

Comparison Study between Three-phase Differential-mode Inverter and Semi Z-Source Inverter for Micro-Inverter Applications



Mohamed A. Ismeil^{1, □}

(<https://orcid.org/0000-0002-9885-8501>)

Abstract: the differential mode converters are presented which offers can reduce the passive elements such as inductors and capacitors. This results in a reduction in the size of the device improve reliability and reduce the total cost. One of the most promising systems in differential mode converters is the Single-Ended Primary-Inductor Converter (SEPIC). SEPIC has some advantages over the other topologies including lower components and the ability of isolation by using a high-frequency transformer. It is worth mentioning that this model is one of the promising models in the use of renewable energy. On other hand, the Semi Z-Source Inverter (SZSI) is presented to reduce the count of components and work as a four-wire system. The system can be achieved by using three single-phase Semi Z-Source Inverter (SZSI). This paper presents a comparison study between two topologies. In addition, the comparison is achieved based on the voltage and current stress. It has been considered the dynamic response. The comparison is validated based on PSIM software.

Keywords: Z-Source Inverter (ZSI), Differential-mode inverters, SEPIC, buck-boost inverter Two-Stage Inverter.

1 Introduction

The vision of countries to benefit greatly from the different types of renewable energies had a great impact on the development of devices that work on power electronics [1]. From this point of view, the research contributed to the development of inverters. As it has been developed in reducing the losses, reducing Total Harmonic Distortion (THD), and reducing the components [2-3]. One of the solutions used in the development of inverters is the use of differential inverters because of their advantages such as

boosting the input voltage, reducing the total number of components, and reducing the cost size [4-6]. The initial principle of the differential inverter is presented in [5] which presents the new inverter based on boost DC-DC converter that generates the output AC voltage, in addition, the output AC generated is larger than the input DC voltage. The AC output voltage is generated by connecting the load differential across the output DC-DC converters and modulated DC-DC converters by insert sinusoidal signals shafted by 180° [5]. The DC shift can be equal or greater than the V_{DC1} when one of the boosting converters are used as shown in Fig. 1

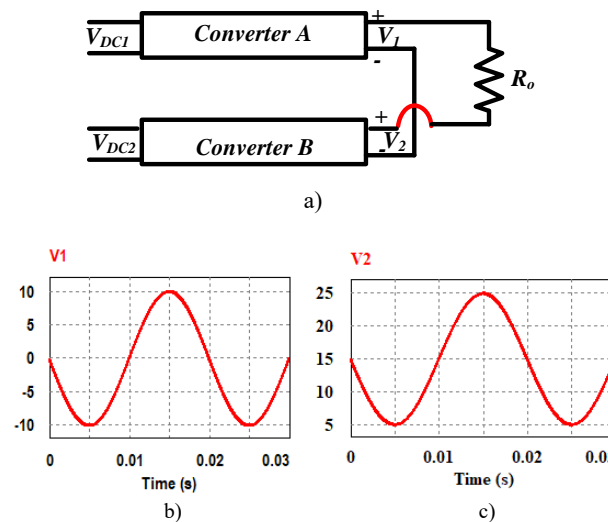


Fig. 1 Basic concept of single-phase differential mode using DC-DC converters

From this point of view, several studies have been presented that deal with the differential principle [7-10]. The main idea is to use the buck-boost stage to create three phase voltage based on sinusoidal modulation as shown in Fig. 2

Received: 20 October 2021/ Accepted: 21 November 2021

□ Corresponding Author: Mohamed Ali Mohamed Ismeil,

mohamedismeil@eng.svu.edu.eg

Electrical Engineering Department Faculty of Engineering, South Valley University Qena, Egypt.

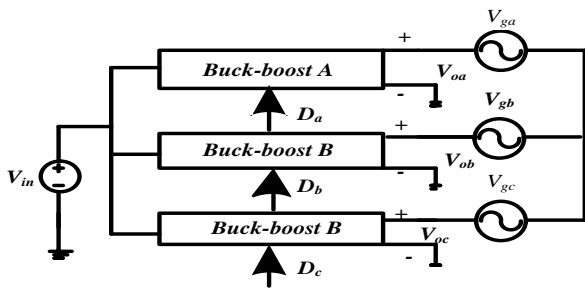


Fig. 2 conception structured of three phase differential inverter

One promising deferential topology inverter is the Single-Ended Primary-Inductor Converter (SEPIC) converter as shown in Fig. 3 [7]. it consists of three modules (A, B, C) each module has been driven with sinusoidal modulation with phase shift 120° between each sinusoidal modulation.

