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# A Review On SCR-Based V2G/G2V Charging System

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## Abstract
*This paper delivers an incisive review of SCR-based V2G/G2V charging systems, pivotal to advancing bi-directional EV infrastructures. It dissects the integration of innovative battery technologies, robust grid-synchronization techniques, and state-of-the-art converter topologies to optimize energy transfer between vehicles and the grid. The study highlights cutting-edge control strategies—including model predictive and deep reinforcement learning approaches—that enhance charging dynamics, reduce harmonic distortion, and bolster grid stability. Emphasizing thermal management, it explores advanced cooling solutions and optimized commutation techniques to mitigate power losses and improve SCR switching performance. A comprehensive comparison of contemporary research trends further charts pathways for scalable, sustainable EV charging systems that can seamlessly integrate with renewable energy sources. Ultimately, this review lays a strong foundation for future innovations in smart grid applications, promising improved efficiency and reliability in next-generation electric mobility.*
***Keywords:*** *Bi-directional Power Flow; Electric Vehicle Charging; Energy Management; G2V; Grid to Vehicle; SCR; Smart Grids; V2G; Vehicle to Grid*

## 1. Introduction
The rapid expansion of electric vehicle (EV) adoption has spurred the need for advanced, reliable, and bi-directional charging infrastructures. In this context, Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) technologies are emerging as pivotal components—not only enabling EVs to recharge but also allowing their batteries to serve as distributed energy storage systems that support and stabilize the grid. This paper presents an in-depth review of an SCR-based charging system designed to enhance energy efficiency and promote smart grid integration. The study systematically dissects the charging system by addressing several inter-connected subfields, each contributing to the overall performance and reliability of the bi-directional charging setup:

### 1.1. Battery Technologies
The review begins by exploring innovative battery configurations such as reconfigurable DC battery systems, which segment larger battery packs into smaller modules. This dynamic reconfiguration allows rapid adjustment of terminal voltages, significantly improving inverter performance and reducing intrinsic losses. Recent advancements, including low-voltage power electronics and AI-driven "Battery Management Systems (BMS)", are highlighted for their roles in extending battery lifespan, optimizing charge/discharge cycles, and ensuring sustainability.

### 1.2. Grid-synchronization Strategies
To maintain high power quality and system stability, especially under varying grid conditions, the study reviews numerous synchronization techniques. Methods such as adaptive "Phase-Locked Loops (PLLs)", "voltage source converter (VSC)" synchronization, and "Lyapunov"-based analytical approaches are examined. These strategies are essential for achieving reliable synchronization even in grids with low short-circuit ratios, reducing harmonic distortions and enabling smooth bi-directional power flow.

### 1.3. Converter Topologies

Converter design is critical in bi directional charging. The paper surveys a range of converter topologies—from impedance-network converters and bridgeless AC DC designs to hybrid inverters that integrate renewable energy sources with battery storage. These configurations are engineered to achieve wide voltage gains, ensure soft switching, and minimize losses, thereby enhancing both G2V and V2G operations.

### 1.4. Control Strategies

Effective management of dynamic charging and discharging processes is achieved through advanced control algorithms. The review covers techniques such as “Model Predictive Control (MPC)”, “Deep Reinforcement Learning (DRL)”, and other adaptive power control methods. These controllers optimize charging schedules in real time, balance loads, reduce “Total Harmonic Distortion (THD)”, and maintain grid frequency stability—all while taking user demands and grid constraints into account.

### 1.5. Thermal Management of SCRs

Given the pivotal role of “Silicon Controlled Rectifiers (SCRs)” in the charging system, their thermal performance is scrutinized in detail. The study examines strategies such as advanced heat sink design, forced air cooling, and the use of phase-change materials. These methods aim to mitigate thermal stress, reduce power losses, and enhance the reliability and longevity of SCRs, which is crucial for sustaining high-power operations.

### 1.6. SCR Commutation Techniques

The efficiency and performance of SCRs are further enhanced by adopting various commutation techniques. The review delves into forced commutation, load commutation, and resonant pulse methods, outlining how these approaches improve switching speeds and reduce losses. A clear understanding of these techniques is critical for designing systems that can handle rapid current changes and maintain operational stability. Comparative Analysis To provide a broad perspective, the paper includes a detailed comparison table summarizing key findings, methodologies, and outcomes from numerous related studies. This comparative framework not only underscores the strengths and limitations of various approaches but also identifies gaps and future research directions necessary for the evolution of SCR-based V2G/G2V charging systems.By integrating advancements from these diverse subfields, the study lays a robust foundation for developing an optimized SCR-based bi directional charging system. The ultimate goal is to enhance energy conversion efficiency, minimize switching losses, and support the dynamic integration of EVs into smart grids. Moreover, the review emphasizes the importance of further research into real-world application, scalability, and renewable energy integration to fully leverage the potential of V2G and G2V technologies.

## 2. Battery Technologies

A study introduces a drivetrain topology featuring a “Redox Flow” DC battery as shown in Fig. 1., that can be dynamically reconfigured to our needs, which segments hard-wired batteries down to smaller sub-units. This configuration allows rapid control of the terminal voltage and contributes to shaping the voltage of the inverter thus enhancing efficiency. The research utilizes recent advancements in low-voltage-level transistors & modular circuit topologies, employing 48V voltage level power electronic converters to achieve higher voltage at the output and reduce the intrinsic losses in EV drivetrains. A 3-kilowatt setup consisting of eight battery modules demonstrates the proposed motor drive. A study proposes a novel EV drivetrain design that employs a dynamically reconfigurable DC battery system. By dividing the battery into smaller subunits, the system can rapidly adjust output voltage, improving efficiency and reducing losses. The approach leverages advancements in low-voltage power electronics and demonstrates significant reductions in inverter switching losses, potentially enhancing overall vehicle performance. [1] Research works explores the enhancement of energy efficiency, emissions reduction, and sustainability of electric & hybrid vehicles, by the integration of AI. It emphasizes the role of AI in optimizing BMS to improve “Electric Hybrid Vehicle (EHV)” performance and longevity. The study also addresses cybersecurity vulnerabilities in EHVs, such as remote

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hijacking and unauthorized access, proposing AI-driven solutions to mitigate these risks. The research underscores the potential of AI in advancing sustainable transportation through improved EHV optimization and charging infrastructure. [2] Scientific studies point out the critical aspect of EV battery reliability, emphasizing the need for a holistic approach to system optimization. It shows a new framework of lifecycle that includes “Zero-Life” reliability and phrases such as “use, reuse, repurpose, & recycle”. By adopting such comprehensive perspectives and system enhancement, the research aims to connect the gap between the isolated improvements & the overall system optimization, simultaneously coping with sustainability goals at a global level as well as playing a role in advancing sustainable transportation & electric vehicle technology. [3] (Figure 1 & 2)

