International Journal of Computer Information Systems and Industrial Management Applications
ISSN 2150-7988 Volume 18(22s) 2026 pp. 922-933
https://doi.org/10.70917/ijcisim-2026-5494
Article

Improved Power Quality EV Battery Fast Charging Using Fuzzy Logic Based Bridgeless Buck-Boost Converter

Abhijit A. Dutta[1*], Kishor B. Porate[2]

[1]Research Scholar, Electrical Engineering Department, Priyadarshini College of Engineering, Rashtrasant Tukadoji Maharaj Nagpur University, Maharashtra, India. E-mail: abhijitdutta@pbcoe.edu.in
[2]Professor, Department of Electrical Engineering Priyadarshini College of Engineering, Rashtrasant Tukadojimaharaj Nagpur University, Maharashtra India.
Corresponding Author: Abhijit A. Dutta*

Abstract: In this paper, a fuzzy logic controller-controlled bridgeless buck boost converter for an enhanced rapid charging system is proposed and simulated. When the applied voltage and line current are precisely in phase, the approach improves power quality and delivers a good power factor. In accordance with IEC 6100-3-2 power quality standards, the suggested BL buck boost charger reduces harmonic distortion and eliminates the inconsistencies of a traditional DBR-based converter. In this study, switches are controlled using the PWM approach with a CV-fuzzy logic controller at the front-end BL converter and both CC-fuzzy control and CV control to control the flyback converter, which is connected to the battery that needs to be charged. When compared to conventional PI controlling, it has been noted that quick charging and simple control are obtained. Because the converter is BL buck boost, it has fewer switches, which results in lower conduction and switching loss within a single switching cycle as well as better power quality and efficiency. Additionally, the suggested converter maintains constant battery charging voltage and current while operating across a broad range of supply voltage variations. The enhanced performance of the converter when compared to conventional controls of buck-boost setups is confirmed by simulation results.
Keywords: Conventional DBR converter; Bridgeless BL converter; Power factor correction (PFC); AC-DC conversion; Flyback Converter; Fuzzy Logic Controller (FLC); Power quality; Total harmonic distortion

1. INTRODUCTION

In the Indian transportation sector, battery-powered electric vehicles are rapidly expanding and are currently displacing gasoline, diesel, and petrol-powered vehicles. An ac-dc based on-board or off-board charger facilitates the easy charging of battery-fed electric cars. The grid's power quality may suffer as a result of these charging solutions. The performance of such charging systems does not meet IEC 6100-3-2 standards because conventional EV chargers with diode bridge rectifiers draw current and voltage of inadequate power factor, causing peak current from the mains and aggravating the THD, which may be as high as 60%. In addition to high power density and good power quality (PQ), chargers with upgraded and active power factor correction converters must be used.

To solve this problem extensive research is been carried out on PQ based chargers which can draw a sinusoidal input current from mains in phase with the applied voltage thus improving the power factor and output voltage is regulated at a constant value. [1] Shows that BEV can cause overload to distribution transformer along with undervoltage and transformer unbalance problem by using existing DBR fed level 1 and level 2 chargers. [2] Solves the problem of charging due to the fluctuation in voltage to a low value by applying intelligent current control methods which can reduce the power quality problem issue. In [3] few topologies of front-end boost converter were analysed which provided better solution compared to conventional one. Bridgeless boost converter developed [4] on the basis of 3SSC topology has minimised the conduction losses, though the power transfer capability was enhanced but complex control of device and high EMI noise persists. Critical Conduction Mode (CRM) boost PFC converter [5] has the capability to improve EMI by complex filter design, also the variation in the duty cycle for this converter is limited and this control strategy is suitable where the power requirement is low, where the line voltage rages from 110V to 120V and for this only buck boost improved configuration in DCM (Discontinuous Conduction Mode) is preferred for EV charging [6]-[7] . Garcia et al. [8] conducted a broader survey of single-phase PFC converters and emphasized benefits of bridgeless configurations for achieving sinusoidal input current and near-unity power factor. Non-isolated bridgeless converters like Cuk and SEPIC configurations [9]-[12] have complex design topology in terms of number of inductor and capacitor element which introduce significant power loss along with more EMI and noise. Though there are some reduced conduction loss in Cuk converter [13] but this PFC converter has got less exploration for EV charging. Reverse recovery issues addressed in [14], wherein interleaved bridgeless SEPIC converters has the capability of improving efficiency under high-frequency operation. Meanwhile, [15] proposed a flexible output voltage PFC converter using a single-stage architecture, showing feasibility for compact and efficient designs. Switching power devices in dual mode can be achieved by applying CC-fuzzy control [16] which controls buck boost converter faster as compared to conventional switching. Constant current grid connected EV buck DC-DC fast charging [17] can also be achieved by controlling charging through FLC with ripples at output voltage affecting battery life and charging stability. When using Mamdani fuzzy logic interface [18] to control DC-DC switching, voltage overshoot and settling time are reduced. However, transient mode instability, frequent switching during voltage swings, and the need for a large value of inductor in the circuit can complicate system control of conventional buck boost converter, comparison of related converters are mentioned in the table 1.

