CHAPTER 1

Introduction

1.1 Background and Motivation

The energy demand of the inflated population and expanding global economy has enormously increased in the last few decades. The increased energy demand is met out by the power generated from conventional energy sources or fossil fuels (coal, oil and gas) [1], [2]. Although fossil fuels are the prime sources of electrical power, the methods of processing and generating electricity from them are causing enormous impacts on the environment such as greenhouse gas emissions, global warming, acid rain, air pollution and so on. Moreover, fossil fuels are finite and would drain out quickly, if they are continuously used for energy generation.

To take care of the said issues, the international community has been focusing more on nonconventional energy sources, also known as renewable energy sources (RESs) [3]-[9]. The RESs produce energy from natural sources like sunlight, wind, rain, tides and geothermal heat, which are available in nature in abundance. Among the RESs, wind power generation is considered as one of the most efficient energy sources, and it can be installed either onshore or offshore [10], [11]. However, they are not suitable for installing on the roof-tops of the residential/commercial buildings to meet the localized demand. To take care of this, solar photovoltaic (PV) systems are better choices for the residential/commercial distribution systems due to a lack of mechanical moving parts, lower maintenance costs, and compactness. The solar PV systems consist of several cells in series/parallel and are used to convert light energy into electrical energy. The solar PV cells are low voltage energy sources that give direct current (DC) output depending on atmospheric conditions [12]-[17]. The continuous research in PV power generation and its use is improving day-by-day through various power electronic converters (PECs) and their efficient control methods. The PECs play a major role in the solar PV generation to enhance the low voltage levels and extract maximum power. The energy conversion by the PECs has to be efficient and reliable without disturbing the distribution grid. Further, the main criterion of PECs design is to achieve high voltage gain at regulated DC output voltage. These requirements must be fulfilled before connecting the solar PV cells to the alternating current (AC) distribution systems.

In the case of PECs design, a DC-AC converter is needed along with a high gain DC-DC converter for the AC residential distribution system, which is operated by low voltage DC sources. A series connection of solar PV cells is another option to achieve the required voltage for the AC residential distribution system. However, occasionally, some solar PV cells can be shaded due to the dust, position and atmospheric conditions. The shaded cells become reverse biased and act as sinks instead of sources. This gives rise to localized power dissipation in the solar PV cells resulting in reduced output power [17].

Moreover, due to higher number of PV cells, the total cost of the system increases. Therefore, use of high gain DC-DC converters is more efficient/economical solution for AC residential systems instead of series-connected PV cells. Further, the control algorithms can be independently operated by each panel for extracting maximum power from the individual PV cells.

The present thesis investigates PECs and their usage at different power conversion stages for residential distribution systems.

1.2 Literature Review

This section discusses various PECs for a two-stage and single-stage AC residential distribution systems and hybrid AC/DC residential distribution system.

1.2.1 Two-Stage AC Residential Distribution System

A schematic of a two-stage AC residential distribution system is shown in Fig. 1.1. It can be observed from Fig. 1.1 that solar energy is extracted and fed to the AC grid/load of the residential distribution system through DC-DC and DC-AC converters. As stated earlier that a DC-DC converter is necessary to step-up the voltage levels of the solar PV cells, which is used as a front-end power converter for the two-stage system. The required characteristics of the DC-DC converter for solar PV cells are high voltage gain, continuous input current, low device voltage stresses, good reliability and efficiency. Moreover, a bidirectional DC-DC converter is needed to store the energy in a battery pack for an uninterruptible power supply.

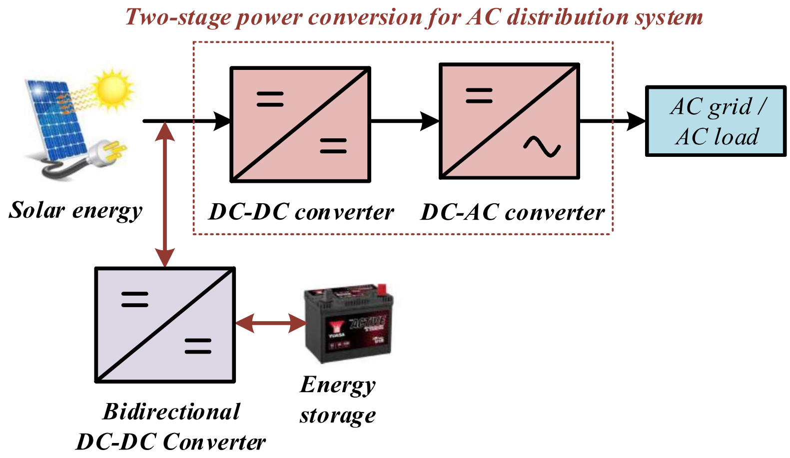


Fig. 1.1. Schematic of a two-stage AC residential distribution system.

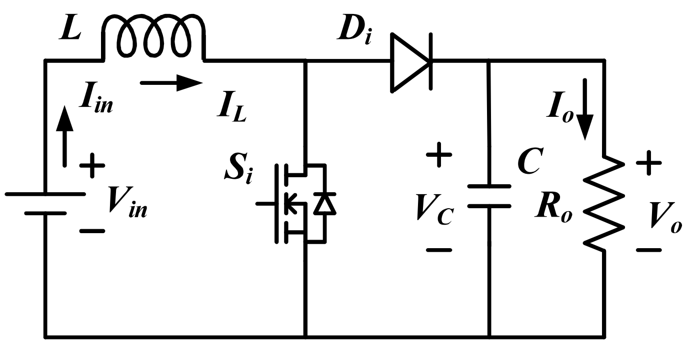


Fig. 1.2. A conventional boost DC-DC converter.

A conventional boost DC-DC converter (CBC) as shown in Fig. 1.2, is simple in construction and is capable of enhancing the low voltages. Although the CBC gives high voltage gain, it has to operate at extreme duty ratios. In practical applications, the voltage gain of the CBC is limited at high duty ratios due to losses in the parasitic components such as DC resistance (DCR) of the inductor, equivalent series resistance (ESR) of the capacitor, on-state resistance and voltages of the power semiconductor devices. Otherwise, conduction losses and severe reverse recovery losses of the diode increase, which leads to decreases in the efficiency of CBC. Also, the switching element of CBC experiences voltage stress as that of output voltage and current stress as that of input current. To overcome this, many high gain DC-DC converters are reported in the literature based on cascaded arrangements, voltage multipliers (VMs), switched inductors (SLs), multilevel/modular concepts, switched capacitors (SCs), hybrid SL/SCs, coupled inductors and high-frequency transformers [18]-[55].

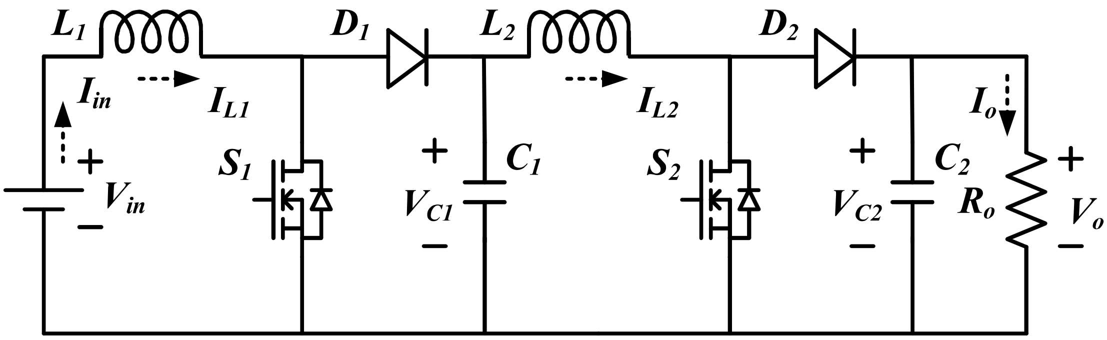


Fig. 1.3. A cascaded boost DC-DC converter consisting of two CBCs.

