A WIDE RANGE HIGH VOLTAGE DC CONVERTER FOR V2G AND G2V HYBRID EV CHARGE.

A PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

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INTERNAL EXAMINER **EXTERNAL EXAMINER**

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ABSTRACT

This paper proposes a new wide range bidirectional dc-dc converter that has an improved voltage gain transfer ratio for use in electric vehicle (EV) applications. The proposed EV charger performance is evaluated for bidirectional power flow in grid connected Vehicle to Grid (V2G) and Grid to Vehicle (G2V) modes. The converter uses a dead-beat current controller in the dc-dc and dc-ac stages which has a smooth, accurate and fast response. Finally, experimental results for a 500 W, 40 V to 200 V prototype are provided under bidirectional power flow in a closed-loop system in the presence of the proposed dead-beat controllers. The obtained results substantiate the theoretical analysis and the applicability of this structure. The converter exhibits the capability for EV battery charging/discharging and demonstrates a peak efficiency of 97.2% and 96.8% in the step-down and the step-up mode of operation, respectively. Index Terms— Bidirectional dc-dc converter, high voltage gain, non-isolated, semiconductor utilization factor, wide range voltage gain. This article proposes a new wide-range bidirectional dc–dc converter that has an improved voltage gain transfer ratio for use in electric vehicle (EV) applications. The converter preserves the common electrical ground between input and output terminals, and presents a low-voltage stress of switches, high utilization factor, and high efficiency. (V2G) and grid-to-vehicle (G2V) modes. The converter uses a dead-beat current controller in the dc–dc and dc–ac stages, which has a smooth, accurate, and fast response. The obtained results substantiate the theoretical analysis and the applicability of this structure. The converter exhibits the capability for EV battery charging/discharging and demonstrates a peak efficiency of 97.2% and 96.8% in the step-down and step-up modes of operation, respectively.

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INTRODUCTION

Especially if snubber circuits are not included,. Due to the safety and electromagnetic interface (EMI) effects, converter structures with a common ground between input and output terminals are more interesting for industrial applications. The common ground, wide voltage range dc-dc converters presented in suffer from restricted voltage gain, and their efficiencies and dynamic responses are limited by the extreme duty cycles of the power switches. The interleaved structures in also s ENERGY decarbonization policies around the world are promoting the increased use of variable renewable generation and the massive electrification of transport. In this context the concept of using the considerable energy storage of electric vehicles as a resource to aid renewable integration, so called vehicle to grid (V2G) has gained considerable traction. Ideally the electric vehicle (EV) battery would be charged during periods of low demand (e.g., night-time) or high renewable generation and the stored energy would be available to supply back to the grid as a form of reserve. This reserve can assist in system frequency support by providing services such as fast frequency support and spinning reserve to mitigate sudden load changes. The potential of providing longer term flexibility for peak shaving and valley filling of load profiles curves is also a possibility. A key element of a V2G system is the bidirectional power converter which acts as an interface circuit stage between the battery pack and the grid side. Such converters should be capable of enabling V2G and grid to vehicle (G2V) operation modes with high efficiency, low cost, safe operation, and provide a fast and high-quality performance. As the voltage level of the EV's battery is relatively low, to match the low voltage (LV) level of the battery and the high voltage (HV) level of the grid side, a wide range, high voltage gain, bidirectional dc-dc converter is needed. A wide range high voltage gain ratio can be obtained by adjusting turns-ratio of the coupled-inductor based converters, but they need to address the additional problems of leakage inductance, such as high voltage spikes across power switches uffer from limitations in voltage range and a high number of switches, which typically present high complexity for the circuit and control system, increase cost and limit power density.Recently, a number of new high voltage gain bidirectional dc-dc converters have been presented in Although they have a high voltage gain, their voltage range are limited, and they do not have a common ground between input and output, or they require more switches and capacitors as in. Quadratic voltage gain bidirectional converters in suffer from high voltage across capacitors especially at high voltage gains. Moreover, the total voltage stress across the semiconductor devices of the converter in is relatively high, which leads to costs and lower efficiency and reliability. In terms of the voltage gain limitations of these existing bidirectional converters, the voltage gain range of converters in is from 0 to 0.5 in step down and from 2 to ∞ in step up. For the converters in the range is from 0 to 1/3 and from 3 to ∞ and converter in [24] is from 0 to 1/4 and from 4 to ∞. Therefore, these converters are inactive for the voltage gain area between 0.5 to 2, 1/3 to 3 and 1/4 to 4, respectively. The practical voltage gain in the step-up and step-down modes of converters in is relatively low. In addition, the bidirectional topologies presented in do does not have a common ground between the input and output terminals, which produces an additional dv/dt issue between the input and output grounds. Thus, its applications are limited. Considering the above limitation of the existing converter topologies there is scope to provide an improved bidirectional converter with a common ground, which has no voltage gain restrictions, is simple and has an improved semiconductor utilization. This paper proposes such a step-down/step-up bidirectional converter suitable for use as the interface converter in V2G and G2V applications. The circuit has a wide and high voltage gain range and so can provide the dynamic matching between the battery voltage and the constant dc link voltage. The range of voltage gain is from 0 to ∞ and there is no limitation, theoretically. The existence of a common ground between the input and output terminals also avoids the additional dv/dt issue, which is beneficial for the operation of the proposed converter. As well as a wide high voltage gain range and low power stress on semiconductor devices (or high utilization factor), this converter also has a simple structure. The maximum total voltage stress of switches is 4VHV and the maximum semiconductors utilization factor (SUF) is 0.71. As a result, the proposed converter can use power switches with low rated power, which can improve efficiency. In summary, the converter proposed in this work offers the highest-wide voltage gain ratio with higher SUF than all previously published bidirectional converters. Furthermore, a dead-beat current controller is adopted for the direct battery current regulation which offers accurate, fast, and smooth operation under different states of charge (SoC). The proposed structure is presented in section II.Section III is devoted to the practical considerations and design of the proposed converter calculation. Comparisons to the previous state of art converters are presented in section IV, the deadbeat current controller implementation is given in section V and the experimental verification is provided in section VI. Finally, section VII concludes the paper.

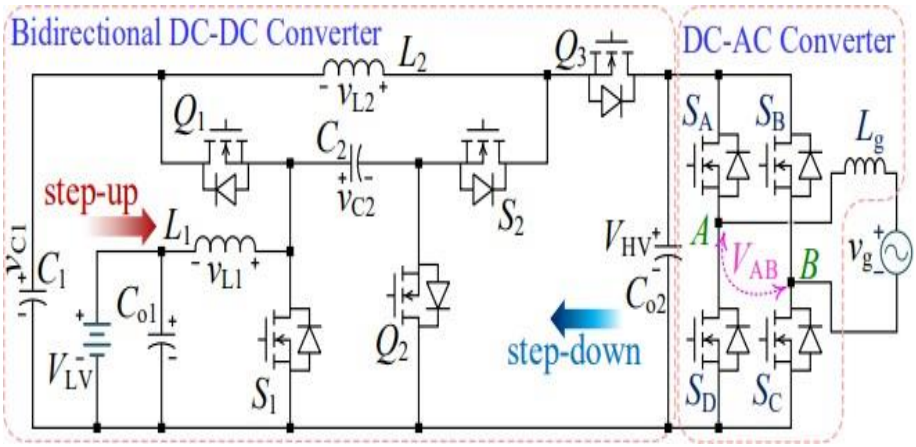


Figure 1 Proposed bidirectional converter structure

CHAPTER-2

LITERATURE SURVEY

TITLE: Modelling of Hybrid Electric Vehicle Charger and Study the Simulation Results

YEAR: 2020

OBJECTIVE: This paper discusses electrical and physical interface between EV and EVSE to facilitate conductive charging and design of an on-board charger for fast charging of the hybrid electric vehicle. The aim of this project is to design interfacing system between EV and EVSE as per automotive industry standard and to design prototype of 3.45 kw on-board charger using in a Matlab software.

TITLE: User Decision-based Analysis of Urban Electric Vehicle Loads

YEAR: 2021

OBJECTIVE: The grid load attributable to electric vehicles (EVs) is affected by the choice behaviors of EV users. To analyze the effects of factors such as travel demand and electricity prices on user behavior, a logit discrete choice model is introduced to simulate the user's decisions to charge/travel. Based on a quasi-steady-state traffic network, a model for cluster electric vehicles considering the user's behavior is designed to obtain the probability distribution of the user's behaviour and the charge and discharge curves of cluster EVs under various scenarios.

TITLE: A Novel Multipurpose V2G & G2V Power Electronics Interface for Electric Vehicles

YEAR: 2020

OBJECTIVE: This paper proposes and analyses a novel multipurpose power electronic interface (MPEI) designed for the new generation plug-in electric vehicles (PEVs), and plug-in hybrid electric vehicles (PHEVs). The proposed topology allows vehicle to grid (V2G) and grid to vehicle (G2V) operation to support the grid in times of high load or stress. The operation principles of the MPEI in its different modes are explained and practical results obtained using a real-time controller are discussed and validated in this paper.

TITLE: Ageing Evaluation of the Distribution Transformer under Varying Load due to Electric Vehicle Charging

YEAR: 2021

OBJECTIVE: Electric vehicles are expected to offer many benefits over conventional vehicles, such as reduction of carbon emission and fuel costs. However, the adoption of electric vehicles would bring great challenges to the distribution transformer, as their charging behavior would make the transformer operate under the varying load and therefore submit to overload risk. Hence, the insulation aging which shortens the transformer lifetime would be accelerated. In this research, we study the impacts of electric vehicle charging on the aging of the distribution transformer with conventional and high-temperature insulations

TITLE: Longitudinal Vehicle Speed Estimation for Four-Wheel-Independently-Actuated Electric Vehicles Based on Multi-Sensor Fusion

YEAR: 2020

OBJECTIVE:

In this paper, an enabling multi-sensor fusion-based longitudinal vehicle speed estimator is proposed for four-wheel-independently-actuated electric vehicles using a Global Positioning System and Beidou Navigation Positioning (GPS-BD) module, and a low-cost Inertial Measurement Unit (IMU). For accurate vehicle speed estimation, an approach combing the wheel speed and the GPS-BD information is firstly put forward to compensate for the impact of road gradient on the output horizontal velocity of the GPS-BD module, and the longitudinal acceleration of the IMU.

TITLE: A switched capacitor interleaved bidirectional converter with wide voltage-gain range for super capacitors in EVs

YEAR: 2019

OBJECTIVE: A switched-capacitor interleaved bidirectional dc–dc converter that combines a three-phase interleaved structure with switched-capacitor cells is proposed. The converter features a wide voltage-gain range, low-current ripple on the low-voltage side, low voltage stresses across power switches, an absolute common ground between input and output, and can be easily extended into a topology family. The operating principle and power switch voltage and current stresses are analyzed in detail. An 800 W prototype with a wide voltage-gain range (U_{high} = 400 V, U_{low} = 30–100 V) is described, demonstrating a maximum efficiency of 95.8% in the step-up mode and 95.9% in the step-down mode.

TITLE: A common ground switch edquasi-z-source bidirectional dc-dc converter with wide-voltage-gain range for EVs with hybrid energy sources

YEAR: 2018

OBJECTIVE: A common ground switched-quasi- Z -source bidirectional dc–dc converter is proposed for electric vehicles with hybrid energy sources. The proposed converter is based on the traditional two-level quasi- Z -source bidirectional dc–dc converter, changing the position of the main power switch. It has the advantages of a wide-voltage-gain range, a lower voltage stress across the power switches, and an absolute common ground. The operating principle, the voltage and current stresses on the power switches, the comparisons with the other converters, the small signal analysis, and the controller design are presented in this paper. Finally, a 300 W prototype with Uhigh=240 V and Ulow=40∼120 V is developed, and the experimental results validate the performance and the feasibility of the proposed converter.

TITLE: “Active virtual ground bridgeless PFC topology,”

YEAR: 2017

OBJECTIVE: The paper presents a new bridgeless power factor correction (PFC) topology, using a recently proposed controllable LCL filter, namely active virtual ground to achieve efficient power conversion, and high-frequency common mode voltage (CM) reduction. The proposed PFC circuit consists of high-frequency semiconductors for shaping inductor current and low-frequency semiconductors to form two different LCL structures for different conditions. This reduces grid differential mode current ripple or inductance. Besides, the PFC CM voltage, a main problem of bridgeless PFCs, is significantly reduced, since the capacitor in the LCL filter clamps the voltage between the grid and the converter ground. The performance of the proposed PFC is experimentally verified. The results show that the proposed PFC guarantees sinusoidal input current, low high-frequency common-mode voltage noise, and has a good agreement with the theoretical findings.

TITLE: “Analysis and implementation of a nonisolated bidirectional dc-dc converter with high voltage gain,”

YEAR: 2016

OBJECTIVE: In this paper, a nonisolated bidirectional dc-dc converter is presented. The proposed converter consists of two boost converters to enhance the voltage gain. Four power switches with their body diodes are employed in the proposed converter. Also, two inductors and a capacitor are used as passive components. The input current is divided to the inductors which causes the efficiency to be high. The voltage gain of the proposed converter is higher than the conventional cascaded bidirectional buck/boost converter (CCBC) in step-up mode. Besides, the voltage gain in step-down mode is lower than CCBC. Besides, the efficiency of the proposed converter more than CCBC while the total stress on active switches are same. The simple structure of the proposed converter causes its control to be easy. The steady-stateanalysis of the proposed converter is discussed in this paper thoroughly. The stress on converters' devices and the efficiency of the proposed converter and CCBC are compared in this paper. Finally, the proposed converter prototype circuit is implemented to justify the validity of the analysis.

TITLE: "Dc-dc converter for dual-voltage automotive systems based on bidirectional hybrid switched-capacitor architectures,"

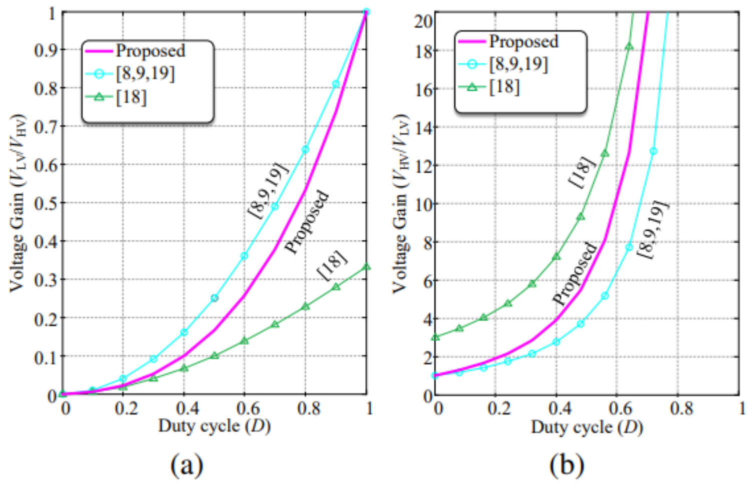
YEAR: 2015

OBJECTIVE: Automotive embedded electronic systems have been increasing in power and complexity and, therefore, more advanced power electronic converters are necessary in these vehicles. Several dual-voltage (42 V/14 V) bidirectional converter architectures have been proposed for automotive systems in recent years. However, most of them have low efficiency or are based in series and parallel configurations with large number of semiconductors and magnetics devices. Therefore, in this paper, we propose a bidirectional high-efficiency converter with lower number of components. This converter was created by merging a switched-capacitor converter and a conventional bidirectional converter, resulting in a hybrid topology. The voltage across the semiconductors of the proposed converter is equal to half of the highest voltage source value. Furthermore, the topology is composed of only one inductor to control the power flow between the two voltage sources. To verify all the mentioned features, a prototype was implemented experimentally, reaching a maximum efficiency of 97.5%

CHAPTER-3

3.PROPOSED METHOD

Some general information on the characteristics of the main bidirectional dc-dc converters and the proposed converter are provided in Table I. Some of these structures suffer from a lack of common ground between input and output terminals such as. A voltage gain comparison is made between the proposed converter and the main bidirectional dc-dc structures in the main point of is that the converter in has the lowest step-down voltage gain. However, due to its voltage gain relationship (D2/(2 + D)), this converter suffers from a limited voltage gain range which only ranges between 0 and 1/3. Hence, in the step-downmode, the proposed converter has the lowest-wide range voltage gain in comparison to the other structures.



