

EV Advanced Power and High Frequency Battery System Using Isolation Transformer Technology

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ABSTRACT: The rapid growth of Electric Vehicles (EVs) necessitates advancements in charging technologies to enhance efficiency, reliability, and speed. Therefore, this work proposes an advanced high-frequency EV battery charging system incorporating isolation transformer technology to enhance safety, efficiency, and power quality. The Bridgeless Canonical Switching Cell (BLCSC) converter for improving input power quality by reducing harmonics and performing Power Factor Correction (PFC). The high-frequency inverter and an LC tank circuit optimizes resonance for improved performance. An isolation transformer ensures electrical safety and stabilizes the system by decoupling the load. The parallel Synchronous Rectifier (SR) facilitates efficient power conversion, minimizing losses during the rectification process. Pulse Width Modulation (PWM) signals, generated by a DSPIC30F4011 controller, along with Proportional Integral (PI) controllers, maintain accurate regulation of voltage and current during battery charging. The proposed system implemented MATLAB simulation that achieves a converter efficiency of 95% and maintains a Power Factor (PF) of 1, ensuring high-performance operation. This system is compact, renewable-energy compatible, and supports fast, sustainable charging.

Keywords: Electric Vehicles, Battery, BLCSC converter, Power Factor Correction, high-frequency inverter, isolation transformer, parallel synchronous rectifier.

1. Introduction

The Internal Combustion Engine (ICE) vehicle attributed as the first type of vehicle to arise, the larger energy density of gasoline [1]. Since greenhouse gas emissions and the environmental crisis continue to worsen, EVs are being driven back into the attention over the past few years [2]. Battery charging is always going to be a critical aspect of EV that, generally derives with an inexpensive, light, compact charger that has a basic AC plug and easy charge at home [3]. Conventional vehicles only contribute to environmental and pollution problems that are unsafe for human existence [4]. EV or Battery Electric Vehicles (BEV) have considerably lower greenhouse gas emissions and help mitigate

pollution. It clearly demonstrates that the battery is the essential component, as it stores the energy required to power the vehicle [5].

A non-PFC charging system draws current with high harmonic content from input supply and presents batteries as mostly capacitive loads [6]. The traditional EV power system normally suffers from factor dimensions, lower efficiency, and little isolation between the input and output stages, which impact safety and reliability of the system. The manufacturing of EVs is growing rapidly and requires growth in fast, high-power charging systems [7]. Typically, EV battery charging systems typically include a PFC converter. The main process in EV power systems is converting AC power into DC power, which is then used to

charge the battery [8]. In reference [9] boost PFC converter selected due to its efficiency and flexibility to distortion from an input voltage distortion at the AC mains-side of the power architecture. However, this methods, the use of fixed switching frequencies, which reduce efficiency and cause distorted current. In review [10] investigated performance of an interleaved bridgeless buck-boost-based PFC AC-DC converter to improve PF, decrease harmonic distortion and increase efficiency. Nevertheless, absence of current and voltage sensors on the input that provide a limited precise control for certain applications.

Also, Traditional systems use large, low-frequency transformers for isolation and voltage step-down, which makes chargers bigger, heavier, less efficient, and slower in high-demand charging [11]. Traditional line frequency transformers fail to achieve the high switching frequency and compaction proposed by advancements in EV system [12]. A high-frequency transformer is used to achieve reduced size, improved power density and bidirectional power flow, particularly in EV charging applications. However, higher costs due to more complex parts and control circuits is more complicated, owing to thermal management and efficiency considerations [13].

To mitigate these issues, the proposed system utilizes a sophisticated high-frequency isolated power conversion topology with BLCSC type PFC for advanced EV power and high frequency battery system. The contributions of the work are,

- BLCSC Converter reduces system losses, switching stress, and improves PF with smoother DC output.
- High Frequency Inverter converts DC to high-frequency AC, making the system faster, smaller, and lighter.
- Isolation Transformer provides safety, voltage adjustment, and better efficiency at high frequencies.
- Parallel SR increases efficiency by reducing conduction losses during battery charging.

