Chapter 1

Introduction

The prosperity of any country is measured based on transportation facilities, industries and living standard of the people. These factors are heavily dependent on the energy supply. However, as the countries are contending among themselves, the energy demand is growing more rapidly than supply. Unfortunately, by the end of this decade, growth in the production of easily accessible oil and gas will not match the projected rate of demand growth. While abundant coal exists in many parts of the world, transportation difficulties and environmental degradation, ultimately pose limits to its growth. Though coal is being used as a fuel for generation of electrical power which serves as energy source for industry and residential loads, it cannot replace the petroleum products required by the automobile. Due to rapid growth in population and demand, industrial and residential loads are continuously increasing. Globally, the number of vehicles will increase from 700 million to 2.5 billion in the next 50 years. The limited availability of conventional sources - coal, petrol and diesel, and CO_2 emission have compelled the world to stand together on the issues of energy generation and usage in wide range of applications. The development of electric vehicle in last two decade substantially reduced the usage of petrol and diesel. However, the demand of coal is increased to produce electricity. To resolve this issue, current trend is to harness the maximum energy from the renewable sources. Several renewable sources such as wind, geothermal, tidal, nuclear, and solar are available which can be utilised to produce electrical energy. However, solar energy, in particular, is easily accessible in most of the areas. The renewable sources have higher installation cost but the running cost is low. solar energy is widely available in India for longer duration of the year. The energy from the sun is extracted in the form of DC using solar panels.

Till recent times, the transmission and distribution of energy are dominated by the AC systems. The DC power generated is generally in the range of 24 V to 48 V from solar panel. So, to feed it to transmission and distribution grid, step-up DC/DC converters are required in addition to the DC/AC converters. However, the losses incurred are high in AC transmission and distribution systems. Additionally, complex control involved in grid synchronization leads to complicated network and sometime makes the system unstable during faulty conditions. To simplify the network and its control, the concept of DC nanogrid is introduced in recent years. This system does not require DC/AC converter for grid synchronization and reactive power transfer. Therefore, the control of DC nanogrid is relatively straightforward. In this system, a particular region of interest is separately connected to a dedicated DC grid as shown in Fig-1.1.

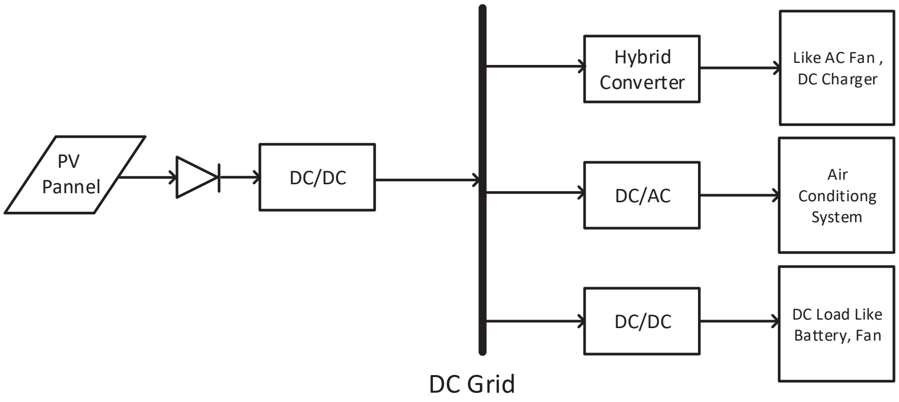


Figure 1.1: Typical structure for HEV/Industry/Houshold application

To optimize the power flow, the control strategies are developed so that bidirectional power can be transferred between the load and DC grid. This system works on relatively smaller power level than the existing AC system but suffers from proper regulation of power among different consumers. To avoid this, individual centric consumer or residential areas distribution system is gaining more attention. In this system, the control challenges are localised within limited number of electronics equipment. This would relieve the control issues and avoid the problem of power regulation. Since in this system only DC is used, so the synchronization complexities, reactive power problem and power factor correction issues can be avoided. Moreover, good number of household and HEV equipment are operated from DC supply, like battery charger, LED lights and TV, laptop and cell phones. The DC supply is readily available from DC nanogrid, making it robust and cost effective. This system becomes more reliable when battery storage is integrated. In case of erratic power supply, they serve as auxiliary source of power supply. In addition to DC loads, household and HEVs consist different kind of AC loads. In particular, for HEVs, a typical structure consisting of different DC and AC load is shown in Fig-1.2 [1].

