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Single Phase Z-Source Matrix Converter with Buck-Boost Capability

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***Abstract*— Matrix converter has been best-known to offer an " all silicon " solution for AC-AC conversion,removing the need for reactive energy storage parts employed in standard rectifier-inverter based systems.The matrix converter is a forced commutated converter that uses an array of controlled two-way switches as the main power elements to produce a variable output voltage system with unrestricted frequency.It doesn't have any dc link circuit and does not want any massive energy storage component.**

A single phase Z-source matrix converter that is an advancement of the traditional matrix converter can step up and step down the frequency and the voltage can be stepped up or stepped down.A MATLAB simulation of the single phase Z-source buck-boost converter at totally different input and output frequencies and voltages that verifies its utility for a number of various applications is given here.

Keywords—Z-source matrix converter; Sparse Matrix Converter;shoot-through states; PWM Techniques

I. INTRODUCTION

A discretionary number of input lines can be associated with a subjective number of output lines specifically utilizing bidirectional semiconductor switches.The various transformation stages and energy storage components of conventional inverter and cycloconverter circuits can be replaced by one exchanging network. A matrix converter is an ac to ac converter prepared to do specifically changing over an ac power supply voltage into an ac voltage of variable amplitude and frequency without a huge energy storage element [1]. The principal portrayal of a matrix converter was distributed in 1976 by Gyugyi and Pelly [2]. In 1980,Venturini and Alesina exhibited the first calculation fit for incorporating output sinusoidal reference voltages [1]. Late research on matrix converters has concentrated for the most part on modulation plans [3]-[8] and on drive applications. Clearly, all distributed studies have managed mostly with three-stage circuit topologies.

The principal investigation of a solitary stage matrix converter was performed by Zuckerberger et al. [9] on a frequency step-up and elementary voltage step-down converter. Utilisation of single-phase matrix converters has been portrayed for induction motor drives, radio-frequency induction heating, audio power amplification, and compensation voltage sags and swells. It has been accounted for that the use of safe-commutation switches with pulsewidth modulation (PWM) control can essentially enhance the performance of ac/ac converters. However, in the conventional single-phase matrix converter topology [9]-[13], the ac output voltage cannot exceed the ac input voltage. Furthermore, it is unacceptable to show both two-way switches of one phase leg on at the same time; otherwise, the current spikes generated by this action will destroy the switches. These drawbacks can be overcome by using Z-source topology [14].Research on Z-source converters has centered primarily on dc/ac inverters and ac/ac converters.The Z-source ac/ac converters focus on single-phase topologies [15]-[17] and three-phase topologies. In applications where solely voltage regulation is required, the group of single-phase Z-source ac/ac converters proposed in [15]-[17] has a variety of deserves, such as providing a bigger range of output voltages with the buck-boost mode, reducing inrush, and harmonic current. However, no one has designed a device primarily based on a Z-source structure and a matrix converter topology that can offer ac/ac power conversion with each a variable output voltage and a step-changed frequency. Here, we apply the Z-source thought to a single-phase matrix converter to produce a new kind of device known as a single-phase Z-source buck-boost matrix converter. This single-phase Z-source buck-boost matrix converter will offer a wide vary of output ac voltages in buck-boost mode with step-down/step-up frequencies. It is shown from operational principles, analyses and simulation that this single-phase Z-source buck-boost matrix converter will buck and boost voltages in step-down/step-up frequency operation. A safe-commutation technique that is very straightforward to implement as a free-wheeling path to provide the needed free-wheeling operation just like what's offered in alternative device topologies is used. The safe-commutation scheme sets up a persistent current way in dead time to wipe out voltage spikes on switches without a snubber circuit.

II. LITERATURE SURVEY

A. Basic Matrix Converter(MC) Topologies

Broadly,the existing frequency converter designs can be classified into 2 categories:direct and indirect converters.To reduce number of switches in the conventional matrix converter, major step was taken with regard to the further development of matrix converter topologies which occurred in 2001 as Indirect matrix converter topologies known as Sparse Matrix Converters as shown in Fig.1 by Kolar et al followed by the first experimental results of a Very Sparse Matrix Converter (Fig.2.). Ziegler et al in 2004 advocated possible circuit topologies referred as S-A-X converters. The same concept was proposed in 2002 by Kolar et al for the Sparse Matrix Converters known as Ultra Sparse Matrix Converter as shown in (Fig.3).