2. Proposed Work Explanation

The EV battery charging system being developed derives power from an AC supply, which is treated as its input supply source. The AC input is processed by a BLCSC converter which converts the AC into regulated DC with a PFC and efforts to minimize conduction losses. The voltage output is regulated by a PI controller as an interface to control system by comparing the actual voltage to a reference value to produce a reference current. The reference current is compared with actual current, and the error is sent to a PWM generator using hysteresis control, implemented with a DSPIC30F4011 microcontroller. The microcontroller generates PWM signals that enter the TLP250 Driver circuit before reaching the BLCSC converter to control the switching in the converter. The DC output is regulated and provides a DC input to high frequency inverter to provide high frequency AC output.

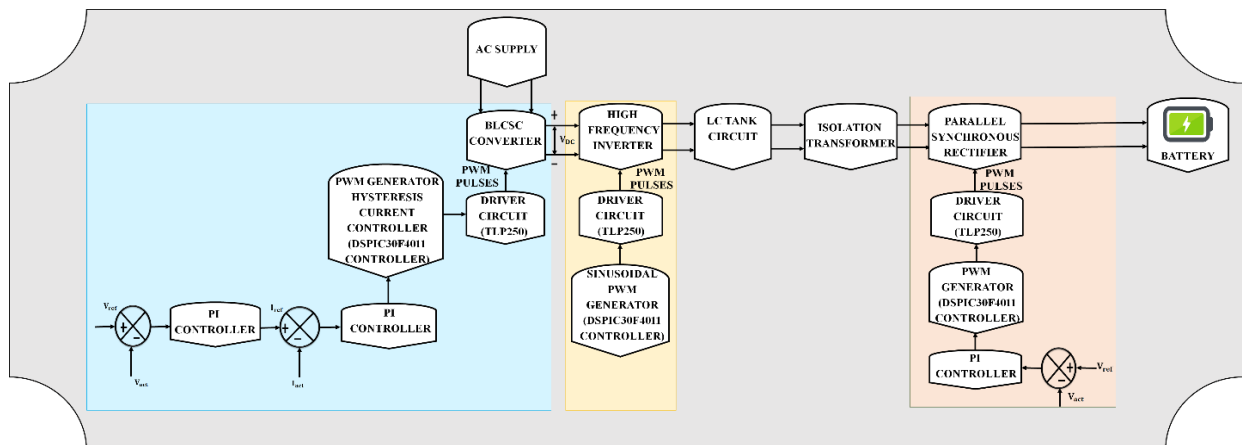


Figure 1: Proposed block diagram EV powered high frequency battery system

The AC output signal from the inverter filtered with an LC tank circuit to remove switching harmonics before sending the output signal to a high frequency isolation transformer. The transformer provides galvanic isolation and changes the voltage level as it passes through to the output stage of charging system. Also, the transformer supplies high frequency AC power to a parallel SR into smooth DC power to charge the battery. This complete system as shown in Figure 1 that provides efficient power conversion, effective isolation, compact size, and consistent battery charging with typical considerations for modern EV applications.

3. Proposed System Modelling

3.1 Bridgeless Canonical Switching Cell Converter (BLSCS)

A BLCSC converter which incorporates a bridgeless structure to provide PFC and enhance power quality as shown in Figure 2. It provides advantages such as reductions in filter size, longer magnetic components, and cost reduction. BLCSC converters are used in EV chargers where high power quality is important, and their operation is classified into two main types.

3.1.1 Working in Positive half cycle and negative half cycle of Input AC Supply

When supplying voltage to bridgeless converter, there is one switch conducting for the positive half-cycle and a second switch conducting for the negative half cycle. In positive half-cycle, input current passes via diode D_p , inductor L_{i1} , and switch S_1 . Both switch S_2 , diode D_n , and inductor L_{i2} operate negative half-cycle. Figure 3 illustrates waveforms for input AC voltage and inductor current ($i_{L_{i1}}$ and $i_{L_{i2}}$) and half-way capacitor voltages (V_{C1} and V_{C2}). Although the proposed model functions in Discontinuous Inductor Current Mode (DICM), the voltage over the capacitor remains constant during the switching time period while inductor currents are discontinuous.