The detailed analysis has been presented in [10] which the principle of Modular Differential Inverter (MDI) is discussed under mathematical model under the assumption of balanced three-phase grid

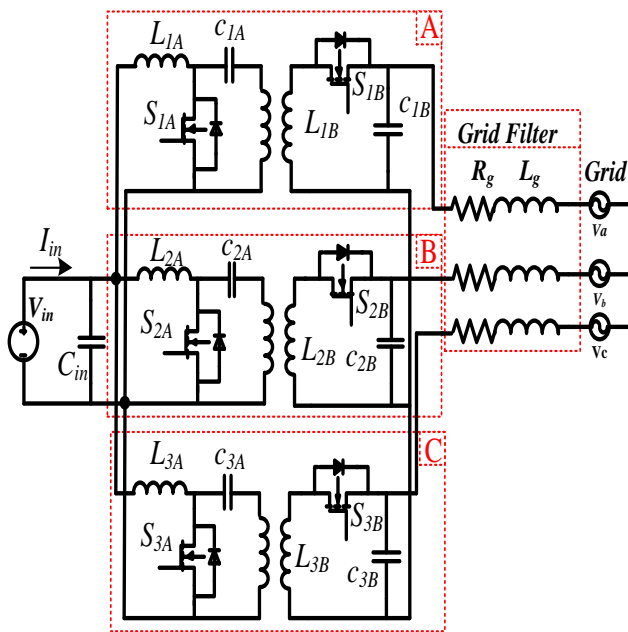


Fig. 3 Isolated Three-Phase SEPIC

On the other hand, the sinusoidal modulation is applied to the Semi- Z-Source Inverter (SZSI) [11-15]. The main disadvantage of the traditional Z-Source Inverter is its need for an extra shoot through state [16] Unlike the traditional Z-Source Inverter (ZSI) the Semi Z-Source Inverter (SZSI) doesn't need an extra shoot through state and has the same reference between DC and AC side. This feature makes the inverter work like four-wire types and results in less leakage ground current. This feature gives preference to this type for the use of PV applications that are connected to the

electrical network without the use of any dielectric transformer [17].

For the single-phase (SZSI) two active switches are needed to get the same output as if using a traditional inverter. The different connection of the components leads to the appearance of two types of semi-source inverters, as shown in Fig. 4 [14-15].

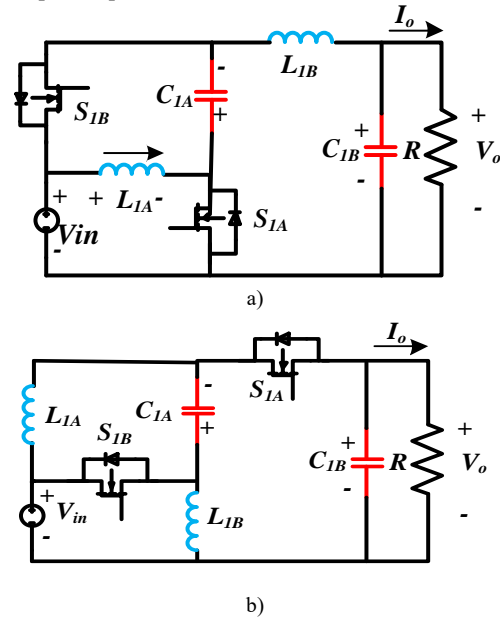


Fig. 4 single-phase semi-Z-source inverters, (a) semi-Z-source inverter (SZSI) (b) semi-quasi-Z-source inverter (SQZSI)

The conception of single-phase Semi quasi Z-Source inverter is collected to make three phase Semi quasi Z-Source inverter [16] as shown in Fig. 5

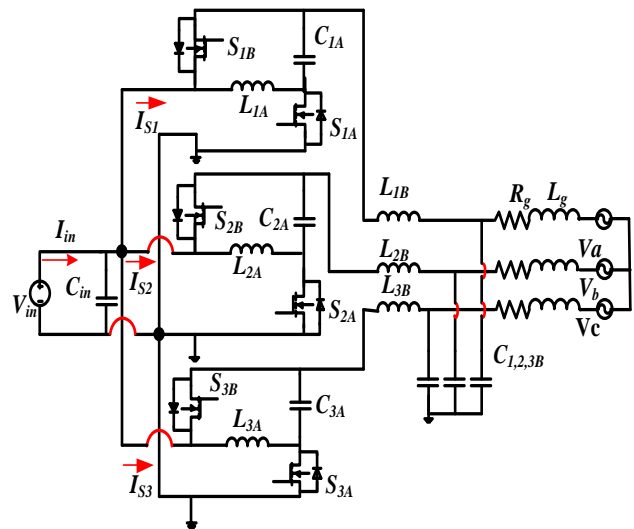


Fig. 5 Three phase Semi quasi Z-Source Inverter

Micro-Inverter (MI) is presented to overcome the problem of shading, as each cell has its inverter with a rating of 50-400W with power conversion efficiencies above 90%. [18-21]. MI has low power so it can be integrated into the frame of the PV panel, in addition, it can be connected to the grid

