Power Quality Improvement Using Open Loop Single Phase Ac Chopper with Comparison of R and RL Load

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Abstract- Some of the sensitive loads like the communication equipments, computer systems and process automation equipments could introduce voltage imbalance in the single-phase power supply. In order to enhance the voltage or to manage the voltage regulators were used which introduced input side and output side harmonics. This paper is an attempt to develop an ac-ac buck boost topology that would introduce the voltage regulation in single phase AC systems. The system consists of an AC chopper which is derived from the DC buck boost chopper. The AC buck boost chopper would work in four quadrant operation and thus needs the bidirectional switches to operate it. According to the IEEE 519 standard for the total harmonic distortion (THD) the input current THD must be less than 5%. Thus, an input side LC filter is used to obtain the input current THD reduction. The higher efficiency AC chopper for voltage regulation is developed with the regenerative DC snubber connected to the switches which observe the energy stored in the stray inductance. Matlab Simulink model is created to have a closed loop operation of the implementation with the zero crossing detectors and to engage in the PWM that it would provide for the voltage regulation. An open loop AC chopper circuit is designed with comparison of RL load and R load. The FFT analysis is carried out in order check the Total Harmonic Distortion of source current, output voltage and current.

I. INTRODUCTION TO AC-TO-AC CONVERTER

The power quality disturbances sensitive loads such as communication equipments, computers and method of automation system results in loss of valuable data, interruption to communication services and long production shutdowns. As per IEEE standard 446-1987 describe the voltage tolerance limits for sensitive loads, such as computer power supplies [1-2]. As per 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, and 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 require large input-output filters to reduce the low order harmonics which are large 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 another current path has to be provided when current paths are changed. This alternative current path is implemented using additional bidirectional switches or ac snubber. 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]. The converter topologies and design of VSI for grid connected PV system and reliable PV system parameter are studied [11]. 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.

II. SINGLE PHASE OPEN LOOP AC CHOPPER USING BIDIRECTIONAL SWITCHES

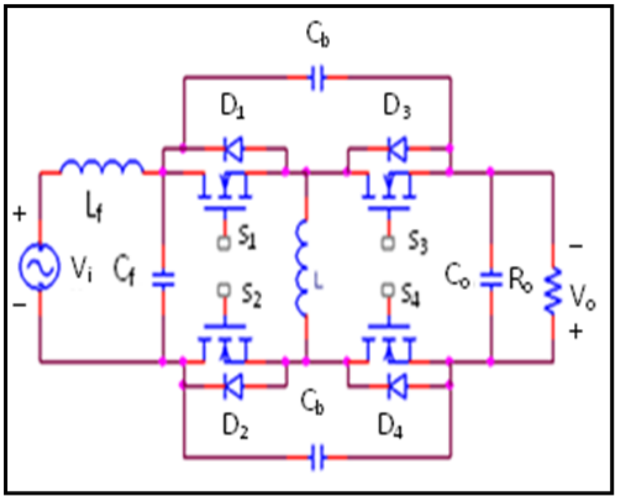

Fig.1 AC chopper using bidirectional switches and regenerative dc snubber

The figure shows the basic circuit of buck-boost AC converter with unidirectional switches and a regenerative DC snubber. The circuit will operate directly by the supply voltage V_s and it will regulate the input voltage by using the switches. The DC snubber consists of capacitor only C_b only. It does not contain any resistance with it and it will absorb bidirectional turn-off spike energy due to line stray inductance. The snubber energy is regenerated during charging mode and it will provide energy to inductor. The input filter L_f and C_f absorb the harmonic currents.

The circuit uses bidirectional switch module that is made up of two MOSFET's, the switches S_1, S_2, S_3 and S_4 are unidirectional and therefore the inductor 'L' which is used to store the input energy and transfer it to the output side. A switching method is used for solving the commutation problem, and it is based on the polarity of the switches the unidirectional switches S2 and S4 are also turned ON, during positive half cycle when input voltage Vi is less than zero then the switch S1 and S3 are turned ON additionally to avoid commutation process of switches and open path for inductor current . Here the inductor current is by passed through the input side or output side that depends on the direction of the inductor current.

- The modes of operation:

i. During Positive Half cycle (V_i>0):

During the analysis of positive half cycle the switch S_2 and S_4 are turned ON and modulating signals are given to switch S_1 and complementary modulating signals to S_3 during positive half cycle, the source current flows through Vs→S1→L1→diode across S2 and back to source.

