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Review of Impedance Source Dc-Dc Converters

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ABSTRACT

Now-a-days due to the requirement of renewable energy sources, distributed generations (DG) are widely used. In such applications, DG grid connection is required through DC-ac inverters. But the DC output from fuel-cell is in low quantity, therefore there must needed the network which boosted up the DC voltage to the required level. To fulfill this requirement, Impedance Source DC to DC converter is required. Impedance Source-Converter is an advanced technology in electrical energy conversion, overcome limitations of traditional converters. This paper presents different types of impedance source networks for DC to DC power conversion. All types of impedance networks adapt a unique impedance network to connect a converter main circuit to source from which the supply is taken. Thus, providing the features that cannot available in the traditional voltage-source and current-source converters in which capacitor and inductor are used, respectively. The impedance source converter overcomes all the problems, barriers and limitations of the traditional converters and provides a new power conversion concept. These impedance source networks can be used in all DC-DC, ac-DC, ac-ac, DC-ac power conversion. So this paper describes the operating principle, simulation results and sizing of components of three types of impedance network and its comparison.

Keywords: Fuel cell, DC-DC converter, Impedance source converter, Quasi Z-source converter, Quadratic converter

I. INTRODUCTION

Now-a-days due to the requirement of renewable energy sources, distributed generations (DG) are widely used. In such applications, DG grid connection is required through DC-ac inverters. But the DC output from fuel- cell and Photo Voltaic panel is so small as compared to grid voltage. Therefore, there must need of the network which boosts up the DC voltage to the required level. To fulfil this requirement DC-DC converter has been connected in between DG and inverter. In conventional method boost, buck-boost converters are used. But, due to their disadvantages all the researchers working on the Impedance Source DC to DC converters [1-2].

There is two traditional converters viz., current source converter and voltage source converter. In voltage source converter, a DC voltage is supplied by a relatively large capacitor which feeds the main converter circuit. The DC source may be a battery, fuel-cell stack, diode rectifier and it may be a capacitor [3-4]. This voltage source is widely used but it has conceptual barriers and disadvantages are as follows [5]-

The ac output voltage is limited and it cannot exceed the DC-rail voltage or DC-rail voltage has to be greater than ac input voltage. Hence, voltage source converter is a buck inverter for DC to ac conversion and the voltage source inverter is a boost converter for ac to DC conversion.

For such application where only one drive is desirable but the availability of DC voltage is limited, in that case an additional DC to DC boost converter is required to obtain a desired output voltage. This additional converter increases system cost and reduces efficiency.

Sometime, shoot-through may occur due to Electromagnetic Interference, it causes the destroying devices and reliability reduces.

In current source inverter, a DC current source feeds the main converter circuit. The current source may be a large inductor supplied by voltage source such as a battery, fuel-cell, diode rectifier, or it may be a thyristor converter. The current source has following disadvantages [5]-

The ac output voltage is greater than the original DC input voltage which feeds the DC inductor or the DC output is smaller than the input ac voltage. Hence, the current source converter for DC to ac conversion and the current source converter is a buck converter for ac to DC conversion.

For application where variable voltage range is required, an extra DC to DC buck or DC to DC boost converter is essential. This additional converter increases system cost and reduces efficiency.

Sometime, shoot-through may occur due to Electromagnetic Interference, it causes the destroying devices and reliability reduces.

Both current and voltage source converters having following common problem [5].
Their output voltage range is limited to either greater or smaller than the input voltage. That is, they are either a boost or a buck converter and they cannot be buck-boost converter simultaneously.
Both the circuits cannot be exchange with each other. That is, voltage source converter cannot be used as a current source converter or cannot be vice versa.
In both the circuits, due to EMI shoot-through occurs and reduces reliability.

Therefore, to overcome all these disadvantages and limitations, the impedance source network is used. There are three impedance networks as follows [6]-

- Z-source converter
- Quasi Z-source converter
- Quadratic Z-source converter

They all having the advantages like higher efficiency, reduces voltage stress, avoid the damaging to the circuit due to EMI etc.

