ACTA TECHNICA JAURINENSIS
Vol. XX, No. Y, pp. ZZ-ZZ, 2026
10.14513/actatechjaur.00836

Research Article

Towards Safe, Stable, and High-Performance Grid Integration of EV Charging Using Power Converter

Amgad Naji Ali Ahmed [1,*], Ahmed Mohammed Saleh[2], György Györök[3]

[1]Óbuda University, Doctoral School on Safety and Security, Népszínház u. 8, 1081 Budapest, Hungary.
[2]Department of Electric Power Engineering, Faculty of Electrical Engineering and Informatics, Budapest University of Technology and Economics, BME V1 Building, Egry J´ozsef u. 18, Budapest 1111, Hungary.
[3]Óbuda University, Alba Regia Faculty, Budai út 45, H-8000 Székesfehérvár, Hungary.
*e-mail: ahmed.amgad@uni-obuda.hu

Submitted: 23/07/2025 Revised: 21/09/2025 Accepted: 01/10/2025 Published online: 28/08/2026

Abstract: The rapid advancement of electric vehicles (EVs) has intensified the need for efficient power electronics, particularly in the performance of battery charging converters, grid reliability, and system safety. This study provides a comparative analysis of two widely used DC-DC converter topologies—Buck-Boost and Cuk—focusing on their influence on total harmonic distortion (THD), input power factor (IPF), and overall energy conversion efficiency. MATLAB simulations were conducted to evaluate both converters under step-up and step-down operating conditions. In step-up mode, Buck-Boost and Cuk converters achieved efficiencies of 97.72% and 92.93%, respectively. In step-down mode, performance improved slightly, with efficiencies reaching 97.81% for Buck-Boost and 94.87% for Cuk. THD values were notably lower in step-down operation—28.9% for Buck-Boost and 23.1% for Cuk—compared to 29.4% and 24.3% in step-up. Similarly, the input power factor was better in step-down mode, recorded at 81.63% (Buck-Boost) and 90.47% (Cuk), slightly higher than in step-up mode (81.58% and 88.93%, respectively). To assess grid-level implications, the converters were tested in a simulation using the IEEE 13-node test feeder in the DIgSILENT PowerFactory/MATLAB environment. This provided insights into their impact on distribution network behavior. Additionally, engineering concerns such as thermal management and switching losses were examined, as they are vital for long-term system stability and battery longevity. The study not only benchmarks converter performance but also outlines future directions, including improved switching strategies, size reduction, and integration with Vehicle-to-Grid (V2G) systems.

Keywords: Electrical Vehicles; Power Converters; Safety and Security; THD; EV Charging

I. INTRODUCTION

Electric vehicles are one of the most widespread popular products in the world, according to the global EV studies in the International Energy Agency, the total EVs will grow from 23 million in 2022 to about 73 million in 2030 [1] indicated in **Fig. 1**, due to the large advantages of EVs as compared to other types of vehicles like fuel, which makes our transportation sector more over-dependent on it and increases the level of pollution in the surrounding environment and spreads diseases, according to **Table 1** [2]. The EVs include lower vibration and noise levels, with low cost for maintenance as well as high efficiency. Several studies related to EVs, like batteries, converters, and the power qualities needed to increase the performance of EVs. Converters are used to control the supply voltage to charge the batteries of EVs, which convert the input power to the load with pure power.

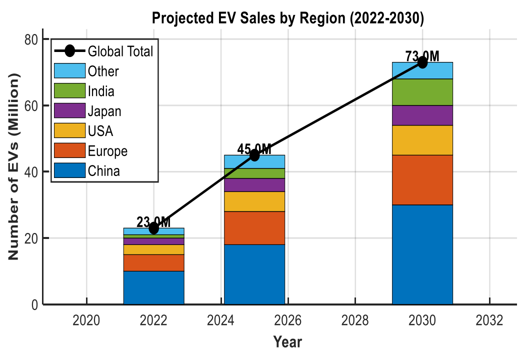


***Figure 1.** Sales Trends for Electric Vehicles and Forecasts by Country for 2022–2023* [1]

Due to the power electronics issues like current stress, voltage stress, ripple, harmonics, heating, and overshoot that can affect the performance of the EV batteries, efficiency, and stability, the EVs should be operated in a safe way to save the EV batteries of the

EVs from damage. Several types of converters are used to control the EVs, like directional and bidirectional converters, to improve the efficiency of the EV [3]. This paper reviews only the bidirectional converters and their control.

Table 1. *Gasoline Vehicles versus Electric Vehicles* [2][3]

Point of view	***Gasoline Vehicles***	***Electric Vehicles***
Energy Efficiency	12%-30%	77%
Greenhouse Gas Emissions	Significant emissions	Zero tailpipe emissions
Operating Costs	Higher and volatile prices	Lower and stable prices
Maintenance Costs	Higher	Lower

In this section, we will thoroughly go over four points: background and growing importance, challenges in EVs' performance and safety, significance of electrical converters, and objectives of the study. Between 2020-2024, significant advancements have been made in EV charging technology, particularly in the speed and availability of fast chargers. DC fast chargers have become more prevalent and powerful, with many now offering charging speeds of 150 kW to 500 kW, enabling rapid replenishment of EV batteries in minutes rather than hours. The growth in public DC fast-charging ports has accelerated, with notable increases in installations in the United States, Europe, and other regions. For instance, the number of public DC fast chargers grew significantly in the U.S., supported by government initiatives and private investment [4], Globally, advancements have also been seen in ultra-fast charging technologies, such as Tesla's V3 Superchargers and other systems capable of delivering 350 kW, which allow vehicles to gain hundreds of miles of range within 20 minutes. This rapid progress addresses the limitations of older level 2 chargers, which are slower but remain relevant for overnight or destination charging. The EV technology requires charging the batteries with high efficiency and safety to control the lifetime energy of the batteries by analysing the specific converters that are used as suppliers to the charger, however, the multi-drive interleaved DC-DC boost converter is best suited for the DC-DC transfer stage with the difference connection and control switching with stress voltage results [5], [6].

1. Background and challenge in EVs performance and safety

In the research, there are abundant papers that have been published on the topic of EVs, from which we can conclude that it is an important trend of research, as shown in the map of **Fig. 2**, which indicates the research area for EVs from 2020 to 2024. However, electrical charging and converters used for EVs are still limited and inadequate, as shown in **Fig. 3**. In this research, we will thoroughly discuss this research gap of the power electronics converters and charging with the safety and security of the batteries of EVs.

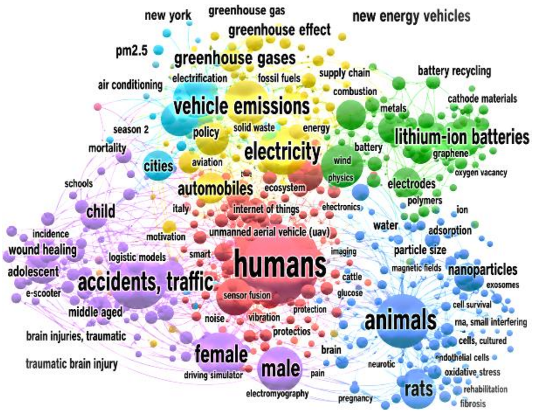


Figure 2. *Research focus areas for EVs between 2020 and 2024*

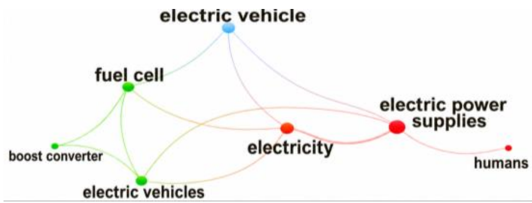


Figure 3. *Research focus areas for electrical charger converters from 2020 to 2024*

The safety and security of EVs and their performance are heavily influenced by the role of electrical converters, such as AC-DC and DC-DC converters, which control the power flow between the batteries and electric motors of EVs. **Fig. 4** indicates the main challenge in EVs.

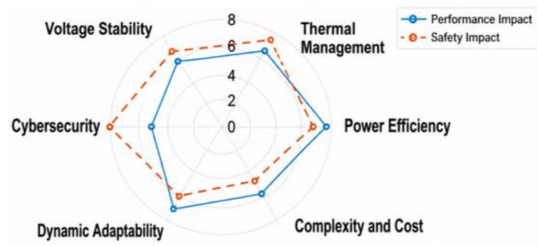


Figure 4. *Impact Analysis of Key Features in EV Charging Systems: Performance vs. Safety*

The radar chart illustrates the challenges impacting EV performance and safety across the six main key points: power efficiency, thermal management, voltage stability, cybersecurity, dynamic adaptability, and system complexity. Performance is greatly impacted by power efficiency since inefficiencies directly lower range and energy use, and thermal management presents a serious safety risk because of overheating issues. Because it

***Table 2.** Differences between paper analysis and previous paper works*

Differences	***Previous works***	***This Paper (Our Contribution)***
Focus on DC–DC Topologies	Most studies analysed basic boost, buck, or isolated converters for EV charging [1][2][3][4].	We compared Buck-Boost and Cuk converters specifically in both step-up and step-down modes, with detailed efficiency, THD, and IPF benchmarks.
Performance Metrics	Efficiency often reported; THD sometimes included PF rarely analysed [5][6][7][8].	We considered three key indicators together: Efficiency, THD, and Input Power Factor (IPF), providing a holistic performance picture.
Novelty in Methodology	Many studies assume conventional converter structures [9][10][11].	We introduced switching inductance capacitance blocks to reduce ripple, voltage stress, and switching losses not covered in previous works.
Grid-Level Impact	Prior works usually limited to converter-level studies, without distribution feeder modelling [12][13][14][15][16].	We carried out a co-simulation in DIgSILENT PowerFactory and MATLAB on the IEEE 13-node feeder, showing system-level impacts of EV charging on grid stability.
Safety and Stability Considerations	Safety is often mentioned but not deeply analysed (thermal issues, cybersecurity rarely included) [17][18][19][20].	We integrated thermal control, ripple reduction, fault protection, and cybersecurity considerations into the analysis of EV converter operation.

influences battery health and operational reliability, voltage stability has a moderate effect on both performance and safety. Although it has less of an effect on performance, cybersecurity remains a serious safety concern because of the possibility of operational failure from possible attacks. Performance is greatly impacted by dynamic adaptability since converters must effectively manage abrupt power fluctuations, although complexity and cost have less impact on both. This graphic aids in prioritizing enhancements by emphasizing the importance of cybersecurity and thermal management for safety, power efficiency, and performance-enhancing dynamic adaptability.