A cascaded boost DC-DC converter consisting of two CBCs is shown in Fig. 1.3. A cascaded configuration consisting of two or more basic DC-DC converters in cascade is a simple method to enhance the voltage levels of low voltage sources. Although the cascaded configuration gives high voltage gain, it has higher number of elements, which results in increased power loss, higher possibility of failure, lower reliability and efficiency. Also, the devices of cascaded configuration experience higher voltage and current stresses. To reduce switching losses in the cascaded arrangement, each stage can be operated at different switching frequencies. The first stage can be operated at a higher frequency due to relatively low voltage stress and the second stage at lower frequency due to relatively high voltage stress, and so on. Designing a control scheme becomes difficult because of different frequency operation of the switches. Also, other types of cascaded configurations of boost converters such as quadratic and cubic DC-DC converters with a single active switch are discussed in the literature, which has fourth and sixth-order dynamic behaviour. Further, a quadratic DC-DC converter with lower voltage stress on the input side capacitor is reported in the literature for the high voltage gain operation.

Many DC-DC converters using VMs are reported in the literature to achieve high voltage gain over the CBC. Fig. 1.4 shows a step-up DC-DC converter with VM cell. To enhance the voltage gain further, a larger number of VM cells can be cascaded. Although it gives high gain with less input current ripple, it uses a higher number of elements, which results in an increased volume of the system and higher power losses. However, the VM cell can also operate with a resonant inductor (typically, 1 μH to 4 μH) in series with the capacitor C_2 to minimize the losses. Due to the resonant inductor, the switch is turned-on at zero-current, and thereby the effect of reverse recovery current of diodes is minimized, which results in low switching loss.

An SL based step-up DC-DC converter is reported in the literature and is shown in Fig. 1.5. It is an enhanced version of the CBC which replaces the input inductor by an SL. It has a slightly higher voltage gain, a greater number of elements and more ripple content in the input current as compared to CBC.

Fig. 1.6 shows an SC based step-up DC-DC converter. As shown in Fig. 1.6, the SC cell is enclosed by a dotted box. By controlling the on/off states of the switch and self-voltage balancing capability of the capacitors, the SC based boost converter can attain high voltage gain. Also, series and parallel connection of the SC cells are possible to enhance voltage gain further, similar to that of SL cells.

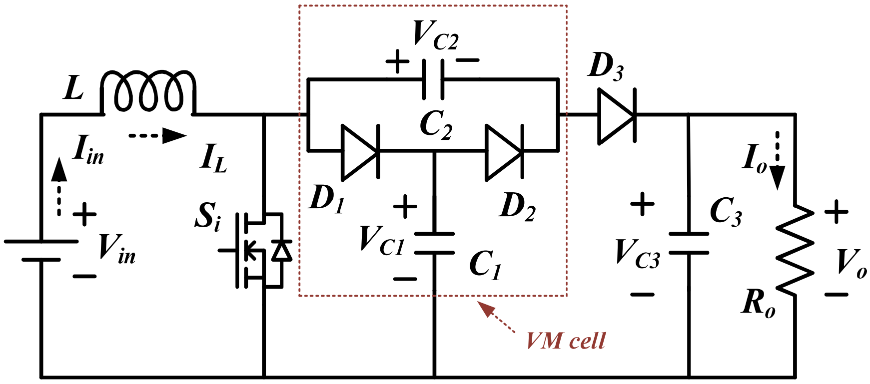


Fig. 1.4. A step-up DC-DC converter using a VM cell.

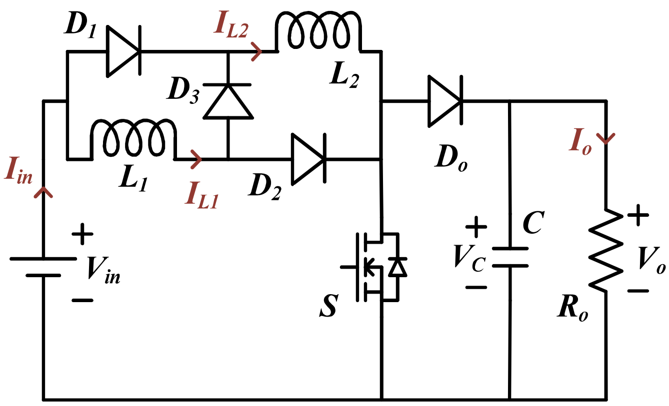


Fig. 1.5. An SL based step-up DC-DC converter.

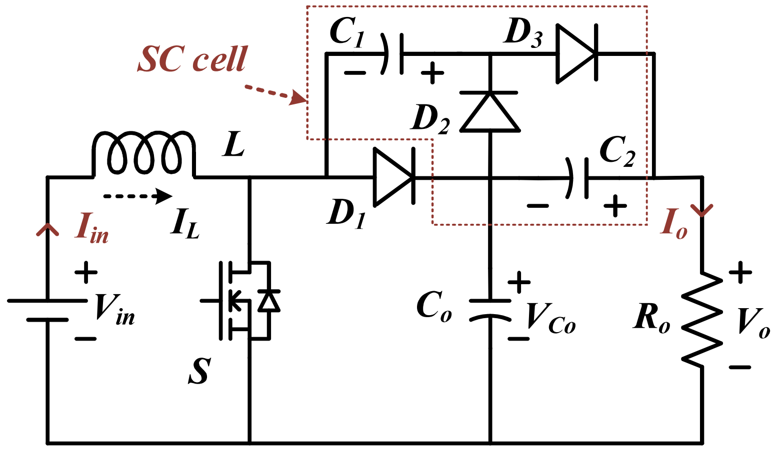


Fig. 1.6. An SC based step-up DC-DC converter.

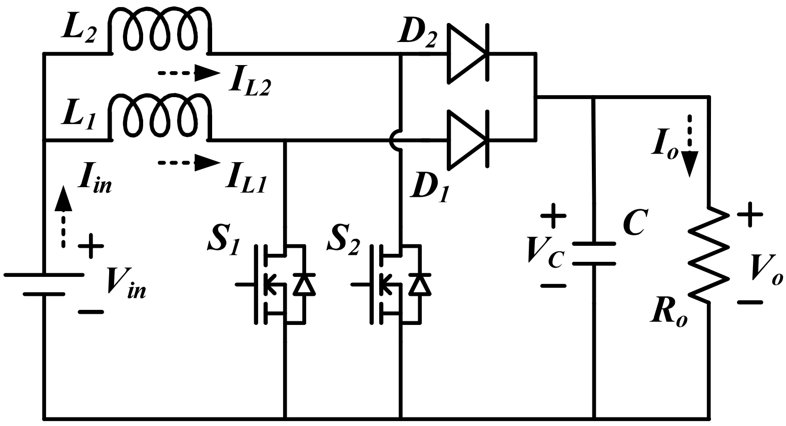


Fig. 1.7. A two-phase interleaved boost converter.

Interleaving the power converters is also a better choice for high-voltage high-power applications. One such development is interleaving two CBCs, as shown in Fig. 1.7, namely a two-phase interleaved boost converter (TIBC). Due to the interleaving, the TIHB has a low ripple in the input current and output voltage. Also, the TIHB has better reliability and fault-tolerance due to its interleaving nature. However, its gain is as same as that of CBC with a greater number of elements.