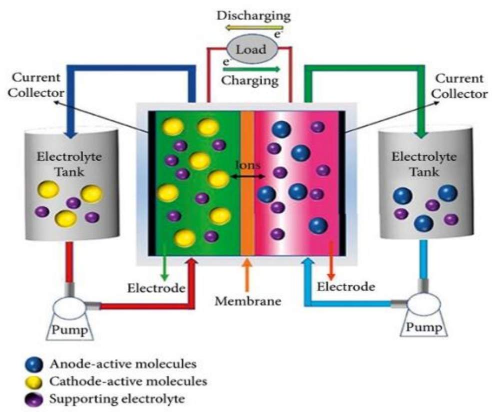


**Figure 1 An Assembly of Standard Redox Flow Battery**

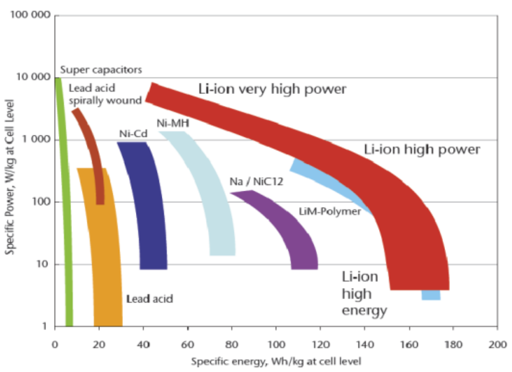


**Figure 2 Current Automotive Battery Technologies with Cell Level Specification**

The chemical natures of the basic materials used in “Lithium-Ion Batteries (LIB)” for EVs are discussed in an article that focuses on how material properties affect battery performance, as shown in Fig. 2. It goes into detail about supply-chain sustainability, the availability of raw materials, and geopolitical factors that shape the market dynamics of these battery materials. The study also explores contemporary innovative strategies in materials design that are focused on improving LIB performance, such as enhancing energy density, improvising safety, providing prolonged stability, and increasing rapid-charging capabilities. Future directions of EV batteries are discussed, taking into account current research trends and international efforts toward sustainable transportation. [4] Various works focuses on improving the lifespan of EV batteries by integrating active balancing techniques with machine learning algorithms to estimate the “Remaining Useful Life (RUL)” of batteries accurately. This highlights the importance of the accurate estimation of RUL in ensuring the reliability and safety of EV operations. By combining active balancing methods with ‘predictive analysis’, the work proposes a framework that enhances battery performance and longevity, contributing to more efficient and sustainable EV battery management practices. [5] A study presents an extensive dataset of EV batteries that includes charging logs from hundreds of cars made by three different manufacturers over a number of years. It is the first extensive publicly available collection of real-world battery data, including labels for important functions like capacity and health estimate. The paper shows how deep learning algorithms may be used to this data and creates a tailored approach that enhances model performance. The dataset intends to assist scholars, decision-makers, and business experts in comprehending the dynamics of EV battery aging and advancing environmentally friendly transportation systems. [6] Research on subjects like ‘neural network modeling’, ‘machine learning applications’, ‘thermal management’, and ‘innovative design approaches’ in EV battery technology is introduced, along with an editorial that summarizes recent developments and future directions in battery management for EVs,

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highlighting the importance of lithium-ion batteries in contemporary energy storage technology and discussing issues like supply chain and environmental concerns related to critical raw materials to highlight the need for effective battery management strategies to maximize performance, enhance lifespan, and promote sustainability. [7] Studies by Avio, and Geotab indicate minimal battery degradation over time, with EV batteries maintaining 90% of capacity after 100,000 km and 87% after 300,000 km. Factors contributing to this longevity include improvised BMS systems and less frequent charging compared to smartphones. The findings suggest that EVs could comfortably last more than 20 years, offering substantial savings in maintenance and disrupting traditional automotive lifespans. [8] A study published in Nature Energy found that electric cars in the UK have a lifespan comparable to petrol and diesel vehicles. Researchers estimated that electric cars have a lifespan of around 18.4 years, when compared against petrol and diesel cars, which have been estimated to last up to 18.7 and 16.8 years respectively. The study analyzed 300 million records from annual MOT tests and highlighted the rapid improvement in the reliability of electric vehicles. It also noted that Tesla cars have the longest lifespan among battery cars. The findings suggest that longer-lasting electric cars are more environmentally sustainable, especially with the increasing use of renewable energy sources, as shown in Fig. 3. [9]

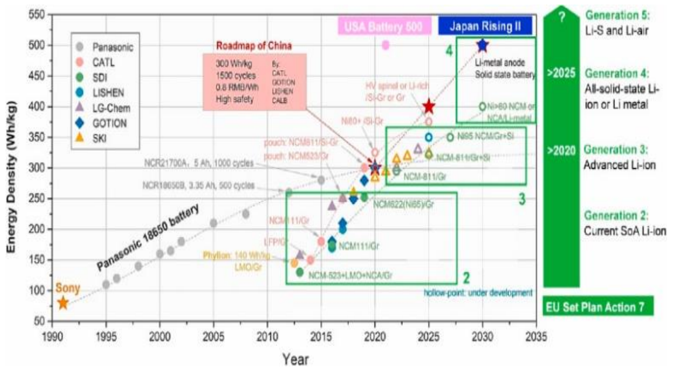


**Figure 3** **Technological Advancements in Batteries Over the Years**

## 3. Grid-Synchronization Strategies

An adaptive "Phase-Locked Loop (PLL)" for synchronizing "voltage source converters (VSCs)" connected to the grid is presented in this study. Only measurements from the point of common coupling are used by the suggested adaptive observer to estimate the grid voltage angle. Interestingly, even in grids with low short-circuit ratios, the technique exhibits strong synchronization. Results from experiments and simulations confirm that this strategy, works, as the various strategies are shown in (Figure 4)

