Simulation and implementation of a modified single phase quasi z source Ac to Ac converter

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Abstract

A modified single-phase quasi-Z-source ac–ac converter is proposed in this paper. The proposed converter has the main features in that the output voltage can be bucked or boosted and be both in-phase and out-of-phase with the input voltage. The input voltage and output voltage share the same ground, the size of a converter is reduced, and it operates in a continuous current mode. A safe-commutation strategy for the modified single-phase quasi-Z-source ac–ac converter is used instead of a snubber circuit. The experimental results verified that the converter has a lower input current total harmonic distortion, a higher input power factor, and a higher efficiency in comparison to a conventional single-phase Z-source ac–ac converter. In addition, the experimental results show that the use of the safe-commutation strategy is a significant improvement, as it makes it possible to avoid voltage spikes on the switches.

Keywords—Buck–boost capability, pulsewidth modulation (PWM), quasi-Z-source converter, reversing and maintaining phase angle, safe-commutation, single-phase ac–ac converter, total harmonic distortion (THD)

I. INTRODUCTION

In industrial practice, ac–ac line conditioners or ac–ac conversions are commonly implemented using ac thyristor power controllers, which employ the phase angle or integral cycle control on the ac supply in order to obtain a desired out- put voltage. However, they have some significant disadvantages, such as a low input power factor, a high total harmonic distortion (THD) in the source current, and poor power transfer efficiency. Often ac controllers can be replaced by pulse width modulation (PWM) ac chopper controllers, which have the following features: provisions for a better power factor, transient response and efficiency, a low harmonic current in the line, and smaller input–output filter parameters [1]–[5]. AC– AC converters can perform conditioning, isolating, and input power filtering in addition to voltage regulation. Direct PWM ac–ac converters can be derived from dc–dc topologies; all of the unidirectional switches are substituted with bidirectional devices [5].

A class of single-phase PWM ac–ac power converters with simple topologies has been presented in [4]–[10]. These include buck, boost, buck–boost, and Cuk converters However, each topology has its drawbacks. An increase of the output voltage above the input voltage is not possible using the buck topology found in [4]–[6]. A decrease of the output voltage under the input voltage is not possible for the boost topology found in [4] and [5]. The buck–boost and Cuk topologies found in [4] and [5] enable the output voltage to be either lower or higher than the input voltage with a reversible phase angle. However, there are discontinuous input and output currents found in the former case. The multilevel or multicell ac–ac converters found in [7]–[9] are step-down multilevel circuits based on the concept of flying capacitors that reduce the voltage stress on the switches and improve the quality of the output voltage. In the multicell converters, however, the voltage of the flying capacitors needs to be in a constant proportion to the input voltage. Therefore, a balancing circuit, such as an *RLC* booster, needs to be connected in parallel to the converter load in order to reduce the imbalance [7], [8]. For isolated ac–ac topologies, current-mode ac–ac converters with high-frequency ac links using a two-stage power conversion were presented in [10]. Direct PWM ac–ac converters can be used to overcome voltage sags and swells [11]–[13] or to compensate for a static VAr [14] in power systems. It has also been reported that the use of safe-commutation switches with the PWM control can significantly improve an ac–ac converter performance [15]–[18].

Z-source converters applied to dc–ac inverters and ac–ac converters have recently been proposed in [1]–[3], [15], [16], and [19]–[31]. The research on Z-source dc–ac inverters has-been focused on the PWM strategy, modeling and control [19], [20], applications [21], high boost factors [22], [23], and other Z-network topologies [24]–[30]. The research on Z-source ac–ac converters has been focused on single-phase topologies [1]–[3], [15], [16] and three-phase topologies [31]. A family of quasi-Z-source converters has been presented in [3], [24], and [25] that overcome the inconveniences found in traditional Z-source inverters Quasi-Z-source converters have advantages, such as reducing the passive component ratings and improving the input profiles The conventional single-phase Z-source PWM ac–ac converters proposed in [1] and [2] have main features in that the output voltage can be bucked/boosted and be in-