During the regeneration process the switch S_1 will gets turned OFF then the inductor current i_L is positive it will passes through switch S_4 and to the load 'R' then it will goes back to inductor 'L' through a switch S_3 across diode D_3($L \rightarrow S_4 \rightarrow R \rightarrow D_3 \rightarrow L$). when the inductor current i_L is negative then it will flows from inductor 'L' to diode D_1 it will come back to supply V_s, from V_s it will flows to switch S_2 to the inductor 'L'($L \rightarrow D_1 \rightarrow Vs \rightarrow S_2 \rightarrow L$).

ii. During Negative Half cycle (V_i<0):

During the analysis of negative half cycle the switch S_1 and S_3 are turned ON then the modulating signal are given to switch S_2. The current will flows to the switch S_2 from the supply V_s and it will passes through the inductor 'L' then to the diode D_1 to the supply V_s ($V_s \rightarrow S_2 \rightarrow L \rightarrow D1 \rightarrow V_s$). When the inductor current i_L is positive then the current will flows through switch S_3 to the load 'R' and passes to diode 'D_4' and come back to inductor 'L'($L \rightarrow S_3 \rightarrow R \rightarrow D_4 \rightarrow L$). The negative inductor current will flows through diode 'D_2' to the supply V_s then to switch S1 and goes back to inductor 'L' ($L \rightarrow D_2 \rightarrow V_s \rightarrow S1 \rightarrow L$).

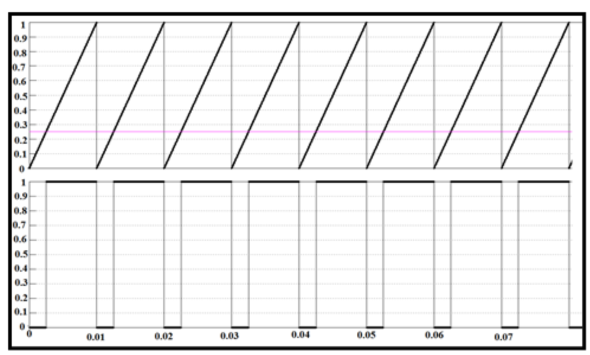

Fig.2. AC voltage controller pulses generated with Ramp and control voltage comparison

Modeling of open-loop single phase AC chopper in Matlab/simulink using bidirectional switches with R and RL load:

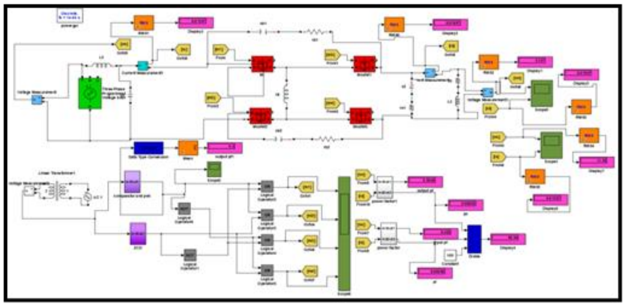

Fig.3. Simulation model of open-loop single phase AC chopper using bidirectional switches

iii. Design of Passive filter Elements for AC Chopper: 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.

We design the converter parameters having the designed step as follows:

a. Peak to peak ripple current result

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

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

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

b. Inductance calculation

$$L = \frac{k_{max}\ V_{\text{imax}}}{\text{F}_s \Delta I_{max}} = \frac{0.5\ X\ 325.24}{20X10^3X0.54}$$

$$= 13.1mH$$

c. Maximum output current

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

d. Output capacitor C_o

$$Co = \frac{I_{omax}}{2F_s\ \Delta \text{V}_c} = \frac{1.845}{2X20X10^3X5}$$

$$= 9.22\mu F$$

e. Load resistance

$$R_o = \frac{\text{V}_o}{\text{I}_o} = \frac{230}{1.85}$$

=124.32Ω

Analysis of open-loop single phase AC chopper using bidirectional switches with R load (V_i =230V):

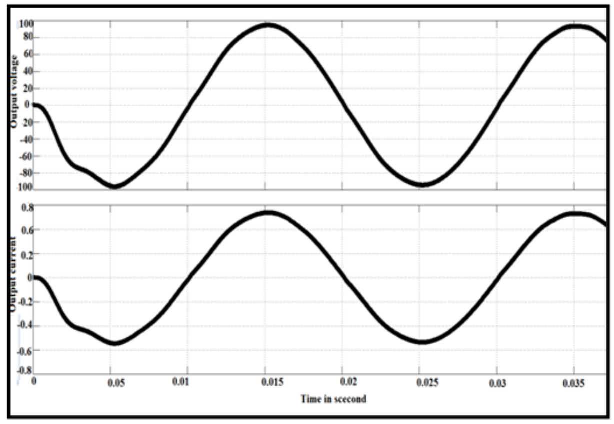

Fig.4. Output Voltage and Current Wave form with Duty ratio 0.2

(V_o RMS=66.21, I_o RMS=0.36)

