Performance Analysis of The Simple Low Cost Buck-Boost Ac-Ac Converter

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***Abstract*- A simple voltage converter based on LC network is capable of bucking and boosting the voltage level of input supply without any phase difference. The number of reactive components and switches used in the circuit is minimum. The paper presents the working principle and elaborates performance evaluation of this converter in different operating conditions. High speed IGBTs are used as bi-directional switch of the ac-ac converter and it is able to deliver smooth variable output voltage across the load without using any additional filter. The optimise use of the LC network helps to make the circuit simple, small size and cost-effective. The effects of L and C were studied separately and the quality of the output was examined with total harmonic distortion. The effect of switching frequency over the performance is also presented. The converter operation was verified with suitable experimental support.**

Keywords- Ac-ac Converter; Z-Source Converter; Buck-Boost; Llow Cost.

I. INTRODUCTION

Different types of power quality problems exist in our power system like transients, voltage sags/ surges, harmonics etc. Many devices have been developed to perform the role of regulating, conditioning, purifying incoming power with adequate power quality standard. Among these problems, short term voltage fluctuations, i.e. voltage surge and voltage sags, constitute the major disturbances and have the largest negative impact on industrial productivity as well as on rural electrification. There are also many sensitive load devices today that cannot withstand this voltage fluctuation and cause frequent failures. Most voltage variations are due to different power circuit faults, line losses or major changes of load current.

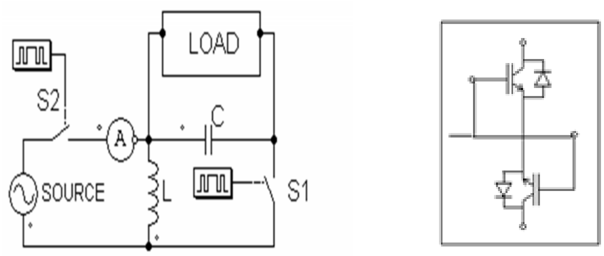
Ac to ac power conversion is the most popular way to generate quality ac power after the introduction of power electronics. Traditionally, an ac voltage converter is made with a transformer tap changer or with an ac-ac converter based on buck topologies or through ac-dc-ac converter. Developments of different topologies and switching techniques make ac-ac converter more versatile.

There are two major areas where ac–ac power conversion is necessary. One is the popular v-f ac drive where output voltage and output frequency both are required to be variable. The most popular topologies for such application are indirect ac–ac converters with a dc link [1]–[3], and matrix converters [4]–[5]. However, in another case where only voltage variation or regulation is needed with no change in frequency, direct PWM ac–ac converters are used, and they perform as ac choppers or power line conditioners. They have some advantages like the provision of better power factor, efficiency, low harmonic current in line, ease of control, smaller size and lower cost. Moreover, it is a single-stage conversion with simple topology. The traditional direct PWM ac–ac converters are implemented by bi-directional ac thyristor power controllers or triac, which use phase angle or integral cycle control of the ac supply to obtain the desired output voltage. However, they have some disadvantages, such as high total harmonic distortion (THD) in the source current, low power factor, and poor power transfer efficiency. Moreover, they do not have any facility of boosting the input voltage without using transformer in the circuit. Recently, Z-source converters applied to ac–ac converters have been proposed in [6]–[7]. In the concept of z-source ac to ac converter, two switches (either bi-directional or single-directional with dc rectifier) are turned on and off in complement with PWM signals. This circuit proposed with high frequency switching is used for boost mode but contains harmonics at the output waveform that requires filter to get smooth output. A new topology PWM buck-boost ac-ac converter using regenerative DC snubbers is proposed and analyzed in [8]. However, the output voltage of the proposed circuit is lagging the input voltage and additional output voltage filtering is required in this topology.

In this paper, the single-phase voltage-fed LC network power converter is presented with a different kind of simple switch topology. The most important achievement resulting from this technique is the reduction of the size and weight of the system. Furthermore, this ac-ac converter can be considered an electronic power transformer.