In this paper there are five sections. Second, third and fourth section represents the review and mathematical modeling of ZSC, QZSC and Quadratic converter respectively. Fifth section signifies the component size and comparison between all impedance converters.

II. REVIEW OF Z-SOURCE CONVERTER

In Figure 1 shows proposed structure of simple Z-source converter. It familiarizes a unique impedance converters network to connect the converter main circuit to the DC source. Load or another DC-AC converter can be connected after Z-source converter, for providing the exclusive features which is not available in traditional voltage source and current source converters in which capacitors and inductors are used, respectively. The Z-source converter overcomes these disadvantages [7]. In the two port network of Z-source converter consists of two capacitors C1 and C2, two inductors L1 and L2 and they are all connected in X shape to provide an impedance source. The voltage source or current source can be used as a DC source. Therefore, DC source can be a fuel-cell stack, an inductor, a capacitor, diode rectifier or a thyristor converter. The inductors used may be split inductors or two separate inductors. In this, same ratings of inductors are used and same ratings of capacitors are used [7].

This Z-source converter can be used for all DC to ac, ac to DC, ac to ac and DC to DC conversion. Example of z- source converter is a Z-source inverter used for DC to ac conversion for fuel-cell applications. Fuel-cell is widely used for fuel-cell vehicles and distributed power generation. Fuel-cell normally produces a voltage (2:1 ratio) depending on current taken from the stacks. Therefore, a boost DC to DC converter is needed because the traditional voltage source inverter cannot produce DC voltage greater than the DC input voltage. The diode is used in series with the fuel-cell before the Z-source network for preventing the reverse current flow. The main feature of the Z-source converter is that output voltage may be any value between zero to infinity inattentive of the fuel-cell voltage. It means that, the Z- source converter is a buck-boost converter that has a wide range of obtainable output voltage. This feature is not available in traditional voltage and current source converters [8].

The Z-source converter operates in two switching states i.e. shoot-through state and non-shoot-through state. The Figure 2 shows equivalent circuit of the Z-source converter in shoot-through state and Figure 3 shows equivalent circuit of Z-source converter in non-shoot-through state. In non-shoot-through state, the output switch is open and diode which is connected at the input side is in forward biased, i.e. it is in on state [9-10]. And in shoot-through state, diode is in off state and the switch which is connected at the output side is closed.

