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Closed Loop Single Phase Bidirectional AC to AC Buck Boost Converter for Power Quality Improvement

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Abstract:- A closed loop bidirectional ac to ac buck boost converter circuit using power MOSFET is analyzed for reducing the output voltage sag and improving efficiency of the converter. The regenerative dc snubbers are used directly to power semiconductor switches to absorb energy stored in stray line inductances. These dc snubbers enhance the conversion efficiency as it has very simple structure consisting only of a capacitor. A fast response peak voltage detector for fast output voltage control is also proposed. It is observed from the simulation results obtained using MATLAB simulink, that the proposed closed loop scheme gives good dynamic and steady state performances with a high-quality output voltage, improved power factor, low harmonics, improved efficiency and significant reduction of the filter size.

Keywords:- ac chopper, dc snubbers, Peak voltage detector, PWM, Harmonics, voltage sag.

I. INTRODUCTION

Power quality disturbances in sensitive loads such as computers, communication equipments and process automation systems can often lead to the loss of valuable data, interruption to communication services and lengthy production shutdowns. IEEE standard 446-1987 describes the voltage tolerance limits for sensitive loads, such as computer power supplies [1-2]. In this standard, a voltage drop of more than 15% cannot be tolerated for more than 25 cycles. Similarly, a 35% voltage drop can be tolerated for only one cycle (20ms). Loads like heaters, illumination control, furnaces, ac motor speed control and theatre dimmers uses ac voltage controllers. Such voltage regulators, however, have slow response, poor input power factor, and high magnitude of low order harmonic at both input and output sides. And they need large input-output filters to reduce large low order harmonics in the line current. These drawbacks have been overcome by designing various topologies of ac chopper [3-9]. In most standard ac choppers, the commutation causes high voltage spikes and an alternative current path has to be provided when current paths are changed. This alternative current path is implemented using additional bidirectional switches or ac snubbers. Such topologies are difficult and expensive to realize and the voltage stress of the switch is also high, resulting in reduced reliability. A fast voltage control technique using a conventional peak voltage detector has been proposed [10]. However, this scheme still has a dynamic speed of the half period of the line voltage when increasing the output voltage and longer dynamic speed when decreasing the output voltage. S Circuit

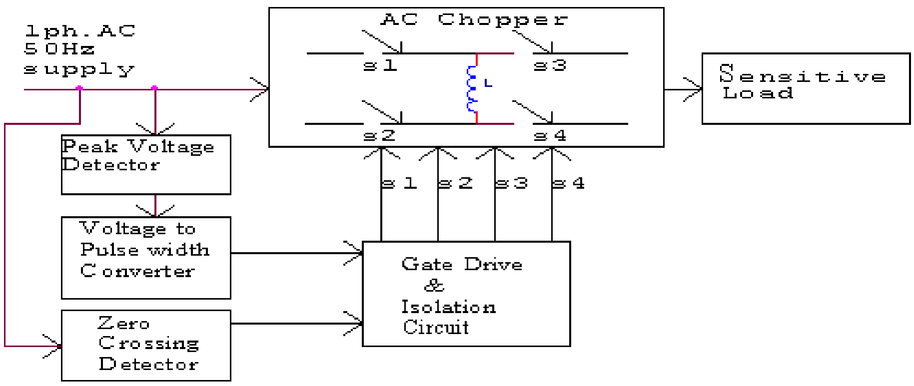


Fig. 1 Connection of the proposed buck boost AC Chopper

In this paper, a closed loop bidirectional ac to ac buck boost converter with fast dynamic characteristics is proposed and analysed as shown in Fig. 1. The power circuit is made up of a PWM buck boost ac chopper with regenerative dc snubbers, which uses 4-quadrant bidirectional switches. In the ac chopper, the commutation scheme allows dead-time to avoid current spikes from switches and at the same time establishes a current path in the inductor to avoid voltage spikes. The ac chopper uses regenerative dc snubbers attached directly to power semiconductor switches to absorb energy stored in stray line inductances. These dc snubbers enhance the conversion efficiency as it has very simple structure consisting of a capacitor only, without a discharging resistor or a complicated regenerative circuit for snubber energy. Therefore, the ac chopper gives high efficiency and high reliability. The voltage regulator is controlled in the equal PWM pattern which is efficient and simple to implement. A fast peak-voltage detector is used to convert the voltage sag into a proportional control voltage $V_{con.}$ The control voltage obtained from the peak voltage detector is compared with saw tooth voltage to generate PWM switching pulses for the switches. Simulated results obtained using MATLAB simulink shows that the proposed scheme gives good dynamic and steady-state performances for a high quality of output voltage. It is also observed that the efficiency of the converter is increased from 94.96% with ac snubber to 99.74% using dc snubber.

