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Analysis of Various Topologies and Control Circuit used in Single Phase EV Charger

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***Abstract:** In remote electric vehicle charging frameworks utilizing inductive power transfer (IPT), power electronic converters assume a basic part in decreasing size and cost, as well as boosting the proficiency of the whole framework. As of late, analysts have led huge examination studies to work on the exhibition of power transformation frameworks, including power converter topologies and control plans.*

Incorporated On-Board Battery Chargers (OBC) have been acquainted as ideal arrangement with increase of electric vehicle (EV) market penetration and limit the general expense of EVs. OBCs are by and large arranged into triphasic and monophasic types with unidirectional or bidirectional power stream. Existing electric vehicle (EV) chargers utilize a hard-core non-linear diode bridge-rectifier (BR) to exploit the DC volt at the contribution of the DC converter and acquaint quality of the power is a counted as a problem with the AC input.

These problems insist improvement in Power Quality for existing battery charger for this purpose the bridgeless Cuk Converter is used with the flyback converter. Cuk Converter used single diode and switch and provide additional advantage like reduction in the switch volt-stress and higher efficiency equated to the other conventional bridgeless (BL) converters. Similarly, bridgeless isolated Zeta-Luo converter with PF correction is also used. The Zeta and Luo is functioned for the half cycle of the supply individually and give the benefits of the both topologies. In this paper BL Zeta, BL Cuk, BL Buck-Boost, BL Luo, BL Single Ended Primary Inductance Converter (BL SPIC), and Canonical Switched Cell (CSC) converters are reviewed.

***Keywords:** Electric Vehicle, Inductive power transfer, On-Board battery charger, Power Quality, Cuk Converter, Zeta topology, Luo topology, Zeta-Luo topology*

I. INTRODUCTION

As indicated by the International Energy Outlook Report, the vehicle area will expand its portion of complete world oil utilization to 55% by 2030 [1]. In this manner, advances connected with the decrease of oil utilization are one of the best difficulties of flow auto research. As of late, elective advances have started to exhibit their market entrance through the presentation of module mixture EVs or PHEVs and all the types of EVs or BEVs [2-6].

In PHEVs and EVs, a 3kW~6kW single-stage on-board charger is generally introduced, so the powerful footing battery can be charged through an outlet [2,3]. The notable geography of an OBC is the two-level assembly. A front-end level, typically a lift converter, is taken on to perform PF remedy to diminish line losses and AC limit [4]. A subsequent stage, normally a high-effectiveness disconnected DC converter, is taken on to satisfy wellbeing guidelines and control charging current [5]. The output power is steady in a 2-level battery charger because of the charging current (CC) is typically a consistent direct current (DC). As we all know that the sinusoidal power is produced by the AC, a DC connect capacitor, going in esteem from a couple hundred to 2 or 3μF, is required as energy cushion [6,7]. The DC connect capacitor is generally a short life electrolytic capacitor, which isn't best for company flitted charger whereas a film capacitor (FC) is a decent solution. Be that as it may, for the worth expected in a conventional two-level charger and FC is excessively costly. It is essential to lessen the worth of the capacitor, so a FC can be utilized without expanding the expense and size.

Incorporated chargers or rectifiers transform AC mains voltage to DC and normally have single directional power. Utilizing further developed geography and regulator than customary strategies accessible available, the coordinated charger can likewise give power quality capabilities like receptive power remuneration (inductive or capacitive), voltage guideline, consonant separating, and power factor rectification (PFR). [8,9].

Rapid battery charging can be accomplished by the utilization either via dc or three-level charging, as portrayed in following table which likewise depict the power level and charging time. Present literature has presented numerous geographies for On-Board Charger that proposition rapid charging of the battery by essentially associating the vehicle to 3-ϕ supply.

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Table 1. Microgrid with Distributed Sources and Loads [10]

Types of Power Level	Location of Charging	Typical Uses	Level of power	Maximum Time to Charge
Type-1 120 AC Volt, 12 A 230 AC Volt, 20 A	OBC (1- ϕ)	Can be charge at Home	1400 W 1500 W	Half Day 1.5 Day
Type-2 240 AC Volt, 17 A 400 AC Volt, 32 A	OBC (1- ϕ or 3-ϕ)	Can be charge privately or publicly	4000 W 8000 W	1-4 Hours 2-6 Hours
Type-3 208-600 AC Volt or DC Volt	Off-Board (3- ϕ)	Can be charge only Commercial	50000 W 100000 W	0.2-0.5 Hours

To give maximum power quality (PQ) with unity PF procedure on the source side, upgraded PQ converters are utilized among the bridge rectifier based on diodes and the yield capacitor. Two-level EV chargers enjoy all the types of benefits of maximum unwavering quality, high DC interface voltage regulation (V_R), and DC capacitor size contrasted with single-level EV chargers. A customary lift power factor rectification (PFR) converter is suggested to achieve the UPF. Be that as it may, because of the enormous variety in DC voltage, a buck-boost converter is mostly preferred over boost converter [11].

Fig. 1 demonstrations the essential grouping of two-directional OBCs, including single-level and 2-level OBCs which are denoted by the single-level OBCs which are rated from 0 to 7000W and 3-level OBCs are rated from 7000W to 22000W. The time used in charging the EV is contrarywise to the power levels of the related converters. Because of more limited charging time necessities, higher power bi-directional OBCs are normally taken into the pictures in future researches. Most single-level topologies can arrive at upto 7000W, while high strain breakers should be avoided. The 3-level OBCs topologies can arrive at up to 22000W. According to the charging time the particular topology could be chosen.

