Modified Bridgeless Landsman Converter Fed EV Battery Charger with Improved Power Factor

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Abstract. This research work focuses on the design and construction of a novel Battery-powered Electric Vehicle (BpEV) and to enhance the power-factor of the input AC. This is accomplished by substituting the prevalent diode converter with a newer, high-quality Landsman converter that is equipped with power-factor tuning. The Flyback-isolated and PFC converters work together to let the EV battery to switch between constant current and constant voltage modes. The recommended PFC converter is regulated using a single entity to attain consistent DC-link voltage and to boost the power-factor close to unity, with simulation carried out using MATLAB. As per the findings, a minimum of 60V DC output is required for charging the battery and suppressing input harmonics. In comparison to the usual architecture, the suggested scheme could provide increased power quality, very little device stress, less ripple at both input and output, and significantly lower harmonics. To validate the simulation results, a prototype is developed and deployed to charge a 48V EV battery with a rating of 100Ah in order to make it compliant with the IEC 61000-3-2 standard, particularly in the case of high voltage spikes at the input. The charger's performance has been deemed to be good in all conditions based on matlab simulation results.

Keywords: Power Factor, Landsman Converter, Flyback converter, Isolation transformer, Harmonics.

1. Introduction
The charging process of any battery used in an electric locomotive is primarily determined by its dimensions and category, such as the magnitude and duration of voltage/current to be applied, the procedure after full-charging is complete, and so on. A few battery types are much more adaptable and capable of sustained charging even after full charge. They are typically recharged using either a constant current or a constant voltage source, depending on the situation. Few other batteries mandate/employ a timer to turn off the charging current at a designated time, usually once the charge is full, and the chargers must be separated manually at almost every charging cycle. Overcharging, damage (reduced capacity, shorter lifespan), overheating, and even exploding are all risks associated with other battery types. The charger comprises temperature and voltage sensor circuits, as well as a
microprocessor, to securely fine-tune the charging current/voltage and diagnose the cut-off at the end of the charge. A slow battery charger may take several hours to reach full charge. High-capacity chargers can promptly rebuild the majority of a battery's capacity; however, they may be too powerful for some battery types. To safeguard the battery from overcharging, such batteries require active monitoring. High-rate chargers are appropriate for electric vehicles. Setting up those chargers, as well as providing the necessary assistance, is a concern, particularly for public accessing electric locomotives. A competent battery charger is the foundation for long-lasting and reliable batteries. Chargers are frequently given minimal importance and are seen as an "afterthought" in a price-sensitive market. The battery and charger, like a horse and carriage, must function together. The power supply is prioritized through prudent planning and is critical at the initial phase, well before implementation. Technologists are more often clueless of the complexities of the power source, particularly while charging in complicated environments.

A trickle-charger delivers a limited electric current to a battery that has been sitting for a long time, just enough to keep it from self-discharging. Trickle charging is not compatible with all battery types, and attempting to do so may result in harm. Indefinite trickle charging is not possible due to the chemical technique utilized in lithium ion battery cells.

2. Literature Review
With stringent regulations on air pollution, fuel cost/consumption, climate change concerns, and sparse energy resources, electric mobility makes a significant contribution to the development of sustainable and efficient transportation alternatives [1-2]. And [3] provides a study based on the actual predicament and technological advances for electric vehicle (EV) propulsion in this regard. Transportation by electricity has a number of benefits than the orthodox gasoline and petrol automobiles. Yet, a researcher's undivided attention is required to fully incorporate transportation electrification. To fit them into the prevailing distribution scheme, certain effective control mechanisms must be created. Some of the aforementioned strategies are linked to the concerns with power quality that EV chargers solve throughout the charging procedure [4-5]. The EVs are outfitted with rechargeable batteries to achieve the desired adhesion/friction strength. EV chargers, that are otherwise AC–DC converters, are typically used to recharge all such batteries. The much more widespread EV charging layout includes a boost converter that precedes an isolated converter [6]. The manufacturer determines the capabilities of such a category of charger exclusively depending on the quality of the DC-DC converter owing to tightly controlled voltage as well as current outputs. [7-10] describe more about interleaved and zero-voltage switching PFC converters with respect to charging units that diminish both the inductor dimension and ripple at the output. The cost of interleaving a PFC converter is substantial. The bridge configuration is perhaps popular for PFC-type EV charging units, and it offers features such as improved power density and quality though the setup of four switches exacerbates charging mechanism [11]. A resonant converter (L-L-C type) [12-13] is a captivating alternative because of its maximum effectiveness, little Electromagnetic interference, noise, and extraordinary power density for a variety of inputs. Due to the additional hardships in the modelling and development of L-L-C converters, this sort of configuration is switched by uni- or bi-directional AC-DC converters in embedded on-board or off-board modules [14]. The conversion from AC to DC is imperative for a large number of single-directional isolated 1-stage or 2-stage converters with no isolation supplied via diode-bridge-rectifiers for charging electrically operated rickshaw [15]. The prescribed rickshaw is observed with a battery as a load to illustrate the power quality of the charger.
supplied via a standard diode-bridge converter. The result clearly shows that the power quality is not as specified by standard IEC 61000-3-2 [16]. Because of the addition of a full-bridge at the input side of the charger, there is a major reduction in harmonic levels at the input, notably throughout charging, but this effect in a low power-factor at the source.