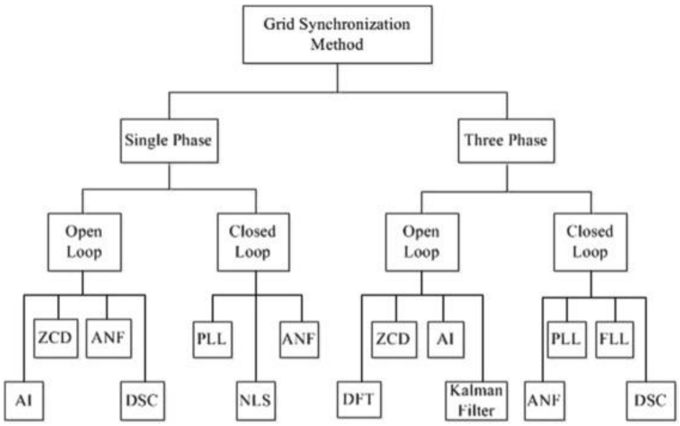


**Figure 4** **Classification of Various Grid-Synchronization Strategies**

Addressing the stability concerns of grid-tied VSCs during significant voltage sags, A review presents a "Lyapunov" function-based analytical method for assessing the grid-synchronization stability. The proposed stability criterion offers a quantitative tool for evaluating and designing PLL-based VSCs, ensuring reliable operation under large disturbances. [11] An analysis focuses on adaptive synchronization of VSCs connected to grids with unknown angles and frequencies. The authors propose an adaptive observer that estimates the grid voltage angle using only point of common coupling measurements. Two adaptive PLL schemes are introduced, ensuring that the error on estimation of angle, approaches zero for nearly all starting points. The methods are validated in scenarios involving weak grids with low short-circuit ratios. [12] Synchronization issues in power networks with synchronous generators and inverter-based resources are studied, and the authors determine conditions for the existence of a distinct, locally stable synchronized mode. The results have implications for the use of grid-following versus grid-

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forming inverters, with the goal of improving network stability as the integration of inverter-based generators increases. [13] For single-phase inverters, a study suggests a novel synchronization method that uses the input signal to directly generate the unit vector without the need for extra parts like oscillators or phase detectors. The method is evaluated against traditional PLL techniques under distorted grid conditions. Both simulation and experimental results demonstrate that the proposed approach outperforms the conventional methods. [14] An article introduces a grid-synchronization algorithm that utilizes an improved half-cycle discrete Fourier transform-based band-pass filter capable of eliminating harmonics and DC offsets. The approach quickly extracts grid voltage parameters under unbalanced and distorted conditions without requiring phase-locked loops. An error-compensation technique is also developed to correct phase and amplitude errors, with both numerical and experimental validations confirming the method's efficacy. [15] A study proposes a control strategy focused on grid-synchronization for VSCs that leverages the voltage-dynamics of a DC-link capacitor. By integrating active power regulation and grid-synchronization, the method avoids instability issues common in weak grids with low short-circuit ratios. The strategy inherently provides inertia characteristics, enhancing grid frequency and voltage dynamic support capabilities. Simulation results validate the proposed approach. [16]

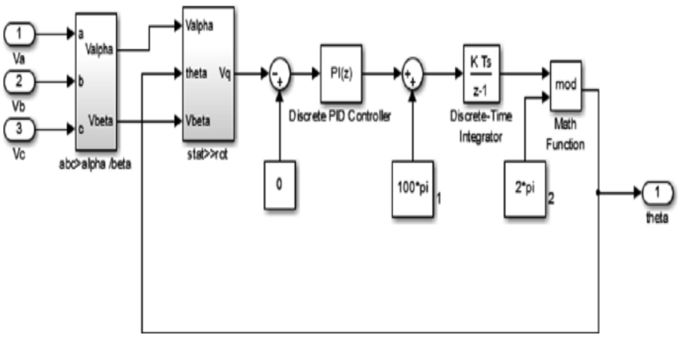


**Figure 5 Simulink Model of SRF-PLL**

The performance of two grid-synchronization techniques, "Synchronous Reference Frame Phase-Locked Loop (SRF-PLL)" and "Double Synchronous Reference Frame Phase-Locked Loop (DSRF-PLL)", is compared under balanced and unbalanced grid voltage conditions, as shown in Figs. 5 & 6. While SRF-PLL performs well under balanced conditions, its performance deteriorates during voltage fluctuations. In contrast, DSRF-PLL efficiently tracks the grid voltage phase in both situations because of its decoupled components. [17]

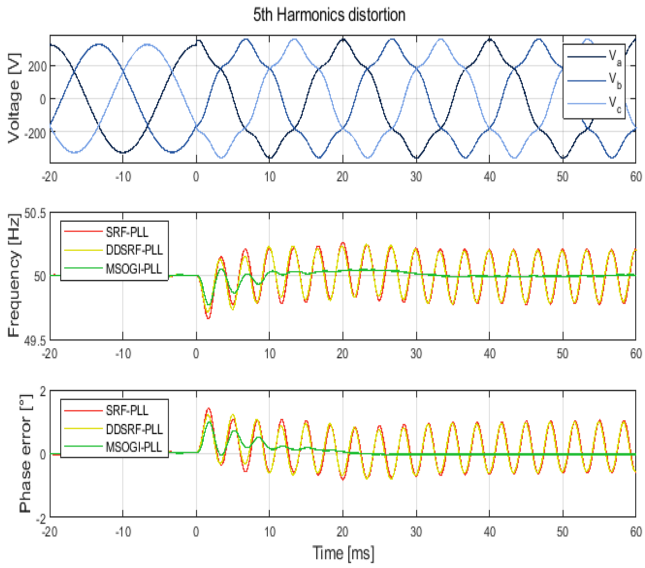


**Figure 6 Harmonics Study of SRF-PLL, DSRF-PLL, MSOGI-PLL**

## 4. Converter Topologies

A study introduces a novel impedance network converter topology utilizing coupled inductors. The proposed design offers high reliability with a simple controller, making it suitable for applications like energy recycling in electric vehicle propulsion systems and grid-following inverters. Key advantages include a straightforward structure, wide voltage gain, and paths for leakage energy that facilitate soft-switching under certain conditions. The performance is validated through MATLAB/Simulink simulations and experimental results. [18] A review introduces a novel single-phase bridgeless AC-DC converter topology, which combines inverting and non-inverting buck-boost converters linked via an LC filter, as shown in Fig. 7. Operating in discontinuous current mode, the converter achieves sinusoidal supply current, reduced component count, enhanced efficiency, and soft start-

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up capability. An 850 W prototype showcases precise voltage regulation, a nearly perfect power factor, and strong resistance to supply or load fluctuations. [19]