In this paper two topologies will be discussed and compared based on the dynamic response, input current behavior, switches stress, capacitors stress, and finally efficiency.

2. Systems analysis

a) SEPIC analysis

The system can be presented as input DC which is converted to AC across three DC-DC and connected directly to Grid. A detailed analysis has been presented in [7]. The grid phase voltages are represented as

$$\begin{cases} v_a = V_m \sin(\omega t) \\ v_a = V_m \sin(\omega t - 120^\circ) \\ v_a = V_m \sin(\omega t + 120^\circ) \end{cases} \quad (1)$$

The DC-DC produce the AC voltage via the PWM control then by connection the three modules as shown in Fig. 3 the DC components will be removed due to the differential connection and the total output voltage with DC offset for each DC-DC converter V_{C1B} can be presented as:

$$\begin{cases} v_{C1B}(t) = -h_a V_{in} \\ h_a = H_{dc} + H_{ac} \sin(\omega t + \theta) \\ v_{C1B}(t) = -[V_{dc} + V_m \sin(\omega t + \theta)] \end{cases} \quad (2)$$

Where h is the conversion ratio, θ is the voltage phase-shift, H_{dc} , and H_{ac} , the DC and AC voltages ratios between output and input, V_{dc} the DC component of the DC-DC output voltage, and V_m is the peak value of the AC component of the DC-DC output voltage

By applying, this on the b and c phase the voltage, V_{C2B} , V_{C3B} , can be presented as :

$$\begin{cases} v_{C2B}(t) = -h_b V_{in} \\ h_b = H_{dc} + H_{ac} \sin(\omega t + \theta - 120^\circ) \\ v_{C2B}(t) = -[V_{dc} + V_m \sin(\omega t + \theta - 120^\circ)] \end{cases} \quad (3)$$

and

$$\begin{cases} v_{C3B}(t) = -h_c V_{in} \\ h_c = H_{dc} + H_{ac} \sin(\omega t + \theta + 120^\circ) \\ v_{C3B}(t) = -[V_{dc} + V_m \sin(\omega t + \theta + 120^\circ)] \end{cases} \quad (4)$$

From (2) the voltage conversion ratio is

$$h_a = \frac{v_{C1B}(t)}{V_{in}} \quad (5)$$

So, the duty ratio can be presented as:

$$D_a = \frac{h_a}{1 + h_a} = \frac{M (\sin(\omega t + \theta) + 1)}{M (\sin(\omega t + \theta) + 1) + 1} \quad (6)$$

where

$$M = \frac{v_m}{V_{in}}$$

b) Semi-Quazi Z-Source Inverter (SQZSI)

The SZSI analysis can be achieved by choosing one cell and the operation can be analyzed by dividing it into two modes of operation as shown in the equivalent circuit in Fig. 5 (a,b). The first mode appears when switch S_{1A} is conducted as shown in Fig. 6(a). During this mode, the inductors L_{1A} and L_{1B} are charging from capacitor C_{1A} and the input voltage source, and therefore the inductor current is increased.

The second mode appears when switch S_{1B} is conducted as shown in Fig. 6(b). During this mode, the two inductors discharge, and the inductor current is decreased. The passes of the currents are shown in Fig. 6 by dotted lines.