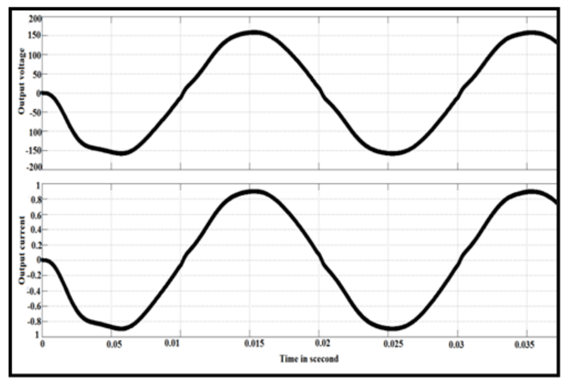

Fig. 5. Output Voltage and Current Wave form with Duty ratio 0.3

(V_o RMS=111.8, I_o RMS=0.62)

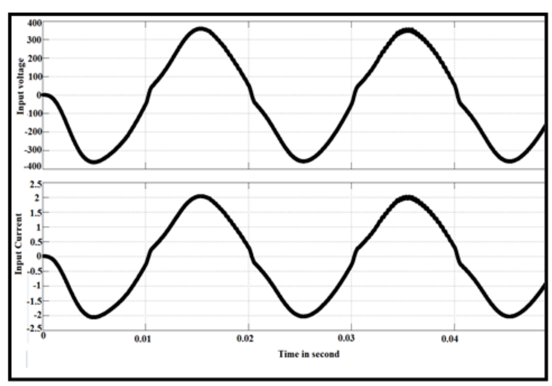

Fig.6. Output Voltage and Current Wave form with Duty ratio 0.4

(V_o RMS=174.4, I_o RMS=0.97)

Table I. Open-loop single phase AC chopper with R load
Supply Voltage V_s=230V

D	Is	Io	Vo	Is THD	Io THD	Vo THD	Power factor		Efficiency	Modes of operation
							Input	Output		
0.1	0.09	0.17	31.75	234.31%	0.49%	0.87%	0.38	0.98	66.69%	
0.2	0.25	0.36	66.21	154.29%	0.36%	0.59%	0.48	0.98	86.94%	
0.3	0.56	0.62	111.8	138.60%	1.00%	2%	0.56	0.98	92.29%	
0.31	0.56	0.62	112	138.47%	1%	1.51%	0.56	0.98	93.00%	
0.32	0.65	0.68	122.7	132.83%	1.11%	1.66%	0.58	0.98	93.60%	Sag 20% Vs=230-20% of 230 =184
0.34	0.76	0.74	134.4	127.62%	1.46%	2.07%	0.6	0.98	94.10%	
0.35	0.76	0.75	134.6	127.60%	1.53%	2.18%	0.6	0.98	94.10%	
0.36	0.88	0.81	146.8	122.65%	1.81%	2.56%	0.61	0.98	95.51%	
0.37	0.88	0.82	147	122.58%	1.86%	2.06%	0.61	0.98	94.51%	
0.38	1.02	0.89	160.1	117.93%	2.15%	2.96%	0.63	0.98	94.84%	
0.4	1.18	0.97	174.4	113.58%	2.66%	3.60%	0.64	0.98	95.09%	
0.41	1.18	0.97	174.7	113.47%	2.73%	3.69%	0.64	0.98	95.10%	
0.42	1.36	1.05	189.8	109.44%	3.13%	4.21%	0.66	0.98	95.30%	
0.44	1.56	1.15	206.33	105.30%	3.65%	4.89%	0.67	0.98	95.47%	
0.45	1.57	1.15	206.6	105.24%	3.66%	4.88%	0.67	0.98	95.47%	
0.46	1.79	1.24	223.8	101.44%	4.02%	5.35%	0.69	0.98	95.60%	Swell 20% Vs=230+20%230 =275
0.47	1.8	1.24	224	101.40%	4.06%	5.39%	0.69	0.98	95.60%	
0.48	2.04	1.34	241.6	97.70%	4.73%	6.02%	0.71	0.98	95.69%	
0.5	2.32	1.45	260	94.28%	5.40%	6.62%	0.72	0.98	95.75%	
0.51	2.32	1.45	260.2	94.18%	5.37%	6.58%	0.72	0.98	95.75%	