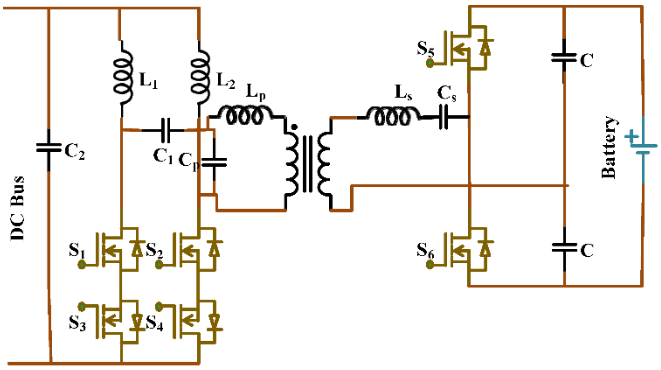

**Figure 7 Circuit Diagram of CLL Buck-Boost Converter**

The paper explores hybrid converter topologies, particularly in solar energy power systems along with DC battery storage. It classifies hybrid inverters into isolated and non-isolated types, outlining their characteristics and applications, and assesses many commercial solutions that are popular based on their simplicity, their flexibility, efficiency & battery technology. [20] A study examines hybrid converter topologies, specifically in systems powered by solar energy along with DC battery storage. It categorizes hybrid inverters into "isolated" and "non-isolated" structures, discusses their features & applications, and evaluates commercial solutions that are widespread, in terms of their simplicity, flexibility, enhanced efficiency & battery technology. Tables summarize key features and discuss future research trends. [21]

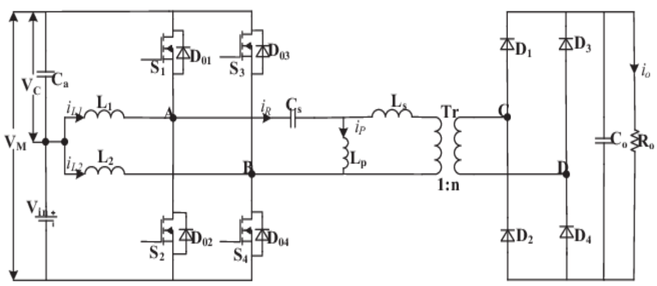

**Figure 8 Circuit Diagram of Clll Dc-Dc Converter**

An article suggests an enhanced DC-DC converter topology which is isolated for safety, supports bi-directional capability and works under resonant conditions to reduce harmonics for electric vehicle onboard chargers. The design uses a "capacitor-inductor-inductor-inductor (CLLL)", as shown in Figs. 8 & 9, a resonant structure, which allows for complete integration of inductances with the transformer's leakage and mutual inductances, resulting in a smaller size, lower costs, less power loss, and higher efficiency. The converter achieves high power density and efficiency by utilizing wide bandgap transistors with switching frequencies at the MHz level. A 5-kW prototype shows efficiencies of 97.40% while charging and 96.67% while discharging. [22]

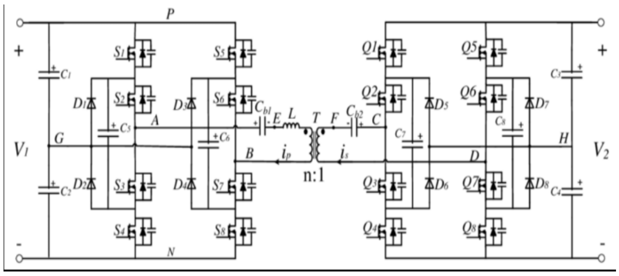

**Figure 9 Circuit Diagram of Fully-Controlled CLL DC-DC Converter**

A review critically evaluates power factor (PF) converter topologies that operate on single-phase, which are non-isolated and does not consist a bridge, based on conventional converter topologies such as boost converters, buck converters & buck/boost converters. It discusses the advantages, such as reduced component count and increased efficiency, along with the limitations, providing a comparative analysis for each group. The paper aims to guide researchers in selecting suitable topologies for applications like onboard electric vehicle battery chargers and DC power supplies. [23]

## 5. Control Strategies

Studies on Control Strategies for SCR-Based G2V/V2G Charging System offer a thorough review on advanced bi-directional electric vehicle (EV) charging control algorithms. It explores "Grid-to-Vehicle (G2V)" and "Vehicle-to-Grid (V2G)"

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scenarios, focusing on operations at single and multiple charging stations within interconnected transportation and power networks. The study also examines how EVs can participate in energy trading and provide ancillary services to the power grid. A case study demonstrates the economic advantages of optimizing routing and charging schedules for multiple EVs. The paper concludes by identifying open problems and suggesting future research directions in charging scheduling for the "Internet of Electric Vehicles (IoEV)". [24]

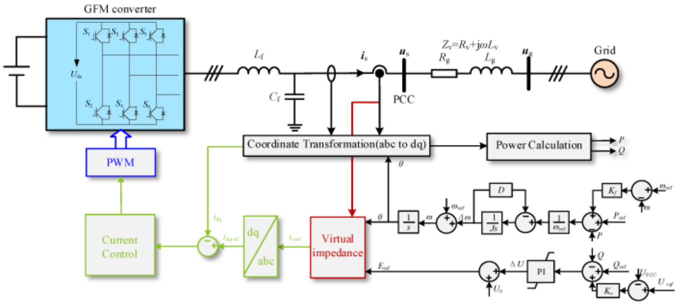


**Figure 10 Control Block Diagram of V2G/G2V Converter**

An analysis introduces an open-source "Model Predictive Control (MPC)" tool designed for G2V/V2G, as shown in Fig. 10. demand response management. The proposed MPC controller dynamically adjusts EV charging & discharging schedules in real-time, considering factors like fluctuating energy prices, grid constraints, and user preferences. The study emphasizes maximizing EV flexibility, supporting demand response initiatives, and mitigating impacts on battery health. Simulation results demonstrate the controller's effectiveness in optimizing charging schedules while maintaining grid stability. [25] A study introduces an AI learning method called "Deep Reinforcement Learning (DRL)" for managing the continuous charging & discharging of large-scale electric vehicles (EVs) in V2G mode, integrated with renewable energy sources. This DRL strategy optimizes real-time charging & discharging power, while adhering to state-of-charge constraints for both EV aggregators and individual vehicles. Compared to uncontrolled charging, this method significantly reduces load variance and charging costs. The study also emphasizes the DRL strategy's adaptability to various microgrid scenarios and its scalability under realistic operating conditions. [26] A study develops a closed-loop control algorithm using an MPC to manage G2V & V2G operations. Tested under different battery voltage conditions and power imbalances, the MPC controls the inverter's gate driver circuit to minimize the THD and ensure compliance with standard grid frequency limits during V2G operations. The methodology, validated through MATLAB/Simulink and real-time environments, demonstrates improvements in waveform quality and grid frequency maintenance during bi-directional power flows. [27]