The steady state equations of currents and voltages can be deduced based on the inductor voltage and capacitor charge balance equations, for one cell as [12]:

$$\frac{V_o}{V_{in}} = \frac{1 - 2D}{1 - D} \quad (7)$$

$$V_{C1} = \frac{D}{1 - D} V_{in} \quad (8)$$

$$I_{L2} = I_o \quad (9)$$

$$I_{L1} = \frac{D}{1 - D} I_o \quad (10)$$

where D refers to the duty ratio of switch S_{1A} and the switches S_{1A} , S_{1B} are conducted in a complementary manner

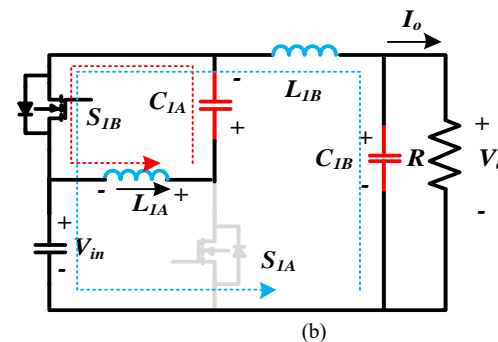
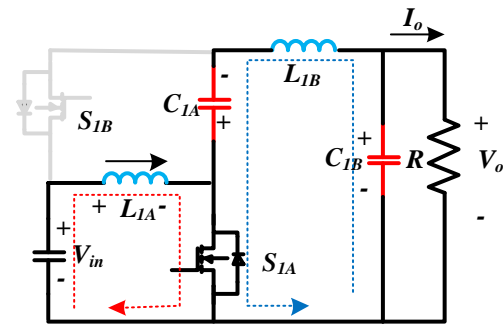


Fig. 6: Semi Quasi Z-source operation modes in one switching period (a) Mode 1 S_{1A} is ON. (b) Mode 2 S_{1B} is ON.

The AC output voltage is shown as:

$$V_o = V \sin(\omega t) \quad (11)$$

The relation between AC voltage and DC input voltage can appear in modulation index M and represented as:

$$M = \frac{V}{V_{in}} \quad (12)$$

From (11) and (12) combining into (7)

$$D = \left(\frac{1 - M \sin(\omega t)}{2 - M \sin(\omega t)} \right) \quad (13)$$

The complement of D is D' which is $D' = (1 - D)$ so, from (13) D' can be presented as:

$$D' = \left(\frac{1}{2 - M \sin(\omega t)} \right) \quad (14)$$

3. Simulation Results

The analysis and all theories are validated using PSIM Software. The using parameters for the two topologies are listed in Table I

TABLE I. TABLE I PARAMETERS OF SQZSI AND SEPIC INVERTER

Parameters	value	Parameters	value
V_{in}	120V	$C_{1,2,3(B)}$	10 μ F
C_{in}	100 μ F	L_g	2mH
$L_{1,2,3(A)}$	400 μ H	Internal resistance R_g	100m Ω
$L_{1,2,3(B)}$ Or mutual for transformer	400 μ H	Phase Grid voltage V_a	50sin(ωt)
$C_{1,2,3(A)}$	10 μ F		

As a comparison between Semi Z-Source and SEPIC Inverter the total count of the component can be summarized as in SQZSI has 6 switches, 9 inductors, and 6 capacitors, however in SEPIC it has 6 switches, 6 inductors, and 6 capacitors, in addition, it can be provided with isolated High-Frequency HF transformer. It should be noted that the total stress across the capacitors C_1 for SEPIC and SQZSI is shown in Fig. 7. the voltage stress of V_{C1A} in SEPIC is less than the voltage stress V_{C1A} in SQZSI. In addition, the stress voltage V_{C1A} has fluctuated between 50 and 170V. The voltage V_{C1B} is fluctuate between 0 and 100V in SEPIC where in SQZSI the voltage V_{C1B} is alternative between -50V and 50V

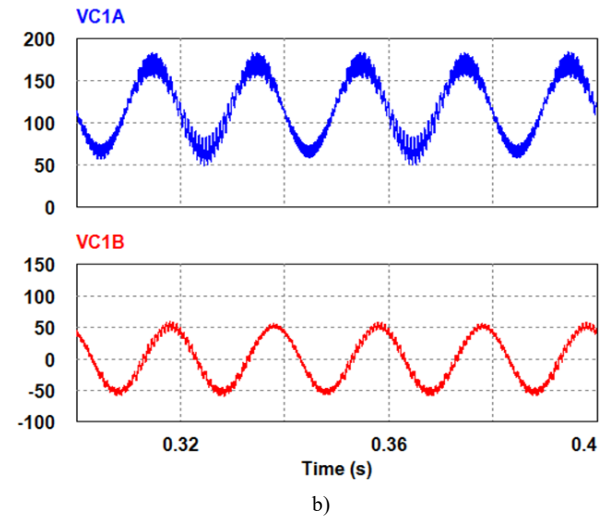
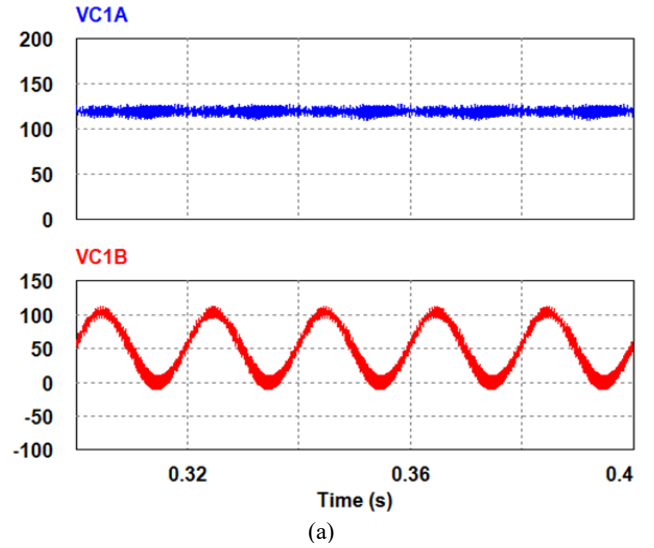