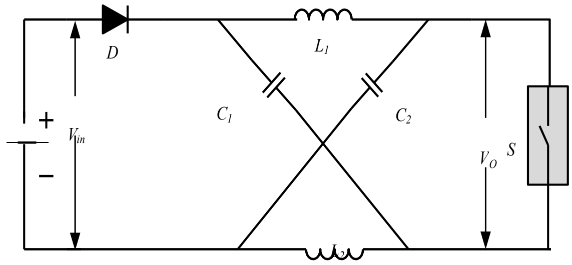

Figure 1: Equivalent circuit of Z-source converter

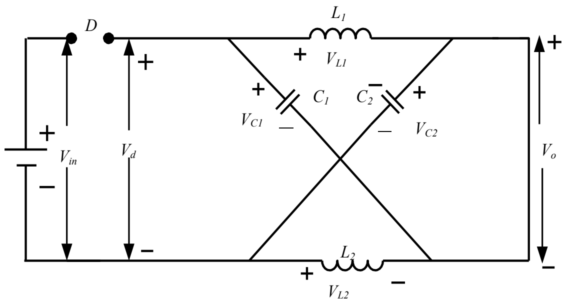

Figure 2: Equivalent circuit of shoot-through state of Z-source converter

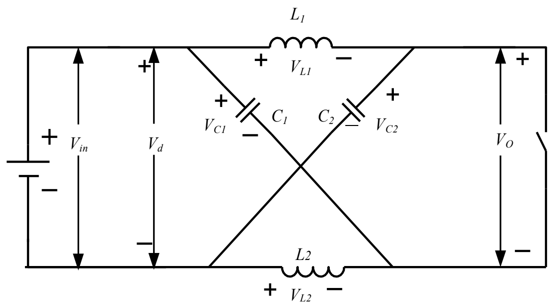

Figure 3: Equivalent circuit of non-shoot-through state of Z-source converter

From the equivalent circuits,

$$V_{c1} \ V_{c2} \ V_c \quad (1)$$

$$V_{L1} \ V_{L2} \ V_L \quad (2)$$

Non-shoot-through state occurs for an interval T_{OFF} during the switching cycle T.

From Fig.3,

$$V_d \ V_{in} \quad (3)$$

$$V_L \ V_{in} \ V_C \quad (4)$$

$$V_0 \ V_c \ V_L \ 2V_C \ V_{in} \quad (5)$$

Shoot-through state occurs for an interval of $T_{ON,}$ during the switching cycle T.

From Fig.2

$$V_0 \ 0 \quad (6)$$

$$V_L \ V_C \quad (7)$$

$$V_d \ 2V_C \quad (8)$$

Here, V_O= V_{DC} source voltage and T_{ON}+T_{OFF}=T

In steady state, the average value of the inductors over one switching period (T) should be zero [11].

Thus, we get

$$V_L \ \frac{T_{ON}.V_C \ T_{OFF}.(V_{in} \ V_C)}{T} \ 0 \quad (9)$$

$$\frac{V_C}{V_{in}} \ \frac{T_{OFF}}{T_{OFF} \ T_{ON}} \quad (10)$$

$$V_i \ \frac{T_{ON}.0 \ T_{OFF}(2V_C \ V_{in})}{T} \ T \quad (11)$$

From equation (11),

$$V_C \ V_{C1} \ V_{C2} \ \frac{1 \ \frac{T_{ON}}{T}}{1 \ 2\frac{T_{OFF}}{T}}.V_{in} \ \frac{1 \ D.V_{in}}{1 \ 2D} \quad (12)$$

$$V_C \ .V_{in} \quad (13)$$

Where, Boost Factor,

$$\frac{1 \ D}{1 \ 2D} \quad (14)$$

III. REVIEW OF QUASI Z-SOURCE DC-DC CONVERTER

The Fig. 4 shows the equivalent circuit for Quasi Z-source converter. Quasi Z-source converter adapts unique impedance network. This network consists of two identical inductances L_1 and L_2 and two identical capacitances C_1 and C_2. Like Z-source converter, QZS converter also operates in two states. With this network shoot through state can be apply to boost the voltage [12]. It helps the network to avoid damage during shoot-through state or any other fault occurrence. Fig. 5 shows the shoot through state of Quasi Z-source converter and Fig. 6 shows the non-shoot through state of Quasi Z-source converter.

During shoot-through state, the higher value of voltage obtained at output due to boost conversion. During non-shoot through state, it will work normally as traditional voltage source converter [13]. The advantages of QZS converter over the Z-source converter are reducing voltage stress, drawing continuous current from the supply and reduced voltage stresses on capacitors [14].