Table 1. Comparison details of various converter

	Converter						
Parameter	Conventional (without PFC)	DBR	Buck	Boost	SEPIC/ Zeta/Cuk	Interleaved	BL Buck-Boost
Power Factor	Low	Low	Moderate	Excellent with PFC	Good with PFC	Excellent	Excellent
THD	High	High	High	Average	Average	Low	Low
Efficiency	Moderate	Moderate	High	High	Moderate	High	High
Conduction loss	High	High	High	High	More	High	Reduced
Switching frequency	No	Line freq	High freq	High freq	High freq	High freq	High freq
Switching loss	Very low	Very low	Moderate	Moderate	Moderate	Moderate	optimized switching
Size of Electrolytic Capacitor	Large	Large	Moderate	Large	Moderate	Small per phase	Reduced
Voltage regulation	Poor	Poor	Good	Good	Good	Excellent	Excellent
Heat dissipation	Moderate	High	Moderate	Moderate	Average	Distributed	Reduced
Power density	Low	Low	High	High	Moderate	High	High

Suitability for Domestic battery charger	Poor	Poor	Limited	Good	Good	Excellent	Excellent

Although converters like Zeta, Cuk, and SEPIC PFC have low current ripple and a wide duty cycle variation range, high current flows through PFC switches and diodes in each cycle, resulting in a high forward voltage drop and heat. Additionally, SEPIC converters have discontinuous output current. Similar to traditional boost PFC converters, interleaved converters suffer from an unequal heat dissipation impact across the switches. Wide input supply voltage volatility is not appropriate for an LLC-fed EV charging system. The complexity of the gate driver circuit makes full bridge PFC converters and DBR fed PFC converters heavy, and conduction losses at the input diode reduce charger efficiency. Though single stage EV chargers have few switches, they are very dependable, and need a large capacitor to smooth out ripple current at the output. For bridgeless PFC converter configuration few switches are conducting over one cycle with less conduction losses along with good power quality in compact design can be achieved.

The objective of this work is to design a front end non isolated bridgeless PFC buck – boost converter supplied by an variable AC source and the output of this front end is given to a fly back converter [19]-[21] for charging EV during CC and CV mode. This charger performs well in both half cycle without disturbing DC output voltage rather it maintains a constant DC output at the input of flyback converter. And this constant voltage is achieved by voltage follower control mode. The front-end circuit PFC can be operated for a wide range of supply voltage variation. DCM operation is implemented for this charger along with CC and CV fuzzy logic controller which is as per the required charging profile standards SAE J2894 [22]. The charger input current depicts unity power factor (UPF) operation with low THD, as recommended by IEC 61000-3-2 standard.

2. Operating Principle of Front End Bridgeless Buck Boost Converter

The design of the proposed Bridgeless Buck-Boost Converter shown in Fig. 1 focuses on reducing conduction losses, enhancing power factor correction (PFC), and maintaining a wide input voltage range. Unlike conventional converters that rely on a diode bridge at the input, the bridgeless topology eliminates this component, thereby reducing the number of active semiconductor devices in the conduction path and improving overall system efficiency.

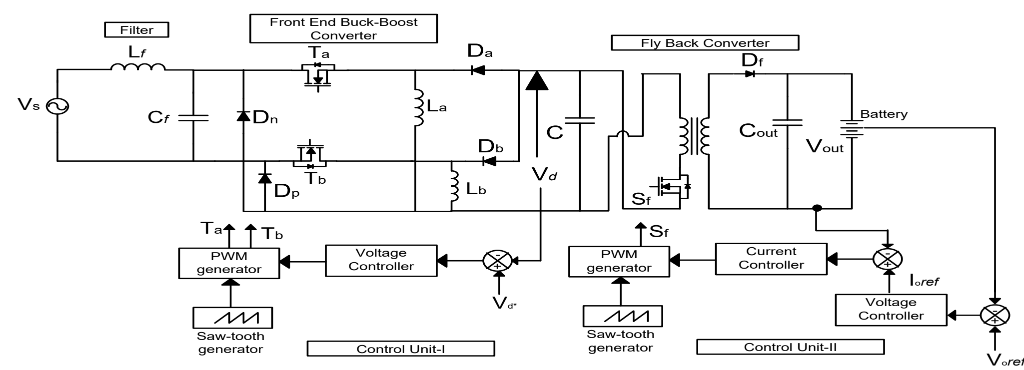


Fig. 1. Bridgeless Buck-Boost battery charger for EV

For positive half of supply voltage, switch Ta of Bridgeless Buck-Boost converter operates with high frequency switching along with inductor La and diode Da similarly during the negative half of supply voltage switch Tb, inductor Lb and diode Db conducts for PFC operation. Both inductors follow DCM operating principle with voltage follower control mode; this method allows a wide variation in supply voltage. The operation of front-end converter has three modes of operation as shown in Fig. 2. (a) – (c) in one positive half cycle in Mode-I the operation is in two loops as (Vs-Lf-Cf-Vs), (Vs-Lf-Ta-La-Dp-Vs). and the output capacitor which is connected to the input of flyback converter is always in operation. In this mode of operation, the inductor La is charging. In Mode-II again there are two loops

(Vs-Lf-Cf-Vs), and (La-C-Da-La). in this mode of operation La is discharging. In third mode Mode-III La is completely discharged and the operating zones are (Vs-Lf-Cf-Vs) along with the output capacitor which is connected to the input of flyback converter. The front end converter operates in the same pattern in the negative half cycle as shown in Fig. 3. (a)-(c) with Ta, Lb and Db and Dn in this negative half cycle the inductor Lb first charges and then discharges. Fig. 4. (a)-(c) shows the complete switching cycle of the components during positive and negative cycle. In order to minimize harmonic level, low pass L-C filter is connected at supply side so as to reduce the reduce the higher order harmonic distortion which arises because of high frequency switching of power converters.