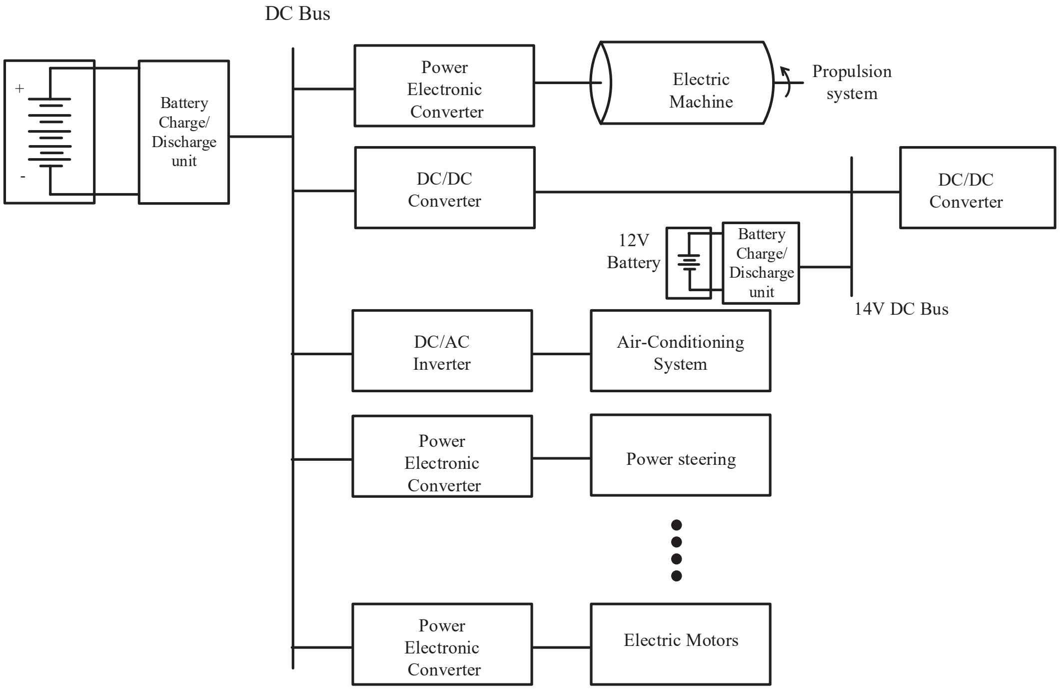
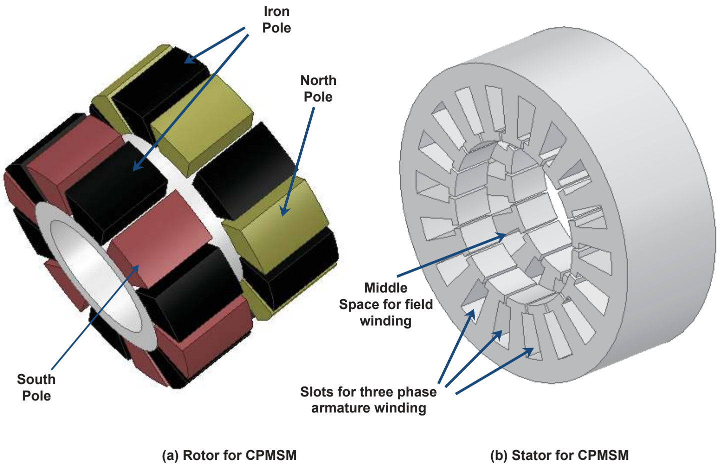


Figure 1.2: Typical structure of HEV

For example: PMSM is widely accepted for driving the vehicle. However, the presence of fixed excitation may cause the problem in controllability over large speed range. Usually, to achieve wider speed range, the armature current is modulated such that it can partially demagnetize the magnets which results in field weakening of PMSM [2], [3]. However, this may cause serious damage to PM due to demagnetization and heating effect. Alternatively, a CPMSM may be used to overcome the said problem which is shown in Fig-1.3 [4]. In CPMSM, field winding and armature winding exist as shown in Fig-1.3b, which can be controlled independently.

A DC field winding is used to magnetize or demagnetize the effective air gap flux without affecting the PM. On the other side, armature winding is supplied by AC supply. Therefore, CPMSM may be an alternative in place of PMSM to operate vehicle in wider



(a) Rotor for CPMSM (b) Stator for CPMSM

Figure 1.3: Rotor and stator configuration for CPMSM

speed range. Moreover, there are some other loads such as air conditioners, and for driving accessories present in the HEV. In this thesis, based on the demand of HEV, DC and AC load are classified into three categories as shown in Fig-1.1, standalone DC load, standalone AC load and hybrid load. In standalone loads, individual DC or AC load is driven by individual power electronic converter, however, in case of hybrid loads, both DC and AC load are operated using single stage converter making the system compact and cost effective. Conventional DC-DC converter are quite rugged to EMI issues, however, DC-AC converter and hybrid converters are prone to EMI and dead time is required. These problems have serious impact in terms of system operating condition. Due to which the converter maintenance cost increases and system reliability gets reduced. The main objective of the thesis is to develop novel DC-DC, DC-AC and hybrid converters which provide energy efficient solution, ruggedness to EMI and avoid dead time which can serve the requirements of HEV.

1.1 DC/DC converters

DC-DC converters with voltage boost capability are widely used in a large number of power conversion applications, from fraction-of-volt to tens of thousands of volts with power level from milliwatts to megawatts. The core behind the switched mode boost DC-DC converter operation is inception of pulse width modulation(PWM) technique. These converters temporary stores the input energy for a particular period of time and then releases into output for remaining duration. The stored energy may be either in the form of magnetic or electrostatic. The inductor(magnetic energy) and capacitor(electrostatic energy) serve the purpose of storage element through active switching element (power switches) and/or passive switching elements (diodes). Since the inception of semiconductor technologies, the step up DC-DC converter accelerated their pace [5]. However, lower switching frequency of the power switches caused the inefficient operation of the converter. The efficiency of the converter was improved owing to introduction of field effect transistor(FET) in late 1980. FET can operate in the range up to hundred of kHz and are able to switch more efficiently at higher frequencies than power bipolar junction transistors. It's switching losses are low and require a less complicated drive circuit [6].