For the non-shoot-through state

$$V_{L1} \ V_{in} \ V_{C1} \quad (15)$$

$$V_{L2} \ V_{c2} \quad (16)$$

$$V_0 \ V_{C1} \ V_{L2} \ V_{C1} \ V_{C2} \quad (17)$$

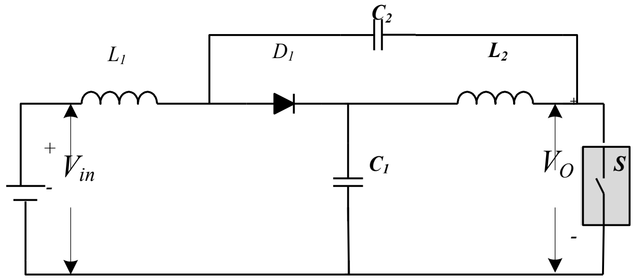

Figure 4: Equivalent circuit of Quasi Z Source Converter

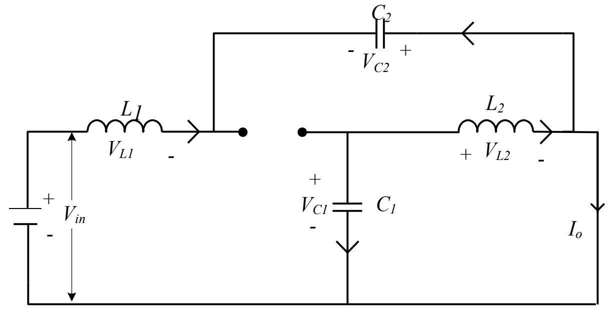

Figure 5: Equivalent circuit of Shoot-through state of Quasi Z source converter

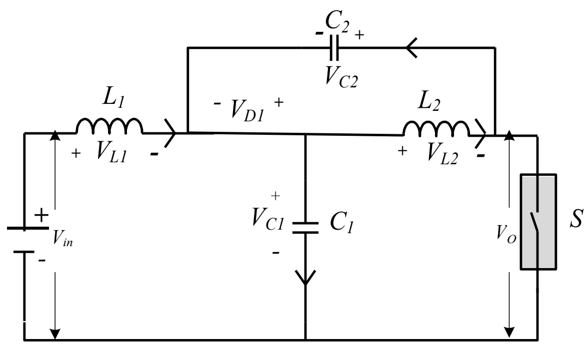

Figure 6: Equivalent circuit of Non-shoot-through state of Quasi Z source converter

For shoot-through state

$$V_{L1}\ V_{C2}\ V_{in} \quad (18)$$

$$V_{L2}\ \ V_{C1} \quad (19)$$

$$V_0\ \ 0 \quad (20)$$

At steady state, the average voltage across the both inductors over one switching cycle is zero.

$$V_{L2}\ \frac{T_{ON}\ V_{C1}\ T_{OFF}\ \ V_{C2}}{T}$$

$$V_0\ \ V_{C1}\ V_{C2} \quad (21)$$

We get,

$$V_0\ \frac{1}{1\ 2D} V_{in} \quad (22)$$

$$V_0\ \ .V_{in} \quad (23)$$

Where, β is the boost factor and D is the Duty Cycle,

$$D\ \frac{T_{ON}}{T}$$

IV. REVIEW OF QUADRATIC CONVERTER

In many industrial applications switched mode DC-DC converters with high voltage conversion ratio are widely used. In traditional converters, the voltage conversion ratio is limited due to power loss of switches as well as component stresses which results in increased duty cycle and limitations on conversion ratio. The modified method to obtain the high voltage gain is quadratic converter [15-16].

The quadratic converter network consists of two identical inductors L_1 and L_2, capacitor C and two diodes D_1 and D_2 shown in Fig.7. The voltage across capacitor is equal to the output boosted voltage. Thus the voltage across capacitor is always higher than the input voltage [17-18]. There are two working states of quadratic converter as shown in Fig. 8 and Fig. 9.