Unlike previous works that mainly evaluate single-stage boost or isolated converters, this study uniquely investigates both step-up and step-down configurations of Buck-Boost and Cuk topologies within a realistic IEEE 13-node feeder environment.

This dual-level assessment bridges converter-level efficiency/THD with system-level grid impacts, offering a more comprehensive perspective. Furthermore, the incorporation of switching inductance/capacitance blocks to reduce ripple and stress distinguishes our methodology from existing analyses.

2. Research contribution

As shown in **Table 2** and **Fig. 5** the research introduces a novel approach to enhancing electric vehicle (EV) charging performance through a comparative simulation-based analysis of non-conventional converter topologies specifically, Buck-Boost and Cuk converters. Unlike existing studies that predominantly focus on basic boost converters, this work explores the integration of step-up and step-down switching inductive/capacitive blocks to improve efficiency, reduce total harmonic distortion (THD), and enhance input power factor (IPF).

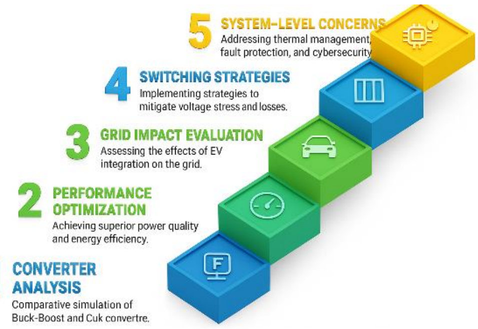


***Figure 5**. Research contributions of the paper*

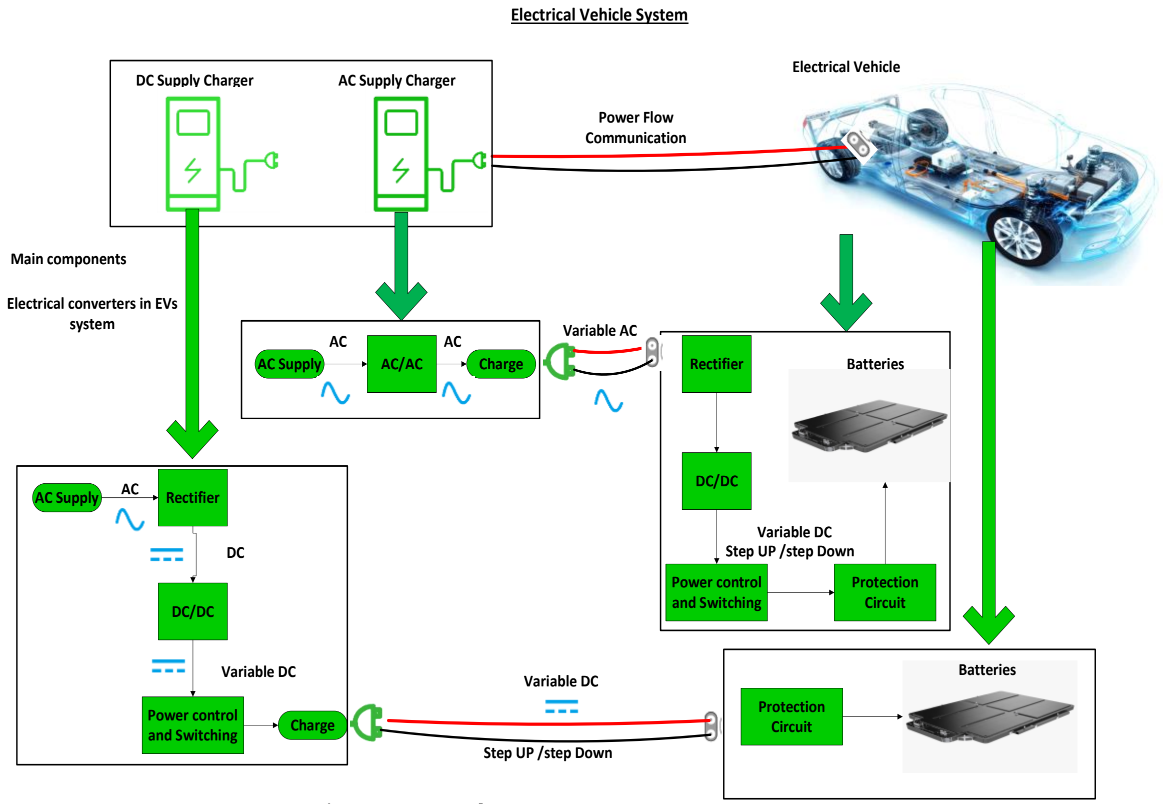


***Figure 6**. EVs charging Converters structure*

The integration of electric vehicle (EV) charging systems into the power grid poses new issues since they have come to be seen as nonlinear loads and major sources of harmonic distortion. Effective harmonic mitigation techniques are becoming increasingly necessary as modern electronic equipment is smaller and more susceptible to power quality issues. It is now more important than ever to use sophisticated control approaches in power electronic converters to combat the increasing amounts of grid-injected harmonics. In order to guarantee the safe, reliable, and high-performing integration of EV charging infrastructure into the power grid, this effort intends to investigate and develop such control approaches. Simulation results reveal that the step-down Cuk converter achieves superior power quality (IPF of 90.47%, THD of 23.1%), while the step-down Buck-Boost converter delivers the highest energy efficiency (97.81%).

Furthermore, the stochastic nature of electric vehicle (EV) charging and discharging introduces significant management challenges for the distribution grid. Uncoordinated power flows can lead to overload or underload conditions, potentially triggering cascading failures and, in extreme cases, resulting in widespread blackouts. To assess the impact of EV integration on grid stability and performance, this study utilizes the IEEE 13-node distribution feeder model implemented through co-simulation in DIgSILENT-PowerFactory and MATLAB. By incorporating switching strategies like step-up and step blocking, the design effectively mitigates voltage stress and switching losses. The research also introduces a structural mapping of compatible switching blocks for different converters, enabling better design scalability. In addition to performance optimization, the paper addresses system-level concerns such as thermal management, fault protection, and cybersecurity, offering a comprehensive framework for a reliable and safe EV charging infrastructure.

This paper's main contribution is its thorough overview of the power converters used for electric vehicles, brought about by the stability and safety of the EV batteries, alongside its in-depth analysis of the new difficulties that emerge. These issues demand careful consideration, especially regarding system stability and the possibility of cascade failure events. The best of our knowledge, among the first to link converter-level ripple and harmonic data directly into an IEEE 13-node feeder simulation, allowing an assessment of distribution network impacts. This holistic approach distinguishes the study from prior literature that typically isolates converter performance from system-level consequences. The paper also discusses the future direction as a baseline for scholars and industries to use specific converters for EVs. This work aims to find out what the different types of converters are that are used to increase the stability of charging the batteries of EVs with lower losses and higher efficiency and safety.

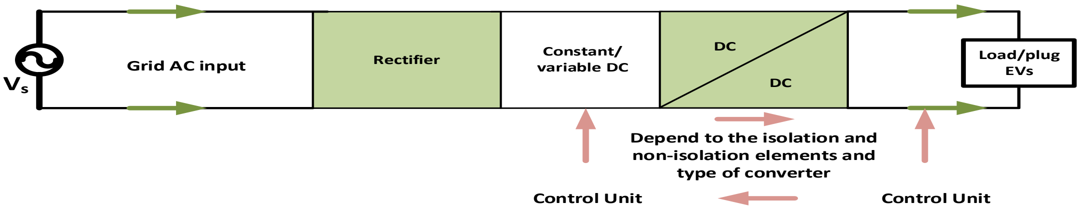


Figure 7. *The DC Converter unit supplies to the EV plug*

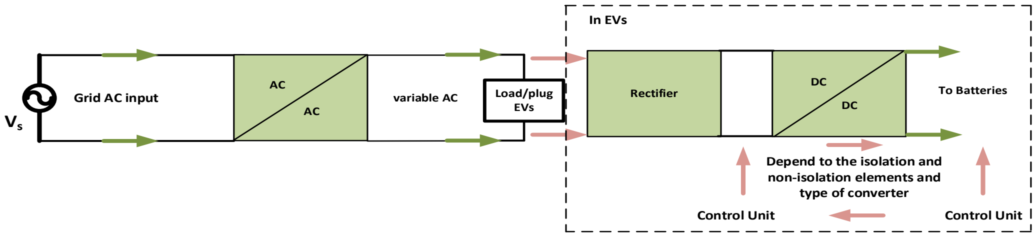


Figure 8. *The AC Converter unit supplies to the EV plug*

II. Fundamentals of EVs converter type

The need for electric power in numerous forms has grown due to increasing focus on electrification for environmental reasons. The processing of high voltages and currents to provide power for various purposes is the focus of the electrical engineering field of power electronics. In this context, the notion of "Energy of Things" is growing as a worldwide phenomenon. Transportation, in particular, is rapidly transitioning from traditional fossil fuels to electrified alternatives. All these places, from home electronics to space equipment, need steady, dependable electricity that satisfies the necessary standards. Power semi-conductor switches and control mechanisms are used to transform power into different forms, creating a regulated and con-trolled power supply that may be enhanced by artificial intelligence (AI) applications [7].

As shown in **Fig. 6**, which covers the converters in the charger and EVs with the possibilities of the converters, which can be inside EVs or in the charger. These converters ensure that the energy stored in the battery is efficiently utilized to drive the electric motor and other auxiliary systems [8].

1. DC supply charging

In this stage, the EV charger operates with DC power flow, incorporating a control unit and step-up/down DC-DC converter connected to the EV plug. As shown in **Fig. 7**, the system uses an AC supply, which is rectified into DC using a front-end rectifier. This rectified DC can then directly power the load or be further processed by DC/DC or DC/AC converters. While rectifiers are essential in power systems, poor design can lead to harmonics and low power factor. DC-DC converters, often called switching regulators, adjust voltage levels between DC sources and loads and are vital in HVDC transmission and offshore power transfer. For EV fast charging, isolation is critical due to high power levels [9], [10], [11], [12]. Non-isolated topologies (like buck, boost, cuk) lack transformer isolation, while isolated converters use transformers for safety and multi-voltage output, though they are more complex and require additional components.