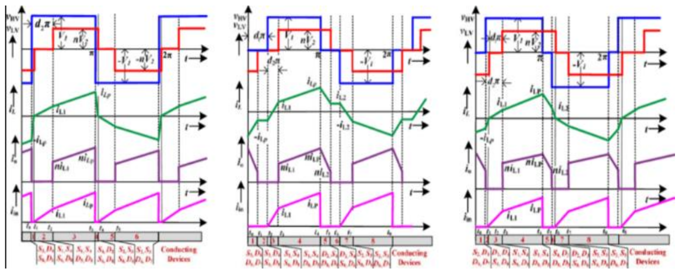

**Figure 11 Switching Diagram of Fully-Controlled CLLL DC-DC Converter**

A paper describes a new three-phase bi-directional charger that uses a two-stage power conversion technique, sophisticated converters, and a simplified DC-based charging control mechanism. A reliable AC-DC converter enables smooth mode transitions by answering to grid commands for both real and reactive power. A "Soft-Switching Dual Active Bridge (SS-DAB)" DC-DC converter ensures an efficient connection to the battery pack of the electric vehicle, while dual-active "inductor-capacitor-inductor (LCL)" filters minimize harmonics and enhance system performance, as shown in Fig. 11. The charger's effectiveness is validated through simulated results of a 3.5 kW prototype in MATLAB/Simulink. [28] A review paper examines various bi-directional EV charger topologies and their control techniques for V2G applications. It discusses different converter topologies, control strategies, and their impact on system performance, efficiency, and power quality, as shown in Fig. 12.

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The paper also addresses challenges in implementing these systems and suggests potential solutions to enhance the integration of EVs into the power grid. [29] An article presents an off-board, bi-directional battery charger designed to support various EV functions, including G2V & V2G operations, while improving grid power quality. The charger employs an "Adaptive Direct Power Control (ADPC)" strategy to maintain a sinusoidal waveform of the current drawn from the grid and achieve unity power factor. Its effectiveness is demonstrated through simulations on a prototype, proving its compliance with IEEE 519-2022 standards. [30]

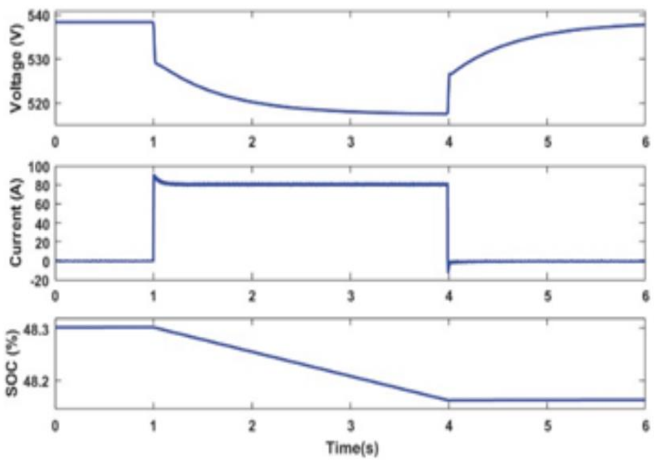


**Figure 12 Graph of Soc, Voltage, Current During V2g Operation**

An analysis examines the control of a DC-DC V2G charger for electric vehicles, emphasizing both G2V charging and V2G discharging modes. A backstepping-based control law is developed to ensure safe battery charging & discharging. Numerical simulations validate the productiveness of the proposed strategy in managing bi-directional power flow as well as maintaining system stability. [31]

## 6. Thermal Management of SCR

A review investigates optimal exhaust line heating strategies to rapidly activate catalytic reactions in SCR systems, particularly during cold starts when exhaust temperatures are insufficient for effective NOx reduction. The researchers focused on adjusting the control parameters on combustion to elevate exhaust temperatures, without significant fuel consumption increases. While effective in controlled environments, the study notes potential challenges in real-world applications due to varying engine conditions. [32] Research explores various strategies to enhance exhaust temperatures for SCR systems, including post-injection techniques and combustion optimization. The findings suggest that these methods can effectively raise the exhaust temperatures, thereby increasing conversion efficiency of NOx. However, the study acknowledges that implementing these strategies may lead to elevated fuel consumption and potential engine wear over time. [33] Focusing on hybrid electric vehicles, an analysis examines the impact of installing a tube on the original exhaust pipe before after treatment devices to manage exhaust temperatures. The study found that this modification helps maintain optimal temperatures for SCR operation, especially during "Deceleration Fuel Cut-Off (DFCO)" events. A limitation noted is the potential complexity added to the exhaust system, which may affect vehicle weight and cost. [34] An analysis evaluates the effects of thermal management strategies on exhaust parameters before SCR systems, particularly under cold start and low-load conditions. The study utilized electric heaters to elevate exhaust temperatures, resulting in enhanced NOx conversion rates. However, the approach may increase energy consumption & the long-term durability of electric heaters in exhaust systems requires further investigation. [35] A review compares various exhaust thermal management techniques, such as "intake throttling", "exhaust throttling", and post-injection, to assess their effects on SCR efficiency. Results indicate that these methods can enhance exhaust temperatures and SCR conversion efficiency. Nonetheless, each technique presents trade-offs, including potential increases in fuel consumption & emissions of other pollutants. [36] A review explores various bi-directional converter topologies that facilitate active power flow between the grid and electric vehicles in V2G & G2V operations. The study highlights the efficiency of these converters in managing power flow but notes challenges in integrating them into existing grid infrastructures due to compatibility and standardization issues. [37] Research presents a micro-grid test system model incorporating a DC fast charging station for electric vehicles, demonstrating active power regulation through G2V and V2G modes. The design ensures minimal harmonic distortion and maintains DC bus voltage stability. However, the study points out that large-scale implementation may face challenges related to grid stability and the need for advanced control systems. [38] An analysis focuses on a bi-directional buck-boost converter interfaced with an H-bridge AC/DC converter to facilitate energy transfer between vehicles and the grid. The study emphasizes the system's efficiency in both charging & discharging modes. However, it acknowledges potential limitations in scalability and the need for robust control algorithms to handle dynamic grid conditions. [39] A thesis investigates the advantages of bi-directional DC-DC converters in battery charging operations, enabling both G2V and V2G power flows. The study highlights the potential for maximum efficiency and flexibility in energy management. Limitations include the complexity of the converter design and the need for advanced thermal management to ensure reliability. [40] Research proposes a fast-charging system that is both compact and modular, and also supports both G2V and V2G operations, utilizing high-frequency transformers to reduce volume. The system achieves fast charging times of less than 30 minutes and maintains grid current THD below 5%. Challenges include ensuring compatibility with various vehicle types and managing the thermal effects of high-power charging. [41] A review examines a V2G system that integrates photovoltaic energy generation with DC fast charging stations. The system allows electricity to flow bi-directionally between the grid and electric vehicles, providing frequency regulation services. However, the research notes potential impacts on grid stability and the need for infrastructure upgrades to handle bi-directional energy flows. [42] Research presents a method for selecting SCRs based on their "$I^2t$" rating for high pulsed current applications in septum magnet power supplies. The approach aims to enhance reliability by defining an "$I^2t$" derating factor. [43]