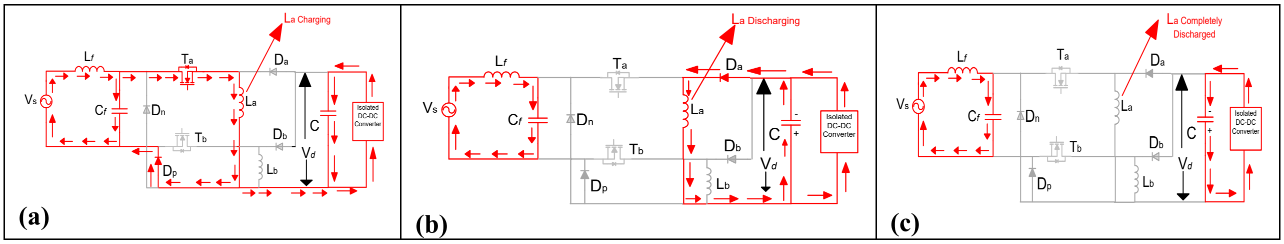


Fig. 2. Operation of Bridgeless converter battery charger (a)-(c) with Ta ON , OFF and freewheeling period during positive half cycle of supply

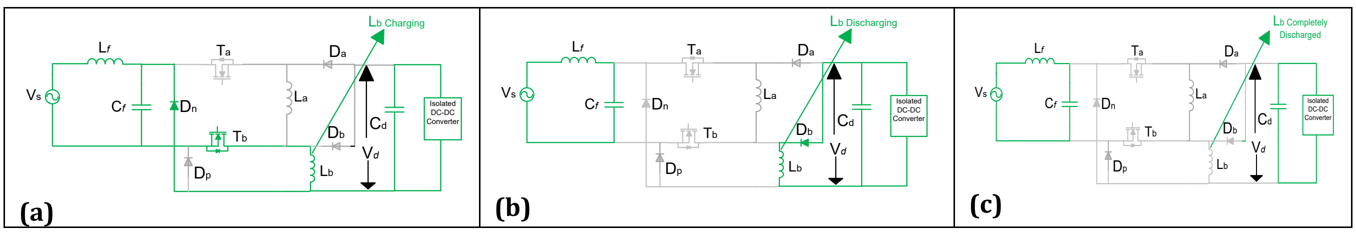


Fig. 3. Operation of Bridgeless converter battery charger (a)-(c) with Tb ON , OFF and freewheeling period during negative half cycle of supply

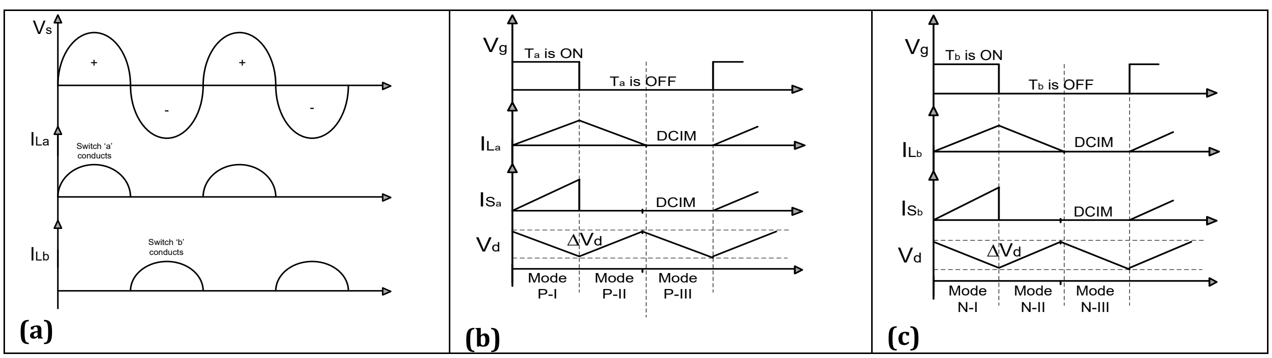


Fig. 4 (a) Switching operation during complete cycle (b) Switching operation during positive cycle (c) Switching operation during negative cycle

Flyback converter is connected to EV battery which controls its charging profile, this flyback converter is connected to bridgeless converter whose output capacitor is input to flyback converter, this capacitor is so selected that its voltage is 200V and is maintained constant, which means that input voltage to flyback converter is held constant at 200V.