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The ultra-sparse matrix converter (USMC), shown in Fig.3, is the most simple form of the IMC, comprising only 9 individual switches and 18 diodes. The Ultra Sparse MC itself is a variant of the sparse matrix converter (SMC), shown in Fig.1. The USMC and SMC operate by creating a dc link,with the input stage and by using the output stage to provide inversion. The main variation between the IMC and SMC is that the USMC only permits unidirectional power flow due to the arrangement of the input switches.

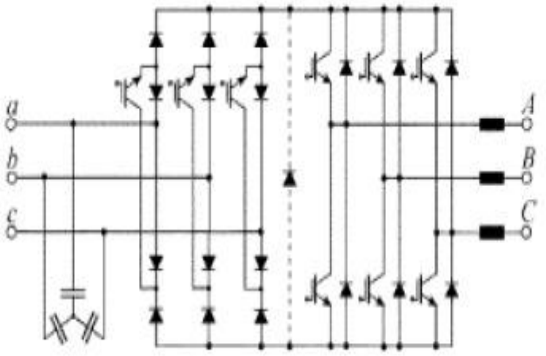

Fig 1. Sparse Matrix Converter

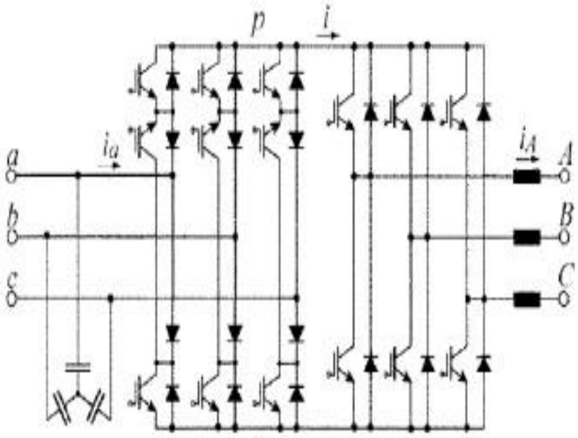

Figure 2.Very Sparse Matrix Converter

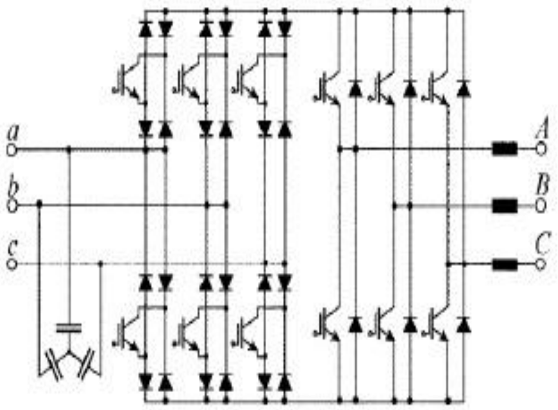

Fig 3.Ultra Sparse Matrix Converter

B. Single phase Matrix Converter(MC) Topologies

Fig.4.(a) and (b) shows a single-phase Z-source, PWM voltage-fed, buck-boost converter and current-fed buck-boost converter, respectively.The output voltage of the proposed ac-ac converter can be bucked or boosted by controlling the duty ratio D. In addition, the output voltage can be in-phase or out-of-phase with the input voltage depending on operating regions . This is a unique feature of the Z-source converter[16]