II. PROPOSED CIRCUIT MODEL

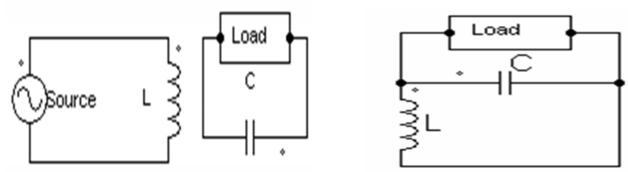
The ac-ac converter based on single-phase LC network is shown in block diagram in Fig. 1(a). The main ac to ac converter block consists of the ac single phase source, an LC-network and two bi-directional switches. The load may be resistive or inductive. The LC-network, a combination of one inductor and one capacitor as shown, is the main elements here that store or release energy accordingly to drive the circuit at a buck or boost mode.



(a) (b)

Fig. 1 (a) Block diagram of the proposed system. (b) Bidirectional switch configuration

The bidirectional switch s1, s2 as shown in Fig. 1(b) are able to block voltage and to conduct current in both directions. The s1 and s2 are provided PWM high frequency switching pulses, complement to each other. Here, a bi-directional switch is realized as a set of two IGBTs connected in common emitter mode back to back with two diodes. The diodes are included to provide the reverse blocking capability. The higher value of switching frequency of PWM signal is selected to keep the value of inductor and capacitor of LC network low. When the switch s2 is on as shown in Fig.2(a), the inductor L stores electromagnetic energy from the ac source. At the same time, switch s1 is off and the capacitor C discharges through the load. When the switch s2 is off and s1 is on, as shown in Fig. 2(b), the stored energy of the inductor supplies current to charge the capacitor C and to provide load current through switch s1.



(a) (b)

Fig 2. Equivalent circuit (a) when switch s1 is on and s2 is off (b) when switch s1 is off and s2 is on

Given that the switch s2 is in the conduction state for an interval of T_{on} and in non-conduction state for an interval of T_{off} during a switching cycle T. From the equivalent circuit of Fig. 2(a) one has that during T_{on}

$$v \quad * \quad , \tag{1}$$

where V is the source voltage, and v is the voltage across the inductor L.

Now considering the interval T_{off}, from the equivalent circuit Fig. 2(b) one has

$$v \quad * \quad , \tag{2}$$

where V is the voltage output across load.

The average voltage of the inductor over one switching period (T) should be zero in the steady state, from (1) and (2) thus we have

$$= v \quad \frac{* \qquad * \quad ff}{\qquad} \quad 0.$$

Thus,

$$\frac{}{} \quad \frac{}{} \quad \frac{}{} \quad , \tag{3}$$

where D is the duty ratio of the PWM signal applied to the switch s2 and G is the open loop gain of the proposed converter. Voltage gain derived from (3) is $G = D/(1-D)$, which shows the buck boost property of the ac-ac converter. The open loop characteristic of the converter is plotted in Fig. 3.

III. RESULTS AND ANALYSIS

The single phase ac-ac converter has the capability to buck/boost voltage, and this can be used to overcome voltage sag or voltage rise in power system. Simulation was carried out first with a fixed ac input voltage and a range of increasing value of duty ratio. The LC- network was selected as C= 10 uF, L= 500 uH. A R-L type load was selected with R=500 Kohm, 1 mH for the simulation. The frequency of the PWM switching signal was chosen as 10 KHz. The set of obtained data during a number of simulations is tabulated in Table I. It shows that the voltage and currents across L and C increased with the increase of duty ratio. An open loop characteristic is drawn on the data based on gain vs. duty ratio in Fig. 3.