With the help of coupled-inductors and high-frequency transformers, high voltage gain is achieved in the DC-DC converters. A conventional high gain DC-DC converter consisting of a high-frequency transformer, namely a flyback DC-DC converter is shown in Fig. 1.8.

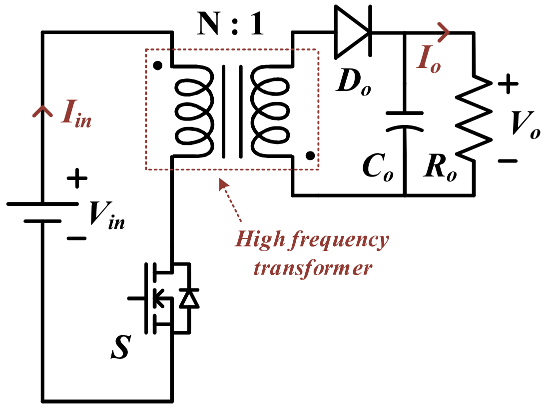


Fig. 1.8. A flyback DC-DC converter.

By adjusting the turns ratio of the transformer, high voltage gain can be achieved by the flyback DC-DC converter. Although transformer-based converters have high voltage gain, they have leakage inductance effect which produces high voltage spikes across the power semiconductor devices during the switching operation. This leads to increased power losses in the converter. To care of this, various snubber circuits (passive and active) are required to reduce the effect of voltage spikes. Although snubbers circuits reduce voltage spikes, they require additional elements which in turn increases the cost and volume of the system.

Recently, Z-source concept has been emerged to achieve high voltage gain power conversion and to overcome the disadvantages of conventional PECs. The Z-source concept has been applied in various PECs design; DC–AC, DC–DC, AC–AC and AC–DC [56]. One such development is a Z-source DC-DC converter for high voltage gain and is shown in Fig. 1.9.

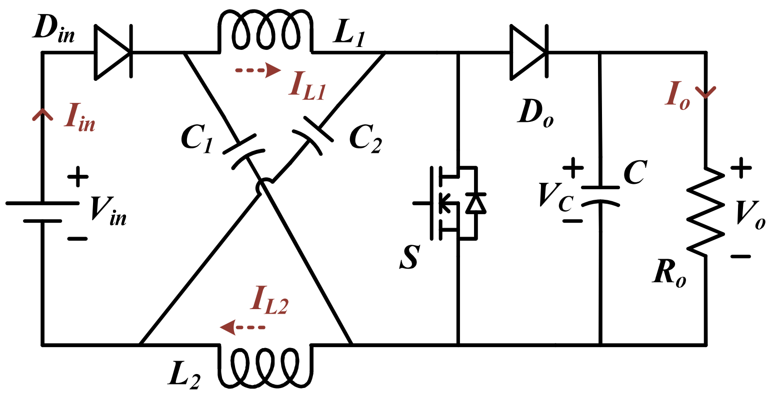


Fig. 1.9. A Z-source DC-DC converter.

Similar to most of the step-up DC-DC converters, the Z-source DC-DC converter stores energy in the inductors and then transfers it to the output. Although it has high voltage gain as compared to CBC, it uses a higher number of elements and draws discontinuous input current. Further, many DC-DC converters based on the Z-source concept have been reported in the literature to enhance the voltage gain with continuous input current using isolated/non-isolated configurations.

The DC-DC converters discussed so far have their own advantages and disadvantages. Their selection can be made according to the requirement of a particular application. A DC-AC converter is also needed along with DC-DC converters to supply the AC grid/AC load. For this, conventional voltage source inverter (VSI) and current source inverter (CSI) are used. Fig. 1.10 shows a conventional single-phase VSI. As shown, the single-phase VSI has an input DC voltage source (V_{dc}) supported by a large dc-link capacitor (C_{dc}), an H-bridge (HB) circuit having switches ($S_1 - S_4$) and a second-order low pass filter having L_f and C_f. Each switch is a combination of an insulated gate bipolar transistor (IGBT) and an antiparallel diode to provide unidirectional voltage blocking capability and bidirectional current flow. Although the VSI is used in many applications, it has the following disadvantages.

- In VSI, the fundamental peak AC output voltage is limited to V_{dc}. Hence, the VSI gives step-down inversion from DC-link to AC-link and step-up rectification from AC-link to DC-link. So, a step-up DC-DC converter is required along with the VSI to connect the low voltage DC sources to the AC grid/load. The two-stage power conversion increases the cost and decreases the efficiency of the overall system.
- It may lead to short-circuit due to mis-gating (turn-on of switches of the same leg) occurred by electromagnetic interference (EMI). Therefore, a short dead time has to be provided between the upper and lower switches of the same leg in the VSI to avoid shoot-through state [57], [58]. This distorts the AC output, and thus higher values of filters are required to remove them. The higher values of filters lead to increased power loss and reduced power density.

Fig. 1.11 shows a conventional single-phase CSI. As shown in Fig. 1.11, the single-phase CSI has a DC voltage source (V_{dc}) in series with an inductor (L_{dc}) feeds an HB circuit consisting of switches ($S_1 - S_4$) and a filter capacitor C_f. Each switch of HB is a series connection of an IGBT and a diode to provide bidirectional voltage blocking and unidirectional current flow.

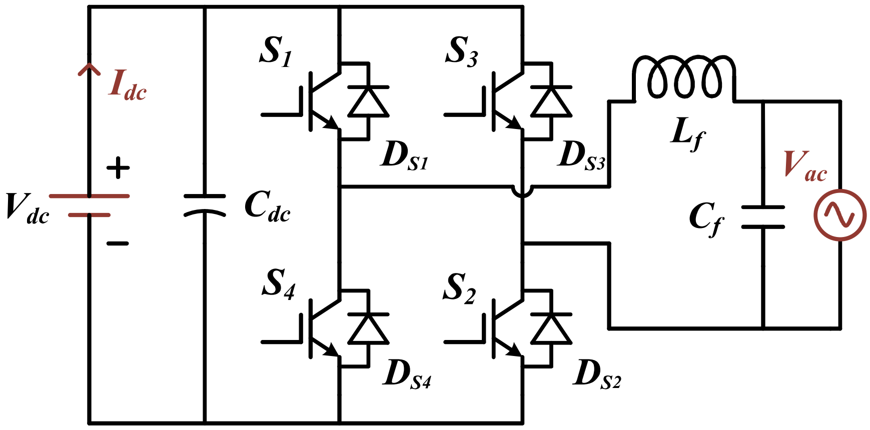


Fig. 1.10. A single-phase VSI.

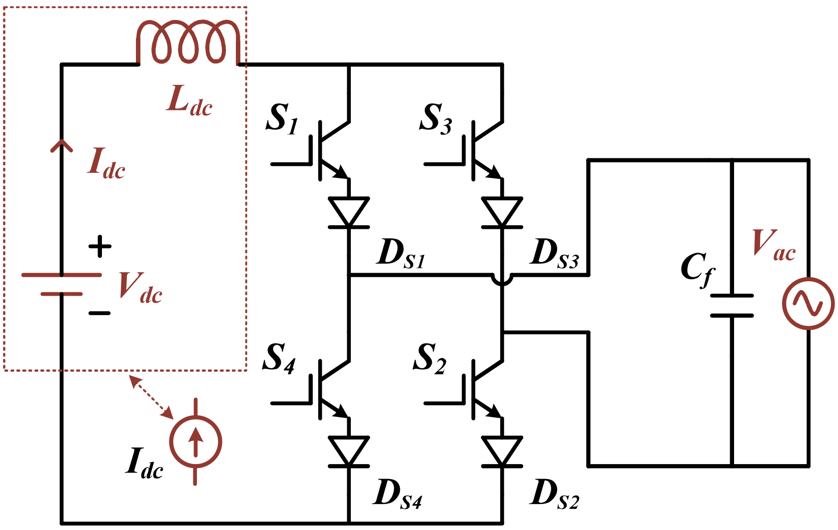


Fig. 1.11. A single-phase CSI.