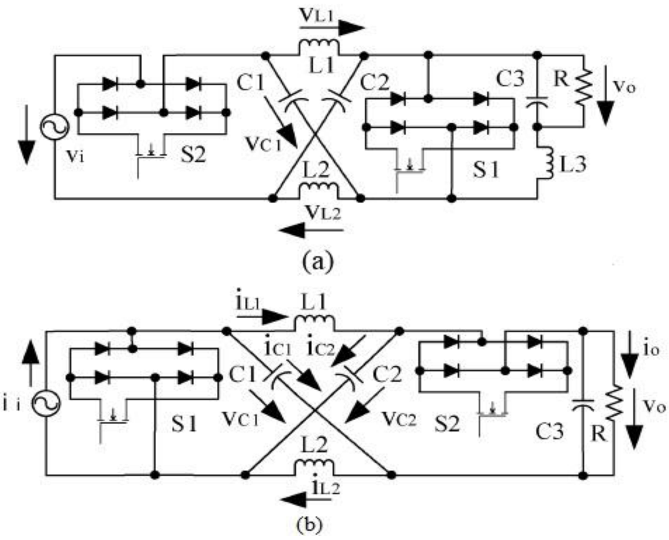

Fig 4. Single-phase Z-source ac-ac converter:(a)voltage-fed and (b)currentfed.

C. Bidirectional switch topologies

A true bi-directional switch must be realized by the combination of conventional unidirectional semiconductor devices. Fig.5.shows diverse bi-directional switch setups which have been utilized as a part of model and/or proposed in [18], [19], [20].

Another problem, tightly related to the bi-directional switches implementation is the commutation problem. The absence of static freewheeling paths gives rise to commutation issues . As a consequence it becomes a difficult task to safely commutate the current, since a particular care is required in the timing and synchronisation of the switches command signals.

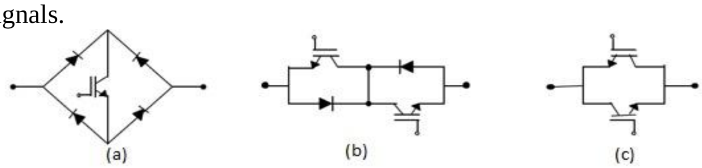

Fig.5.Basic input filter configurations used in matrix converter prototypes(.a)Capacitorsstar or delta connected.(b)Second order L-C filter (c)L-C filter with parallel damping resistor

D. The input filter

The input filter design for static power converters operating from an ac power system has to meet three main requirements:

1. carry out the required switching noise attenuation;
2. having a low input displacement angle between filter input voltage and current;
3. guaranty overall system stability.

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In addition to these requirements, a set of considerations related to cost, system efficiency,voltage attenuation, and filter parameter variation have to be made for an optimized input filter design [21], [22]

III. SINGLE PHASE Z-SOURCE MC TOPOLOGY

A.GENERAL DESCRIPTION

The basic system is that of a single phase Z-source buck-boost matrix converter whose general block diagram is as shown in Fig.6.The ac voltage across the single-phase matrix converter v_a is boosted by the ac/ac Z-source converter with the input voltage v_i . Then, the single-phase matrix converter modulates the frequency of v_a. The output voltage is obtained with a variable amplitude and step-changed frequency .Fig.7 shows the single-phase Z-source buck-boost matrix converter. It employs a Z-source network,an L-C input filter, bidirectional switches, and an RL load. The LC input filter is required to reduce switching ripple in input current. The single phase Z-source buck-boost matrix converter discussed here requires four bidirectional switches S_{1j} , S_{2j} ,S_{3j} , and S_{4j} (j = a, b) to work as a single-phase matrix converter and one source bidirectional switch,S_{sj} (j = a, b), where a and b refer to drivers 1 and 2, respectively. All the bidirectional switches used are common emitter back-to-back switch cells.