phase/out-of-phase with the input voltage. However, the conventional Z-source PWM ac–ac converters found in [1] and [2] have a significant drawback in that the input current is operated in a discontinuous current mode. When the input current operates in this discontinuous current mode, its waveform is nonsinusoidal, which in- creases the input current THD. Moreover, the peak of the input current in the discontinuous current mode is higher than it is in the continuous current mode. Another drawback is that the input voltage and the output voltage of the original Z-source PWM ac–ac converter [1] do not share the same ground. As a result, the desired feature that enables the output voltage to reverse or maintain its phase angle relative to the input voltage is not well supported. In an effort to overcome the inconveniences of the traditional Z-source ac–ac converters, a single-phase quasi-Z-source ac–ac converter has recently been proposed in [3]. In comparison to the conventional Z-source ac–ac converters, the single-phase quasi-Z-source ac–ac converter has the following unique advantages: the input voltage and the output voltage share the same ground; the converter operates in the continuous current mode with special features such as a reduction in the in-rush, a harmonic current, an improved power factor, and an efficient power transfer.

A modified single-phase quasi-Z-source ac–ac converter without input or output filters is presented. The proposed converter inherits all of the advantages of the traditional single-phase Z-source ac–ac converter; it has buck–boost capabilities and can maintain or reverse the output phase angle all the while sharing the same ground. Moreover, the modified single-phase quasi-Z-source ac–ac converter has the following unique advantages: a smaller converter size, an operation in the continuous current mode that enables special features such as a reduction in the in-rush, a harmonic current, an improved power factor, and an increased efficiency. A safe-commutation strategy is provided for the proposed converter that eliminates voltage spikes on the switches without the need for a snubber circuit. The operating principles, compared to those of a conventional single-phase Z-source ac–ac converter, are thoroughly outlined.
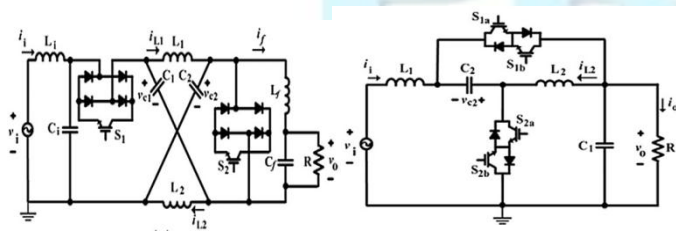
converters. The original single-phase Z-source ac–ac converter [1] with an LC input/output filter and no shared ground is shown in Fig. 1(a). The proposed modified single-phase quasi-Z-source ac–ac converter with a shared ground and no LC input/output filters is shown in Fig. 1(b). In the conventional converters [1], [2], as shown in Fig. 1(a) and 1(b), an LC input filter is required in order to reduce the switching ripple found in the input current. Furthermore, in the original converter [1], as shown in Fig. 1(a), an LC input filter cannot be added because inductor L_1 connects directly to the input. However, an LC output filters needs to be added in order to decrease the high harmonic components that appear on the load side. In a compact topology, the modified single-phase Z-source ac–ac converter, as shown in Fig. 1(b), uses only a quasi-Z-source network with two inductors L_1, L_2, two capacitors C_1, C_2, and two bidirectional switches S_{1j}, S_{2j} ($j = a, b$). Because the load is directly connected to capacitor C_1, the LC output filter can be omitted. Therefore, the modified single-phase Z-source ac–ac converter topology is smaller when compared to the other topologies.