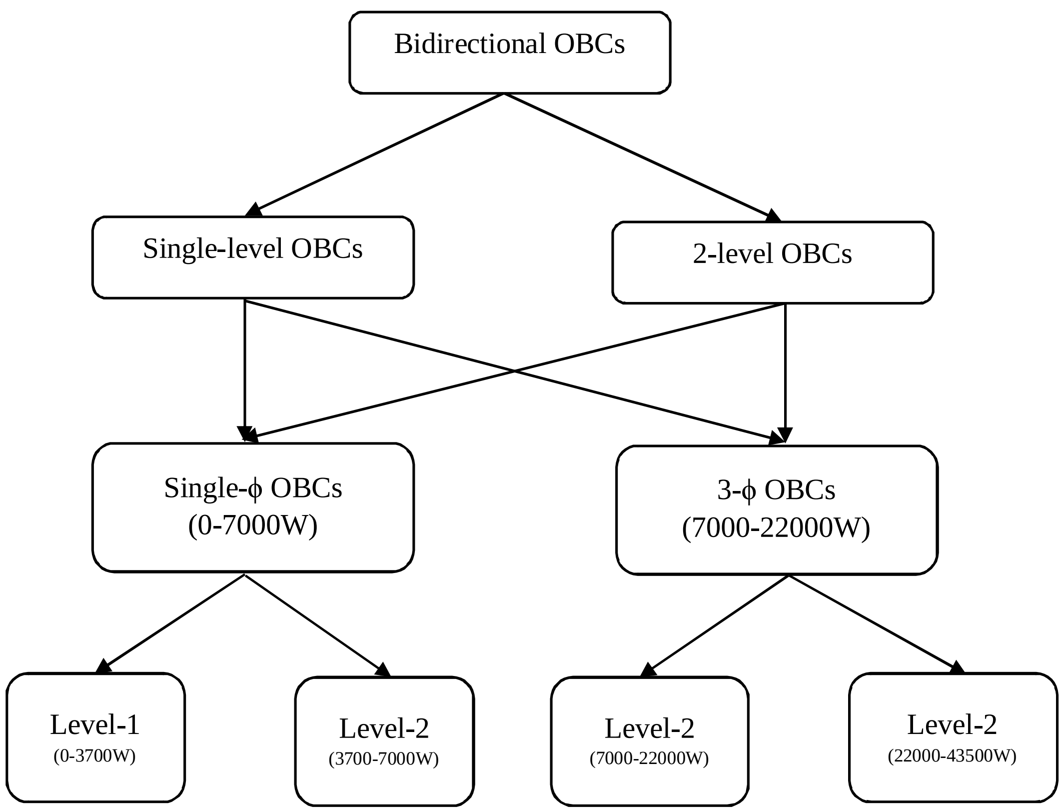

Fig. 1. Classification of Bidirectional OBCs [27]

II. DIFFERENT BRIDGELESS CHARGER

A significant number of these buck-boost based setups give extra compensations of less transmission losses in the PFR stage with BL innovations. This multitude of arrangements like Zeta Converter (ZC), Cuk Converter (CKC), SEPIC, and CSC converter utilize just two-line diodes. In this way, the basic uses of the switches are enhanced and the conduction loss of diode is diminished contrasted with Diode Bridge Rectifier-based better PQ converters. Numerous BLPFC converters in light of Zeta [14], Cuk [12] and SEPIC [13] designs are introduced in the literature.

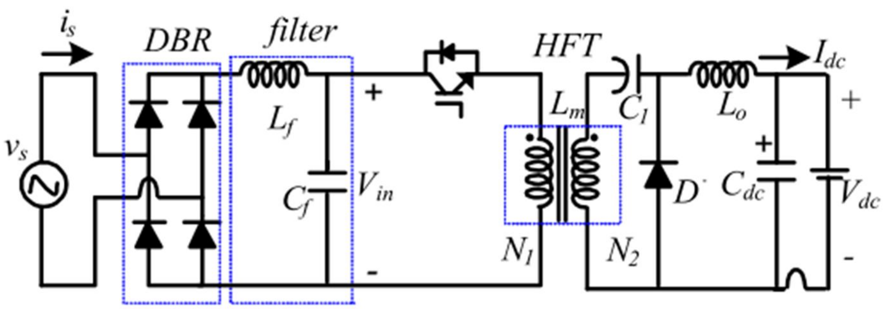

Fig. 2. (a) An Isolated Zeta converter [15]

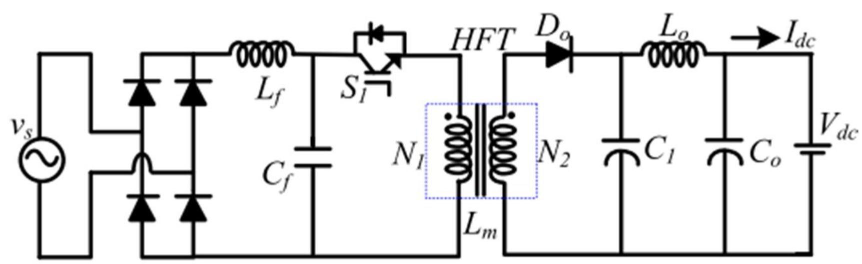

Fig. 2. (b) Circuit of Isolated Luo converter [15]