TABLE . 1 OPEN LOOP DATA OF THE CONVERTER

Vin (rms volts)	D %)	Vout / Vc (rms volts)	V_L(rms volts)	Ic (rms amp)	I_L(rms amp)	Gain
230	10	25.57	76.67	0.15	0.16	0.11
	20	57.53	115	0.31	0.35	0.25
	30	98.64	150.6	0.50	0.61	0.43
	40	153.5	187.9	0.75	0.99	0.67
	50	230	230	1.14	1.66	1
	60	346	282.2	1.83	2.96	1.50
	70	539.5	352.7	3.24	6.01	2.35
	80	931.4	464.6	6.82	15.41	4.05
	90	2177	722.1	22.61	71.85	9.47

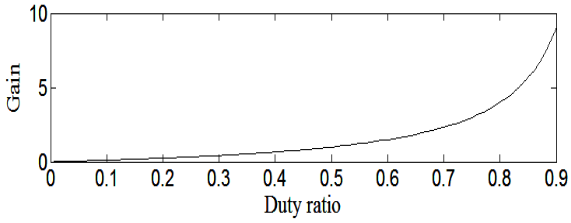


Figure 3. Open loop characteristics of the converter

Two sets of waveforms were recorded for 40% and 60% duty cycles respectively. Input voltage and corresponding load voltage and current, capacitor and inductor currents, inductor voltage were recorded through scope and are presented in Fig. 4(a) and Fig. 4(b), respectively. The voltage across capacitor Vc is the same with the load voltage as it is connected across the load. It is required to note that there is no phase difference between load and input voltages. Moreover, no additional filter was used to get smooth sinusoidal output voltage across the load for this topology.

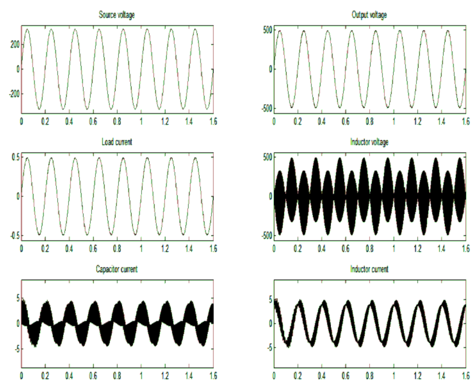


Figure 4(a). Waveforms for 60% duty cycle

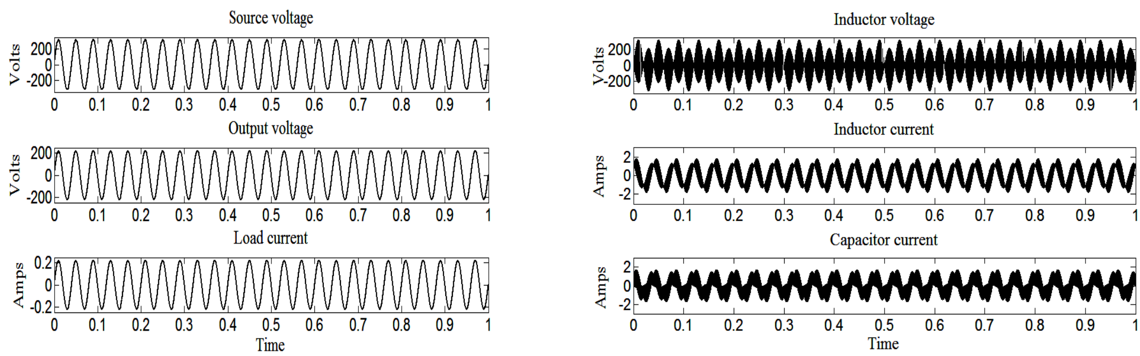


Figure 4(b). Waveforms for 40% duty cycle

In a second stage, simulation was carried out to study the effect of circuit parameters. Performance of the ac-ac converter was judged by the inductance L and capacitance C of the circuit topology. First, a variable range of inductance L was selected with a fixed capacitor 10 uF and switching frequency 10 kHz. The steady state results for a constant source voltage and 50% duty cycle are tabulated in Table II. Corresponding load voltage, input current and load voltage and harmonic distortion (THD) were measured. As for 50% duty cycle, the gain should be 1, and this was achieved at the range of L valued between 1 to 2 mH.

