

# ANALYSIS OF FUEL CELL BASED CONVERTERS IN APPLICATION OF MICRO GRIDS

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**Abstract:** This paper focuses on, three converters such as Voltage source inverter (VSI), VSI with boost converter and Z – Source Inverter (ZSI) are analyzed for a low-cost, efficient, and reliable inverter for micro grids of fuel cell. For the purpose of comparison the converters are simulated for the same input Fuel cell voltage, switching frequency and modulation index. These simulation results have been developed for fuel cell based micro grid because of wide output voltage range of fuel cell. The comparison is made based on the following factors, such as Total Harmonic Distortion (THD), cost of inverter etc. The comparison results show that Z-source inverter could be a cheap and reliable solution for this application.

**Key words:** VSI, Fuel cell, Z – Source Inverter, Micro Grid, THD.

## 1. Introduction

Micro grid is an individual power system serving one or more customers from the bulk power system. Examples of some possible micro-grid applications include single customer sites, residential housing developments, college campuses, commercial/industrial office parks, and city-scale Micro-grids serving thousands of customers. Micro-grids may offer the potential for lower total cost, greater efficiency, increased reliability, and increased security. The micro grids are also employed fuel cell and other renewable energy sources. Now a day the potential use of micro grids is tied to strong because of power electronic devices revolution and used for better controlling and power conditioning by using inverters [1 - 5].

In general the micro grids are classified as AC or DC micro grids. If the renewable voltage sources like solar, fuel cells etc. are using in that case definitely we have to use an inverter, to convert DC – AC. If Voltage Source inverter in Fig. 1, is used for this applications, an additional DC – DC boost converter called DC/DC Boost Voltage Source Inverter in Fig. 2 will be required, which causes reduced efficiency and high cost of overall system. Recently proposed Z – source inverter in Fig. 3, is suited for many

applications. The main advantages are 1) It either boosts or buck input voltage based on the modulation index, does not require an additional converter 2) It provides ride through capability against sags & swells 3) It improves the overall system efficiency and power factor [6].

The fuel cell voltage to the inverter decreases with an increase in power drawn from the fuel cell. Therefore, the obtainable output voltage of the traditional PWM inverter is low at high power for this application, so an oversized inverter must be used to meet the requirement of high-power operation. The dc/dc–boosted PWM inverter does not have this problem; however, the extra dc/dc stage increases the complexity of the circuit and the cost and reduces the system efficiency. To demonstrate the superiority of the Z-source inverter for AC micro grids, a comprehensive comparison of the three inverters was analyzed.

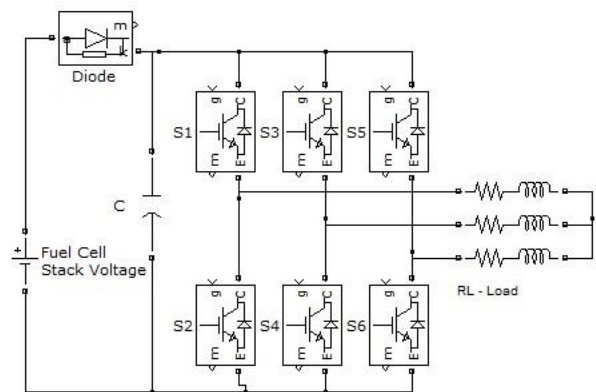


Fig. 1. Voltage Source Inverter

## 2. Fuel Cell

At present, most of energy demand in the world relies on fossil fuels such as petroleum, coal, and natural gas that are being exhausted very fast. Fossil fuels can have as an alternative renewable energy sources like solar, wind, Fuel Cell, biomass, and so; among them the Solid Oxide Fuel Cell (SOFC) [7] is an electrochemical device which allows the electric

energy conversion of the chemical energy into electrical energy. The temperature effects have been taken into account in the typical range of (80–1000°C). This model is built by utilizing the relationship between the output voltage and potential pressure of hydrogen, oxygen, and water, given equation (1) and named as Nernst equation. Fig. 4 shows the detailed SOFC model, which is then embedded into the Sim Power Systems of MATLAB-controlled voltage source and integrated into the overall system. The polarization (V –I) characteristics is in Fig. 5.

$$V = E_o + \frac{RT}{2F} \ln \frac{P_{H_2} P_{O_2}^{0.5}}{P_{H_2O}} - rIA \ln(i) + me^{ni} \quad (1)$$