II. DESCRIPTION OF BUCK BOOST CONVERTER

Fig. *2a* shows the buck-boost ac chopper derived from the dc buck-boost chopper, where the normal unidirectional switches are replaced with four quadrant bidirectional switches. For practical realizations it is required to take into account delays in the drive circuits and switches. The buck-boost ac chopper is powered by the source voltage V_i and the input filter elements L_f & C_f to reduce the total harmonic distortion THD of the input current $I_i \leq 5\%$. The dead-time is requisite to avoid current spikes of practical non-ideal switches and at the same time a current path of the inductive load has to be provided to avoid voltage spikes. The control of the switches is based on the equal PWM technique. This ensures that the output voltage is sinusoidal for a sinusoidal ac input voltage. The output voltage is controlled by changing the duty cycle of the control pulses. In practical realizations of the converter, stray inductances increase the voltage stress of the bidirectional switches and may destroy the switches. This situation requires the converter using ac snubber having elements R_s & C_s as shown in Fig. 2a. The buck boost ac chopper using bidirectional switches can be converted equivalently to the ac chopper using unidirectional switches as shown in Fig 2b. Fig 2b shows the modified ac chopper using unidirectional switches and regenerative dc snubbers. This dc snubber consists of only capacitors C_b without any resistances in series with it. This is because snubber energy is regenerated during charging mode, providing energy to the inductor.

In the configuration of the modified buck boost ac chopper, as shown in Fig. 2b, the commutation policy is that switches S_2 and S_4 for $V_i > 0$ are additionally turned on and the switches S_1 and S_3 are turned on for $V_i<0$, at least during dead time without respect to the control strategy. The other switches are modulated according to the duty ratio determined from the control strategy. If the inductor current i_L is positive, the inductor current is bypassed through output side using S_4 and diode across S_3. If the inductor current is negative, the inductor current is bypassed through the input side using S_2 and diode across S_1. Similarly when V_i is negative, the switches S_1 and S_3 are turned on additionally for safe commutation.

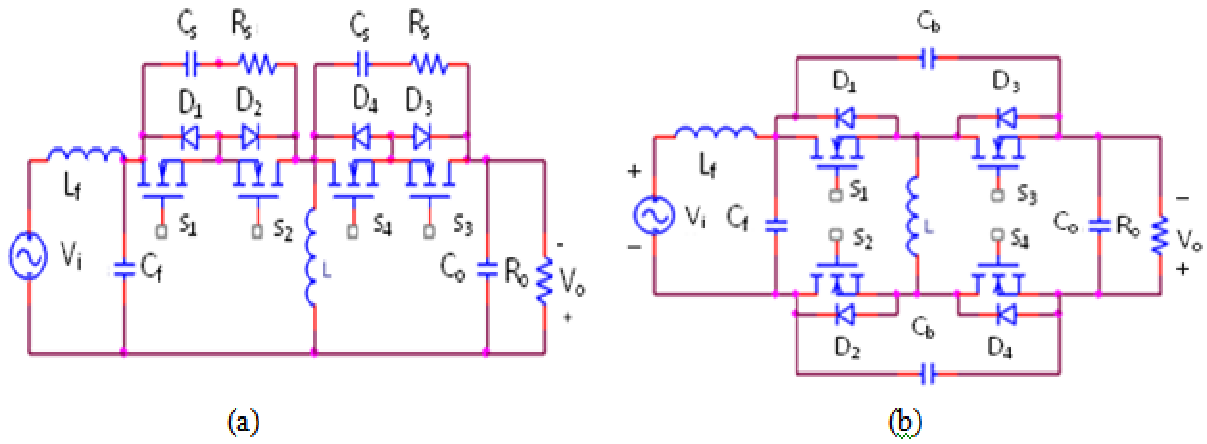


Fig.2 Modification of single-phase buck-boost ac choppers
(a) ac chopper using bidirectional switches and ac snubbers.
(b) ac chopper using unidirectional switches and regenerative dc snubbers.