A. OPERATING PRINCIPLES

Fig. 2 illustrates the switching strategy of the modified single- phase quasi-Z-source ac–ac converter. In the in-phase mode where the input voltage and the output voltage are in the same phase, if the input voltage $v_i > 0$, switches S_{1a} and S_{2b} are fully turned ON while S_{1b} and S_{2a} are modulated complementary to the dead time. If $v_i < 0$, switches S_{1b} and S_{2a} are fully turned ON while S_{1a} and S_{2b} are modulated complementary to the dead time. In the out-of-phase mode in which the input voltage and the output voltage are in opposite phases, if $v_i > 0$, switches S_{1b} and S_{2a} are fully turned ON while S_{1a} and S_{2b} are modulated complementary to the dead time. If $v_i < 0$, switches S_{1a} and S_{2b} are fully turned ON while S_{1b} and S_{2a} are modulated complementary to the dead time.

Fig. 2 shows the operation states in the in-phase mode when $v_i > 0$. Switches S_{1a} and S_{2b} are fully turned ON while S_{1b}

Fig. 1. Single-phase Z-source ac–ac converter topologies. 1.(a) Original single- phase Z-source ac–ac converter with LC input/output filter with no ground sharing [1].(b) Modified single-phase quasi-Z-source ac–ac converter with ground sharing and no LC input/output filters

II. MODIFIED SINGLE-PHASE QUASI-Z-SOURCE AC–AC CONVERTER

Fig. 1 shows the original single-phase Z-source ac–ac

(a) (b) (c) (d)

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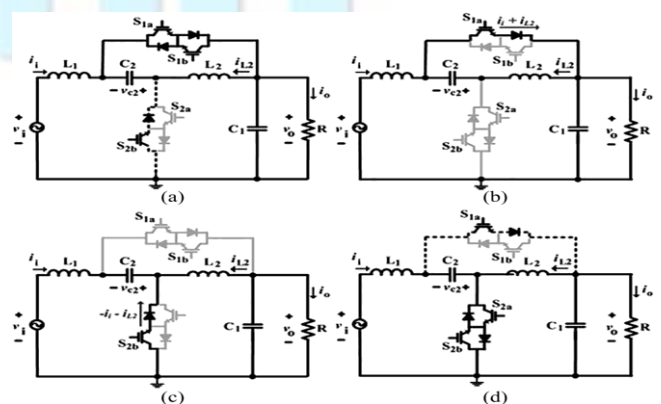ISSN: 2320 - 8791
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Fig.2 Operation states of the modified single-phase quasi-Z-source ac–ac converter in the in-phase mode when $v_i > 0$.

(a) State 1. (b)Commutation state when $i_i + i_{L\,2} > 0$. (c) Commutation state when $i_i + i_{L\,2} < 0$. (d) State 2.
and S_{2a} are modulated complementary to the dead time. In state 1, as shown in Fig. 2(a), S_{1a} is turned ON and conducts the current during the increasingly positive cycle of the input voltage; S_{1b} is turned ON and conducts the negative current from the load to the source, if possible; S_{2b} is turned ON for commutation purposes. S_{1b} is then turned OFF while S_{2a} has not yet turned ON, and so there are two commutation states that occur. If $i_i + i_{L\,2} > 0$, the current flows along a path from S_{1a}, as shown in Fig. 2(b); if $i_i + i_{L\,2} < 0$, the current flows along a path from S_{2b}, as shown in Fig. 2(c). In state 2, as shown in Fig. 2(d), S_{2a} is turned ON and conducts the current from the source to the load; S_{2b} is turned ON and conducts the negative current from the load to the source, if possible; S_{1a} is turned ON for commutation purposes. In these switching patterns, the current path is always continuous regardless of the current direction. This eliminates the voltage spikes during the switching and commutation processes. The analysis when $v_i < 0$ is similar to that found when $v_i > 0$. The dotted line

TABLE I
SWITCHING CONTROL SEQUENCE FOR THE MODIFIED SINGLE-PHASE QUASI-Z-SOURCE AC–AC CONVERTER OPERATION

Mode	v_i	Switch "on" states			
		State 1		State 2	
		Active	Commutation	Active	Commutation
In-phase	> 0	S_{1a}, S_{1b}	S_{2b}	S_{2a}, S_{2b}	S_{1a}
	< 0	S_{1a}, S_{1b}	S_{2a}	S_{2a}, S_{2b}	S_{1b}
Out-of-phase	> 0	S_{1a}, S_{1b}	S_{2a}	S_{2a}, S_{2b}	S_{1b}
	< 0	S_{1a}, S_{1b}	S_{2b}	S_{2a}, S_{2b}	S_{1a}

Table I provides the switching sequences for the operations of the modified single-phase quasi-Z-source ac-ac converter.