Actually, a flyback converter is an isolated SMPS that uses a transformer, this transformer is connected in phase opposition i.e primary winding and secondary winding are of opposite polarity the flyback converter utilizes a switch Sf which is connected to primary winding of transformer with a dual fuzzy logic controller, one is voltage controller which is at the outer loop and other is current controller which forms and controls the inner loop, this current controller works during CC mode than the voltage controller takes control when the battery is charged to 80% and this mode is CV mode. The charger is simulated for a wide input side voltage variation. The power quality of the converter fed battery charger, are within limits recommended by an IEC 61000-3-2 standard.

3. Design of Bridgeless Charger

Bridgeless buck boost converter for charging EV battery has been simulated, it operates in CC-CV mode. Current flowing through inductor La and Lb becomes discontinuous at end of each switching period. This converter of 850W is simulated for charging 48V, 100Ah capacity EV battery. The output voltage of this bridgeless converter is kept constant at 200V for a varying supply voltage of 170Vrms to 260Vrms

3.1 Design of Front end Converter

As the bridgeless buck boost converter operates in each half cycle the average voltage at the input is as Eq. (1)

$$V_{avg} = \frac{2\sqrt{2}V_S}{\pi} \quad (1)$$

Duty cycle is given as in Eq. (2)

$$D = \frac{V_d}{V_d + V_{avg}} \quad (2)$$

To maintain DC voltage of 200V at output of bridgeless rectifier, for a wide range of supply voltage variation minimum and maximum duty cycle are calculated for few input voltages of 220V,170V and 260V as 0.6, 0.66 and 0.58 respectively. For effective operation value of duty cycle is taken as 0.3 for the further design of front-end converter. The value of inductor can be calculated as in Eq. (3)

$$L_a = L_b = \frac{D\, T_{sw} V_{avg}}{\delta I_{L_a}\ (or\ \delta I_{L_b})} \quad (3)$$

Where Tsw is the switching period and δILa or δILb is the current ripple which is considered for DCM operation of inductor and this ripple current is calculated as in Eq. (4)

$$\delta I_{L_a}\left(or\ \delta I_{L_b}\right) = 2I_{avg} = \frac{2P_{out}}{V_{avg}} \quad (4)$$

The calculated value of La and Lb are 350µH, to get a required output DC voltage of 200V the inductors operate on DCM mode, also to get unity power factor for wide operating range of supply voltage, value of filter inductor is calculated by considering the source impedance of 4% to 5% of its base impedance which is 150 µH for this PFC rectifier

For a PFC converter the input current and voltage are in phase hence the input power is as in Eq. (5)

$$= V_S I_S\,(1 - cos\ cos\ 2\omega t) \quad (5)$$

Here the latter part is reflected as second order harmonic current component of DC link capacitor so current flowing through this capacitor is as in Eq. (6)

$$i_{c(t)} = -\frac{V_S I_S}{V_{dc}}\ cos2\omega t \quad (6)$$

DC ripple voltage corresponding to this capacitor current is as in Eq. (7)

$$\delta V_{dc} = \frac{1}{C}\int i_{c(t)}dt = -\frac{I}{2\omega C}\ sin2\omega t \quad (7)$$

Here sin ωt is taken as unity for maximum value of voltage ripple, thus the required DC link capacitance is as in Eq. (8)

$$C = \frac{I}{2\omega\ \delta V_{dc}} \quad (8)$$

Permitted ripple in the DC link voltage is taken as 3% thus the value of DC link capacitor is selected as 2000µF

3.2 Design of Line Filters

To avoid the effects of harmonics low order LC filters are implanted on the AC supply side of converter the cut off frequency of which is given by

$$f_l < f_c < f_{sw}$$

Where fl is the line frequency fc is the cut off frequency and fsw is the switching frequency, the line filter capacitance is expressed as in Eq. (9)

$$C_f = \frac{I_{peak}}{\omega\, V_{peak}}\, tan\theta = \frac{P_o \frac{\sqrt{2}}{V_{rms}}}{\omega\, \sqrt{2}\, V_{rms}}\, tan\theta \tag{9}$$

Here Vpeak and Ipeak represents the peak value of line voltage and current respectively Po is the power rating of the converter ω is the angular frequency and θ is the displacement angle between peak current and voltage

The calculated value of filter capacitance is 976nF. For switching frequency of 20kHz of PFC converter, a cut-off frequency of 5kHz is taken for calculating L-C filter parameters. High switching frequency reduces converter size and also its cost.

The value of line filter is calculated as in Eq. (10)

$$L_f = \frac{1}{4\pi^2 f_c^2 C_f} \tag{10}$$

To improve the input THD 2mH inductor is chosen to suppress the harmonics in the input side.