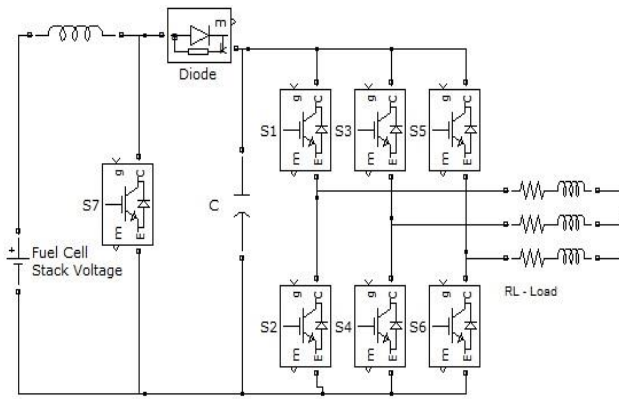


Fig. 2. Voltage Source Inverter with Boost Converter

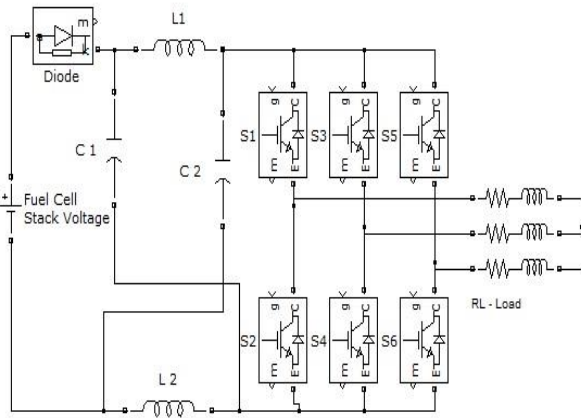


Fig. 3 Z – Source Inverter

### 3. Z – Source Inverter

The main objective of static power converters is to produce an AC output waveform from a dc power supply. Impedance source inverter is an inverter which employs a unique impedance network coupled with the inverter main circuit to the power source. This inverter has unique features in terms of

voltage (both buck & boost) compared with the traditional inverters. The DC source/load can be either a voltage or a current source/load. Therefore, the DC source can be a battery, diode rectifier, thyristor converter, fuel cell, PV cell, an inductor, a capacitor, or a combination of those. Switches used in the converter can be a combination of switching devices and anti-parallel diode as shown in Fig. 3. The output peak phase voltage from the Z – Source inverter is

$$V_{out} = M.B.V_0/2 \quad (2)$$

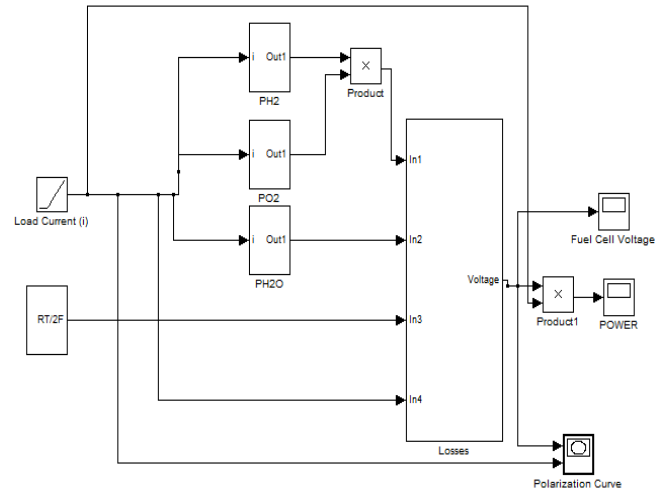


Fig. 4. MAT Lab / SIMULINK Modeling Block of SOFC

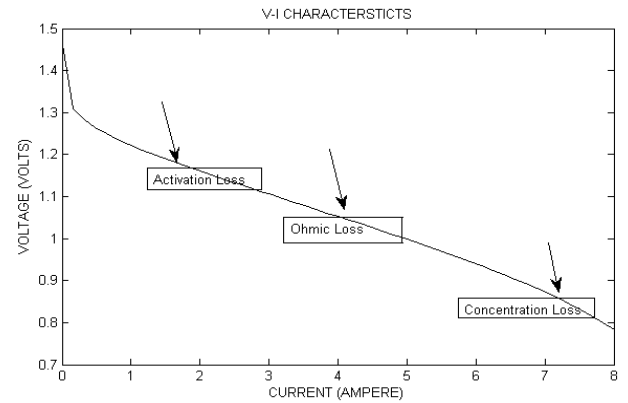


Fig. 5. V – I Characteristics of SOFC

The output voltage can be stepped up and down by choosing an appropriate buck - boost factor B\*

$$B^* = B.M \text{ (it varies from 0 to } \alpha \text{)}$$

The capacitor voltage can be expressed as  $V_{C1} = V_{C2} V_C (1 - T_0/T). V_0 / (1 - 2 T_0/T)$  (3)

The boost factor B is determined by the modulation index M. The boost factor B can be controlled by duty cycle of the shoot-through zero state over the non-shoot through states of the PWM inverter. The

shoot-through zero state does not affect PWM control of the inverter. Because, it equivalently produces the same zero voltage to the load terminal, the available shoot-through period is limited by the modulation index. There are many PWM techniques for ZSI but among all the PWM techniques constant boost control [8] technique having more advantages.