III. HARD SWITCHING AND SOFT SWITCHING TECHNIQUE

Power switches have to cut off the load current within the turn-on and turn-off times under the hard switching conditions. Hard switching refers to the stressful switching behavior of the power electronic devices. The switching trajectory of a hard-switched power device is shown in the figure given below. During the turn-on and turn-off processes, the power device has to withstand high voltage and current simultaneously, resulting in high switching losses and stress. Dissipative passive snubbers are usually added to the power

circuits so that the dv/dt and di/dt of the power devices could be reduced, and the switching loss and stress are diverted to the passive snubber circuits. However, the switching loss is proportional to the switching frequency, thus limiting the maximum switching frequency of the power converters. Typical converter switching frequency was limited to a few tens of kilo-Hertz (typically 20 kHz to 50 kHz) in earlier. The stray inductive and capacitive components in the power circuits and power devices still cause considerable transient effects, which in turn give rise to electromagnetic interference (EMI) problems. Fig.5 shows ideal switching waveforms and typical practical waveforms of the switch voltage. The transient ringing effects are major causes of EMI.

The concept was to incorporate resonant tanks in the converters to create oscillatory (usually sinusoidal) voltage and/or current waveforms so that zero voltage switching (ZVS) or zero current switching (ZCS) conditions can be created for the power switches. The reduction of switching loss and the continual improvement of power switches allow the switching frequency of the resonant converters to reach hundreds of kilo-Hertz (typically 100 kHz to 500 kHz). Consequently, magnetic sizes can be reduced and the power density of the converters increased.

Various forms of resonant converters have been proposed and developed. However, most of the resonant converters suffer several problems. When compared with the conventional PWM converters, the resonant current and voltage of resonant converters have high peak values, leading to higher conduction loss and higher V and I ratings requirements for the power devices. Also, many resonant converters require frequency modulation (FM) for output regulation. Variable switching frequency operation makes the filter design and control more complicated.

In later further improvements have been made in converter technology. New generations of soft-switched converters that combine the advantages of conventional PWM converters and resonant converters have been developed. These soft-switched converters have switching waveforms similar to those of conventional PWM converters except that the rising and falling edges of the waveforms are 'smoothed' with no transient spikes. Unlike the resonant converters, new soft-switched converters usually utilize the resonance in a controlled manner. Resonance is allowed to occur just before and during the turn-on and turn-off processes so as to create ZVS and ZCS conditions. Other than that, they behave just like conventional PWM converters. With simple modifications, many customized control integrated control (IC) circuits designed for conventional converters can be employed for soft-switched converters. Because the switching loss and stress have been reduced, soft-switched converter can be operated at the very high frequency (typically 500 kHz to a few Mega-Hertz).

Soft-switching converters also provide an effective solution to suppress EMI and have been applied to DC-DC, AC-DC and DC-AC converters. This chapter covers the basic

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technology of resonant and soft-switching converters. Various forms of soft-switching techniques such as ZVS, ZCS, voltage clamping, zero transition methods etc. are addressed. The emphasis is placed on the basic operating principle and practicality of the converters without using much mathematical analysis
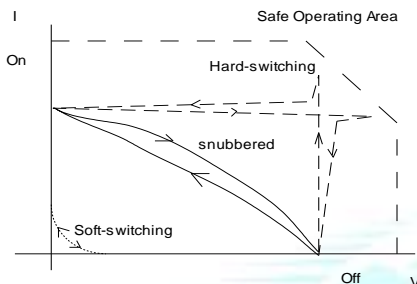

