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To cite this article: M. Bharathidasan and V. Indragandhi 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **906** 012006

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Review of Power Factor Correction (PFC) AC/DC-DC Power Electronic Converters for Electric Vehicle Applications

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Abstract: This article fully discusses the general review on power factor correction of single-phase AC/DC-DC power electronic converters for electric vehicle applications. To magnify power quality in the declaration of Power Factor Correction (PFC) make the proposal of assorted for demand of solid-state DC-DC converters. These converters are look forward to minimize the Total Harmonic Distortion (THD) at the both input and output side and then to synchronize the DC voltage in DC-DC converters representation of both Uni/Bi- Directional power flow are analyzed. A complete review of Improved Power Quality Converter (IPQC) configuration, design feature, and specific value of selection are presented in this paper. The battery charger necessity to have a converter flow of power ability, a solution needs for an on/off-board charger of an Electric Vehicles (EVs).Due to high power density and efficiency, a DC-DC converters is preferred for medium power and high voltage applications, the most attractive feature of DC-DC converters that makes it suitable for handling medium power supplies is its soft-switching capability. This paper is aimed to research, design and to improve the working applications on clean energy and smart grid field.

Keywords: DC-DC converter, Uni/Bidirectional converter, Power Factor Correction (PFC), Total Harmonic Distortion (THD), Electric Vehicles (EVs)

1. Introduction

Over the last years, research on power factor correction AC/DC power electronic converters techniques have been thoroughly rising. These rectified power electronics converters are generally utilized in various applications like telecommunication equipment, battery charger, medical, industrial machinery, military, etc. The charging is mostly encouraged by unidirectional charging of the battery that keeps up a single flow of power mode grid to vehicle. Conventional electric vehicles are analyzed only as a load, still now they consume grid power to EVs for recharge the battery. The power factor correction division can be successfully achieved by applying a boost inductor and diode with a transformer and power electronic switch specifically. When the grid line is provided, the PFC step employ as a half-bridge converter which operates [2] likes the conventional boost PFC converter.

Two PFC switches share the inductor input during both the half period or cycle, which results in minimized switching and conduction losses and then minimize the charger size and cost [6]. The grid collects the power from both renewable and non-renewable energy sources. The technique state helps to connect the vehicle to the grid network which intern helps the grid to connect with the battery of EVs and permit bidirectional power flow between them. During flow of power in each direction, a soft switching is achieved and it is keep all over operation range, without any additional component [7].Consistently, a bidirectional link having the ability to match with variable level of voltage is needed between the source and load (EVs), the battery will be charging while producing low harmonic current and to consume the power of battery reverse to the grid under act. Here, converter of power electronics employ as voltage of grid to rechargeable dc voltage and inversely. The representation of Bi/Uni-directional converter has shown in figs. 1& 2 accordingly. However, using unidirectional converters will result in increased by system weight, volume and cost. With the modern

development in solid-state topology, bidirectional converters only favour for electric vehicle application.

Nomenclature			
AC	Alternating Current	HRPWM	Hybrid Resonant Pulse width modulation
ACM	Average Current Mode	IPQC	Improved Power Quality Converter
ANN	Artificial Neural Network	HUT	Hold-Up Time
A-PWM	Asynchronous Pulse Width Modulation	IVFF	Input Voltage Feed Forward
ASLFR	Adaptive Sliding mode based Loss Free Resistor	LLC	Inductor –Inductor- Capacitor
		LMS	Least Mean Square
BADC	Bidirectional AC-DC converter	MBLPOL	Modified Bridgeless Positive Output Luo
BHB	Bridgeless boost Half-Bridge	MC	Matrix Converter
BL	Bridgeless	MLC	Multilevel Converter
CC	Constant Current	MOSFET	Metal Oxide Semiconductor Field Effect Transistor
CCM	Continuous Conduction Mode	MPPT	Maximum Power Point Tracking
CICM	Continuous Inductor Conduction Mode	OBC	On-Board Charger
CV	Constant Voltage	PEI	Power Electronics Interface
CVM	Constant Voltage Mode	PEV	Plug-in Electric Vehicles
DAB	Dual Active Bridge	PFC	Power Factor Correction
DBR	Diode Bridge Rectifier	PFM	Pulse Frequency Modulation
DC	Direct Current	PI	Proportional- Integral
DCM	Discontinuous Conduction Mode	PLL	Phase-Locked Loop
DM	Differential Mode	PP	Propulsion
EMI	Electromagnetic Interference	PV	Photovoltaic
ESS	Energy Storage System	PWM	Pulse Width Modulation
EVBC	Electric Vehicle Battery Charger	RB	Regenerative Braking
EVs	Electric Vehicles	SEPIC	Single Ended Primary Inductance Converter
FB	Full-Bridge	SiC	Silicon Carbide
FC	Fuel Cell	Si	Silicon
G2V	Grid –to-vehicle	SPV-SVC	Solar Photovoltaic Standalone Voltage Control
HB	Half Bridge	THD	Total Harmonic Distortion
HESS	Hybrid Energy Source System	V2G	Vehicle-to-grid
HF	High frequency	ZCS	Zero Current Switching
HFT	High frequency transformer	ZVS	Zero Voltage Switching

This paper reviews the different converters of power electronic techniques that have been reported for electric vehicle applications. Different methods of charging/discharging systems have been developed. All of this order has been viewed in this paper along with the current concepts of EVs charger /discharger. This paper is sort out as follows: segment 2 reviews the converter techniques of Uni/Bi-directional, Segment 3 discusses the different Power factor corrections techniques, Segment 4 studies the different methods of charger and discharger systems, Segment 5 presents the design of DC-DC converters for EVs and Segment 6 Remarks of this paper is concluded.

2. Uni/Bi-directional converter

The initial stage of the converter, needed for smooth bidirectional AC-DC power electronic converter and power factor correction. Although more than a few recent researches focus on applying a single rectifier to reduce the losses, component count and cost of the system and also to increase the efficiency. A large number of literatures have been reported with help of AC/DC-DC converter for application of EV.Generally, a bidirectional converter is employed at two methods of current control. In grid side, a sinusoidal Pulse Width Modulation (PWM) is created with help of the indirect current control method of PWM control. The closed current control loop is agonizing from quiet performance of transient and dc component showing in the grid side. The indirect current control method has some disadvantages can be eliminated. Discontinuous Conduction Mode (DCM) that involve of two closed

control system – the inner current loop is used for to control the inductor current and the dc voltage is stabilized in a outer voltage loop. Indirect control method is treated for to increase the system performance (Static and dynamic) in [1]

2.1 Bidirectional AC-DC converter

The Bidirectional AC-DC converter (BADC) employ as a rectifier and inverter mode as required by the system. In AC side, the total harmonic distortion and power factor correction of BADC is achieved with IEEE standard, dc voltage Bidirectional converter in between two levels, with the ability of bidirectional power flow on modulation topology and control algorithm to secure soft-switching each operating span of the converter in[7].The important function of BADC can be precisely stated as follows: 1) Primary side switches by use of Zero current turn-offs and 2) Secondary side devices by use of Zero current turn-on, each operation without any extra components for battery charging application. For EVs charger existing of half-bridge converter of current fed on the input side and full-bridge converter on the output side, with transformer of high frequency in the middle of supplying galvanic isolation as mentioned in [7]. As a result, current fed technology supply a high current profile on the AC side and IEEE 519 standards of Total Harmonic Distortion (THD) is achieved.

The advantage of bidirectional DC-DC converter has an easy circuit with less component count that provides a wide range of voltage gain, a command ground and less stress of voltage. In extension the synchronous AC-DC converter permit ZVS turn on and turn off without anyone additional tools needed and the converter efficiency is developed in [4]. As a Hybrid Energy Source System (HESS) is a combination of a supercapacitor and battery, an electric vehicle is considered as the best way to increase the lifespan of battery and general efficiency of the vehicle. For greater power density, more life period and good charge/discharge efficiency, the supercapacitor with the high voltage dc bus, keep away from any enhancement in current from the battery is used.

The energy storage and converter components are used as perfect, [4] and Continuous Conduction Mode (CCM) is employed in this converter and each the capacitors are more enough, so we consider all capacitor's voltage is fixed over all switching cycle or state. Regenerative braking and acceleration of supply power with the battery meets the requirements for long-range operation of energy storage density. As a result, a very easy circuit, a number of component counts is reduced, gain of maximum voltage, a common ground, minimum stress of voltage, and are achieved.

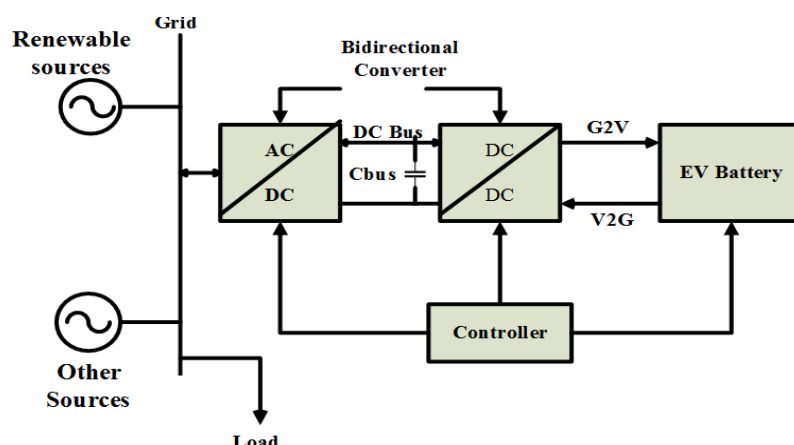The schematic diagram of the bidirectional converter show in Fig.1.

Fig.1. Bidirectional converter for vehicle to grid

To draw sinusoidal grid currents by use of modulated converter, Single-Step Three- Phase AC-DC

Converter in a bidirectional Soft-Switched DAB was presented in [1]. For the application of maximum voltage and medium power, the DAB converter is required, results in: 1) low-loss switching: in ac side ZCS and ZVS at dc side. 2) Without dc-side load current sensing, a power factor correction of open loop input is achieved and 3) the control input or phase shift is proportional to the shifted active power in closed loop control. This uses a strategy of space vector modulation and rectifier followed by converter of DAB, [10] control loops are needed in [27] bidirectional T-type Multilevel Converter (MLC). When the average of current inductor is greater than its ripple, the converter of boost is worked at Continuous Conduction Mode (CCM).To minimize the voltage stress and more-frequency period - by- period voltage balance at power switches and originate a maximum output voltage magnitude make use of power electronic switches with half of the maximum opposite voltage. More switches and capacitors are required in T-type MLC, to balance the voltage and also increase the switching and conduction losses.