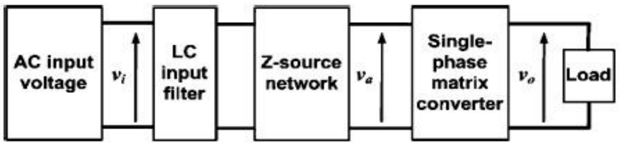

Fig 6. General block diagram of the existing topology

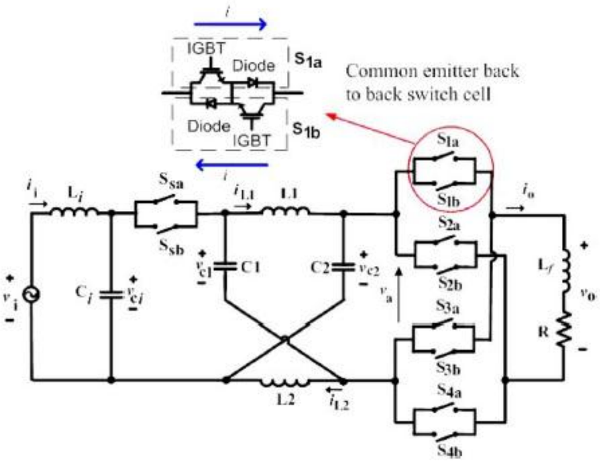

Fig 7. Single-phase Z-source buck-boost matrix converter topology

B. MODES OF OPERATION

The frequency of input voltage f_i is assumed to be 50 Hz, and the desired output frequency f_o is decided to be 100 Hz (i.e.step-up frequency), 50 Hz (i.e.same frequency), or 25 Hz (i.e.step-down frequency). To double the output frequency of the input voltage, the operation of the converter is divided into four stages, as shown in the Fig.8.

Fig.8. defines stage 1 in the boost mode when both input voltage and output voltage are positive. The switches S_{sa}; S_{1a}; S_{2b}, and S_{4a} are completely turned on (S_{2b} is turned on for commutation purposes, while S_{sa} and S_{4a} are turned on for continuous current flow);

S_{1b},S_{3b},and S_{4b} are modulated complementary to the dead time. In state 1, as shown in Fig.8(a),S_{4b} is turned on and it conducts current flow during the increasing positive cycle of input voltage;$S_{sb}$and S_{1b} turn on and conducts negative current flow from the load to the source, if possible;S_{2b} turns on for commutation purposes. Then, S_{sb} and S_{4b} turn off, and S_{3b} has not yet turned on, and there are two commutation states that occur.If $i_{L1} + i_{L2} + i_o > 0$, the current flows along a path which is from from S_{sa} , as shown in Fig. 8(b); if $- iL1 - iL2 + io > 0$, the current flows along a path which is from S_{4a} and S_{2b}, as shown in Fig.8(c). Because switch S_{2b} must be conducting, the current condition for this state is given as $-iL1 - iL2 + io > 0$. In state 2, as shown in Fig.8(d), S_{3b} turns on and conducts current flow as a shoot-through path; the positive load current may be freewheeled through S_{2b} and S_{1a}; the negative load current may be freewheeled through S_{3b} and S_{4a}. In these switching patterns, the current path is always continuous whatever the current direction be. Thus, the voltage spikes are eliminated during switching and commutation processes. The analysis for stages 2, 3, and 4 is identical to that for stage 1. The dotted line in Fig.8.indicates the safe-commutation switch during each stage. The operations at other output frequencies of 50Hz and 25 Hz are performed by varying the switching strategies. The operation for an output frequency of 50 Hz is implemented by omitting stage 2 and stage 3 and making the time intervals for stage 1 and stage 4 twice . Similarly, the operation for an output frequency of 25 Hz is carried out by interchanging stage 2 and stage 3 and doubling the time intervals of all stages. In the operations for output frequencies of 50Hz and 25 Hz, the time interval of each stage is 8.33 ms.

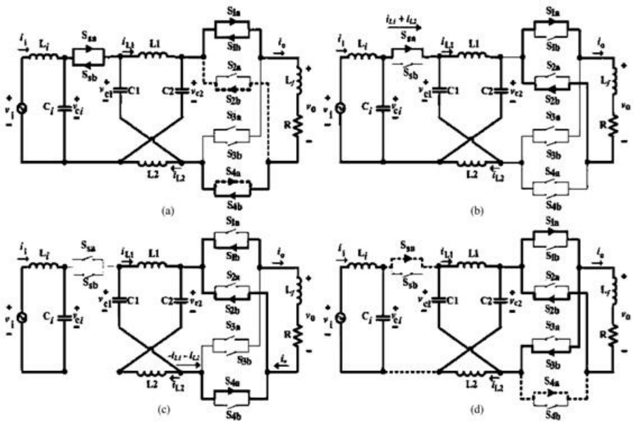

Fig 8. Stage1 for the boost mode for a frequency of 100 Hz. (a) State 1. (b) Commutationstate when $i_{L1}+i_{L2}+i_o > 0$(c) Commutation state when $-i_{L1} - i_{L2} + i_o > 0$(d) State 2.