Open-loop single phase AC chopper using bidirectional switches with RL (V_i =230V):

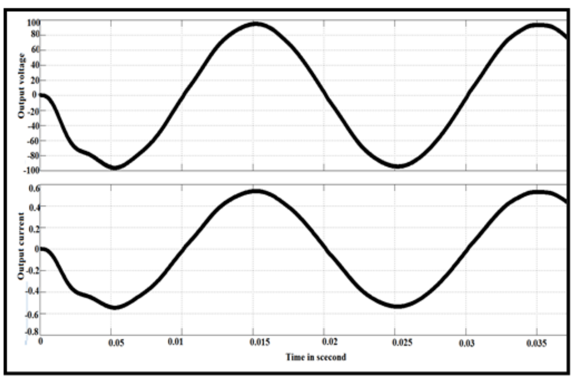

Fig. 7. Output voltage and current waveform with duty ratio 0.2

(V_o RMS=66.21, I_o RMS=0.36)

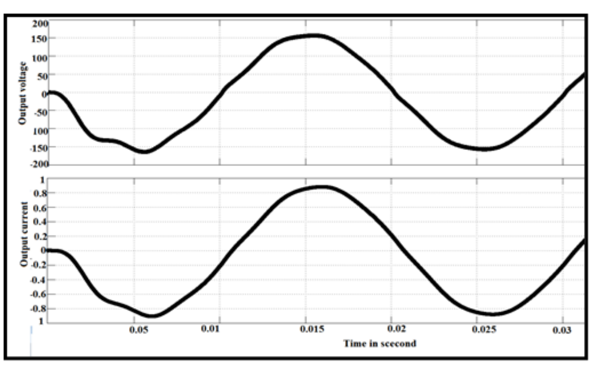

Fig.8. Output voltage and current wave form with duty ratio 0.3

(V_o RMS=111.8, I_o RMS=0.62)

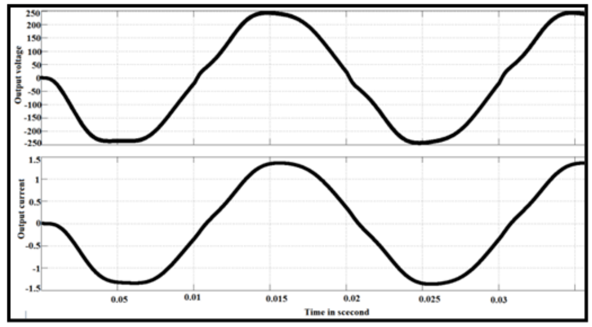

Fig.9.Output voltage and current wave form with duty ratio 0.4

(V_o RMS=174.4, I_o RMS=0.97)

Table II. Open-loop single phase AC chopper with RL load
Supply Voltage V_s=230V

D	Is	Io	Vo	Is THD	Io THD	Vo THD	Power factor		Efficiency	Modes of operation
							Input	Output		
0.1	0.09	0.17	31.75	234.31%	0.49%	0.87%	0.38	0.98	66.69%	
0.2	0.25	0.36	66.21	154.29%	0.36%	0.59%	0.48	0.98	86.94%	
0.3	0.56	0.62	111.8	138.60%	1.00%	2%	0.56	0.98	92.29%	
0.31	0.56	0.62	112	138.47%	1%	1.51%	0.56	0.98	93.00%	
0.32	0.65	0.68	122.7	132.83%	1.11%	1.66%	0.58	0.98	93.60%	Sag 20% Vs=230-20% of 230 =184
0.34	0.76	0.74	134.4	127.62%	1.46%	2.07%	0.6	0.98	94.10%	
0.35	0.76	0.75	134.6	127.60%	1.53%	2.18%	0.6	0.98	94.10%	
0.36	0.88	0.81	146.8	122.65%	1.81%	2.56%	0.61	0.98	95.51%	
0.37	0.88	0.82	147	122.58%	1.86%	2.06%	0.61	0.98	94.51%	
0.38	1.02	0.89	160.1	117.93%	2.15%	2.96%	0.63	0.98	94.84%	
0.4	1.18	0.97	174.4	113.58%	2.66%	3.60%	0.64	0.98	95.09%	
0.41	1.18	0.97	174.7	113.47%	2.73%	3.69%	0.64	0.98	95.10%	
0.42	1.36	1.05	189.8	109.44%	3.13%	4.21%	0.66	0.98	95.30%	
0.44	1.56	1.15	206.33	105.30%	3.65%	4.89%	0.67	0.98	95.47%	
0.45	1.57	1.15	206.6	105.24%	3.66%	4.88%	0.67	0.98	95.47%	
0.46	1.79	1.24	223.8	101.44%	4.02%	5.35%	0.69	0.98	95.60%	Swell 20% Vs=230+20%230 =275
0.47	1.8	1.24	224	101.40%	4.06%	5.39%	0.69	0.98	95.60%	
0.48	2.04	1.34	241.6	97.70%	4.73%	6.02%	0.71	0.98	95.69%	
0.5	2.32	1.45	260	94.28%	5.40%	6.62%	0.72	0.98	95.75%	
0.51	2.32	1.45	260.2	94.18%	5.37%	6.58%	0.72	0.98	95.75%	