Calculation of high frequency inductor, the total losses in the transformer and the conductor losses in primary and secondary bridge are has been presented in [10] due to bidirectional power flow ability , loss-less switching, and high power density, the present solution may list out a favorable solution for vehicle to grid application. Increased power density by use of the switching frequency and loss-less switching of the converter.

2.2 Unidirectional converter

The unidirectional converter circuit, shown in fig.2. The charging pattern encouraged by battery chargers of unidirectional that maintains up a single power flow way source to load, the electric vehicles are analyzed only as a load on the power system, still now battery is recharged from a grid power.
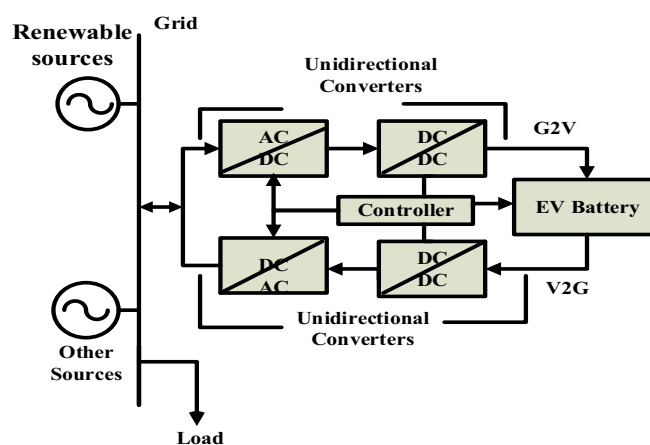

Fig.2. Unidirectional converter for electric vehicle

3. Power Factor Correction (PFC)

The converter of in active step up PFC use as the efficient HB converter during the Hold-Up Time (HUT), it can be operated normal state only, [2]. High current stress, high voltage, and Electromagnetic interference (EMI) noise due to the reverse recovery problem of Diode are reduced by using ZCS. The converter of HB-LLC is obtained normal dc-link voltage at the normal state PFC, during Hold-Up Time (HUT), converter of bridgeless boost PFC is inactive, which help to cover maximum voltage range. The converter of HB-LLC operates at normal state is designed with variation of limited switching frequency and large magnetizing inductance and without the aforementioned drawbacks. To decrease the conduction loss by use of PFC step boost transformer, the efficiency also slightly improved by using this converter.

3.1 Hybrid Resonant PWM Bridgeless AC–DC Converter

For sensing positive and negative input ac cycle operation, the converter does not required extra circuitry due to sharing a gate signal to all PWM switches. The operation mode of hybrid resonant boosts the problem of reverse recovery for the PWM switches. To improve the reliability of the system by limiting inrush current and improve the efficiency. A bridgeless rectifier PFC converter of a hybrid resonant pulse width modulation is similar to a boost converter. By eliminating the problem of reverse recovery with PWM switches of body diode, principle operation, design, and analysis of the converter is explained in [5]. To achieve power factor correction by use of boost converter of single – step working in a Continuous Conduction Mode (CCM), the system efficiency is improved and minimizes the conduction losses by the use of CCM. The PFC is reached by the use of average current control mode, which enables surge protection and allows simple implementation of lightning of system.

3.2 Hold-Up Time operation of DC-DC full-bridge converter

As a requirement, DC-DC Full-Bridge converter of ZVS must also take care of PFC by interleaved boost converter and total harmonic injection is obtained from the grid. An important aspect to be considered of this converter is to reliably expose the possibility grid zero voltage switching. This can conduct to voltage waveform, current waveform, efficiency, and Hold-Up Time (HUT) operating waveforms as in [8]. In rated input, converter is controlled with help of the variable frequency and the phase shift control and operation of HUT. DC-DC Full-Bridge converter of ZVS is operated under variable control methods were analyzed and described in detail in [8].
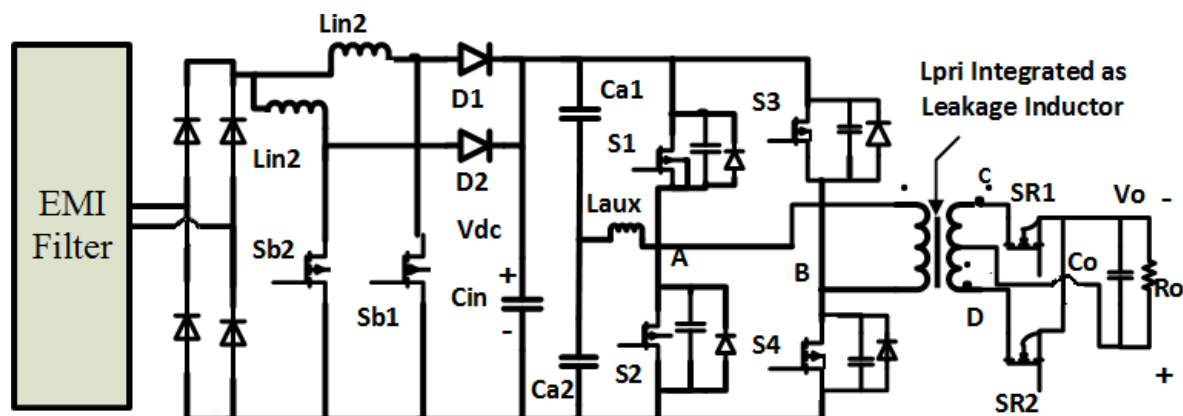

Fig.3. Complete implementation topology of Hold-Up Time operation of DC-DC full-bridge converter [8]

The DC-DC converter with HUT ability, reducing the losses and dc-link storage capacitance, thereby increasing the reliability of the system. **.**Complete implementation topology ZVS converter of DC-DC Full-Bridge with Hold-Up Time is shown in fig.3.

3.3 A Soft-Switching Bridgeless AC–DC Converter

A soft -switching, bridgeless boost converter for PFC for power supply and battery charging application is presented in [3]. The integrated converter functions as an in pulse width modulation and resonant mode one and all switching cycles that make use of average current control. Design analysis and working principles of ZVS HRPWM converter have been reported in [3].A continuous conduction mode and the achieved ZVS is used for minimizing losses of switching and system efficiency is increased To increasing reliability of the system due to minimize the PWM switches turn-off losses and neglecting switching losses that also reverse recovery losses is minimized by using diode output employ with controlled di/dt turn off and THD, and battery heating is limited in the operation of

power quality.

3.4 Modified Bridgeless Positive Output Luo Converter

In output side, defined DC voltage is maintained and power quality is increased at the input side, it can be reached by design control of a modified bridgeless positive output Luo (MBLPOL). In input side a Discontinuous Conduction Mode (DCM) is applied for PFC with a minimum riddle, a single voltage sensor with a circuit of feedback control and to manage the DC load voltage for supply voltage and various load condition is implemented for PFC. A design, working principles, and testing point are discussed in [13]. Unity power factor is maintained with rated load and supply current total harmonics distortion is reduced. This can lead to voltage and current waveform, THD is in [13].

3.5 Single-Phase/-Step Buck/Boost converter

Rectifier technique is obtained for the plug-in electric vehicle application of on-board battery charging, assumed from converter of buck-boost pulse width modulation. The power factor correction (PEC) is designed for the following factor (a) Dc link voltages ripple (b) Damped input filter less influences (c) inductive current ripple is converter operation. A differential mode (DM) filter is used to reach a great converter performance as it takes on less output impedance with high –frequency attenuation. A two fast current control loop is used to manage PEC. The design and implementation a single-step/phase PWM PFC rectifier of control stragies and battery charger topology have been discussed in [20] to present maximum efficiency, power density, and power factor. The schematic structure of single- step/phase AC-DC unidirectional buck-boost topology shown in fig.4.

As a result, in full load condition, to achieve, maximum power factor and efficiency, the switching and conduction losses are analyzed in [20].In single state topologies with employed power processing, to minimize area and weight, because it is a transformerless techniques and minimum number of modules are employed. An operation of PFC is an analysis of the worked rectifier has been performed [20], and more conduction step, operation section, control strategy and explanation of the modulation structure.
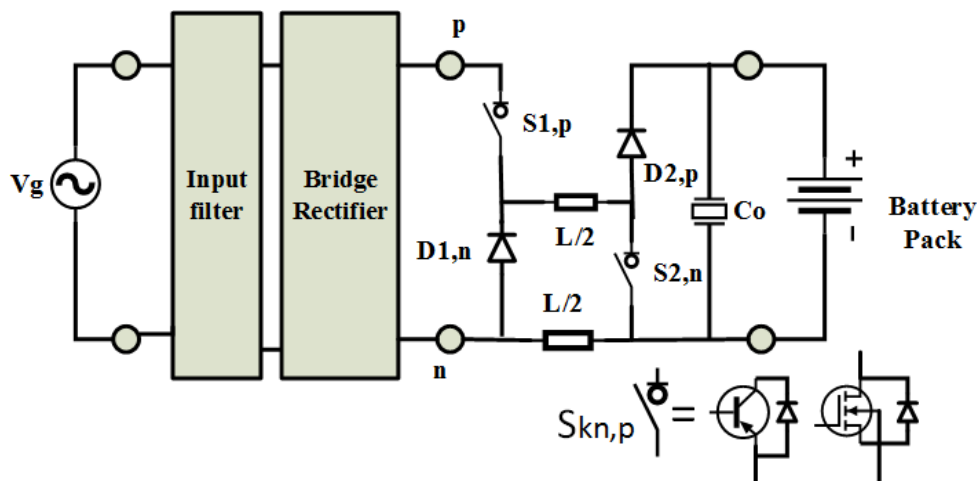

Fig.4. Schematic diagram of single-step/phase AC-DC unidirectional buck-boost topology [20]

3.6 Power Electronic Interface

The Power Electronics Interface (PEI) converter obtained from a secondary ended primary inductance isolated converter is developed to work productively in battery charging, Regenerative Braking (RB) and propulsion (PP). To optimize the power factor correction using continuous conduction mode,

MPPT is applied to take out the maximum number of power with help of this converter for battery charging from solar photovoltaic sources, this neglect the required of another DC-DC converter through operation of charger for MPPT. The solar photovoltaic and grid based converter of isolation, controller design, control algorithm, comparative analysis, and operation of PP and RB have been presented in [6] for battery charging and reducing conduction losses.