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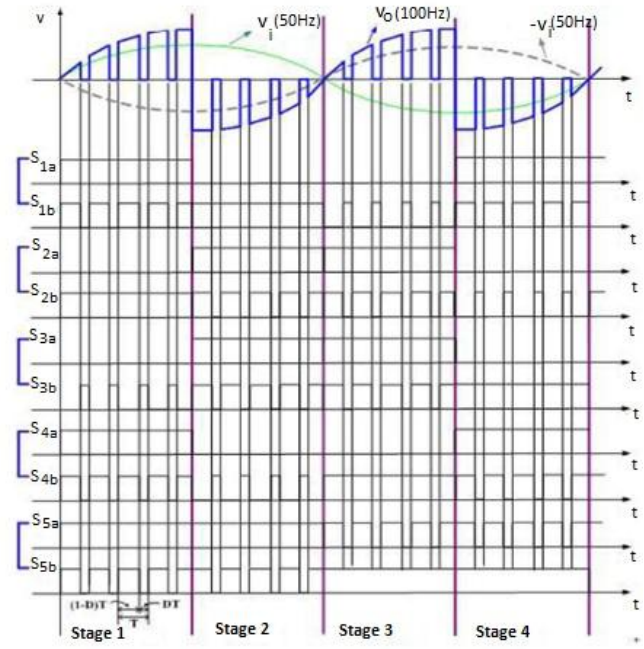

Fig 9. Switching pattern of the single-phase Z-source buck-boost matrix converter for a 100 Hz output frequency in boost mode

C.OBSERVATIONS AND OUTCOMES OF STUDY

From the survey of different topologies of matrix converters the following observations are made:

Table.1. Comparison of different topologies

Converter	No:of active device	No:of diodes	Isolated driver potentials	Simultaneous buck-boost capability
MC	18	18	6(CC),9(CE)	NO
IMC	18	18	8	NO
SMC	15	18	7	NO
VSMC	12	30	10	NO
USMC	9	18	7	NO
ZSMC	21	21	6(CC),9(CE)	YES

An Z-source structure and a matrix converter topology that can provide ac/ac power conversion with both a variable output voltage and a step-changed frequency is opted.Z-source concept is applied to a single-phase matrix converter to create a new type of converter called a single-phase Z-source buck-boost MC.

From the observations made we decide to use a safe-commutation technique that is very simple to implement as a free-wheeling path to provide the free-wheeling operation required identical to what is available in other converter topologies. The safe-commutation scheme gives a continuous current path in dead time to eliminate voltage spikes on switches without a snubber circuit.
Four bidirectional switches to serve as a single-phase matrix converter and one source bidirectional switch can be selected for the topology discussed.All bidirectional switches selected are common emitter back-to-back switch cells.

IV.SIMULATION RESULTS

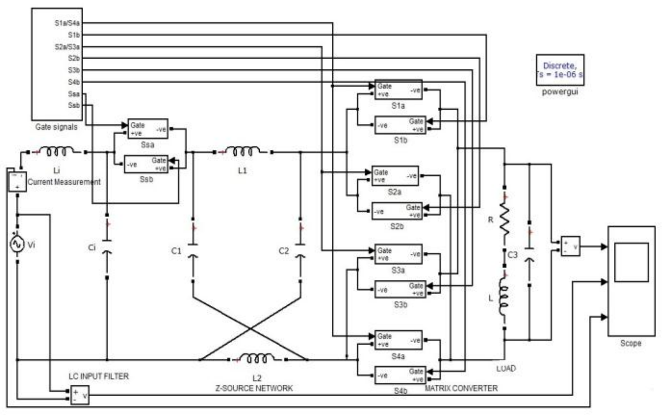

Fig.10. Simulation diagram for single phase Z-source buck-boost matrix

Simulated waveform of single phase Z-source buck-boost MC for boost operation at 25Hz