Voltage gain comparison: (a) step-down and (b) step-up modes.

Figure 3.1 Voltage gain comparison: a) Step-down b) Step-up modes

Similarly, from in step up mode due to voltage gain relationship ((3 − D)/(1 − D) 2), the minimum voltage gain of the converter is 3, whereas for the proposed converter it is 1Thus, the proposed converter offers the highestwide range voltage gain in the step-up mode in comparison to the other structures. Furthermore, as shown in the quadratic voltage gain converters in are the main competitors for the proposed converter in regard to voltage gain. Another comparison can be made between the proposed converter and its main competitors in based on normalized total voltage of semiconductor devices (ΣjVSj/VHV) and normalized total voltage of capacitors (ΣjVCj/VHV) as shown in Fig. 8. Hence, the proposed converter offers lower(ΣjVSj/VHV) than converters in. Also, (ΣjVCj/VHV) of the proposed converter is lower than converters in at the voltage gains higher than 6. It must be mentioned that the (ΣjVSj/VHV) of converter in is lower than the proposed converter. However, the converter in [18], is inactive in the voltage gain area between 1/3 to 3, which is demonstrated in as the inactive area. It is also useful to compare the semiconductor utilization factor (SUF) of the proposed converter and the main competitor approaches. The SUF of a converter should be as high as possible to reduce the cost of the semiconductor devices. As was mentioned, in a good converter design, the voltage and current imposed on a semiconductor device is minimized, while the output power (Po) is maximized. The SUF can be defined as where n is number of semiconductor devices, VSj and ISj is the peak voltage and the peak current of semiconductor device j, respectively. shows the SUF curves of the main compared converters and the proposed converter versus voltage gain. It is clear that the proposed converter has the highest SUF compared to the other bidirectional converters. Furthermore, as will be shown later, the measured maximum efficiencies during the step-down and the step-up modes are 97.2% and 96.8%, respectively for the proposed converters. Therefore, the proposed converter presents a good balance of

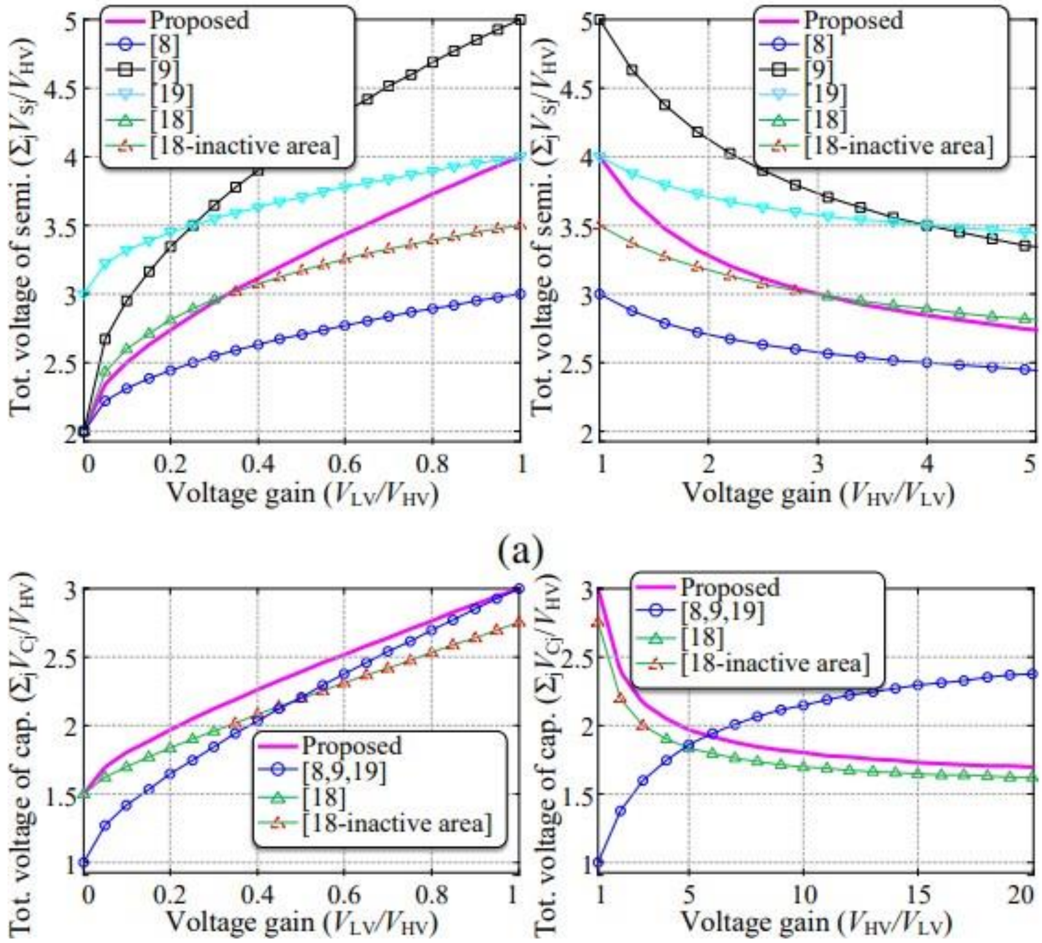


Figure 3.2 (a) Comparison of total voltage of semiconductors and (b) the total voltage of capacitors (step-down left and step-up right).

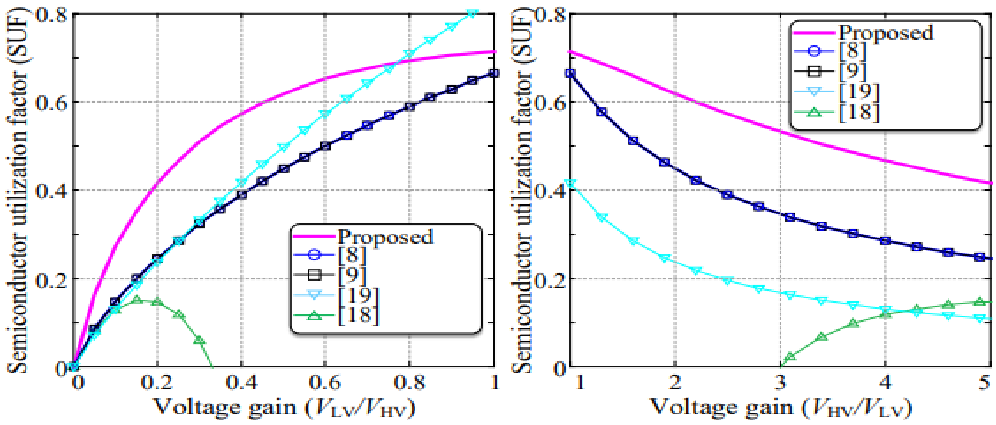


Figure 2.3 Semiconductor utilization factor (step-down left and step-up right)

The component count voltage gain range, semiconductor device ratings, common ground between input and output terminals and efficiency which makesit a very practical solution for an EV power converter unit.

3.1 Proposed DC-DC converter operation

In this section the operation of the dc-dc converter alone is verified. illustrates the performance of step-down mode under steady state operation and under a step change in LV side current reference from 6 A to 12.5 A. It can be seen that the input HV side voltage is 200 V and the voltage across the load changes from 18.2 V up to 40 V with the step change in the reference LV side current. Subsequently, D varies stepwise from 0.38 to 0.54, as, the LV side current varies from 6 A to 12.5 A. shows the voltage and the current of switchesin step-down mode which validates the equations of Section III-B. Similarly, shows the performance of the converter in step-up mode under steady state operation and in response to a step change in LV side current command from 6 Ato 12.5 A. In this case, the input LV side voltage is 40 V and since the inverter isnot connected, the output voltage is not regulated but steps from 140 V up to 200V with the step

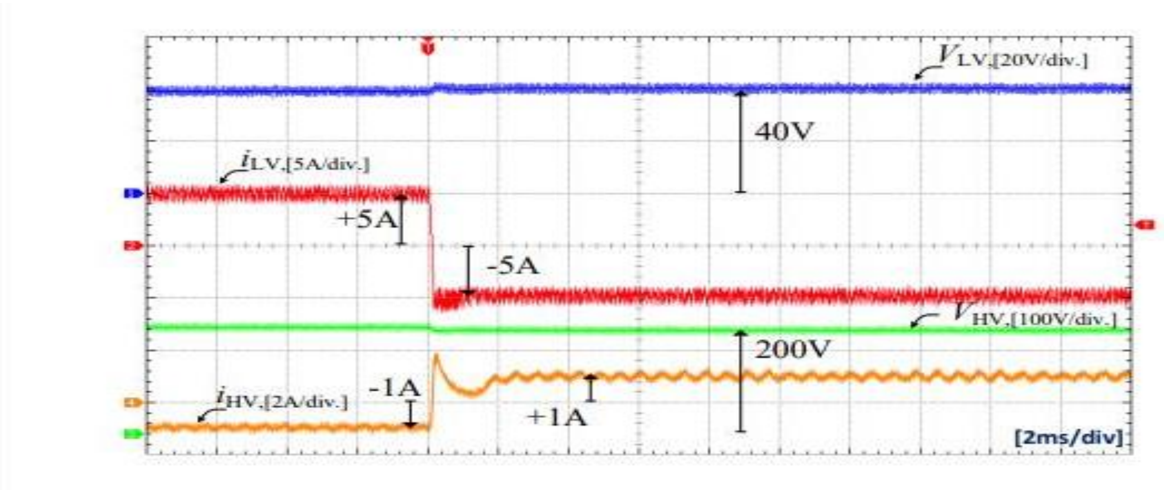


Figure 3.3Bidirectional charging and discharging operation

increase in current. Also, D increases stepwise from 0.37 to 0.45. These results demonstrate the proper performance of the proposed current controller under the change of reference

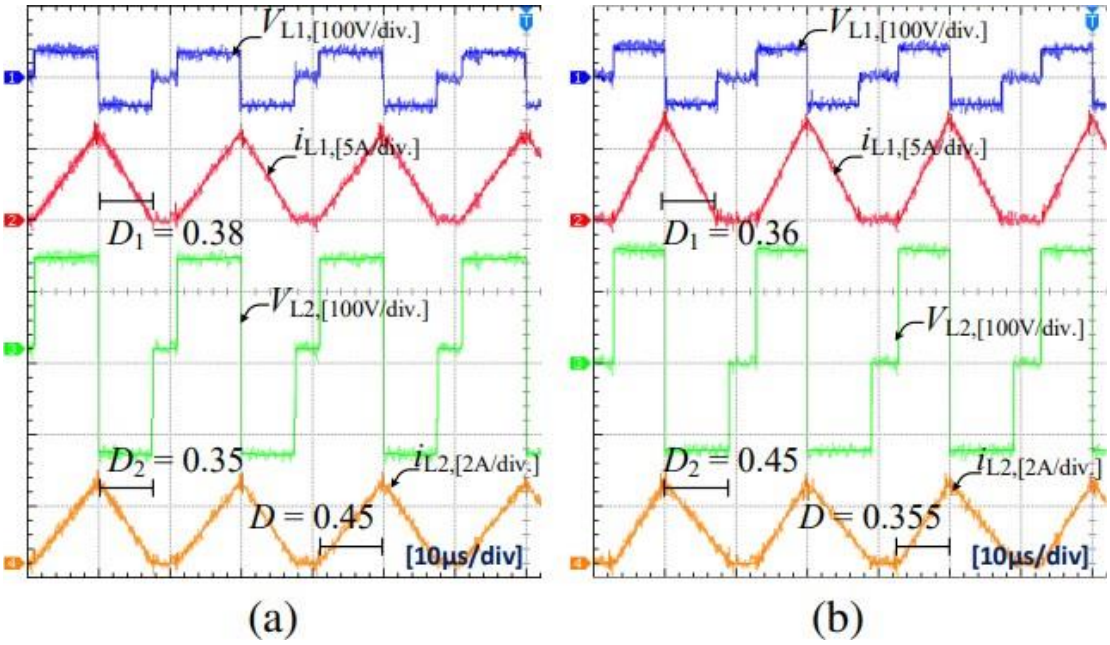


Figure 3.5 Voltage and current of in DCM mode: (a) stepdownand (b) step-up modes.

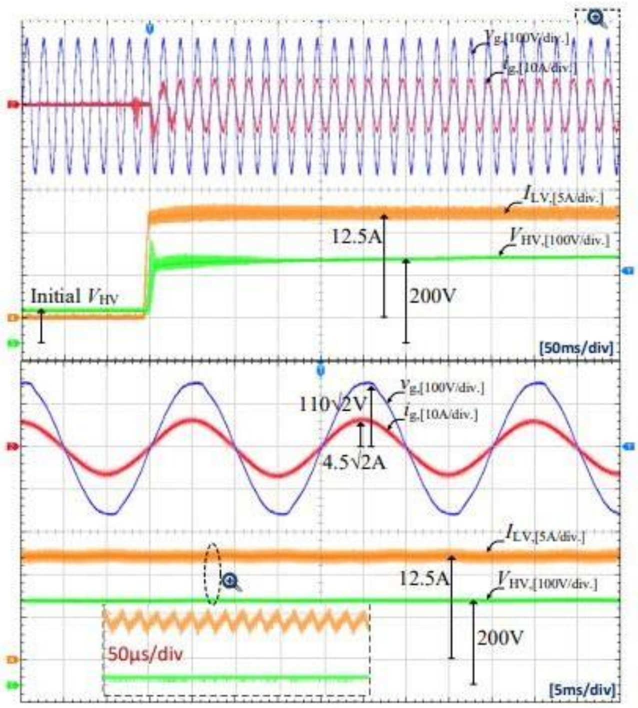
of LV side current which is essential for an appropriate and smooth behavior of the proposed converter when grid connected, which is examined in the next section. The voltage and current of switches during step-up mode are shown in. The output of the converter in response to a step change in current direction, i.e., from charging to discharging is shown in. As shown in this figure, the battery side current command changes from +5 A (charging) to -5 A (discharging), as a consequence of which, the HV side current changes from -1 A to +1 A. The DCM operation of the proposed converter during stepdown and step-up modes are shown in 16(a) and (b), respectively. The values of VLV and VHV with respect to D, D1 and D2 confirm the DCM voltage gains.

3.2 Grid-connected results

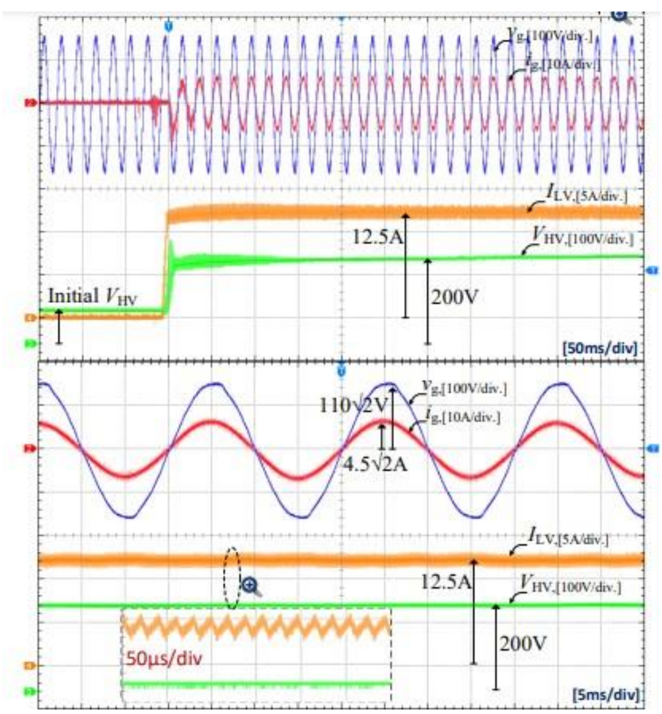
The steady state experimental results of the proposed EV charger for the grid connected mode in terms of G2V and V2G performance. The LV side current (or battery current Ib) reference and the HV side voltage reference is 12.5 A and 200 V, respectively. the step change in VHV and VLV simply indicates the point at which the inverter side dc link voltage control is activated. Battery voltage and grid voltage is 40 V and 110 V, respectively. As shown in this figure, the battery is charged (G2V) and discharged (V2G) with sinusoidal grid current.