As a result, the charger has low stresses and increasing compactness of the charger and also construction, it is the greatest solution for the onboard battery charging application. Moreover, the PEI carries out buck/boost operation effectively, without any design modification for all vehicle modes. Because of this, due to availability of charging point the battery will be charged. The characteristics of the Photovoltaic (PV) panel, grid voltage and current shows in [6].The battery charging/discharging conduct to attain power and load levelling together with increase in system reliability. To encourage a uninterrupted power to the grid, hence increasing the possibility of the Battery Energy Storage (BES) hold up to the system, converter of voltage source perform as an active power filter and carry out the mitigation of harmonics with compensation of reactive power, a special control is expanded [9] due to mitigation of failure ,grid to be reconnected. To keep an uninterrupted power supply to the load with help of Phase-Locked Loop (PLL), maintaining the power balance, and increases the battery lifespan through the attainment of the operation of the system. The switches are controlled in zero crossing voltage and current. Solar Photovoltaic Standalone Voltage Control (SPV-SVC) is obtained to maintain an endless power to the loads. Instantaneous quantities of proportional –Integral and load current is taken out appling adaptive filtering along with the LMS algorithms in [9].

3.7 Bridgeless Isolated SEPIC Converter

Restriction of efficiency in an EV battery charging due to more condition losses correlated with a DBR at input side in a conventional Power Factor Correction (PEC). To diminish this issue, a great power quality with a Bridgeless (BL) Single Ended Primary Inductance Converter (SEPIC) is given in [14].During charging mode, the current input display a operation of unity power factor. To achieve greater power density and high efficiency, using the operation of Discontinuous Conduction Mode (DCM) with BL isolated SEPIC converter has been analyzed in [14]. Due to constant current /constant voltage control mode the current of battery is controlled. A control topology of PWM create the need gate pulse for the converters by emulate the current of output managing a cascaded both Proportional-Integral (PI) controller to give the response of fast dynamic loop, saw tooth carrier and minimum number of steady state error.

As a result, conduction losses and conduction of current through less number of devices are crucially reduced by eliminating BDR.To improves the efficiency and intrinsic PFC thus, enhances the complete performance of the charger. A charging technique is existence of a usual inductor input in the course of all the half period. Two switches are sharing the inductor input and as solution, minimize the battery charger size and cost.

3.8 Bridgeless / and switched inductor Cuk Converter

A DC-DC converter with common voltage input comprises of a boost converter for PFC during the two-step converters for battery charging of electric vehicle. This two-step conversions conduct to increased component count and poor efficiency, A Bridgeless (BL) Cuk converter based Electric Vehicle (EV) battery charging with great power quality, maximum efficiency is developed and implemented in [11]. By eliminating DBR, to reduce the additional conduction losses and this charger absorb a minimum number of devices running over period of one switch. Hence, it is increasing the charger's efficiency. To keep the desired charger current throughout the battery followed by the CC & CV charger regions, the instructions are synchronized by a flyback converter.

To improve efficiency, high stage down gain, less current stress, and power electronics component count is minimized in PFC converter based a single-step switched inductor Cuk converter is applied in this scheme. The design equation, operational analysis for different items of cuk converter are follow up in Continuous Current Mode (CCM) using a multiplier approach of current that has been presented in [21] concerning power quality sign like voltage THD and current THD. The DCM of action in BL cuk PFC converter is designed in [11], control of voltage follower mode is used, it is developed using PI controller no circulating current succeeding through the inductor inputs. Due to cascaded dual PI controller, converter of flyback is controlled and output of controller to supply CC charging to the each operating condition of battery. Completely charged the battery in CV mode at the end area of all period and the drawn source of current is cut down to completely charged condition of battery depicting value is less.
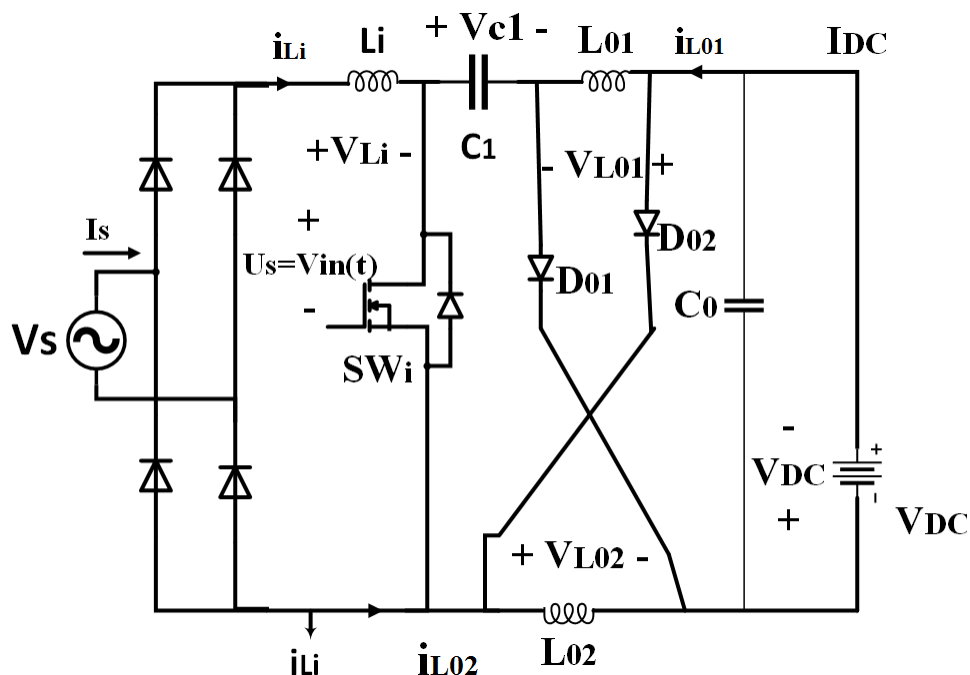

Fig.5. Circuit diagram of Switched inductor Cuk converter. [21]

The DCM, due to voltage follower approach, the scheme of control is minimized by need of sensor and converter of output voltage is sensed by quantity.BL cuk converter based charger extract a sinusoidal current from the ac main and THD in the current of supply is minimized. Undesired conduction by the diode body of the idle switch in the earlier on advanced converter of BL cuk is ignored, also unpopular coupling of capacitive loop is erased and minimize the number of components count over one switching period. This significantly increases the efficiency of charger's. To reduce voltage stress and low output voltage on devices, a transformer may be need, which is more prices, mainly if galvanic isolation is not needed. Cuk converter by dividing inductor into two equal inductors and rectifier diode into two diodes. Here frequency of supply line is lower than the frequency of switch. The total power factor is follow out with different methods of battery load and resistive load in one and the other CC and CV mode.PFC converter is successfully developed, the following assumptions are create in [21].Circuit diagram of switched inductor Cuk converter show in fig.5.
As a result, large voltage ripples in the intermediate capacitor, current stress in switch, and voltages of the battery are notice to develop during this cycle. And also to reduced conduction losses, switching losses, diode conduction losses, and input inductor losses and increased efficiency can be noted. This topology consists of two converters, first-step cuk converter for PFC by working in the converter of

LLC resonant, while the CCM of the primary inductor and the second stage the CVM and CCM control algorithms are operated for essential charging of EV battery. To minimize the turn off losses in LLC converter, the converter employ a control algorithm of frequency to actively change the dc-link voltage based on the state of the battery. The benefit of cuk converter of the control algorithm based LLC resonant and phase-shifted zero voltage switching converters are presented in [23] used for high power fast charger. As result, the input current of harmonic free is realized by pulse width modulation (PWM) control of the cuk converter utilizing a two-loop design, neglecting any battery charging risk by use of LLC controller, to minimise turn off losses & switching losses, less LLC transformer flux density and then to increase efficiency.

3.9 Three-level topology

To minimize the size of inductor filter and switching losses considerably in a [37], full-bridge (FB) BADC operating an asymmetrical three-level circuit. The FB- BADC is created by the power switches and the asymmetrical three-level converters are also created. As can be seen from the figure, to charge the battery from asymmetrical three-level converters, thus minimize the power losses and rating of the alike BDC. The BADC is employed with the help of sinusoidal PWM techniques. As a result, achieving a high efficiency either controlling methods for a more voltage selection is done.

3.10 A Modified Luo Converter

To increase current and voltage through the semiconductor in terms of single step/switch PFC a modified isolated Luo a high power AC-DC converter based EVs charger two switches and enclose clamped diodes at High-Frequency Transformer of primary isolation is used. A modified negative output Luo converter fed EV charger with minimized voltage switch is shown in fig.6. Minimize the complexity of control due to minimum number of sensors in the operation of Discontinuous Conduction Mode (DCM) at a modified Luo converter have been in [15], to obtain PF correction capability at sources side. Constant Current (CC)-Constant Voltage (CV) modes provided operate at better low ripple based charger and increase the long term battery service life.
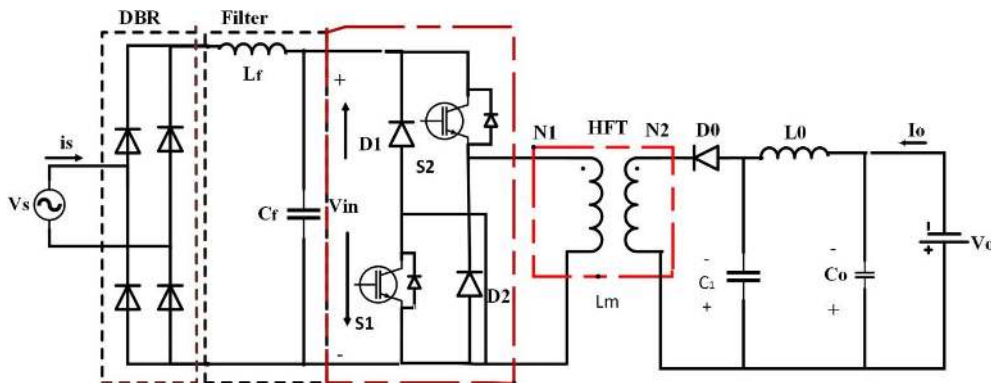

Fig.6. Modified negative output Luo converter fed EV charger with reduced switch voltage. [15

The limitations of high ripple, high component stress and high voltage stress by use of single-phase/stage PFC based EVs charger. Which in turn, result in lesser efficiency and conduction loss is very low since the conduction of line diode in all switching period are bisected. This can lead to voltage and current waveform and THD are in [15].

3.11 A Bridgeless Boost Half-Bridge DC-DC Converter

The characteristics of bridgeless, it is a single-step and galvanic isolation, converter input is permit to accurate the power factor , to encourage ZVS for all of its switches by the Asynchronous Pulse Width Modulation (A-PWM) in more to keeping a minimum semiconductors. a Bridgeless boost Half-

Bridge (BHB) DC-DC converter as a battery charging for electric vehicle is designed & operated, as well as the loop control will be presented in [18]. A control structure has been controlled by an average current of conventional, keeping a compact adjustment in [18]. As a result, obtaining a minimize the number of semiconductor and losses increase the efficiency.