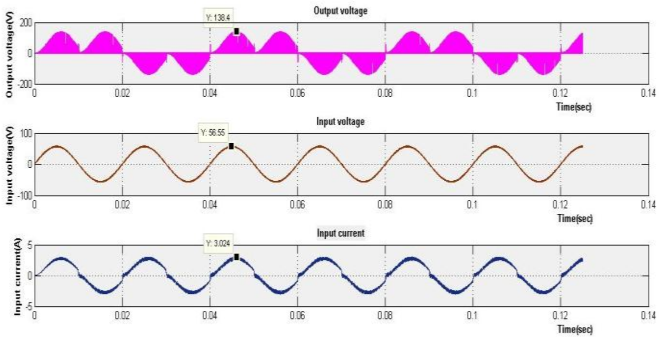

Fig.11. Simulation diagram for single phase Z-source buck-boost matrix converter for boost operation at 25Hz

Fig.11. shows the input voltage whose amplitude was 40V rms,50 Hz which was boosted to 138.4V at a frequency of 25 Hz.The input current was observed to be 3.02A

Simulated waveform of single phase Z-source buck-boost MC for boost operation at 50Hz

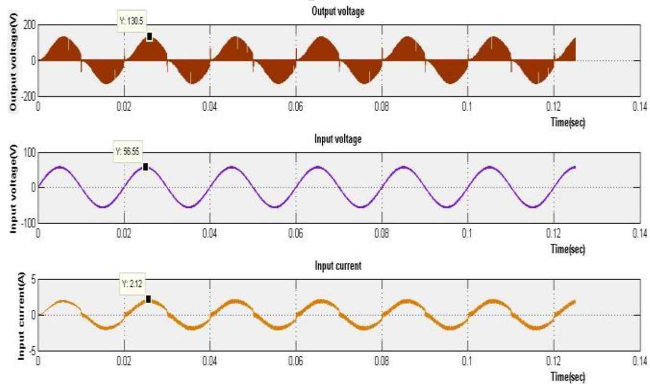

Fig.12. Simulation diagram for single phase Z-source buck-boost matrix converter for boost operation at 50Hz

Fig.12.shows the input voltage whose amplitude was 40V rms,50 Hz and was boosted to 130.5V at a frequency of 50 Hz.The input current was observed to be 2.12A.

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Simulated waveform of single phase Z-source buck-boost MC for boost operation at 100Hz

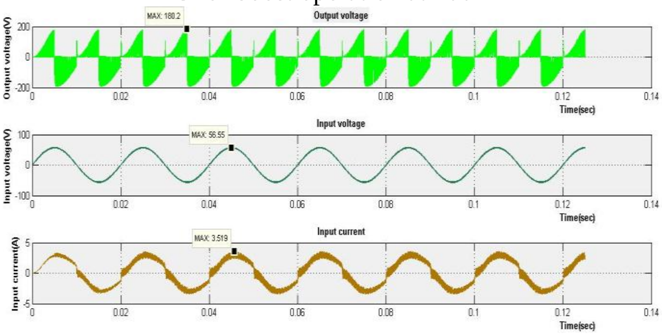

Fig.13. Simulation diagram for single phase Z-source buck-boost matrix converter for boost operation at 100Hz

Fig.13. shows the input voltage whose amplitude was 40V rms,50 Hz and was boosted to 180.2V at a frequency of 100 Hz.The input current was observed to be 3.519A.

Simulated waveform of single phase Z-source buck-boost MC for buck operation at 25 Hz

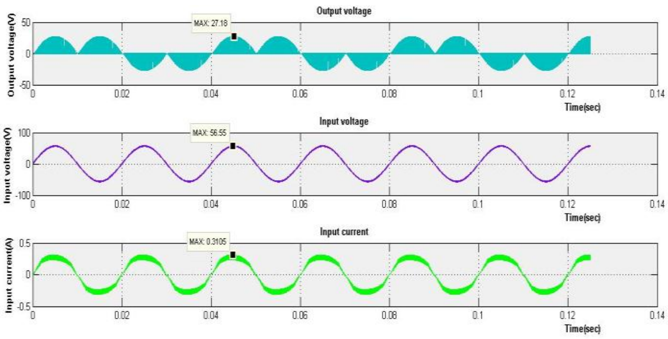

Fig.14. Simulation diagram for single phase Z-source buck-boost matrix converter for buck operation at 25Hz

Fig.14.shows the input voltage whose amplitude was 40V rms,50 Hz and was bucked to 27.18V at a frequency of 25 Hz.The input current was observed to be 0.3105A.