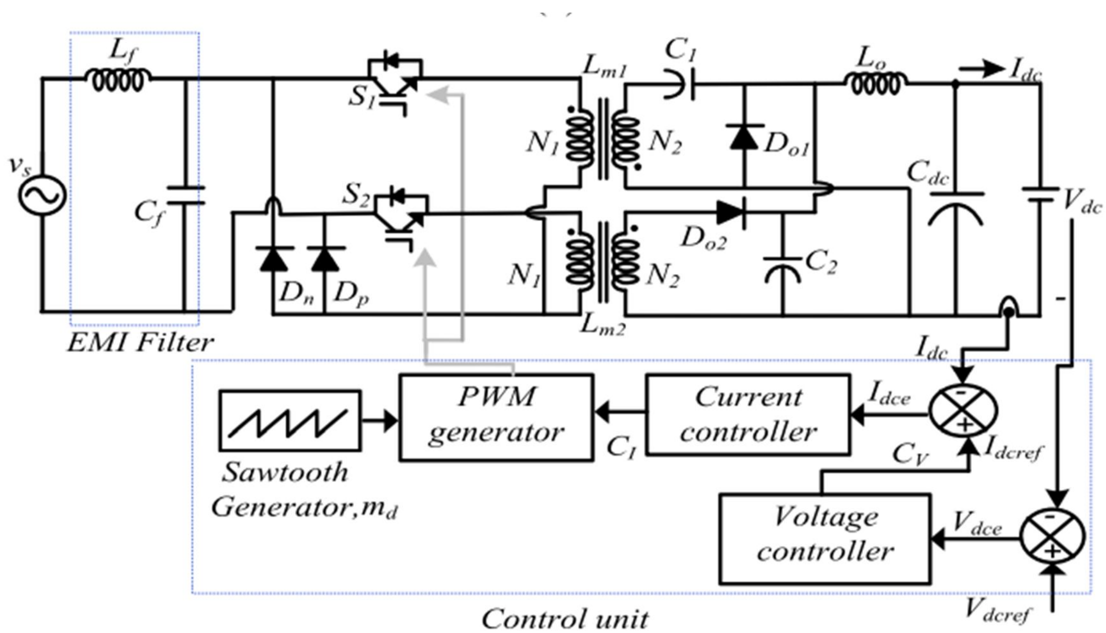

Fig. 2. (c) BL Zeta–Luo Converter [15]

The disservice of the beating yield current and the enormous size of the channels to limit output load ripple in the detached single-level SEPIC converter make it unsatisfactory for the PF pre-set charger. The CKC is extremely famous in this reach in light of the fact that decreased wave is accomplished on both information and result.

Notwithstanding, it needs a capacitor in series with rms current to work at an expanded power. Both the ZC and LC offers astounding PQ enhancement attributes, great less load guideline and the benefit of low load current. Additionally, to develop more effectiveness of the charger, numerous BLPFC converter geographies with disconnection are accounted. Now, it diminishes losses which are related to the semiconductors. The circuit design of regular separated ZC and LC is showed in Figs. 2 (a) and (b). Consequently, in view of the DBR-based topologies referenced over an EV charger with a coordinated BL separated Zeta-Luo setup [15], as displayed in Fig. 2 (c).

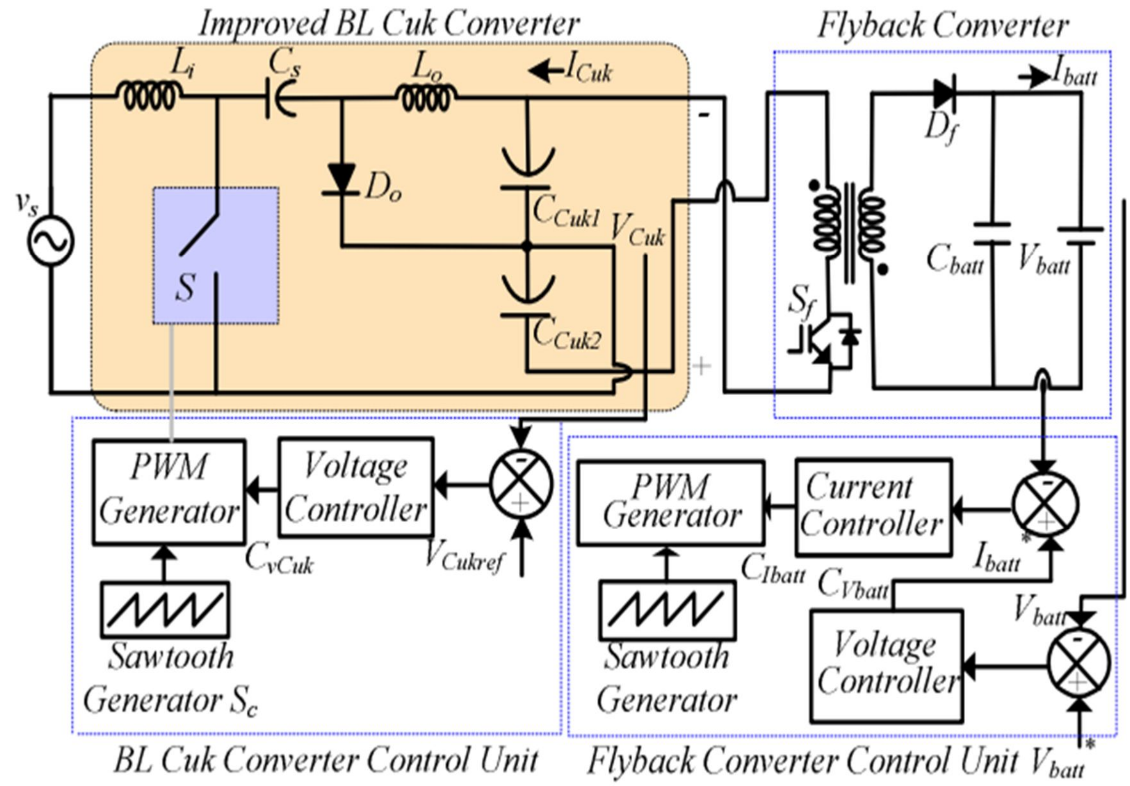

Fig. 3. Conventional bridgeless CKC based EV Charger [25]

CKC is the utmost suggested topology for PQ enhancement in EV battery chargers in light of the fact that the ripple is coming up short on input and output. To diminish the weight on the regular bridgeless Cuk converter, many delicate exchanging techniques are accounted for in the writing. For the PFC in the EV chargers we need extra attractive parts and capacitors.

