Modeling and Simulation of a New Single Phase AC-AC Converter

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Abstract

This paper presents a new single phase ac-ac converter. After a brief discussion about species of Z-source converters, dynamic model of converter is analyzed. This converter can step up and down input ac voltage. Simplicity and high power quality operation are its specific advantages. Proposed converter is designed based on main core of Z-source converters. Finally, this converter is simulated in different conditions using PSCAD/ EMTDC simulation software.

1. Introduction

The impedance-source power converter (Z-Source) is a new electronic circuit recently recognized because of its applications in power conversion [1,2]. The Z-Source found to be more efficient than other commonly used power converters [3]. For example, voltage buck-boost capability needed in dc to ac fuel cell applications [4] other applications are related to the improvement in the performance of electric drives [5]. Z-source inverter is a novel topology that overcomes the conceptual and theoretical barriers and limitations of the traditional voltage-source converter and current-source converter. Its operating principle and applications for fuel cell inverters and ASD (adjustable speed drive) systems have been presented in [2], [6-8]. For ac-ac power conversion that normally requires variable output voltage and variable frequency, the most popular topology is the voltage-source inverter with a dc link, i.e., a pulse width modulation (PWM) inverter with a diode-rectifier front end and dc capacitor link. However, for application where only voltage regulation is needed, a direct PWM ac-ac converter is a better choice to achieve smaller size and lower cost. AC–AC converters, or ac–ac line conditioners, can also perform conditioning, isolating, and filtering of the incoming power in addition to voltage regulation [9]. Another developed converters in recent years, are Z-Source ac-ac converters which can step up and down input voltage. They are composed of two active switches, two full diode bridges and a Z-network. The most important advantage of these converters is their ability in voltage step up and down with least harmonics. These converters are presented in [4], [10-12]. Basic circuit in all of these converters is a simple structure that consists of inductors and capacitors. Fig .1 shows Z-network schematic.

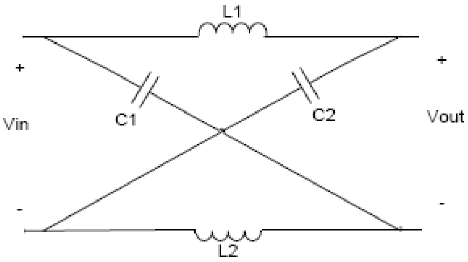

Fig. 1. Z-network

Based on above mentioned capabilities of the Z-Source converter, this paper presents a simple step up and down ac-ac converter. We use Z-network behavior in this converter.

2. Z-Network Feature Study

As Fig .1 shows, the Z-Source topology is very simple to describe: two-port network that consists of a split-inductor L1 and L2 and capacitors C1 and C2 connected in X shape. It is define that C1 is C, C2 is βC, L1 is L and L2 is αL. Now, it is desired to calculate dynamic model for a Z-Source. The equations that describe the dynamic model for the Z-Source are given by (1), (2), (3), (4), (5) and (6) [1].

$$\frac{\partial V_{C1}}{\partial t} = \frac{1}{C1}(I_{L2} - I_{in}) \tag{1}$$

$$\frac{\partial V_{C2}}{\partial t} = \frac{1}{C2}(I_{L1} - I_{in}) \tag{2}$$

$$\frac{\partial V_{L1}}{\partial t} = \frac{1}{L1}(V_{out} - V_{C2}) \tag{3}$$

$$\frac{\partial V_{L2}}{\partial t} = \frac{1}{L2}(V_{out} - V_{C1}) \tag{4}$$

$$V_{in} = V_{C1} + V_{C2} - V_{out} \tag{5}$$

$$I_{in} = I_{C1} + I_{C2} - I_{out} \tag{6}$$

Using mesh analysis, and considering the initial conditions equal to zero, transfer function is obtained by (7)-(9) [1].

$$(\frac{1}{sC_1} + sL_2)I_{C1} - (sL_2)I_{out} = V_{in} \tag{7}$$

$$(sL_2)I_{C1} - (sL_2 + \frac{1}{sC_1} + R)I_{out} + (\frac{1}{sC_2})I_{L1} \tag{8}$$

$$-\left(\frac{1}{sC_2}\right)I_{out}+\left(sL_1+\frac{1}{sC_2}\right)I_{L1}=-V_{in} \quad (9)$$

After some calculations, we can get V_o/V_i:

$$\frac{V_o}{V_i}=\frac{s^4\alpha\beta C^2L^2-1}{(\alpha\beta RC^2L^2)s^4+(\beta+1)\alpha CL^2s^3+(\beta+\alpha)RLCs^2+(\alpha+1)Ls+R} \quad (10)$$