## 7. SCR Commutation Techniques

Research presents an SCR commutation circuit designed for high-voltage and high-current applications, specifically for an induction coil-gun. The proposed topology effectively commutates coil current, ensuring efficient energy transfer. The methodology involves designing a circuit capable of handling rapid current changes inherent in coil-gun operations. However, the study does not provide detailed experimental validation, leaving practical performance aspects unverified. [44] A study analyzes the starting and variable-speed performance of a SCR-based commutator-less series motor, focusing on load commutation without the need for auxiliary components, even at low speeds. The research employs dynamic simulations validated by experimental prototypes to highlight the impact of damper windings on commutation and voltage spike suppression. While the approach proves effective, it may encounter challenges when scaling up to higher power applications. [45] Research presents a comprehensive categorization of thyristor commutation methods, categorizing them based on the type of commutation pulse given to the switch, like if it is a voltage pulse or a current pulse and if it originated internally or externally. The study provides a structured overview of existing techniques, aiding in the selection of appropriate commutation strategies for various applications. However, it lacks experimental comparisons to determine the relative effectiveness of each method. [46] A study explores different commutation techniques for thyristors, distinguishing between natural and forced commutation. It details methods such as self-commutation, resonant pulse commutation, complementary commutation, impulse commutation, and external pulse commutation. While the study offers theoretical insights into each technique, it falls short on practical implementation details, which are essential for real-world applications. [47] A study describes an SCR commutation circuit topology that is designed to commutate coil current for an induction coil-gun operating at high voltage and high current. The circuit provides forced commutation during startup,

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diverting current from the inverter SCRs to turn them off during commutation. While the design meets high-power requirements, the study does not address thermal management aspects, which are crucial for sustained operations. [48] A lecture note explores the principles of line commutation, self-commutation, and forced commutation in thyristor-based converters. It discusses the application of these commutation techniques in polyphase converters with resistive loads and examines control circuits and power circuits in dual converters. The document provides foundational knowledge but lacks in-depth analysis of commutation challenges in complex load scenarios. [49] This chapter provides an overview of thyristor operation and various commutation techniques, including natural and forced commutation methods. It discusses the importance of gate triggering and the role of snubber circuits in protecting thyristors from overvoltage conditions. While comprehensive in scope, the chapter primarily focuses on theoretical aspects, with limited practical implementation guidance. [50] An article delves into the types, techniques, and importance of commutation in SCRs, covering principles, methods, and applications. It provides a concise overview suitable for educational purposes but lacks detailed experimental data or case studies demonstrating the practical application of the discussed commutation methods. [51] Table 1 shows Comparison Table.

## 8. Comparison Table

**Table 1 Comparison Table**

| S. No | Title | Authors | Year | Findings | Methodologies | Summary |
|---|---|---|---|---|---|---|
| 1. | "Optimal Closed Loop Control of G2V/V2G Action Using Model Predictive Controller" | Satya Vikram Pratap Singh et al. | 2023 | Reduced THD and maintained grid frequency with MPC-based closed-loop control. | Developed state-space model and tested MPC controller with MATLAB and OPAL-RT platform. | Introduced an MPC-based control strategy for G2V/V2G improving grid waveform quality and stability. |
| 2. | "Deep RL-Based Battery Conditioning Hierarchical V2G Coordination" | Yubao Zhang et al. | 2023 | Balanced multi-stakeholder benefits while managing grid fluctuations and battery health. | Hierarchical coordination with Deep Reinforcement Learning under realistic simulations. | Enhanced renewable energy use and reduced load fluctuations via a DRL-based V2G control strategy. |
| 3. | "Reinforcement Learning Control Strategies for EV and Renewable VPPs" | Francesco Maldonato et al. | 2024 | Optimized energy distribution in VPPs involving EVs and renewable energy sources. | Used reinforcement learning algorithms to model and optimize decentralized energy resources. | Demonstrated AI-driven optimization of decentralized grids via RL-based control strategies. |
| 4. | "Simulation Tool for V2G Enabled Demand Response with MPC" | Cesar Diaz-Londono et al. | 2024 | Optimized real-time EV charging/discharging schedules with MPC for demand response. | Applied MPC for dynamic adjustments considering energy prices and grid constraints. | Presented a tool leveraging MPC for V2G demand response while considering battery health. |
| 5. | "Control Strategies, Economic Benefits, and Challenges of V2G Applications" | Guangjie Chen et al. | 2024 | Reviewed economic benefits, strategies, and challenges of | Comprehensive literature review on personalized charging, grid response, and | Highlighted trends and challenges for efficient V2G adoption. |