3.12 Matrix Converter based topology

Matrix Converter (MC) is a combination of DC-AC and AC-DC converter; it is simply called a direct AC-AC converter and straight converting high-frequency ac voltage to power frequency ac grid and power frequency ac voltage to high frequency ac voltage. To achieve high frequency in the condition of ZVS, each power devices turn-on below ZVS state and turn –off below AVS situation. For greater reliability, greater power density capability, reasonable THD, simple control strategy, fast response, and fast charging of the EV, the BADC is recommended. The downside for the considerable problem in the configuration model needs sixteen power devices for it's in action and tolerate from less-frequency ripples attended in the battery current charger. An isolation transformer-based single phase full – bridge converter has been detailed in [38].

Current Trends

The channel resistance and less output capacitance of Silicon Carbide (SiC) power devices along with more voltage closing ability can allow maximum operation of frequency, less reverse recovery charge, high power density and good thermal characteristics [32].

3.13 A SiC-Based LLC converter

 In the LLC converter can work in closeness of resonant frequency and more efficiencies above the maximum collection of battery store voltage utilized in PEV, the dc- link voltage can be actively adjusted. Conventional boost type PFC converters can't supply ultra-wide dc-link voltages, due to conventional constant dc-link strategy of control, Silicon Carbide (SiC) based onboard PEV charging is designed and controller in [22] . LLC converters of resonant are worked due to short circuit, galvanic isolation and soft switching. To keep greater efficiency, when battery voltage is lesser than it's assess voltage at a minimum step of charger it leads to increased switching losses and circulating losses. A sic based converter [22] is minimizing conductor losses & switching loss and have greater efficiency capability. By varying the air gap in the middle of the two slices of magnetic cores due to magnetizing inductance.

The circuit modeling of LLC resonant converter along with converter of SEPIC PFC, a two-step isolated charger is presented in fig. 7, the frequency operation of the LLC resonant converter is put moderately greater than resonant frequency to secure the ZVS running at dissimilar loads. To reach the required voltage gain & lower efficiency, when the battery voltage is under the rated voltage, the switch frequency turning off from the resonant frequency.
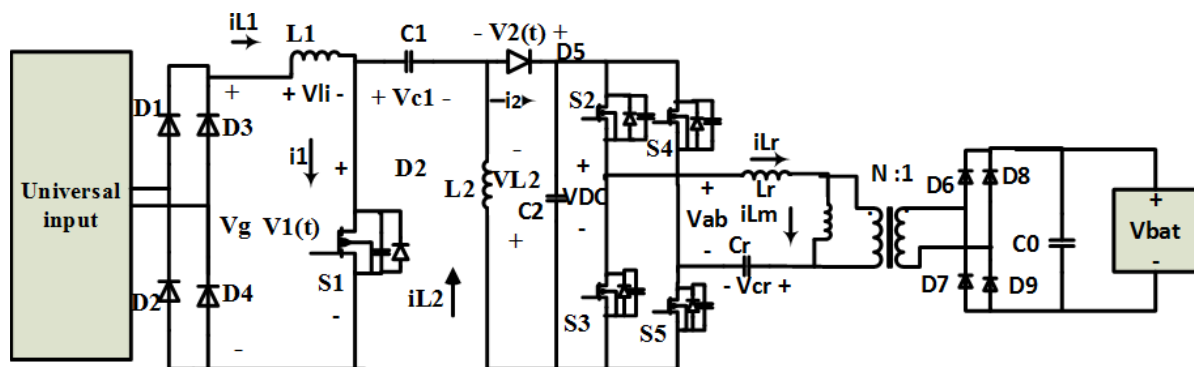

Fig.7.A two-step isolated charging based on SEPIC PFC and LLC resonant converter. [22]

The unity power factor is achieved along with low THD in a SEPIC PFE converter and an increase in overall efficiency of the charger of the rated load to full load.

3.14 A Soft Switched Boost Cascaded-by-Buck converter

A two-step converter couple the input supply of grid to the battery store whose voltage generally vary for different type of vehicle, for maintaining power factor and smooth input current, ZCS boost cascade operated by buck converter and analysis worked in application of PFC in [25].A mixing of resonant capacitor and inductor are managed to generate ZCS throughout turn-off switch. Due to less line input voltage the switching stress is more and size of the components, the boost structured PFC topologies is designed in [25]. As a result, to achieve higher efficiency and keep a power factor, the structure of control loop supply the unfixed DC-link voltage outputs at PFC with general voltage input is designed in [25].

3.15 Boost DC-DC Converter

Generally, the stress of voltage is minimized in the half of the voltage input, the absolute value of voltage gain is 1/(1-d),power inductor and switches are less than those of the more voltage gain in two-step cascaded and three-level boost DC-DC converter, but it's the result of the efficiency of all step ,more voltage stress in output step. A maximum voltage gain but stress of voltage beyond the power electronic switch is similar to the voltage output in an inductor of switched DC-DC boost converter. The single switch with diode capacitor units boost DC-DC converter is a easy structure, the principles of operation, the enlarge step, converter steady state characteristics and operation of fault-tolerant are analyzed and given in [30] and also small-signal sample is derived. The converter is operated at the state-space average mode; the capacitor is charged in parallel and discharged in series. Due to voltage loop control PWM and Proportional –Integral (PI) voltage controllers are adopted in this converter, which provides less voltage stress, less switching losses and voltage gain is more.

3.16 A Step-Up Multi-input DC-DC Converter

The input sources of Energy Storage System (ESS), Fuel Cell (FC) and Solar Photovoltaic (PV) for the step-up multi-input DC-DC converter in [12].
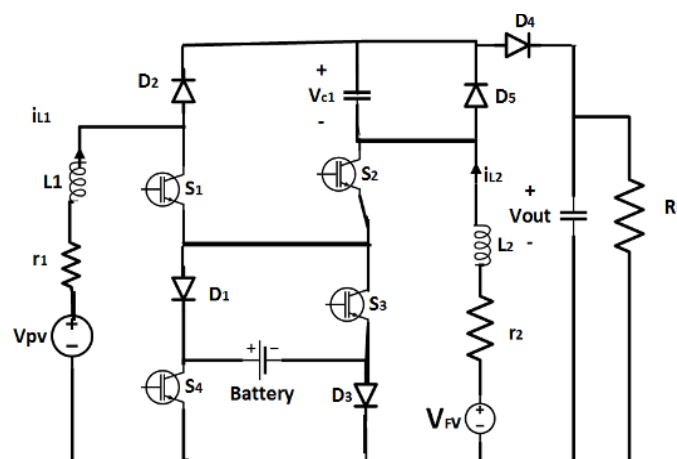

Fig.8. Three-input boost DC-DC converter [12]

The DC-DC converter has the potentiality of arranging the requested power by load in the non-attendance one or more resources. The FC is considered a main source for clean electricity generation, output current ability of high density, and to charge the battery by use of PV minimizes the fuel economy and improve the efficiency. Three-input boost DC-DC converter shown in fig.8. A continuous conduct mode to provide smooth current with minimum current ripple in a multiple-input boost DC-DC converter. The state-space sample is prepared for DC-DC converter modelling and control in [12]. The MPPT is applicable for to obtain the high power from photovoltaic and the system steady state error is neglected with help of Proportional –Integral controller (PI).As a result, the inductor current and switching losses are more in the session.

3.17 Step-Up Resonant DC-DC Converter

The ZVS in two power electronic switches and ZCS in the rectifier diode operation over the full load range to achieve maximum efficiency. To minimize the stress of the component, and also decreases the transformer requirements with the help of interleaved step-up technique. To reach ZCS and ZVS also to extended voltage control with help of series resonant tank, DC-DC converter of more voltage gain boost employing resonant technology has been presented in [16]. It gives the voltage step up through its turn's ratio but brings needed galvanic isolation between the high output voltage and low input voltage, Discontinuous Conduction Mode (DCM).To reach a high voltage gain and high switching frequency in an unregulated LLC topology cascade with a step-up topology.
The limitations of the topology in [16] to reduce copper losses, iron losses and conduction losses, easier flux design, employing an interleaved boost topology, and also in transformer stress of current is minimized and improve the efficiency. In voltage gain, uniform operation of the interleaved topology, in resonant mode component stress and power loss. For operation mode of D=1/2, since the positive and negative cycle is uniform in [16], positive cycle only analyzed.

3.18 Dual input–dual output DC-DC converter

To transfer the power between input sources to loads/EVs. A dual input-dual output DC-DC converter is developed in [19] for the incorporation of solar photovoltaic, battery, and ultra capacitor for the EV application. DC-DC converter is controlled inappropriate switches and different modes using the same architecture by [19]. This converter is used for neglecting current stress and minimizes weight and size impact on the formation of minimum cost and more efficient electrical system, and also involved conduction and switching losses and high component count.

3.19 Isolated/Non-isolated topologies

The isolated bidirectional converter is mostly used for high voltage range applications, it is used to limit the diode reverse recovery problem, voltage and current spikes, and switching transients. However, it essential a right design to increase the soft- switching range and inductor to enhance the circulating energy in such a converter. Current- fed DAB BADCs give maximum voltage gain [43].The non-isolated bidirectional converter make use of an energy transfer devices, inductor for transfer the power from source to load, and thus utilize easy controller plan. When the switch is turn on during operation of boost, the magnetic formation of inductor energy is stored, so that it can be deliver when the switch is turn off at boost operation. To realize fast transient response in a direct current control method. A full-bridge BADC coupled with two-step interleaved buck-boost bidirectional converter has been recorded in [39, 40]. The circuit keeps away from the usage of an irresponsible dc-dc capacitor as in-between storage devices, resulting in current ripple of inductor is more; the feed forward control and direct current authority has been utilized to track the quantity of power flow and direction, secure energetic response of the system and to regulate the voltage with help of PI controller.