2. AC supply charging

EV is powered through an AC supply connected directly to the plug via an AC-AC converter, while internal components like the rectifier, DC-DC converter, and control units are placed inside the EV, as shown in **Fig. 8**. AC-AC converters are more complex due to voltage and frequency transformation and the need for bipolar voltage blocking. These converters include types like VVFF (variable voltage, fixed frequency) for simple applications like dimmers and motor control, and VVVF (variable voltage, variable frequency) cycloconverters or matrix converters for more advanced functions. Another approach involves AC/DC and DC/AC stages connected through a DC link [13], [14]. This combined method supports bidirectional energy flow, power factor control, and DC link regulation. However, AC-AC converters have limited application in EVs compared to AC/DC and DC/DC systems. Therefore, this study focuses on enhancing the performance of AC/DC and DC/DC converters, particularly multi-input configurations, to improve battery charging and drive control in EVs.

3. Step-up and Step-down switching

Current and voltage stresses, including ripple effects, are evaluated under continuous conduction mode (CCM), with output voltage regulated through both step-up and step-down switching topologies

[76]. Modern DC-DC converters often use active switched-inductor or capacitor networks to achieve higher or lower voltage gains, reducing voltage stress to 26–48% of the output voltage [15]. Two main switching types—hard and soft—are used in both isolated and non-isolated bidirectional or unidirectional converters to regulate power flow. To reduce switching losses, zero-voltage switching (ZVS) is commonly applied to active switches.

Step-up and step-down operations are critical for voltage regulation in electric vehicles (EVs) as shown in **Fig. 9** and **Fig.10**. While hard switching is structurally simpler, it causes abrupt transitions that result in high voltage and current stress, leading to increased power loss, heat, and lower reliability [16]. Soft switching methods—such as Zero Voltage Switching (ZVS) and Zero Current Switching (ZCS)—mitigate these issues by allowing transitions to occur near zero voltage or current, improving efficiency and extending component lifespan. For high-demand EV applications, where efficiency and durability are essential, soft switching is particularly advantageous [17].

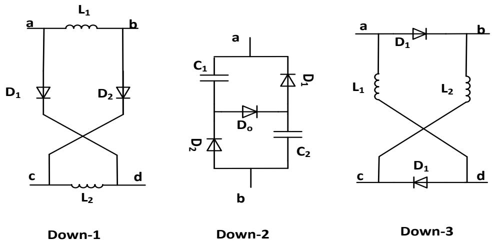


Figure 9. *Switching inductance/capacitance block—step down*

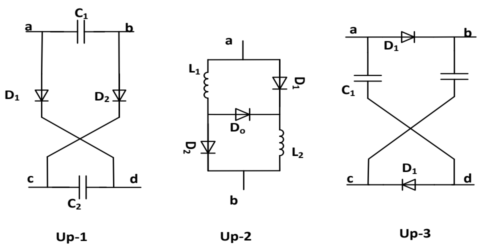


Figure 10. *Switching inductance/capacitance block—step up*

III. ENHANCING EV PERFORMANCE WITH ELECTRICAL CONVERTERS

Electrical converters play a crucial role in improving the performance energy efficiency and sustainability of EVs, for the electrical converters' stability three important points must improve, efficiency, THD, and IPF.by managing power flow and integrating advanced technologies, converters enable optimal utilization of energy, enhance battery rang, and support innovative network for smart charging [18]. The problem is made more complex by the fact that existing DC-DC converter designs for semiconductor components do not adequately incorporate stress-mitigating methods. These disadvantages lead to inefficiency, higher losses, and a restricted ability to use converters for electric vehicle battery charging. Therefore, there is an urgent need for a sophisticated converter design that not only addresses these problems but also goes beyond current limitations to provide a highly efficient and stress-optimized solution. THD is one of the biggest problems facing electrical converters due to its effects on the grids and loads. This phenomenon is produced by passive switching [19]. Voltage and current generated by an electrical load of some kinds are known as harmonics. A stream that is not precisely sinusoidal is produced when a nonlinear load, like a rectifier, is coupled to a power system. The current waveform can counteract the impacts of other complicated system components, depending on the load. Fourier analysis can be used for basic wave analysis for power system frequencies that occur at integer multiples of the fundamental frequency, regardless of how complex the current waveform is. Office supplies, including computers and printers, as well as variable speed drives, are additional instances of nonlinear loads [20]. IPF or designed power factor correction (PFC) phenomena appear for AC-DC converters, which increase the voltage and current through the semiconductor devices, resulting in lower efficiency in the power converters and the load. In the design of electrical converters for electric vehicles, efficiency, THD, and PFC/IPF are crucial performance indicators. The range and battery life of an EV are directly impacted by high converter efficiency, which guarantees little energy loss throughout the power conversion process. For instance, a well-designed PFC converter can optimize energy use and lower operating costs by achieving efficiencies of over 95%. To make sure that the energy taken from the grid is used efficiently, PFC or IPF is essential. Reactive power losses are reduced and charging speed and grid interaction are enhanced by a high-power factor, which is near unity. Bidirectional PFC converters facilitate effective energy transfer while charging and even facilitate energy transmission between vehicles for smart grid applications [21]. By increasing energy conversion, lowering losses, and guaranteeing compatibility with cutting-edge charging systems, these factors work together to improve EV performance and increase efficiency and sustainability. Switching losses and thermal stresses are critical concerns in power converter design. Reliability can be enhanced through appropriate IGBT or MOSFET selection, snubber circuits, and thermal management strategies.

IV. ROLE IN SECURITY OF EVS

Electrical converters in EVs are pivotal not only for Energy management but also for ensuring the security and reliability of the vehicle’s operations.

Their role encompasses safeguarding communication channels and detecting malfunctions to maintain optimal performance. The EVs are the new generation of smart vehicles with the ability to drive themselves by using various electronic devices and methods. One of these is that EV battery charging should be operated in a secure way and with high efficiency.

1. Cybersecurity in electrical converters

ECs facilitate communication between different EV components, including chargers and controllers. The interconnection between the EVs and the electronics converters with the power network creates a complex hyperphysical [22]. The power grids, electrical converters with EVs, high-level and low-level voltage lines, their monitoring, and coordinated control in a way to ensure cybersecurity. By using the grid forming and feeding for the EVs converters with the control, this decentralized arrangement is considerably safer, as it is difficult for attackers to access the security system of the EVs that even the least sophisticated cyberattacks have the potential to cause instability, damage to household products, and system shutdown. The attack methodologies on the frequency, DC voltage, attack on active power dispatch, attack on data integrity, and attack on load consumption pattern lead to damage to the system operation of the EVs. As a future area of research, attack-resilient control solutions must be developed to overcome these issues and lessen the impact of cyberattacks on the electrical grid [23]. By using these channels, malicious actors might get access to customer data, interfere with charging, or even trigger more widespread grid instability. It's critical to put strong cybersecurity measures in place to reduce such dangers, such as encryption methods and secure authentication systems, new electrical converters that operate with higher performance, and strong controllers to guarantee that data transferred between converters and other components stays private and unmodified.

2. Protection Against Malfunctions

Advanced diagnostic capabilities are built into intelligent converters to identify and address issues with the EV's power systems. These converters are capable of detecting abnormalities in real-time, like overvoltage situations or component failures, by employing sensor-based tactics and advanced fault analysis techniques [24]. The system can take corrective measures, such as modifying operating settings or separating malfunctioning parts, after detection to stop possible harm and guarantee ongoing safe operation. This helps improve system reliability and minimize the impact of faults. It also supports faster recovery during abnormal operating conditions. Furthermore, these actions help maintain stable system performance.

Case study: converters supplied to EVs

As the integration of electric vehicles into the power grid grows, it creates opportunities and difficulties for grid stability and efficiency. Opportunities such as EVs provide more integration of renewable energy sources. For example, the V2G system enables EVs to store and send back energy to the grid, then helps in mitigating the power system stability and balancing supply and demand. Smart charging and demand response solutions improve charging times, reduce grid congestion, and increase renewable energy usage. The difficulties are due to the random and uncoordinated charging, which produces demand surges during peak hours, straining local networks. This random nature of EV charging and discharging behavior is a significant difficulty since it can cause swings in energy demand and supply. Without effective management, increasing EV adoption can result in transformer overloading, higher transmission losses, and diminished grid dependability. Advanced grid infrastructure is required for bidirectional power flow from EVs, which necessitates changes to substations, transformers, and control systems. In addition, the digitization of the grid raises data management and cybersecurity risks. To avoid interruptions or unwanted access, smart charging and V2G technologies must be integrated using sophisticated data analytics and secure communication mechanisms [24], [25].

The research design follows a two-stage methodology: first, MATLAB/Simulink was used to model Buck-Boost and Cuk converters under varying load capacities (100–1000 Ah). Second, the extracted parameters (THD, efficiency, input current ripple) were integrated into DIgSILENT PowerFactory using the IEEE 13-node feeder. This co-simulation framework enables validation of how converter-level dynamics propagate to grid-level behavior—a design not commonly employed in prior EV converter studies. The IEEE 13-node distribution test feeder was selected due to its widespread use as a benchmark for distribution system studies. The feeder operates at 4.16 kV with a base apparent power of 100 MVA. It includes 13 buses with a total system load of approximately 3.49 MW + 2.15 MVAr, supplied radially through a 5000 kVA Δ–Yg transformer. Line impedances range between 0.45–0.46 Ω/km resistance and 0.15 Ω/km reactance, while shunt capacitor banks (600 kVAr) provide reactive compensation. Load models are defined as a combination of constant PQ and ZIP characteristics. EV charging demand was superimposed at buses 633 and 671, with aggregated power levels reaching 10–18 MW to reflect high-penetration charging scenarios. All converters were simulated under identical conditions in MATLAB/Simulink. The following assumptions were applied: (i) losses were modelled through series resistances in passive components, (ii) diode reverse recovery losses were neglected, using standard Simulink diode packages. A 360 V Li-ion battery was selected as the load, with capacity varied from 100 Ah to 1000 Ah, corresponding to nominal power levels between 16.2 kW and 180.5 kW. The switching frequency was fixed at 50 kHz. The passive component values were chosen as: Ln = Lo = Lm = Ls = 10 mH ,C1 = C2 = Cm1,2 = 470 µF , and Co = C4 = 2200 µF.

of converter topology and duty cycle. Varying the duty cycle directly altered the effective voltage conversion ratio, which in turn modified the input power factor (IPF), total harmonic distortion (THD), and ripple current. In this study, the term IPF refers to the ratio of real power drawn by the DC supply to the apparent power at the converter input.