### 3.1 Constant Boost Control (CBC)

In this technique third harmonic is injected into the reference sin waves as shown in Fig.6. The injected third harmonic having a magnitude of 16% of fundamental and the two straight lines  $V_p$ ,  $V_n$  will control the shoot through duty ratio. The corresponding generated pulses are shown in Fig. 7. From [9], the shoot through duty ratio is defined as

$$D_o = 1 - \frac{\sqrt{3}M}{2} \quad (4)$$

Because of third harmonic injection the range of modulation index is increased to  $\frac{2}{3}\sqrt{3}$ . The boost factor and Voltage Gain can be calculated as

$$B = \frac{1}{\sqrt{3}M-1} \quad (5)$$

$$G = MB = \frac{M}{\sqrt{3}M-1} \quad (6)$$

From equation (6), we have

$$M = \frac{G}{\sqrt{3}G-1} \quad (7)$$

The switching device voltage stress ( $V_s$ ) can be written as

$$V_s = BV_o = \frac{V_o}{\sqrt{3}M-1} = (\sqrt{3}G-1)V_o \quad (8)$$

## 4. Simulation & result analysis

The analysis of three converters is analyzed in this section by considering different factors and corresponding simulation results are presented.

### 4.1 Total Switching Device Power Rating Comparison

In an inverter system, each switching device has to be selected according to the maximum voltage impressed and the peak and average current going through it. The voltage and current stress of an inverter system can be introduced [10] by SDPR (Switching Device Power Rating). The SDPR of a switching device/cell is expressed as the product of voltage stress and current stress. The total SDPR of an inverter system is defined as the aggregate of the SDPRs of all the switching devices used in the circuit. The definitions are summarized as follows [10]:

The average and peak SDPRs of the conventional voltage source inverter are, respectively.

For Voltage Source Inverter,

$$(SDPR)_{av} = \frac{8V_{max}P_o}{\pi MV_i \cos \phi} \quad (9)$$

$$(SDPR)_{pk} = \frac{8V_{max}P_o}{MV_i \cos \phi} \quad (10)$$

For Voltage Source Inverter with Boost converter

$$(SDPR)_{av} = \frac{8P_o}{\pi M \cos \phi} + \frac{P_o}{V_i} \cdot V_{DC} \quad (11)$$

$$(SDPR)_{pk} = \frac{8P_o}{M \cos \phi} + \frac{P_o}{V_i} \cdot V_{DC} \quad (12)$$

For Z – Source Inverter

$$SDPR_{av} = \frac{2P_o(2-\sqrt{3}M)}{\sqrt{3}M-1} + \frac{4\sqrt{3}P_o}{\pi \cos \phi} \quad (13)$$

$$SDPR_{pk} = \frac{4P_o}{\sqrt{3}M-1} + \frac{4P_o}{M \cos \phi} \quad (14)$$

Where,

$P_o$  = maximum power = 37.3 KW

$M$  = Modulation Index = 0.8

$V_i$  = Fuel cell stack Voltage = 420V

$\cos \phi$  = Power factor = 0.8

$V_{DC}$  = Out Put Voltage of Boost Converter = 840V

Based on these equations, a comparison of total SDPRs is performed and summarized in Table I.

Table I : Switching Device Power Comparision.

Name of the Inverter	SDPR <sub>av</sub> (KVA)	SDPR <sub>pk</sub> (KVA)
VSI	247.35	497.33
VSI + Boost Converter	223.01	540.85
ZSI	221.66	620.015

The Z-source inverter's average SDPR is the smallest among the three, while the conventional voltage source inverter's SDPRs are the highest in both average and peak values. The average SDPR also indicates thermal requirements and conversion efficiency.