3.20 Single-Step Three-Phase PFC Converter

A single-Step isolated cuk converter using Three-phase AC-DC converter of PFC is developed and analyzed for the CCM is modulated for charging of EV. The PFC along with compact voltage order is obtained in the control scheme of Adaptive Sliding mode based Loss Free Resistor (ASLFR). The Total Harmonic Distortion (THD) is met the grid standard in [29], Front converters operate a two-stage rectifier of a resistor emulator of the active method is free harmonic rectification and second converter for improved voltage regulation. To reduce efficiency and extra PFC units improved the number of component, complexity, and reduce the efficiency. The circuit diagram of the expansible three-phase rectifier using Cuk converter is shown in fig.9.
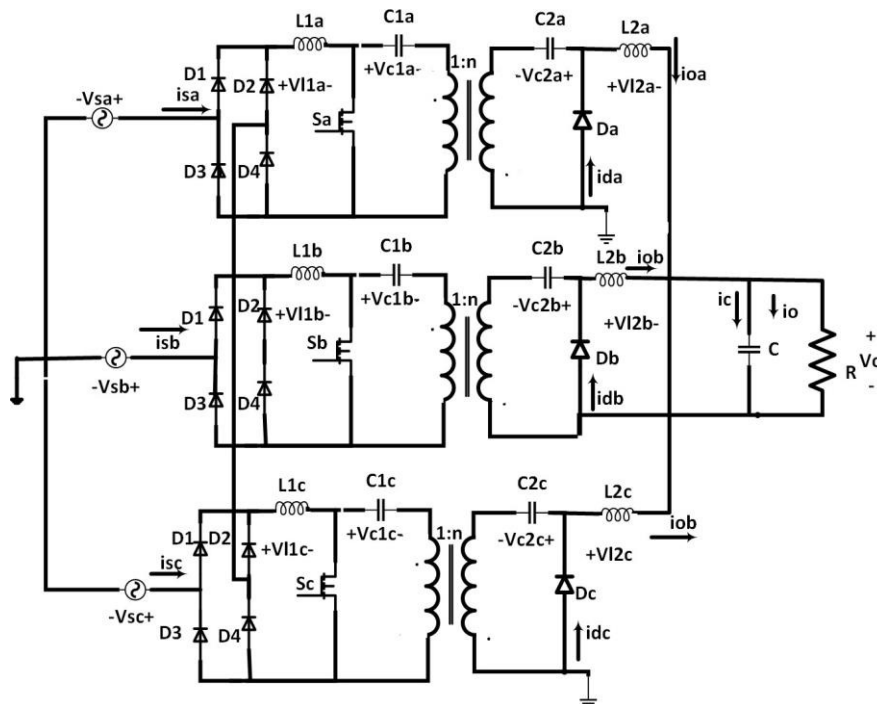
Fig.9. Circuit diagram of the expansible three-phase rectifier using Cuk converter. [29]

Single-step approach generally, high efficiency but current input is not a complete sinusoidal, besides it has a minimum size as balanced to the two-step converter, maintained unity power factor nearly to provide a trade-off, which can increase the power delivery while inscribe number of component and cost. To keep the response of fast transient even with the lower conversion steps while offering an increase the response, high efficiency, and emulating an adaptive losses free resistor.

Comparison of various BDCs

A full-bridge converter is given isolated Bidirectional DC-DC Converter (BDC) technique, but the buck/boost converter is almost all common nonisolated BDC technique. The advantages of non-isolated topologies are less weight, less cost, lower footprint, and easy control, mostly due to non-appearance of the isolation transformer. In converter, increase the component for less switching. However, they restrict the power density by reason of conduction loss created by maximum current pass through the switching scheme and further component of passive element, so that in this converter get less efficiency. For fast charging/discharging capability, the interleaving is applied in nonisolated BDCs. The switching losses are addressed in soft switching techniques, nonisolated BDCs do not apply ZVS/ZCS in the control algorithm. The scaling flexibility in case more power

transfers ability is considered in a cascaded buck/boost topology and it give the good transient performance. The good safety during a fault condition, the isolated BDC topologies are considered, but at the amount of a high-frequency transformer is required. Isolation is all-important according to international standards, for the most part, when maximum power transfer is carried out. Comparison of Power factor correction and BDCs developed for Electric Vehicle application is given in table 1.

To increase the reliability of the converter and minimize the elements, on resonant topologies is prepared. When matched to non-resonant technology, the current pass through the switching scheme is somewhat on the higher side. As a result, more conduction losses and less efficiency. As a result of more bandgap devices, maximum efficiency, high power density potentiality and good thermal quality and can display to be power tools for maximum power charging/discharging systems. If further minimizing the area and footmark of the bidirectional converter is require, but battery shame is inescapable, sinusoidal charging is considered. In-vehicle to grid applications, nonisolated BDC topology is considered.

The comparative performance characteristics of bidirectional and unidirectional converter using silicon and silicon carbide with respect to various switching frequency and efficiency of DC-DC converters is measured with help of Si & SiC technology has been shown in fig.10.Furthermore, when the more number of switching frequency in Silicon Carbide (SiC) as compared with silicon (Si), the minimum significant of reduction efficiency. Where the maximum number of losses in Si as switching frequency is varied from 20 to 80 KHz, while a minimum number of losses in SiC.
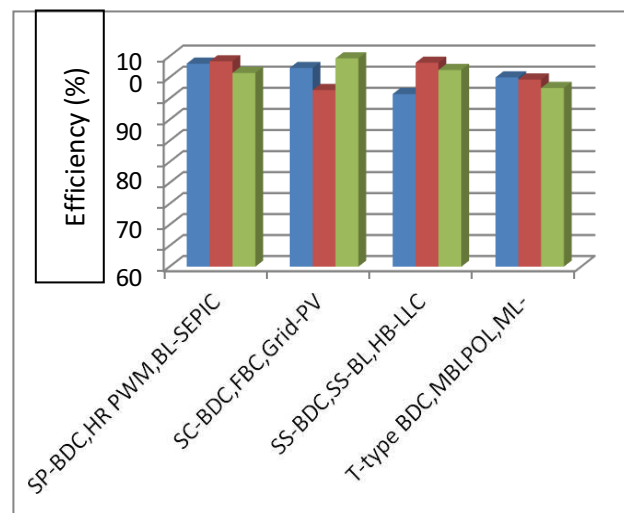
Fig .10. Measurement of efficiency in a DC-DC converter using Si and SiC technology

Table 1: Comparison of Power Factor Correction and BDCs advanced for Electric Vehicle applications as established in the literature

Topology	Rated power	Charging quantity	Range of battery voltage	No. of switching tools	Passive required	Power factor	Switching frequency (KHZ)	Isolation (Galvanic)	Efficiency (%)	Reference	Remark
Boost PFC converter is required in PSUs	480W	2	-----	4	C	0.98	20	Yes	<90	2	Conduction losses copper loses & switching losses are much more high. Max. current stresses of L&D
(HRPWM) Bridgeless	650W		---	2	C	0.9	70	No	97.5	5	More complex impedances in EMI filter, grow the losses
Soft-Switching Bridgeless boost Converter (ZVS HRPWM)	650W	1	----	3	C	0.999	150	No	96.95	3	More complex impedances in EMI filter and grow the losses, maximum current at less duty cycles when the voltage input is more
BDC	1.5KVA	1	220–336 V	8	L&C	Unity	100	Yes	96.5	7	Great conduction losses, High ON state resistance by reason of less current rating
BL SEPIC converter	760W	1	48V	2	C	Unity	20	Yes	92.1	6	Maximum current stress of 28A, Maximum voltages stress of 520 V
BL cuk converter	1.2KV	2	48V	2	C	Unity	20	No	93	11	Maximum current stress
Modified Luo converter	760w	2	48V	2	L&C	Unity	20	yes	90	15	Converter bulky, high switch stresses
Boost Cascaded-by-Buck	1KW	2	-----	2	C	0.99	30	No	96.4	25	Maximum stress of voltage ,Big areas with indirect power transfer capabilities
Switched inductor cuk converter	500W	1	48V	1	C	0.99	25	No	Standard	21	Output inductor losses , ESR losses of the intermediate capacitor
LLC resonant converter with cuk converter	500	2	Upto 20Ah	3	L&C	Unity	30	Yes	Standard	23	Increase the number of components count
Soft-Switching Single-Stage Converter	3.3KW	2	360v	2	C	Unity	50	No	96	17	Poor soft switching and circulating current , Two-stage structural problem
L3C resonant converter (PV)	3 kW	2	230–430 v	4	C	---	180-400	No	97.5	33	More conduction losses, Converter efficiency decreases at light loading conditions
Half-Bridge resonant	3.3kW	1	360V	4	C	Unity	180-200 KHz	Yes	96	42	Minor footprint and More Complex

4. Methods of charging/discharging systems

For Electric Vehicle (EV) applications charging/discharging are generally classified into (a) On-board or off-board systems, (b) Integrated or Non-integrated systems, and (c) Inductive or capacitive. All of the above mentioned methods have been discussed in the following sub-segments. An inductive charging/discharging system is one of a non- integrated design system, where one scrap of the system is assigned over on-board of the electric vehicle and further scrap over the off-board of the EVs.

4.1 On-board and off-board charging/discharging

Accommodation to charging/discharging the vehicle in on-board systems, wherever an electric power is available at outlet, as well the EV battery voltages match from an onboard system. The voltage from grid is normally constant, whereas the voltage of battery is not and it differs from V2V. The on-board systems are specifically fabricated by EV construct for all vehicles in order to meet the particular voltage need of the grid and battery. The same doesn't suits with off-board systems that are developed in order to keep a large collection of battery voltages. However, design parameters and schematic diagram of the on- board charger/discharger system [25]. Fast charging/discharging is achieved by a current focus, which request maximum power heavy converter system and battery profile shown in [22]. It can be concluded that the EV operation should incur the cost of both charging / discharging but its reduced switching and conduction losses increase the efficiency of the system due to low diode conduction losses. The characteristics of on-board systems as [21].

4.2 Integrated and Non-Integrated charging / discharging

In a non-integrated method of charging/discharging, the system drive is free of the charger/discharger [35], this demands a committed converter system to look after the charging/discharging of the EV battery. A Non-integrated type is preferred for charging/discharging of the system. However, if grid to vehicle and verse visa operation and tracking are shown in [27]. Such an integrated charger/discharger is called an on-board system. An integrated system minimizes the voltage and current stress, conduction losses of an inductor, neglect the sub-harmonic oscillation in voltage output unexpected load changes, and the effect of thermal ageing is been eliminated. Some other integrated charging/discharging systems has been discussed in [32] that use an on-board three-phase full-bridge BADC for propulsion as well as to the regenerative braking and the three-phase permanent magnet synchronous motor windings to promote the power flow in both directions.