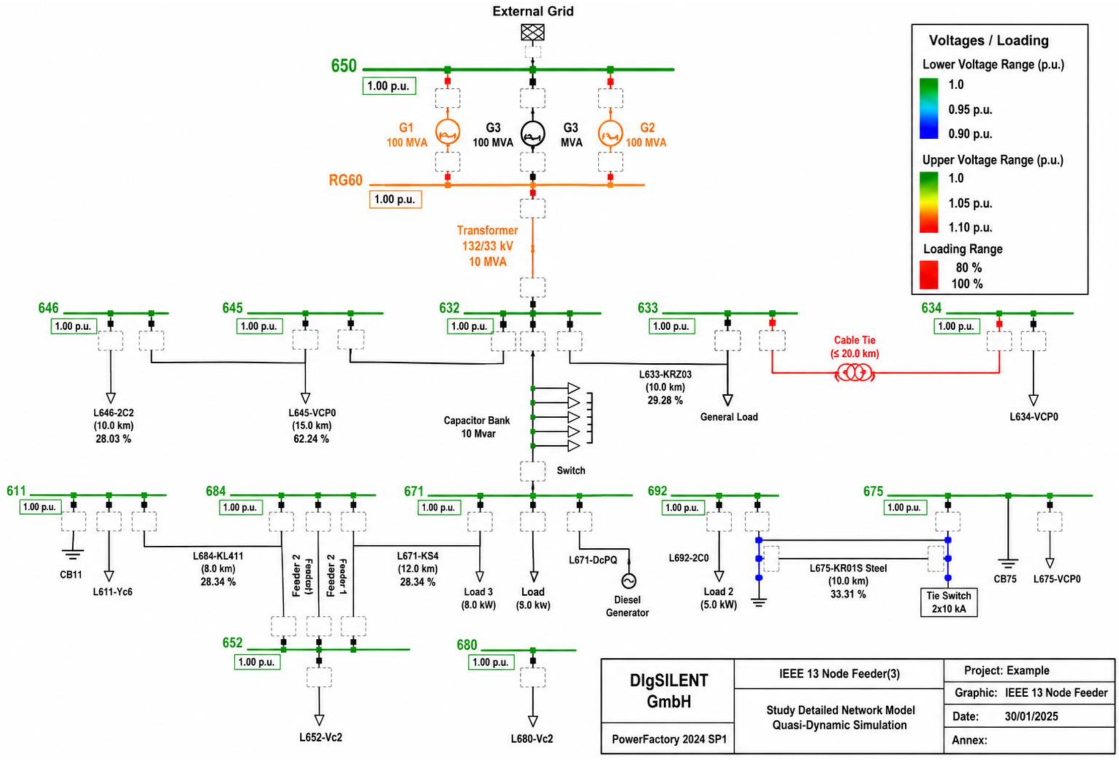
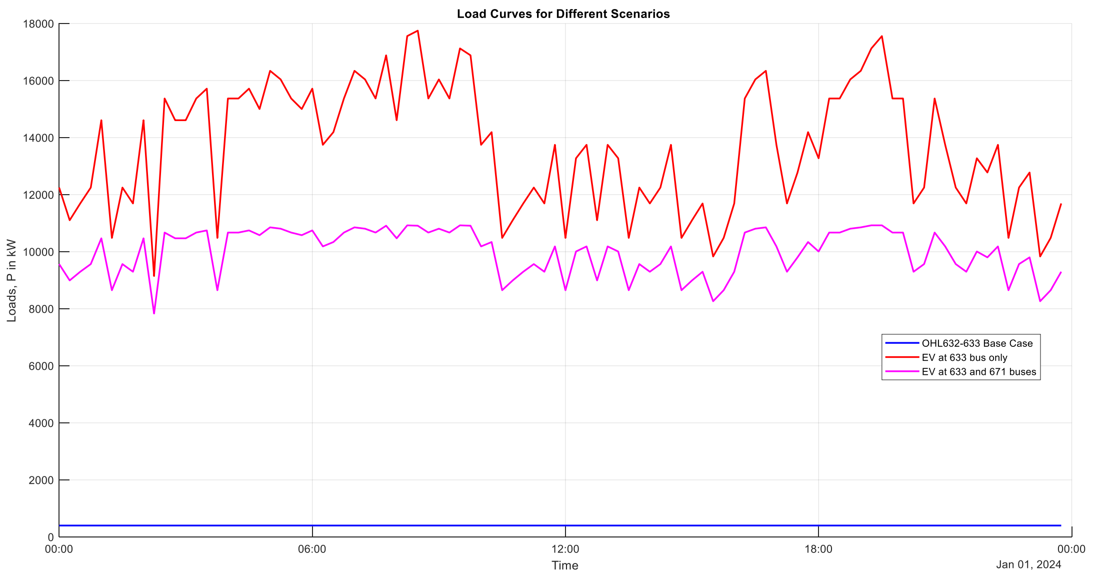


Figure 11. *IEEE 13-node feeders*



cc

Figure 12. *Load Curves for Different Scenarios*

We recognize that power factor is rigorously defined only for AC systems; here, IPF is used in a comparative sense to indicate how effectively the converter topology utilizes its input supply under different duty-cycle conditions. This definition allows consistent benchmarking across Buck-Boost and Cuk converters, but it should not be confused with AC-side power factor used in grid compliance standards.

This allowed a transparent and reproducible benchmarking of Buck-Boost and Cuk converters under step-up and step-down conditions. To demonstrate this, the IEEE 13-node test feeder network, as shown in **Fig. 11**, is simulated using DIGSILENT Power Factory/MATLAB Software. The reason for taking this network is that the IEEE 13 Node Feeder is a standard test for examining and simulating the behavior of power distribution networks. This network is particularly relevant as EVs are typically integrated into the distribution network, making it an ideal model for studying their impact and performance. It is one of the benchmark distribution networks created by the IEEE Power and Energy Society's Distribution System Analysis Subcommittee to assist researchers, engineers, and utility operators in assessing various power distribution challenges such as voltage regulation, power losses, and fault diagnosis. This system provides a realistic but simplified framework for analyzing distribution network performance under various scenarios [26]. We are using this network to investigate how the integration of EVs affects the distribution network's behavior. This integration necessitates careful attention and analysis while determining the best charging station locations and timings. By investigating these issues, we can guarantee that the distribution network stays stable and efficient while maximizing the benefits of EV adoption. This study is critical for establishing solutions that reduce possible interruptions while improving the overall operation of the power system. The daily load curve of the EV's charging station is taken from [27].

The simulation result shown in **Fig. 12** depicts load curves for several scenarios in a power distribution network at different integration of EV charging stations, emphasizing the effect of electric vehicle integration on the system's demand profile and loading of overhead lines and network. The x-axis indicates the time during 24 hours on January 1, 2024, while the y-axis displays loads of overhead line in kilowatts (kW). The three curves depict the base case without EVs, the situation in which EVs are integrated at bus 633, and the scenario in which EVs are dispersed between buses 633 and 671. The blue line depicts the original system load without EV inclusion at bus 633 or 671. In this case, the load is constantly low, which is equal to 400 kW, showing that EV charging does not contribute to demand. This is a critical reference point for assessing the impact of EVs on the system. By comparing this basic case to scenarios that include EVs, we may gain a better understanding of how EV charging impacts load distribution, peak demand, and overall grid stability. This research is critical for designing strategies to maximize EV integration and provide a dependable and efficient power distribution network. When EVs are integrated entirely at bus 633, as shown by the red line, the load increases significantly, with abrupt oscillations and great variability. These changes indicate that uncoordinated EV charging behavior is producing rapid increases and decreases in power consumption. The peak demand is around 18,000 kW, illustrating that adding EVs on a single bus may put significant pressure on the distribution network.

In comparison, when EVs are spread between buses 633 and 671, as represented by the magenta line, the load curve seems smoother than the red one. While peak demand remains high, overall swings are less unpredictable, most likely due to the balancing effect of dividing the charging load over numerous buses. The load typically ranges between 10,000 and 12,000 kW, showing that a more spread EV charging plan can help avoid significant swings in power consumption. This simulation provides numerous crucial findings. Primarily, EV charging dramatically increases peak load, putting a strain on transformers, feeders, and voltage control systems if not managed effectively. In addition, the random and uncoordinated nature of EV charging can cause instability in the power grid, as seen by the extremely changing red curve. Lastly, dispersing EV charging across numerous buses can assist in alleviating localized stress and generate a steadier load profile, as shown by the magenta curve. To overcome these issues, multiple techniques may be applied. Smart charging techniques that optimize when and how EVs charge can assist in smoothing the load curve and minimizing sharp peaks. Vehicle-to-Grid (V2G) technology can help to stabilize the grid by allowing EVs to discharge power back into the system during times of peak demand. Load balancing across many buses, as depicted in the magenta example, can better spread demand and prevent particular grid components from overflowing. Furthermore, including energy storage systems (ESS) can assist in absorbing surplus demand during peak hours and provide electricity when needed.

To solve the load shedding and losses and the high-power consumption when the EVs connected to the grid, by using some kinds of converters that increasing the efficient operation of the EVs with grids and worked with the higher efficiency, IPF, and lower THD by different type of the step up and step-down converters with some blocks that improve the performance of the EVs converters and charging batteries with lower impact to the grids in case of the several loads connected to the networks. Power electronic converters are pivotal while designing any charging scheme, regardless of the battery capacity and application. Nowadays, Power Factor Correction converters have become popular for Electric Vehicle charging systems due to their simple configuration. Single-ended primary inductor converters SEPIC, Cuk, zeta, and buck-boost PFC converters are preferred over conventional converters in this regard due to their higher efficiencies, lower current ripples, and continuous input current features. Despite having almost identical configurations, those converters have their pros and cons. These converters can be controlled together with a single switch to obtain a bipolar output. This novel bipolar converter holds the advantages of both the converters mentioned earlier. In addition, the inclusion of a switched-inductor configuration at the input side exhibits higher voltage gain in the lower duty cycle, resulting in lower conduction losses in the switch.