Fig. 7 stress voltage on capacitor C1A and C1B
a) SEPIC b) SQZSI

The inductors currents in both topologies are shown in Fig. 8. The current stress across L_{1A} in SEPIC is less than current stress across L_{1A} in SQZSI, where is the peak value inductor current I_{L1A} is 8A in SEPIC and the peak value of the inductor current I_{L1A} is 15A in SQZSI. On other hand, the peak value inductor current I_{L1B} is -10A in SEPIC and the peak value of inductor current I_{L1A} is -2A in SQZSI which means that also the current stress in SEPIC is less than in SQZSI as shown in Fig. 8

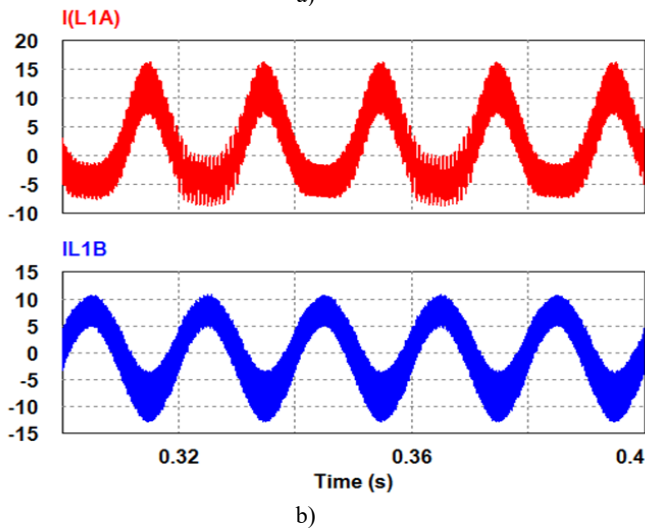
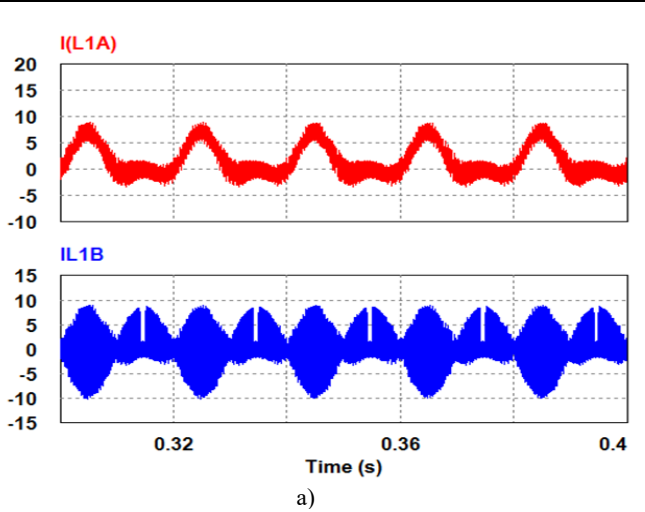


Fig. 8 Inductor Currents I_{L1A} , I_{L1B} a) SEPIC b) SQZSI
 The shape of the input current directly affects the life span of the topology, as shown in Fig. 9 the value of input current for the same power rating in SEPIC is 10A which is less than the value in SZSI topology, It is worth noting that the current in SQZSI topology is alternating between negative value (-10A) and positive value 23A for the same power rating which gives a bad impression on the life span of the SZSI.