### 4.2 Passive Components Comparision

The detailed list of passive components is in Table II and the inverter cost mainly includes the semiconductors, passive components, and control circuit. A gate drive board for 6 switches is enough to control the Z-source inverter; therefore the controller board cost should be the same as a traditional PWM inverter and lower than the dc/dc boosted inverter because the Z-source has the least component count, thus requiring least number of gate

Table II : Passive Components Comparison

Name of the Inverter	No. of Inductors	Inductance Value	No. of Capacitors	Capacitance Value
VSI	N/A	----	1	10 $\mu$ F
VSI + Boost Converter	1	1 m H	2	1mF & 10 $\mu$ F
ZSI	2	1.6mH	2	1300 $\mu$ F

drive circuits, power supplies, and communication connections.

#### 4.3 Efficiency Comparison

Efficiency is an important criterion for any power converter. High efficiency can reduce thermal requirements and cost. An efficiency comparison is conducted based on the following conditions: the conventional inverter is always operating at a modulation index of 0.8, the dc/dc boost plus PWM inverter boosts the dc voltage to 840 V and the Z-source inverter outputs the maximum obtainable voltage while keeping the switch voltage under 420 V. The load power rating taken as 37.3Kw. The calculated efficiencies of inverters are listed in Table III.

Table III Efficiency comparison of converters

Parameter	VSI	VSI with Boost Converter	ZSI
Power rating	37.3Kw	37.3Kw	37.3Kw
Fuel cell Voltage	1035V	840V	420V
Efficiency	74.6%	88.53%	96.5%

#### 4.4 Simulation Results

Simulation results of the three converters given to verify the each converter operation. The simulation parameters are: Fuel cell Voltage = 420V, Load: three phase R - L load of Active power  $P = 37.3$  KW and Reactive Power  $Q = 1$  KVAR; the Z – source network:  $L_1 = L_2 = 1.6$  mH,  $C_1 = C_2 = 1300\mu$ F; Filter is L-C type and the parameters are inductance ( $L$ ) = 20mH & capacitance ( $c$ ) = 2mF; switching frequency = 10 KHz. The simulation results with the modulation index  $M = 0.8$  is in Fig. 8. The corresponding FFT (Fast Fourier Transform) analysis is in Fig. 9.

Referring to the FFT analysis, Z – Source inverter having the low value of Total Harmonic Distortion (THD) compared to the remaining converters. Table IV summarizes the all Converters and shows that compare to all converters Z – Source inverter best suits for AC micro grids.

#### 5. Conclusion

A comprehensive comparison of the three inverter systems has been performed. The comparison results show that the Z-source inverter reduces the SDPR, which leads to cost reduction. Thus the Z-source inverter system can minimize stresses and increase output power greatly. Along with these promising results, the Z-source inverter offers a simplified single-stage power conversion topology and higher reliability because shoot-through can no longer destroy the inverter. The existing two inverter systems suffer the shoot-through reliability problem. In summary, the Z-source inverter is very promising for this application.

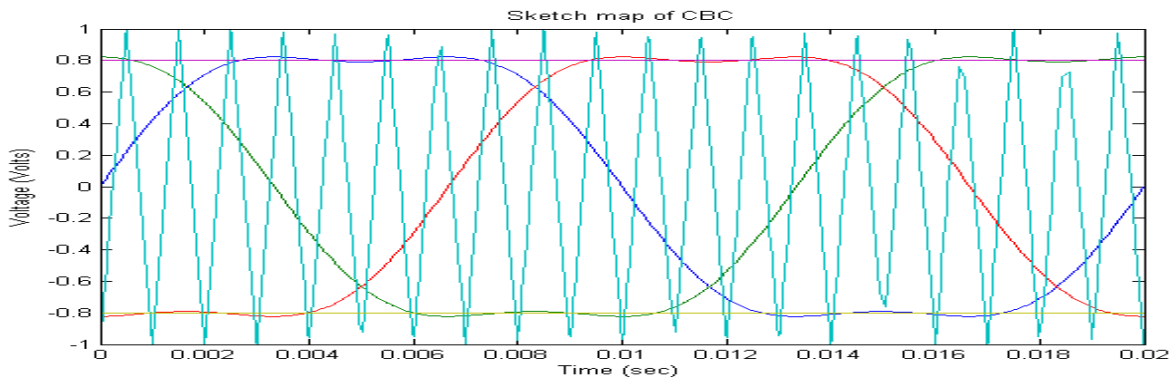


Fig. 6. Constant Boost Control (CBC)