Furthermore, the input current is no longer sinusoidal, resulting in an increase in source voltage and current displacement. As a result, at the front-end of a traditional DBR fed charger, an effective power factor correction (PFC) technique is required, which also eliminates the negative impacts of input DBR. Furthermore, the input current becomes non-sinusoidal, necessitating the use of an appropriate power-factor correcting mechanism in conjunction with the existing DBR in order to negate the adverse influence of the input DBR. This, in turn, reduces system/conduction losses, enhancing efficiency and abolishing the need for such a bridge. A fair comparison of bridge and bridgeless charges with and without power-factor correcting devices are available in literature in [17-21]. The Bridgeless configurations possess large electromagnetic interference, increased noise and it is difficult to control them while it offers higher efficiency and lower thermal stress when the power level is high. Besides that, there is a limit to adjusting the duty ratio for regulating DC-link voltages, particularly at low source voltage values. As a result, many buck-boost converters are debated in order to attain a substantial increase in duty cycle [22-28]. Due to the total absence of a bridge, they can achieve high charger efficiencies and minimize losses even when the voltage at the source is low. The Landsman converter produces superior results, which have been authored in the literature [29].

The proposed work makes an effort to combine the beneficial aspects of many converters presented in the literature while minimising their drawbacks. It is attempted to develop a fly-back converter without the bridge structure and to outfit it with a modified Landsman converter for power-factor adjustment. The aforementioned converter is simulated and demonstrated to charge a 48 V, 100Ah capacity battery in accordance with the IEC 61000-3-2 power quality standards.

3. Operation of Modified BL Converter Fed Charger
The designed charger has two stages of operation: a modified bridgeless converter with superior wave-shaping of input and an isolated converter for charging the electrified locomotive through constant-current or voltage mode based on their monetary or voltage stress constraints. Because the cost of the battery charger is more crucial across most cases, the discontinuous current operation is chosen (DCM i.e. Constant Voltage). Another key reason is that it requires fewer sensors to stabilize battery charging.

3.1 Proposed method
Figure 1 depicts an Electrified Vehicle charger fed by a bridgeless converter, the voltage of which is regulated using an intermediate stage DC-link voltage. This set-up employs a single-phase AC voltage at the input of the charger. The input side diode bridge is eliminated when using two Landsman converters, one for each of the positive and negative half lines. Because fewer elements are used per switching cycle, losses during the conduction period are nearly reduced to 50%. To achieve better switching performance, the two converters use synchronised switching at a frequency of around 20 kc/s. The output inductor currents through Lop and Lon are made discontinuous at each half cycle for a period of one switching cycle, allowing a single sensor to detect the intermediate output voltage. The intermediate DC-voltage at the output of the charger is very well modulated over a wide input range by a two-term (PI) controller in voltage mode. This tightly controlled voltage, tuned with a bridgeless
power-factor correcting device, serves as the isolated converter's input. The EV battery thus earns a synchronised charging current proportional to its state of charge.

Figure 1. Modified BL Landsman PFC Converter-Fed Battery Charger for Electrified Automobile - Block Diagram

The block diagram of modified-bridgeless landsman-converter fed battery charger for electric vehicle input of the Alternating source supply of 230V AC source and the input voltage is present with some harmonics in order to reduce the harmonics present in the AC source filter circuit are used in the front end side. Modified circuit of landsman converter is implemented and the converter is controlled by the driver circuit of TLP 250 and the controller is PWM controller is used for the gate pulse. In between the landsman converter and flyback converter isolation transformer is implemented the output of the flyback converter dc output voltage of around 60V is fed to the battery for charging. In this modified BL landsman power factor converter the power factor value is increased to 0.9443. The ultimate purpose is to boost the power factor and mitigate the harmonics in the AC supply side of the circuit.

Figure 2. Modified-BL Landsman PFC Converter-Fed Battery Charger for Electrified Automobile

3.2 Proposed Isolated Converter Operation

Because of its simple form, the flyback converter is widely used to implement battery chargers for low-cost battery-operated vehicles such as E-rickshaws. In mode-I, Sf is turned "ON," and the magnetic inductance goes up to store energy in the high-frequency transformer with ferrite core, causing the current to grow. The polarity of the flyback transformer and the position of the output diode in the network clearly show that no energy is transferred to the battery side. The output DC-link capacitor supplies the battery with the essential charging current.
In mode II, the voltage polarity of the primary and secondary windings is reversed while Sf is turned "OFF." The energy deposited in the transformer's core is thus released to the battery via the diode rectifier at the output.