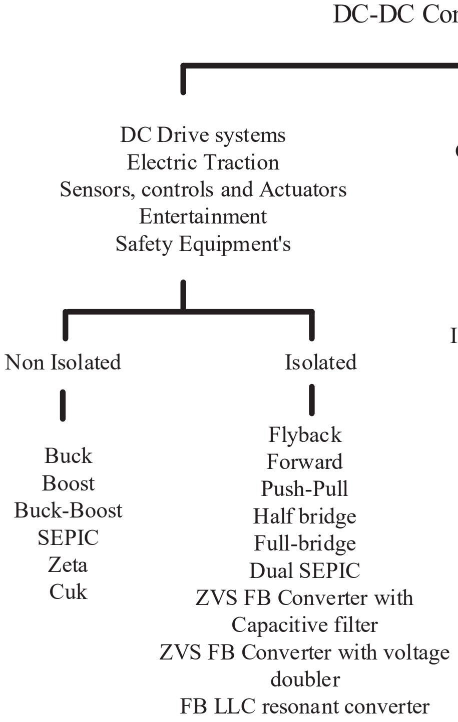


Figure 1.4: DC-DC converter used in HEV

DC-DC converters ability to operate in boost mode is dependent on the input inductor current. Based on the inductor current profile, the step up DC-DC converter can operate in continuous current mode(CCM) and discontinuous current mode(DCM). In continuous current mode, the inductor current is triangular in nature and never reaches to zero. However, in discontinuous current mode, the current reaches to zero and remains zero for certain period of time. The CCM is widely popular due to load independent voltage gain, lower current ripple and better efficiency. However, DCM is suitable where higher stability and smaller inductor size(i.e. compact size), is prime requirement. Moreover, DCM operation exhibit higher voltage gain as compared to CCM [7].

There are several DC-DC converters which can be used in HEV as shown in Fig-1.4. The classification of these converters are based upon the isolation property. Traditional boost, sepic, zeta and cuk which can fulfill the demand of boosting the voltage level, however, fails to provide galvanic isolation. Moreover, flyback, forward, pushpull, half-, and full-bridge converters are still popular and are employed for use at various voltage and power levels in where galvanic isolation is required [8]- [13]. This structure makes the system complicated and bulky. Moreover, these topologies have restricted range of boosting the voltage level along with higher voltage stress and therefore bigger in size. There are various voltage boosting techniques reported. Some of the popular techniques involved are multilevel, interleaved, or cascaded topologies, or using voltage multiplier cells (VMC), combined with switched capacitors (SC) and/or switched inductors(SL). The classification of these topologies is depicted in Fig-1.5.

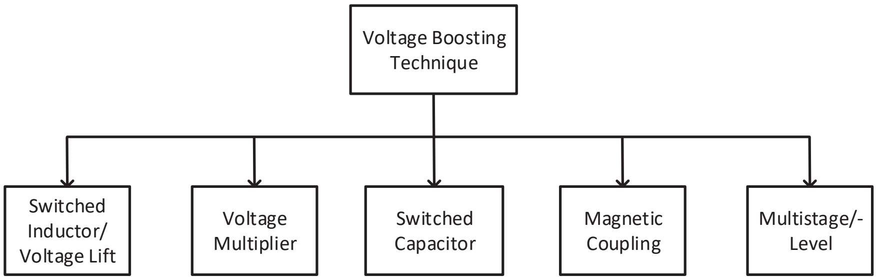


Figure 1.5: Classification of boosting techniques for DC-DC converter

1.1.1 Switched inductor/Voltage Lift

The voltage lift technique is a useful method to boost the voltage in DC-DC converters. The switched inductor (SL) utilizes the voltage lift technique. Axelord et al introduced the switched inductor arrangements to lift the voltage gain [14] as shown in Fig-1.6. In switched inductor arrangement, the inductors charge in parallel and discharge in series. Since the inductors have same operating condition and have equal values, therefore they can be integrated on a single core to reduce the size of the converter. Various voltage lift cells are reported in the literature such as elementary lift cell, self lift SL cell and double self lift SL cell. Correspondingly, SL based power electronic structures are reported in the literature [15]. Jiao et al introduced a generalized n-cell structure to further enhance the gain of the converter [16]. However, the main limitation of these converters is to operate in 0-1 range of duty cycle, which ultimately impresses large voltage stress across the switch.