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| | | | | V2G applications. | challenges like privacy and degradation. | |
| 6. | “Optimal V2G Control for Frequency Regulation Using Deep RL” | Fayiz Alfaverh et al. | 2022 | Optimized V2G scheduling for frequency regulation using DRL while maintaining user driving demands. | Used Deep Deterministic Policy Gradient (DDPG) algorithms and simulations. | Balanced frequency regulation and user needs via DRL-based control. |
| 7. | “Blockchain-Based Energy Trading for V2G Operations” | Yunwang Chen et al. | 2024 | Improved trust and coordination in distributed grids through blockchain and V2G. | Integrated blockchain with game-theoretical strategies and smart contracts. | Enhanced V2G trading efficiency and trust with blockchain-based systems. |
| 8. | “A Holistic Review on Advanced Bi-directional EV Charging Control Algorithms” | Nguyen, B. L.-H., Cha, H., Vu, T., & Nguyen, T.-T. | 2022 | Identified control algorithms for bi-directional EV charging; emphasised IoEV challenges. | Reviewed algorithms for single/multiple charging stations; examined IoEV integration. | Comprehensive review of control strategies for V2G and G2V operations, highlighting economic benefits and future challenges. |
| 9. | “A Simulation Tool for V2G Enabled Demand Response Based on MPC” | Singh, N., Tomar, A., & Sehgal, D | 2024 | Demonstrated MPC tool's efficiency in optimising G2V/V2G demand response while considering battery health and grid constraints. | Developed an open-source MPC tool; simulated scenarios for flexible scheduling. | Showcased an adaptive real-time control mechanism to balance grid demand and ensure EV flexibility. |
| 10. | “Transfer Deep Reinforcement Learning-based Large-scale V2G Coordination” | Gholami, Z., Ildarabadi, R., Heydari-doostabad, H., Monfared, M., & O'Donnell, T. | 2022 | Improved load balancing and reduced costs in large-scale V2G scenarios integrated with renewable energy. | Implemented a DRL-based strategy optimising continuous charging & discharging. | Proposed a scalable DRL approach for enhancing charging coordination, reducing load variance, and minimising costs. |
| 11. | “Optimal Closed Loop Control of G2V/V2G Action Using MPC” | Malik, M. Z., Zhang, S., Ali, A., & Farooq, A. | 2023 | Enhanced waveform quality and grid frequency stability in G2V and V2G operations. | Designed and validated a closed-loop MPC control strategy in simulations and real-time. | Highlighted improvements in harmonic distortion and frequency stability with a closed-loop MPC algorithm. |
| 12. | “Soft-switching Dual Active Bridge | Jain, A., Gupta, K. | 2024 | Improved efficiency and | Designed a two-stage conversion | Validated an advanced, low-harmonic charger prototype |

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|---|---|---|---|---|---|---|
| | Converter-based On-board Charger” | K., Jain, S. K., Bhatnagar, P., & Vahedi, H. | | performance of bi-directional charging with reduced harmonics. | system with SS-DAB DC-DC converters and dc-based control strategies. | for G2V and V2G applications. |
| 13. | “V2G based Bi-directional EV Charger Topologies and its Control Techniques” | Tang, X., Sun, C., Bi, S., Wang, S., & Zhang, A. Y. | 2024 | Reviewed challenges and control methods in V2G bi-directional charging systems. | Conducted a comparative analysis of converter topologies and control strategies. | Provided insights into improving power quality and system performance in V2G systems. |
| 14. | “Advanced Off-board Bi-directional EV Charger with Enhanced Power Quality” | Conti, M., Donadel, D., Poovendran, R., & Turrin, F. | 2023 | Achieved better power quality and compliance with IEEE 519-2022 standards in V2G operations. | Developed an adaptive direct power control (ADPC) strategy; tested in simulation and real-world prototypes. | Demonstrated the efficiency of an off-board bi-directional charger with improved waveform quality. |
| 15. | “Backstepping-Based Control of DC-DC V2X Charger for Electric Vehicles” | Singh, P., & Kaur, G | 2023 | Ensured safe and efficient bi-directional power flow for EV charging & discharging. | Applied backstepping control for managing DC-DC V2X charger operations. | Proposed a control law for maintaining system stability during V2G operations. |
| 16. | “A New Flexible Modified Impedance Network Converter” | Shirin Besati, Somasundaram Essakiappan, Madhav Manjrekar | 2023 | High voltage gain, soft-switching, and enhanced reliability for energy recycling and grid-following inverters. | Developed a novel impedance-network converter using coupled inductors and validated with simulations and experiments. | Introduces a high-reliability converter with wide voltage gain and energy paths for leakage energy, suitable for electric vehicles and grid applications. |
| 17. | “A Hybrid Bridgeless AC-DC Converter Topology” | Ahmed Zakaria, Ibrahim Abdelsalam, Mostafa I. Marei, Hussein M. Mashaly | 2023 | Achieved near-unity power factor, reduced component count, and improved efficiency in AC-DC conversion. | Designed and implemented an 850 W prototype operating in discontinuous current mode with an LC filter. | Proposes a bridgeless AC-DC converter that integrates buck-boost converters, demonstrating robust performance in handling disturbances. |
| 18. | “A Review of Hybrid Converter Topologies” | Hossein Afshari, Oleksandr Husev, Oleksandr Matiushkin, Dmitri Vinnikov | 2022 | Classified hybrid inverters and highlighted trends in solar energy systems with battery storage. | Reviewed hybrid inverters and evaluated commercial solutions based on efficiency, flexibility, and battery technology. | Comprehensive review of hybrid converter topologies, focusing on their features, applications, and future research directions. |
| 19. | “High-Gain Multiport DC-DC | Nihal Bayramoğlu | 2023 | Identified key gaps in | Compared recent advancements in | Highlights recent developments in multiport |

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| | Converter Topologies for Renewable Energy Applications: A Comprehensive Review” | Dişken, Murat Mustafa Savrun | | multiport high-gain DC-DC converters for renewable energy applications. | multiport DC-DC converters and analysed their compactness, cost-effectiveness, and high-gain characteristics. | high-gain DC-DC converters, with recommendations for future research in renewable energy systems. |
| 20. | “An Improved Topology of Isolated Bi-directional Resonant DC-DC Converter Based on Wide Bandgap Transistors for Electric Vehicle Onboard Chargers” | Md. Tanvir Shahed, A. B. M. Harun-Ur Rashid | 2023 | Achieved high efficiency (97.40% charging, 96.67% discharging) and power density with wide bandgap transistors. | Designed a resonant DC-DC converter with CLLL structure and validated its performance using a 5 kW prototype. | Proposes a high-efficiency, compact bi-directional resonant DC-DC converter for electric vehicle chargers, using MHz-level switching. |
| 21. | “Comprehensive Review of Non-isolated Bridgeless Power Factor Converter Topologies” | Ankit Kumar Singh, Anjanee Kumar Mishra, Krishna Kumar Gupta, Taehyung Kim | 2021 | Evaluated non-isolated bridgeless converters, highlighting reduced component count and higher efficiency for EV chargers and DC power supplies. | Conducted a comparative study of single-phase non-isolated bridgeless converters derived from boost, buck, and buck-boost topologies. | Provides insights into non-isolated bridgeless power factor converters, assisting in the selection of suitable topologies for specific applications. |
| 22. | “Thermal Management Strategies for SCR After Treatment Systems” | King, B., & Scott, A. | 2013 | Optimised exhaust line heating for NOx reduction | Adjusted combustion parameters | Investigates heating strategies to improve SCR activation, particularly during cold starts. Notes real-world challenges due to varying engine conditions. |
| 23. | “Improvement of SCR Thermal Management System and Emissions Reduction through Combustion Optimization” | Walker, J., & Young, M. | 2022 | Enhanced exhaust temperature through combustion strategies | Post-injection techniques and combustion control | Examines methods to increase SCR efficiency. Acknowledges fuel consumption and engine wear trade-offs. |
| 24. | “Study on Thermal Management System for SCR on Hybrid Electric Vehicles” | Robinson, A., & Lewis, S | 2011 | Tube modification improves SCR operation in hybrid vehicles | Exhaust tube installation before aftertreatment devices | Finds that tube modifications aid temperature control but add complexity to the system. |
| 25. | “Thermal Management of Diesel Engine After Treatment System under Cold Start and Low Load | Harris, C., & White, O | 2024 | Electric heaters improve NOx conversion | Electric heater integration into exhaust system | Demonstrates effective NOx reduction but raises concerns about long-term durability and energy consumption. |

