 V is applied to the input of the step down transformer and 50V is step down to 5V. This 5V is applied to input of two half bridge which gives two rectified +ve sine waveforms (i.e. one for + ve half cycle and other for -ve half cycle). Then, this signal is amplified and applied to zero crossing detectors. After that, the zero crossing detectors produce two pulse of same period of half cycle of ac voltage input [1- 3]. Simultaneously pulse generators produce two square pulses. One at 0 to 8.6ms period of one half cycle and other at 10ms to 18.6ms of another half cycle of input. Both zero crossing detector output and pulse generator output are fed to the AND gates. Delay circuit output ANDed with zero crossing output time inverted to give a delayed pulse for thyristor gate (CD4049). In this converter, motoring or regenerating mode can be controlled. In motoring mode switch is closed and in regenerating mode, switch is open. Depending on the opening and closing of switch, the multiplexer gives single pulses which is AND ed with 5KHz-pulse train, the output is applied through isolated gate driver to the thyristors.

4. PRACTICAL IMPLEMENTATION OF BIDIRECTIONAL AC/DC POWER CONVERTER

In this practical implementation of bi-directional AC/DC power converter, synchronization network for triggering circuit and some of the control circuit is discussed. The control circuit consists of electronic PI controller, average current mode controller and low pass filter is designed and presented. Figure 3 shows main block of bi-directional AC/DC power converter. Its operation was already discussed. Figure 3 shows the detailed circuit for power conversion circuits. Power conversion stage consists of four thyristors and two power Mosfets, two diode D1 and D2, one inductor L, one capacitor C [6- 8]. The selections of device, inductor and capacitor designs are already discussed. IRFP460 MOSFET is used for switches (S1, S2), which is operated at a high switching frequency of 40KHZ. IRFP460 MOSFET also provide internal anti parallel diode. This is used for protection. TYN616 SCR (T1-T4) is used as front side AC/DC conversion which is operated at 50Hz. The use of SCR thyristors in the AC/DC front rectification power stage advantageous because;

- SCRs are low cost and robust
- They can be commuted naturally and making switching control simple.

4. 1. Converting Mode: In this mode, this is act as a Boost converter.

$$\frac{|V_s|}{V_{out}} = 1 - d$$

$$|V_s| = \frac{2Vm}{\pi} \cos\alpha = \frac{2 * 141}{\pi} \cos 34.5 = 88.9V$$

$$1 - d = \frac{88.9}{200}$$

$$d = 0.5667$$

$$T_{on} = dT_s = 0.5667 * 25 * 10^{-6} = 14.16 \mu \text{ sec}$$

4. 2. Inverting Mode: In this mode, this is act as a Buck converter

$$\frac{|V_s|}{V_{out}} = d$$

$$|V_s| = \frac{2Vm}{\pi} \cos\alpha = \left| \frac{2 * 141}{\pi} \cos 165 \right| = 88.9V$$

$$d = \frac{88.9}{200}$$

$$d = 0.4335$$

$$T_{on} = dT_s = 0.4335 * 25 * 10^{-6} = 10.68 \mu \text{ sec}$$

5. SIMULATION AND HARDWARE RESULTS

In this motoring mode, experimental results of a bi-directional AC/DC power converter are compared with simulated results and are validated.

6. CONCLUSION

The bi-directional AC/DC power converter is studied, implemented and the design performance is validated with simulated results. It has the advantages of the proposed converter which can be operated with unity power factor for bi-directional power flow conditions. Thus, it can reduce source side current harmonic content and the power factor corrected AC/DC converter uses a phase controlled thyristor rectifier. This converter is robust and low cost. Since the converter has bi-directional power flow capability, the energy storage requirement and the size of the dc link capacitor is reduced. The direction of the current flow in the inductor is the same under both motoring and regenerating mode. This proposed model makes the current control simple.

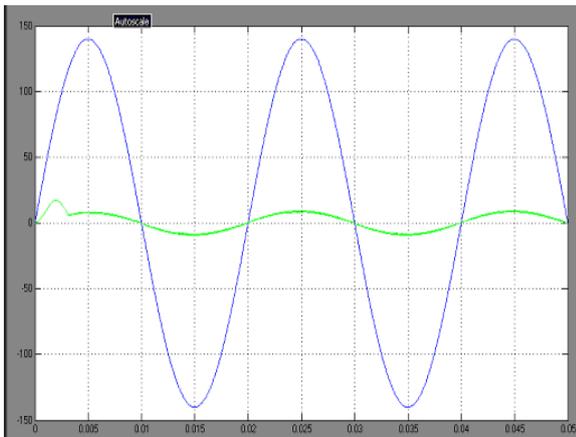


Figure 4. Simulated result of Supply current & supply voltage (Boost Converter mode)