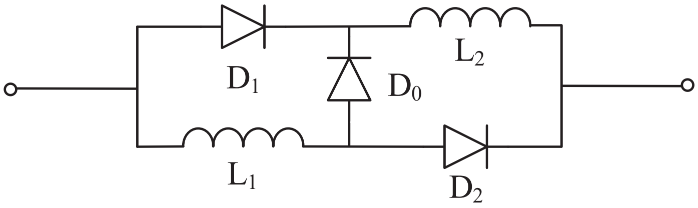


Figure 1.6: Basic switched inductor cell

Yang et al introduced the active impedance network to lift the voltage gain [17]. This network utilizes the two active switches instead of three diodes. Moreover, there is no requirement of external switch for boosting purpose. These converters are commonly called as active switched impedance(A-SL) network. Improved A-SL and hybrid A-SL are enhanced version of A-SL. Tang et al further utilized the switched capacitor arrangement with switched inductor to lift the gain of the converter [18]. Although these topologies enhance the gain of the converter, problem of wide duty cycle variation still prevails. Therefore, some modifications are required to achieve restricted duty cycle operation.

1.1.2 Voltage multiplier

Voltage multiplier structures are normally low cost, simple in structure and efficient in nature. A voltage multiplier circuit is shown in Fig-1.7. They typically consist of arrangement of diodes and capacitors. These circuits are broadly classified as voltage multiplier cell and voltage multiplier rectifier. Several modification in voltage multiplier cell have been made to improve the voltage gain along with to reduce in size and cost. Ismail et al proposed switched capacitor voltage multiplier cell to enhance the gain of the converter [19], [20]. Axelrod et al introduced an active voltage multiplier cell which includes a power switch. This circuit operates with the switch present in the network itself and does not require external switch. The limitation of these converters is to produce limited gain and wide duty cycle variation.

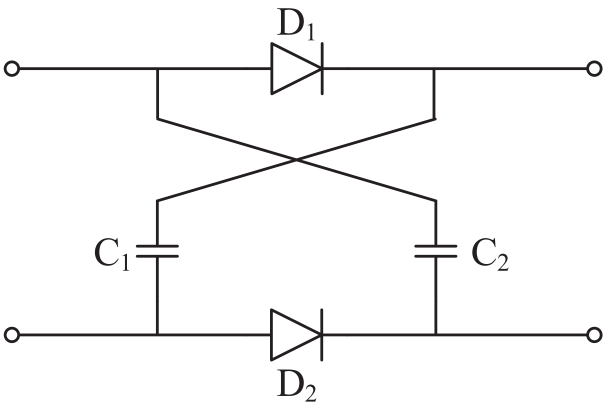


Figure 1.7: Voltage multiplier cell

A different configuration of voltage multiplier is called as voltage rectifier, is of two types: half wave and full wave. These configuration can only be applied if the input to rectifier is either AC or pulsating DC. In the half wave category, Greinacher voltage doubler rectifier(G-VDR) is quite popular, however, it has higher stress across the diodes and output capacitor. An improved version of G-VDR is also reported which reduces the voltage stress across the diode and capacitor to half of earlier [21]. In this category, Cockroft Walton voltage multiplier is also widely accepted which is known for their simple cascading structure [22].

1.1.3 Switched capacitor

Switched capacitor (SC) topologies are popular as charge pump techniques. The boosting in these topology is solely governed by capacitive energy and does not involve magnetic energy [23] as shown in Fig-1.8. Starzyk et al introduced two phase SC voltage doubler [24]. In this structure, the first capacitor is charged to input voltage and in second phase, second capacitor is connected in series with the input voltage which theoretically doubles

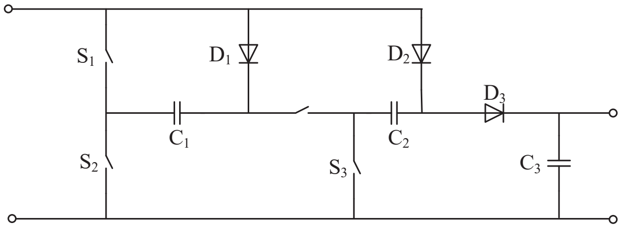


Figure 1.8: Switched capacitor network

the output voltage. Based on cascading of TPVD structure, different voltage levels can be achieved. Subsequently, various topologies are introduced based on the switched capacitor theory such as series, parallel, ladder arrangement, Dickson SC, Makowski SC [25], [26]. A modular multilevel capacitor clamped DC-DC converter is proposed to achieve high voltage gain, higher power transfer capability, fault by passing and bidirectional power management capabilities [27]. However, these structure are large in size and have higher transient currents, which has degrading effect on both power density and efficiency.

1.1.4 Magnetic coupling

Magnetic coupling is the widely popular technique to lift the voltage gain in both isolated and non isolated topologies. Magnetic coupling is achieved in two ways either by coupled inductor or transformer connection. A coupling network is depicted in Fig-1.9. Transformer topologies are increasingly popular due to two degree of freedom. In transformer topologies, the transformer turns along with the duty cycle of the converter can be tuned. These transformer topologies are divided into two groups: Isolated transformer and Built in transformer. In isolated topologies, the output is electrically isolated from input. Several studies have been focussed on isolated topologies such as dual active bridge, dual half bridge topologies etc [28], [29]. On the other hand in case of built-in topologies, transformer type structure is integrated within the converter and therefore, input and output are electrically connected [30]. Contrary to isolated topologies, there is involvement of direct power transfer between input and output stage in non isolated topologies. In these topologies, one part of the built in transformer is directly dependent on the load current while other part receives energy from coupling effect. The advantage of a built-in trans-