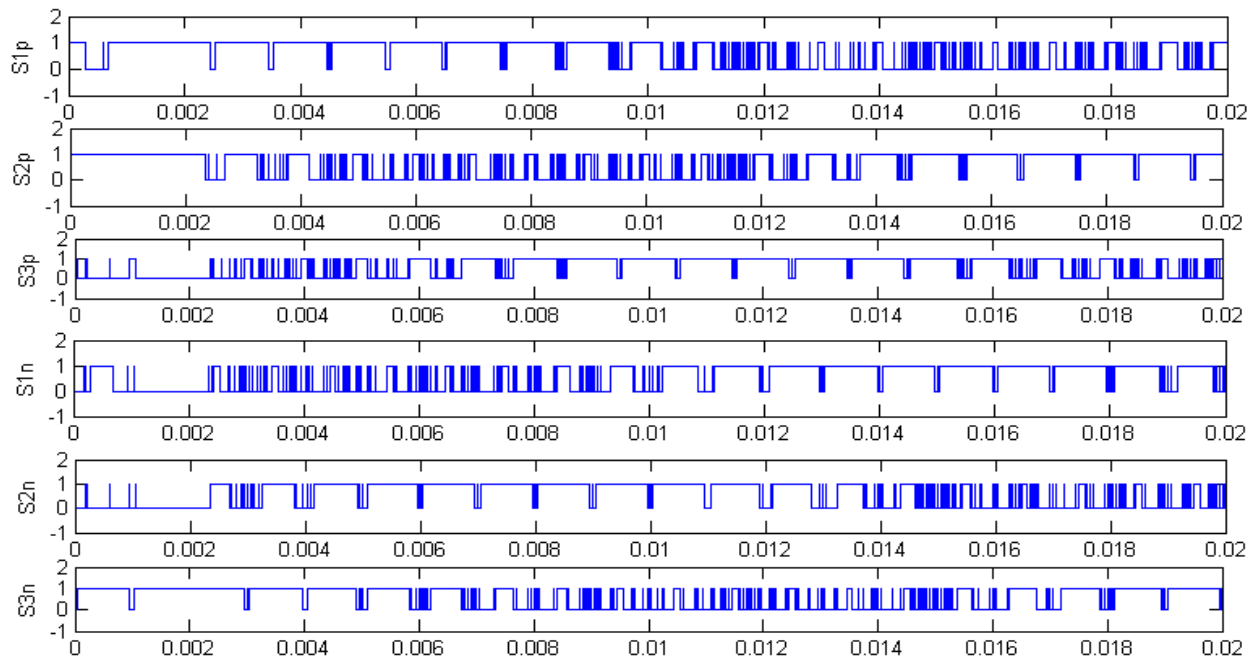
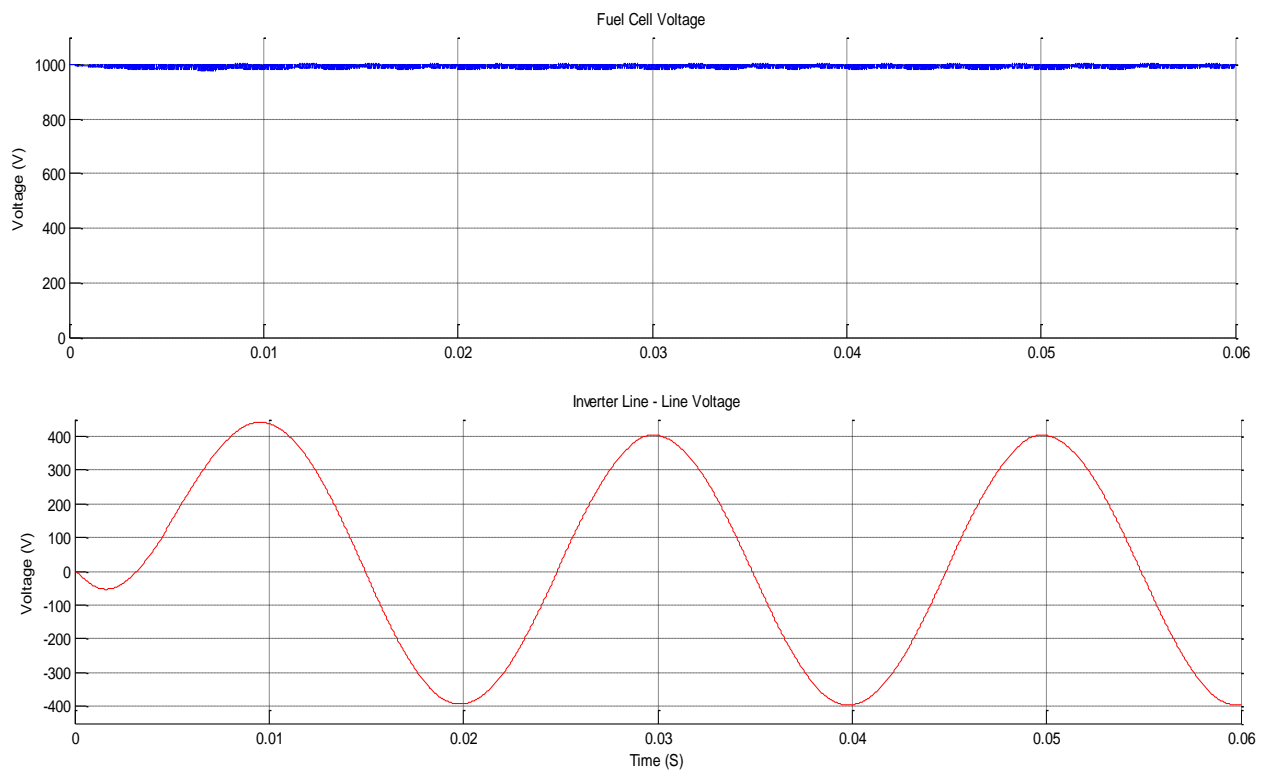