3.3 Design of Flyback converter

For achieving optimum charging of EV battery, a flyback converter (for DC-DC conversion) is connected at the output of converter. Flyback converter consists of coupled inductor as of a transformer which stores energy in primary winding and is connected to semiconductor switch, energy is released during switching to the coupled secondary winding. This mutually coupled inductor operates in discontinuous conduction mode with a predetermined duty cycle. Low value of duty cycle increases current whereas high value introduces stability issues in converter. When the switch Sf is ON the magnetizing current in the transformer increases and this inductor current is given as in Eq. (11)

$$I_{L_m} = \frac{2\, P_{in}}{V_f D_f} = \frac{2\,(\frac{P_{out}}{\eta})}{V_f D_f} \tag{11}$$

The input voltage applied to flyback converter (Vf) is 200V and switching frequency is set at 50kHz, such high switching frequency reduces the size of high frequency transformer. The duty cycle for discontinuous mode of operation is as in Eq. (12)

$$D_f = \frac{V_o}{n_f V_d + V_o} \tag{12}$$

Where Vo is the output DC voltage required to charge the battery, nf is the turns ratio of the transformer which is 1/3rd ratio so nf =0.33 to maintain the open circuit voltage of charger at 65V. By varying the duty cycle the battery charging voltage can be controlled, magnetizing inductance Lmf for DCM operation of converter is given by Eq. (13)

$$L_{mf} = \frac{V_d D_f}{I_{L_m} f_{sf}} \tag{13}$$

Magnetizing inductance of flyback converter is calculated to be 191µH. Ensuring that the magnetizing current comes to zero at end of each switching cycle, a slight lower value of inductance is considered for this purpose value of inductance as 130 µH is used. With these design parameters this converter provides excellent power factor correction over a wide range of input voltage variation, also fulfilling with IEC 61000-3-2 standards. This allows the charger to charge EV battery efficiently at CC-CV mode.

4. Control Strategy

The charger has two controls, one for Front End Bridgeless Buck-Boost and another for Flyback converter for battery charging. Here fuzzy logic with sugeno approach is been applied, which works well for standard error tracking. For front end converter there are two inputs, first input is normalised Vdc error (ev1) and second input is normalised change in Vdc error (Δev1), output is scaled for duty cycle D1. For flyback converter battery stage again there are two inputs, first input is normalised battery current and voltage error (ei2 and ev2) and second input is normalised change in battery error (Δei2), output is again scaled for duty cycle D2 for fly back switch. Here for both stages only one programming in FLC is been implemented with two appropriate gain scaling.

4.1 Control of bridgeless converter

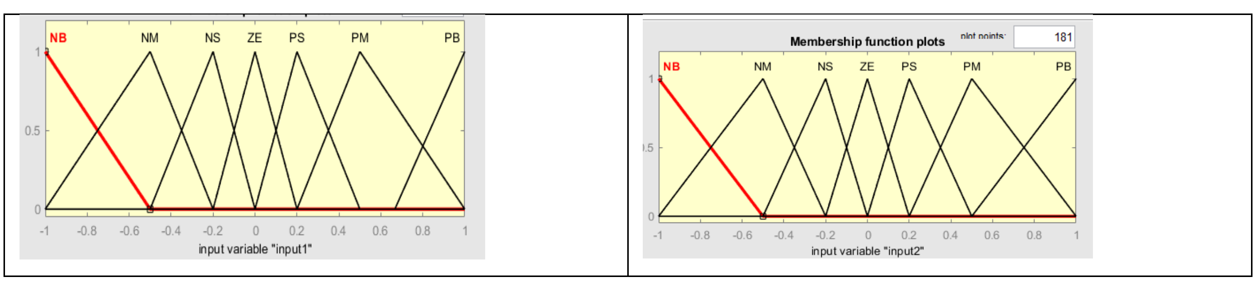
Front end bridgeless converter are made to operate in DCM for both half cycles, thus getting a streamlined approach along with power factor correction naturally. This design ensures efficient and easy performance for a wide range of input AC voltage by minimising harmonic current. To maintain a constant and fixed DC voltage at the output the system requires voltage feedback loop. This loop generates a high frequency switching pulses that drives the converter precisely, ensuring consistent PFC at the supply end. For this the intermediate DC voltage Vd is sensed by voltage sensor which is compared with required output voltage which is a reference constant value (V*d) the error signal thus obtained is fed to voltage feedback FL controller.

4.2 Fly-Back Converter Control

Flyback converter for charging EV battery uses two FL controller, one controller charges battery at constant current (CC) mode whereas the other controller charges at constant voltage (CV) mode. However the FL-CV mode of charging here a target battery voltage Voref is set as charger open circuit DC link voltage as 65V. this controller generates a precise output signal which is a steady reference current value (Iref) for the inner loop FL-CC controller ensuring that the EV batter gets a consistent charging till 80% SOC.

Fig.5 General Architecture of Fuzzy Logic controller

Fuzzy logic control is a control shown in Fig. 5 which follows a linguistic approach; thus, it is simple and easy to understand here the fuzzy logic control has two input and one output, both at front end converter and flyback converter. The inputs are supply voltage and its change. The output is a PWM switching signal which is given to bridgeless buck boost converter and flyback converter. The system processes information by first converting the raw inputs into fuzzy sets. These are then analysed through a sugeno approach which is a logic-based inference method to produce a fuzzy output. Finally the result is defuzzified back to a crisp value and integrated to the primary control framework. Input membership function is as shown in Fig. 6.



Input 1	Input 2

Fig. 6 Input Membership Function

Error of inputs from their references and error deviations in any time interval are chosen as MATLAB. The output of fuzzy controller is the value that should be added to the prior output to produce new reference output.