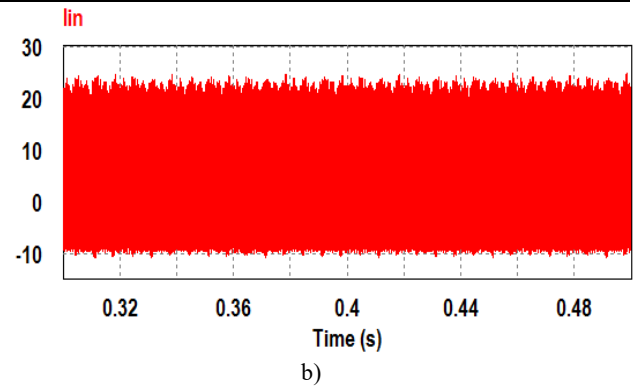
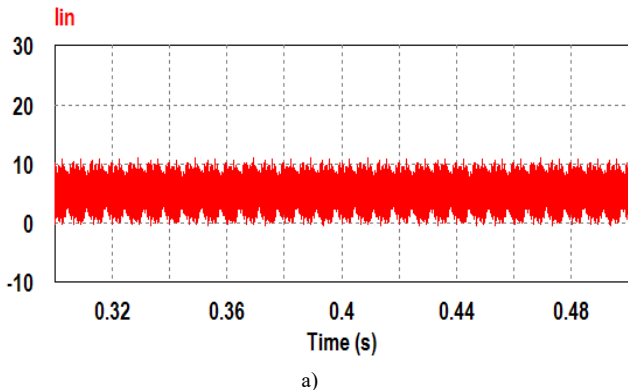


Fig. 9 Input current a) SEPIC b) SQZSI
 The current stress on the switches for both topologies can be presented for two switches S_{1A} and S_{1B} for example. It is clear to show that the stress on SEPIC for both switches are less than stress on SQZSI topology as shown in Fig. 10

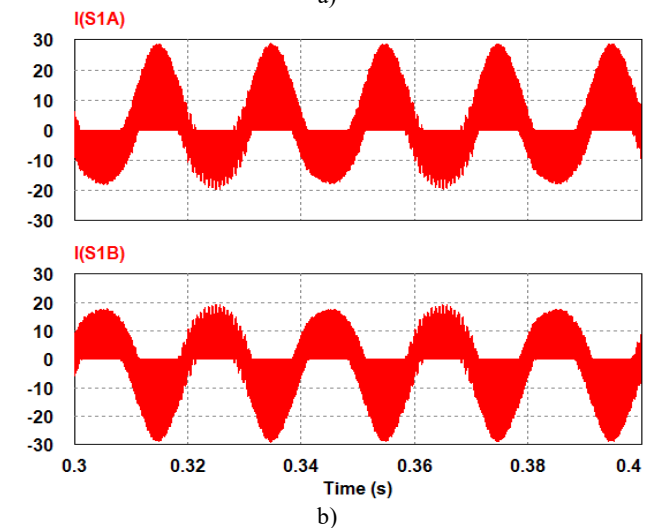
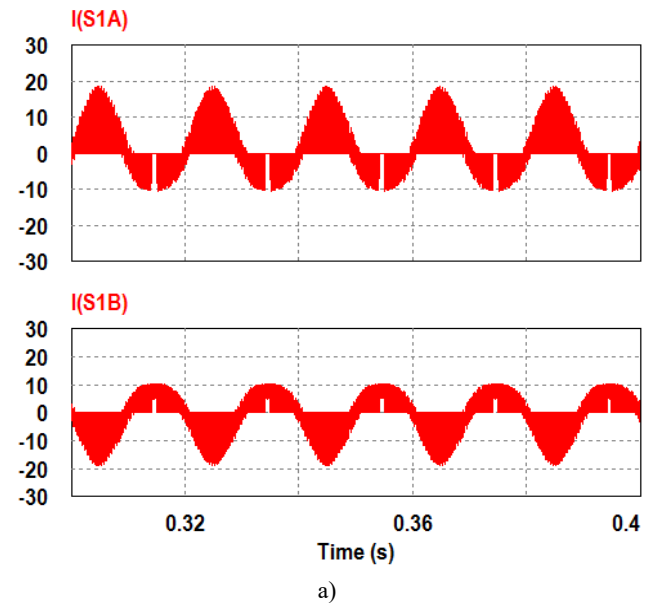


Fig. 10 the switches currents on switch S_{1A} and S_{1B} for a) SEPIC b) SQZSI

4. block diagram

For both topologies, the block diagram of the feedback control is shown in Fig. 11. The three output currents are measured then it has been transformed into the D-Q platform. The reference I_{dref} is added to I_d