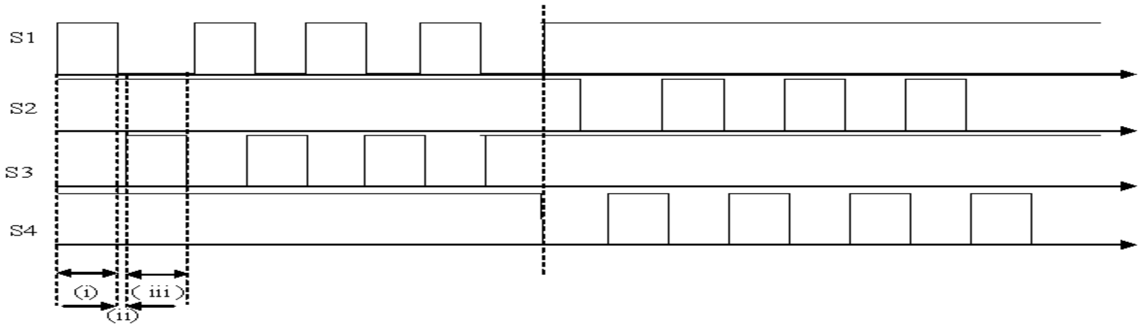


Fig.3 PWM pattern gate control signals (i) Charging Mode (ii) Dead time mode (iii) Discharging mode

Fig. 3. Shows the gate signals for four switches while transition from positive half cycle to negative half cycle of the supply voltage. During charging mode, power flows from source to the inductor through the switches S_1 and diode across S_2. The discharging mode is complementary to the charging mode. During this mode, the switches S_3 and S_4 are turned on and the inductor current flows through the output side. Similarly two switches are additionally turned on for safe commutation and they are utilized during dead time mode.

III. PEAK VOLTAGE DETECTOR & GATE CONTROL CIRCUIT

The output voltage can be regulated by sensing the input voltage and converting it to PWM pulses for switching the four bidirectional switches. The fast dynamic response is essential in order to overcome from power quality disturbances. For fast output-voltage control by the voltage regulator, a fast input voltage sensing technique is required (line regulation). Generally, the conventional peak-voltage detector with diodes, capacitor, and resistor is used as a voltage-sensing circuit as shown in Fig. 4a. When the input signal is decreased the capacitor is discharged through the resistor, and when increased the capacitor is charged directly. Therefore, the charging speed is faster than the discharging speed.