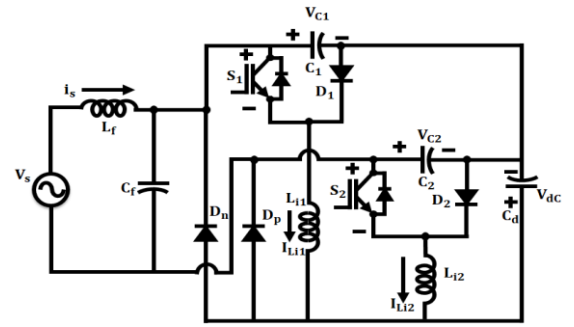


Figure 2: Circuit diagram of BLCSC converter

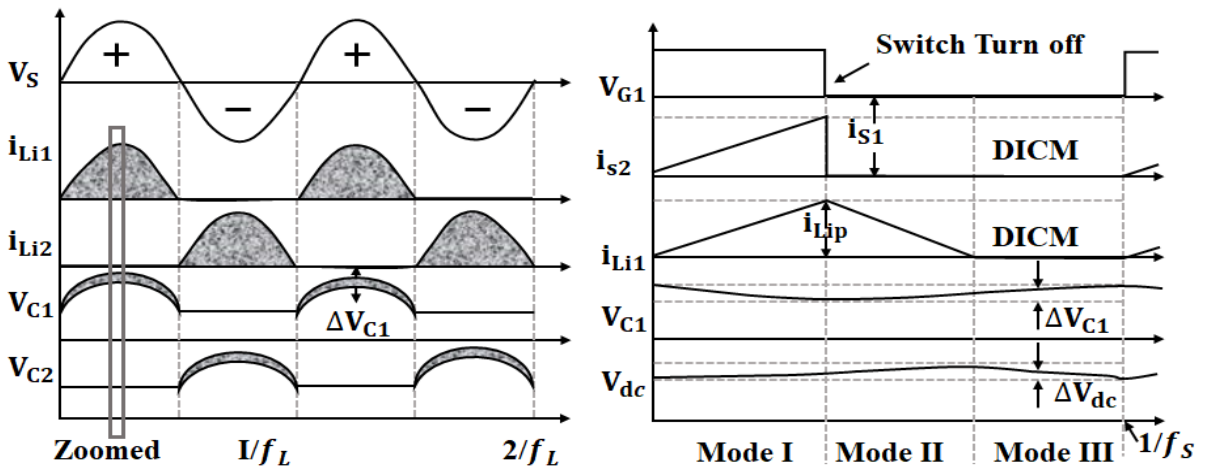


Figure 3: Waveform for various state of working for proposed BLCSC

3.1.2 Functioning throughout the Complete Switching Period

BLCSC converter made to operate in DICM, the operation of each individual half cycle of input AC voltage in different modes of operation.

Mode 1 : In the first mode switch S_1 ON state, inductor L_{i1} , starts charging input side via diode D_p and current I_1 rises and halfway capacitor C_1 , initiates to discharge by way of switch S_1 in order

to charge capacitor C_d . For this mode, the voltage V_{C1} decreases and the voltage V_{dc} increases.

Mode II: In mode II switch S_1 OFF state. If switch S_1 is OFF, the inductor L_{i1} discharges to the DC link capacitor with the diode D_1 while current iL_1 decays. Voltage on DC link is increasing constantly in that mode. Capacitor C_1 begins charging, through that increase of voltage V_{C1} .

Mode III: Current flowing through the inductor L_{i1} , which also discharges the entire inductor becomes zero at discontinuous mode of operation. The capacitor C_d supplies the load with the demand needed. The other capacitor C_1 retains its energy and so it holds it while with the inductors have served the load.