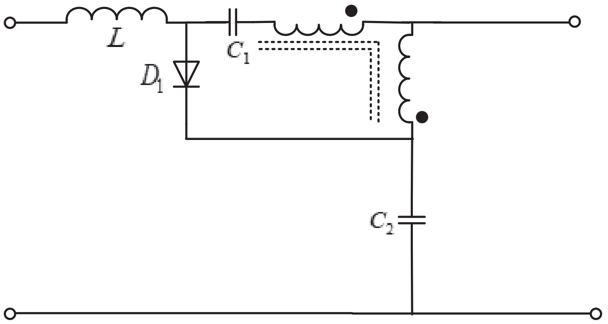


Figure 1.9: Magnetically coupled network

former is that there is balanced magnetic flux in the core, which allows for utilization of small core owing to the inherent saturation avoidance [31].

Coupled inductor technique is suitable for providing high boost in application where electrical isolation is not required. Moreover, coupled inductor utilizes the reduced number of magnetic cores as compared to transformer topologies. Coupled inductor based topologies are two fold: Tapped inductor/autotransformer [32] and Magnetically coupled based converters [33]. Tapped inductor arrangements are classified into three categories: switched tapped, diode tapped and rail tapped. Theoretically, better efficiency and high gain are the key factor of tapped inductor arrangements along with input current ripple cancellation. On the other hand, root mean square(RMS) current of the switches, RMS current of the inductors and diode blocking voltages are increased [34]. In magnetically coupled inductor based topologies, the gain of the converter can be increased, however, they are prone to leakage inductance effect, therefore, producing voltage spikes and ringing. A clamping circuit is required to avoid switching spikes and recovery the leakage energy [35].

1.1.5 Multistage/-Level

Multistage or connecting several stages is a suitable method to boost the voltage. Broadly, three kind of arrangements are possible : cascaded system, interleaved system and multilevel system.

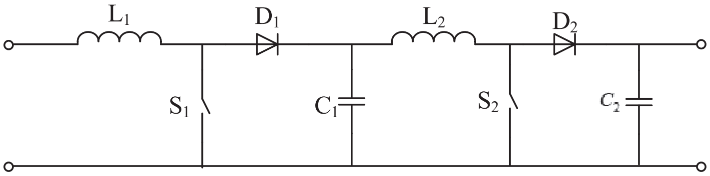


Figure 1.10: Cascaded network

A simple cascaded network is shown in Fig-1.10. Cascading of stages can be achieved in two different ways: quadratic and hybrid cascaded. Wu et al developed a single stage quadratic boost converter having two boost converter connected in cascading form. In this arrangement, two active switches are present which can be independently controlled. Moreover the voltage stress on the first stage is relatively low [36]. To reduce the complexity of the circuit, a modified quadratic boost converter having single switch is proposed, however, in this, two stages cannot be independently controlled [37]. Several other arrangements are proposed for quadratic boost converter to either reduce the circuit complexity or to reduce the voltage stress across the elements present in the circuit. In hybrid connection, the quadratic boost converter is cascaded with coupled inductor in several ways [38]. Furthermore, combination of zeta and quadratic boost converter are reported [39]. A hybrid connection of quadratic boost converter and forward converter is also presented [40].

For high gain converter, handling the input inductor current ripple is a big challenge. To resolve this, interleaved boost converters was reported. These converters have lower inductor current ripple and smaller switching duty cycle than the traditional boost converter. To further lift the voltage gain, various interleaved converters are connected in series with the switched capacitor network [41], [42]. However, the size and cost are their main concern.

The purpose of the multilevel converter is to decrease or eliminate the magnetics in circuit which ultimately reduces the size and weight [43]. To achieve this objective, two techniques are reported: converters with single DC sources and with multiple DC sources. Single DC source multilevel converters are suitable for electric vehicle and hybrid electric vehicle application where power is drawn from fuel cell or Battery. There are various topologies reported consisting submodules of switches/diodes and capacitors. The main advantages of these converters are simplicity, modularity and flexibility [44]. These converters drives huge amount of current from single source therefore which imposes some form of limitation. In multiple DC source topologies, several sources are connected to power load through several arrangements i.e. share the amount of the load current among themselves. These converters are claimed to have better reliability, safety, and maintainability [27].

To address the issues related to voltage gain and components counts, a new DC-DC converter will be proposed.

1.2 DC/AC converters

Now a days distributed generation systems(DGs) are widely popular due to small size, easy installation and flexible control [45]. These DGs are mostly powered by PV array [46], [47] that generates only DC power. Since most applications in industry and residential systems require AC supply for their operation, demand of AC supply was traditionally fulfilled by incorporating voltage source or current source inverters within PV system. However, voltage source inverter(VSI) has following limitations:

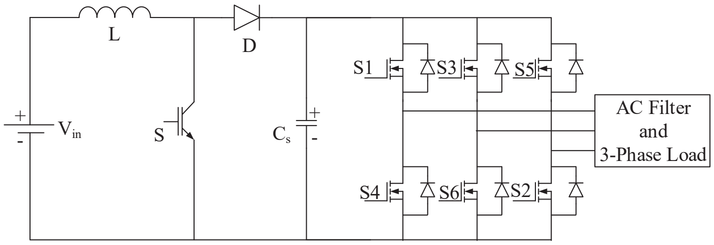


Figure 1.11: Traditional boost three phase inverter

- Traditional VSI has inherent capability to buck the input voltage, i.e., AC output voltage will be always lower than DC input voltage. However, variety of applications demand wider range of AC voltage. For this purpose, an additional DC-DC converter is cascaded with the traditional VSI, as shown in Fig-1.11. Nevertheless, the augmented structure increases the cost of the system and consequently reduces the efficiency [48].