Although CSI is used in many applications, it has the following disadvantages.

- In case of CSI, the fundamental peak AC output voltage is more than V_{dc}. Hence, it gives step-up inversion (from DC-link to AC-link) and step-down rectification (from AC-link to DC-link) due to the presence of L_{dc}. For wider voltage range applications, an extra DC-DC converter (for buck/boost operation) is needed. Additional power conversion stages increase the cost and decrease the efficiency of the system.

- Because of EMI noise, mis-gating occurs which results in switching OFF of the HB switches. This leads to open-circuit of L_{dc}. To avoid such a situation, a small overlap period has to be provided in case of CSI.

1.2.2 Single-Stage AC Residential Distribution System

To care of the issues related to the two-stage system, in recent times, various high gain DC-AC converters have been reported, based on impedance-source/Z-source concept through a single-stage power conversion. A schematic of a single-stage AC residential distribution system is shown in Fig. 1.12. The Z-source based converters are not only used in solar-based AC residential distribution systems but also in other applications like electric vehicles, motor drives, power generation from fuel cells, power quality improvement and high-frequency AC operation [56].

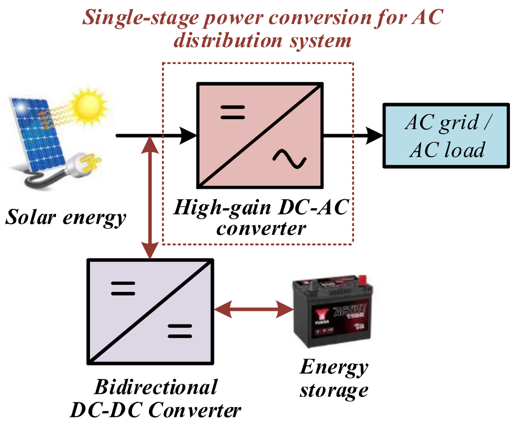


Fig. 1.12. Schematic of a single-stage AC residential distribution system.

An impedance-source/Z-source inverter (ZSI) is reported in [59] and is shown in Fig. 1.13. It consists of Z-source/impedance network (a combination of inductors, capacitors and diode) in between the DC voltage (V_{dc}) and HB circuit ($S_1 - S_4$). The forbidden shoot-through state of the VSI is used in the ZSI to boost the V_{dc} to higher voltage levels for achieving high gain AC output. Also, the shoot-through state increases the reliability of the ZSI as compared to the VSI. Further, the ZSI has a single-stage buck-boost voltage inversion characteristic and it can produce better output waveform due to the elimination of the dead and overlap periods. Due to these features, the Z-source concept has been gaining more interest in recent times in terms of pulse width modulation schemes, modeling and control, different power conversion converters and other ZS based topologies for various applications [59]–[70]. Although the conventional ZSI is advantageous over the conventional VSI, it has few demerits which are discontinuous input current, higher capacitor voltage and floating ground of the HB circuit. To address these issues, an enhanced version of the ZSI, named as a quasi-Z-source inverter (qZSI), is derived and is shown in Fig. 1.14. As the qZSI has input inductor, it gives continuous input current. Also, the qZSI has lower component stress as compared to ZSI.

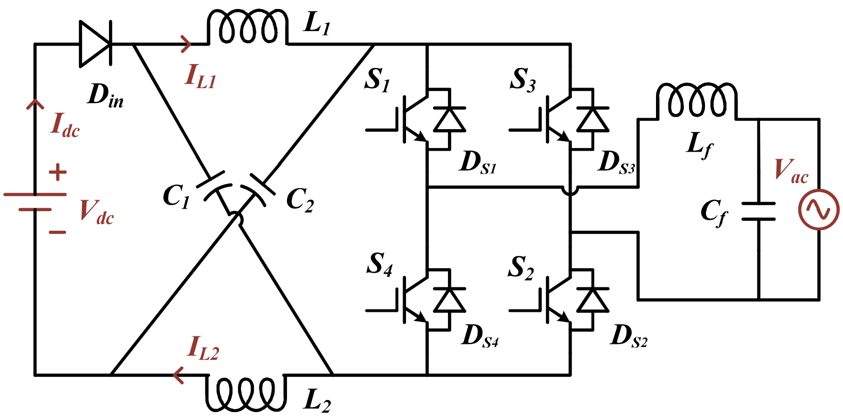


Fig. 1.13. A single-phase Z-source inverter (ZSI).

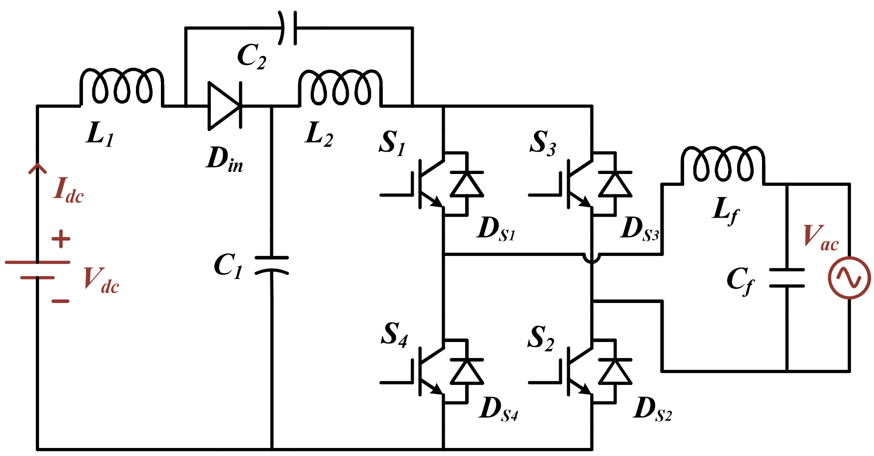


Fig. 1.14. A single-phase quasi-Z-source inverter (qZSI).

Although the conventional ZSI/qZSIs have infinite theoretical gain, their practical boosting ability is limited due to parasitic effects and higher device stresses, which results in lower efficiency of the system. The boosting ability (B) and voltage gain (G) of the single-phase ZSI/qZSIs are given in (1.1). The boosting ability is achieved due to the shoot-through state of the HB switches.

$$\left.\begin{aligned} B &= \frac{V_{inv}}{V_{dc}} = \frac{1}{1-2D_{st}} \\ G &= \frac{V_{ac(pk)}}{V_{inv}} = M \end{aligned}\right\} \tag{1.1}$$

where V_{dc} is the input DC source, V_{inv} is the voltage across the HB circuit, D_{st} is the shoot-through duty ratio, $V_{ac(pk)}$ is the fundamental peak AC output voltage and M is the modulation index. It can be observed from (1.1) that the D_{st} has to be increased to enhance the boosting ability of the ZSI/qZSI. Moreover. the D_{st} and M are interdependent in case of single-phase ZSI topologies under an operating condition, $D_{st} + M \leq 1$. Increase in D_{st} would reduce M and thereby, the inversion at low values of M gives distorted AC output voltage [68], [69].