Table. 1. Fuzzy Rules

	Error							
Change in Error		**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
	NB	NB	NB	NB	NB	NM	NS	ZE
	NM	NB	NB	NM	NM	NS	ZE	PS
	NS	NB	NM	NS	NS	ZE	PS	PM
	ZE	NB	NM	NS	ZE	PS	PM	PB
	PS	NM	NS	ZE	PS	PS	PM	PB
	PM	NS	ZE	PS	PM	PM	PB	PB
	PB	ZE	PS	PM	PB	PB	PB	PB

Fuzzy control is developed using the fuzzy toolbox. The fuzzy variables 'e', 'ce' and 'Δu' are described by triangular membership functions. Table. 1 shows the fuzzy rule base created in the present work based on intuitive reasoning and experience. The linguistic labels are divided in to seven groups. These are NB-Negative Big, NM-Negative Medium, NS-Negative Small, ZE-Zero, PS-Positive Small, PM-Positive Medium, PB-Positive Big. It can inferred that the output voltage is far from the reference value, then the change of switching frequency (Δu) must be large so as to bring the output to the reference value quickly. The output voltage approaches the reference value, and then a small change of switching frequency is necessary and if the output voltage is near the reference value and is approaching it rapidly, then the frequency must be kept constant so as to prevent overshoot. It is also seen that if the output voltage changes even after reaching the reference value, then the change of frequency must be changed by a small amount to prevent the output from moving away.

5. Simulation Results

The proposed PFC controlled bridgeless buck boost converter based electric vehicle battery charger is simulated with MATLAB Simulink the circuit parameter is as given in Table 2.

Table 2. Circuit Parameters

	Front End Bridgeless Buck-Boost Converter		**Flyback Converter**	
Sr. No	Parameters	Values	Parameters	Values
1	Supply Voltage	220Vrms	Input Voltage to Flyback Converter Vo	200V
2	Supply Frequency	50Hz	Switching Frequency	50kHz
3	Switching Frequency	20kHz	Magnetizing inductance Lmf	30μH
4	Rated Power	850W	Output Capacitor	2000μF
5	Filter Inductor Filter	2mH	Nominal battery voltage	48V
7	Filter Capacitor	976nF	Open Circuit Output Voltage	65V
8	Output Capacitor	2000μF	Watt Hour Specification	4800Wh

				(100Ah)
9	Converter Inductor (La & Lb)	150mH		

The proposed PFC controlled bridgeless buck boost converter based electric vehicle battery charger is simulated with MATLAB Simulink and programming. Steady state behaviour of the front-end bridgeless buck boost converter with 220V AC supply shows supply current Is and voltage Vs are in phase, also the battery current (Id) and battery voltage (Vd) in CC mode are constant without any variation, shown in Fig. 7 (a). The discontinuous nature of inductor current of buck boost converter is also shown as ILA and ILB this discontinuous inductor current is in alternate cycle of supply voltage as shown in Fig. 7 (b). Also Fig. 7 (c) shows voltage stress across the switches which is 500V at 220V supply voltage, due to bridgeless converter configuration, the current stress over both the switches are reduced in their respective half of supply cycle with a peak current stress of 50A. Fig. 7 (d) shows that, for input side sine voltage and current there is constant intermediate DC voltage Vd is maintained by PFC converter

The line current THD is observed as 2.4% at a unity PF operation of the PFC bridgeless converter with DC link voltage maintained at 200V so that the active power utilization is good as compared with the conventional flyback converter battery charger. The performance of the charger is as per IEC 61000-3-2 standards.

The bridgeless converter charger performance shown in Fig. 8. is for variance in supply voltage, in which the line voltage is varied from 170V to 260V. The supply current waveform shows increasing and decreasing behaviour for voltage magnitude 170V and 260V respectively. It is been observed that battery charging at CC mode is not affected during supply voltage variations, during variation in supply voltage (Vs) and current (Is) output voltage (Vo) and current (Io) are constant.