3.3 Proposed converter evaluation

The measured efficiency curves under different modes of operation. The maximum efficiency of the proposed converter during charging (G2V) and discharging (V2G) modes is 97.2% and 96.8%, respectively. The input and output powers for the measurement of efficiency have been obtained by using the math functions of the RIGOL DS4024 digital oscilloscope on the measured voltage and current waveforms. A breakdown of the DC converter losses is presented. It can be seen that a large portion of the losses is attributed to the conduction losses.



(a)



(b)

Figure 3.6 Grid connected operation during: (a) V2G and (b) G2V.

CHAPTER-4

4.INTRODUCTION OF POWER ELECTRONICS

Power Electronics is the art of converting electrical energy from one form to another in an efficient, clean, compact, and robust manner for convenient utilization. A passenger lift in a modern building equipped with a Variable-Voltage-Variable-Speed induction-machine drive offers a comfortable ride and stops exactly at the floor level. Behind the scenes it consumes less power with reduced stresses on the motor and corruption of the utility mains.

POWER ELECTRONICS INVOLVES THE STUDY OF

• Power semiconductor devices - their physics, characteristics, drive r

equirements and their protection for optimum utilization of their capacities,

• Power converter topologies involving them,

• Control strategies of the converters,

• Digital, analogue and microelectronics involved,

• Capacitive and magnetic energy storage elements,

• Rotating and static electrical devices,

• Quality of waveforms generated,

• Electro Magnetic and Radio Frequency Interference

Power electronic converters- to modify the form of electrical energy (voltage, current or frequency).

Power range- from some milli watts (mobile phone) to hundreds of megawatts (HVDC transmission system). With "classical" electronics, electrical currents and voltage are used to carry information, whereas with power electronics, they carry power. Thus, the main metric of power electronics becomes the efficiency.The first very high-power electronic devices were mercury arc valves. In modern systems the conversion is performed with semiconductor switching devices such as diodes, thyristors and transistors. An AC/DC converter (rectifier) is the most typical power electronics device found in many consumers electronic devices, e.g., television sets, personal computers, battery chargers, etc.The power range is typically from tensof watts to several hundred watts. In industry the most common application is the variable speed drive that is used to control an induction motor. The power range of VSDs start from a few hundred watts and end at tens of megawatts.

The power conversion systems can be classified according to the type of the input and output power

❑ AC to DC (rectification)

❑ DC to AC (inversion)

❑ DC to DC (chopping)

❑ AC to AC (transformation)

PRINCIPLE

The instantaneous dissipated power of a device P = V.I

Thus, losses of a power device are at a minimum when the voltage across it is zero (the device is in the On-State) or when no current flows through it (Off-State). Therefore, a power electronic converter is built around one (or more) device operating in switching mode (either On or Off).

APPLICATIONS

Power electronic systems are found in virtually every electronic device. For example:

- DC/DC converters are used in most mobile devices (mobile phones, PDA etc.) to maintain the voltage at a fixed value whatever the voltage level of the battery is. These converters are also used for electronic isolation and power factor correction.

- AC/DC converters (rectifiers) are used every time an electronic device is connected to the mains (computer, television etc.). These may simply change AC to DC or can also change the voltage level as part of their operation.

- AC/AC converters are used to change either the voltage level or the frequency (international power adapters, light dimmer). In power distribution networks AC/AC converters may be used to exchange power between utility frequency50 Hz and 60 Hz power grids.

- DC/AC converters (inverters) are used primarily in UPS or emergency lighting systems. When mains power is available, it will charge the DC battery. If the mains fail, an inverter will be used to produce AC electricity at mains voltage from the DC battery.

4.1 COMMON POWER DEVICES

Some common power devices are the power diode, thyristors, power MOSFET and IGBT To its low-power counterpart but is able to carry a larger amount of current and typically is able to support a larger reverse-bias voltage in the off-state. Structural changes are often made in power devices to accommodate the higher current density, higher power dissipation and/or higher reverse breakdown voltage. The vast majority of the discrete (i.enon integrated) power devices are built using a vertical structure, whereas small- signal devices employ a lateral structure. With the vertical structure, the current rating of the device is proportional to its area, and the voltage blocking capability is achieved in the height of the die. With this structure, one of the connections of the device is located on the bottom of the semiconductor.

4.1.1 Power semiconductor devices

These are semiconductor devices used as switches or rectifiers in power electronic circuits (switch mode power supplies for example). They are also called power devices or when used in integrated circuits, called power ICs. Most power semiconductor devices are only used in commutation mode (i.e they are either on or off) and are therefore optimized for this. Most of them should not be used in linear operation.

4.2 COMMON POWER SEMICONDUCTOR DEVICES

The realm of power devices is divided into two main categories:

- The two-terminal devices (diodes), whose state is completely dependent on the external power circuit they are connected to;

- The three-terminal devices, whose state is not only dependent on their external power circuit, but also on the signal on their driving terminal (gate or base). Transistors and thyristors belong to that category. A second classification is less obvious but has a strong influence on device performance: Some devices are majority carrier devices (Schottky diode, MOSFET), while the others are minority carrier devices (Thyristor, bipolar transistor, IGBT). The former use only one type of charge carriers, while the latter use both (i.e electrons and holes). The majority carrier devices are faster, but the charge injection of minority carrier devices allows for better On-state performance.

4.2.1 Diodes

An ideal diode should have the following behaviour:

- When forward-biased, the voltage across the end terminals of the diode should be zero, whatever the current that flows through it (on-state);

- When reverse-biased, the leakage current should be zero whatever the voltage (off-state).

Moreover, the transition between on and off states should be instantaneous.

In reality, the design of a diode is a trade-off between performance in on-state, off-state and commutation. Indeed, it is the same area of the device that has to sustain the blocking voltage in off-state and allow current flow in the on-state. As the requirements for the two states are completely opposite, it can be intuitively seen that a diode has to be either optimised for one of them, or time must be allowed to switch from one state to the other. This trade-off between on-state, off-state and switching speed is the same for all power devices. A Schottky diode has excellent switching speed and on-state performance, but a high level of leakage current in off-state. PiN diodes are commercially available in different commutation speeds but any increase in speed is paid by lower performance in on-state.

4.2.2 Switches:

The trade-off between voltage, current and frequency ratings also exist for the switches.Actually, all power semiconductors rely on a PIN diode structure to sustain voltage. This can be seen in figure 2. The power MOSFET has the advantages of the majority carrier devices, so it can achieve very high operating frequency, but can't be used with high voltages. As it is a physical limit, no improvement is expected from silicon MOSFET concerning their maximum.

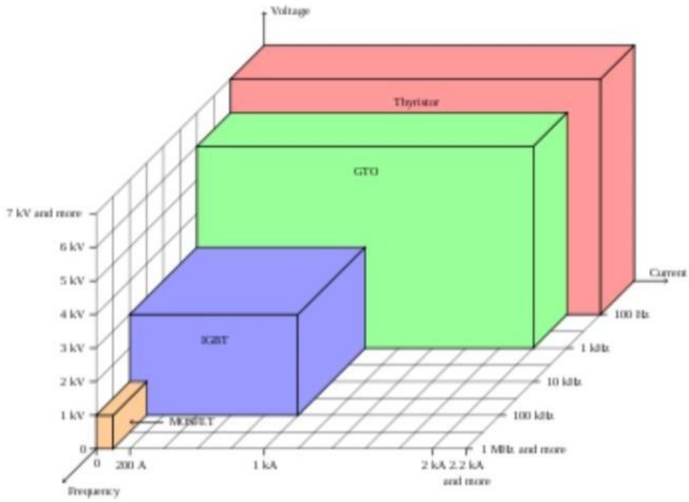


Fig 4.3.2 Performance of silicon MOSFET

However, its excellent performance in low voltage makes it the device of choice for applications below 200 V. By paralleling several devices, it is possible increase the current rating of a switch. The MOSFET is particularly suited to this configuration because its positive thermal coefficient of resistance tends to balance current between individual devices. The IGBT is a recent component, so its performance improves regularly as technology evolves. It has already completely replaced the bipolar transistor in power applications, and the availability of power modules (in which several IGBT dice are connected in parallel) makes it attractive for power levels up to several megawatts, pushing further the limit where thyristors and GTO become the only option. Basically, an IGBT is a bipolar transistor driven by a power MOSFET: it has the advantages of being a minority carrier device with the high input impedance of a MOSFET. Its major limitation for low voltage applications is the high voltage drop it exhibits in on-state (2 to 4 V). Compared to the MOSFET, the operating frequency of the IGBT is relatively low, mainly because of a so-called 'current-tail' problem during turn-off. This problem is caused by the slow decay of the conduction current during turn-off resulting from slow recombination of large number of carriers, which flood the thick region of the IGBT during conduction. The net result is that the turn-off switching loss of an IGBT is considerably higher than its turn-on loss. Generally, in datasheet, turn-off energy is mentioned as a measured parameter and one has to multiply that number with the switching frequency of the intended application to estimate the turn-off loss. At very high-power levels, thyristor-based devices are still the only choice. Though driving a thyristor is somewhat complicated, as this device can only be turned on. It turns off by itself as soon as no more current flows through it. This requires specific circuit with means to divert current, or specific applications where current is known to cancel regularly. Different solution has been developed to overcome this limitation. These components are widely used in power distribution applications.

4.3 PARAMETERS OF POWER SEMICONDUCTOR DEVICES

The power semiconductor dies of a three-terminal device (IGBT, MOSFET or BJT). Two contacts are on top of the die, the remaining one is on the back. Breakdown voltage: Often the trade-off is between breakdown voltage rating and on-resistance because increasing the breakdown voltage by incorporating a thicker and lower doped drift region leads to higher on-resistance.On-resistance: Higher current rating lowers the on-resistance due to greater numbers of parallel cells. This increases overall capacitance and slows down the speed. for the two states are completely opposite, it can be intuitively seen that a diode has to be either optimised for one of them, or time must be allowed to switch from one state to the other. it is possible increase the current rating of a switch. The MOSFET is particularly suited to thisconfiguration because its positive thermal coefficient of resistance tends tobalance current between individual devices.

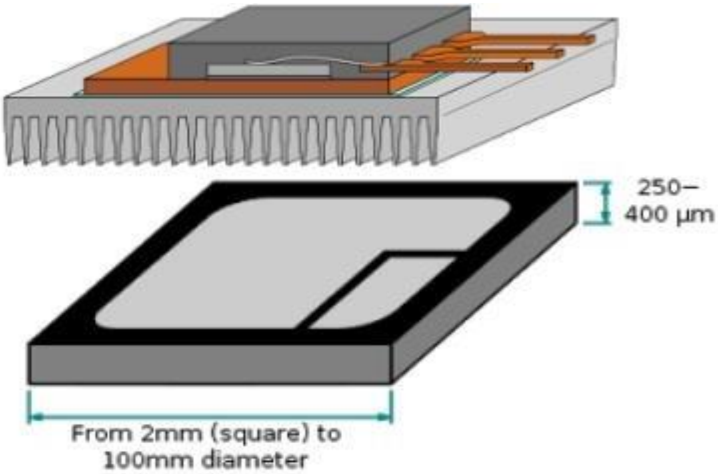


Fig 4.3.3 Three terminal IGBT AND MOSFET

Safe-operating area (from thermal dissipation and "latch-up" consideration) Thermal resistance: This is an often ignored but extremely important parameter from practical system design point of view. Semiconductors do not perform well at elevated temperature but due to large current conduction, all power semiconductor device heat up. Therefore, it needs to be cooled by removing that heat continuously. Packaging interface provides the path between the semiconductor device and external world to channelize the heat outside. Generally, large current devices have large die and packaging surface area and lower thermal resistance. TRIS bit to make a pin an output, while other peripherals override the TRIS bit to make a pin an input.

CHAPTER-5

5. HARDWARE METHODOLOGY

5.1 Hardware methodology

- Battery-powered Electric Vehicles (EVs) are considered as an effective solution to curb carbon emissions and fight global warming.
- V2V charging allows the sharing of charge between two EVs so that if an EV is stranded far from a charging station, it can be VariousV2Vchargers have been studied.
- It has been found that the traditional chargers involve many power conversion stages, which reduces the efficiency in the energy exchange.
- In this paper, an off-board DC V2V charger is presented.
- It reduces the power conversion stages while dispensing with the use of any on-board charger.
- To implement the off-board DC V2V charger, a bidirectional DC-DC converter is adopted. charged from another EV.