The operation of the ZSIs dependent on D_{st} and M, where the D_{st} decides the required DC voltage appearing across the HB circuit from the input DC source and the M decides the required fundamental AC output voltage. Therefore, a trade-off between D_{st} and M has to be made to achieve high gain AC output at reduced harmonic distortion from the low voltage input DC sources.

To achieve the above-desired characteristic, various developments have been occurred in ZSI based on SCs, SLs, hybrid SC/SLs, voltage-lift circuits, cascaded connection, VM cells, high-frequency transformers, coupled inductors and modulation schemes [61]-[78]. Although transformers and coupled inductors based ZSIs give high gain inversion, high voltage spikes appear across the power semiconductor devices of the ZSIs due to their leakage inductance effect. The various developments taken place over the years in ZSIs have distinctive ways of achieving high gain AC output at reduced harmonic distortion [70]-[74]. Among the reported techniques, successful integration of SL cells in the ZSI provides high gain inversion output at reduced harmonic distortion (i.e., at low values of the D_{st}) as compared to conventional ZSI [72]. Some non-isolated SL based ZSIs are discussed in this section.

A single-phase SL based ZSI (SL-ZSI) reported in [72] to achieve high gain inversion at low D_{st} values and is shown in Fig. 1.15. Although the SL-ZSI gives high gain inversion at low D_{st}, it has a more passive component count, which in turn increases the volume and decreases the efficiency of the system. Also, it has drawbacks such as discontinuous input current and high start-up inrush current. The obtained relation of the B for the SL-ZSI is given in (1.2).

$$B = \frac{1+D_{st}}{1-3D_{st}} \tag{1.2}$$

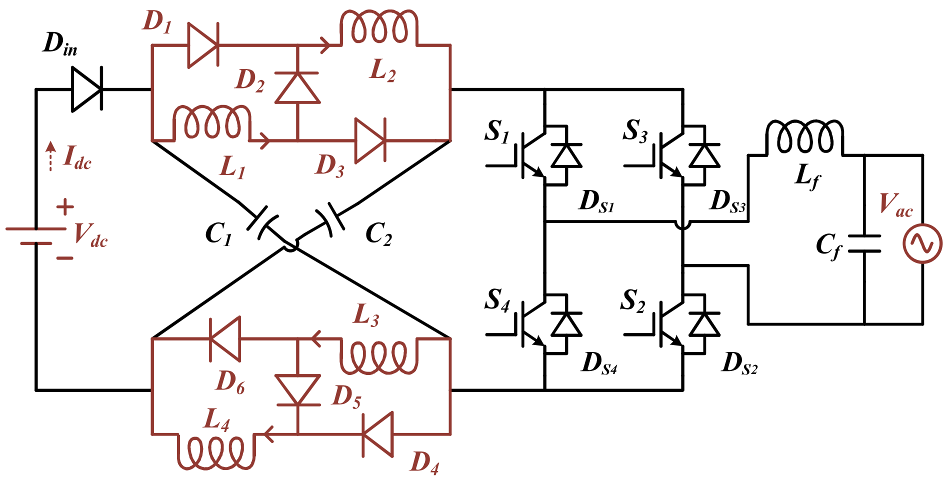


Fig. 1.15. A single-phase SL based ZSI.

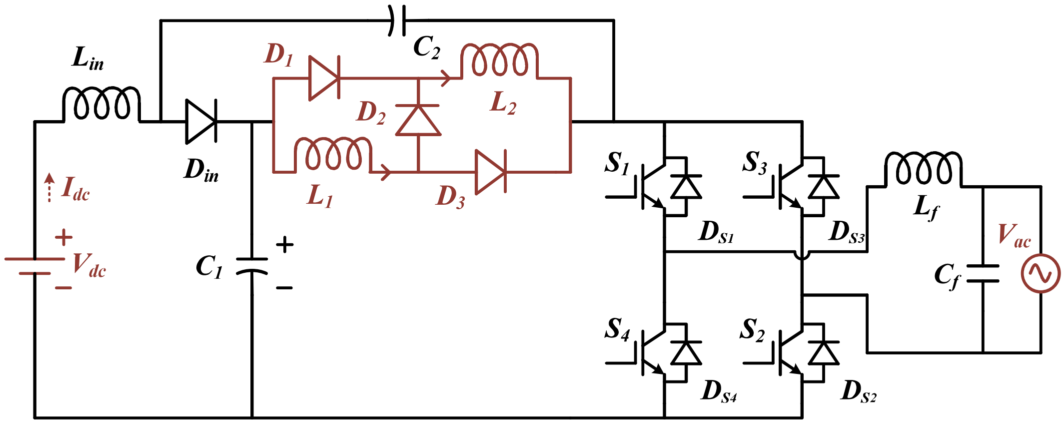


Fig. 1.16. A single-phase SL based qZSI.

Further, a single-phase SL based qZSI (SL-qZSI) has been reported in [73] to address the challenges of the SL-ZSI and is shown in Fig. 1.16. Although the SL-qZSI overcomes the drawbacks of the SL-ZSI [72], it has low gain inversion as compared to SL-ZSI at low D_{st}. The obtained relation of the B for the SL-qZSI is given in (1.3).

$$B = \frac{1+D_{st}}{1-2D_{st}-{D_{st}}^2} \tag{1.3}$$

Two modified SL-qZSIs, namely ripple input current SL-qZSI (rSL-qZSI) and continuous input current SL-qZSI (cSL-qZSI) are reported in [74] to achieve high gain inversion at low D_{st} and are shown in Figs. 1.17 and 1.18, respectively. Although they give high gain inversion, they use higher number of elements similar to SL-ZSI.

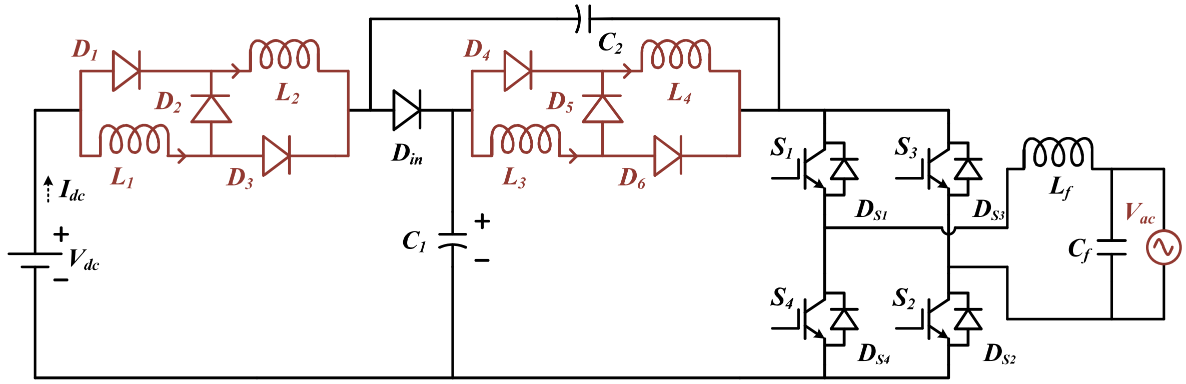


Fig. 1.17. A single-phase ripple input current SL-qZSI (rSL-qZSI).