Hence, to conquer the above disadvantages in the ordinary geography, a better BL CKC with decreased parts sum and diminished exchanging volt requirement is introduced. This bridgeless CKC is utilized for EV battery charger for updated PQ which utilizes the flyback converter. This bridgeless Cuk PFC converter involves a single diode for bridgeless activity as showed in next figure.

III. WORKING OF BRIDGELESS CHARGER IN DIFFERENT MODES

The battery of the electrical vehicle is distinguished in steady current and consistent voltage modes when proportional-integral (PI) regulator is used. This technology of BL converter intended to work freely throughout positive and negative power cycles in ZC or LC mode.

As per the figure 2(c) demonstrated, the arrangement of bridgeless-segregated ZL converter-based vehicle charger, working on distinct half-cycles, freely. The BL converter activity is completed in irregular method of activity to give pre-guideline of PF at constant voltage and in many variable mains voltages. During ZC activity, the switch S_1, transformer polarizing inductor L_{m1}, middle capacitor C_1, and diode D_{01} direct during the positive portion of the stockpile cycle. In any case, the activity of the LC through the negative portion of the stock is helped by the switch S_2 which is based on semiconductor, the polarizing inductance of the transformer L_{m2}, the middle of the road capacitor C_2 and the result diode D_{02}. The hypothetical examination during the activity in consistent condition of this detached converter BL is itemized beneath.

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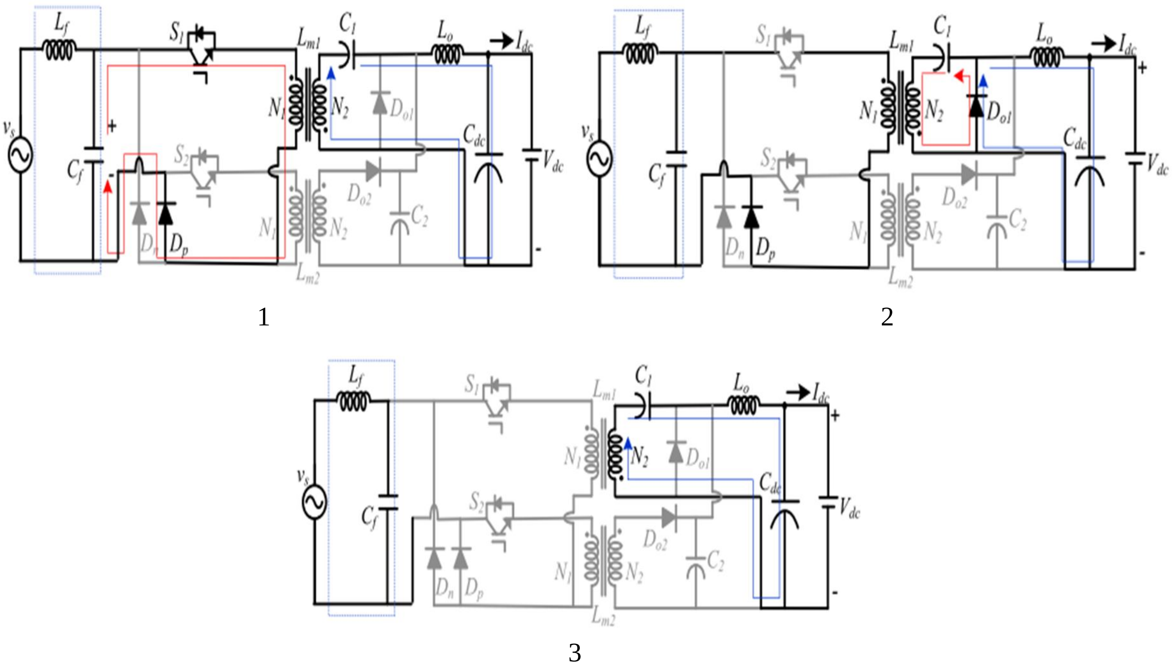

Fig. 4. (a) 1, 2 & 3 respectively shows the mode-I, II & III in Zeta Mode (Positive cycle)