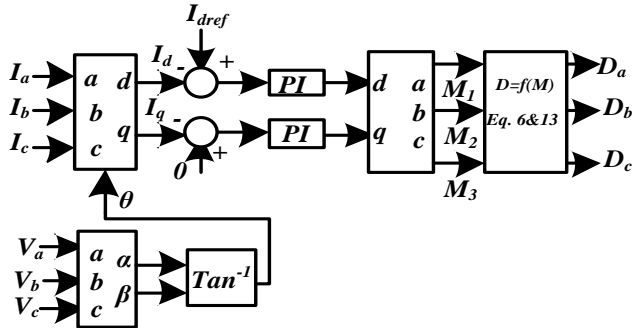


Fig. 11 block diagram of feedback control

In this paper, the control design of such converters has not been discussed. however, the dynamic performance will be presented under the control parameter of PI as follows. The time constant is chosen to be 13m and the gain is 2m with SEPIC topology. on other hand, the time constant is chosen to be 0.05m and the gain is 2m with SEPIC topology. The dynamic response of the SEPIC is better than SQZSI because it reaches a steady state rapidly than the other one as shown in Fig. 12.

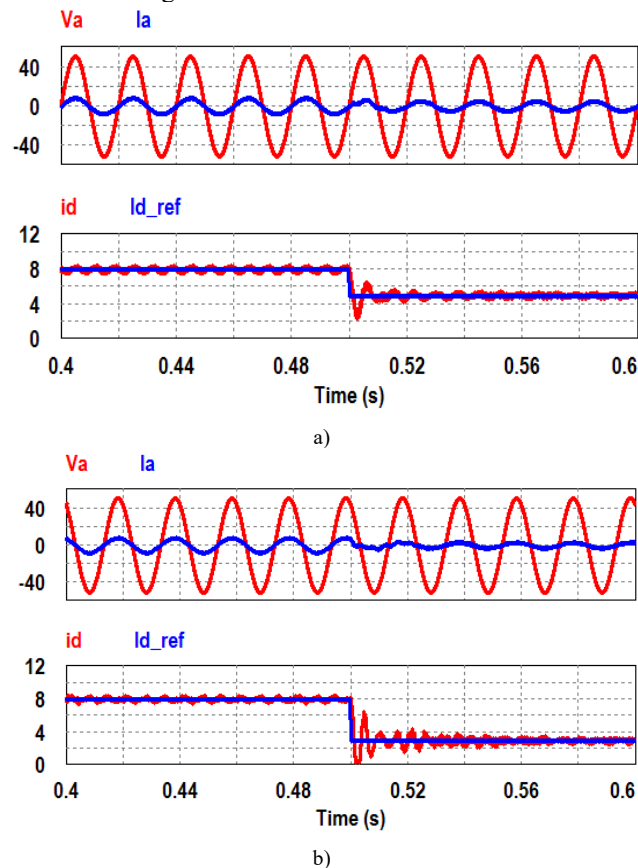


Fig. 12 dynamic performance of output current and its D-coordinate
a) SEPIC b) SQZSI

5. CONCLUSION

In this paper, two topologies are presented SEPIC and SZSI. Systems have been investigated using PSIM software, considering three parallel modules in each phase for both SEPIC and SZSI. SEPIC topology presents low stress for currents and voltages. Also, the input current for SEPIC is working in Continuous Conduction Mode (CCM). The performance of the topologies is tested under dynamic change and the dynamic response of the SEPIC is better than the SZSI. In addition, simulation results clearly show that the method of control technique pushes the power of the system to follow the reference value and extract the sinusoidal currents at the grid having a unity power factor. For future work, both systems should be studied for details under the losses mathematical model. In addition, both systems should be investigated under new control schemes as predictive control.