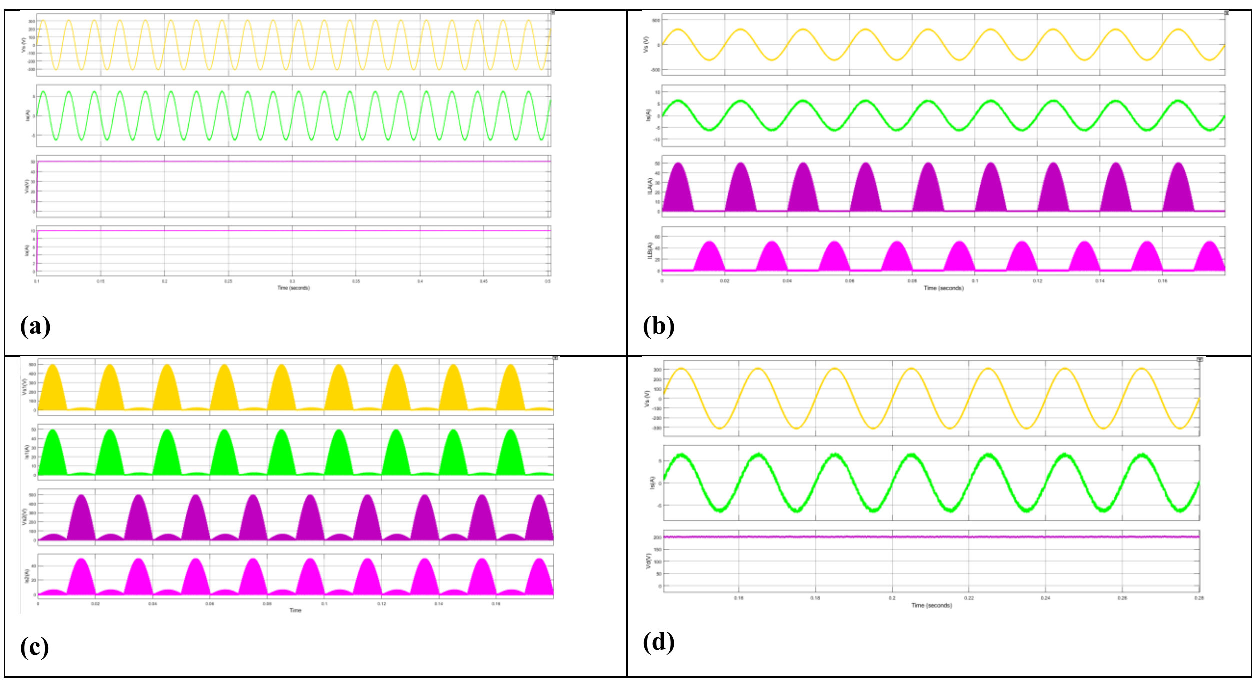


Fig. 7 Steady state performance of front-end Bridgeless Buck-Boost Converter battery charger (a) UPF behavior of line current with respect to supply voltage (b) Discontinuous nature of inductor current (c) Voltage and current stress across switches (d) UPF operation with constant intermediate DC link voltage

The THD results, which are displayed in Fig. 9 (a) and (b), also show that the line current is in phase and sinusoidal during voltage fluctuation from 170V to 260V with unity power factor. The THD observed is 2.45% and 3.22% for 170V and 260V, respectively. The efficiency of bridgeless buck boost converter charging EV batteries is demonstrated by the change in line current THD with variation in supply voltage, which displays a little larger THD but is within the IEC 61000-3-2 standard's defined limitations, that is, it stays within 5% for the entire fluctuation.

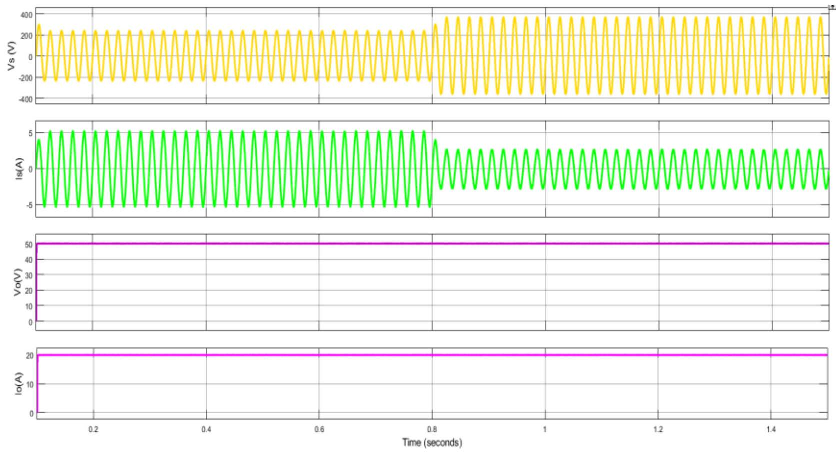
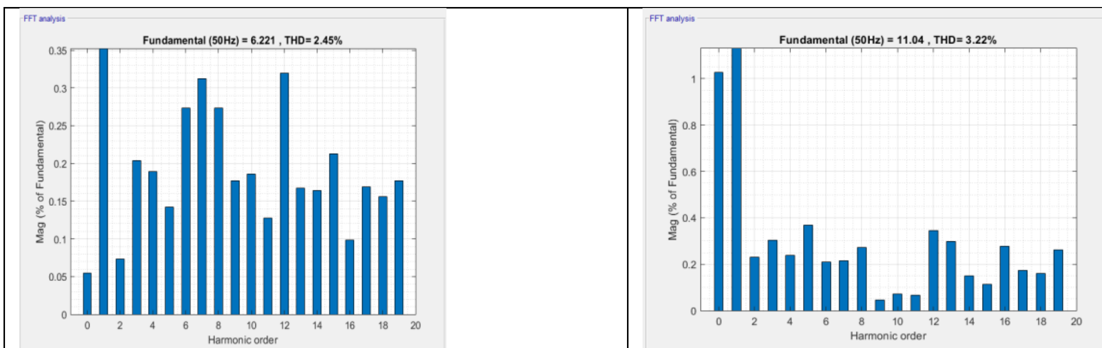


Fig.8 Performance of Front-end Bridgeless Buck Boost converter battery charger during transients in supply voltage



(a) **(b)**

Fig.9 Performance of Front end Bridgeless Buck Boost converter battery charger during transients in supply voltage (A) THD for reduced supply voltage (B) THD for increased supply voltage