5.2Wide Range High Voltage Gain

Scientists have been interested in renewable energy sources such as photovoltaic (PV) to produce electricity because they appeared to be the most efficient and effective solution to the environmental problems that the world facestoday. The unregulated low-level DC output voltage from these sources isconsidered the biggest and the most important challenge that requires to be boosted to a regulated higher level using power electronic conditioning. The power electronic interface specification is dependent not only on the renewable energy supply but also on its effects on the power-system operation. To obtain the voltage step-up function, a conventional non-isolated DC/DC boost converter was used because of its simple structure, simple control, and low cost. But it provided a limited practical gain because of their parasitic elements and must be operated at an extreme duty cycle in order to obtain high voltage gain. That causes a high-semiconductors voltage stress, diode reverse recovery problems, and highswitching loss which decrease the system performance and efficiency.In, cascaded boost converter has been successful in solving some of the problems appeared with conventional boost converter as it can attain a reasonable high voltage gain without working at extreme duty cycle, and the voltage stress through the switches remains lower than the voltage across the load. But it has higher losses, lower efficiency, and electromagnetic interference problems. In switched-capacitor-based converters and switched capacitor/switched inductor- based converters high-voltage gain with small duty cycle, small voltage stress across the switches can be attained, and these converters can be used in a wide range of power. However, they have some problems such as higher losses, lower efficiency, electromagnetic interference problems, and reverse recovery problem.The use of high-frequency transformers can increase the voltage gain aswell as isolation, and then, full-bridge-based topologies can be use, but with limited power capability, higher losses, lower efficiency, and higher cost. Full- bridge, half-bridge, fly back, forward, and push–pull converters are used at various voltage and power levels where isolation is needed. However, they sufferfrom numerous restrictions which reduce their efficiency, reduce performance inhigh step-up applications, and make the system more complicated and bulkier. They have also a limited range of increasing the voltage level besides higher voltage stress. Also, a massive turn-off voltage spikes in the power switch is generated due to the leakage inductance, which results in additional voltage stresson the components that require a snubber circuit to clamp the switch voltage resulting in a bigger size and more expensive. A high gain DC/DC converter utilizing coupled inductor and voltage multiplier cell that achieves high gain at asmall duty ratio, and low voltage stress across the semiconductor components is presented. However, it is a hard switching circuit that shortens the life of its components, furthermore, the voltage multiplier cell makes the system bulky and more expensive. Magnetically coupled inductors topologies are presented in which increase the output voltage gain of the converter with transfer energy stored in coupled inductance and decrease the normalized voltage stress across the semiconductors. However, a clamping circuit is needed to prevent switchingspikes and recover the leakage energy due to the leakage inductance which produces voltage spikes and ringing.Recently, several DC/DC converters are presented such as a high voltage gain quasi-Z-source DC/DC converter that givesa high voltage gain at the low duty cycle and low voltage stress on the semiconductors. However,it works with hard switching making more losses thataffect the system performance and efficiency, and it has a limited gain as it is used only for duty cycles less than 0.3. In, a single switch DC/DC converter withnon-coupled inductors is used that achieves high voltage gain with high efficiency. The major drawback is it has a large number of passive components that make the system bulkier and more expensive. A high voltage gain p-type DC/DC converter is presented in that has the advantages of high gain with smallduty cycle, continuous input current, common ground, and low voltage stress onsemiconductors devices. However, it operates with hard switching and requires ahigh number of components that making the system larger and more expensive. To improve the voltage gain, a single switch three-Z-network converter is presented in. Although a high voltage gain is achieved, it has a large number of passive components which increase the losses and reduce the efficiency. An impedance network DC/DC boost converter is used in that reaches a high voltagegain with a small number of diodes and small duty cycle that avoids instability caused by saturation of its inductors. But the main drawback of the converter is the lower efficiency. In, a step-up DC/DC converter with switched capacitor cellsis presented. The converter provides high voltage gain at low duty ratios, low voltage stress on the switches and, switched capacitors, and it can be expanded. However, it has a large number of active and passive components that makes theconverter size larger and more expensive.A single power switch high gain DC/DC converter with advantages of continuous input current, a small number of active components, and low voltage stress across the power switch and diodesis proposed in. But it is limited power and has a large number of passive components. A non-isolated high gain DC/DC converter for dc micro grid applications with a single switch is presented in, with the advantage of simple control, and low voltage stress across the semiconductor devices. Even so, it operates with hard switching and has a large number of passive components. A transformer-less DC/DC converter based on a coupled inductor and switched capacitor–boosting techniques that increase the voltage gain with a low duty cycle is presented in. Although the voltage stresses across the active components are reduced, it operates with hard switching, has large losses and large number of elements, and hence large size and high expensive. A switched-inductor double power switches high gain DC/DC converter (SL-DS-DC) with higher voltage gain is presented in. However, it has more passive and active components which make the system bulkier and more expensive. A simple control scheme to improve the performance of a quadratic boost converter is presented in. This scheme provides a faster transient response and better noise immunity, but it has a large number of passive components, high losses because of hard switching, low efficiency, large size, and more expensive. High gain-switched boost DC/DC converters contain switched capacitor/switched inductor cells are presented in. The converters have advantages such as high voltage gain at non-extreme duty cycle, low voltage stresses across the switches and output diode, and they can be expanded to give higher voltage gain. To provide higher gain, more cells should be added but this makes the system bulkier and is more expensive. In, a transformer-less high step-up DC/DC converter consisting of an active switched-inductor with quasi-Z-source circuit is offered. High voltage gain at the low duty cycle and high efficiency are achieved. The main drawback is the semiconductors' components increased by increasing the switched-capacitor cells. A double boost-fly back converter is introduced in, the static gain is increased with the reduction of input current ripple where a combination between two conventional boost-fly back converters with input-parallel and floatingoutput is done. However, if the converter operates with a duty cycle less than 0.5,the input current will be discontinuous with greater ripple. Also, with the increased number of fly back cells more sensors are needed which makes the system bulkier and more expensive.In this paper, a new design of a non-isolatedhigh-voltage gain DC/DC boost converter operating with a reasonable duty cycleby integrating dual boost converter with switched inductor structure is presented. The proposed converter operates with soft-switching (zero current switching (ZCS) mode for all switches and diodes. High voltage gain, low switching stress, small switching losses, and high efficiency are achieved. The operating modes, steady-state analysis, and design guidelines of the proposed circuit are discussed.Experimental results for the open and closed loops are conducted to verify the validity of the proposed circuit.

5.3 DC-DC CONVERTER

Before the development of power semiconductors, one way to convert thevoltage of a DC supply to a higher voltage, for low-power applications, was to convert it to AC by using a vibrator, then by a step-up transformer, and finallya rectifier. Where higher power was needed, a motor–generator unit was often used, in which an electric motor drove a generator that produced the desired voltage. (The motor and generator could be separate devices, or they could be combined into a single "dynamotor" unit with no external power shaft.) These relatively inefficient and expensive designs were used only when there was no alternative, as to power a car radio (which then used thermionic valves (tubes) that require much higher voltages than available from a 6 or 12 V car battery). The introduction of power semiconductors and integrated circuits madeit economically viable by use of techniques described below. For example, first is converting the DC power supply to high-frequency AC as an input of a transformer - it is small, light, and cheap due to the high frequency — that changes the voltage which gets rectified back to DC Although by 1976 transistorcar radio receivers did not require high voltages, some amateur radio operators continued to use vibrator supplies and dynamotors formobile transceivers requiring high voltages although transistorized power supplies were available. While it was possible to derive a lower voltage from a higher with a linear regulator or even a resistor, these methods dissipated the excess as heat; energy-efficient conversion became possible only with solid-stateswitch-mode circuits.

5.31USES

DC-to-DC converters are used in portable electronic devices suchas cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub- circuits, each with its own voltage level requirement different from that suppliedby the battery or an external supply (sometimes higher or lower than the supply voltage). Additionally, the battery voltage declines as its stored energy is drained.Switched DC to DC converters offer a method to increase voltage from a partiallylowered battery voltage thereby saving space instead of using multiple batteries to accomplish the same thing. Most DC-to-DC converter circuits also regulate the output voltage. Some exceptions include high efficiency LED power sources, which are a kind of DC-to-DC converter that regulates the current through the LEDs, and simple charge pumps which double or triple the output voltage. DC-to-DC converters which are designed to maximize the energy harvestfor photovoltaic systems and for wind turbines are called power optimizers. Transformers used for voltage conversion at mains frequencies of 50–60 Hz must be large and heavy for powers exceeding a few watts. This makes them expensive, and they are subject to energy losses in their windings and due to eddy currents in their cores. DC-to-DC techniques that use transformers or inductors work at much higher frequencies, requiring only much smaller, lighter,and cheaper wound components. Consequently, these techniques are used even where a mains transformer could be used; for example, for domestic electronic appliances it is preferable to rectify mains voltage to DC, use switch-mode techniques to convert it to high-frequency AC at the desired voltage, then, usually, rectify to DC. The entire complex circuit is cheaper and more efficient than a simple mains transformer circuit of the same output. DC-to-DC convertersare widely used for DC microgrid applications, in the context of different voltagelevels.

5.4 ELECTRONIC CONVERTION

Practical electronic converters use switching techniques. Switched-mode DC-to-DC converters convert one DC voltage level to another, which may be higher or lower, by storing the input energy temporarily and then releasing that energy to the output at a different voltage. The storage may be in either magneticfield storage components (inductors, transformers) or electric field storage components (capacitors). This conversion method can increase or decrease voltage. Switching conversion is often more power-efficient (typical efficiency is75% to 98%) than linear voltage regulation, which dissipates unwanted power as heat. Fast semiconductor device rises and fall times are required for efficiency; however, these fast transitions combine with layout parasitic effects to make circuit design challenging. The higher efficiency of a switched-mode converter reduces the heatsinking needed and increases battery endurance of portable equipment. Efficiency has improved since the late 1980s due to the use of power FETs, which are able to switch more efficiently with lower switching losses [de] at higher frequencies than power bipolar transistors and use lesscomplex drive circuitry. Another important improvement in DC-DC converters is replacing the flyback diode with synchronous rectification using a power FET, whose "on resistance" is much lower, reducing switching losses. Before thewide availability of power semiconductors, low-power DC-to-DC synchronous converters consisted of an electro-mechanical vibrator followed by a voltage step-up transformer feeding a vacuum tube or semiconductor rectifier, or synchronousrectifier contacts on the vibrator.Most DC-to-DC converters are designed to move power in only one direction, from dedicated input to output. However, all switching regulator topologies can be made bidirectional and able to move powerin either direction by replacing all diodes with independently controlled active rectification. A bidirectional converter is useful, for example, in applications requiring regenerative braking of vehicles, where power is supplied *to* the wheels while driving, but supplied by the wheels when braking.Although they require few components, switching converters are electronically complex. Like all high-frequency circuits, their components must be carefully specified and physically arranged to achieve stable operation and to keep switching noise (EMI / RFI) at acceptable levels. Their cost is higher than linear regulators in voltage-dropping applications, but their cost has been decreasing with advances in chip design.

DC-to-DC converters are available as integrated circuits (ICs) requiring few additional components. Converters are also available as complete hybrid circuit modules, ready for use within an electronic assembly.Linear regulators which are used to output a stable DC independent of input voltage andoutput load from a higher but less stable input by dissipating excess volt-amperesas heat, could be described literally as DC-to-DC converters, but this is not usualusage. (The same could be said of a simple voltage dropper resistor, whether or not stabilised by a following voltage regulator or Zener diode.)There are also simple capacitive voltage doubler and Dickson multiplier circuits using diodes and capacitors to multiply a DC voltage by an integer value, typically delivering only a small current

5.41Magnetic

In these DC-to-DC converters, energy is periodically stored within and released from a magnetic field in an inductor or a transformer, typically within a frequency range of 300 kHz to 10 MHz By adjusting the duty cycle of thecharging voltage (that is, the ratio of the on/off times), the amount of power transferred to a load can be more easily controlled, though this control can also be applied to the input current, the output current, or to maintain constant power.Transformer-based converters may provide isolation between input and output. In general, the term DC-to-DC converter refers to one of these switching converters. These circuits are the heart of a switched-mode power supply. Manytopologies exist. This table shows the most common ones.

<table>
<tr><th></th><th>Forward (energy transfers through the magnetic field)</th><th>Flyback (energy is stored in the magnetic field)</th></tr>
<tr><td rowspan="3">No transformer (non-isolated)</td><td>Step-down (buck) - The output voltage is lower than the input voltage, and of the same polarity.</td><td>Non-inverting: The output voltage is the same electric polarity as the input.
o Step-up (boost) - The output voltage is higher than the input voltage.
o SEPIC - The output voltage can be lower or higher than the input.
Inverting: the output voltage is of the opposite polarity as the input.
o Inverting (buck-boost).
o Ćuk - Output current is continuous.</td></tr>
<tr><td colspan="2">True buck-boost - The output voltage is the same polarity as the input and canbe lower or higher.</td></tr>
<tr><td colspan="2">Split-pi (boost-buck) - Allows bidirectional voltage conversion with theoutput voltage the same polarity as the input and can be lower or higher.</td></tr>
</table>

With transformer (isolatable)	Forward - 1 or 2 transistor drive. Push-pull (half bridge) - 2 transistors drive. Full bridge - 4 transistor drive.[8]	Flyback - 1 transistor drive.

Table 5.4.1 Characteristics of magnetic switch

The current fluctuates but never goes down to zero. Discontinuous The current fluctuates during the cycle, going down to zero at or before the end of each cycle

A converter may be designed to operate in continuous mode at high power, and in discontinuous mode at low power.The half bridge and flyback topologies are similar in that energy stored in the magnetic core needs to be dissipated so that the core does not saturate. Power transmission in a flyback circuit is limited by the amount of energy that can be stored in the core, while forward circuits are usually limited by the I/V characteristics of the switches .Although MOSFET switches can tolerate simultaneous full current andvoltage (although thermal stress and electromigration can shorten the MTBF), bipolar switches generally can't so require the use of a snubber (or two).High- current systems often use multiphase converters, also called interleaved converters. Multiphase regulators can have better ripple and better response timesthan single-phase regulators. Many laptop and desktop motherboards include interleaved buck regulators, sometimes as a voltage regulator module.

5.5Bidirectional DC-to-DC converters

Specific to these converters is that the energy flows in both directions of the converter. These converters are commonly used in various applications, and they are connected between two levels of DC voltage, where energy is transferred from one level to another.

- Boost bidirectional DC-to-DC converter

- Buck bidirectional DC-to-DC converter
- Boost-buck non-inverting bidirectional DC-to-DC converter
- Boost-buck inverting bidirectional DC-to-DC converter
- SEPIC bidirectional DC-to-DC converter
- CUK bidirectional DC-to-DC converter

Multiple isolated bidirectional DC-to-DC converters are also commonly used in cases where galvanic isolation is needed.

- Bidirectional flyback
- Isolated ĆUK & SEPIC/ZETA
- Push-pull
- Forward
- Dual-active bridge (DAB)
- Dual-half bridge
- Half-full bridge
- Multiport DAB

5.5.1 Capacitive

Switched capacitor converters rely on alternately connecting capacitors tothe input and output in differing topologies. For example, a switched capacitor reducing converter might charge two capacitors in series and then discharge themin parallel. This would produce the same output power (less that lost to efficiencyof under 100%) at, ideally, half the input voltage and twice the current. Because they operate on discrete quantities of charge, these are also sometimes referred toas charge pump converters. They are typically used in applications requiring relatively small currents, as at higher currents the increased efficiency and smallersize of switch-mode converters makes them a better choice. They are also usedat extremely high voltages, as magnetics would break down at such voltages.

5.5.2Electromechanical conversion

A motor–generator set, mainly of historical interest, consists of an electricmotor and generator coupled together. A dynamotor combines both functions into a single unit with coils for both the motor and the generator functions woundaround a single rotor; both coils share the same outer field coils or magnets. Typically, the motor coils are driven from a commutator on one end of the shaft,when the generator coils output to another commutator on the other end of the shaft. The entire rotor and shaft assembly is smaller in size than a pair of machinesand may not have any exposed drive shafts.

Motor–generators can convert between any combination of DC and AC voltage and phase standards. Large motor–generator sets were widely used to convert industrial amounts of power while smaller units were used to convert battery power (6, 12 or 24 V DC) to a high DC voltage, which was required tooperate vacuum tube (thermionic valve) equipment.

For lower-power requirements at voltages higher than supplied by a vehicle battery, vibrator or "buzzer" power supply were used. The vibrator oscillated mechanically, with contacts that switched the polarity of the battery many times per second, effectively converting DC to square wave AC, which could then be fed to a transformer of the required output voltage(s). It made a characteristic buzzing noise.

5.6Introduction of Vehicle-to-Grid V2G

The first V2G requirement is the power connection. Battery vehicles mustalready be connected to the grid inorder to recharge their batteries; to add V2G capability requires little or no modification to the charging station and nomodification to the cables or connectors, but on-board power electronics must bedesigned for this purpose had "zero incremental cost."The second requirement forV2G is control, for the utility or system operator to request vehicle power exactlywhen needed. This is essential because vehicle power has value greater than the cost to produce it only if the buyer (the system operator) can determine the precisetiming of dispatch. The automobile industry is moving towards making real-time communications a standard part of vehicles. This field, called "telematics" has already begun with luxury vehicles; over a period of time, it will be available formost new car models. Whether using built-in vehicle telematics, or in the interim using add-on communications, the vehicle could receive a radio signal from the grid operator indicating when power is neededThe third element of precision, certified, tamper-resistant metering, measures exactly how much power or ancillary services a vehicle did provide, and at which times. The telematics couldagain be used to transmit meter readings back to the buyer for credit to the vehicleowner's account Thinking about the metering of V2G expands the usual conceptof a "utility meter." Electronic metering and telemetric appear to have efficiency advantages in eliminating the meter reader, transfer of billing data to the central computer, and the monthly meter-read cycle. More unnerving, electronic metering and telemetric also eliminates the service addressed An onboard meter would transmit its own serial number or account number with its readings, via telemetric, and presumably this would be billed in conjunction with a traditionalmetered account with a service address.A large-scale V2G system would automate accounting and reconciliation of potentially millions of small transactions, similar to the recording and billing of calls from millions of cellularphone customers.Thus the mobile metered KWhs or ancillary services wold be added or subtracted to the amount registered on the fixed meter to reconcile bothbilling amounts.