3.2 Design Procedure for PFC based BLCS Converter

The proposed PFC converter designed to function with DICM. As a result, inductor currents (iL_{i1} and iL_{i2}) are discontinuous, but capacitor voltages C_1 and C_2 are continuous throughout operation of switching.

The input voltage given by,

$$V_s(t) = V_m \sin(\omega t) \quad (1)$$

Here V_m represents maximum input voltage, voltage between the inductor combinations and switches is calculated as follows:

$$V_{in}(t) = |V_m \sin(2\pi f t)| \quad (2)$$

The CSC converter's voltage output, V_{dc} , is provided as follows:

$$V_{dc} = \frac{\alpha}{1-\alpha} V_{in} \quad (3)$$

Here, α -Duty ratio. The required voltage for the DC connection V_{dc} and voltage input $V_{in}(t)$ determine the value of $\alpha(t)$. Equations 2 and 3 are substituted in the following way to obtain the instantaneous duty cycle $\alpha(t)$:

$$\alpha(t) = \frac{V_{dc}}{V(t) + V_{dc}} = \frac{V_{dc}}{|V_m \sin(\omega t)| + V_{dc}} \quad (4)$$

The P_i is observed to have a linear utility of V_{dc} as altering voltage through DC link alter the drive's speed.

$$P_i = \frac{P_{max}}{V_{dcmax}} (V_{dc}) \quad (5)$$

where the DC link voltage is denoted by V_{dc} . P_{max} denotes PFC converter's desired power. The proposed BLCS converter's maximum power transfer capacity is denoted by P_{max} . For efficient power conversion, a high-frequency inverter converts DC to AC at elevated frequencies, enabling reduced size, weight, and improved performance of the overall system.

3.3 High Frequency Inverter

The high-frequency inverter is vital because it takes the regulated DC voltage and converts it into a high-frequency AC voltage. This conversion is necessary to enable efficient wireless power transmission, voltage harmonic control, and reactive power compensation. The inverter is designed to work in resonance within the power transfer path, during which time the input impedance is purely resistive, where input current in phase with voltage input. At this stage, the PF is close to unity (1), allowing maximum output power transfer, and harmonic distortion is very low. The inverter operates by using four switches (Q_1, Q_2, Q_3 , and Q_4) that alternately turn on in complementary diagonal pairs (Q_1 with Q_2 , and Q_3 with Q_4).

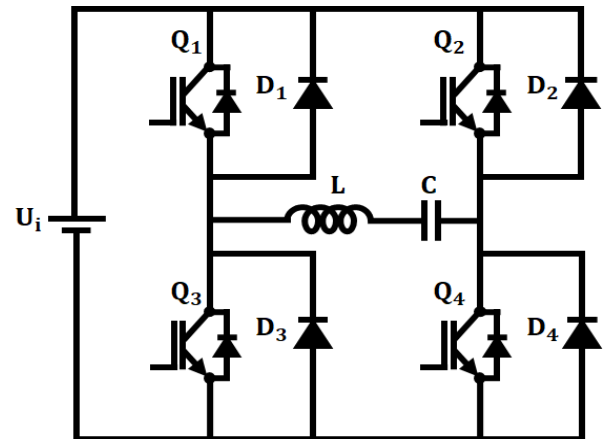


Figure 4: Circuit structure of high frequency inverter

The alternation of the two pairs reverse polarity of output voltage and create a high-frequency alternating waveform. The inverter alters the on time of each of the switches via PWM control. The PWM control is dependent on a rotating cycle for switching and allows the input DC voltage to be inverted into a high-frequency AC output. Therefore, the inverter deliver stable, regulated, and efficient power supply to the isolation transformer stage. To improve conversion efficiency, parallel synchronous rectification uses multiple synchronized switches to reduce power losses during the rectification process.