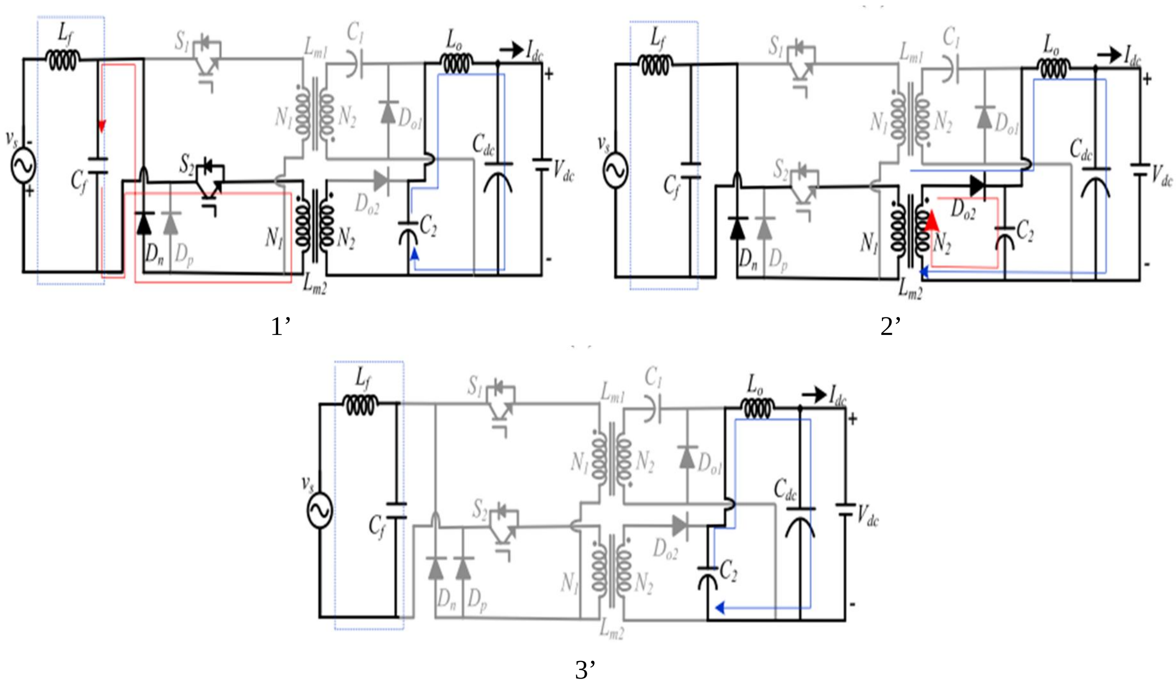

Fig 4 (b) 1’, 2’ & 3’ respectively shows Mode-I, II & III in Luo Mode (Negative cycle)

Three unique methods of activity and the related key activity of this segregated converter are displayed beneath, in ZC mode and LC modes for the comparing power parts. Mode-I [t_0-t_1]: During this mode, gate pulse if given at the instant that is t_0 to the switch s_1. The present inductor L_{m1} shows the charging current due to the line diode (D_p) provide the path to inductor for storing the energy. The voltage across the power capacitor C_1 starts to diminish as the ongoing invented a way through the result inductor L_{01} on the optional side, as displayed in Fig. 4 (a)-1. During this span the diode D_{01} is found in the off state. When the switch $S_1$is in Off state the mode t_1 is closed.

Mode II [t_1-t_2]: During this span, switch S_1 switches off and diode D_{01} begins directing. The polarizing inductor Lm1 discharges the put away energy through the capacitor C_1 to the result diode D_{01} and the optional twisting of the transformer. When the battery current is constant during the constant current mode the output DC connect capacitor begins to charge through the L_0 inductor.
Mode-III [t_2-t_3]: During this span, switch S_1 stays in Off state and the drive is used in the direct current mode. As demonstrated in the fig 4(a)-3 and 5 the amount of the flows through the charging inductor L_{m1} and the result inductor L_0 prompts zero current through diode D_{01}. In the mode-III the capacitor C_{dc} keeps on and providing charging current to the battery.

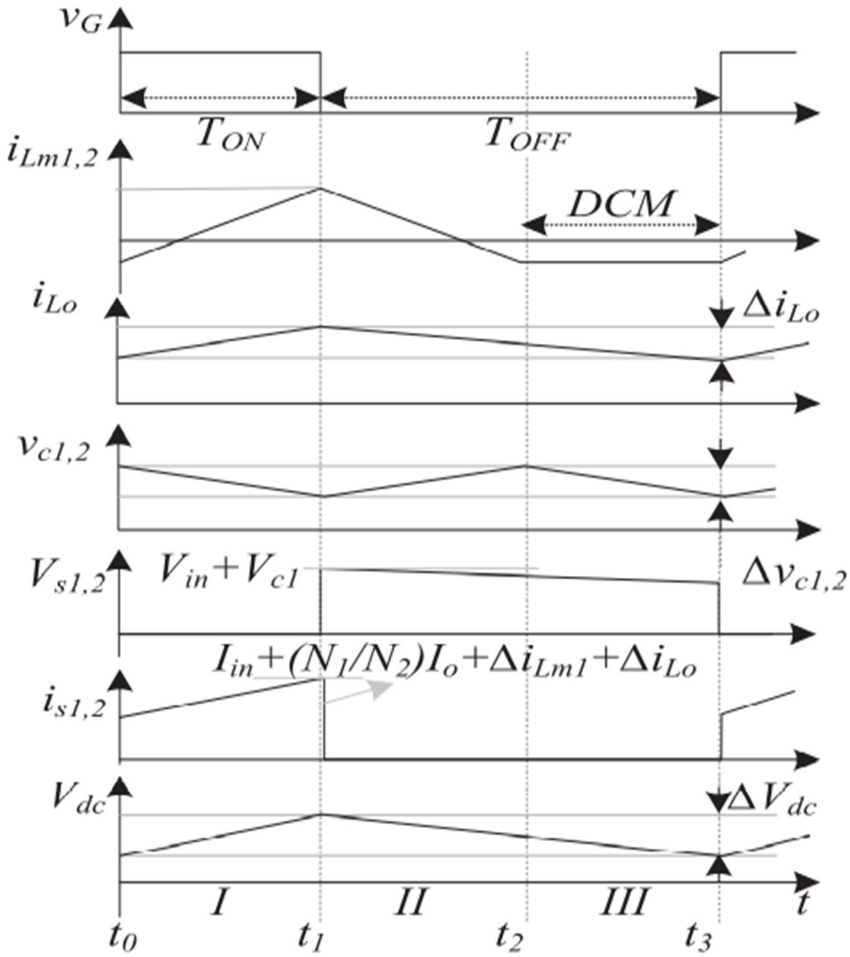

Fig. 5 Charging and Discharging Sequence for Zeta and Luo Modes [15]