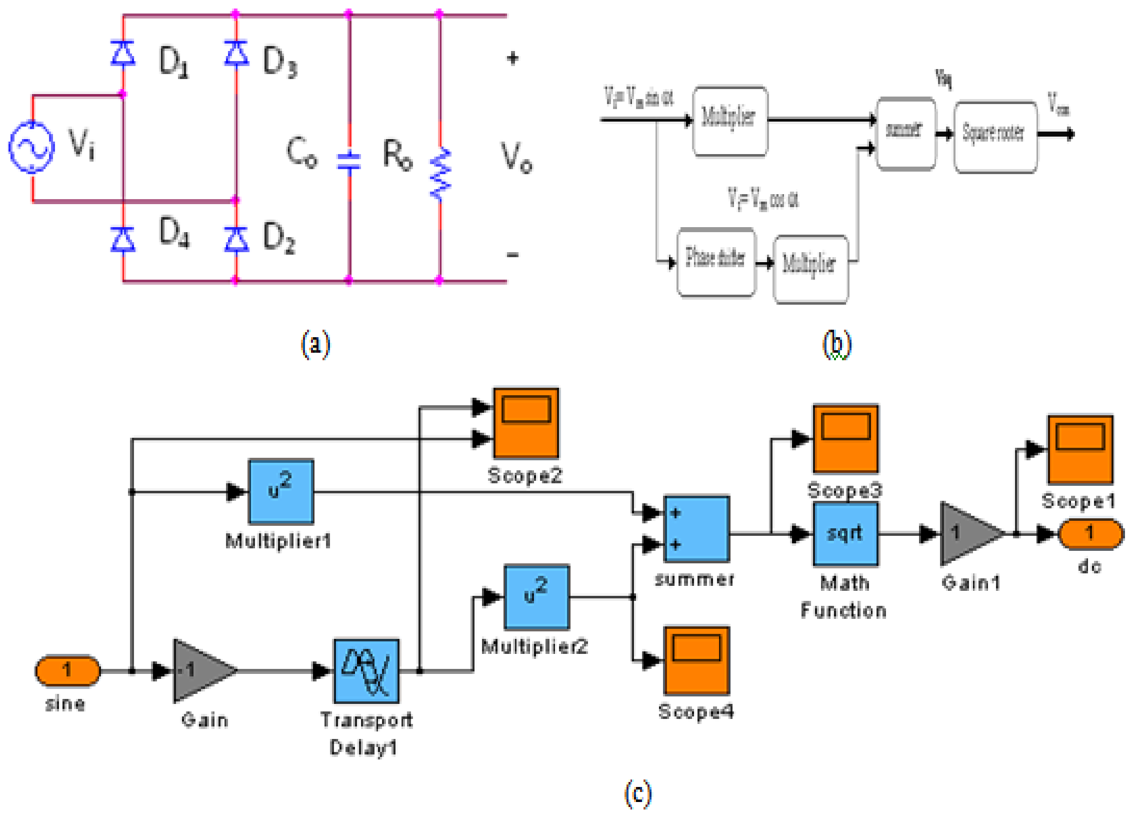


Fig. 4 Peak-voltage detectors a. Conventional peak-voltage detector b. Modified peak-voltage detector. c Simulation block for modified peak voltage detector.

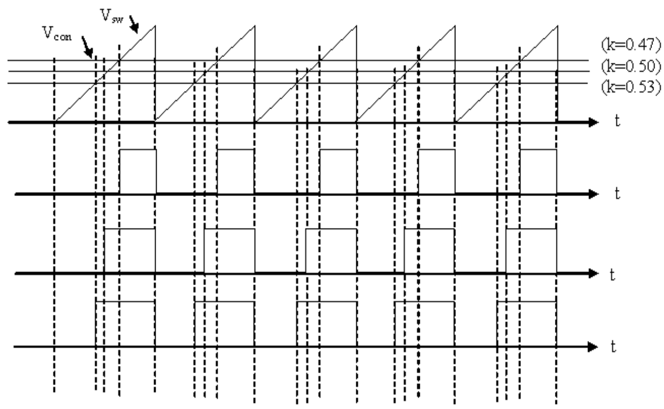


Fig. 5 PWM pulses generated by comparator.

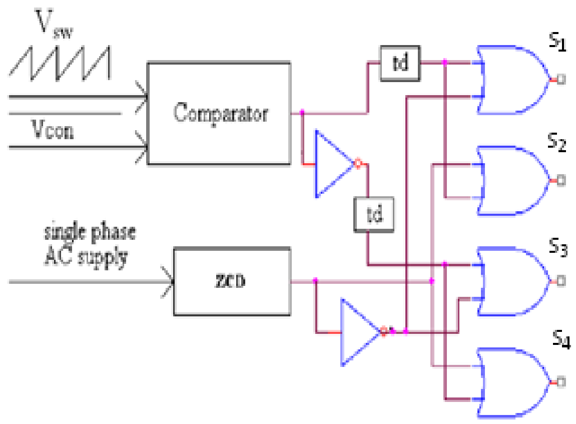


Fig. 6 Control circuit for generating switching pulses

As the resistor value is reduced, the discharging speed increases. But the waveform of the sensed signal has more ripple component. A fast peak-voltage detector shown in Fig. 4b uses step down input voltage of 5V, which consists of multipliers, phase shifter, summer and square-rooter circuits. The phase shifter leads the input voltage by 90^0 to get cosine waveform, and each waveform is multiplied and then summed up. The input to the square-rooter is

$$V_{sq}= V_m^2\sin^2\omega t + V_m^2 \cos^2\omega t \quad \rightarrow(1)$$

And output of square-rooter circuit is obtained as

$$V_{con} = \sqrt{(V_m^2\sin^2\omega t + V_m^2 \cos^2\omega t)} = V_m \quad \rightarrow (2)$$

The sensed input voltage V_i of the proposed detector is the magnitude or peak value of the input voltage in dc form. This peak detector quickly responds to the voltage sag and swells due to the line voltage disturbances.

Under normal operating condition, the duty cycle will be set for k=0.5, so that $V_o=V_i$. The control voltage V_{con} should be decreased in order to increase the duty cycle k for encountering the voltage sag. And similarly V_{con} should be increased for encountering voltage swell. Fig. 5 shows the PWM pulses generated by comparator. The comparator circuit compares saw-tooth voltage V_{sw} with control voltage V_{con} obtained from fast peak detector circuit. Ideally the duty cycle can be varied from k=0.47 to k= 0.53 for ±10% voltage variation of input voltage from the reference value of 230V. Fig. 6 shows the block diagram of the control circuit. This circuit generates the PWM pattern gate control signals with delay time of t_d=1μs for four switches as per the waveforms shown in Fig. 3. The PWM of these switching pulses is controlled by the control voltage V_{con} obtained from fast peak voltage detector.