- In VSI/cascaded VSI, the simultaneous turn on of upper and lower devices of each phase is prohibited to avoid the shoot through fault. This shoot through fault is caused due to either EMI noise or malfunctioning of devices(due to turn off delay). The later issue could be avoided by introducing dead time between the switches [49]-[50], however, it would lead to distortion in AC output voltage. Even with the dead time, the shoot through fault due to EMI noise remains unresolved. Consequently, inverter switches could be damaged if shoot through fault sustains [51].

- In VSI/cascasded VSI, DC-link capacitor lifetime is affected by two type of faults: sudden short circuit of the capacitor leading to catastrophic failure, and long-time degradation of capacitor causing wear out failure [52]. Therefore, in VSI/cascasded VSI, shoot through fault worsens as capacitor connected across the inverter is subjected to sudden increase in current through it.

These persistent problems in the converter reduces reliability of the converter, and increases cost and size of the converter. Z source concept is a breakthrough to mitigate these problems. [53–55]

Z-source inverter(ZSI) was introduced by F Z Peng [53], which is immune to EMI problem and does not require dead time compensation [56]. These properties of ZSI, facilitates inverter to be used in hostile environmental condition. The ZSI consists of two inductor(L_1=L_2), two capacitor,(C_1=C_2) in symmetrical manner and a diode(D) at the input. Though improved reliability is an attractive feature, yet a high inrush current at start up and discontinuous input current are its limitation [57]. To restrict surge current, Z network of ZSI is re-arranged and connected after the inverter [58]. This results in zero input current at start up. However, the discontinuous input current problem remains unsolved. Later on, to remove the surge and common ground problems present in ZSI, quasi Z-source inverter(qZSI) was reported [59]. The qZSI offers the advantage of constant input current but has limited gain. In qZSI, the capacitors, inductors, and diode are arranged such that inductor directly comes in series with the source. The inductor current is continuous while maintaining the same voltage gain as that of ZSI. Furthermore, enhanced ZSI, improved ZSI and improved trans ZSI were reported aiming to achieve higher gain [60–62]. These arrangements make the system more costly and decrease the power density. Semi ZSI/semi quasi ZSI were reported to be suitable for PV applications. It has double ground feature that eliminates the need to float /isolate PV panels, and hence no leakage current [63, 64]. However as compared to conventional ZSI, voltage stress across the switching devices are high. The switched boost inverter(SBI) topology was proposed which inherently uses the ZSI features with reduced number of passive element [65]. The SBI consists of one capacitor, one inductor, two diodes and one active switch which makes it compact and more reliable [66], [67]. However, the gain of SBI is lower than Z-source inverter. To increase the gain of SBI, embedded quasi SBI having continuous input current was proposed [68–70] which has same gain as ZSI. Embedded structure of multiple DC sources in SBI/ZSI is particularly suitable for PV power generation [71, 72]. For single phase application, high voltage gain half bridge switched boost inverter topology was proposed [73], [74]. Efforts were made to increase the gain by replacing the single inductor element with switched inductors network [75–78]. Li et al analyzed the Z-source inverter performance for generalized multi cell switched inductor network and suggested to use as many as cell, depending on the requirement [79]. This structure provides continuous input current with lower voltage stress. An embedded Z source with multi cell approach was proposed to have high boost ratio, reduced capacitor voltage stress and low input ripple current. However, huge number of passive elements in the structure reduces the efficiency drastically. By adding extra element to the converter like diode assisted network [80], capacitor assisted network [81], [82] and combination of these [83], the gain of the converter is lifted. However, more number of passive elements is the main concern in these topologies. Three switch three state impedance converter was reported to have higher gain by Huang et al [84]. This structure is suitable for PV application, it has feature of dual grounding. However it has more number of switch which increases the complexity of the circuit. Distributed impedance network is reported to lift the gain of the converter [85]. The distributed Z source network are difficult to implement, however, they do not require any extra switch to boost the gain. To address these requirements, coupled inductor concept is introduced [86], [87]. Two winding [88] and three winding [89] coupled inductor are reported to increase the gain without adding extra element to the network. Loh et al proposed a Z-source inverter based on coupled inductor which is derived from the basic Z source converter. Trans Z source converter was proposed to further lift the gain which resulted in reduced voltage stress. It reduces Z source network to single coupled inductor and capacitor [77, 90]. The T source converter imbibes the two winding coupled inductor and a capacitor which is suitable for neutral point clamped inverter(NPC) application as it shares common ground [91]. A continuous input current coupled inductor was proposed which is named as LCCT Z source [92]. This converter filters out the high frequency ripple from the input current. Loh et al implemented a $\Gamma - Z$ source network [93]. Unlike other Coupled inductor network such as T source, trans Z source, TZ source and LCCT Z source, the $\Gamma - Z$ source gain increases with decrease in turns ratio. Y source is an interesting converter to increase the gain with lesser number of components [94]. This arrangement reduces the size of the inverter and has more degree of freedom as compared to traditional converters. Nag et al proposed a sub unity turns ratio coupled inductor inverter to enhance the gain [95]. This converter, however has chopped current phenomenon. Coupled inductor L-source inverter was proposed to lift the gain with continuous input current and lesser number of components [96]. The leakage flux is the prime concern in coupled inductor networks which reduces the gain [97]. To minimize leakage flux, special core is required which increases the cost of the inverter. A comprehensive classification of these topologies is presented in Fig-1.12: isolated and non isolated. In summary, non isolated topologies are bigger in size and therefore, higher cost while isolated topologies have reduced size, increased cost. Moreover, isolated topology may have leakage effect if proper magnetic cores are not utilized. Moreover, few Z source inverters operate aberrantly in wider duty cycle. In view of these issues, new inverters will be proposed those will have better prospect than existing inverters.