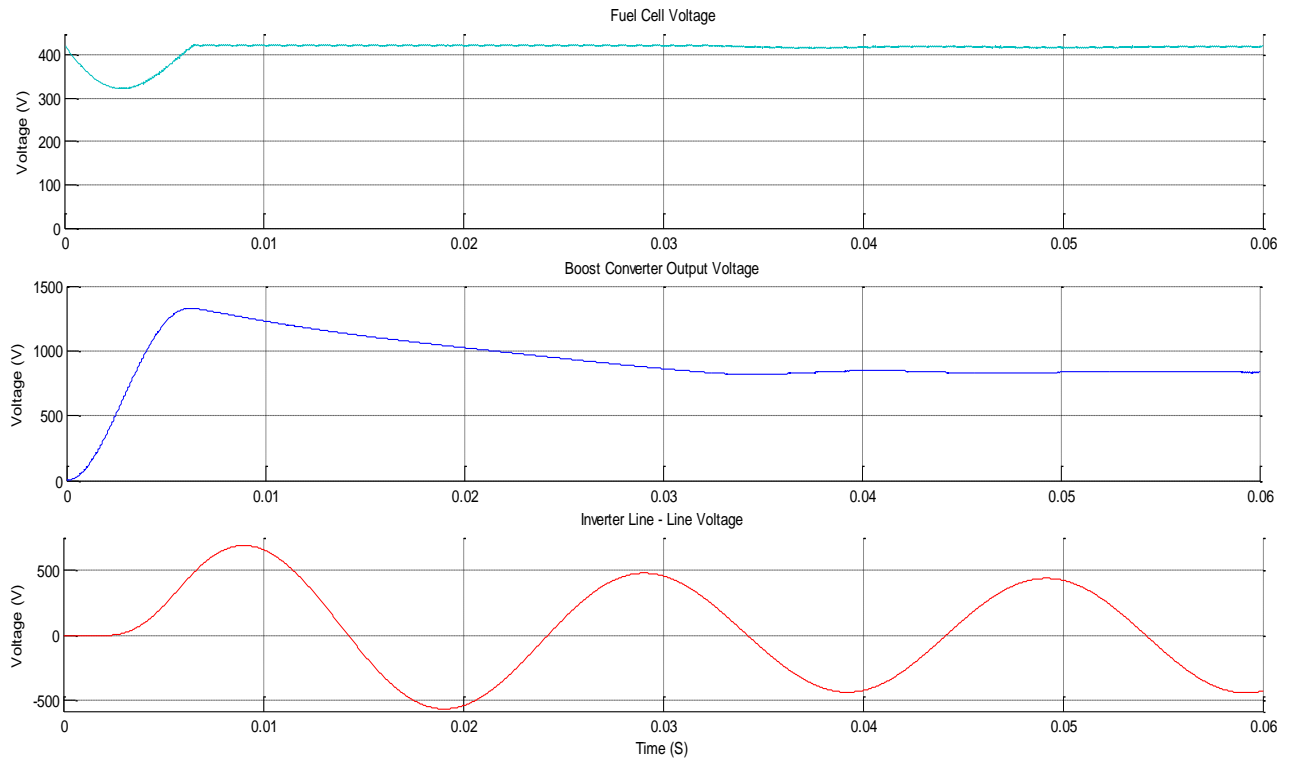