A plot presenting the relation of THD with the variable inductor in micro henry is shown in Fig. 5. It shows that THD decreased with the increase of inductor value.

TABLE- II PERFORMANCE WITH VARIABLE INDUCTOR

L(uH)	C(uF)	V_{in} (rms volts)	D (%)	V_{out} (rms volts)	I_{in}(rms amp)	THD(%)
10	10	130	50	249.4	186.585	267.4
50				105.7	28.314	32.82
100				116	14.239	13.7
200				123.53	7.31	6.35
300				125.8	5.04	4.18
400				126.9	3.92	3.15
500				127.72	3.26	2.5
1000				129.34	1.99	1.5
2000				129.52	1.45	1.1
3000				131.25	1.3	0.9
4000				131.86	1.236	0.9
8000				134	1.16	0.8

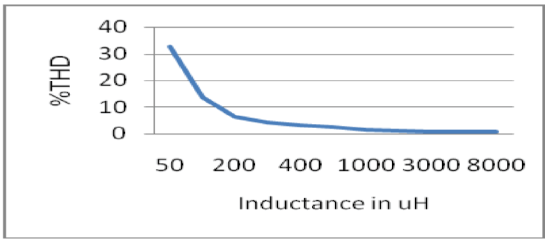


Figure 5. Load voltage THD vs. inductor (L)

Similarly, a variable range of capacitor C was selected with 1 mH inductance L and switching frequency 10 kHz. The steady state results of corresponding load voltage, input current and load voltage harmonic distortion (THD) were measured in the same conditions and are shown in Table III. The gain 1 was achieved at the range of C between 20 to 50 uF. A plot presenting the relation of THD with the capacitor is shown in Fig. 6. It shows the different kind relation unlike the previous one.

Again, under a variable switching frequency 3 kHz to 20 kHz, steady state results of corresponding load voltage, input current and load voltage harmonic distortion (THD) were measured keeping the components L and C unchanged. The results show better performance in higher frequency as presented in Table IV. A plot presenting the relation of THD with the switching frequency is shown in Fig. 7.

TABLE- III PERFORMANCE WITH VARIABLE CAPACITOR

C (uF)	L (uH)	Vin (rms volts)	D (%)	Vout (rms volts)	Iin (rms amp)	THD (%)
1	1000	130	50	115.4	1.81	15.6
5				126.65	1.92	2.9
10				128.4	1.99	1.5
20				130	2.24	0.82
50				132.56	3.49	0.52
100				134.41	6.25	0.46
500				160.54	35.3	12.02

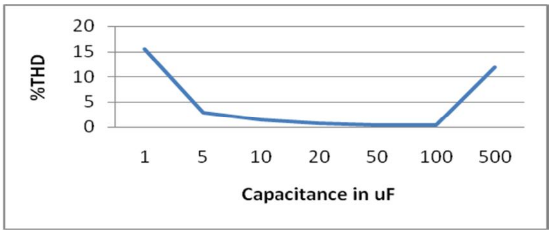


Figure 6. Load voltage THD vs. capacitor (C)

A set of data with 20 kHz frequency for 50% duty cycle was studied, too. For two sets of given value of capacitors, different ranges of inductors were chosen. The results are tabulated in Table V. It is clear that higher values of switching frequency reduced the size of the energy storing elements L and C.