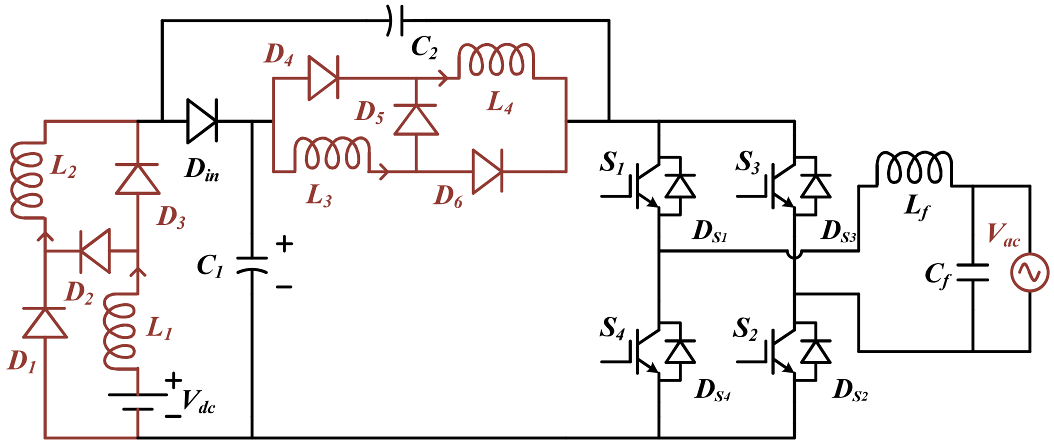


Fig. 1.18. A single-phase continuous input current SL-qZSI (cSL-qZSI).

The obtained relation of the B for rSL-qZSI is given in (1.4).

$$B = \frac{1+D_{st}}{1-3D_{st}} \tag{1.4}$$

The obtained relation of the B for cSL-qZSI is given in (1.5).

$$B = \frac{1}{1-3D_{st}} \tag{1.5}$$

1.2.3 Hybrid AC/DC Residential Distribution System

In recent times, DC loads are gradually increasing along with the existing AC loads of the AC residential systems [79]. Hence, the two-stage and single-stage AC systems are required to be modified as a hybrid AC/DC residential distribution system for supplying AC and DC loads [80]-[94]. Fig. 1.19 shows a schematic of a hybrid AC/DC system to supply AC and DC loads using separate PECs.

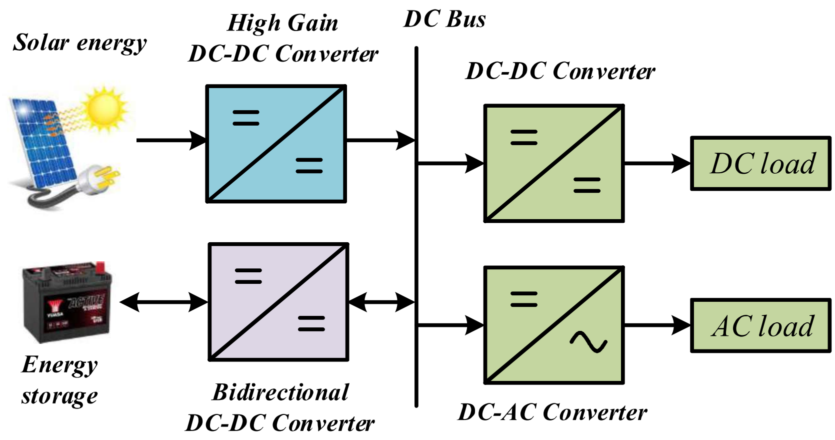
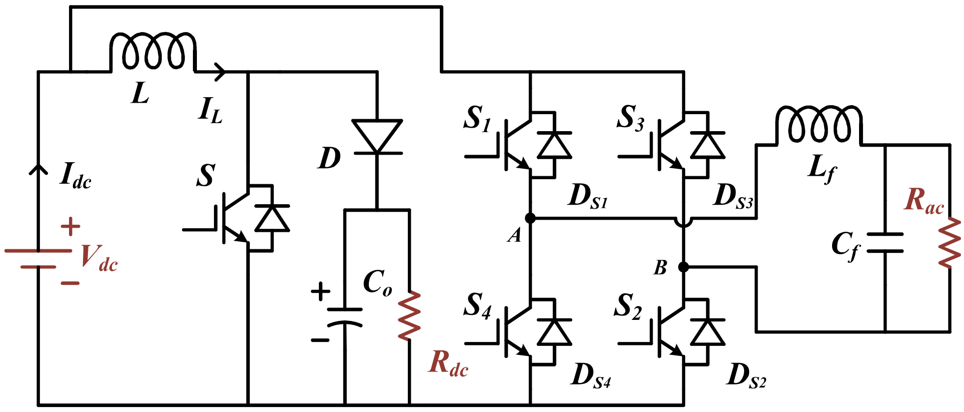


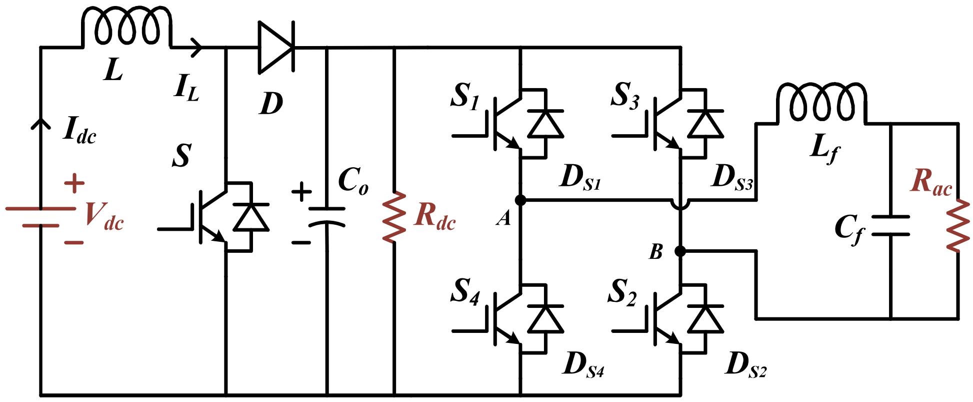
Fig. 1.19. Schematic of a hybrid AC/DC system for supplying AC and DC loads using separate power converters

As shown in Fig. 1.19, separate PECs are required for supplying AC and DC loads. A step-up/step-down DC-DC converter is required for DC loads and a DC-AC converter is required for AC loads. For this, two types of configurations can be considered as shown in Fig. 1.20. One of them is a parallel connection and another one is a cascaded connection of DC-DC and DC-AC converters as shown in Figs. 1.20(a) and 1.20(b), respectively. However, these two configurations are less reliable due to the inherent shoot-through effect of VSI. Although the ZSIs (as discussed in the previous section) can mitigate the shoot-through problem of the VSI, they increase the volume of the overall system due to the use of separate converters for supplying AC and DC loads.

To address the said issues, some researchers have explored hybrid converters [95]-[104] for supplying AC and DC loads using only one power converter. Fig. 1.21 shows a schematic of a hybrid AC/DC system to supply AC and DC loads using only one power converter. As shown in Fig. 1.21, the hybrid converter has improved power density, reliability and reduced component count as compared to converters shown in Fig. 1.19. It can be observed from Fig. 1.21 that hybrid converter can supply power to AC and DC loads from a single DC input source.



(a)



(b)

Fig. 1.20. Hybrid AC/DC system using separate PECs for supplying AC and DC loads **(a)** parallel connection of DC-DC boost converter and VSI **(b)** cascaded connection of DC-DC boost converter and VSI.