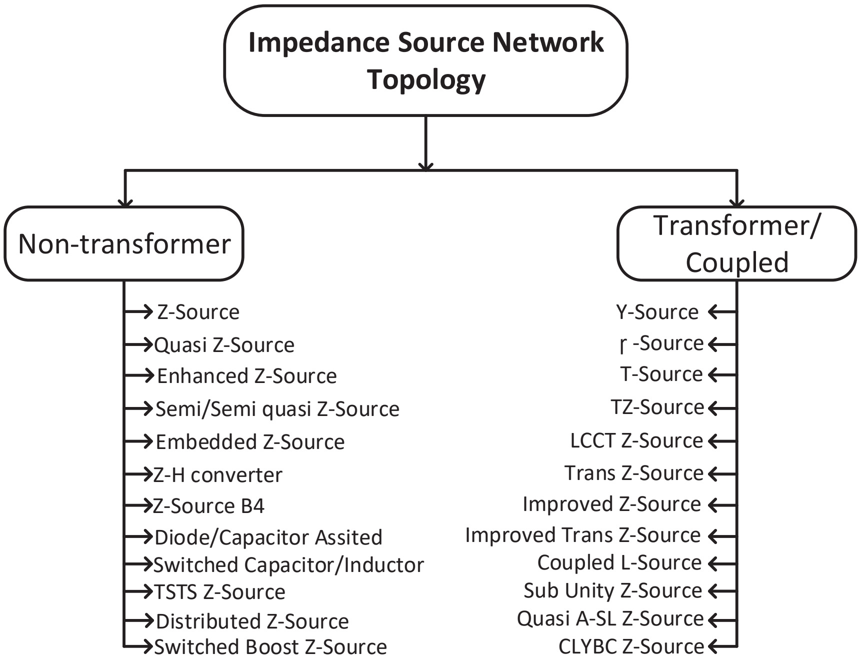


Figure 1.12: Impedance network topologies

1.3 Hybrid converters

Managing accessories required to operate day-to-day AC and DC (or hybrid) loads is a cumbersome task. For example, nanogrid residential system [98], hybrid AC/DC microgrid [99] [100], hybrid electric vehicle [101], aircraft architecture [102] have both AC/DC loads. More number of conversion stages required for hybrid loads, is pushing research towards integrated solutions. Since voltage boosting is mandatory, for battery and solar applications, the state of the art is cascaded boost inverter. It consists of boost converter for DC-DC conversion and voltage source inverter (VSI) for DC-AC conversion.

However, VSI is prone to electromagnetic interferences (EMI), and need dedicated auxiliary arrangements for protection and EMI suppression. Glitches in design and functioning of these auxiliary circuitry sometimes lead to shoot through fault, creating a short-circuit. Generally, a dead time is introduced to mitigate these problems but it reduces the voltage level and creates distortion. Though effects of dead time can be improved by compensation, it introduces complexity [103]. Literature [53], [104] had been reported to integrate boost and inverter together in the form of Z-source converter.