IV. DESIGN PROCEDURE AND EXAMPLE

The procedure for designing the buck boost converter with the following specifications is given below. Input voltage V_i=230V, Peak value V_{imax}=325.25V, Output voltage V_o=230V, Peak value V_{omax}=325.25V, Switching frequency F_s=20KHz, Input power P_i=300W, Load resistance R=176.4 ohms & inductance L=100mH, Efficiency η=1 or 100% (efficiency of the ideal converter). dc snubber capacitor C_b=0.1μF, Dead time t_d=1μs. From this information, we design the converter parameters having the designed step as follows:

a. Peak to peak ripple current calculation

$$\Delta I_{max} = 2\left(I_{imax} - \frac{2P_i}{V_{imax}\, k_{max}}\right)$$

$$\Delta I_{max} = 2\left(4 - \frac{2X300}{325.25X0.5}\right)$$

$$\Delta I_{max} = 0.62A$$

b. The inductor calculation

$$L = \frac{k_{max}\ \ V_{\mathrm{imax}}}{\mathrm{F_s}\Delta I_{max}} = \frac{0.5\ X\ 325.24}{20X10^3X0.54} = 13.1mH$$

c. Maximum output current

$$I_{omax} = \frac{2P_o}{V_{omax}} = \frac{2X300}{325.25} = 1.85A$$

d. Output capacitor C_o

$$Co = \frac{I_{omax}}{2F_s\ \Delta V_c} = \frac{1.845}{2X20X10^3X5} = 9.22\mu F$$

e. Input filter elements calculations

According to the usual specification, the total harmonic distortion of the source current is I_i≤ 5%. Taking into account only the dominant harmonic components, reducing its value to 3% of I_i, the THD ≤5% is ensured. According to the analysis given in [5], input filters can be calculated using the following relation as follows

$\omega_s^2 L_f C_f \approx 32$ let C_f=0.1uF ⇒ L_f=20mH

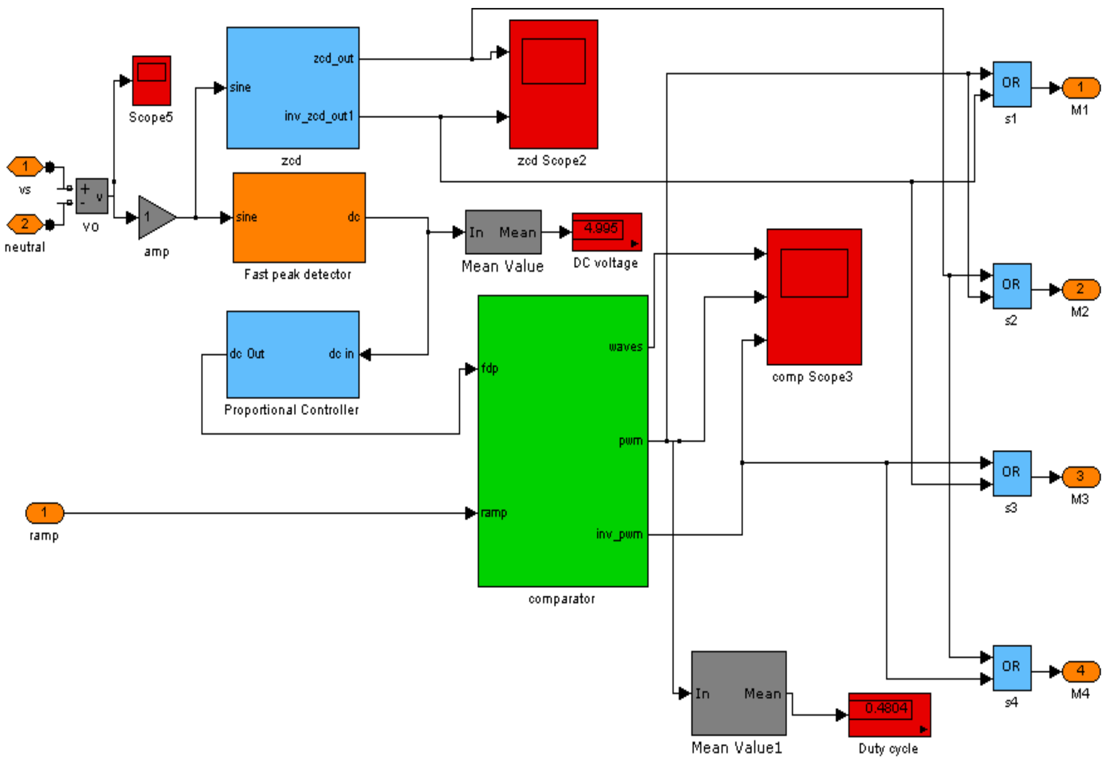


Fig. 7 Simulation block for generating PWM pulses for switches (control circuit1in system topology)