Figure 3. Typical switching waveforms of hard-switched and soft-switched devices
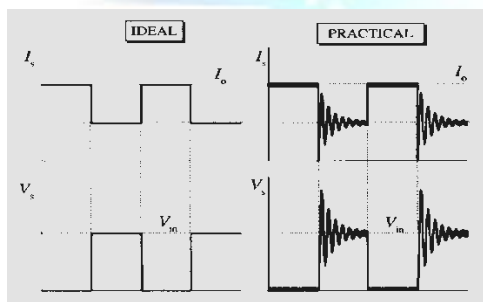
Figure 4. Typical practical wave form of power switches.

IV. CIRCUIT ANALYSIS

circuit analysis of the modified single-phase quasi-Z-source ac–ac converter begins with the following assumptions: 1) the converter is operating in the continuous conduction mode; 2) the parasitic resistances of L1 and L2 are the same and equal and denoted by r_L ; 3) the equivalent series resistances of C1 and C2 are the same and equal and denoted by r_C ; 4) the on-resistance of the switches S1j and S2j (j = a, b) are the same and equal and denoted by r_s ; and 5) the switching frequency is more than the frequency of the input and output voltages.

$$
\begin{bmatrix} L_1 & 0 & 0 & 0 \\ 0 & L_2 & 0 & 0 \\ 0 & 0 & C_1 & 0 \\ 0 & 0 & 0 & C_2 \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_i(t) \\ i_{L2}(t) \\ v_o(t) \\ v_{C2}(t) \end{bmatrix}
$$
$$
= \begin{bmatrix} -(r_L + r_s) & -r_s & -1 & 0 \\ -r_s & -(r_L + r_C + r_s) & 0 & -1 \\ 1 & 0 & -1/R & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}
$$
$$
\times \begin{bmatrix} i_i(t) \\ i_{L2}(t) \\ v_o(t) \\ v_{C2}(t) \end{bmatrix} + \begin{bmatrix} v_i(t) \\ 0 \\ 0 \\ 0 \end{bmatrix}. \qquad (1)
$$

Ignoring the dead time effects, the modified single-phase quasi-Z-source ac–ac converter has two operating states

in one switching period, which are denoted as state 1 and state 2, as shown in Figure.7(a) and (b), respectively. In state 1, S1j is turned ON and S2j is turned OFF, as shown in Fig. 7(a). The time interval of this state is DT, where D is the equivalent duty ratio of S1j and T is the switching period, . Therefore
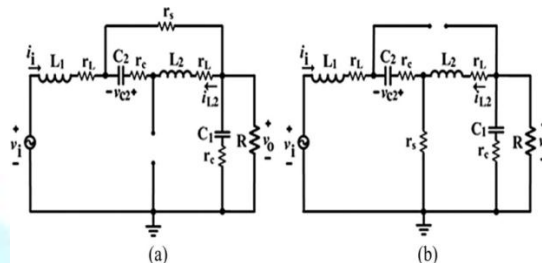

Figure5. Equivalent circuits for the proposed converter. (5a) State 1. 5(b) State 2. In state 2, S1j is turned OFF and S2j is turned ON, as shown in Figure5 (b). The time interval of this state is (1−D)T. Therefore

$$
\begin{bmatrix} L_1 & 0 & 0 & 0 \\ 0 & L_2 & 0 & 0 \\ 0 & 0 & C_1 & 0 \\ 0 & 0 & 0 & C_2 \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_i(t) \\ i_{L2}(t) \\ v_o(t) \\ v_{C2}(t) \end{bmatrix}
$$
$$
= \begin{bmatrix} -(r_L + r_C + r_s) & -r_s & 0 & 1 \\ -r_s & -(r_L + r_s) & 1 & 0 \\ 0 & -1 & -1/R & 0 \\ -1 & 0 & 0 & 0 \end{bmatrix}
$$
$$
\times \begin{bmatrix} i_i(t) \\ i_{L2}(t) \\ v_o(t) \\ v_{C2}(t) \end{bmatrix} + \begin{bmatrix} v_i(t) \\ 0 \\ 0 \\ 0 \end{bmatrix}. \qquad (2)
$$