5.7 Concept of V2G:

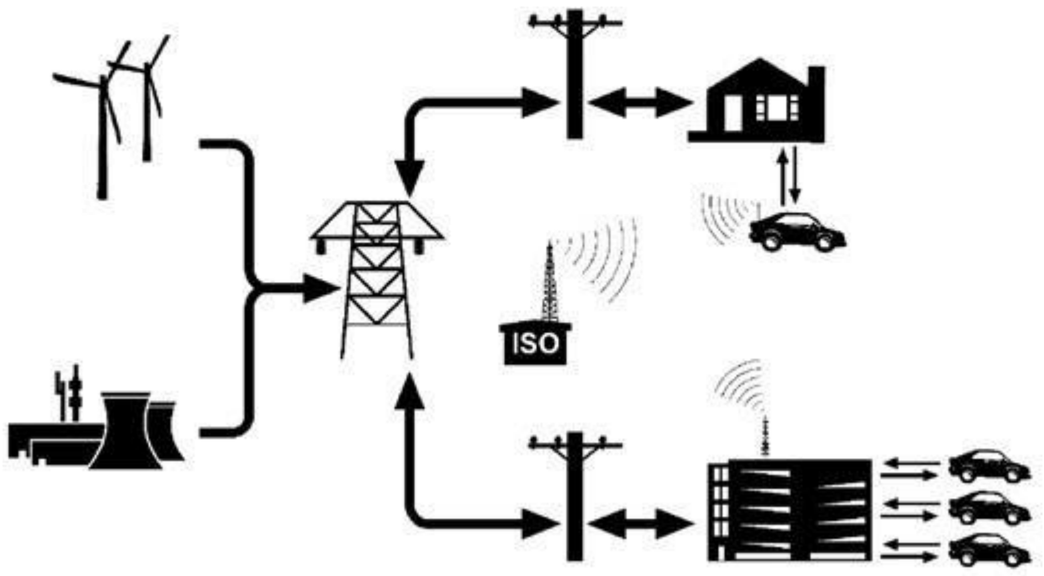


Fig 5.2 Schematically illustrates connections between vehicles and the electric power grid.

Electricity flows one-way from generators through the grid to electricity users. Electricity flows back to the grid from EDVs, or with battery EDVs, the flow is two ways (shown in Fig. as lines with two arrow). The control signal fromthe grid operator (labelled ISO, for Independent System Operator) could be a broadcast radio signal, or through a cell phone network, direct Internet connection, or power line carrier. In any case, the grid operator sends requests forpower to a large number of vehicles.

5.8 Concept of G2V

This Special Issue "Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) Technologies" was in session from 1 May 2019 to 31 May 2020. For this Special issue, we invited articles on current state-of-the-art technologies and solutions in G2V and V2G, including but not limited to the operation and control of gridable vehicles, energy storage and management systems, charging infrastructure and chargers, EV demand and load forecasting, V2G interfaces and applications, V2G and energy reliability and security, environmental impacts, and economic benefits as well as demonstration projects and case studies in the aforementioned areas. Articles that deal with the latest hot topics in V2G are of particular interest, such as V2G and demand-side response control technique, smart charging infrastructure and grid planning, advanced power electronics for V2G systems, adaptation of V2G systems in the smart grid, adaptation of smart cities for a large number of EVs, integration, and the optimization of V2G systems, utilities and transportation assets for advanced V2G systems, wireless power transfer systems for advanced V2G systems, fault detection, maintenance and diagnostics in V2G processes, communications protocols for V2G systems, energy management system (EMS) in V2G systems, IoT for V2G systems, distributed energy and storage systems for V2G, transportation networks and V2G, energy management for V2G, smart charging/discharging stations for efficient V2G, environmental and socio-economic benefits and challenges of V2G systems, and building integrated V2G systems (BIV2G). Five manuscripts are published in this Special Issue, including “An Ensemble Stochastic Forecasting Framework for Variable Distributed Demand Loads” by Agyeman et al., “Where Will You Park? Predicting Vehicle Locations for Vehicle-to-Grid, An MPC Scheme with Enhanced Active Voltage Vector Region for V2G Inverter” by Shipman et al., “Electric Vehicles Energy Management with V2G/G2V Multifactor Optimization of Smart Grids” by Xia et al., and “A Review on Communication Standards and Charging Topologies of V2G and V2H Operation Strategies” by Savitti et al.

5.9 Hybrid EV Charger

A battery charger can allow a unidirectional or bidirectional power flow at all power levels. The bidirectional power flow adds to the grid-to-vehicle interaction(G2V) also the vehicle-to-grid (V2G) mode. This latter technology can bring significant improvement in the overall reliability of the distribution grid, since incase of system failure, peak load demand or other unexpected scenarios, with a bidirectional power flow, the EVs can be used as back up generation, supplying the energy back to the grid when needed. With V2G, as all the energy storage systems, EVs battery can be used not only as back up resource but also to improvethe power quality, the stability and the operating cost of distribution network. Moreover, in the long run, V2G could reduce investment in new power generationinfrastructure. All the just listed reasons are increasing researchers' interest in thistechnology.

Not only the choice of the charging technology, but also the selection of the correct charging method is a feature that has to be considered during the charging procedure. The most popular charging strategies to recharge Li-ion batteries are constant-current/constant-voltage (CC/CV) and pulse current charging methods.However, these methods do not take into account the several internal process of the battery which influence its charging capability and aging. As a result, some promising charging strategies which are based on more complete models of lithium-ion batteries are now under research.

EV battery and power electronic devices costs are steadily falling. This rapid decline is mostly due to a growing manufacturing industry, which is constantly increasing the knowledge, the number of applications and the improvements of both these technologies. As the costs are falling, the trends of EV battery energy density, gross weight and semiconductor devices performances are following exactly the opposite direction; in fact, with equal capacities, batteries are becoming ever smaller and lighter and the power electronic devices ever more performing. All this impacts the choice and the size of the charging systems. The sizing procedure of a suitable charging system is made even more difficult by the presence of many different technologies of the onboard and off-board chargers and also different cost, dimensions, weights, power rating; and so on. This the paper is organized as follow. In Sects. and, respectively, on-board and off-board charger most common architectures are presented, and their operating principles are explained. In Sect. the concept of fast charging stations is introduced. The available and most suitable charging methods are listed in Sect. with particular attention to the charging methods most suitable for direct-current (DC) fast charging. Finally, a genetic algorithm is used in Sect.to estimatethe optimal charging system size and its possible future trends.

5.10 ONBOARD CHARGER

Battery charges can br implemented inside (on-board) or outside (off- board) the vehicle. Onboard battery chargers (OBC) are limited by size, weight and volume for this reason they are usually compatible with level 1 and level 2 chargers. They usually have unidirectional power transfer capability; nevertheless, in some case the configuration, a bidirectional power transfer can be achieved. shows the typical architecture of an electric vehicle charging system, in such figure both the on-board charger and the off board one is represented. As the costs are falling, the trends of EV battery energydensity, gross weight and semiconductor devices performances are following exactly the opposite direction; in fact, with equal capacities, batteries are becoming ever smaller and lighter and the power electronic devices ever more performing. the EVs can be used as back up generation, supplying the energy back to the grid when needed. With V2G, as all the energy storage systems, EVs battery can be used not only as back up resource but also to improvethe power quality, the stability and the operating cost of distribution network. the concept of fast charging stations is introduced.

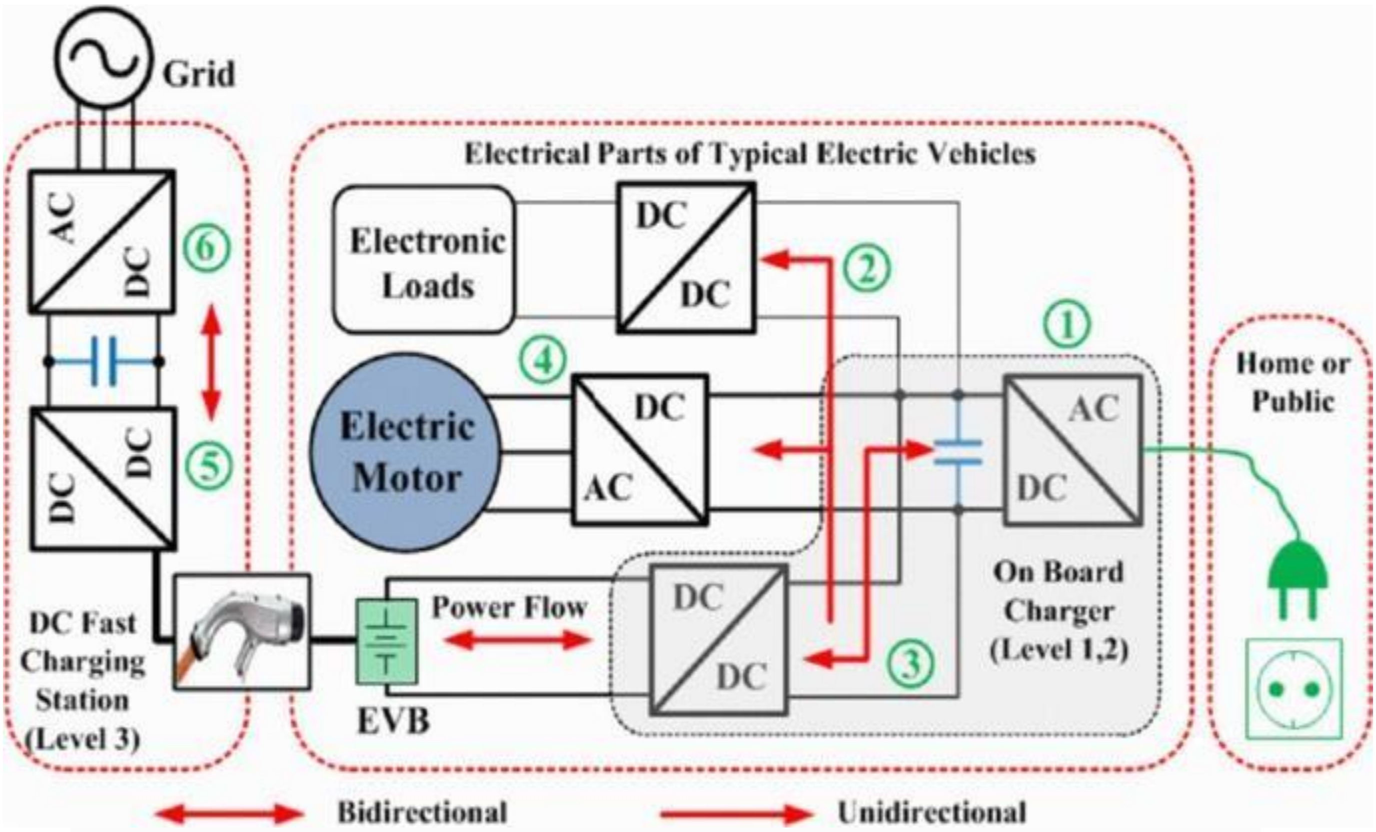


Fig 5.3 Outline of ON-BOARD AND OFF-BOARD CHARGER

5.9.1 TWO STAGES

Onboard chargers are typically composed by two stages: a front-end AC–DC stage and a back-end DC-DC stage. Very different topologies are proposed in literature for both the converters.

The front-end rectifier usually contains a boost power factor correction (PFC) converter to achieve high power factor and low harmonic distortion. The rectifier stage can be performed by a half-bridge, full-bridge or multilevel diode bridge. Half-bridge rectifier is less expensive since it contains less number of diodes/switches, full-bridge rectifier is more complex, but the components are subjected to lower stresses. If instead higher power ratings should be achieved a good choice for the ac–dc converter is a multilevel configuration. Figure shows a full-bridge diode rectifier with a conventional PFC boost converter By substituting all the diodes with active switches, a bidirectional power flow can beobtained.

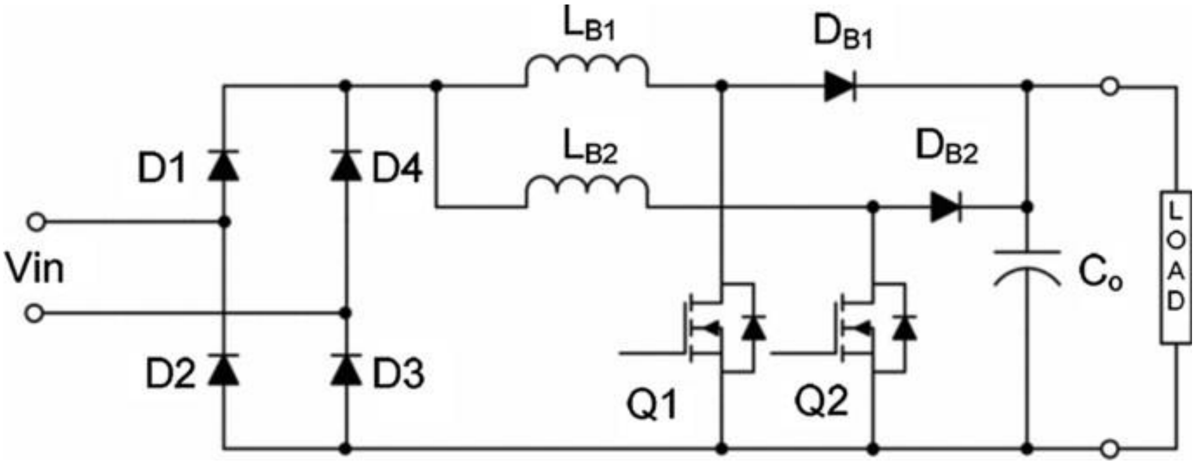


Fig 5.5 Full-bridge rectifier with interleaved PFC boost converter

In PFC converter the interleaved boost converter is becoming more and more popular. As shown in an interleaved boost converter simply consists in two boost converters in parallel, operating 180° out of phase. The main aim of this interleaving is to increase the output current by reducing the input current ripple and hence by reducing the overall volume of the input ElectroMagnetic Interference (EMI) filter and of the boost inductor. On the other hand, interleaving means increasing the cost and the complexity of the design. The front-end converter is followed by a second dc-dc converter. Resonantpower converters are very common to perform this second stage, because of the potential to achieve at the same time both higher switching frequency and lower switching losses. Among all the resonant converter, LLC configuration, is achieving resounding interest, thanks to its several advantages over other resonanttopologies, such as: (1) the ability to operate at zero-voltage switching (ZVS) or zero-current switching (ZCS), (2) containing a high frequency transformer it performs the galvanic isolation between the grid and the EV, (3) a wide output voltage regulation is possible, (4) the output filter consists only in a capacitor andnot in an LC filter.