V. SIMULINK MODEL USING MATLAB SIMULINK

Fig. 7 shows the simulation block for generating PWM pulses for the switches, which is designed on the basis of control circuit shown in Fig. 6. And in Fig. 8, the simulation model of the closed loop system as that of Fig. 1 is built in MATLAB simulink. The input voltage sensed for line voltage regulation is used to generate control voltage $V_{con.}$ The control voltage is compared with ramp voltage for generating PWM pulses. With the help of logic & control circuits, four independent pulses are generated to drive four unidirectional MOSFET switches of ac chopper. With the help of programmable voltage source $V_{i,}$ the voltage sag is generated for four cycles from 0.08secs to 0.16secs and performance of the circuit is observed. Simulated results obtained using MATLAB simulink shows that the proposed scheme gives good dynamic and steady-state performances for a high quality of output voltage.

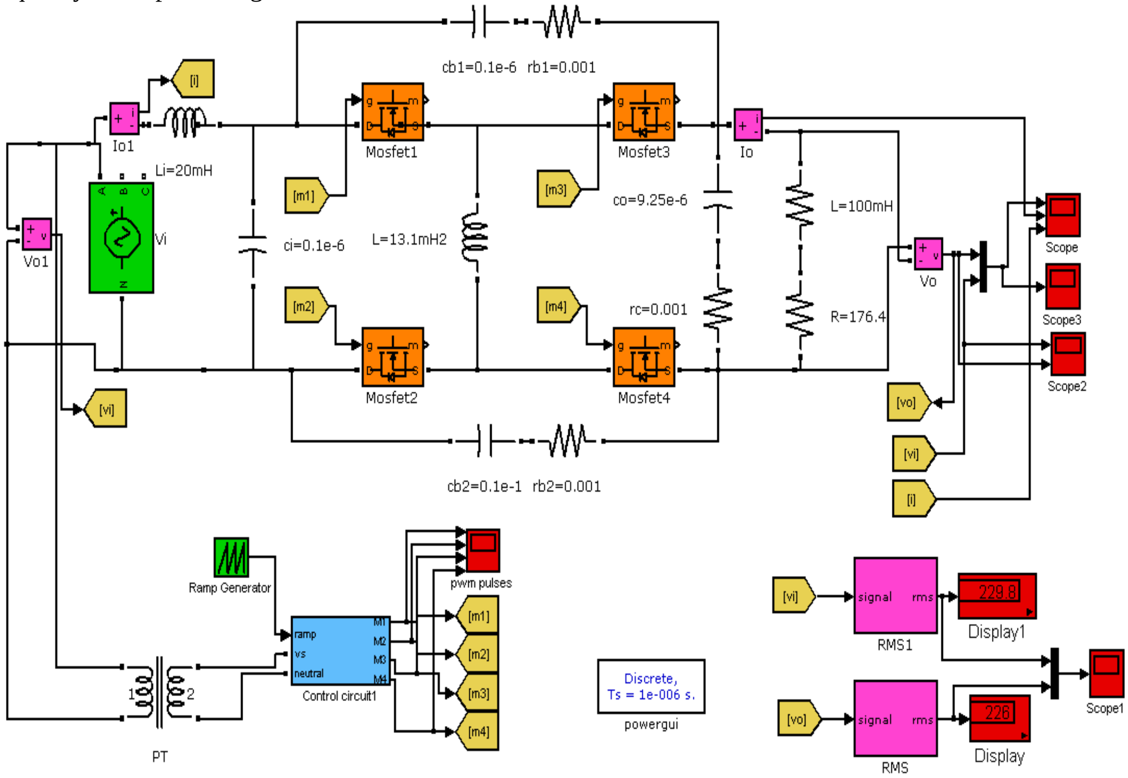


Fig. 8 Simulation model for the system topology of Fig. 1

VI. SIMULINK RESULTS

A bidirectional ac snubber as well as dc snubber based ac to ac buck boost converter circuit using power MOSFET is simulated using MATLAB simulink. The efficiency of the converter with ac snubber is found to be 94.96%. And the efficiency of the converter with dc regenerative snubber is found to be 99.75%. Therefore regenerative dc snubber based unidirectional switching ac choppers are preferred for higher efficiency. Fig. 9 shows the waveforms of PWM pattern gate control pulses for four unidirectional switches of ac chopper circuit. The switching frequency of the switching pulses is 20 kHz. The voltage waveform across dc snubber capacitor C_b and inductor L are shown in Fig 10. The Voltage sag of 15% from 0.08secs to 0.16secs for 4 cycles