In the steady state, it is found that

$$
\begin{bmatrix} L_1 & 0 & 0 & 0 \\ 0 & L_2 & 0 & 0 \\ 0 & 0 & C_1 & 0 \\ 0 & 0 & 0 & C_2 \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_i(t) \\ i_{L2}(t) \\ v_o(t) \\ v_{C2}(t) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \qquad (3)
$$

The output voltage gain and the inductor L2 current gain can be defined, respectively, as
Thus

$$
\begin{cases} v_o = \dfrac{D(2D-1)R}{(2D-1)^2 R + r_s + (2D^2 - 2D + 1)r_L + D(1-D)r_C} v_i \\[2mm] v_{c2} = \dfrac{(1-D)(2D-1)R - r_s - (1-D)r_L - D(1-D)r_C}{(2D-1)^2 R + r_s + (2D^2 - 2D + 1)r_L + D(1-D)r_C} v_i \\[2mm] i_i = \dfrac{D}{2D-1} \dfrac{v_o}{R} \\[2mm] i_{L2} = \dfrac{1-D}{2D-1} \dfrac{v_o}{R}. \end{cases} \qquad (4)
$$

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$$K_o = \frac{v_o}{v_i} = \frac{D}{2D-1}$$

$$\times \left[\frac{1}{1 + \frac{r_s + (2D^2 - 2D + 1)r_L + D(1-D)r_C}{(2D-1)^2 R}} \right] \quad (5)$$

It should be noted that the output profile in (6) can be used for both resistive and inductive loading. The equations from (1) to (5) which lead to the output profile in (6) are unchanged when the load is inductive. Figure.7 shows the output voltage gains versus the duty cycle D with a variable ratio of $kr = (rs + rL)/R$ in the case of $rL = rC/2$. In the ideal case $(rs = rL = rC = 0\ \Omega)$ from (5), the following is obtained.

$$\begin{cases} v_o = \dfrac{D}{2D-1} v_i \\[2mm] v_{c2} = \dfrac{1-D}{2D-1} v_i \\[2mm] i_i = \dfrac{D}{2D-1} \dfrac{v_o}{R} \\[2mm] i_{L2} = \dfrac{1-D}{2D-1} \dfrac{v_o}{R}. \end{cases} \quad (6)$$

The output voltage gain has features that were reported. It is clear that there are two operation regions, as shown in Figure.7. When the duty cycle is greater than 0.5, the output voltage is boosted and is in-phase with the input voltage. When the duty cycle is less than 0.5, the output voltage is bucked/boosted and out-of-phase with the input voltage. Figure. 6 show the relationship between the inductor L2 current gain and the duty cycle. When the converter is operating in the boost in-phase mode (D > 0.5), the inductor L2 current is bucked. When the converter is operating in the buck/boost out of- phase mode (D < 0.5), the inductor L2 current is boosted. The inductor L2 is in-phase with the input current.
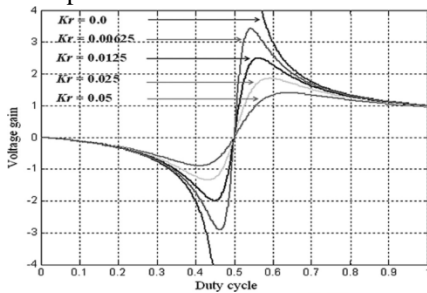