In mode-III, the energy stacked in the transformer core is totally receded at the end of every switching cycle. The DC-link capacitor at the output delivers the charging energy to the battery. In the next switching cycle, Sf is switched “ON” again in the same sequence. To keep the final output DC voltage above the nominal battery voltage, the flyback converter with cascaded dual PI controller should be functioned in DCM conduction mode. In this way, the battery is charged in CC mode at a constant current rate until it reaches 80 percent SOC, and now in CV mode at a lower current rate until it reaches 100 percent SOC. Finally, an appropriate PI controller with voltage and current tuning is added to ensure for secure charging of the battery with limited ripple. The input voltage of the envisaged improved BL front-end converter is investigated throughout rated and dynamic EV battery charger operation.

Table 1. Performance Assessment of Recommended BL-Converter Fed-Charger and Orthodox Chargers

| Configuration Features | Orthodox Charger (No PFC) | Orthodox Charger (DBR+PFC) | Recommended BL-Converter Fed-Charger |
|------------------------|---------------------------|-----------------------------|-------------------------------------|
| Number of elements     | _                         | More                        | Increased                           |
| Control (with PFC)     | -                         | Voltage Follower            | Voltage Follower                    |
| Control(Battery)       | Hard                      | Simple (dual PI)            | Simple (dual PI)                    |
| Sensor (with PFC)      | -                         | 1 for output voltage        | 1 for output voltage                |
| Losses (with DBR and PFC) | -                        | 6.5% of total power         | 5.88% of total power                |
| PFC                    | -                         | Yes                         | Yes                                 |
4. Simulation Model

In the Simulation model the first part of the circuit is AC source voltage of 230V with harmonics present in the circuit. In order to reduce the harmonics present in the AC source filter circuit are used in the front-end side. Main concept of landsman converter is to boost the power factor and to diminish the harmonics present in the supply side. The inductor values 1e-3, and 22e-3 and capacitor values 15e-3, 220e-6 are used in landsman converter with two MOSFET switches which is triggered by the gate pulse signal and which is separated by an isolation transformer is implemented. The flyback converter dc output voltage of around 60V is fed to the battery for charging. In this modified BL landsman power factor converter the power factor value is increased to 0.9443.
In the figure 5 shows the input source voltage of 230V AC source which the harmonics and ripple factor present in the circuit in order to reduce the input side harmonics in the AC source filter circuit with inductor and capacitor are connected across the circuit.

In figure 6 waveform represents the input current of the AC input side the current waveform oscillate from 0 to 500ma peak to peak current with respect to time duration 1ms value. The modified BL landsman converter is used to increase the power factor value in the circuit with increase in value of 0.944 when compared with older type of converter which is suitable for increasing the power factor value.

![Figure 5. AC Input voltage](image)

![Figure 6. AC Input Current](image)

![Figure 7. Output waveform for Modified BL Landsman Converter](image)
In figure 8 waveform denotes the voltage and current outputs of the battery; voltage reading is around 56.64V and current value 0.08mA to 0.1mA. In figure 9 represent the battery output voltage and output dc voltage of fly back converter in matlab Simulink result the output voltage is around 56V dc which is used to charge the EV battery.
5. Hardware

![Figure 10](image1.png)

**Figure 10** Power Factor value measurement (PF = 0.944)

![Figure 11](image2.png)

**Figure 11** Output DC voltage measurement in Digital Oscilloscope

![Figure 12](image3.png)

**Figure 12** MOSFET Gate pulse Trigger signal measurement
6. Conclusion
This article suggests, analyses, and validates an enhanced EV charger that uses a modified-BL Landsman converter accompanied by a flyback converter to charge EV batteries with innate PF Adjustment. The suggested EV charger's design and operation in DCM mode has the benefit of less quantity of sensors. Furthermore, the suggested BL converter had also shrunk the ripples due to the presence of inductors at supply/load sides. The supremacy of the suggested charger is validated for both constant and rapidly changing input voltages. The hardware experimental findings also ensure that the new method of EV charging meets the required levels of power-quality. In simulation result it is simulated with 48V battery with input 230V AC source with power factor improvement of 0.944 value and output of the Landsman converter is 40V AC output in simulation and fly back converter output value is 56.4V which is used to charge the EV battery in matlab result. In the hardware result are validated with landsman converter output voltage is 9.7 V AC and the output of Flyback converter is 24.4V DC voltage which is used to charge a 12V battery. Furthermore, the input current THD is decreased to as low as 4.3 percent to fulfil the IEC 61000-3-2 power quality standard criteria. As a result, the suggested BL converter fed charger seeks to be a cost-effective, dependable, and appropriate alternative to the traditional lossy and inefficient EV battery charger.
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