3.4 Parallel Synchronous Rectification

A parallel SR uses multiple SRs in parallel to achieve larger output currents, faster switching, greater efficiency, and increased thermal performance. There is reduced conduction losses and better current sharing between the SRs through parallel use of many devices that provide even spreading of heat across any number of SRs. In this work adopt a controller-driven approach with synchronous rectifier gate signals that are accurately timed and correspond to the output side of the inverter stage voltage switching. The gate signals for the SR from the PWM generator using the DSPIC30F4011 controller to provide accurate timing and switching. The signals are then passed to the TLP250 driver circuit to actually drive the parallel SR. This control-based, drivers that are synchronous with the system operation, helps achieve a better power conversion efficiency while providing reliable battery charging. The system charging reliability is improved due to lower power dissipation and improved efficiency.

4. Result and Discussion

This paper presents BLCSC converter based PFC and high frequency inverter using EV power battery system is designed and tested in MATLAB Simulink for different load applications. Table 1

represents parameter specification of proposed work. The detailed results are discussed below.

Table 1: Parameter Specification

Parameter	Specifications
Input AC Supply	230V
Inductance (LF)	$1.5e^{-3}$
Capacitance (CF)	$330e^{-9}$
Blcsc Converter	$L1 = 330e^{-6}$
	$L2 = 330e^{-6}$
	$C1 = 10000e^{-6}$
Rectifier	Capacitance = $650e^{-6}$
	Resistance = 100 ohm
	Switching Frequency = 10K Hz

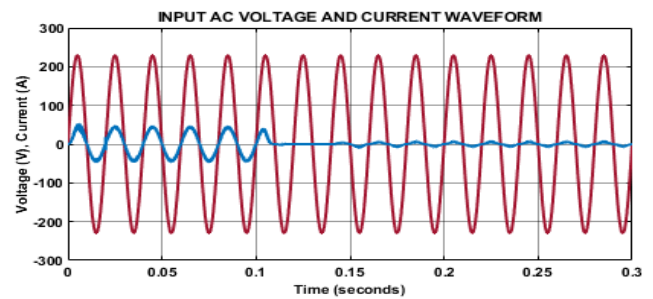


Figure 5: Input Ac Voltage and Current Waveform

Figure 5 shows input AC voltage and current waveforms over a time period of 0.3 s. Each of these waveforms exhibits a sinusoidal wave that the voltage value is 230V, and the current waveform derives close to occupied cycle as the input is sinusoidal AC.

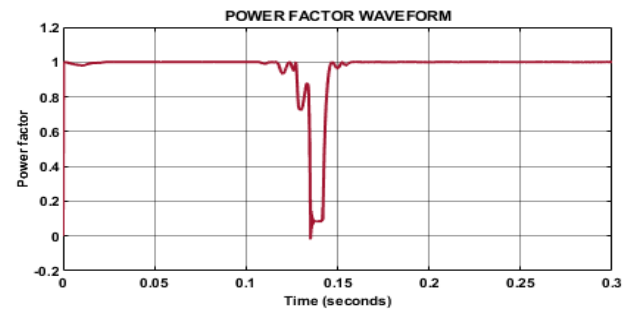


Figure 6: Power Factor Waveform

Figure 6 shows the PF waveform over a time period of 0.3s that measure of the efficiency of power transmission, with a value of 1 identifies maximum efficiency.

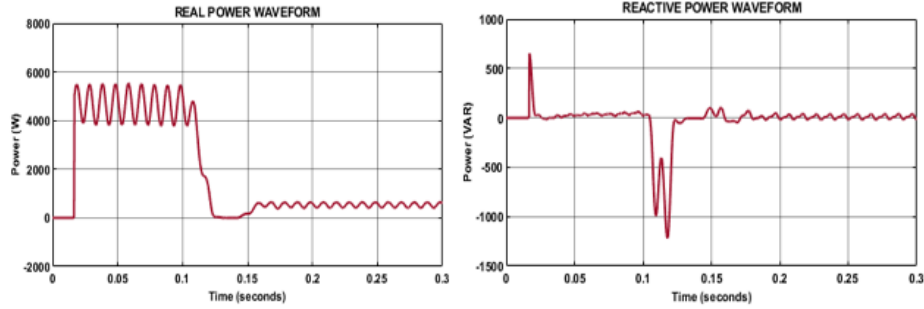


Figure 7: Real & Reactive Power Waveform

Figure 7 shows real and reactive power of the power conversion system over period of 0.3 s. The real power is actual power that is transmitted and changes a lot over this time. The reactive power is stored temporarily in components such as a capacitor or inductors, and it eventually flow back to the source.

voltage level within power conversion circuitry of the overall system.