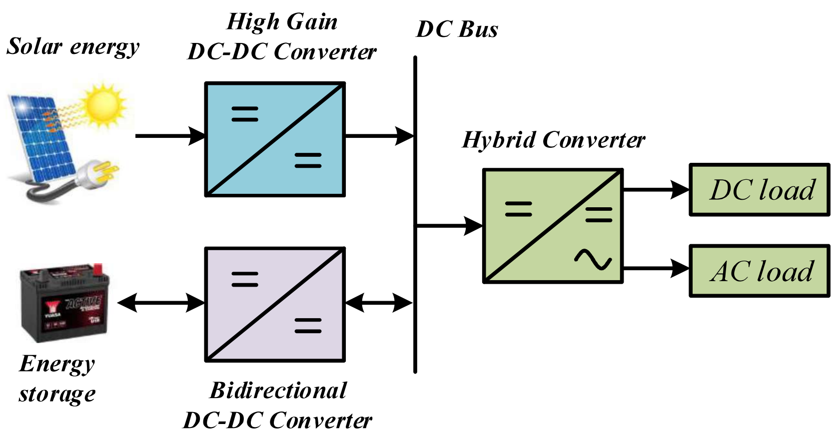


Fig. 1.21. Schematic of a hybrid AC/DC system for supplying AC and DC loads using a hybrid power converter.

A switched boost inverter (SBI) is reported in [95] for supplying AC and DC loads and is shown in Fig. 1.22. It has advantages similar to ZSI, with a lesser number of passive components. Although it has a high gain conversion using a single DC input source, it has discontinuous input current and uses an additional switch.

To take care of the issues related to SBI, a boost derived hybrid converter (BDHC) is reported in [97], which is derived from the CBC by replacing its active switch by a single-phase VSI. Fig. 1.23 shows a single-phase BDHC for supplying AC and DC loads simultaneously. Although the BDHC has continuous input current and lesser number of components as compared to SBI, it has a low voltage gain. To achieve higher voltage gain as compared to BDHC, a single-switch quadratic boost derived hybrid converter (QBDHC) is reported in [97] and is shown in Fig. 1.24.

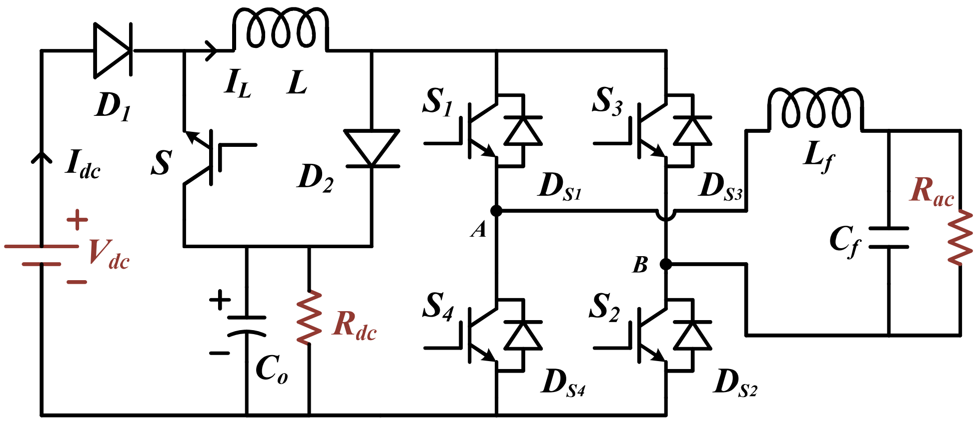


Fig. 1.22. A single-phase switched boost inverter

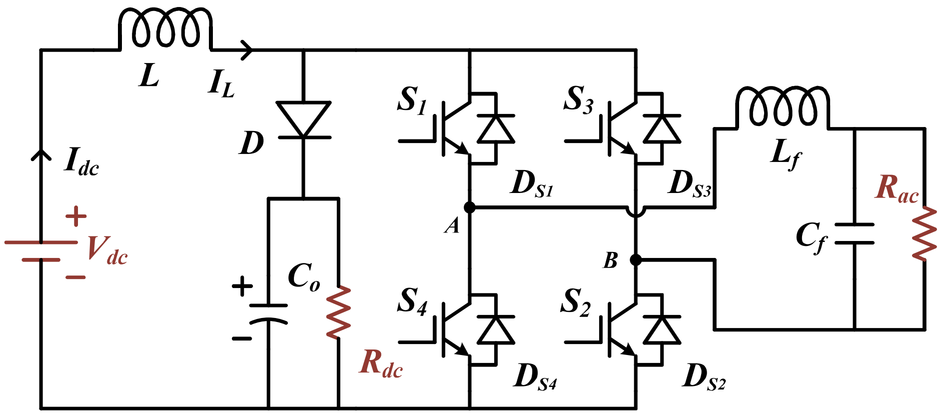


Fig. 1.23. A single-phase boost derived hybrid converter.

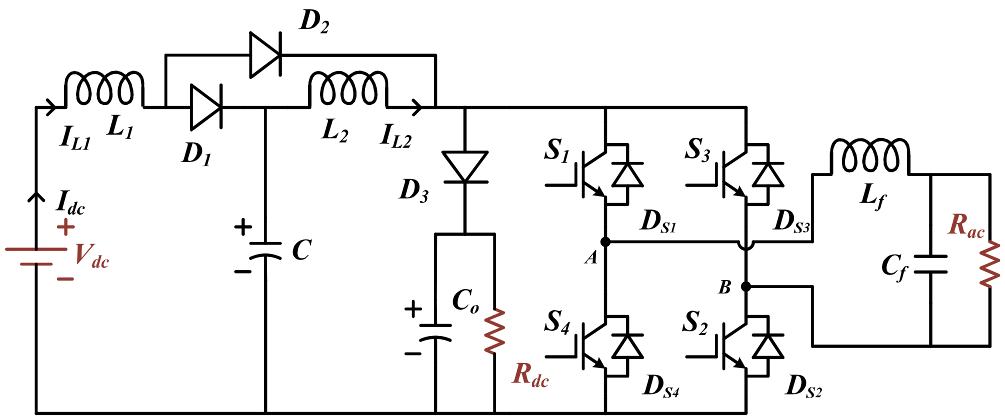


Fig. 1.24. A single-phase single-switch quadratic boost derived hybrid converter.

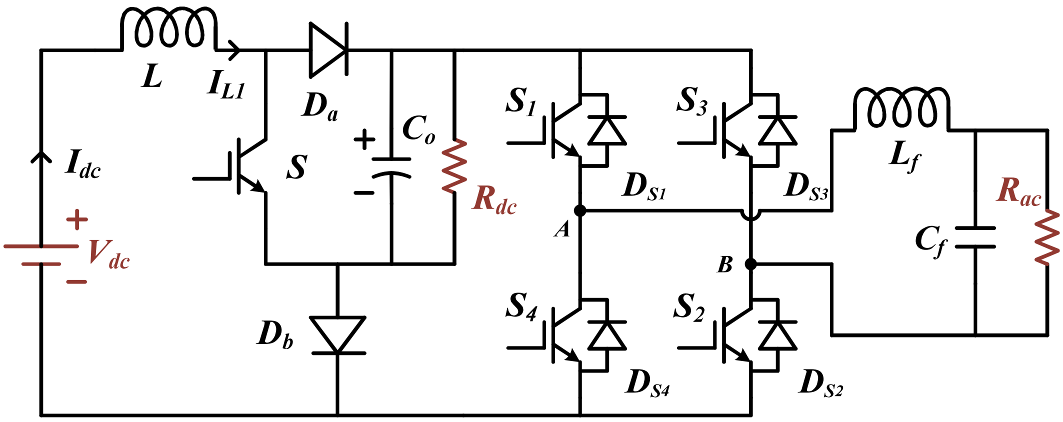


Fig. 1.25. A single-phase current fed source inverter.