3. Proposed AC – AC Converter

If we plot V_o/V_i versus β, Fig .2 is obtained. As we can see from Fig .2, output voltage is regulated by β varying. So parallel capacitors with C_2 can be a good idea to have desired and continues voltage in converter output. For Fig .2 we use (10) by replacing α,f ,L and C with following values:

$$\alpha=4 \qquad f=50\ \ Hz$$

$$L=79.56\ \ \mu H \qquad C=7.956\ \ \mu F$$

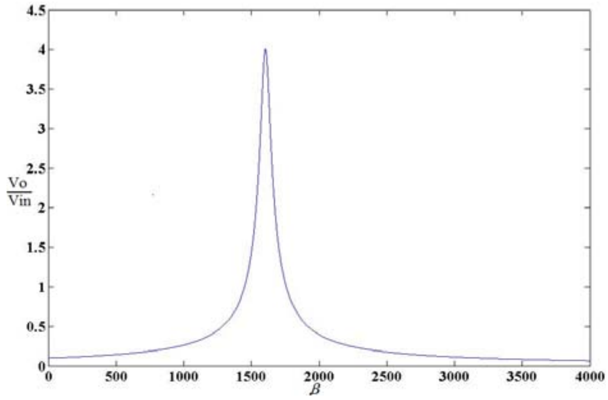

Fig. 2. Vo/Vi Versus β

As Fig .2 shows, we can determine C_2 and so regulate converter output voltage. Converter operation in resonant frequency is notable. It's possible to calculate resonance frequency with given equations in frequency domain (i.e. jω). It's assumed the load is resistive. After some simplification, the imaginary part of the Z-Source dynamic model is equal to zero, then we have:

$$[\alpha+1-\omega^2(\alpha\beta LC+\alpha LC)]j\omega L=0 \quad (11)$$

The resonant frequency is given by (12):

$$\omega_0=\frac{\sqrt{\alpha+1}}{\sqrt{\alpha LC(\beta+1)}} \quad (12)$$

If we substitute the resonant frequency in transfer function of Z-source converter, we can obtain the expression of circuit operation when works under resonance condition. This expression is given by (13). Also, the quality factor of Z-source converter is given by (14).

$$\frac{Vo}{Vi}=\frac{\alpha\beta-1}{\alpha-\beta} \quad (13)$$

$$Q=\frac{\omega_0L\sqrt{\alpha(\beta+1)}}{R\sqrt{\alpha+1}} \quad (14)$$

We usually select small α to minimize inductances size. Note that with a big difference between the values of α and β, the gain expression can be approximated by (15) [1].

$$\frac{Vo}{Vi}=-\alpha \quad (15)$$

Fig .2 shows this converter amplify input voltage for 4 times in resonant frequency. Clearly for various Q this amplification is different. Fig .3 shows our proposed converter structure based on above mentions. In this converter, we use parallel capacitors with C_2 to regulate output voltage by determination of number of parallel capacitors.

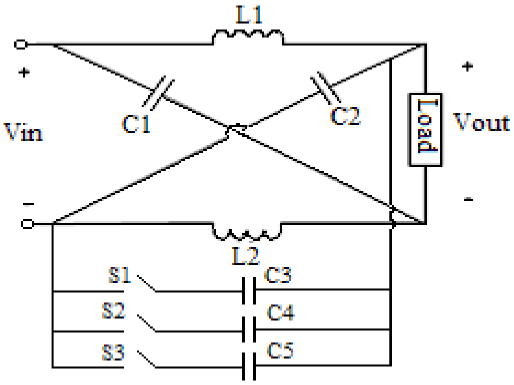

Fig. 3. Proposed converter structure

In this converter we use capacitor steps. Obviously, more capacitor steps, result more accuracy in voltage regulation and converter is controlled more continual. In normal condition that there is no over and under in input voltage, a number of parallel capacitors should switch on that output voltage be equal to input one. For voltage sags and under voltages in converter input, a number of parallel capacitors should switch on that output voltage doesn't have any dip and for voltage swells and over voltages case, a number of parallel capacitors should switch on or off that output voltage doesn't have any nub.