is generated using programmable input voltage source block. It is observed from Fig. 11a, that there is a drop in control voltage from 5V to 4.4V during this period in order to compensate for voltage sag. This reduced control voltage increases the width of the PWM pulses instantly to boost the voltage to reference value as shown in Fig. 11b. The phase angle between input and output voltage is almost remains to be zero degrees. Therefore the proposed closed loop ac to ac converter with fast peak detector operates dynamically in order to compensate for voltage sag. The dc snubbers with simple capacitors enhance the conversion efficiency of the converter. The proposed scheme has advantages in comparison with electronic tap-changing schemes using triacs or back-to-back connected thyristors to allow a bidirectional current flow and rectifier-inverter schemes that need a rectifier for bidirectional power flow & an inverter for output voltage control. These previous schemes require a line frequency transformer to compensate the output voltage. But our proposed scheme operates as a direct power electronic transformer. The electronic tap-changing schemes need large inductors or resistors to avoid current spikes when switches are turned on or off for tap changing. The rectifier-inverter schemes need more switches and complex control circuits than the proposed scheme. Therefore, since it is required to use only two standard switch modules or four identical switches with regenerative dc snubbers consisting of a capacitor is found to be simple and cost effective in comparison with alternative methods.

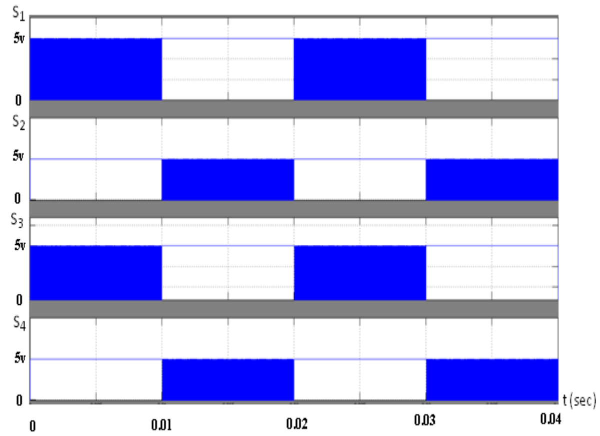


Fig. 9 PWM pattern gate control signals

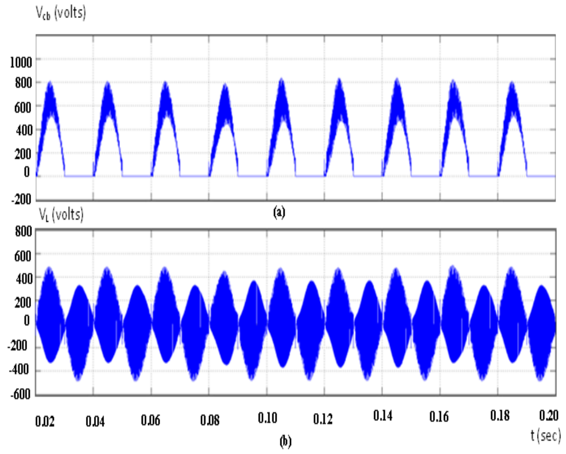
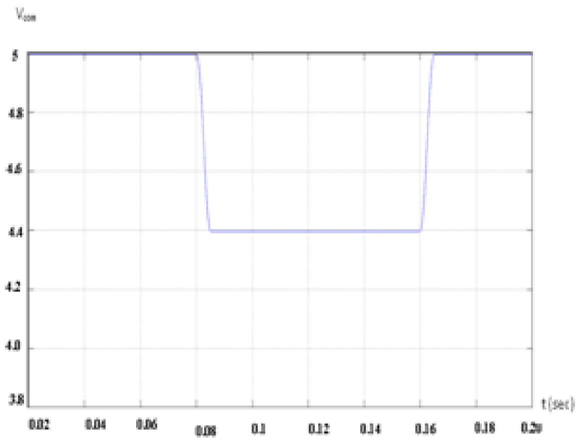
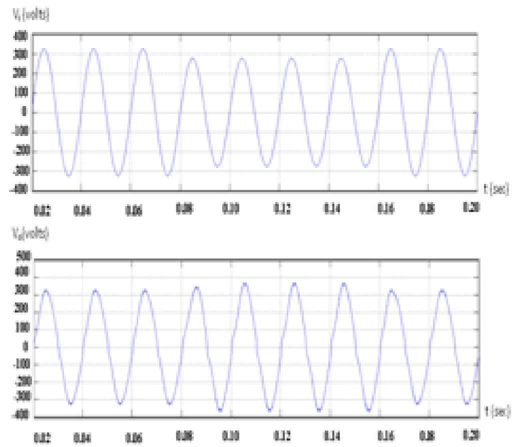