References

- [1] J.G. Kassakian, and T.M. Jahns, "Evolving and Emerging Applications of Power Electronics in Systems", IEEE Journal of Emerging and Selected Topics in Power Electronics, vol.1, no.2, pp. 47 - 58, Jun. 2013
- [2] Marinov, A., & Valchev, V. "Power loss reduction in electronic inverters trough IGBT-MOSFET combination". Procedia Earth and Planetary Science, 1(1), (2009). 1539-1543.
- [3] Oliva, A. R., Chiacchiarini, H. G., Aymonino, O. A., & Mandolesi, P. S. (2005). Reduction of total harmonic distortion in power inverters.
- [4] S. Mehrnami and S. K. Mazumder, "Discontinuous Modulation Scheme for a Differential-Mode Cuk Inverter," IEEE Transactions on Power Electronics, vol. 30, pp. 1242-1254, 2015.
- [5] Y. Chen and K. Smedley, "Three-phase boost-type grid-connected inverter," IEEE Trans. Power Electron., vol. 23, DOI 10.1109/TPEL.2008.2003025, no. 5, pp. 2301-2309, Sept. 2008.
- [6] R. O. Caceres and I. Barbi, "A boost DC-AC converter: analysis, design, and experimentation," IEEE Transactions on Power Electronics, vol. 14, pp. 134-141, 1999.
- [7] A. Darwish, A.M. Massoud, D. Holliday, S. Ahmed, and B.W. Williams: "Single-Stage Three-Phase Differential-Mode Buck-Boost Inverters with Continuous Input Current for PV Applications", in IEEE Transactions on Power Electronics, Vol.31, No.12, pp.8218-8236 (2016)
- [8] A. Darwish, D. Holliday, S. Ahmed, A.M. Massoud, and B.W. Williams: "A single-stage three-phase inverter based on Cuk converters for PV applications", IEEE J. Emerging and Sel. Topics on Power Elec., Vol.2, No.4, pp.797-807 (2014)
- [9] S. Mehrnami, S.K. Mazumder, and H. Soni: "Modulation Scheme for Three-Phase Differential-Mode Cuk Inverter", in IEEE Transactions on Power Electronics, Vol.31, No.3, pp.2654-2668 (2016)
- [10] Ahmed Shawky, Mahmoud A. Sayed, and Takaharu Takeshita. "Analysis and experimentation of modular differential inverter utilizing SEPIC modules and SIC devices for grid connected applications." IEEE Journal of Industry Applications 9.5 (2020): 573-583.

- [11] Ahmed, Tofael, and Saad Mekhilef. "Semi-Z-source inverter topology for grid-connected photovoltaic system." *IET Power Electronics* 8.1 (2014): 63-75.
- [12] Ahmed, Tofael, Tey Kok Soon, and Saad Mekhilef. "A single-phase doubly grounded semi-Z-source inverter for photovoltaic (PV) systems with maximum power point tracking (MPPT)." *Energies* 7.6 (2014): 3618-3641.
- [13] Ahmed, Tofael, Saad Mekhilef, and Mutsuo Nakaoka. "Single-phase transformerless semi-Z-source inverter with reduced Total Harmonic Distortion (THD) and DC injection." 2013 IEEE ECCE Asia Downunder. IEEE, 2013.
- [14] D. Cao, S. Jiang, X. Yu, &F. Peng, "Low-cost semi-Z-source inverter for single-phase photovoltaic systems". *IEEE Transactions on Power Electronics*, 26(12), (2011). 3514-3523.
- [15] T. Gunnam, S. Sadik, A. Khan, F. Mohammed, A. Naresh, "Modeling of Single-Phase Semi-Z-source Inverter" *International Journal of Research in Computer and Communication Technology*, Vol 2, Issue 9, September -2013.
- [16] M. Ismeil, M. Orabi, R. Kennel, and H. Abu-Rub, "Modeling and Experimental Study of Three-phase Improved Switched Inductor Z-Source Inverter," *EPE Journal*, Vol 24, Issue 4, 2014, 14-27.
- [17] M. Abdelrahem , R. Kennel, M. Ismeil, and M. Orabi. "Three Phase Semi-Z-Source Inverter for PV Applications." In *PIM Europe*. 2019.
- [18] Özgür Çelik, Ahmet Teke and Adnan Tan, "Overview of micro-inverters as a challenging technology in photovoltaic applications," *Renewable and Sustainable Energy Reviews*, Volume 82, Part 3, 2018, Pages 3191-3206, ISSN 1364-0321
- [19] W. J Cha, J.M Kwon and B.H Kwon. "Highly efficient step-up dc-dc converter for photovoltaic micro-inverter" . *Sol Energy* 2016;135:14-21.
- [20] C.L Trujillo, F. Santamaría, and E.E. "Gaona. Modeling and testing of two-stage grid connected photovoltaic micro-inverters". *Renew Energy* 2016; 99: 533-542.
- [21] G. Zhu, Mu L and J. Yan "A novel multi-function PV micro-inverter with an optimized harmonic compensation strategy." *Journal of Power Electron* 2016;16(6):2284-2293.