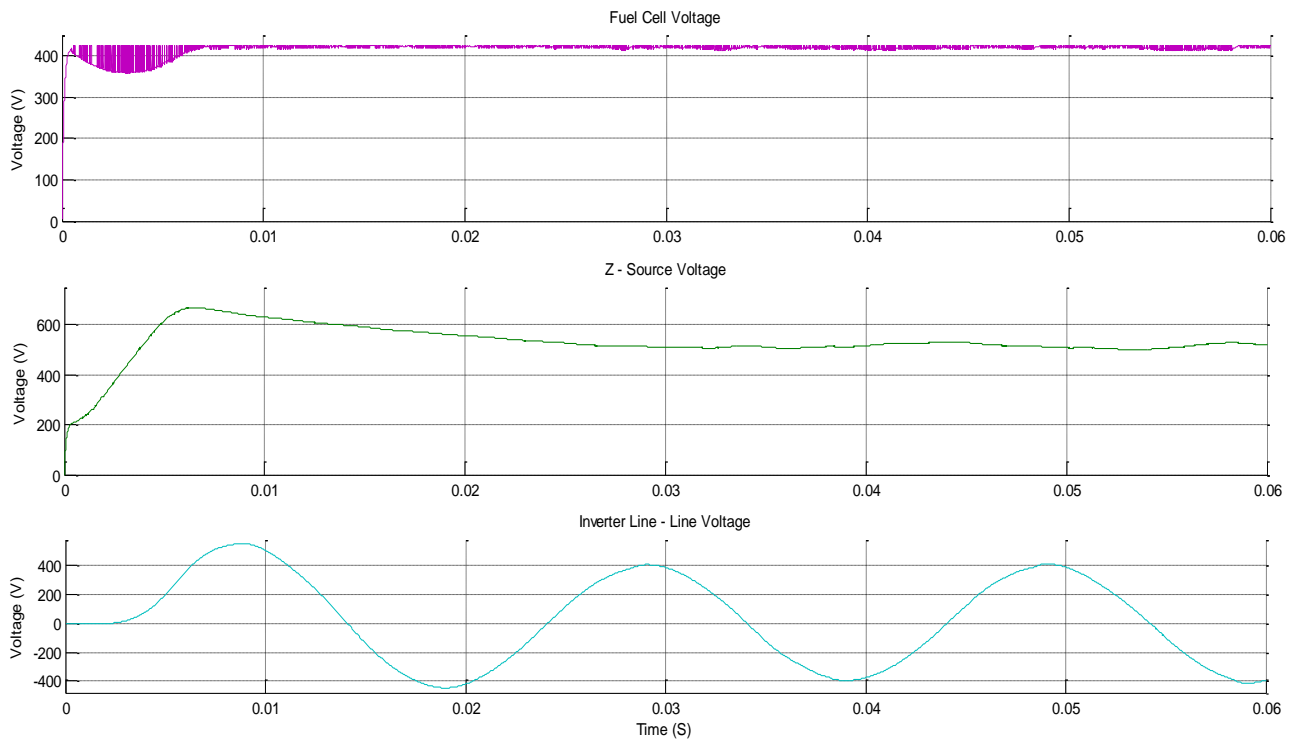
Fig. 7. Switching pulses of CBC



( a )



( b )

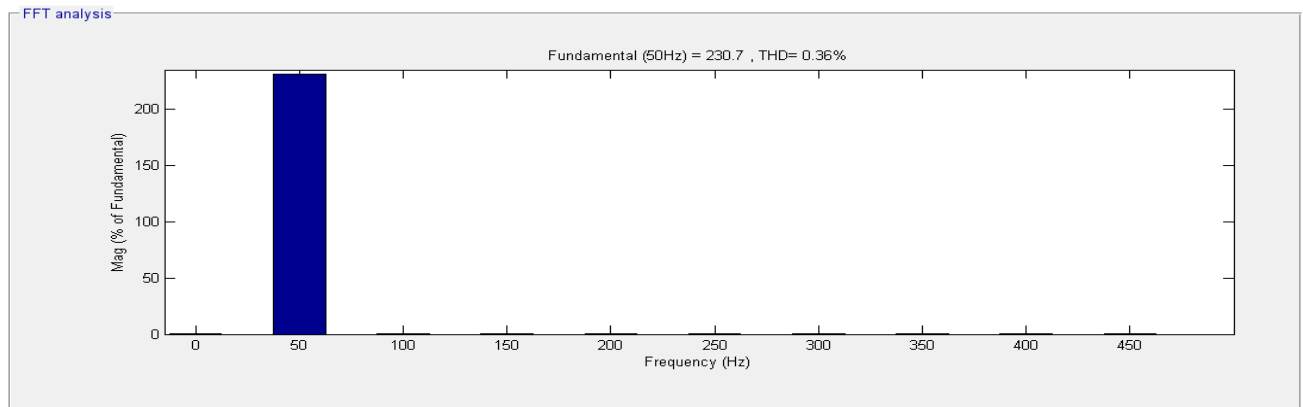


( c )