Comparative groupings of activity are seen in LC mode during the half cycle when counted as negative, as displayed in Fig. 4(b) 1', 2' & 3'. The main distinction is that the DCM activity in the Luo converter is related to zero current in the polarizing inductor. Fig. 5 shows the related waveforms of various exchanging parts during an exchanging cycle.
A LC [16], is the maximum utilized dc power, change due to having better V_R over a wide info voltage range and higher productivity at light load condition [17]. An examination investigation of LC with other single stage spanned and BLPFC converters in the writing, is displayed in next table that is Table-II. Series LC for dc change with the voltage-lift component, for example, re-lift, ultra-lift and super-lift, are accounted [18]-[20]. It is found in Table-II that LC display fantastic power quality execution with voltage is higher as much as can and move gain, less voltage and current wave. Nonetheless, the capability of LC with BL setup actually should be investigated. A changed BLLuo converter with positive result is planned and examined by Gnanavadivel et.al [21] yet with huge number of parts and an info channel.
If one rate from 1 to 3 so the various terms of dual stage converter, Buck Converter and Boost converter is demonstrated in fig. 6 and Table 2 shows the compassion between various single phase power factor correction converters on the basis of literature review. Similarly, table 3 indicates the comparison of inverter topologies regarding the requirement of the components.

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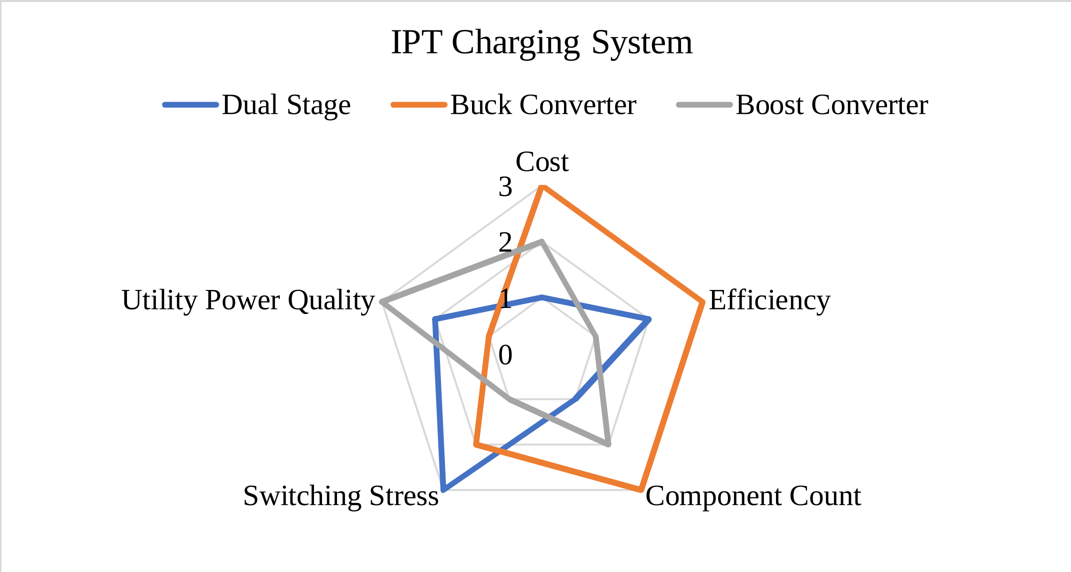

Fig. 6 Comparison between Dual-Stage and Single-Stage IPT Charging Systems

Table 2. Comparison Between Various Single-ϕ PFC

Configuration	BL Buck-Boost [15]	BL-SEPIC [23]	CSC [26]	BL LC [21]	BL ZC [24]	BL CC [23]
V_o	Negative	Positive	Negative	Positive	Positive	Negative
No. of line diodes	Two	Two	Zero	Two	Two	Two
High Freq. Indicators	Two	Four	One	Four	Four	Four
Diode with High Frequency	Two	Two	One	Two	Two	Two
Capacitor with DC-Link	One	One	One	One	One	One
Midway Capacitor	Absent	Present	Present	Present	Present	Present
Power Electronics Components	Two	Two	One	One	Two	One
Total Conduction Loss	M	H	M	L	M	L
Switch Stress	H	H	M	H	H	H
Current Ripple (Input Side)	H	L	L	H	H	L
Voltage Ripple (Output Side)	H	H	H	L	L	L

IV. CONTROL TECHNIQUES

Fig. 7(a), Fig. 7(b), and Fig. 7(c) separately represents the control procedure in plug-in charging mode, boost mode, buck propulsion mode, and regenerative braking down mode. Fig. 8 [29]-[32] examines different control strategies for various converters utilized in EV. Based on the outsider feedback system the control strategy inputs drawn from DC connect voltage, torque and speed. In this module of charging mode, 2 PID regulators are utilized, as displayed in Fig. 10. The internal side proportional-integral-derivative controller have the TF provided by $Z = K_p\left[1 + \frac{T_s}{T_i(Z-1)} + T_d\frac{(Z-1)}{T_s}\right]$ which regulate the battery current and outsider PID controller regulates the battery voltage. [28]