Simulated waveform of single phase Z-source buck-boost MC for buck operation at 50 Hz

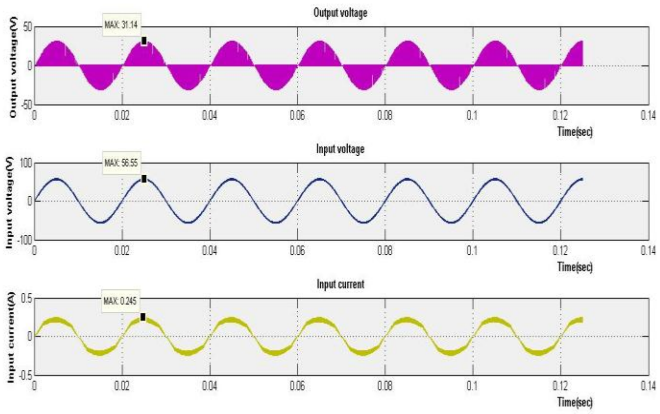

Fig.15. Simulation diagram for single phase Z-source buck-boost matrix converter for buck operation at 50Hz

Fig.15.shows the input voltage whose amplitude was 40V rms,50 Hz and was bucked to 31.14V at a frequency of 50 Hz.The input current was observed to be 0.245A

Simulated waveform of single phase Z-source buck-boost MC for buck operation at 100 Hz

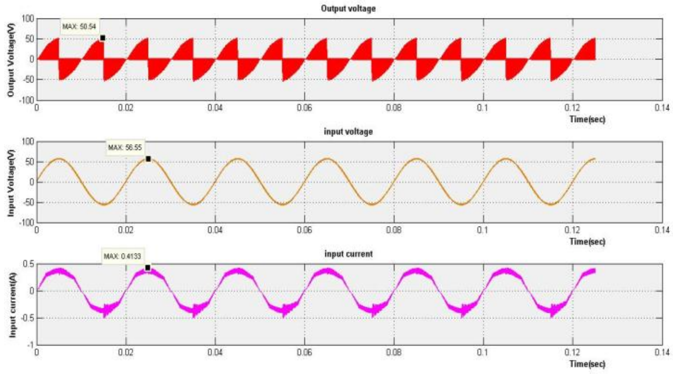

Fig.16. Simulation diagram for single phase Z-source buck-boost matrix converter for buck operation at 100Hz

Fig.16. shows the input voltage whose amplitude was 40V rms,50 Hz and was bucked to 50.54V at a frequency of 100 Hz.The input current was observed to be 0.413A

Table.2. Output voltage with step-changed frequency in buck and boost mode

	25Hz	50Hz	100Hz
Boost mode	138.4V	130.5V	180.2V
Buck mode	27.8V	31.8V	50.54V

Table.3. Input current with step-changed frequency in buck and boost mode

	25Hz	50Hz	100Hz
Boost mode	3.024A	2.12A	3.51A
Buck mode	0.31A	0.24A	0.41A

Table.4. THD of input current

	25Hz	50Hz	100Hz
Boost mode	9.04%	9.70%	12.19%
Buck mode	12.87%	11.23%	11.57%

V.CONCLUSION

A new single-phase Z-source buck-boost MC that can buck and boost the desired output voltage frequency which is step-changed was studied. The output frequency is either an integer multiple or an integer fraction of the input frequency. A continuous current path by using a commutation strategy is used. The use of this safe-commutation strategy is a significant enhancement as it makes it possible to avoid voltage spikes on the switches without the use of a snubber circuit. A steady-state circuit analysis was presented and the operational stages were described. Based on the simulation results, the performance of the existing system were analyzed.

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