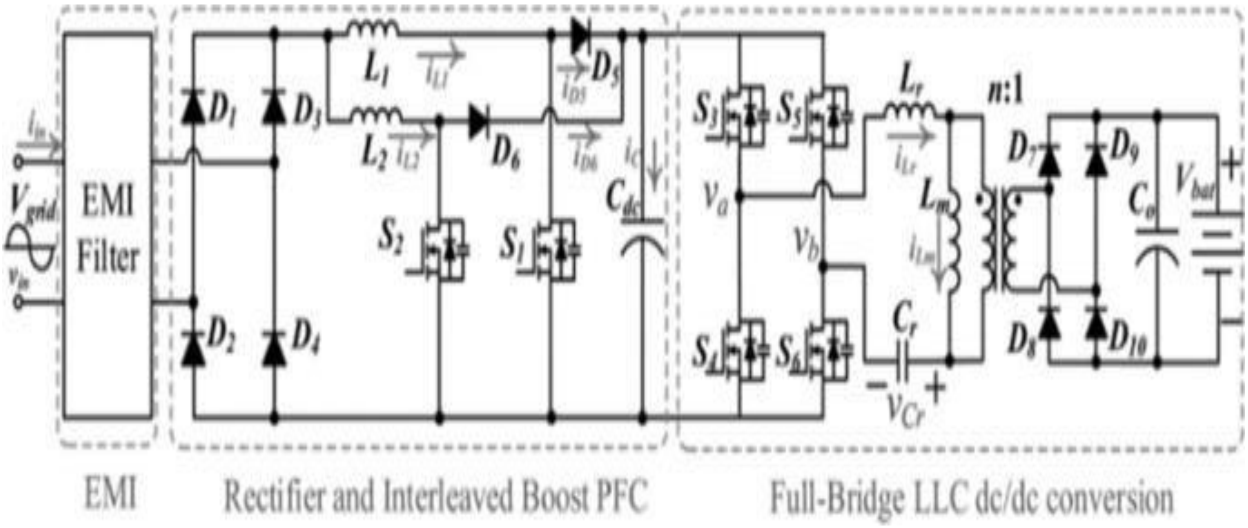


Fig 5.6 ONBOARD charger with LLC converter

However, in literature other types of dc–dc converter has been proposed. In a bidirectional buck-boost non-isolated dc/dc converter is proposed whose principal aim is to allow a reduction of the dc-link capacitor. In is proposed for the dc–dc stage a cascade structure of a high-frequency LLC converter followed by a buck converter. The advantage of this configuration consists in a constant switching frequency operation of the active switches of the LLC converter while the charge control is performed by the buck converter. On the other and by adding an additional stage to the dc–dc converter, the complexity and the cost of the converter increases. Finally, in a dc–dc non-isolated buck converter is employed. This latter topology is easy to implement but it works only if the dc-link voltage is higher than the battery pack voltage.

5.9.2 Single Stage

If the ac–dc rectifier is combined with the dc-dc converter, a single stage battery charger is obtained. This topology of battery charger is used if lower cost and size are required in fact single stage battery charger allows the elimination of some bulky and expensive components such as inductors and dc-link capacitors which instead are required in two-stage charger. However, the drawback is that single stage battery chargers with non-isolated converter suffer from a limited conversion ratio, which limits their application for the wide range of output voltage. If instead a high frequency isolation is present, as in the OCB configuration proposed in, the low frequency component generated by the rectification stage pass through the high frequency transformer leading to large magnetizing current. Moreover, to achieve power factor correction, a large number of diodes and active switches could be necessary, increasing in this way the complexity of the configuration and hence decreasing the reliability of the overall charger.

5.10.3 Integrated

To maximize the reduction of components number and hence to further reduce the size, weight and cost of the battery charger several integrated topologies have been proposed and studied in literature. The concept of integration consists of reusing some of the drivetrain components (inverter and motor windings) to implement the onboard charging system. However, some problems may be born from this combination: the configurations proposed in required access to inaccessible points of the motor windings, in a rearrangement of the motor windings is necessary during the transition between differentoperation modes. Finally, by using the charger configuration proposed in, even ifneither access to the neutral point of the motor windings nor their rearrangementare required, the control of the active switches becomes more difficult.

5.9.1 Multifunctional

The last type of proposed OBC is the so called multifunctional OBCs. In this type of battery charger some components are shared to accomplish differentaims. In this way higher fuel efficiency can be reached by smaller and lighter design. In, the proposed multifunctional battery charger can charge the auxiliarybattery via the propulsion battery when the vehicle is in a driving state, acting inthis way as an OBC and as low-voltage dc-to-dc converter (LDC) jointly. In a similar configuration, with the same duties is presented.

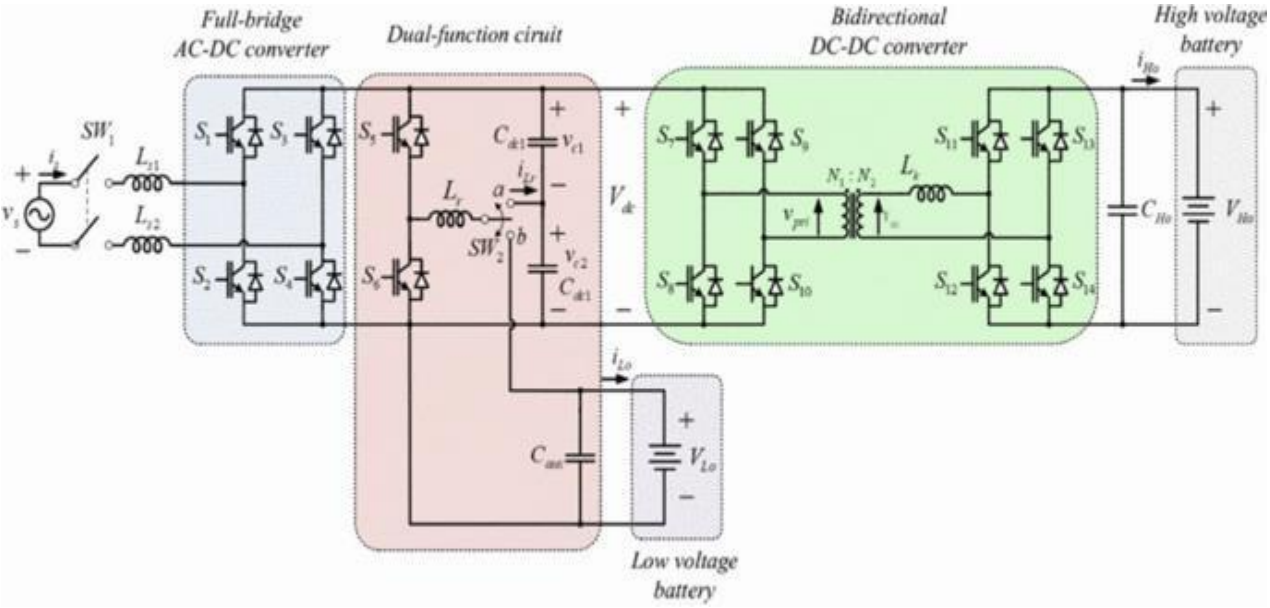


Fig 5.7 Multifunctional OBC

5.11 OFF-BOARD CHARGES

charger, because of their rating powers, are usually installed outside the vehicle (off-board). Also for level 3 off-board charger a large amount of differentsolutions is studied in literature. Since it is mandatory to guarantee galvanic isolation between the AC supply circuit and the DC output circuit according to the IEC EN 61,851–23 standard, in this paragraph only isolated off-board chargerhave been presented. The off-board charging system is most commonly composed of two stages: a grid-facing AC/DC converter followed by a DC/DC converter providing an interface to EV battery. Based on the converter topology,both these stages can allow unidirectional or bidirectional power flow.

5.11.1Bidirectional AC/DC Converter

One of the most widely used bidirectional AC/DC converter is the three-phase LCL active rectifier, whose scheme is reported

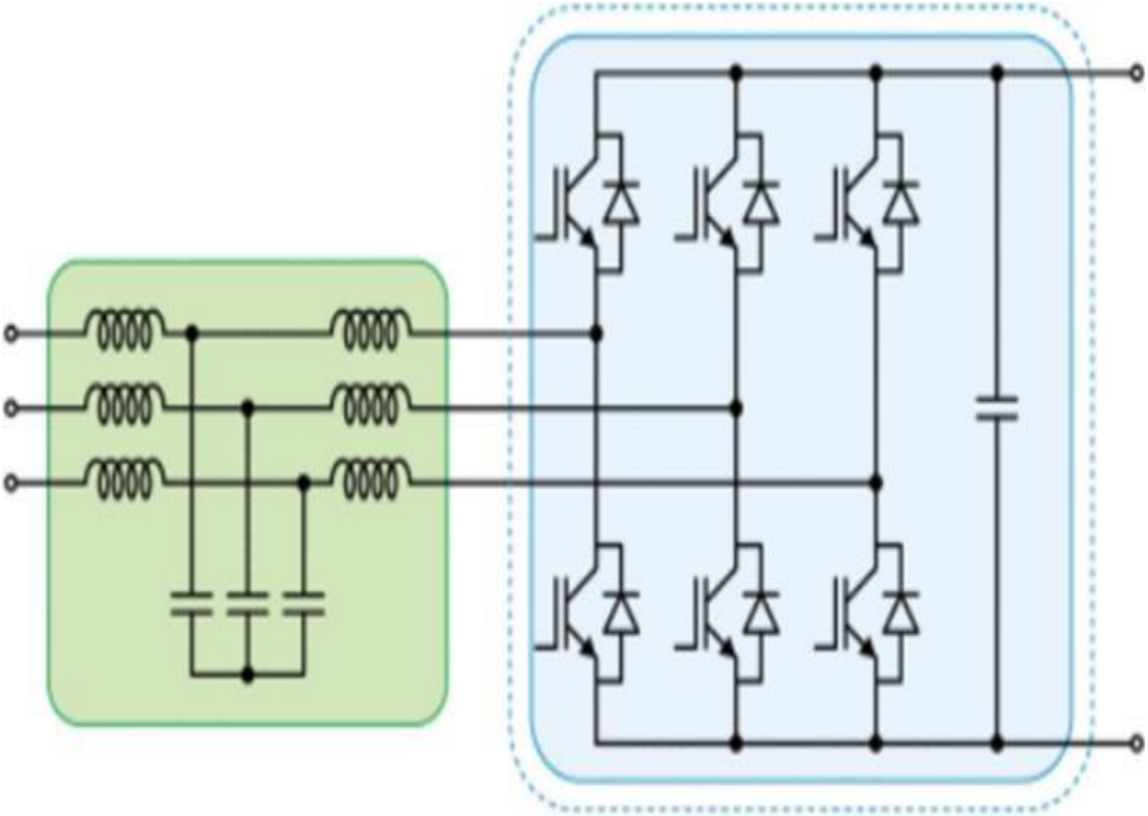


Fig 5.8 Three-phase LCL active rectifier

The advantages of this type of converter are low harmonic input currents, bidirectional power flow and power factor (PF) regulation.In and the front-end ac–dc conversion is performed by a neutral-point-clamped (NPC) three-phase three-level converter. This converter has been used to increase the power density and to achieve low current harmonics distortion. Another advantage is that it allows the creation of a bipolar dc bus which can be used for the implementation of partial-power converters. However, the NPC causes imbalance of power and, as a result, voltage balancing problem across the DC bus capacitors.

5.11.2 Unidirectional AC/DC Converter

The most common unidirectional AC/DC converter used in off-board charging system is the Vienna rectifier. It has advantages such as low voltage stress on each switch and high efficiency. However, the main limitations are the restricted reactive power control and the need of a dc-link capacitor voltage balancing. In the authors propose a 25 kW off-board charger prototype composed by a single-switch Vienna rectifier, as depicted in, and four three level dc/dc modules parallel connected.

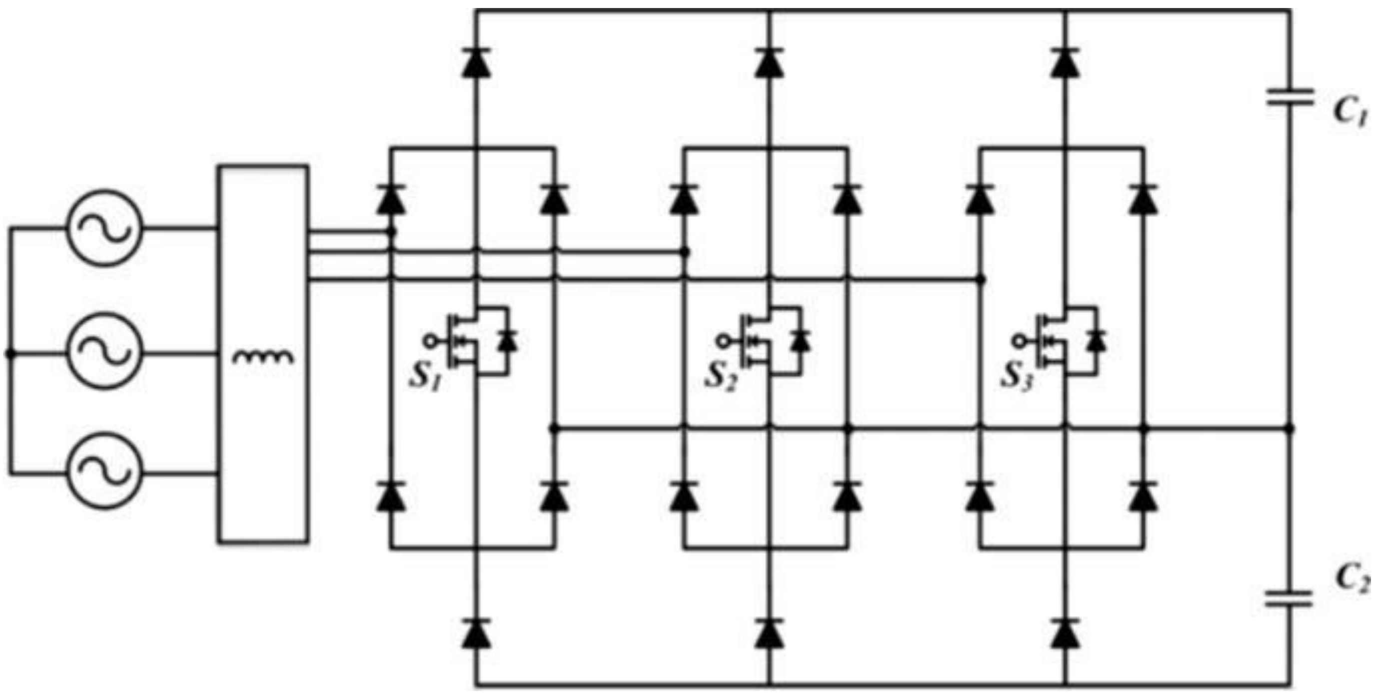


Fig 5.9 A Schematic diagram of Vienna Rectifier

5.11.3 Bidirectional DC/DC Converter

The main isolated DC/DC converter used in case of bidirectional power flow is the dual active bridge (DAB), reported in Fig., and its variants (resonant DAB, multilevel DAB. In particular, this topology is gaining interest thanks to the capabilities of the new wide-bandgap semiconductor (Gan/SiC) devices which enabled the converter efficiency and power density improvements.

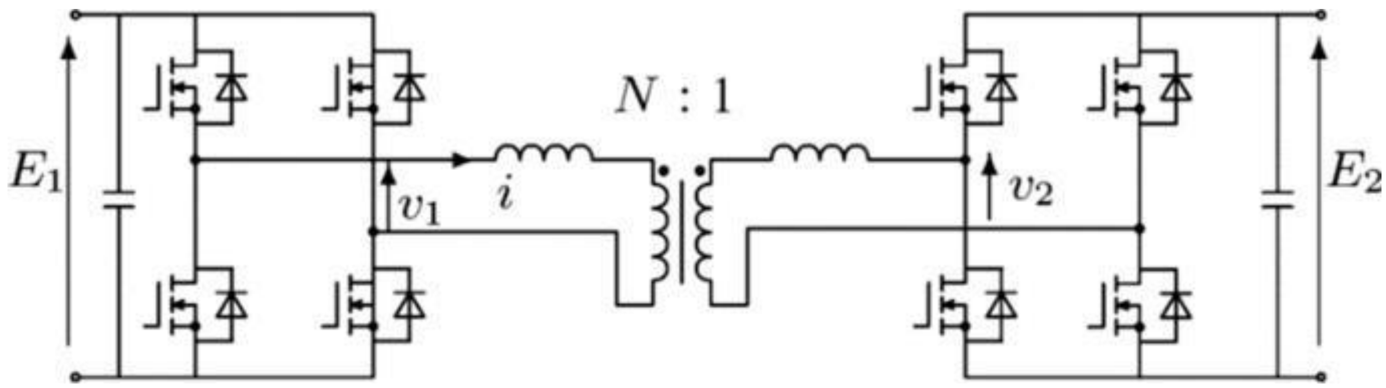


Fig 5.10 A Schematic diagram of Dual Active Rectifier

5.11.4 Unidirectional DC/DC Converter

If unidirectional power flow is required, a LLC resonant converter is chosen, in most cases, as power interface between the dc bus of the AC/DC converter and the EV battery because of to its advantages over other resonant topologies , such as: the ability to operate at zero-voltage switching (ZVS) or zero-current switching (ZCS), it allows a wide output voltage regulation, the output filter consists only of a capacitor and not of an inductor and capacitor (LC) filter .Another unidirectional DC/DC converter used in case of unidirectional off-board charger is the phase shifted full bridge converter, whose scheme is reported. This type of converter has different advantages such as high-power density, low magnetic interference and high efficiency which make it well suitable for the implementation in battery chargers.