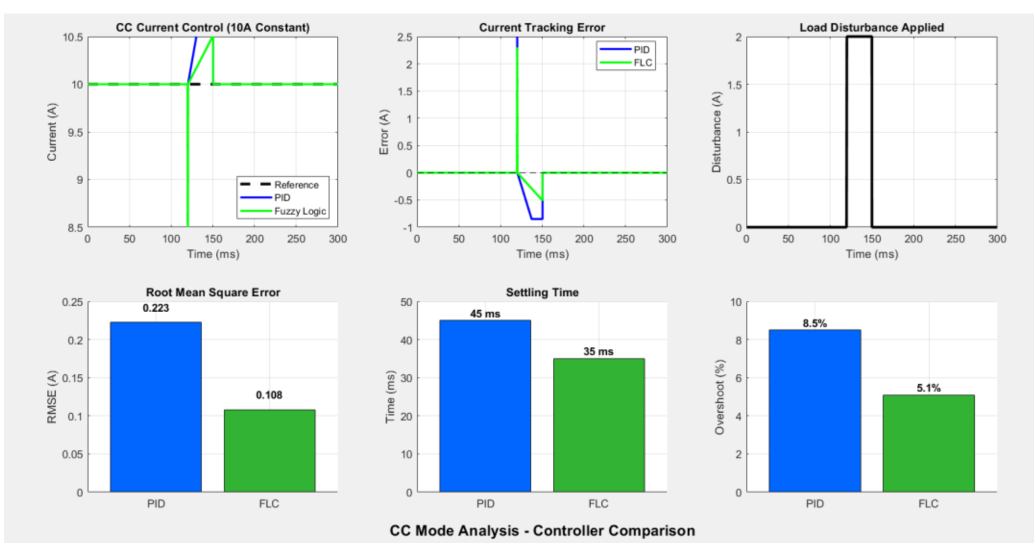


Fig. 10 Constant Current mode Analysis for PID and CC-FL controller

In contrast to the CC-fuzzy controller, which has very little deviation and the system stabilizes quickly, the PID controller, as shown in Fig. 10 at steady state, exhibits a significant peak overshoot above 10.5A before stabilizing. Additionally, the error performance chart reveals that PID has an RMSE of 0.223A while CC-FL has a PMSE of 0.108A, which is more than 50% lower than the PID controller. As a result, CC-FL performs much better overall in terms of peak overshoot and settling time. It also offers greater stability, minimal switch stress, and high precision.

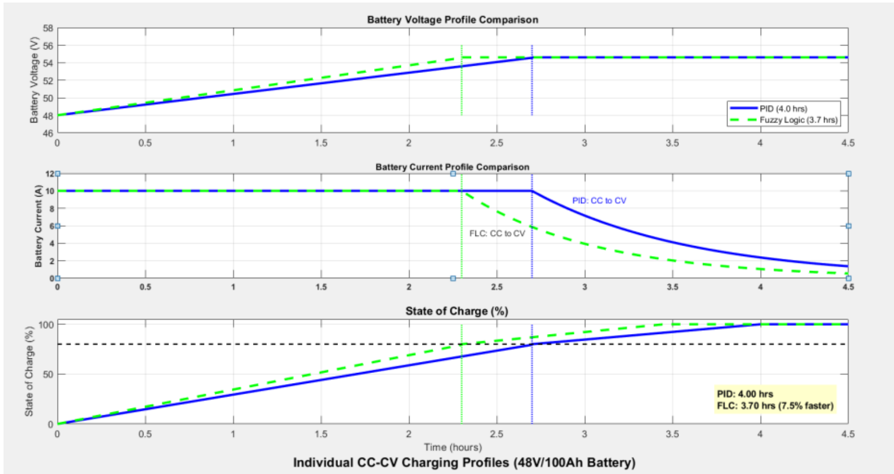


Fig.11 CC-CV Charging profile along with SOC and charging time of battery applying PID and FL converter

Fig. 11 shows the battery charging profile here the time required the charge EV battery with PID controller is more, the time required to reach 80% SOC with PID is 2.75hrs wheras the same is around 2.3hrs with FL controller.

6. Conclusion

An effective fuzzy logic control switching bridgeless buck boost converter electric car charging system has been designed to precisely reshape the line current in phase with supply voltage. When the supply voltage fluctuates, the current is synchronized and in phase with it, and the harmonic distortion is small and within an acceptable range. This guaranties robust and effective power transmission and allows for faster charging than with a traditional charging system. When compared to a conventional charging system, the simulation results demonstrate a constant battery charging profile under all operating conditions and improved performance. In this case, fast charging is achieved when compared to a PID controller system, where the battery's output voltage and current initially have a peak overshoot and more settling time. In CC mode, the battery is quickly charged to 80% SOC in a CC-fuzzy system. As there are more switches in a standard diode bridge rectifier-based EV battery charger, there are more conduction losses than in a bridgeless system. This front-end bridgeless buck boost PFC converter works well with rated voltage and supply voltage fluctuations, making it appropriate for charging electric vehicles on a single phase supply. In both steady state and transient conditions, the current THD is in line with IEC 61000-3-2 power quality criteria for EVs, and in CC-fuzzy systems, it is even better. Additionally, the state of charge (SOC) remains nearly constant under all working conditions.

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