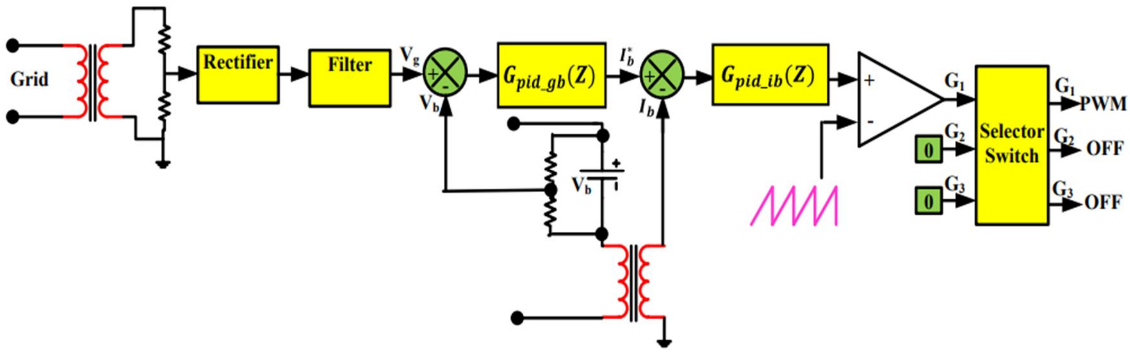

Fig. 7(a) Control Technique in Plug-in Charging Mode

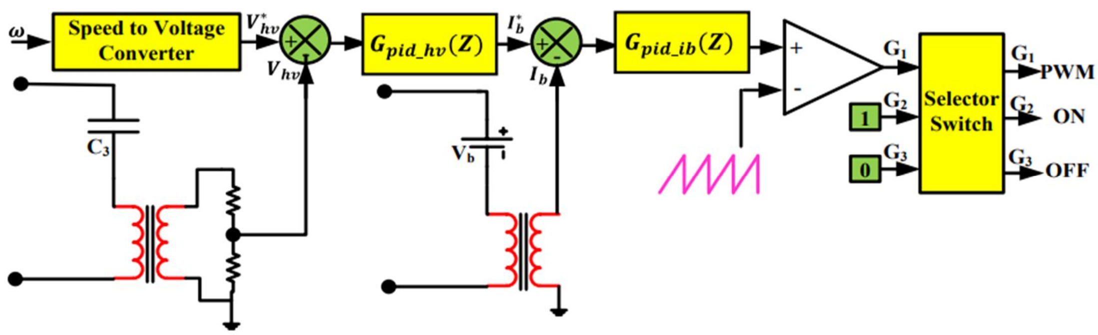

Fig. 7(b) Control Technique in Propulsion Boost mode

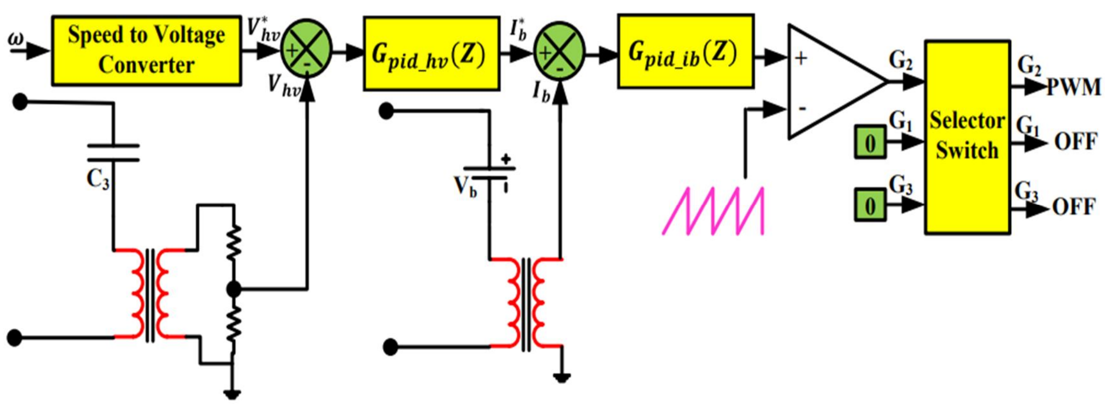

Fig. 7(c) Control Technique in Propulsion Buck mode

To acquire the error signal (E_g) the gain voltage V_g is contrasted with the deliberate battery voltage (V_b). And to produce the current which is reference current I_{b*} the error signal is fed back to the input which is contrasted with the deliberate battery current I_b to get the error signal expected for the inward PID regulator. A step signal which is sawtooth in the shape is needed to drive the switch S_1 and to get a modulated width of pulse. To work in PWM mode the switch S_1 is selected by the selector and in this situation the switches S_2 and S_3 are in OFF mode. The second technique where the switch S_2 is ON and the switch S_3 is in Off mode and the switch S_1 is operate in PWM mode. The fig 7(c) demonstrated the control technique for propulsion mode. Although the propulsion mode is almost similar in buck mode and in boost mode. The basic difference in between both these technique is the state of switch in buck mode that is switch S_2 is in On state where switch S_1 and S_3 in Off state.