4. Simulation Results

In this section, simulation results of proposed ac-ac converter are presented. We use PSCAD / EMTDC to simulate this converter. First, for normal input voltage, ac-ac converter step up and step down this voltage. Fig .4 shows input voltage and Fig .5 and Fig .6 shows stepped up and stepped down output voltage respectively. We use values which are related to ω_0 for converter elements to simulate converter operation under resonant condition. As we said before, gain expression can be approximated by (15) with big difference between the values of α and β. So we expect 4 times (because α=4) amplification in output voltage with respect to input voltage. Fig .7 shows output voltage in resonant condition. Note that, input voltage is same as Fig .4. Voltage with fast variations is applied to converter. Converter mitigates voltage sags and swells by adjusting capacitor steps. Fig .8 shows input voltage swells and Fig .9 shows output compensated voltage. Fig .10 shows input voltage sags and Fig .11 shows output compensated voltage.

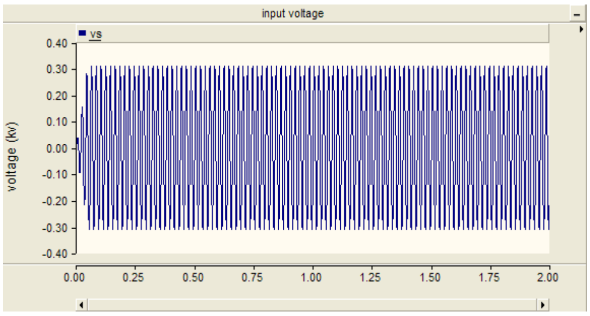

Fig. 4. Input normal voltage

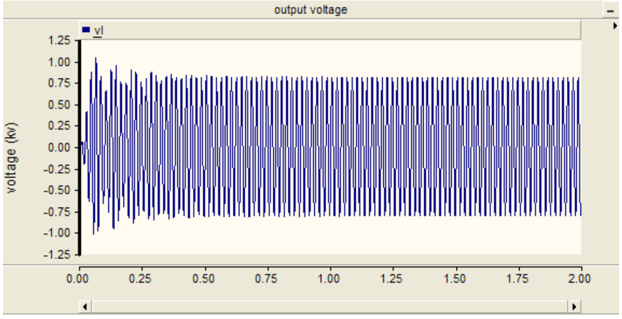

Fig. 5. Stepped up output voltage

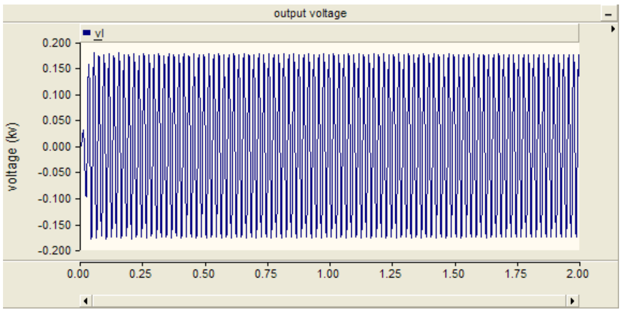

Fig. 6. Stepped down output voltage

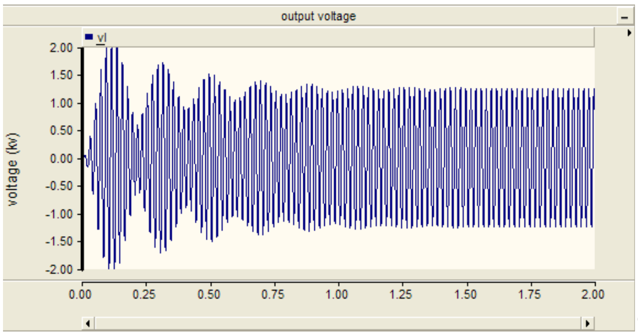

Fig. 7. Output voltage in resonant condition

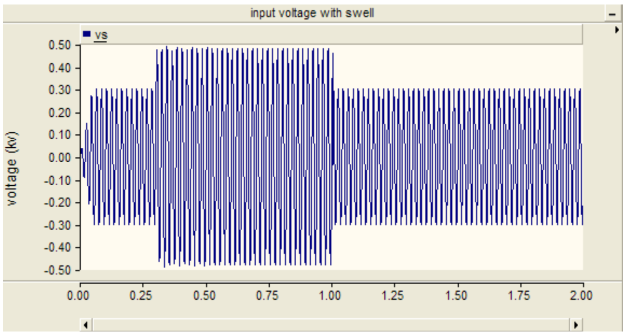

Fig. 8. Input voltage swells