To better power quality an isolated LLC resonant of cuk converters for an Electric Vehicle Battery Charger (EVBC) is planned definitely to charging a small Electric Vehicle (EV). The technique contain a two converters comprising of the first step cuk converter for PFC by operating in the LLC resonant converter, while the CCM of the primary inductor and the second stage the CVM and CCM control algorithms. To minimize the turn off losses in LLC converter switching devices, the converter make use of a frequency control algorithm to sincerely vary the in-between dc-link voltage based upon the state of the battery. The lead- acid batteries are charged by the C/10 ratio due to the battery thermal characteristics the keep up charging time limits their time of EV driving and but lithium batteries solve these issues under fast charging time (C/5,1C) minimum charging duration with travel long distance.
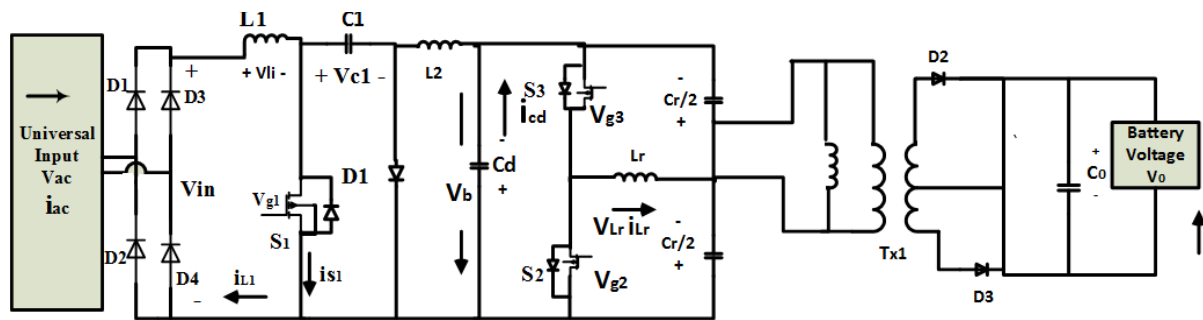
Fig.11. Configuration of PFC-Cuk converter fed isolated HB-LLC converter. [28]

The benefit control algorithm of the cuk converter based LLC resonant and phase- shifted zero voltage switching converters are presented in [28] used for high power fast charger. As result, the input current harmonic less is achieved by Pulse Width Modulation (PWM) a two loop structure of cuk converter is controlled, neglecting any battery charging risk by use of LLC controller to reduce turn off & switching losses, with less flux density of the LLC transformer and then to increase efficiency. Configuration of the PFC-Cuk converter fed isolated HB-LLC converter is shown in fig.11.The On-Board Charger (OBC) supplies ZVS of each switches and minimize the reverse recovery problems by ZCS of the diode outputs. Two interleaved cells sharing a full-bridge diode rectifier for OBC in [17], all cells are composed of a series resonant and active clamp circuits.

The interleaved technique helps to keep the actual power quantity with maximum efficiency and the control algorithm permit power quality by the OBC without need of auxiliary circuit and the current input is balanced in between the two cells and also converter make sure compact size, a long lifetime and need no electrolytic dc-link capacitor. For low power application (less than 1kW) single stage topologies are applied. Single-stage, single cell OBC is shown in fig.12, the control algorithms and development of a soft-switching single-stage converter, and then OBC transformer transforms the ac-voltage input into the desired dc-voltage output in a single stage is presented in [17], to achieve desired power factor and maximum efficiency. This converter is comprises of full bridge diode rectifier, along with a maximum-frequency DC-DC converter combined with a full-bridge series resonant circuit and an active clamp circuit. The main advantages of this converter is absorbed, the simple structure and maximum efficiency was conferred by soft switching of all elements. Moreover, to enable sharing power distribution between the interleaved cells, there needs an auxiliary PFC circuit. To achieve unity power factor at ac mains, a PFC step up converter based half-bridge LLC resonant converter which utilizes as a front end converter is operated in CICM for Electric Vehicle Battery Charging (EVBC) application.
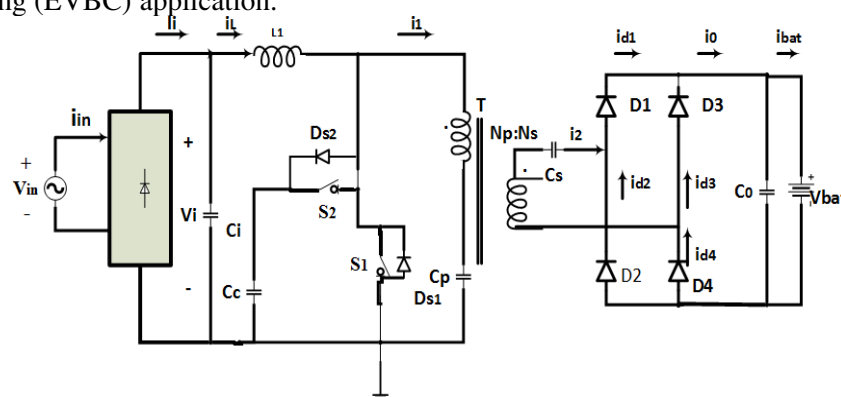
Fig.12. Single-stage, single cell OBC [17]

LLC converter uses a Pulse Frequency Modulation (PFM), whereas a step up converter is works in PWM technique at a constant frequency to keep the power delivered to the battery. To measure the low value of inductor current, boost inductor that works in CCM and Average Current Mode (ACM) control is operated for less power loss.PFC boost converter is developed below CICM mode using ACM control at a desired switching frequency is described in [31]. A smooth rectified sine template even below the poor voltage quality control for the current generation is obtained in the phase-locked loop technique. DC link voltage is sensed by a less-cost possible divider that forms supply a reference current for inner current loop and outer voltage control loop. As a result, less ripple current throughout the inductor less the stress of current in semiconductor, high efficiency, and reduced charging time with less-cost developed power quality EVBC. An Asymmetrical Pulse Width Modulation (APWM) technique is used for controlling the output voltage and foremost switches, resulting in maximum efficiency.

The design and implementation of the controller and control technique are introduced in [24], which minimize the switching current stress , as well as the conduction losses and the circulating losses during the freewheeling session compared with the auxiliary inductor current is controlled by use of conventional phase shift modulation method, so that can increase the system efficiency. In full-bridge DC-DC converter topology, maximum power density, high reliability of the system, and isolation ability. A bidirectional DC-DC converter of switched-capacitor is shown in fig.13, reduces the number of component count, and gets a large range of voltage gain along with less stress of voltage and a common ground. Additionally the synchronous rectifier permits to achieve ZVS turn on and turns off without need anyone additional hardware and converter efficiency is better in [26]. As a Hybrid Energy Source System (HESS) is a combination of a super capacitor and battery, an electric vehicle is considered as the best way to increase the battery life and overall efficiency of the vehicle. For maximum power density, greater cycle life and high efficiency, the supercapacitor with the high voltage dc bus which keep away from any change in step in current from the battery is used. Regenerative braking and acceleration of supply power with the battery meets the requirements for long-range operation of energy storage density.
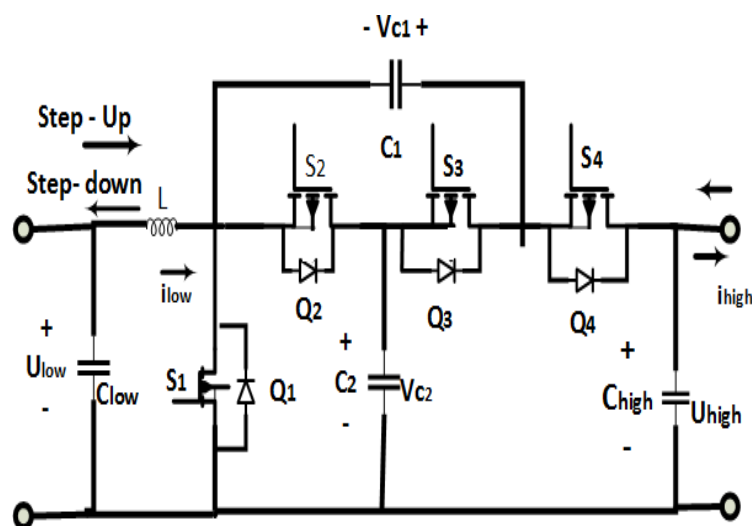

Fig.13.A bidirectional DC-DC converter of switched-capacitor [26]

As a result, a very easy circuit of minimized number of components count of greater voltage gain, a less stress of voltage, and a common ground, but conduction and switching losses are high. A

switched inductor-capacitor, coupled inductor, Walton multiplier, boosts converters with greater voltage gain ability as the nonisolated DC-DC power conversion step for Photovoltaic to applications of grid. Successfully, DC-DC boost converter helps the Photovoltaic (PV) voltage to reach the maximum-performance level, but they are not suggested for EV applications since they need a mandatory galvanic isolation in the middle of the PV panel and the greater voltage battery store. These proposed converters prosperous handle the PV voltage variations and MPPT demands to respond to the different battery charging state, but it doesn't address the pair of input and output variations simultaneously.

From complete discharged condition to the charged floating voltage phase, the charger must operate in CVM and CCM or constant power modes based on the battery charge state. A schematic structure of full-bridge L3C resonant converter with capacitive output filter is shown in fig.14, applicable for PV to more-voltage battery applications. The challenge of the converter is to combine both variables PV input voltage and an energy system utmost voltage gain variations from input to output at different current and voltage quantities. A high-efficiency fourth-order L3C resonant converter has been presented in [33], resonant converter all the time operate in ZVS for different load control and have less noise output voltage. L3C converters not only come up with protect the full-bridge inverter form over current and short circuit control but also charging the battery pack at constant current.
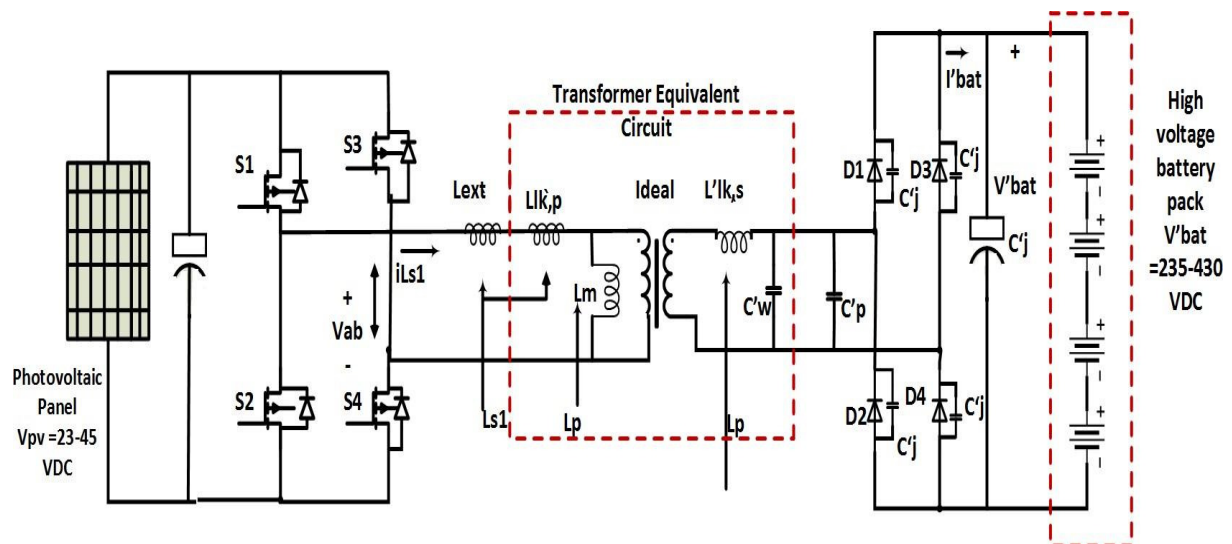
Fig.14 A schematic diagram of L3C resonant converter of full bridge function with capacitive output filter [33]