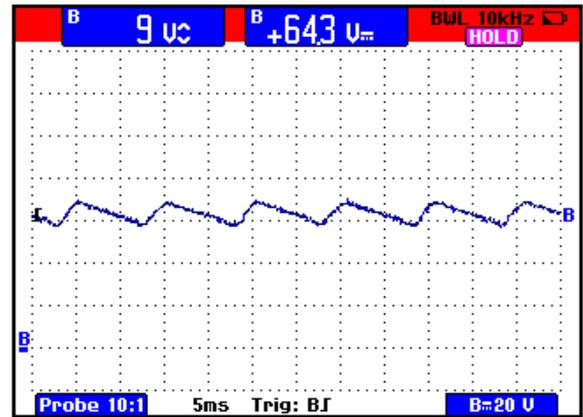


Figure 7. Hardware result of Output voltage

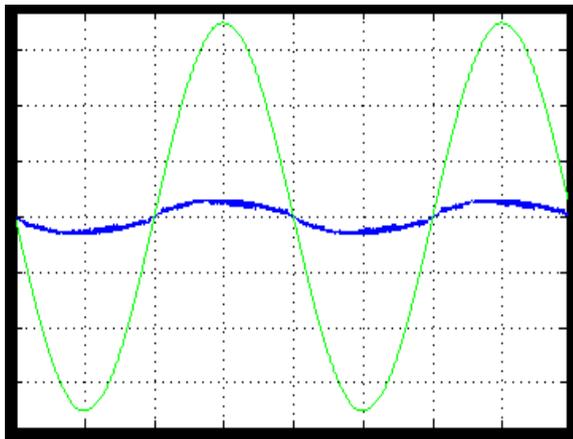


Figure 5. Simulated result of Supply current & supply voltage (Buck Converter mode)

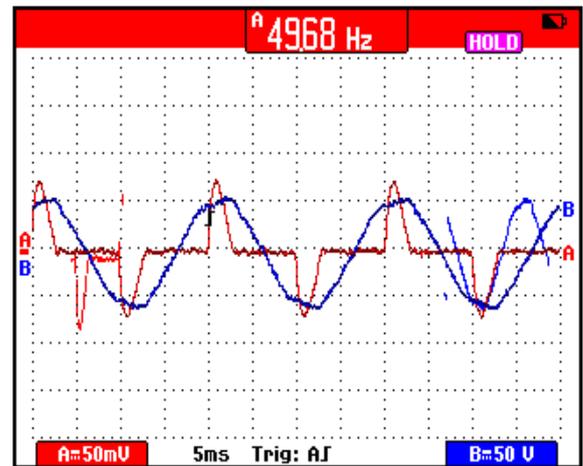


Figure 8. Hardware result of Supply current & supply voltage

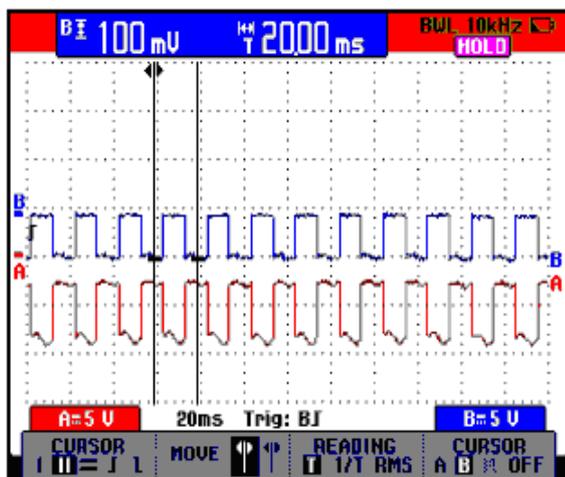


Figure 6. Hardware result of Thyristor firing pulse



Figure 9. Photograph of the Hardware setup

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M. Sasikumar ^a, S. Chenthur Pandian^b

^a *Electrical & Electronics Engineering Department, Jeppiaar Engineering College, Chennai, P.O. Box 600119, India*

^b *Principal, Dr.Mahalingam College of Engineering & Technology, Pollachi, P.O. Box 642003, India*

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اغلب مبدل های قدرت و سیستم های موتور درایو صنعتی موجود جریان های غیر سینوسی را برای تغذیه رسم می کنند. جریان های غیر سینوسی حاوی هارمونیک های مضر، مزاحم منبع تغذیه هستند که نگرانی جدی برای اطمینان را سبب می شود. تجهیزات دیگر که از همان منبع تغذیه استفاده می کنند به صورت عکس تحت تاثیر قرار می گیرند. این مقاله عملیات و عملکرد یک مبدل AC/DC اصلاح شده جدید را نشان می دهد که به جریان دو جهته توان اجازه می دهد. آن همچنین پارامتر توان بهبود یافته را ایجاد کرده و بزرگی و مزاحمت ذخیره شده توسط سیستم را کاهش می دهد. ساختار دو جهته به وصول انرژی احیاشده بارگذاری شده و بازگشت به منبع تغذیه و تبدیل کننده ها اجازه می دهد. مبدل های پیشنهادی، پتانسیل بالایی برای کاربردهای صنعتی از جمله سیستم الکترونیکی کنترل کشش، آسانسور و به طور کلی سیستم های موتور درایو صنعتی دارند و می توانند کارایی کلی و قابلیت اطمینان را افزایش دهند.

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