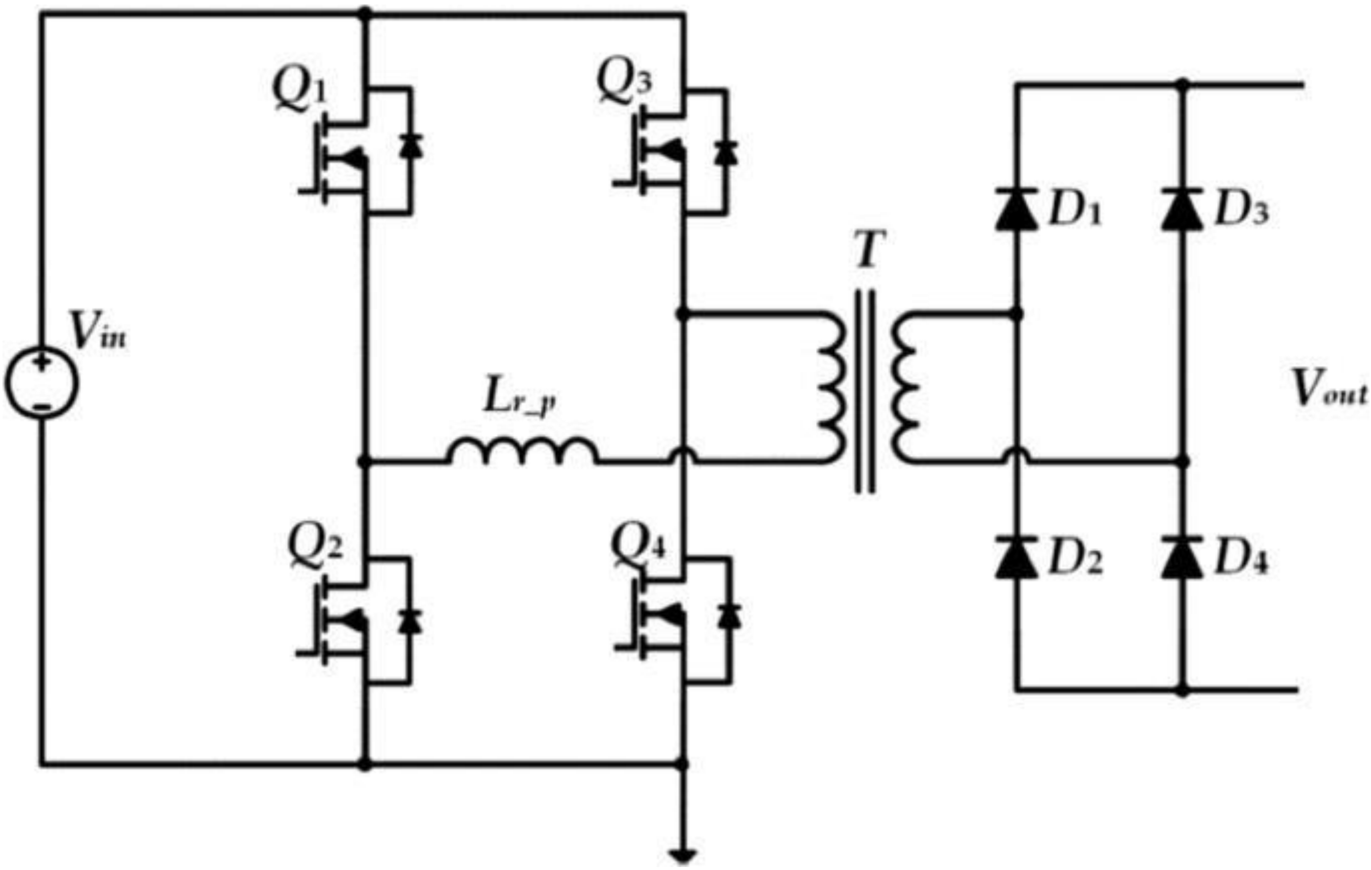


Fig 5.11 Phase Shift Full Bridge Converter

5.12 Fast Charging Stations

To reduce the driving range anxiety and hence to support a stronger increase of the penetration of EVs worldwide there is the need of a charging system which is able to replace the current existing oil station. A fast charging station (FCS) can allow the charging of an EV at 80% within a half of hour fromits depletion, but to reduce the charging time from 7–8 h to 30 min, FCS requireshigh power from the grid and for this reason they are usually connected to the MV network , even if some FCS connected to the LV grid are proposed too. Theconnection of such charging stations requires a huge capital investment, and it could easily overload the distribution network. Another critical aspect to be considered consists in the voltage drop that the connection of FCS can cause along the lines of the distribution networks, which according to the standard EN50160 has to remain lower than 10%. According to the impact of fast charging stations on distribution

MV grid can be mitigated with the use of energy storage systems (ESSs) which can shave peak power demand and provide additional network services. Moreover, ESS can also increase the voltage level in case of too high voltage drop along the lines, this service requires the implementation ofa voltage control.To further minimize the impact of the FCS on the grid, renewable energy resources can integrate within the FCS too. In fact, in normal operation, during daytime, the EV batteries can be charged from the solar PV byreducing in this way the possibility of overloading the MV network. In night- time, instead, when solar energy is not available the EV batteries can be chargedfrom the grid. EVs also can support to the grid at the peak load demand if needed.By this way, the grid will never become unstable with a high pulse power of charging from EVs.

5.12.1Architecture

The configuration chosen in for the ultra-fast charging station is shown. The isolation between the AC side and the DC side is performed by the line-frequency transformer. The ac–dc stage is common to all the EV; in fact, the output of the Cascade H Bridge (CHB) multilevel converter creates a unipolar common DC voltage bus at which all dc–dc converters are connected. The power interface between the dc bus and the integrated storage or the EV battery is performed by an LLC resonant converter. In a bipolar dc bus architecture is proposed. The charging station here adopted is. The bipolar dc bus is necessary to feed the three-level dc–dc converter. On one side, this architecture increases the capability of the FC station and reduce the THD; on the other hand, this system requires a DC powerbalance management mechanism.

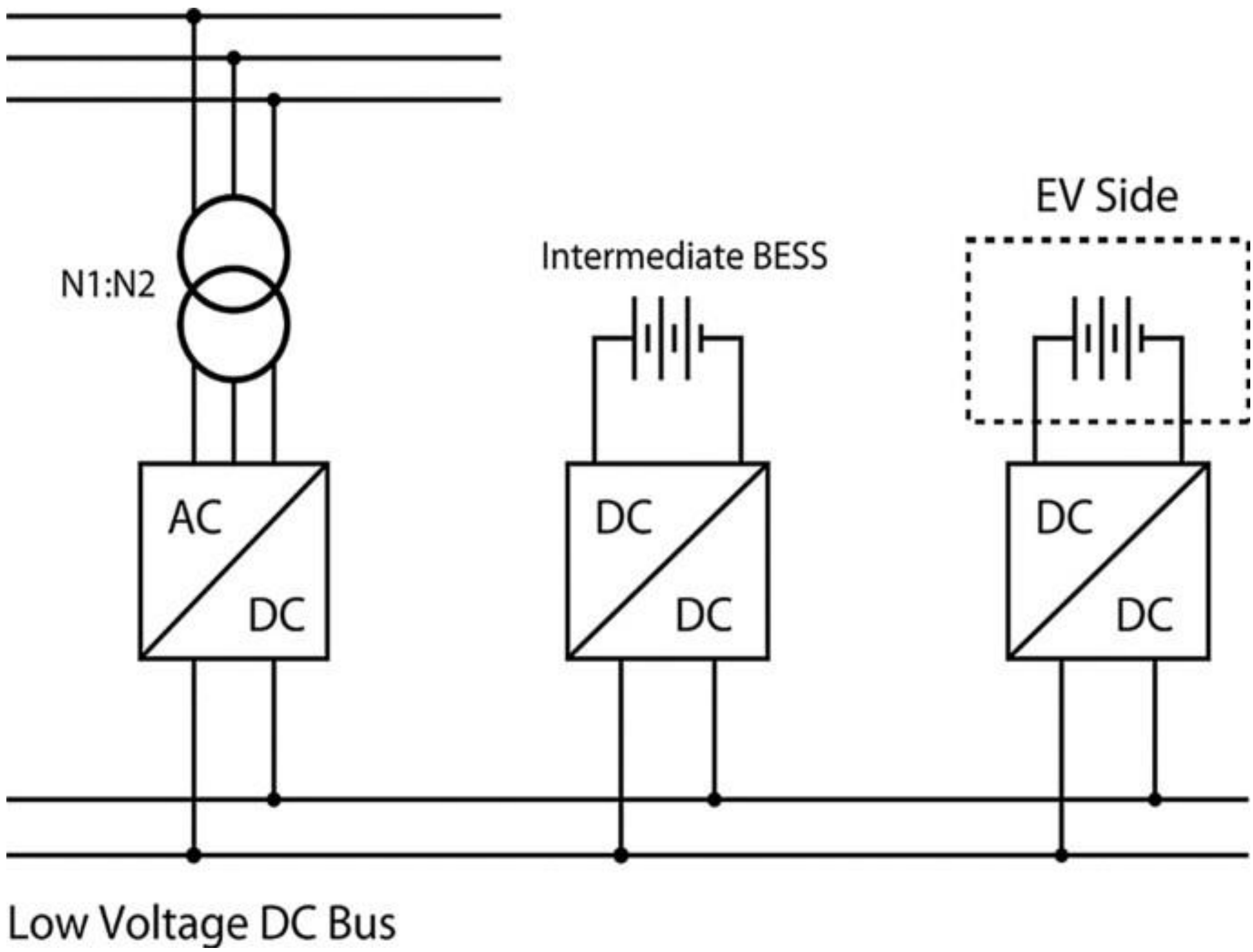


Fig 5.12 Fast charging station with unipolar dc voltage bus

5.13Power Control Strategies

A number of studies have been carried out also on the control strategy ofEV charging station. The first difference among them concerns the choice of uncoordinated charging or coordinated charging. In uncoordinated charging scheme the EV battery starts charging immediately when it is plugged in or after a fixed start delay chosen by the user. If the EVs are charged according tothis scheme, their impact on the grid will result in very high peak demand and hence in huge grid issues such as: feeders and transformers overloading, high losses, high voltage drops, and more cost. For all the aforementioned reasons, the research has focused on EV coordinated charging strategies, in particular.

Authors in propose a coordinated control strategy for an FCS with an ESS, their principal aim is that of reducing the electricity purchase cost and flatten the peak load. In the FCS contains both ESSs and RESs, the coordinated energy management proposed here is obtained by using a Fuzzy Logic based control

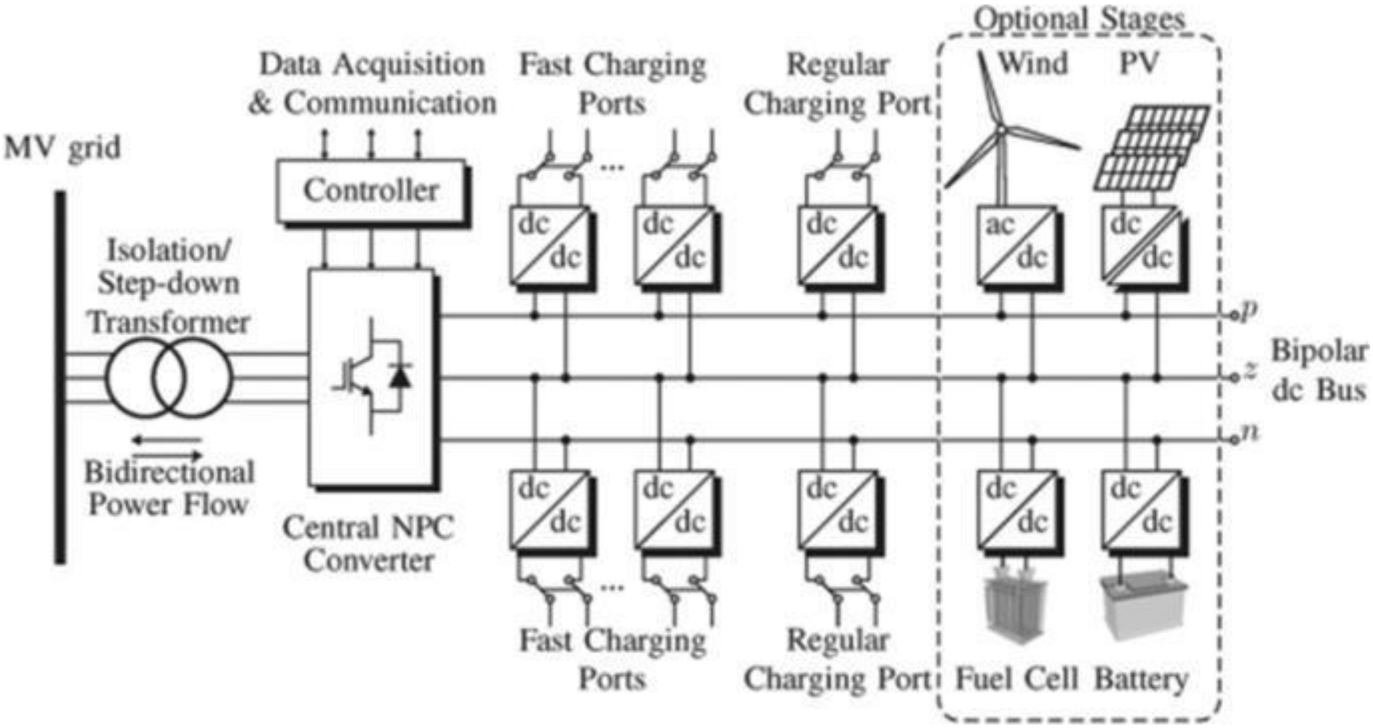


Fig 5.13 Fast charging station with bipolar dc voltage bus

defined by three inputs and two outputs. Other control strategies based on very different and numerous algorithms have been proposed in literature. Authors in investigate and compare three different control strategies for a charging station. The charging strategies coordinate in different ways the energy flow of the ESS and PV panels. The results prove that the control strategy which uses the energy of the ESS within response to the number of EVs plugged in and takes into account also the amount of generated renewable energy has the best performance. Furthermore, according to this control method the SoC of the ESSis restored during night and during excess of solar energy.

5.14Charging Methods

The advantages of a lithium-ion battery over other types of energy storage devices such as high energy and power density, low memory effect and resulting capacity loss, make this type of battery the best candidate for the field of electric vehicles. However, li-ion battery charging must be carried out very carefully, since the charging method greatly affects how actively electrochemical side reactions occur inside the battery, and hence the cycle life of the battery itself. For this reason, finding the optimal technique to charge a battery in the shortest period of time with high efficiency and without damagingthe cells, has become a new challenge for many researchers.