To neglect the maximum voltage constructed by the reverse recovery current of diodes and to drop the noise level in the receiving end voltage, a function of rectifier diode output in a Zero Current Switching (ZCS). In order to charge the Li iron battery at a lesser price with an extended time of charge without lesser the life and allowed maximum current charger with the help of constant voltage and constant current mode. As a result, show the high-quality voltage output, the output current is limited, during the CCM a battery current is controlled, over current protection, maximize the converter efficiency, and during light loading conditions a converter efficiency is reduced and it's having more conduction losses. Fig.15 shows the Single-step, two-way AC/DC converters topology for OBC, the output voltage always great or less than the input voltage, and smooth transitions between the modes are operated in CCM and performance of the converter is expressed in [34].
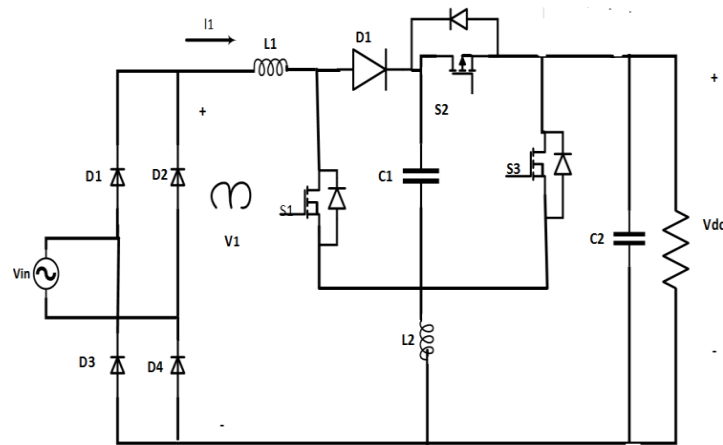
Fig.15 Single-step, two- way AC/DC converters topology for OBC [34]

The input current as the inner loop and voltage output as an outer loop is implemented in an Average Current Mode (ACM). To take the variations of input voltage throughout both step up and step down modes and the Input Voltage Feed Forward (IVFF) terms is as well attached with gain. Voltage and current controller depends on carrier generation block and Pulse Width Modulation (PWM). The simplicity of design and robustness is well-established for all applications, the Proportional -Integral controllers are used. A single-stage, two-mode AC/DC converter is implemented for low voltage and current stress, inductor conduction losses, neglect the subharmonic oscillations in voltage output unexpected change of load the effect of thermal ageing is been eliminated. In the front step, due to a less number of active elements they have maximum power, maximum efficiency and reliability of the system with lower application cost and low harmonics of input current. The control of Average Current Mode (ACM) rectifier step up PFC type designed and analyzed with maximum efficiency and to reach unity power factor.

In the second stage, maximum power factor and less THD for extended battery lifespan, maximum efficiency and permit EVs to get extra miles per charge. An Artificial Neural Network (ANN) is designed to control the half-bridge LLC resonant converter. ANN is applied to synchronize the LLC resonant converter load voltage with feed-forward back propagation technique and Levenberg Marquardt (LM) activation algorithm for fixed voltage battery charge methods in [36]. The control method of current mode is favour for PFC with a pulse width modulation based PI controller. LLC resonant converter is operated under maximum voltage and power conditions, a minimum number of voltage stresses on the diode output, and the potentiality to employ the ZVS with a broad load range. To increase power quality, efficiency, battery lifespan, and then reduce in harmonics of the input current is achieved by use of this topology.

4.3 Inductive / conductive charger / discharger

Conductive charging/discharging systems are any one integrated or non-integrated systems and apply a direct conductive approach, normally a cable with Z connector to permit power flow in the middle of the grid and the EV. Such systems can supply a fast charging station to the EV [41]. However flexibility and convenience is compromised since the EV has to plug in the wire all time. Inductive charging/discharging systems are all the time non- integrated method, where the pick-up side is placed on-board the EV and the primary side off-board the EV.Uneven in between the primary and pick-up side inductive plan of action is the major of the problem of the inductive charging/discharging. Which small change the magnetic coupling between each sides leads to power transfer level and variable resonant frequency. When power is transferred inductively, perceptive

configuration is important. As a result of bidirectional power flow, when the pick-up side LCL network of every one Electric Vehicle is tuned to the frequency of the track current and the load side converters are employed either in rectification or inverting method depending on the regulation of the power flow.

A fallback phase angle solution in power flow from the source to load side, while leading phase angle outcomes in power flow load to the source side. The direction of power flow depends on the corresponding phase angle and magnitude between the voltages at primary to load side. A phase-modulated square wave voltage is generated from a PI controller and a triangular wave is generated at source or load side control system. The output voltage and current harmonics are reduced with the help of the LCL network.

5. Design of DC-DC converters for EVs

A design condition of DC-DC converters for EV is represented in this segment. To determine the duty cycle, inductor, capacitor, average input voltage and resonant frequency value of DC-DC converters with help of design equations. Each parameter is taken from both simulation and hardware models discussed in the above literature. Based on value of design and parameters, the prototype test is designed, and performance characteristics of dc-dc converter are analyzed.

5.1 Bridgeless Isolated SEPIC DC-DC Converter

There are three operating principles in bridgeless isolated SEPIC DC-DC Converter (i) ON mode switch (ii) OFF mode switch (iii) Switch OFF .When switch is turned ON, the inductor current linearly rises as it energy is stored from the input supply. An energy stored in magnetizing inductor, the energy transfer capacitor is discharged from it. During this condition the output diode is reverse bias and the dc-link capacitor supply the battery form battery current. During turned OFF condition, the two inductor currents are force to conduct the output diode. Releasing the energy from inductors to the voltage output, when both inductor currents are decreasing. In mode iii, primary inductance of HFT energy is completed depleted and still in switch is OFF. The current inductor remains on and off for the remain of the switching period, in this condition, there is no energy moving between the HFT primary to secondary, as a diode output is reverse biased and the need power of charging is delivered by the dc-link capacitor.

When switch S1 is ON

$$i_{L_i}(t) = I_{L_i}(t_0) + \frac{V_{in}}{L_i}(t - t_0) \text{ For } t_0 \leq t \leq DT_s \tag{1}$$

$$i_{L_{m1}}(t) = I_{L_{m1}}(t_0) + \frac{V_{c1}}{L_{m1}}(t - t_0) \tag{2}$$

When switch S1 is OFF

$$V_{in}(t)D + \left(V_{in}(t) - V_{c1} - nV_{dc}\right)D_1 = 0 \tag{3}$$

$$i_{L_i}(t) = I_{L_i}(t_0) + \frac{V_{in}}{L_i}DT_s - \frac{D}{D_1}\frac{V_{in}}{L_i}(t - t_1) \tag{4}$$

$$i_{L_{m1}}(t) = I_{L_{m1}}(t_0) + \frac{V_{in}}{L_{m1}}DT_s - \frac{D}{D_1}\frac{V_{in}}{L_{m1}}(t - t_1) \tag{5}$$

When switch S1 is still OFF

$$i_{L_i}(t) = I_{L_i}(t_0) + \frac{V_{in}}{L_i} DT_s + \frac{V_{in} - V_{C1}}{L_i}(t - t_2) \tag{6}$$

$$i_{L_{m1}}(t) = 0$$

$$V_{sav} = \frac{2\sqrt{2} \; X \, V_s}{\pi} \tag{7}$$

The input and magnetic inductances are

$$L_i = \frac{V_s D}{2 f_s \Delta_{i_i}} \tag{8}$$

$$L_{mc} = \left(\frac{N_1}{N_2}\right)^2 \frac{V_{dc}(1-D)^2}{2 D f_s I_{dc}} \tag{9}$$

The resonant frequency

$$f_r = \frac{1}{2\pi \sqrt{L_i + L_m} C_1} \tag{10}$$

The design equations of capacitors are

$$C_{1,2} = \frac{N_2}{N_1} \frac{V_{dc} D}{(\Delta V_{c1,2} f_s R_{dc})} \tag{11}$$

$$C_{dc} = \frac{I_{dc}}{2\omega \Delta V_{dc}} \tag{12}$$

The specification value of bridgeless isolated SEPIC DC-DC converter is given in [6]

5.2 Single-phase Single-Stage Isolated AC–DC Converter

In this converter, a current-fed bidirectional based half bridge converter on primary side and full-bridge converter interlinking battery on secondary side. A four quadrant operation of voltage and current also is performed in [7]. In first mode of this converter, when the input voltages is positive half period and transfer the power from grid to battery, primary switches are worked at high frequency with modulation of duty ratio and 180 degree phase shifted in a gate pulse. In second mode, two switches of S1a & S2a are maintained at ON step and switches of S1b & S2b are employed at HT with modulation of duty ratio is greater than 0.5 and 180 degree phase shift are maintained. S1b & S2b switches are maintained ON and switches of S1a & S2a are kept OFF stage, negative direction of current is maintained in third mode of this converter. Phase angle should be differing from 0 to 0.5 and voltage output also varied. In fourth mode of this converter, a switching state of primary devices are maintained based on the direction of current input.S1b and s2b switches are ON-stage and current flow through s1a and s2a of diode.

The output voltage is

$$V_0 = \frac{n \; X V_{in}}{(1 - d_1)} \tag{13}$$

Transformer turns ratio

$$n = \frac{V_{0,min} \cdot (1 - d_{1,min})}{V_{in,max}} \qquad (14)$$

$$L_1 = L_2 = \frac{V_{in,max} \cdot d_{1,min}}{\Delta I_L f_s} \qquad (15)$$

$$C_{dc} = \frac{2P_0}{\Delta V_0 . \omega . V_{0,min}} \qquad (16)$$

5.3 Improved bridgeless Cuk Converter

A flyback converter is worked as constant voltage and constant current charging and a improved bridgeless Cuk converter is recommend outstanding PFC characteristics of Discontinuous Conduction Mode (DCM) and there are three modes of operating: (i) ON mode switch (ii) OFF mode switch (iii) DCM mode. When first mode is activated, its works at positive half cycle, capacitor voltage being decreasing through the S1 switch and inductor output is supply the need load current to fly back converter. Due to polarity of capacitor voltage, the diode output is reverse bias in this condition. When switch is OFF, the output diode is conducted and decreasing the stored energy of input inductor as the capacitor voltage being to increasing. As the addition of input and output current of inductor becomes zero and output diode current also zero, a fixed current pass through the circuit in the mode of DCM.