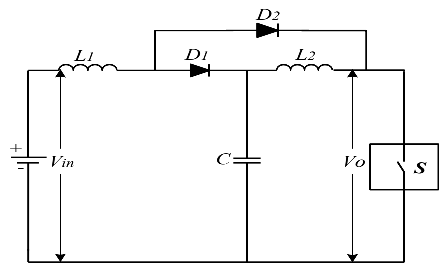

Figure 7: Equivalent circuit of Quadratic Converter

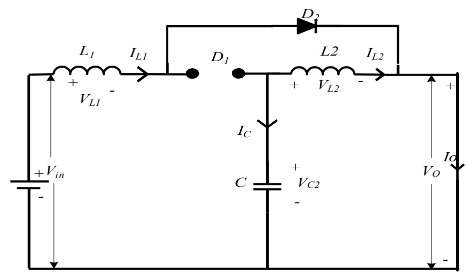

Figure 8: Equivalent circuit shoot-through-state of Quadratic Converter

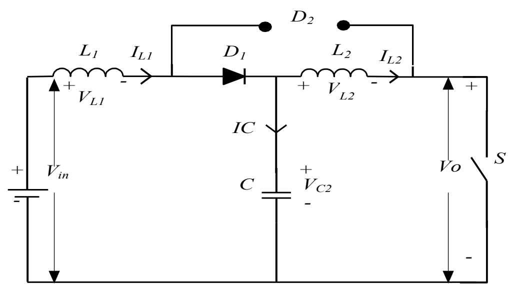

Figure 9: Equivalent circuit of non-shoot-through-state of Quadratic Converter

When switch S is ON, the diode D_2 will be ON and diode D_1 in OFF condition for duration T_{ON} of switching cycle T. At this state, capacitor of quadratic converter charges its inductors. When the switch S is

for duration T_{OFF} of switching cycle T. At this state quadratic converter inductors charge capacitor and provide voltage at output.

From Fig. 8,

$$V_{in}\ \ V_{L1}\ V_{L2}\ V_C \quad (24)$$

$$V_C\ \ V_{L2} \quad (25)$$

$$V_{in}\ \ V_{L2} \quad (26)$$

From Fig. 9,

$$V_{in}\ \ V_{L1}\ V_C \quad (27)$$

$$V_C\ \ V_{L2}\ V_0 \quad (28)$$

$$V_{L2}\ \ V_C\ V_0 \quad (29)$$

Let, the average voltage in inductor L_1 is zero then,

$$V_{L1}\ \ \frac{T_{ON}\ V_{in}\ \ T_{OFF}\ \ V_{in}\ \ V_C}{T}\ \ 0 \quad (30)$$

$$\frac{V_C}{V_{in}}\ \ \frac{T_{ON}\ T_{OFF}}{T_{OFF}}\ \ \frac{T}{T\ T_{ON}} \quad (31)$$

$$\frac{V_C}{V_{in}}\ \ \frac{1}{1\ \frac{T_{ON}}{T}} \quad (32)$$

$$\frac{V_C}{V_{in}}\ \ \frac{1}{1\ D} \quad (33)$$

Let, the average voltage in inductor L_2 is zero then,

$$V_{L2}\ \frac{T_{ON}V_C\ T_{OFF}\ V_C\ \ V_0}{T}\ \ 0 \quad (34)$$

$$\frac{V_0}{V_C}\ \ \frac{T_{ON}\ T_{OFF}}{T_{OFF}} \quad (35)$$

$$\frac{V_0}{V_C}\ \ \frac{1}{1\ \frac{T_{ON}}{T}} \quad (36)$$

$$\frac{V_C}{V_{in}}\ \ \frac{1}{1\ D} \quad (37)$$

$$\frac{V_C}{V_{in}}\ \frac{V_0}{V_C}\ \frac{V_0}{V_{in}}\ \ \frac{1}{1\ D^2} \quad (38)$$

OFF, the diode D_1 will be ON and diode D_2 is in OFF condition

$$\beta = \text{Boost factor}\ \ \frac{1}{1\ D^2} \quad (39)$$

Therefore, the quadratic converter provide high voltage gain and suitable for high voltage ratio applications.