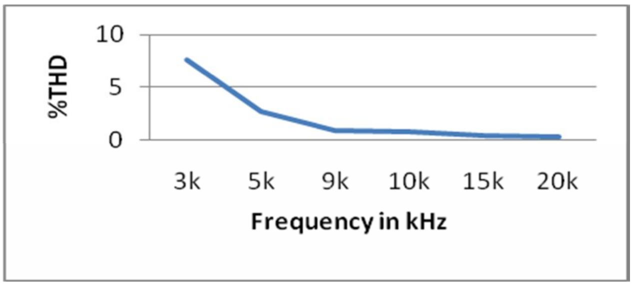


Figure 7. Load voltage THD vs. capacitor (C)

TABLE- IV PERFORMANCE WITH VARIABLE SWITCHING FREQUENCY

F (kHz)	Vin (rms volts)	L (uH)	C (uF)	D(%)	Vout (rms volts)	Iin (rms amp)	THD(%)
3	130	1000	20	50	123.04	4.6	7.6
5					127.34	3.14	2.7
9					130	2.1	0.9
10					130	2.23	0.8
15					130.65	1.86	0.4
20					130	1.57	0.3

Hardware representation of the above circuit was also made and corresponding measurements were done with different values of duty ratios. It showed the buck-boost capability clearly. One of the captured results, showing source and load voltages together under a boost mode, is presented in Fig. 8. Table VI presents the measured values of output voltage, capacitor and inductor currents under different ranges of duty cycles and fixed value of source voltage, switching frequency and load.

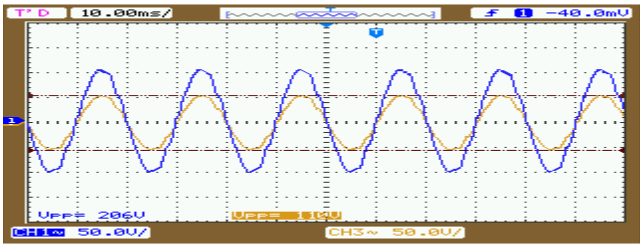


Figure 8. Source (yellow) and Load voltage (blue) of the experimental circuit

TABLE- V PERFORMANCE WITH HIGHER SWITCHING FREQUENCY

f (kHz)	Vin (rms volts)	D (%)	L (uH)	C (uF)	Vout (rms volts)	Iin (rms amp)	THD (%)
20	130	50	100	10	127.36	5.75	2.6
			200		129.23	3.2	1.3
			400		129.63	1.96	0.7
			600		130.23	1.59	0.53
			800		129.97	1.4	0.46
			1000		130.83	1.31	0.44
			1500		131.25	1.18	0.41
			2000		131.3	1.12	0.4
			3000		131.6	1.1	0.4
			4000		132.62	1.05	0.4
			100	20	128.76	5.8	1.3
			200		130.15	3.32	0.7
			300		130.27	2.52	0.46
			400		130.69	2.16	0.38
			500		130.68	1.95	0.33
			800		131.10	1.7	0.28
			1000		131.09	1.58	0.26
			2000		132.19	1.43	0.25
			3000		133.50	1.402	0.25

TABLE- VI EXPERIMENTAL RESULTS

Vin (rms volts)	D (%)	Vout / Vc (rms volts)	Ic (rms amp)	I_L (rms amp)	Gain
130	10	15.6	0.09	0.1	0.12
	25	46.8	0.23	0.26	0.36

	40	89.7	0.48	0.70	0.69
	50	131.8	0.84	1.11	1,01
	60	192.5	1.33	2.26	1.46

IV. CONCLUSIONS

Detailed performance study was done in this study through both simulation and experiments for the simple topology single-phase ac-ac converter based on LC network. The single-phase ac-ac converter can provide variable output voltage under steady state condition by operating at buck and boost mode. Operating principle and steady-state analysis of the system was presented in different operating conditions. The effects of different components and operating parameters were studied in detail, which will help to optimize the design of converter. It will help to reduce the size and cost of the converter. The advantage of getting smooth sinusoidal waveform of same phase is possible here without using any additional filter circuit, making this converter popular. This converter can be effectively used in closed loop systems to develop voltage regulator or power conditioner.

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