The main purposes of the step-up and step-down are to create converters with higher gain and lower gain to enhance the efficiency and strength of the electrical circuits [28]. The voltage gain of every converter will affect about whole the system regarding the blocks of the step-up and step-down but in some cases, the increasing in the voltage gain can be increased in the switching losses, but the mitigation strategies topologies of those block will improve the efficiency and all the step-up and down blocks cannot use for every converter some of them can use some blocks regarding the structured circuit of the converter [25]. **Fig. 16** and **17** indicate all the switching blocks.

In this paper, we highlight the case study of the two converters (buck-boost and cuk) to show the performance of the switching inductors/capacitors switching to improve the converter in EV battery charging. While additional components introduce conduction and switching losses, proper design choices such as synchronous rectification, optimized switching frequency, and efficient magnetic components mitigate these losses. The net efficiency gain is observed due to reduced conversion stages and improved energy management. The voltage gain of the buck-boost converter, and Cuk converter with the step-up and step-down block topology as shown in the equations.

Buck- boost converter voltage gains for the Conventional,

$$\gamma = \frac{-\gamma_i \, \delta}{[1-\delta]} \tag{1}$$

During the step-up block the voltage gain will be,

$$\gamma = \frac{-\gamma_{i\,2\,\delta}}{\delta} \tag{2}$$

And the step-down will be,

$$\gamma = \frac{-\gamma_{i\,\delta}}{[1-\delta][2-\delta]} \tag{3}$$

The voltage gain of each converter involves different equations with the varying duty cycle of the high-frequency wave generated by switching elements with the blocks of the step-up and step-down functions,

$$\gamma = \frac{-\gamma_i \, \delta}{[1-\delta]} \tag{4}$$

During step-up block the voltage gain will be,

$$\gamma = \frac{-\gamma_i \, \delta \, [1+\delta]}{\delta} \tag{5}$$

And the step-down will be,

$$\gamma = \frac{-\gamma_i \, \delta}{2 \, \delta} \tag{6}$$

3. Buck-boost converter

As compared to the type of converters as shown in **Figs. 13,14**, and **15** with the step-up and down operation of the buck-boost converter, the input power factor comparison, THD comparison, and efficiency comparison as shown in **Figs. 14, 15**, and **16**.

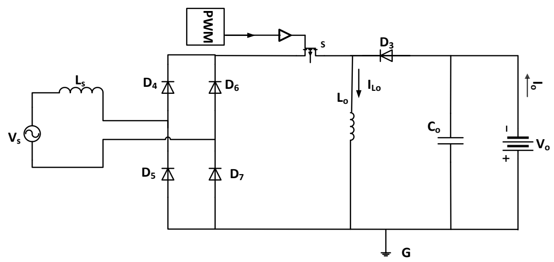


Figure 13. *Buck-boost converter with the conventional connection*

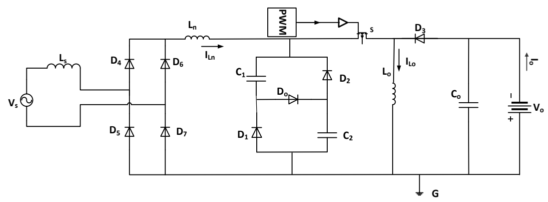


Figure 14. *Buck-boost converter with step-down-2 connection*

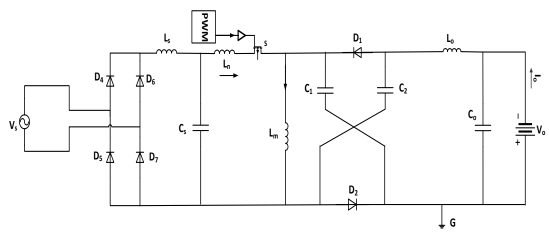


Figure 15. *Buck-boost converter with step-up-3 connection*

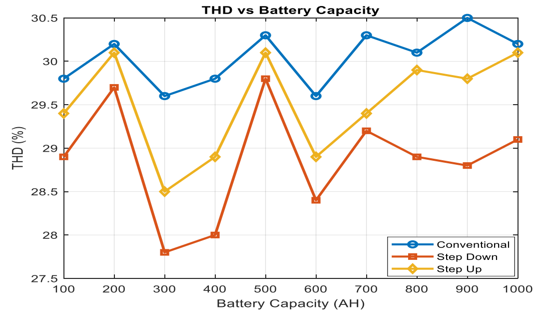


Figure 16. *Input current THD comparison*

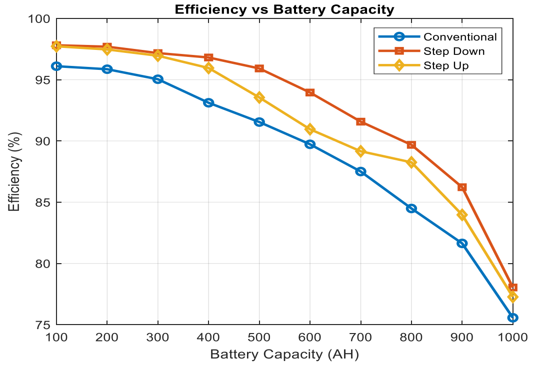


Figure 17. *Efficiency comparison for the Buck-boost converter charging the battery*

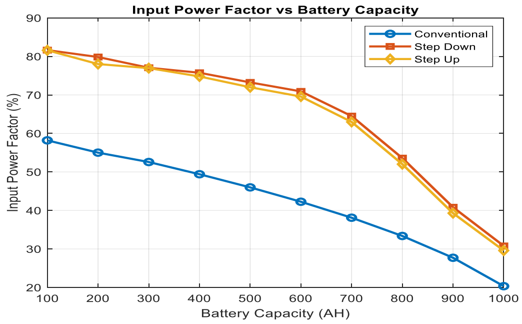


Figure 18. *IPF comparison for Buck-boost converter charging to the battery*

Regarding **Figs. 16, 17**, and **18**, the power factor of the step-up and step-down buck-boost converter is higher than the conventional converters, which indicates a lower deviation in the angle between the input voltage and current. The THD that indicated the heating of the converters and the charger in the step-up and step-down with switching blocks is lower than the conventional, but for the step-down, it is higher because the ripple for the step-up is higher than the step-down and lower than the conventional, as indicated by the ripple current. For those comparisons, the efficiency of the step-up and step-down converter is higher than the other, but in step-up, it will be less than the step-down because that ripple appears in case the capacity of the load is increased but is still better than the conventional converter, which makes the system operation with lower heating and loads as well due to the efficiency of the converter, efficiency presenting calculated using the power format μ = (power output cross load/power input from DC supply) * 100. In the items of the input power factor, the step-down models reach the highest performance with 81.63% at the capacity of the 100 AH battery. The efficiency was highest in step-down mode, achieving 97.81% at 100 AH, while step-up was slightly lower but still effective, with a high efficiency of 97.73% in the conventional mode. Regarding the THD, the step-down mode has the lowest distortion, with values decreasing from 29.1% at 1000 AH to 28.9% at 100 AH. However, the step-up mode showed improvements with lower THD than the conventional mode.

4. Cuk converter

As compared to the type of converters as shown in **Figs. 19, 20**, **21, 22** and **23** with the step-up and down operation of the Cuk converter, the input power factor comparison, THD comparison, and efficiency comparison.

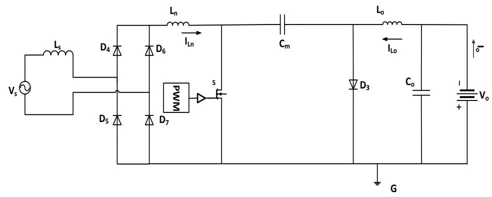


Figure 19. *Cuk converter with the conventional connection*

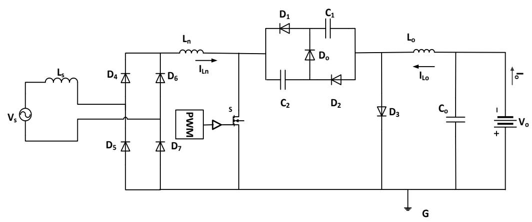


Figure 20. *Cuk converter with step-down-2 connection*

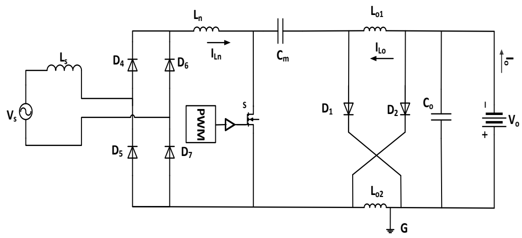


Figure 21. *Cuk converter with step-down-1 connection*

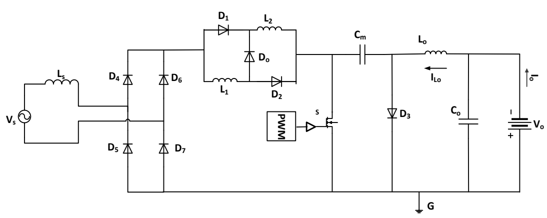


Figure 22. *Cuk converter with step-up-2 connection*

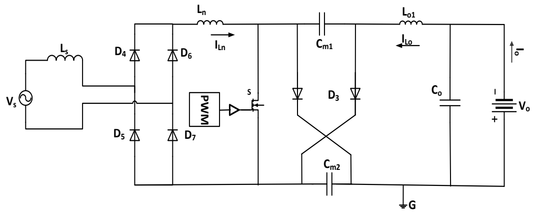


Figure 23. *Cuk converter with step-up-1 connection*

Regarding the results of the Cuk converters with the switching blocks in **Fig. 24**, **Fig. 25**, and **Fig. 26**, which were evaluated under the conventional, step-up, and step-down conditions concerning the IPF, efficiency, and THD. As a buck-boost converter, the performance of the Cuk converter will be higher than the conventional. The step-down mode fared better than the others, offering the best efficiency (94.87% at 100 AH) and the highest IPF (90.47% at 100 AH). Although it was marginally less effective, the step-up mode still did well, reaching a peak efficiency of 92.92%. Those values were calculated using the power format efficiency μ = (power output cross load/power input from DC supply) * 100. The step-down mode improved from 23.9% at 1000 AH to 23.1% at 100 AH, exhibiting the least amount of distortion in terms of THD. In comparison to the conventional method, the step-up mode demonstrated a moderate improvement in THD. When comparing the buck-boost and Cuk converters, it is evident that the step-down mode of both setups provides the best results in every parameter. In terms of IPF and THD, the Cuk converter performs better than the buck-boost converter, although the buck-boost converter is most efficient when the step-down configuration is used, as shown in **Fig. 17**. Superior energy efficiency is offered by the buck-boost converter, while superior power quality is achieved by the Cuk converter. Therefore, whether improving energy efficiency (buck-boost) or power quality (Cuk) is the top priority will determine which option is best.