V. SIZING OF COMPONENTS

The major components of the impedance network based DC-DC converter are inductor and capacitor. For designing the converter the size of inductor and capacitor play important role and it should be as minimum as possible. At shoot through state during boost conversion mode, inductor will limit the current ripple $I\ \ (R_C\%)$ through the devices. The maximum power $P_{\max}$ operation is chosen, the inductor value is calculate by,

$$L_1\ L_2\ L\ \frac{V_{C1}\ \ \ T}{I} \quad (40)$$

$$L\ \ \frac{(1\ D)\ V_{in}^2\ T_s D}{(1\ 2D)P_{max}\ R_C\%} \quad (41)$$

The capacitor absorb the current ripple and limit the voltage ripple $V\ (R_V\%)$ on the devices and so as to keep the output voltage constant can be calculated by,

$$C_1\ \ C\ \frac{i\ \ T_1}{V} \quad (42)$$

$$C\ \ \frac{(1\ D)\ P_{max}\ T_s\ D}{V_{in}^2\ R_V\%} \quad (43)$$

The values of the passive component i.e. inductor and capacitor for impedance source converters are calculated in the Table with the following specification-

V_{in}=230V, D=0.3, P_{max}=4kW, Switching Frequency F_s=10kHz, Current Ripple R_C=25%, Voltage Ripple R_V=3%;

TABLE I

INDUCTOR AND CAPACITOR RATING FOR DIFFERENT IMPEDANCE CONVERTERS

Sr. No.	Converter Name	Inductor Size Formulae (L_1 L_2 L)	Capacitor Size Formulae (C_1 C_2 C)	Inductor and Capacitor Size
01	Z-source converter	$L \frac{(1 D)V_{in}^2 T_s D}{(1 2D)P_{max} R_I \%}$	$C \frac{(1 2D) P_{max} T_s D}{V_{in}^2 R_V \%}$	L = 277mH C =30µF
02	Quasi Z-source converter	$L \frac{(1 D)V_{in}^2 T_s D}{(1 2D)P_{max} R_I \%}$	$C \frac{(1 2D) P_{max} T_s D}{V_{in}^2 R_V \%}$	L = 277mH C =30µF
03	Quadratic Converter	$L \frac{V_{in}^2 T_s D}{(1 D) P_{max} R_C \%}$	$C \frac{(1 D) P_{max} T_s D}{V_{in}^2 R_V \%}$	L = 226mH C = 53µF

TABLE II

COMPARISION OF Z-SOURCE, QUASI Z-SOURCE AND QUADRATIC Z-SOURCE CONVERTER

Parameters	Z-Source converter	Quasi-Z-Source converter	Quadratic Z-Source converter
Boost factor	$\frac{1 D}{1 2D}$	$\frac{1}{1 2D}$	$\frac{1}{1 D^2}$
Input current	Discontinuous	Continuous	Continuous
Capacitor	Higher voltage stress	Less voltage stress	Very less voltage stress
Component rating	Moderate	Low	Low
Losses	Low	Comparatively low	Lower than both the converters
Voltage range	Higher than boost	Higher than Z-source	Higher than Quasi Z-source

III. CONCLUSION

In present days, Distributed Generations are widely used. For this, dc to ac inverters are required. But more power generation from dc is not possible. Therefore, there is requirement of dc to dc boost converter. Therefore, this paper has presented different types of impedance-source converters for obtaining dc to dc power conversion. All three types of impedance converter adapt unique impedance network to connect the converter main circuit to the power source. Thus it provides main feature which cannot be implemented in the traditional voltage and current source converters. Thus, all types of impedance converters overcome theoretical limitations found in voltage-source converter and current-source converter and provide an important power conversion concept. The paper described the proposed structure and operating principle of Z-source, Quasi Z-source and Quadratic Z-source converters. This paper also described the factor (boost factor) which is responsible for boosting up the voltage. Because of impedance networks the cost reduces, component minimizes and the efficiency increases. The paper also described the applications of converters like Z-source converter is most suitable for fuel-cell applications, Quasi Z-source converter is most suitable for PV power generation and Quadratic converters are used where the used of Z- source converter and Quasi-Z source converter is restricted.

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