A flyback diode is a diode connected across an inductor used to eliminate flyback, which is the sudden voltage spike seen across an inductive load when its supply current is suddenly reduced or interrupted. It is used in circuits in which inductive loads are controlled by switches, and in switching power supplies and inverters. This diode is known by many other names, such as snubber diode, commutating diode, freewheeling diode, suppressor diode, clamp diode, or catch diode. It reduces the harmonics and it also reduces sparking and arching across the mechanical switch so that it reduces the voltage spike seen in an inductive load.

Open-loop single phase AC chopper using bidirectional switches with RL Load (V_i =15V):

The hardware of AC chopper is designed with input voltage Vs=15V. Therefore, simulation is carried out with input voltage 15V. Therefore, all the passive elements are redesigned for the same and hardware is implemented.

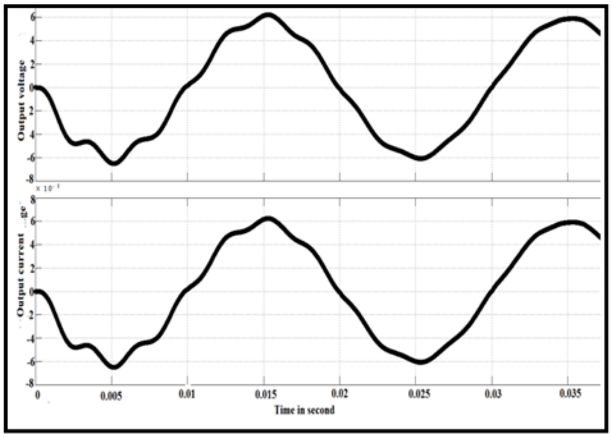

Fig.10. Output voltage and current wave form with duty ratio 0.2

(V_o RMS=4.2, I_o RMS=0.004)

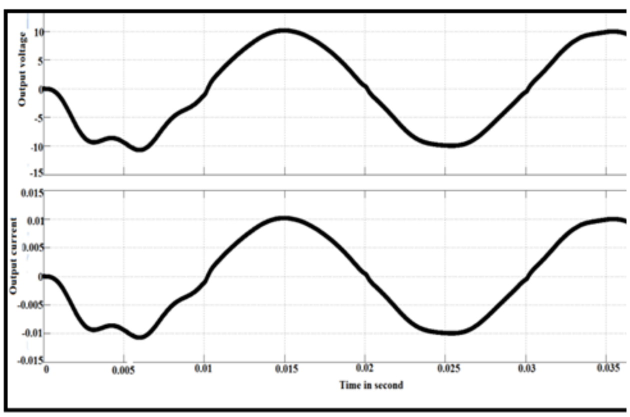

Fig.11. Output voltage and current wave form with duty ratio 0.3

(V_o RMS=7.86, I_o RMS=0.007)

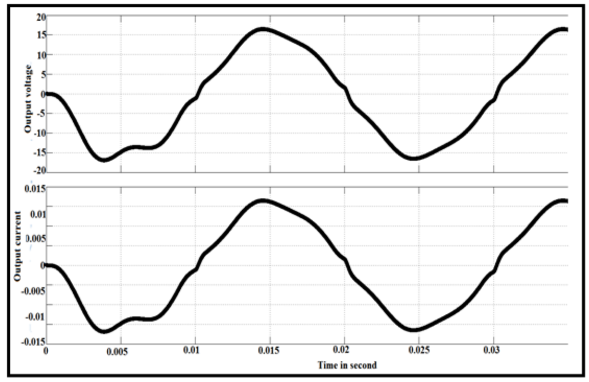

Fig.12. Output voltage and current wave form with duty ratio 0.4

(V_o RMS=11.31, I_o RMS=0.01)