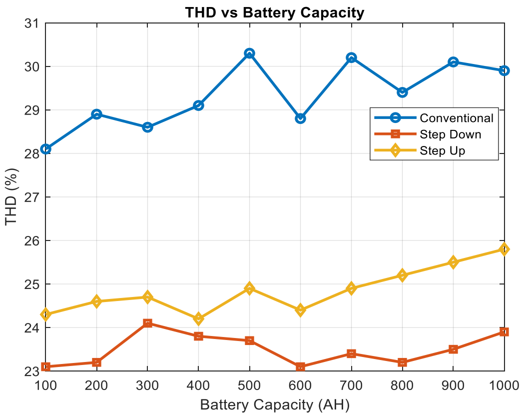


Figure 24. *Input current THD comparison for Cuk converter*

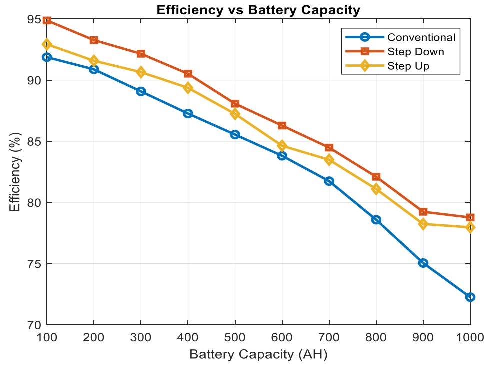


Figure 25. *Efficiency comparison for the Cuk converter charging the battery*

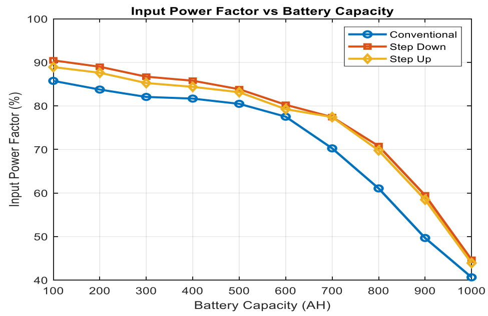


Figure 26. *IPF comparison for Cuk converter charging to the battery*

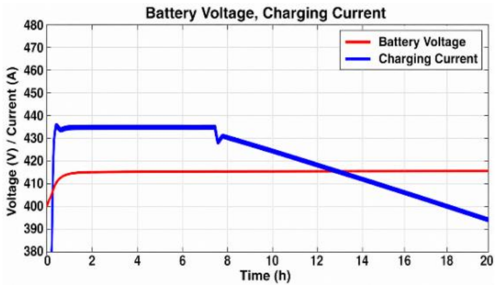


Figure 27. *Battery voltage vs. charging current for converters Cuk and buck boost*

All the parameters were kept the same for simulating each of the converters. Losses in the compensators were discarded. The same transfer function-based classical control technique was applied to all the converters. A 360-volt Li-ion battery was chosen. The simulation was conducted by varying the battery capacity from 100 ampere-hours to 1000 ampere-hours. Therefore, the nominal power of the converters ranges from 16.2 kW to 180.5 kW. **Fig. 27** shows the battery voltage along with the charging current. The simulation started at 98.5% SOC. Initially, the battery is being charged by a constant 435 A current. As soon as the battery voltage reaches 415 V, the charging current starts decreasing to keep the battery voltage constant. For both converters, the current and voltage will be the same waveshapes. It should be emphasized that the reported THD values in converters (23–29%) exceed the limits typically required for EV chargers (<5%).

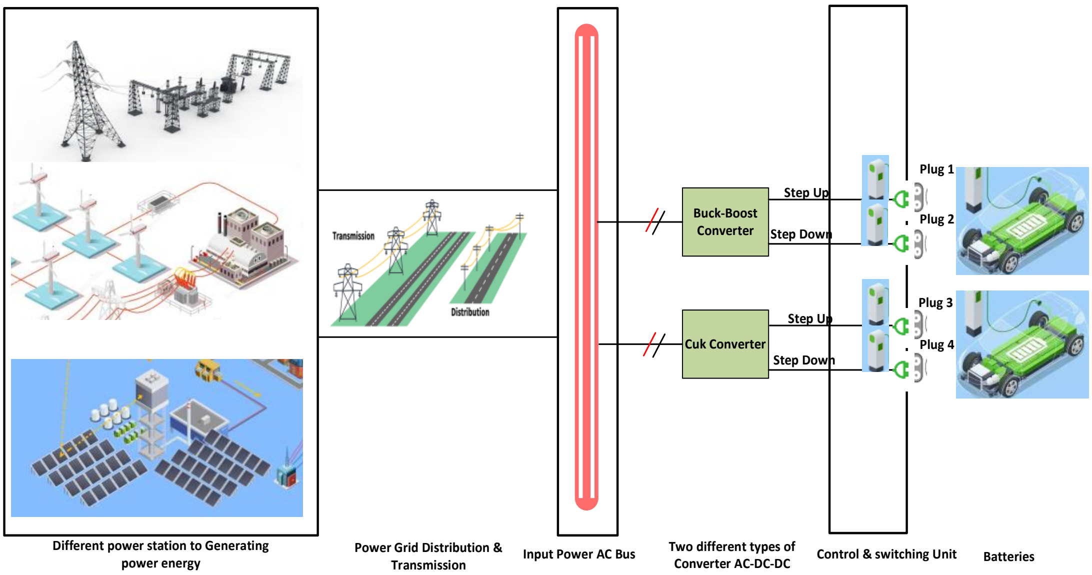


Figure 28. *Summary Result Values of the Simulink MATLAB*

Table 3. *Summary of MATLAB/Simulink Simulation Results*

Battery Capacity	IPF Conventional (%)	IPF Step-Down (%)	IPF Step-Up (%)	Efficiency Conventional	Efficiency Step-Down (%)	Efficiency Step-Up (%)	THD Conventional (%)	THD Step-Down (%)	THD Step-Up (%)
Buck-boost converter									
1000	20.330521	30.781072	29.581072	75.5664537	78.0377564	77.2672941	30.2	29.1	30.1
900	27.70445	40.827239	39.28697	81.6365014	86.2233878	83.968163	30.5	28.8	29.8
800	33.36645	53.588037	52.01864	84.4871616	89.6810261	88.25426	30.1	28.9	29.9
700	38.109973	64.497323	62.98264	87.5023318	91.574194	89.15683	30.3	29.2	29.4
600	42.256877	70.916865	69.572921	89.7262748	93.9519235	90.9545	29.6	28.4	28.9
500	45.988344	73.252044	71.99	91.5415425	95.9175116	93.546654	30.3	29.8	30.1
400	49.402272	75.755227	74.79692	93.1154884	96.8125983	95.952745	29.8	28	28.9
300	52.57054	77.05437	76.95672	95.0369048	97.1716348	96.9564	29.6	27.8	28.5
200	55.00941	79.844083	78.014083	95.855238	97.6951005	97.46872	30.2	29.7	30.1
100	58.198889	81.634614	81.5834614	96.1007767	97.8104775	97.726416	29.8	28.9	29.4
Cuk Converters									
1000	**40.645362**	**44.671204**	**43.92654**	**72.2550111**	**78.7694934**	**77.96541**	**29.9**	**23.9**	**25.8**
900	49.67621	59.472574	58.472558	75.0443156	79.2349328	78.2349328	30.1	23.5	25.5
800	61.06245	70.781529	69.781529	78.5823848	82.0961602	81.0961602	29.4	23.2	25.2
700	70.261439	77.442883	77.442883	81.7378931	84.4798081	83.48518	30.2	23.4	24.9
600	77.534506	80.270234	79.26562	83.8089049	86.2801215	84.62801215	28.8	23.1	24.4
500	80.485198	83.847545	83.16582	85.5441903	88.0690356	87.23292	30.3	23.7	24.9
400	81.69007	85.801791	84.3924	87.2621709	90.5178347	89.3642	29.1	23.8	24.2
300	82.07417	86.724483	85.2642	89.0724011	92.1473827	90.64648	28.6	24.1	24.7
200	83.76546	89.002888	87.62196	90.8739852	93.2664831	91.574987	28.9	23.2	24.6
100	85.761291	90.474411	88.9319	91.8690151	94.8729757	92.9264	28.1	23.1	24.3

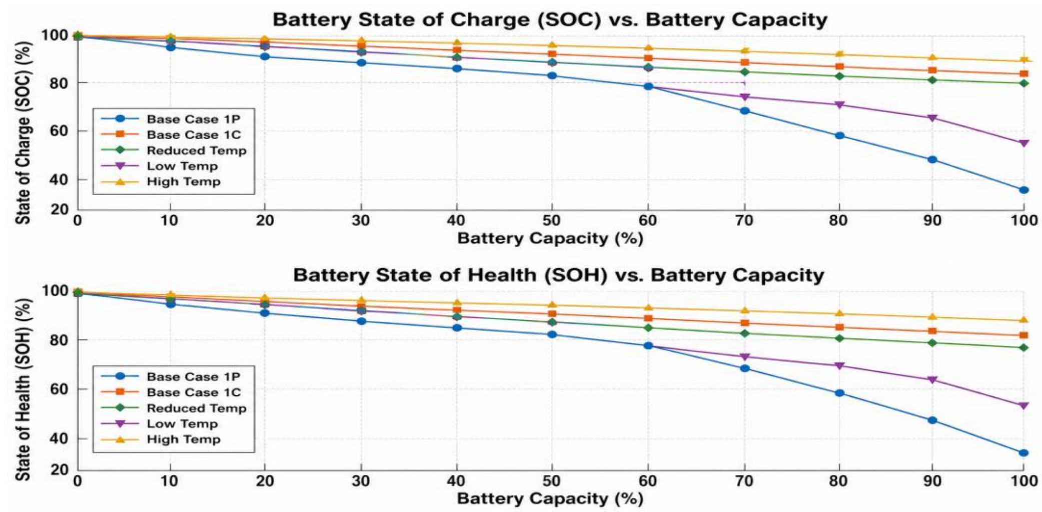


Figure 29. *Normalized performance of the buck-boost and Cuk converters with step-up and step-down mode*

This outcome arises because the present study did not explicitly incorporate advanced PI/PID controller schemes in the buck-boost and cuk converter models. In practical EV charging systems, the inclusion of such controllers significantly reduces harmonic distortion and ensures compliance with grid standards. Future work will therefore extend the model to integrate PFC stages and control strategies to achieve results consistent with improving real-world charger performance.