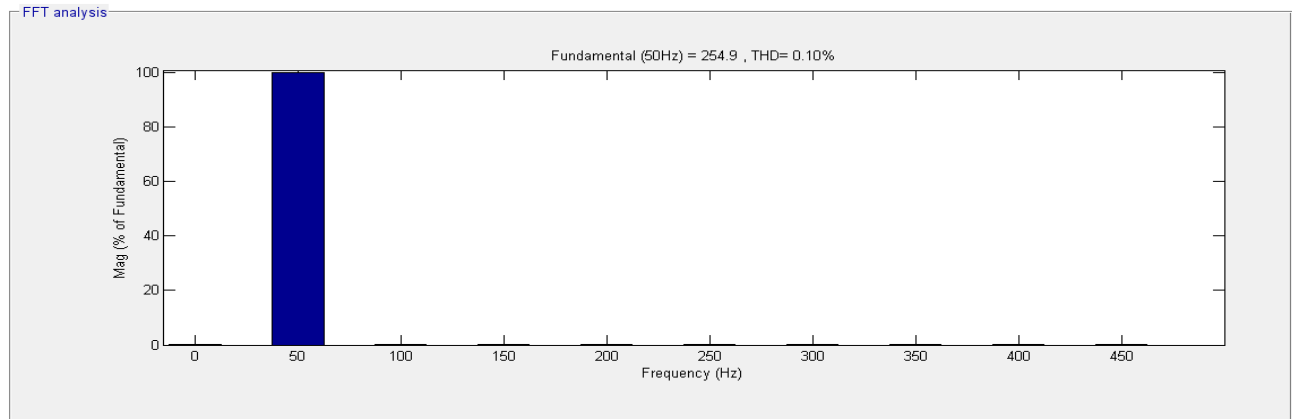
Fig. 8. Simulation results of converters with modulation index  $M = 0.8$ : (a) VSI; (B) VSI with Boost converter; (c) Z – Source Inverter;

Table IV Comparison of converters

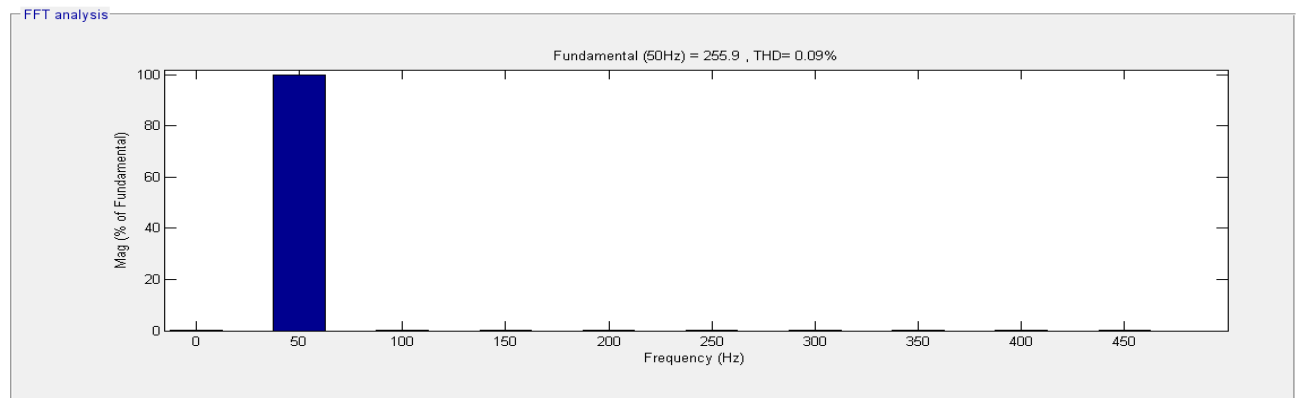
S. No.	Name of the Converter	Boost converter Voltage/ Z – Source Voltage	Inverter Line – Line Voltage	Fundamental Component (Peak value)	THD%
1	VSI	N/A	400 V	230.7	0.36
2	VSI with Boost Converter	820 V	400 V	254.9	0.10
3	Z – Source Inverter	520 V	400 V	255.9	0.09



( d )



( e )



( f )

Fig. 9. FFT analysis of converters with Modulation index (M) = 0.8: (d) VSI; (e) VSI with Boost Converter; (f) Z – Source Inverter;

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