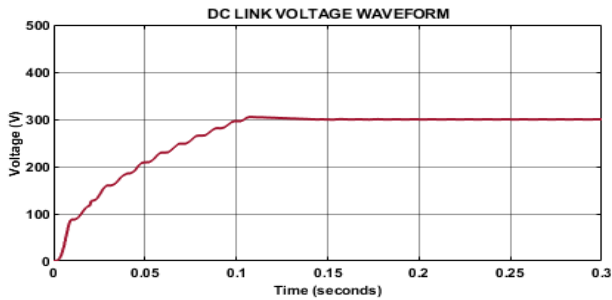


Figure 8: DC Link Voltage Waveform

Figure 8 shows DC link voltage waveform over a time period of 0.3 s as measured via the regulated

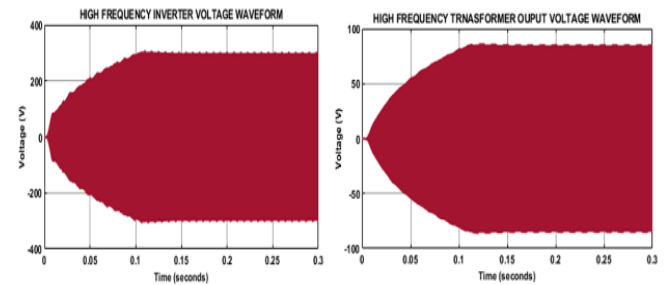


Figure 9: High Frequency Inverter and transformer Voltage Waveform

Figure 9 shows high-frequency inverter voltage and transformer output voltage waveform. The inverter voltage varies from ± 400 V and transformer output voltage varies from ± 100 V. Both of exhibit gradual build up and settled oscillation over a period of 0.3 s.

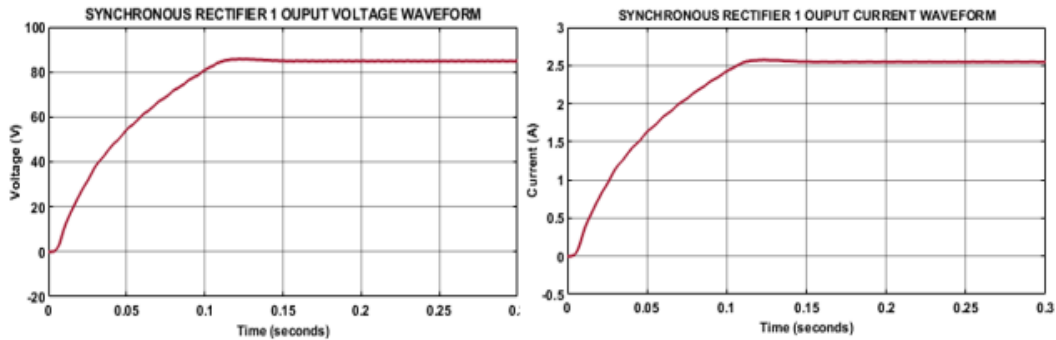


Figure 10: Synchronous Rectifier 1 Output Voltage & Current Waveform

Output DC voltage and current waveforms of SR1 are presented in Figure 10. The output voltage gradually rises to about 85V at zero for about 0.3

s, and when the output voltage at about 85V, the current increases to 2.5 A in about 0.3 s. Showing a smooth rectifying process without fluctuations.