The efficiency, THD, and IPF for each converter will be different as shown in **Table 3** and **Fig. 29** but will be close to others, and regarding the control and type of the converter, step-up or step-down, the current and voltage will be changed. Buck-boost is suitable when input voltage varies significantly and a fast response is needed, while Cuk is preferred for applications requiring low output voltage ripple and smoother current profiles.

V. CHALLENGES AND FUTURE TRENDS

The development of electric vehicles keeps pace with electrical converter technology, but system challenges still exist. The current limitations are described in the previous sentence. The limitations include size, high costs because of the requirement for improved materials and components, and efficiency problems that result in decreased battery range and vehicle performance. The existing problems can be solved by applying new technologies such as Wide Bandgap (WBG) semiconductors, including silicon carbide (SiC) and gallium nitride (GaN). These materials provide better efficiency and lower energy losses, whichresults in the creation of smaller and lighter converters. Intelligent power modules with AI-based monitoring increase system reliability through real time fault prediction and power flow optimization. Advanced converters will be essential for the operation of autonomous and connected EVs, which need stable power systems to support sensors, control units, and communication modules for vehicle-to-everywhere (V2X) connectivity. To support V2G, the converter must enable bidirectional power flow. This requires full-bridge or dual-active bridge topologies and enhanced digital control to handle reverse current while maintaining safety and grid compliance, which is one of the future works. Real-time data exchange in these systems depends on efficient power management for the safe and effective operation of next-generation EVs. Size, cost, and efficiency remain problematic areas that continue to need to be addressed through converter technology improvements if we are to achieve the full potential of electric mobility. Regarding to our solution to decreasing the issues of the performance of the conventional converters by using the switching inductor/capacitor block for the study case at the buck-boost and Cuk converter for the future it will be in SEPIC and zeta converter that is the limitations of this paper and the control units of the converters with the difference type of controls. Furthermore, in terms of grid integration, the EV threatens power system stability and makes smooth operation a challenge. The challenges originate from random and uncoordinated charging, which causes demand surges during peak hours, putting pressure on local network infrastructure. The unpredictable nature of EV charging and discharging behavior poses a significant challenge since it might generate fluctuations in energy demand and supply, as shown in the previous case study of the IEEE 13-node feeder, underlining the need for effective efforts to minimize these effects, such as the following:

1. Smart charging infrastructure

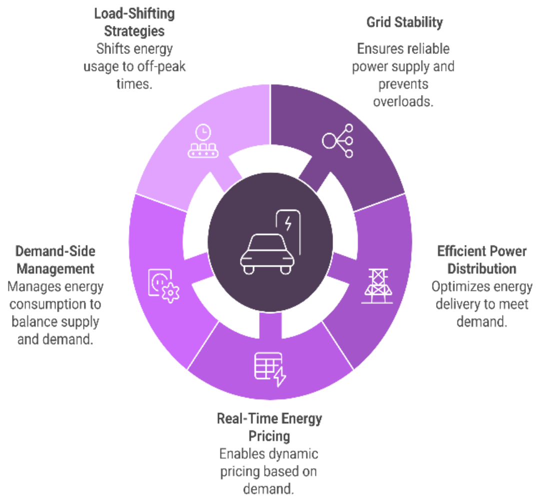


Figure 30. *AI in EV charging demand forecasting* [25][29]

Implementing smart charging systems is critical for balancing power consumption by moving electric vehicle charging to off-peak times. These systems use time-of-use pricing and demand response techniques to encourage consumers to charge when the grid has extra capacity as shown in **Fig. 30**. This strategy improves grid stability to accommodate voltage changes at EV charging stations while also optimizing energy use. Also, to improve control of charging events, new technologies such as the Open Charge Point Protocol (OCPP) or Electric Vehicle Aggregator (EVA) are necessary. EVA serves as a link between EVs, charging stations, and the power grid. OCPP provides effective communication between EVs and charging stations. OCPP has numerous significant capabilities, such as remote management, which enables operators to monitor, update, and operate charging stations remotely. It also supports load balancing, which distributes electricity effectively across many charging stations, lowering the danger of grid overload. The protocol secures data sharing by enabling encrypted communication for transaction logs, real-time charge status updates, and error reporting. It is also extremely scalable, making it suited for both small-scale and large-scale charging networks, as well as easy integration into smart grids [25].

2. Advanced load forecasting and AI-based grid management

To enhance energy efficiency, optimize power management, and boost system reliability, artificial intelligence (AI) plays a critical role in managing power systems with high integration of electric vehicles. Better prediction, problem detection, and real-time adaptation are made possible by the integration of AI into smart grids and energy management systems (EMS). These features are crucial for managing the dynamic nature of power networks with a high EV penetration rate. Artificial intelligence tools like machine learning and deep learning are essential for anticipating battery conditions, optimizing energy storage systems, efficiently controlling energy supply and demand, and preventing overload. With AI tools can be predicted the demand for short-term electric vehicle charging. As EV usage increases, standard forecasting models face significant hurdles due to the unpredictable nature of charging patterns. In order to address this, current research has used optimization methods in conjunction with sophisticated machine learning approaches. Particle Swarm Optimization (PSO) and Long Short-Term Memory (LSTM) neural networks are two efficient ways to increase the precision and versatility of short-term load forecasting [29]. The LSTM component captures the temporal and nonlinear patterns in EV charging demand, while PSO fine-tunes the LSTM's internal parameters, enhancing both learning performance and convergence speed.

According to [30], this hybrid PSO-LSTM model yielded a 20% improvement in Mean Absolute Error (MAE) compared to standard LSTM models, demonstrating its potential for reliable, multi-step forecasting in real-world EV charging networks. Suitable for complicated and dynamic energy systems, the method demonstrated minimal sensitivity to hyperparameter se-lection in addition to improving accuracy. As shown in **Fig. 28**, the modern grid operators looking to adopt demand-side management, load-shifting, and real-time energy pricing will find these enhancements very beneficial. Such models assist utilities in more effectively allocating resources, anticipating peak loads, and mitigating the danger of grid instability brought on by widespread EV charging. For the next generation of intelligent grid infrastructure, AI-based forecasting models such as PSO-LSTM provide useful tools.

Fig. 31 presents a structured overview of electrical converters within electric vehicle systems and their essential functions. It is worth mentioning that the AI may be applicable through charging efficiency, grid interaction, and intelligent control by optimizing charging efficiency through intelligent scheduling and battery health monitoring, AI greatly improves the man-agreement of power networks with high EV integration. By facilitating smooth grid interaction, EVs may offer essential services like demand response and V2G, supporting grid stability and the integration of renewable energy sources. Finally, by making predictive and adaptive judgements, AI offers intelligent control, turning EVs from passive loads into useful, active parts of a robust and sustainable power system. When used in tandem, these apps guarantee effective, reliable, and economical energy management.

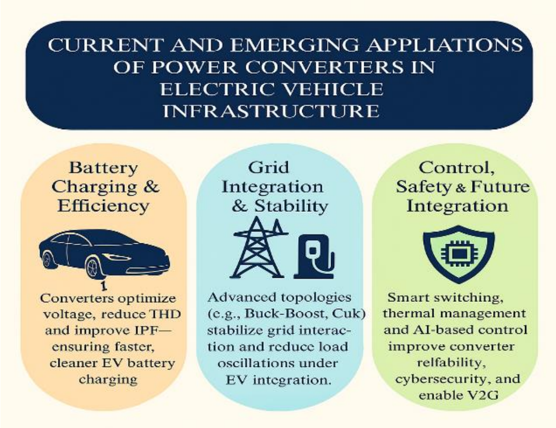


Figure 31. *Key applications of power converters in EVs, supporting efficient charging, grid stability, and intelligent control integration* [29][30]

VI. Conclusion

This study highlights the indispensable role of electrical converters in shaping the performance, safety, and sustainability of modern electric vehicle charging infrastructures. Through a comprehensive comparison of buck-boost and Cuk converter topologies in both step-up and step-down modes, this work provides clear evidence that advanced converter configurations have a substantial impact on total harmonic distortion (THD), input power factor (IPF), and overall system efficiency—three key indicators for evaluating EV charging performance and grid compatibility. Simulation results confirm that the Cuk converter, particularly in step-down operation, consistently outperforms both buck-boost and conventional converters in maintaining superior power quality. Its IPF peaks at 90.47%, and THD reduces to 23.1%, offering more stable voltage delivery and reducing strain on both the vehicle battery and power distribution networks. Conversely, while the buck-boost converter shows slightly higher harmonic distortion levels (28.9% THD in step-down), it achieves the highest energy efficiency at 97.81%, making it the ideal candidate for high-efficiency, fast-charging applications. Traditional converter models, by comparison, demonstrate inferior performance across all metrics.