5.14.1Constant Current-Constant Voltage (CC–CV)

In this method, represented in Fig. both an initial constant current and afinal constant voltage are used. The charging process start with a constant current until a certain voltage value, known as cut-off voltage, is reached. ForLi-ion with the traditional cathode materials of cobalt, nickel, manganese and aluminium typically the cut-off voltage value is around 4.20 V/cell. The tolerance is ± 50 mV/cell. Battery charging continues with a constant voltage

just equal to the cut-off value. Full charge is reached when the current decreasesto between 3 and 5% of the rated current. Trickle or float charge at full charge isnot suitable for a Li-ion battery; since it would cause plating of metallic lithium and compromise safety. Instead of trickle charge, a topping charge can be applied when the voltage drops below a set value.

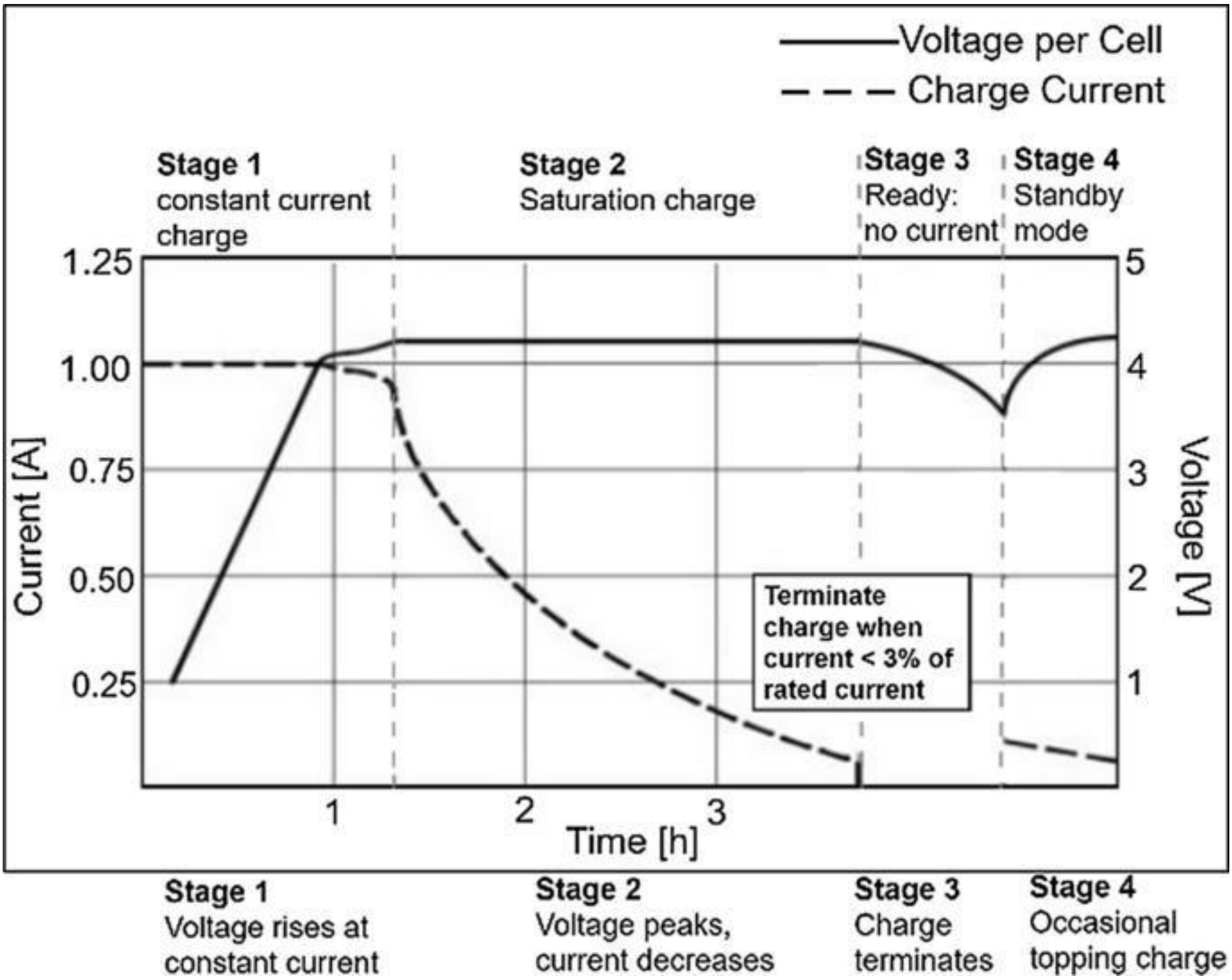


Fig 5.14 A Graph of CC–CV charge stages for a Li-ion battery

In, a little bit different variant is proposed, in fact the first stage consists now in a trickle charge. This stage is activated only if the battery is deeply discharged, i.e., the cell voltage is below 3.0 V and after it the CC–CV method keeps place with the aforementioned way.

5.4.12Five-Step Charging Pattern

An alternative method is here described in order to obtain faster and safer charging and longer battery cycle life. The five-step charging pattern consists in a multistage (five stages) constant-current charging method, in which the charging time is divided into five steps. In each stage, the charging current is set to a constant threshold value. During charging, the voltage of the battery will increase and when it reaches the pre-set limit voltage, the stage number will increase, and a new charging current set value will be applied accordingly. This process will continue until the stage number reaches illustrates the concept of the five-step constant current charging pattern.

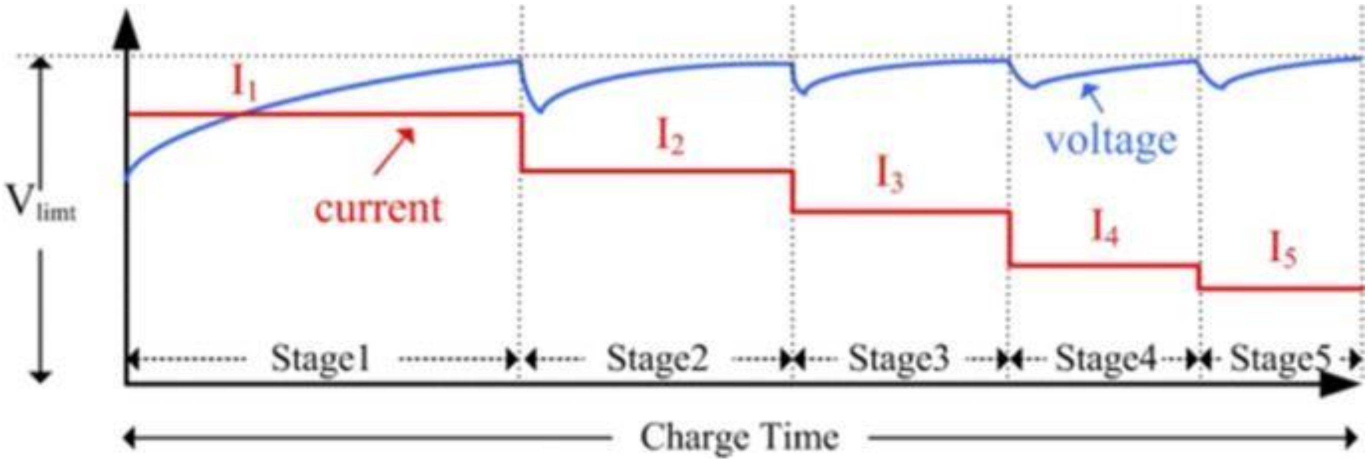


Fig 5.15 Five-step charging pattern for a Li-ion battery

5.12.3 Pulse Charging Method

With this charging strategy the charging current is injected into the battery in form of pulses, so that a rest period is provided for the ions to diffuse and neutralize. The charging rate, which depends on the average current, can be controlled by varying the width of the pulses. It is claimed that this method can really speed up the charging process, slow down the polarization effect and increase life cycles, every pulse charge current that is applied to the battery is characterized by the following factors: peak amplitude I_{pk}, a duty cycle $D = t_{on}/T_p$, and frequency f.

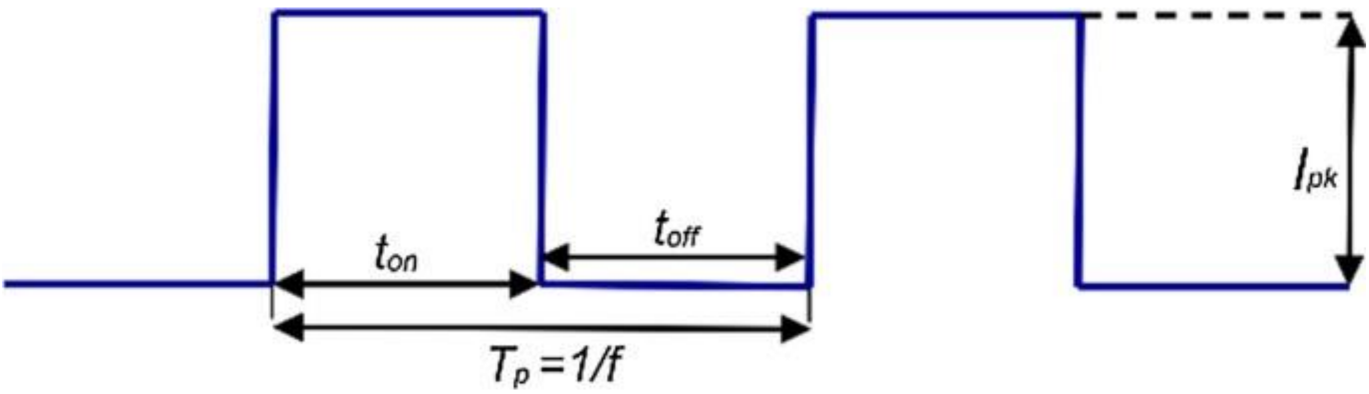


Fig 5.16 Pulse charge current parameters

Two different pulse charging methods exist: duty-fixed and duty-varied pulse-charge strategy. According to the duty-varied strategy can increase the charging speed and the charging efficiency with respect to the conventional duty-fixed method.

5.15 Charging Strategies Based on Battery Physical-Based Models

In all the charging methods reported so far, only current and voltage limitsare considered. Anyway, these limits do not take into consideration the aging process and the side reactions occurring inside the battery; and hence they mightresult too conservative for new batteries and possibly dangerous for aged batteriesdue to the altered behavio and characteristics. This, hence, motivates the development and the research of innovative charging algorithms which tackle the issue of the charging impact on battery state-of-health (SoH) and aging. In fact, recently, many research are focusing on develop new charging methods which minimize the charging time and extend the battery life at the same time.This newcategory of charging strategies employs the electrochemical lithium-ion battery models to calculate quantitatively and almost precisely the amount of battery aging and to directly minimize the aging in a given charge time. The electrochemical battery model estimates the internal states of a battery in a moreaccurate way since it is built starting from the internal microstructure of the lithium-ion battery. However, it is very arduous to precisely estimate the parameters because the electrochemical model is composed of complicatedcoupled partial differential equations (PDEs) and involving a large number of parameters and boundary conditions it requires a large computation burden. Therefore, the complexity of these models often leads to the necessity for more memory and computational effort and thus they may not be practically implemented in the fast and real-time computations of EV BMS.In recent years, many works focus on identifying simplified internal electrochemical models of the battery for efficiently determining the battery operation and hence finding the optimal charging profile.For example, in Klein et al. aim at achieving a fast- charging rate while not excessively aging the cell, using nonlinear model predictive control (NMPC) techniques founded on a single particle model (SPM)of the lithium-ion battery. In the single particle model (SPM) the electrodes are represented by two single spherical porous particles in which intercalation and de-intercalation phenomena take place. However, the variations in the electrolyteconcentration and in the potential are ignored. This electrochemical model is exhaustively explained. Anyway, even if this model is more exhaustive than theSPM one, it is subject to a complicated mathematical structure including PDEs, ordinary-differential equations and algebraic equations. Therefore, the corresponding model-based algorithms can be computationally too arduous to beimplemented in typical battery management systems (BMSs). In light of this, in Zou et al. propose and validate a simplified ODE-based SPMeT model to achievefast charging control. Once validated the reduced model, the authors present a charging strategy based on model predictive control (MPC) techniques which aims to charge the battery in the fastest possible manner, without excessively degrading the battery's SOH.Another widely employed electrochemical battery model is the pseudo two-dimensional model (P2D). This model is constructed based on the assumption that electrodes are seen as an aggregation of spherical particles (2D representation) in which the Li + ions are inserted. The first spatialdimension of this model, represented by variable x, is the horizontal axis. The second spatial dimension is the particle radius r. The cell is comprised of three regions that imply four distinct boundaries. The full description of this model canbe found. Finally, in the authors present an effective method to estimate the parameters of the P2D model using a neural network-based estimation scheme. The electrochemical battery model estimates the internal states of a battery in a more accurate way since it is built starting from the internal microstructure of thelithium-ion battery.

CHAPTER-6

CONCLUSION

In this paper, a wide range high voltage gain bidirectional dc-dc converterfor V2G and G2V applications is presented. This converter benefits from high step-down and high step-up voltage gains, high efficiency, low rating of switches, having common ground and bidirectional capability. The proposed converter hasutilized a dead-beat controller which ensures

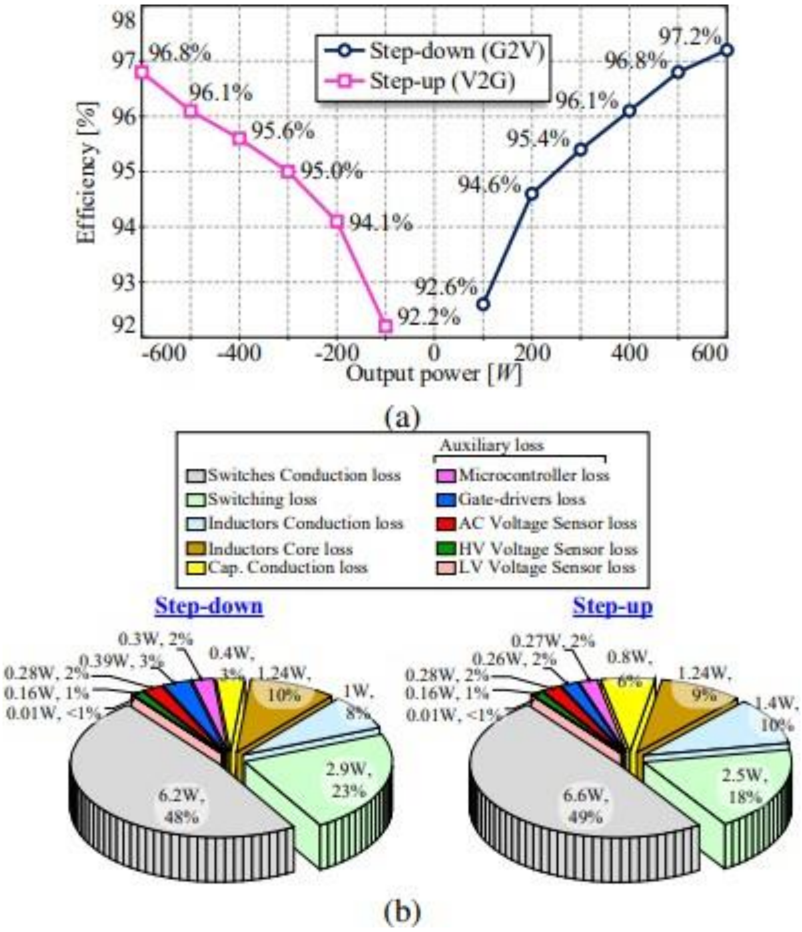


Fig 6.1 Proposed converter (a) efficiency curve, (b) calculated loss breakdown for step-down (left) and step-up (right) modes.

Smooth and accurate current control for both directions of operation. The charge and discharge of the battery has been successfully demonstrated under both directions using the developed prototype. The proposed EV charger has a maximum efficiency of 97.2% at VLV = 40 V, VHV = 200 V, Pout = 500 W, and fs = 50 kHz. The measured waveforms from the prototype have validated the analysis and operation of the converter. The advantages of the converter in terms of wider voltage range and higher SUF make it a more practical and versatile topology compared to previously published converters.

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