Fig. 10 Simulation waveforms

(a). Voltage across dc snubber capacitor (b). Voltage across Inductor L



(a)



(b)

Fig. 11 Simulation waveforms

(a) Control voltage V_{con} shows dip in voltage due to voltage sag. (b) upper trace: input voltage (V_i) with voltage sag of 15% for 4 cycles Lower trace: Output Voltage (V_o)

VII. CONCLUSIONS

A closed loop bidirectional ac to ac buck boost converter circuit with regenerative dc snubbers has been designed, simulated and analysed. In the ac chopper, the commutation scheme allows a dead-time to avoid current spikes from switches and at the same time establishes a current path in the inductor to avoid voltage spikes. The ac chopper utilizes regenerative dc snubbers attached directly to power semiconductor modules to absorb energy stored in stray line inductances. These dc snubbers enhance the conversion efficiency as it has a very simple structure consisting of only a capacitor. A fast peak-voltage detector for fast output-voltage control has also been proposed. Since this detector gives a fast output response to encounter voltage sag or swell, it is adequate for the line voltage controller which demands fast output voltage correction. The simulation results obtained using MATLAB simulink have shown that the proposed scheme gives good dynamic and steady-state performances for high-quality output voltage.

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REFERENCES

[1]. CLARK, J.K.: ‘AC power conditioner: design and applications’, Academic, New York, 1990.

[2]. IEEE Orange Book, IEEE Standard 446-1987: 'IEEE recommended practice for emergency and standby power systems for industrial and commercial applications' IEEE, 1987.

[3]. HAMED, S.A.: 'Steady-state modeling, analysis, and performance of transistor-controlled ac power conditioning systems',IEEE Trans .Power Electron.. 1990, **5,** pp. 305-313.

[4]. ADDOWEESH, K.E., and MOHAMADEIN, A.L.: 'Microprocessor based harmonic elimination in chopper type ac voltage regulators',IEEE Trans. Power Electron., 1990, **5,** pp. 191-200NGO, I.D.T.: 'A new flyback ac/ac voltage converter', IEEE Power Electron. Spec. Con$ Rec., 1986, pp. 497-503

[5]. BARBI, I., FAGUNDES, J.C., and KASSICK, E.V.: 'A compact ac/ ac voltage regulator based on an ac/ac high frequency flyback converter', IEEE Power Electron. Spec. Con$ Rec., 1991, pp.84G352

[6]. HOFMEESTER, N.H.M., VAN DEN BOSCH, P.P.J., and KLAASSENS, J.B.: 'Modeling and control of an ac/ac boost buck converter'. Proceedings of European conference on *Power electronics and applications*, EPE'93, 1993, Vol. 7, pp. 85-89

[7]. SRINIVASAN, **S.,** and VENKATARAMANAN, G.: 'Comparative Evaluation of PWM AC-AC converters', ZEEE Power Electron. Spec Con$ Rec., 1995, pp. 529-535

[8]. VESZPREMI K, HUNYAR M., "New application fields of the PWM IGBT AC chopper," Eighth International Conference of Power Electronics and Variable Speed Drives, pp. 46-51, 2000M. Shell. (2002) IEEEtran homepage on CTAN. [Online]. Available: http://www.ctan.org/tex-archive/macros/latex/contrib/supported/IEEEtran/

[9]. Balci M.E., Hocaoglu M.H. "Effects of Source Voltage Harmonic Distortion on Power Factor Compensation in Triac Controlled AC Chopper Circuits," *International conference on PEDS*, Vol. 2, pp. 1199 – 1204, Nov., 2005.

[10]. KWON, B.H., and YOUN, M.J.: 'Optimal observers using timeweighted performance index with prespecified eigenvalues', Trans. ASME **J.** Dyn. Syst. Meas. Control, 1986, **108,** pp. 366-368