The regulation of dc-link voltage and the multiplier approach of current to supply a basic wave model characteristic in a Continuous Conduction Mode (CCM). More sensors are need in a CCM and the sensing precondition of the input current and voltage as well as output voltage. However, due to voltage follower approach, the need sensors are minimized as the control structure and voltage output is only sensed in this converter. The input and output inductance, magnetizing inductance, output capacitor and duty cycle equations for Improved bridgeless Cuk Converter design and value are [11].

$$L_{i1,2} = \frac{V_s \, X D_{Cuk}}{\Delta_{i_{Li1,2}} \, X f_s} \qquad (17)$$

$$L_{01,2} \le \left(\frac{L_{eq} L_{i1,2}}{L_{eq} - L_{i1,2}} \right) \qquad (18)$$

$$C_{batt} = \frac{D_{fb} \, X \, V_{batt}}{f_{sf} \left(V_{batt}^2 / P \right) \gamma V_{batt}} \qquad (19)$$

$$D_{fb} = \frac{V_{batt}}{\left(n_s / n_p \right) V_{Cuk} + V_{batt}} \qquad (20)$$

5.4 A modified isolated Luo converter

To reduce the stress of voltage across the switch and voltage input is clamped in a modified isolated Luo converter with clamping input diodes at the primary side of an isolated HFT and two switches.PFC ability to achieve in a discontinuous conduction mode of this converter , minimize the number of sensor required and minimize the complexity of control, Three mode of operation is

discussed in a converter.Mode-1: Two switches are ON, the supply current increase linearly as energy stored in a magnetizing inductor. Voltage of capacitor is reducing through inductor L_0 as inductor being charging through in-between capacitor C_1.Mode-II: The diode will be conduction when the switches are OFF. During this condition, the magnetizing inductance supply the energy to diode output, capacitor voltage vC_1 is being rising through the magnetizing inductor energy at the secondary winding of HFT, with help inductor output the energy is supplied to capacitor of output and the need current of charger is transferred to the battery. Mode-III: The two switches are OFF and two diodes are reverse biased. The magnetizing inductor store the energy in DCM operation of this converter, supply the battery energy is need by a capacitance of dc-link through inductor and the energy provide capacitor. In this converter, expression of filling efficiency, relation between input and output voltage, magnetizing inductance , maximum capacitor filter are analyzed in [15]

$$m = \frac{1}{\zeta_m} = \frac{M^2}{D^2 \frac{R}{2fL_m}} \tag{21}$$

$$M = \frac{V_0}{V_{in}} = \frac{D}{n(1-D)} \tag{22}$$

$$L_{m\,min} = \frac{Rn^2(1-D)^2}{2Df_s} \tag{23}$$

$$C_{f\,max} = \frac{I_{s\,max}}{\omega V_{s\,max}} \tag{24}$$

5.5 Single –step converter for OBC

A single-cell, Soft switching converter for on-board battery charging consists of full- bridge diode rectifier with two interleaved cells, which is keep the desired power level with maximum efficiency. A series resonant and active clamp circuits are relaxed in all cells, this converter supply ZVS of each switches and diode output of Zero-Current Switching is used for minimize the reverse recovery problem. When ZVS is ON, transformer leakage inductance and magnetizing inductance to store the recycle energy and main switch of surge voltage is clamped in this circuit. The resonant capacitor is composed in this series resonant circuit, a full-bridge diode and the leakage inductance of the transformer. Resonance intermediate the leakage inductance and resonance capacitor supply ZCF is OFF. The three mode of operation is presented in [17]. During ZVS –ON, the negative current of main switch is flow in an initial time interval. Input current of rectifier is calculated, during one grid time interval with assumption of the average output power distributed equally and null power losses. When the current is reaches zero, diode of ZCS turn OFF.

The expression of duty ratio, primary inductance, relation of input voltage and battery voltage and battery voltages are given below

$$D = 1 - \frac{nV_i}{2V_{bat,ref}} + L_1 \frac{n}{2V_{batt.re}T_s} \Delta i_1 \tag{25}$$

$$D_n = 1 - \frac{nV_i}{2V_{bat,ref}} \tag{26}$$

$$L_1 \frac{\Delta i_1}{T_s} = V_i D + \left(V_i - V_{C_c}\right)(1 - D) \tag{27}$$

$$\frac{V_{batt}}{V_{in}} = \frac{n}{2(1-D)} \tag{28}$$

$$V_{batt} = \frac{nDV_i}{1-D} - V_{cs} \tag{29}$$

$$\Delta D = L_1 \frac{n}{2V_{batt.ref}T_s} \Delta i_1 \tag{30}$$

The different mode of principle operation is presented in [17]

5.6 Single –step switched inductor Cuk Converter

In this converter is designed for maximum efficiency, less current stress, maximum gain of step-down with minimum number of component current and converter is operated with continuous conduction mode. Two mode of operation is presented in this converter, during charging mode of inductor, switch is ON and diodes are turn OFF by capacitor average voltage is free ripple.

The instantaneous value of inductor input, output capacitor and duty ratio are expressed as.

The average value of inductor current input is

$$I_{Li} = I_{dc} \frac{V_{dc}}{V_{in}} \tag{31}$$

Output capacitor is carried out by effective series resistance

$$\Delta V_{dc} = \frac{\Delta I_{c1}.T_s}{8C_0} \tag{32}$$

Based on input voltage, a duty ratio is expressed as

$$D = \frac{2V_{dc}}{2V_{dc}+V_{in}} \tag{33}$$

The intermediate capacitor is

$$C_1 = \frac{DT_s}{2\frac{\Delta V_{C1}}{V_{dc}}.R_0} \tag{34}$$

5.7 LLC Resonant Converter

Four mode operation of Half-bridge LLC converter with Cuk converter is operated in this converter, dc-link voltage regulated for to keep sinusoidal current input and converter is operates in CICM. During mode 1, both inductors current is increased linearly and energy stored in input inductor only. While first capacitor energy is discharged to the capacitor dc- link through switch S1.The stored energy is discharged from L2 through capacitor dc-link. The LLC converter work under frequency of resonant, thus keep away from series resonant during high voltage condition of ac mains. The LLC transformer work at fixed flux density all over variation of ac voltage.

$$L_1 = L_2 = \frac{1}{\Delta i_{L1\Delta} X f_s} \left(\frac{V_s^2}{P_{max}}\right) \left(\frac{V_{dc}}{V_{dc}+V_{s_{peak}}}\right) \tag{35}$$

$$C_1 = \frac{1}{\omega_r^2 \, X \, (L_1 + L_2)} \tag{36}$$

$$C_{dc} = \frac{P_{max}}{2 \, X\omega_L \times \delta \times V_{dc}} \tag{37}$$

$$C_r = \frac{i_{Lr_{peak}}}{2 \times \pi \times f_s \times 0.5 \times V_{dc}} \tag{38}$$

$$L_r = \frac{1}{2 \times \pi \times f_r^2 \times C_r} \tag{39}$$

$$L_m = 6 \times L_r$$

Different value of capacitor, inductor and transformer ratio is expressed in [28, 31]

The following equations for losses evaluation of DC-DC converter

    MOSFET losses during the ON/OFF-state

$$P_{son} = \frac{1}{2} f_s V_{ds} I_d (t_{12} + t_{23}) \tag{40}$$

Switching loss is

$$P_{sw} = 2P_{son} \tag{41}$$

MOSFET of conduction loss is

$$P_{R_{ds}} = f_s \int_{t_4}^{t_5} i_{ds} R_{ds} dt \approx D I_d^2 R_{ds(on)} \tag{42}$$

MOSFET of Reverse Recover loss is

$$P_{bdrr} = Q_{rr} V_{ds} f_s \tag{43}$$

MOSFET of driving loss is

$$P_{drive} = Q_g V_{gs} f_s \tag{44}$$

Core loss is

$$P_C = W_t \left(6.5 f_{sw}^{1.51} B_{ac}^{1.74} \right) \tag{45}$$

Conduction loss is

$$P_R = R_L I_{L,rms}^2 + R_C I_{L,rms}^2 \tag{46}$$

Diode loss is

$$P_D = I_{Drms}^2 r_f + V_{F0} I_D + \left(\frac{V_0}{V_{cc}} \right)^{0.6} E_{rr} \left(\frac{I_{d,rms}}{I_c} \right)^{0.6} f_{sw} \tag{47}$$

Semiconductor loss is

$$P_T = I_{s,rms}^2 r_{CE} + V_{CE} I_s + \left(\frac{V_0}{V_{CC}} \right)^{1.2} \left[E_{off} \left(\frac{I_{s,rms}}{I_C} \right) + E_{on} \left(\frac{I_{s,rms}}{I_c} \right) \right] f_{sw} \tag{48}$$

Total losses of converter is

$$P_{con} = N_{ph} (P_T + P_D + P_R + P_C) \tag{49}$$

Efficiency of converter is

$$\eta = \frac{P_{out}}{P_{out} + P_{con}} \times 100 \tag{50}$$

6. Conclusion

Grid to vehicle and in reverse is a favorable technology that permits EV to utilize as circulated resources, which can distribute or store energy at a suitable time, thus allowing an power exchange between the grid and EV and vice- versa, this boost reliability, stability, efficiency of the grid and expand the overall power generation capacity. To transfer power between grid and EVs, a bidirectional converter is normally used. Different classification of bidirectional converters have been reported and effectively developed in electric vehicle applications. This paper reviewed the different bidirectional and unidirectional topologies are applied to the electric vehicle applications. Moreover, the method of charger/discharger systems implemented for EVs application was studied. Formed on the review, it is possible to recommended that a standard power electronics converters and Uni/Bi-directional c h a r g e r /discharger system planed for improved quality based EVs. Interrelated must meet the following requirement: 1) To minimize the conduction and switching losses, 2) high power density potentiality for fast charging, 3) Rule of grid and EV battery voltage, 4) Fast response, 5) Stability of power factor correction and THD, 6) High reliability, 7) To meet the interrelated requirement and standards, 8) soft-switching of the power devices reduce the stress, EMI and losses, 9) simple and efficient control system, 10) to minimize the component count and system price (cost) and 11) The efficiency of the system will be upgraded. These devices can take switching power into such region of capacity with high efficiency when compared to nowadays performance levels. Furthermore, the recent research address smart charging / discharging of Electric Vehicles can inflate the working and behaviour of the upcoming renewable incorporated grid bodywork.

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