Table III. Open-loop single phase AC chopper with RL load

Supply voltage Vs=15V

D	Is	Io	Vo	Is THD	Io THD	Vo THD	Power factor		Efficiency	Modes of operation
							Input	Output		
0.1	0.003	0.002	2.06	252.65%	2.91%	2.91%	0.29	1	26.95%	
0.2	0.008	0.004	4.2	183.34%	2.53%	2.53%	0.25	1	55.48%	
0.3	0.01	0.007	7.14	144.28%	2.37%	2.37%	0.25	1	72.59%	
0.31	0.01	0.007	7.16	144.32%	3%	3%	0.25	1	72.54%	
0.32	0.02	0.007	7.86	138.96%	2.76%	2.76%	0.26	1	75.01%	Sag 20% Vs=15-20%15=12
0.34	0.02	0.008	8.63	136.43%	4.35%	4.35%	0.25	1	76.88%	
0.35	0.02	0.008	8.64	136.47%	4.61%	4.61%	0.25	1	76.90%	
0.36	0.03	0.009	9.47	133.50%	5.77%	5.77%	0.25	1	78.54%	
0.37	0.03	0.009	9.48	134.15%	6.20%	6.20%	0.25	1	78.50%	
0.38	0.03	0.01	10.36	125.71%	4.84%	4.84%	0.26	1	80.01%	
0.4	0.03	0.01	11.31	121.00%	4.64%	4.64%	0.27	1	81.60%	
0.41	0.03	0.01	11.32	120.74%	4.71%	4.71%	0.27	1	81.64%	
0.42	0.04	0.01	12.34	119.90%	5.65%	5.65%	0.28	1	82.99%	
0.44	0.05	0.01	13.46	117.64%	6.41%	6.41%	0.29	1	83.83%	
0.45	0.05	0.01	13.48	117.55%	6.38%	6.38%	0.29	1	83.81%	
0.46	0.05	0.01	14.7	114.85%	7.18%	7.18%	0.3	1	84.65%	Swell 20% Vs=15+20%15=18
0.47	0.05	0.01	14.71	115.43%	7.34%	7.34%	0.3	1	84.55%	
0.48	0.06	0.01	16.05	112.70%	8.14%	8.14%	0.3	1	85.43%	
0.5	0.08	0.01	17.56	112.08%	9.37%	9.37%	0.3	1	86.24%	
0.51	0.08	0.01	17.56	112.47%	9.53%	9.53%	0.3	1	86.28%	
0.52	0.09	0.01	19.27	112.04%	11.17%	11.17%	0.3	1	86.73%	

In the above table shows that efficiency versus duty ratio. Efficiency increases from 26.95% to 86.73% with increase in duty ratio. The variation of duty ratio from 0.1 to 0.52, the output voltage, output current, V_o THD, input power factor and efficiency increases gradually. But input source current I_sTHD reduces gradually with the increase of duty ratio from 0.1 to 0.52.

Sag correction can be done by varying duty ratio from 0.42 to 0.47 (V_o varies from 12V to 15V).

Swell correction can be done by varying duty ratio from 0.47 to 0.52 (V_o varies from 15V to 18V)

CONCLUSION

The Comparison of R load with RL open loop bidirectional AC to AC boost converter with regenerative circuit has been designed, simulated and implemented. In this project to avoid the voltage and current transients for the short duration the commutation scheme uses dead time. At the same time, it will set up a current path in the inductor to avoid voltage transients. The output voltage, current, power factor and efficiency with increase in duty ratio. The Total Harmonic Distortion of source current is decreased with increase in duty ratio. But the Total Harmonic Distortion of voltage and current is increasing with increase in duty ratio. In the comparison of R load with RL, the efficiency is less in R load compare to RL and total harmonic distortion (THD) the input current THD must be less than 5%. Thus, an input side LC filter is used to obtain the input current THD reduction. The higher efficiency AC chopper for voltage regulation is developed with the regenerative DC snubber connected to the switches which observe the energy stored in the stray inductance.

FUTURE SCOPE

The project work is carried out to analyze efficiency, power factor and Total Harmonic Distortion of buck-boost topology by simulation with comparison of R and RL load. In future the hardware implementation for 230V can be done. And it can be compared with simulation results. By using this topology and with different control technique it is required to reduce the Total Harmonics Distortion of output voltage and current and hence efficiency can be further increased.

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