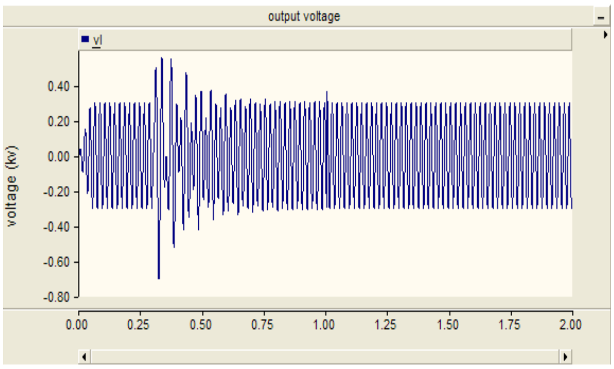

Fig. 9. Output voltage for input voltage swells

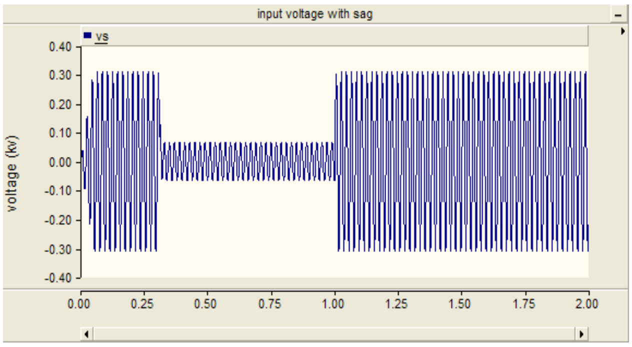

Fig. 10. Input voltage sags

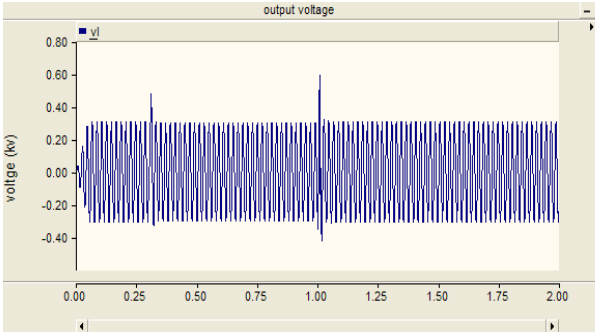

Fig. 11. Output voltage for input voltage sags

Final section of simulation is about harmonic quality of converted voltages. Fig .12 shows input voltage (which is same as Fig .10) harmonics amplitude for voltage sags and Fig .13 shows output voltage harmonics amplitude via Fast Fourier

Transform (FFT). As these two figures show, output voltage harmonics are same as input voltage harmonics. It results that this converter converts voltage without harmonic generation.

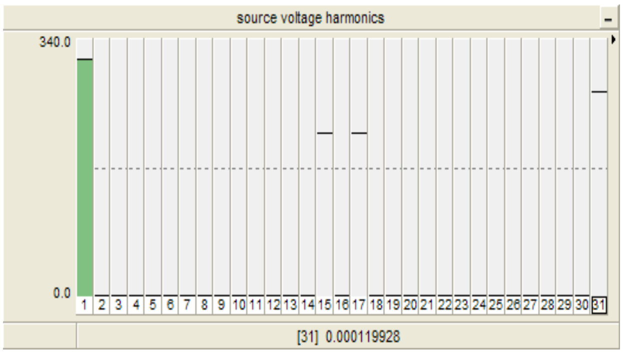

Fig. 12. Input voltage harmonics amplitude

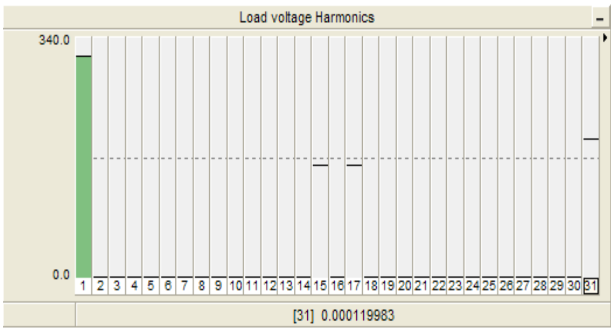

Fig. 13. Output voltage harmonics amplitude

5. Conclusion

In this paper a new single phase ac-ac converter is proposed. Simplicity and high power quality operation are its specific advantages. Simulation results shows harmonics generated in this converter are much less than which are generated in traditional ac-ac choppers. Also this converter has a more simple structure than most of new converters. Because of these advantages, this converter control and maintenance are much easy.

As simulation results show, we can use this converter to mitigate voltage sags and swells in order to keep sensitive loads.

6. References

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