Figure 6.1. Output voltage gain versus the duty cycle with the variable ratio of
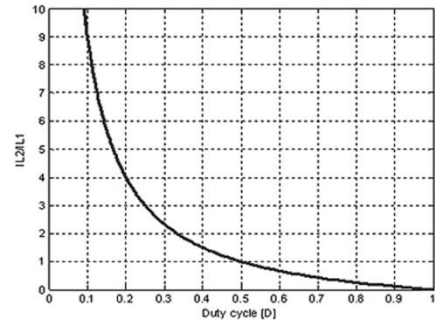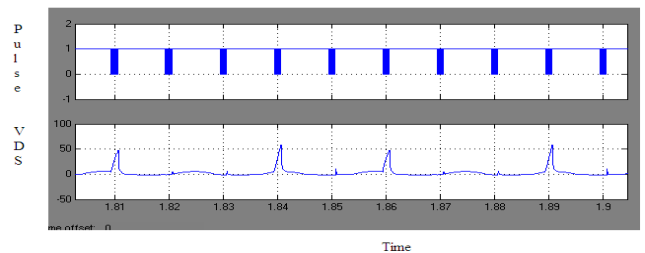kr = (rs + rL)/R.

Figure 6.2.Inductor L2 current gain versus the duty cycle of the modified single Phase quasi-Z-source ac–ac converter
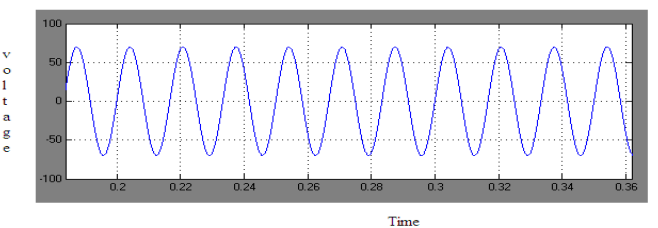
V.SIMULATION CIRCUIT

In this circuit simulation of a modified quasi z source ac To ac converter with R load. Proposed converter IGBT switch are instead using MOSFET shown in the figure.7 In this circuit either increase or decrease the voltage depends Upon the application
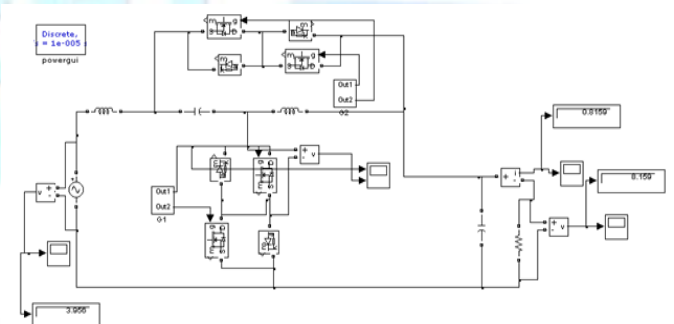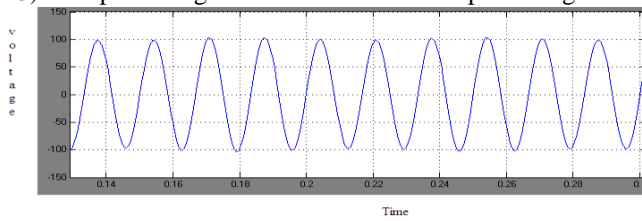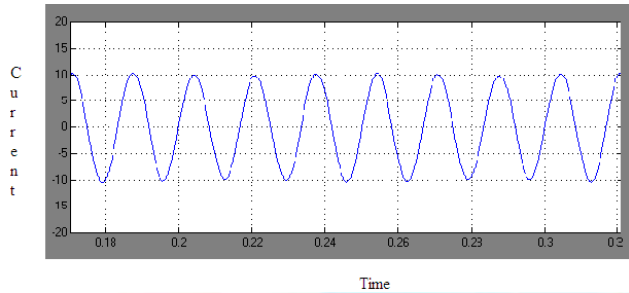

A) Switching pulse and drain to source voltage

B) Input voltage 70v are applied to the input of the modified quasi Z source Ac to Ac converter