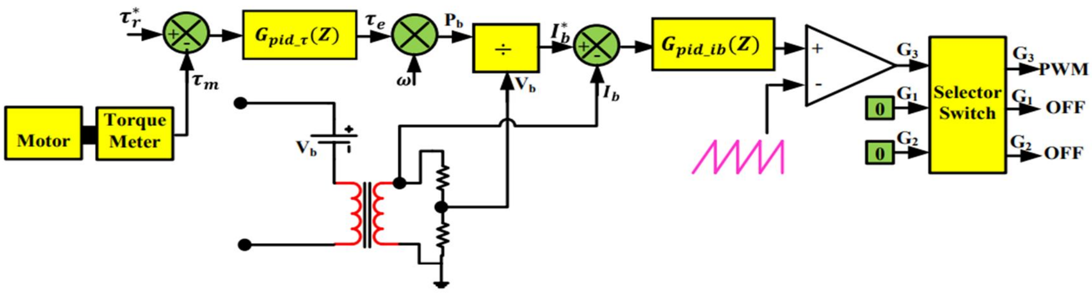

Fig. 7(c) Control Technique in Regenerative Braking mode

Table 3 Comparison of Inverter Topologies

Ref	Configuration	Switches	Passive Components	Control Scheme
[33]	Buck Converter	2 bidirectional	None	Discrete energy injection Pulse width modulation (PWM) (duty cycle control) Secondary-side control (SSC)
[34]	Half Bridge Converter	2 bidirectional	2 Capacitors	Dual-side control DSC)
[34]	Full Bridge Converter	2 bidirectional	None	Discrete energy injection Pulse width modulation SSC and DSC
[34]	Boost Drive Full Bridge	2 bidirectional	1 Inductor	PWM SSC DSC
[15]	Bridgeless Boost	2 diodes, 4 reverse conducting	1 Inductor 1 Capacitor	PWM SSC DSC
[21]	BL Luo	2 bidirectional	2 Inductor 2 Capacitor	Single voltage sensor
[24]	BL Zeta	2 bidirectional	2 Inductor 2 Capacitor	Peak current mode control scheme

V. CONCLUSION AND FUTURE SCOPE

The size of the converter is depended on the use of number of components in the converter. So, to reduce the size of the inverter one has to use the smaller number of components and the disposal of information channel as well as plan of converter in DCM. To charge the battery on the regular constant voltage and current the flyback dc converter is used with the BL converter. To produce the better output from the BL converter one has to regulate the PQ attributes which is proficient to mitigate PQ issues present in the regular EV charger. The better PQ implementation of charger resulted wide info voltage variety range with decreased mains current THD as low as 1.8% to 2%. Also, EV charger has accomplished during fire over-top extensive variety. Consequently, this EV charging arrangement apparently is the most prescribed and worked on choice to supplant the customary chargers used in the EVs.

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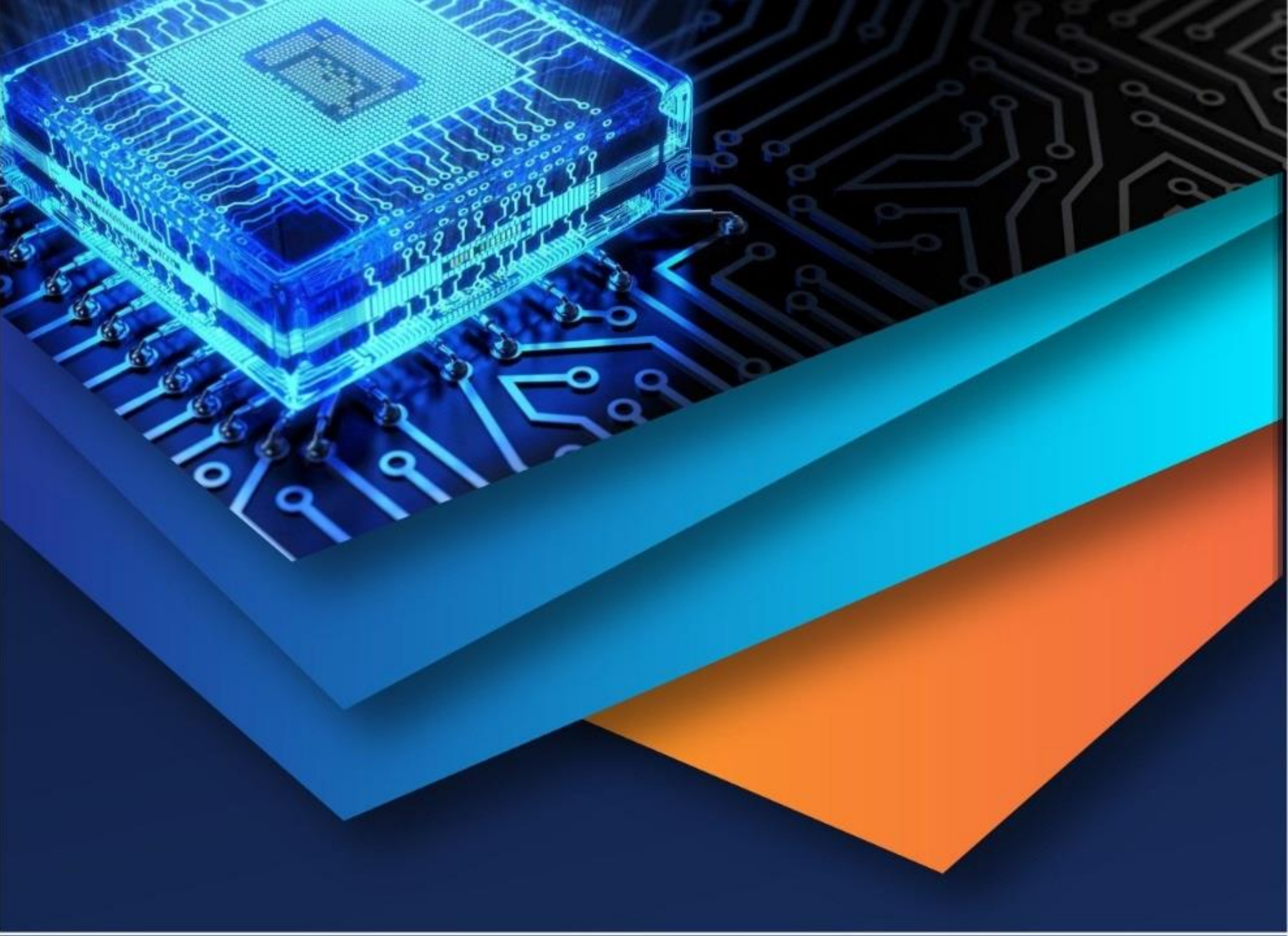

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