The use of an IEEE 13-node feeder model further emphasizes the grid-level implications of EV integration. The random nature of EV charging can introduce new challenges, such as overloading, load imbalances, and voltage oscillations, which necessitate the need for smart deployment of optimized converters to ensure smoother load profiles, better voltage regulation, and improved grid resilience. Beyond power quality and efficiency, this study also considers broader engineering concerns such as thermal stress, ripple control, and switching losses. The inclusion of switching inductance/capacitance blocks significantly reduces overshoot and ripple current, thereby extending battery lifespan and improving converter durability. Furthermore, the research touches on the emerging necessity of cybersecurity in EV power electronics. As converters become smarter and more interconnected, protecting against cyber vulnerabilities in control logic becomes a critical aspect of system safety. While the buck-boost converter is advantageous in applications prioritizing maximum efficiency, the cuk converter demonstrates superior grid compatibility due to lower THD and higher input current smoothness. Thus, depending on the EV charger deployment context fast charging hubs vs. residential or distribution-constrained networks the appropriate topology can be selected. This dual-level recommendation directly connects converter performance to grid stability, strengthening the applicability of the study. Looking forward, the evolution of EV converter systems will depend on several innovations. These include the adoption of AI-based control algorithms for real-time optimization, enhanced bidirectional flow management for Vehicle-to-Grid (V2G) integration, and compatibility with renewable energy inputs. Adaptive switching strategies and hybrid converter topologies will also play a pivotal role in balancing grid demands, improving load scheduling, and minimizing harmonic interference. The study demonstrates that future EV charging systems must be built on robust, intelligent converter architectures to meet the demands of scalability, sustainability, and reliability in next-generation transportation networks.

AUTHOR CONTRIBUTIONS

A. N. A. Ahmed: Conceptualization, Methodology, Formal analysis, investigation, Writing - original draft preparation.

A. M. Saleh: Methodology, Validation, Investigation, Data curation, Writing - review and editing, Project Administration.

Gy.Györök: Validation, Investigation, Supervision, Writing - review and editing, Visualisation, Project administration.

DISCLOSURE STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ORCID

A.N.A. Ahmed: https://orcid.org/0009-0000-9463-2903

A.M. Saleh: https://orcid.org/0000-0001-5950-0016

Gy. Györök: https://orcid.org/0000-0003-3668-7855

REFERENCES

[1] IEA, Electric vehicle sales by region, 2022–2030, International Energy Agency, Paris (2023). https://www.iea.org/data-and-statistics/charts/electric-vehicle-sales-by-region-2022-2030

[2] R. Sisodia, "Top 8 Benefits of Electric Vehicles," EV Mechanica, Nov. 30, 2024. https://www.evmechanica.com/battery-technology-revolutionizing-the-future-of-electric-vehicles/?utm_source=chatgpt.com

[3] I. Latin and A. Transactions, Review of Bidirectional DC-DC Converters and Trends in Control Techniques for Applications in Electric Vehicles-(2024). https://latamt.ieeer9.org/index.php/transactions/article/view/8288

[4] A. Brown, J. Cappellucci, A. Heinrich, M. Gaus, and E. Cost, Electric Vehicle Charging Infrastructure Trends from the Alternative Fueling Station Locator: First Quarter 2024, National Renewable Energy Laboratory,(2024). https://www.nrel.gov/publications/

[5] R. Islam, S. M. S. H. Rafin, and O. A. Mohammed, Comprehensive Review of Power Electronic Converters in Electric Vehicle Applications, MDPI, vol. 5, no. 1 (2023). https://doi.org/10.3390/forecast5010002

[6] A. Brown, J. Cappellucci, E. White, A. Heinrich, and E. Cost, "Electric Vehicle Charging Infrastructure Trends from the Alternative Fueling Station Locator: First Quarter 2023," National Renewable Energy Laboratory (NREL), NREL/TP-5400-86446, 2023,42pp. https://doi.org/10.1109/INTLEC.2016.7749103

[7] X. Shen, Y. Zuo, J. Kong, and W. Martinez, Artificial Intelligence Applications in High-

Frequency Magnetic Components Design for Power Electronics Systems: An Overview, IEEE Transactions on Power Electronics 39 (7) (2024) pp. 8478–8496. https://doi.org/10.1109/TPEL.2024.3381431

[8] I. Jagadeesh and V. Indragandhi, Review and comparative analysis on DC-DC converters used in electric vehicle applications, IOP Conference Series: Materials Science and Engineering 623 (1) (2019) 012005. https://doi.org/10.1088/1757-899X/623/1/012005

[9] R. Aravind, B. Chokkalingam, R. Verma, S. Aruchamy, and L. Mihet-Popa, Multi-Port Non-Isolated DC-DC Converters and Their Control Techniques for the Applications of Renewable Energy, IEEE Access 12 (2024) pp.88458–88491. https://doi.org/10.1109/ACCESS.2024.3413354

[10] P. Górecki and K. Górecki, Methods of fast analysis of DC-DC converters—a review, Electronics-10 (23) (2021). https://doi.org/10.3390/electronics10232920

[11] A. Naji, A. Ahmed, E. Laufer, J. Lukács, and G. Györök, Improving Switching Efficiency with a Step-Up/Step-Down Hybrid Buck-Boost Converter Using Fuzzy Logic Control. http://bk.bgk.uni-obuda.hu/index.php/BK/article/download/248/186

[12] A. Naji, A. Ahmed, G. Györök, and A. N. A. Ahmed, Evaluating Conventional and Hybrid Buck-Boost Converters using Fuzzy Logic-Decision-Making 22,9, (121-140)-2025. https://doi.org/10.12700/APH.22.9.2025.9

[13] W. Guo and P. K. Jain, A power-factor-corrected AC-AC inverter topology using a unified controller for high-frequency power distribution architecture, IEEE Transactions on Industrial Electronics 51 (4) (2004) pp. 874–883. https://doi.org/10.1109/TIE.2004.831746

[14] H. Jafari and A. I. Sarwat, Resonant AC-AC Converter With Multi-Power Level Controller for Inductive EV Charging Systems, IEEE Transactions on Vehicular Technology 71 (11) (2022) pp. 11589–11602. https://doi.org/10.1109/TVT.2022.3194011

[15] H. Wu, K. Sun, L. Chen, L. Zhu, and Y. Xing, High Step-Up/Step-Down Soft-Switching Bidirectional DC-DC Converter with Coupled-Inductor and Voltage Matching Control for Energy Storage Systems, IEEE Transactions on Industrial Electronics 63 (5) (2016) pp. 2892–2903. https://doi.org/10.1109/TIE.2016.2517063

[16] A. J. Hanson, R. S. Yang, S. Lim, and D. J. Perreault, "A Soft-Switched High Frequency Converter for Wide Voltage and Power Ranges," 2016 IEEE International Telecommunications Energy Conference (INTELEC), Austin, TX, USA, 2016, pp. 1–8. https://doi.org/10.1109/INTLEC.2016.7749103

[17] S. Heydari, P. Fajri, R. Sabzehgar, and A. Asrari, Optimal Brake Allocation in Electric Vehicles for Maximizing Energy Harvesting during Braking, IEEE Transactions on Energy Conversion 35 (4) (2020) pp. 1806–1814. https://doi.org/10.1109/TEC.2020.2994520

[18] A. S. Kamaraja, M. Karuppasamypandiyan, and K. K. Kumar, Enhancing electric vehicle battery charging efficiency through advanced DC to DC conversion in solar PV-integrated PRHGHECIC for improved energy storage, Journal of Energy Storage 99 (2024)p.113247. https://doi.org/10.1016/j.est.2024.113247

[19] S. G. Farkoush, C. H. Kim, and S. B. Rhee, THD reduction of distribution system based on ASRFC and HVC method for SVC under EV charger condition for power factor improvement, Symmetry 8 (12) (2016). https://doi.org/10.3390/sym8120156

[20] R. Kushwaha and B. Singh, A Modified Luo Converter-Based Electric Vehicle Battery Charger with Power Quality Improvement, IEEE Transactions on Transportation Electrification 5 (4) (2019) pp. 1087–1096. https://doi.org/10.1109/TTE.2019.2952089

[21] R. T. Yadlapalli, A. Kotapati, R. Kandipati, and C. S. Koritala, A review on energy efficient technologies for electric vehicle applications, Journal of Energy Storage (2022). https://doi.org/10.1016/j.est.2022.104212

[22] S. Acharya, Y. Dvorkin, H. Pandzic, and R. Karri, Cybersecurity of Smart Electric Vehicle Charging: A Power Grid Perspective-(2020). https://doi.org/10.1109/ACCESS.2020.3041074

[23] S. Sahoo, T. Dragicevic, and F. Blaabjerg, Cyber security in control of grid-tied power electronic converters—Challenges and vulnerabilities, IEEE Journal of Emerging and Selected Topics in Power Electronics 9 (5) (2021) pp. 5326–5340. https://doi.org/10.1109/JESTPE.2019.2953480

[24] M. Altaf et al., PSO-based optimal placement of electric vehicle charging stations in a distribution network in smart grid environment incorporating backward forward sweep method, IET Renewable Power Generation 18 (15) (2024) pp. 3173–3187.

[25] A. M. Saleh, I. Vokony, M. Waseem, M. A. Khan, and A. Al-Areqi, Power system stability with high integration of RESs and EVs: Benefits, challenges, tools, and solutions, Energy Reports 13 (2025) pp. 2637–2663. https://doi.org/10.1016/j.egyr.2025.02.001

[26] H. Heydari-Doostabad and T. O'Donnell, A Wide-RangeHigh-Voltage-Gain Bidirectional DC-DC Converter for V2G and G2V Hybrid EV Charger, IEEE Transactions on Industrial Electronics 69 (5) (2022) pp. 4718–4729. https://doi.org/10.1109/TIE.2021.3084181

[27] B. Axelrod, Y. Berkovich, and A. Ioinovici, Switched-capacitor/switched-inductor structures for getting transformerless hybrid DC-DC PWM converters, IEEE Transactions on Circuits and Systems I: Regular Papers 55 (2) (2008) pp. 687–696. https://doi.org/10.1109/TCSI.2008.916403

[28] M. Kumar, K. P. Panda, R. T. Naayagi, R. Thakur, and G. Panda, A Critical Analysis of Quadratic Boost Based High-Gain Converters for Electric Vehicle Applications: A Review, Sensors 24 (7) (2024). https://doi.org/10.3390/s24072186

[29] A. Badjan, G. I. Rashed, A. O. M. Bahageel, H. Ali I Gony, H. I. Shaheen, and F. M. Tuaimah, Efficient grid management: smart forecasting of short-term power load using PSO-LSTM, Engineering Research Express 6 (3) (2024). https://doi.org/10.1088/2631-8695/ad7ad8

[30] X. Yang, L. Zhang, and X. Han, Electric Vehicle Charging Load Forecasting Method Based on Improved Long Short-Term Memory Model with Particle Swarm Optimization, World Electric Vehicle Journal 16 (3) (2025). https://doi.org/10.3390/wevj16030150