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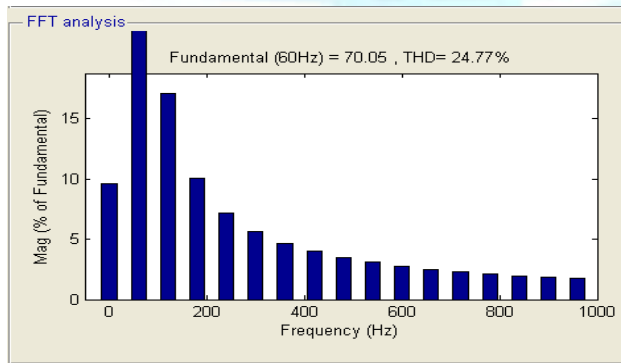ISSN: 2320 - 8791
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C) Output voltage are boosted with the input voltage

D) output current of modified quasi z sour

E) total harmonic distortion of modified quasi z source Ac to Ac converter with R load

A Modified Ac To Ac Converter Using Quasi Z- Source With Motor Load

The motor load is used because of the current is continuous to achieve controlling the induction motor using PID controller
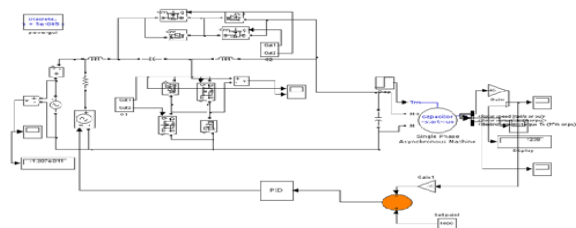

Figure 8. A Modified Ac To Ac Converter Using Quasi Z Source With Motor Load

Motor Speed

The speed of the motor value is set to reach the steady state speed by using PID controller
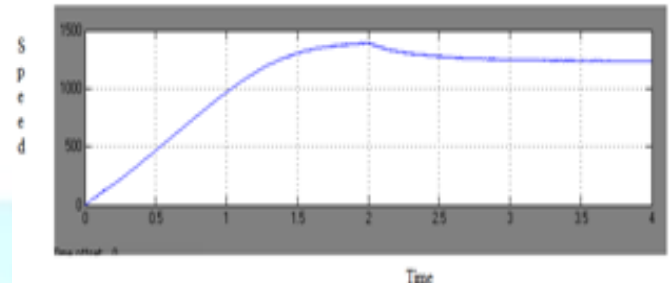

Figure8.1 Motor Speed

THD

The input of the total harmonic distortion is reduced to compare the conventional circuit
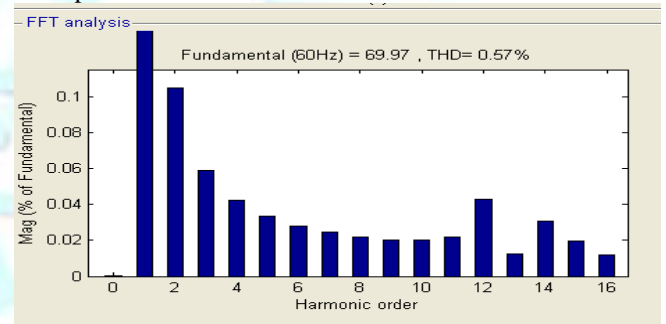

Figure 8.2 Total Harmonic Distortion

VI.CONCLUSION

A single-phase Z-source converter for ac–ac power conversion has been implemented in this project. The proposed converter, called a modified single-phase ac–ac converter by using quasi Z source, the boosted value for the provided input were obtained by traditional single-phase Z source ac–ac converter, In addition, the modified single-phase quasi-Z-source ac–ac converter has the unique advantages in that the size of the converter is reduced and the operation of the input current is continuous with additional features, such as a reduction in the in-rush, a harmonic current, and an improved power factor. A safe-commutation strategy is applied to the modified single-phase quasi-Z-source ac–ac converter. The use of this safe-commutation strategy is a significant improvement, as it makes it possible to avoid voltage spikes on the switches without the use of a snubber circuit. Experimental results show that the modified single-phase quasi-Z-source ac–ac converter has a higher efficiency in comparison to the conventional single-phase Z-source ac–ac converters

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