The ZSI inherently uses the shoot-through pulses for boost operation. To enhance the gain of the Z-source converter, improved modulation strategies are proposed [105], [106] but the gain is still restricted. Several extended boosting Z-source topologies are proposed to increase the gain of the inverter [107], [108]. Nguyen et al incorporated switched inductor networks in the quasi Z-source inverter to boost the gain [75]. Li et al analyzed the Z-source inverter performance for generalized multicell switched inductor network and suggested to use as many cells, depending on the requirement [79]. Further extension of this approach was implemented in two different networks to enhance the gain [76]. Nevertheless, increased boosting factor offered by these topologies increases the size of the converter [81]. The size could be reduced by the introduction of coupled inductor network [86]. The various coupled inductor approaches are reported to increase the gain [88], [87]. However coupled inductors require special ferrite core and must be tightly wounded(to reduce leakage reactance) [97]. These issues may be avoided by the switched boost topologies [66], [70]. Despite having reduced number of passive components these topologies only feed AC loads. Several kinds of loads are present in industries, HEVs and household. These loads are categorized into two types: they can be either AC load or DC load. These loads require dedicated power electronic converter, which leads to increase in size and cost. To address this issue, hybrid converter is an interesting solution which can supply both DC and AC load from a single converter. For hybrid (AC and DC) output, the boost converter is cascaded with the inverter. However, the cascaded boost inverter require additional switch and large DC link capacitor, resulting in large size converter with reduced efficiency [48]. Moreover, capacitor is prone to shoot through problems which degrades the life of the capacitor and inverter is subjected to EMI, dead time problems. Though replacement of VSI by ZSI seems immediate solution, extra passive elements complicate the design and size of the converter. Switched boost derived hybrid converter is proposed by Add et al, which has an active switch, an inductor, a capacitor, a diode and three/single phase inverter. Later on, Ray et al proposed a hybrid converter which is derived from the boost converter along with impedance source converter. This converter is named as boost derived hybrid converter(BDHC). The BDHC consists of a single inductor, a diode and a capacitor with three/single phase inverter. However, the gain of the converter was limited. Moreover, BDHC is not able to operate in wider operating region. So, few hybrid converter will be proposed in this thesis to overcome these issues.

1.4 Motivation

The motivation of this thesis is to initially find suitable energy resource with better prospects to meet the stringent energy demand. Then based on the requirement of voltage level, new converter are analysed, designed and developed for application like HEV. There has been a continuous development in the field of high gain converters. Yet, there are possibilities to look for other solutions which can meet the requirement with minimum possible components count, better efficiency and reduced filter size. The primary focus of this thesis is to design and develop high gain power electronic circuitries.

- At the start of the project, an extensive literature survey is carried out to identify the issues in existing literature. Based on the state of art, numerous converters have been simulated to asses their performance. But the challenge was, how to proceed for the new proposals which can fulfill the demand. Initially, the plan was to have separate DC-DC and DC-AC converter with advancement. Later on, the hybrid converter is thought off to serve the purpose of both DC-DC and DC-AC converter with the advancement.

- The second challenge was to analyse the converters in charging and discharging period of the inductor. The converters steady state analysis is carried out to derive the gain produced by the converters.

- Depending on the nature of inductor current, several modes may exist in the converter. Continuous current mode and discontinuous current mode are popular. However, in few converters, a new kind of current waveform was existing. Therefore, the third challenge was to identify the problems due to new waveform and suggestion for naming the new waveform.

- After identifying the problems, fourth challenge is to remove this problem, therefore, improving the performance of the converter. Through this analysis, various conclusion could be drawn.
- After analysis, the challenge was to develop the prototypes for the proposed converters. The designing of printed circuit board is one of the important task. Next step was to investigate the performance of the converter and validation of ideas. Through this analysis, important conclusion have drawn.

1.5 Structure of the thesis

This thesis is arranged into nine different chapters. A brief description of the chapters is as follows:

Chapter 2 elaborate the proposed DC-DC converter. A detailed steady state analysis of the converter is presented. Design guidelines for the inductor and capacitor are discussed. The proposed converter is compared with its contemporary converters. Finally, a prototype is developed to evaluate the performance in terms of steady state operation and efficiency.

Chapter 3 presents the analysis of switched boost inverter. The switched boost inverter is operated in wide duty cycle variation. A new phenomenon, called NZ-DCM is reported and its adverse effects on the converter are analysed. The effects of inductor, switching frequency, and load on converter performance are discussed in detail. A solution is reported to overcome NZ-DCM. These results are validated in experiment.

Chapter 4 discusses the newly proposed quasi mutually coupled active impedance source inverter. The steady state analysis of the proposed converter is reported. The advantages of coupled inductor network are discussed. An experimental set up is developed to verify the proposed converter. Moreover, dynamic performance of proposed converter is validated.

Chapter 5 proposes a new inverter to reduce the filter size along with higher gain. To achieve higher gain in MLI, Z-source network is integrated. Two new modulation techniques are discussed for the proposed MLI. A comparison is made between these two modulation techniques. These techniques are simulated in MATLAB to verify the feasibility. Finally, a conclusion is drawn to select the better technique.

Chapter 6 presents a modification in boost derived hybrid converter. The BDHC shows inappropriate behaviour under large duty cycle variation and standalone AC operation. These aspects are analyzed in detail and problem is identified. The solution is suggested to overcome this problem. The efficiency of modified BDHC and BDHC is calculated analytically and compared. A prototype is tested, based on the experimental data, several conclusions are drawn.

Chapter 7 explores the idea to increase the gain of hybrid converter. The proposed converter is analyzed in steady state and a gain formula is derived. The converter is operated in different modes. In order to increase the gain further, converter is operated in DCM. To test the feasibility of the converter operation in DCM, the converter is tested for resistive and inductive loads. Finally, a closed loop system is developed.

Chapter 8 discusses the aspect of Buck Boost derived hybrid converter. A steady state gain is derived. It is found that NZ-DCM also prevails in BBDHC. Similar solution, as in above chapter, is proposed. The converter is validated experimentally and important conclusion is drawn. A closed loop system is developed to achieve regulated voltage by BBDHC.

Chapter 9 put forth the concluding remarks and suggestions for future work.