Although the QBDHC has high voltage gain and continuous input current, it has a higher number of elements, including two bulky inductors. To overcome the limitations of SBI, BDHC and QBDHC, a current fed source inverter (CFSI) is reported in [99] and is shown in Fig. 1.25. The CFSI has high voltage gain and continuous input current using lesser number of elements.

A hybrid impedance-source converter based on SL cell is reported in [100]. It is an enhanced version of BDHC by replacing the input inductor by an SL cell. It has a slightly higher voltage gain as compared to BDHC using a higher number of elements. However, it has more ripple in the input current as compared to BDHC. Its voltage gain can be further enhanced using a higher number of SL cells. However, this increases the weight and volume of the system. A modified boost derived hybrid converter is reported in [101] and its performance is investigated in different conduction modes. An integrated dual-output L-Z-source inverter with a high voltage gain is reported in [102] for hybrid electric vehicles. However, it has leakage inductance effect of the coupled inductors which gives rise to voltage spikes. Further, a minimum phase hybrid coupled inductor quadratic boost converter is reported in [103], which has minimum phase behaviour along with high voltage gain. However, it also has a leakage inductance effect due to the coupled inductor. A transformerless hybrid converter is reported in [104] and is shown in Fig. 1.26. It has reduced leakage current because of constant common-mode voltage [104] as compared to BDHC. However, it has the same voltage gain as that of BDHC using a higher number of elements.

The aforementioned hybrid converters [95]-[104] have inherent shoot-through protection, and their outputs are controlled by D_{st} and M similar to ZSI. Also, they have an operating condition $D_{st} + M \leq 1$.

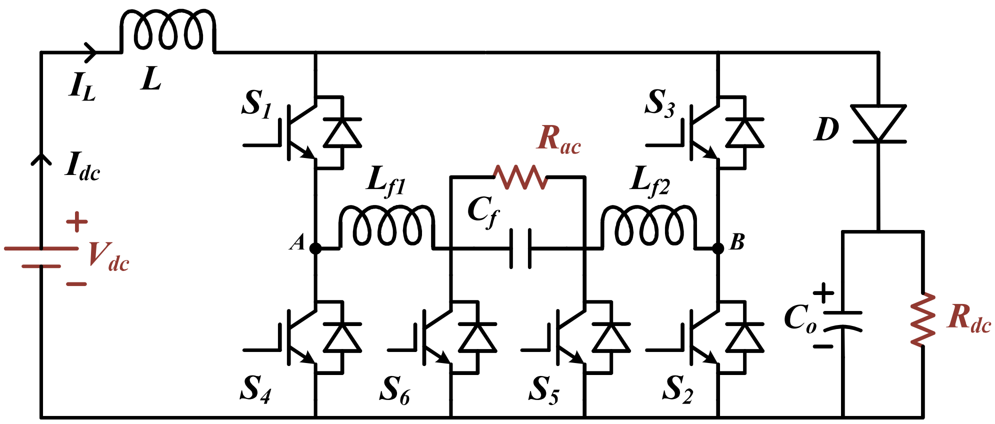


Fig. 1.26: A single-phase transformerless hybrid converter for simultaneous AC and DC outputs at reduced leakage current.

1.2.4 Summary of the Literature Review

As per the requirement of the AC residential distribution system, three classes of the PECs are studied during the literature review. Each class of the PECs has some advantages and disadvantages for two-stage, single-stage and hybrid AC/DC residential distribution systems. After carrying out a detailed literature study, some of the points are outlined as follows.

- To achieve high voltage gain, existing DC-DC converters use a higher number of elements. Also, the converters require a high value of input inductance for continuous input current with low ripple.
- The existing DC-DC converters have a single operating region only. Hence, they cannot be operated at the desired voltage gain of a particular application with cost-effective device selection.
- Although the existing SL based ZSIs have a high voltage gain operation, they use a higher number of elements.
- The exiting SL based ZSIs have low values of M for a high gain operation which results in increased harmonic distortion. Also, they have higher voltage/current stresses.
- To supply AC and DC loads simultaneously, conventional hybrid converters (CHCs) have an operating condition $D_{st} + M \leq 1$, which results in trade-of between DC output with high gain and AC output with reduced harmonic distortion.

1.3 Objectives of Thesis

It is evident from the literature study that there is a scope of further improvement in the design of PECs for residential distribution systems. The objectives of the present thesis are as follows.

- As per the requirement of residential distribution systems, non-isolated high gain converters are proposed in this thesis along with their mathematical modelling. Further, they are compared with some reported converters to show their effectiveness.
- Simulation studies are carried out using the PSIM simulation tool to verify the proposed converters at ideal operating conditions.
- Laboratory prototypes are developed to verify the proposed converters at non-ideal operating conditions.

1.4 Organization of Thesis

Apart from this chapter, the thesis consists of six more chapters. The brief description of the remaining chapters is outlined as follows.

Chapter 2 presents a two-switch high gain DC-DC converter (TSHGC) as a front-end DC-DC converter for the two-stage AC residential system. It has a high voltage gain using lesser number of elements as compared to some reported high gain non-isolated DC-DC converters. The TSHGC also has continuous input current. Detailed mathematical modelling of TSHGC is discussed and it is verified through simulation and experimental results.

Chapter 3 presents a high gain interleaved boost DC-DC converter (HGIBC) as another front-end DC-DC converter for the two-stage AC residential system. The HGIBC is capable of giving different voltage gains in three operating regions based on two switching logics; 180° phase-shifted and complementary switching. It has a continuous input current with less ripple due to the presence of interleaved inductors at the input side. Based on the voltage levels of the low voltage DC sources, the HGIBC can be operated at one of the three operating regions. Further, the HGIBC is compared with some reported high gain DC-DC converters in terms of a number of elements and voltage gain.

Chapter 4 presents two switched LC Z-source inverters (SLC-ZSIs); Type 1 SLC-ZSI and Type 2 SLC-ZSI as DC-AC converters for the single-stage AC residential system. The two SLC-ZSIs eliminate the two-stage power conversion due to their high voltage gains. The SLC-ZSIs are capable of giving high gain inversion at reduced harmonic distortion. A comparison is made in terms of number of elements, voltage gain and current/voltage stresses on the elements of SLC-ZSIs and some reported high gain SL based ZSIs.

Chapter 5 discusses an enhanced high gain switched LC Z-source inverter (eSLC-ZSI) for the single-stage AC system to achieve further higher voltage gain as compared to proposed SLC-ZSIs. The eSLC-ZSI is an improved version of Type 2 SLC-ZSI. The eSLC-ZSI has continuous input current with less ripple and higher voltage gain at reduced harmonic distortion. A comparison is carried out in terms of a number of elements, voltage gain, nature of input current and voltage/current stresses on the elements among some reported high gain ZSIs and the proposed eSLC-ZSI.

Chapter 6 presents an interleaved hybrid converter (IHC) for the hybrid AC/DC system to supply AC and DC loads simultaneously. The IHC reduces the number of power conversion stages for supplying AC and DC loads of modern residential systems due to its dual output.

The IHC also has the inherent shoot-through protection similar to SLC-ZSIs. The IHC has two operating conditions $D_{st} + M \geq 1$ and $D_{st} + M \leq 1$, unlike CHCs. Further, it has three modes of operation in the two operating conditions, which lead to different voltage gains, unlike CHCs. However, it is validated in the three modes of operations at $D_{st} + M \geq 1$ only.

Chapter 7 presents the overall conclusion of the thesis and discusses the future work of the research work discussed in the thesis.