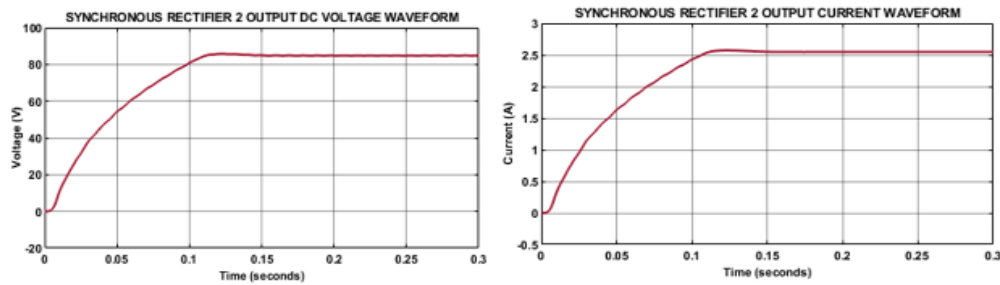


Figure 11: Synchronous Rectifier 2 Output Voltage & Current Waveform

Output DC voltage and current waveforms of SR 2 are shown in Figure 11. The output voltage slowly increases and stabilizes at about 85V with no shifting or unstable current. From the output current, it is seen that it consistently stabilizes at about 2.5 A with respect to the voltage.

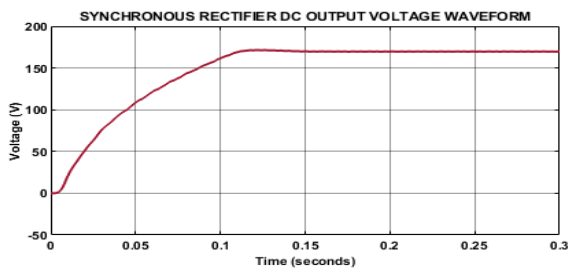


Figure 12: Synchronous Rectifier DC Output Voltage Waveform

Figure 12 depicts a DC output voltage waveform of a SR, wherein the output voltage rises smoothly to stabilize at approximately 170V in about 0.3 s of operation..

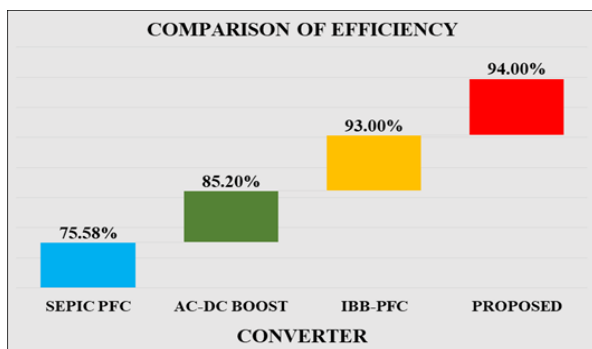


Figure 13: Comparison of Accuracy

Figure 13 presents a comparison of converter efficiencies, showing that the SEPIC PFC [14] achieves 75.58%, AC-DC Boost [15] reaches 85.20%, Interleaved Buck Boost-PFC [10] delivers 93.00%, while the proposed converter outperforms all with the highest efficiency of 94.00%.

Table 2: Comparison of PF

Converters	Power Factor
Ac-Dc Boost [15]	0.90
Sepic Pfc [14]	0.96
Interleaved Buck-Boost Pfc [10]	0.99
Proposed	1

Table 2 presents a comparison of converter PF, showing that the proposed converter outperforms the conventional designs by maintaining a higher PF under various operating conditions.

5. Conclusion

The proposed EV battery charging system presented in this study provides a high-performance, and efficient way to integrate modern power electronic technology with isolation transformer technology. The use of a BLCSC converter establishes outstanding power quality with a PF of 1 and a very high conversion efficiency of 95%. The high-frequency inverter with its LC tank circuit along an isolation transformer allows for safe and efficient transfer of energy, while the parallel synchronous rectifier proposals protection against power losses. The DSPIC30F4011 for PWM generation along with closed-loop PI control of voltage and current levels enables precise regulation and smooth transitions during the entire charging process. The compact and modular design of the proposed here offers both performance and support for future renewables integration in modern EV infrastructure.

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