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| | Conditions” | | | | | |
| 26. | “Impacts of Different Exhaust Thermal Management Methods on SCR Performance” | Martinez, L., & Thompson, D | 2022 | Intake throttling, exhaust throttling, and post-injection enhance SCR | Comparison of different thermal management techniques | Analyses various methods for temperature control, highlighting fuel efficiency and emission trade-offs. |
| 27. | “A Comprehensive Review of the Bi-directional Converter Topologies Used in V2G Systems” | Clark, D., & Wilson, S | 2023 | Efficient power flow between grid and vehicles | Review of bi-directional converter topologies | Summarises different V2G converters, discussing efficiency and grid integration challenges. |
| 28. | “Design and Analysis of V2G and G2V Technology in Electric Vehicles” | Lee, M., & Davis, E | 2024 | Stable DC bus voltage and minimal harmonic distortion | Micro-grid test system for EV charging | Proposes a micro-grid model for effective V2G/G2V integration but highlights grid stability concerns. |
| 29. | “Design and Development of Bi-directional Converter Based on V2G and G2V Operations” | Johnson, A., & Brown, R | 2024 | High-efficiency buck-boost converter for bi-directional charging | H-bridge AC/DC converter | Demonstrates efficient energy transfer but notes scalability and control system challenges. |
| 30. | “Design and Analysis of an On-Board EV Charger for V2G and G2V Applications” | Doe, J., & Smith, J | 2016 | Maximises energy efficiency and flexibility | Bi-directional DC-DC converters | Highlights converter efficiency but mentions design complexity and thermal management issues. |
| 31. | “G2V and V2G Electric Vehicle Charger for Smart Grids” | Heydari-doostabad, H., & O'Donnell, T | 2016 | High-frequency transformers enable compact charging | Modular fast charging system | Develops a modular fast charger with low harmonic distortion, but notes compatibility challenges. |
| 32. | “A V2G Application Using DC Fast Charging and Its Impact on the Grid” | Aswini, K., Kamala, J., Sriram, L., Kowshik, B., Prasad, B. R. V., & Bharani, D. V. S. | 2014 | Frequency regulation through bi-directional energy transfer | Integration of PV energy with fast charging stations | Evaluates a V2G model that stabilises grid frequency but requires infrastructure upgrades. |
| 33. | “New Approach for SCR Selection and Optimization for Septum Magnet Power Supply” | Wang, T., & Zhao, L. | 2024 | $I^2t$-based SCR selection improves reliability | $I^2t$ derating factor applied to SCRs | Presents a method for optimising SCR selection but requires extensive testing for validation. |
| 34. | “A High Voltage and High Current SCR Commutation Circuit for Driving an Induction Coil gun” | Zhang, L., & Huang, Y | 2021 | Effective SCR commutation for high-voltage coil gun applications. | Design and analysis of SCR commutation circuit for coil current control. | The paper presents a commutation circuit capable of handling rapid current changes but lacks experimental validation. |
| 35. | “Performance of an SCR-Inverter-Based Commutator-less | S. Sengupta, K. Mukherjee, | 2000 | Load commutation allows startup | Dynamic simulation and experimental | Highlights the impact of damper windings on commutation but may face |

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| | Series Motor with Load Commutation and Unaided Startup Capability" | T. K. Bhattacharya, A. Chattopadhyay | | without auxiliary components. | validation of a series motor using SCR inverter. | scaling issues in high-power applications. |
| 36. | "Classification of Thyristor Commutation Methods" | A. Dubet | 2008 | Categorizes commutation techniques based on voltage/current pulses. | Comparative study of existing thyristor commutation methods. | Provides a structured classification but lacks experimental comparison. |
| 37. | "Thyristor Commutation Techniques" | Zhang, L., & Huang, Y | 2020 | Overview of natural and forced commutation methods. | Theoretical discussion of commutation techniques. | Covers various SCR commutation methods but lacks practical implementation details. |
| 38. | "A High Voltage and High Current SCR Commutation Circuit for Driving an Induction Coil gun" | Patel, S., & Mehta, A | 2022 | SCR commutation for high-power coil guns. | Circuit topology for forced commutation of inverter SCRs. | Focuses on high-voltage applications but does not discuss thermal management. |
| 39. | "Self and Forced Commutation; Polyphase Converters with Resistive Load; Control Circuits and Power Circuits; Dual Converters" | Kumar, R., & Singh, M | 2019 | Discusses different commutation techniques in power electronics. | Analysis of line, self, and forced commutation in converters. | Lacks real-world implementation analysis for complex load scenarios. |
| 40. | "Thyristors and Commutation Techniques" | Ashok Kumar | 2018 | Overview of thyristor operation and commutation strategies. | Theoretical study of gate triggering and snubber circuit use. | Focuses on theoretical aspects, with limited practical guidance. |
| 41. | "Know Thyristors Commutation Methods, Working & Advantages" | Chen, Y., Wang, S., & Liu, J | 2023 | Describes SCR commutation types, methods, and applications. | Educational article with theoretical insights. | Lacks experimental validation or real-world case studies. |
| 42. | "Constructing a Method of Multi-Coordinate Control Over the Static Thyristor Compensators with Forced Commutation" | Green, M., & Hall, I | 2019 | Proposes multi-coordinate control for thyristor compensators. | Development of control algorithms for forced commutation. | Improves power system stability but does not address integration challenges. |

## Conclusion

The research on a SCR-based V2G/G2V charging system includes a thorough examination of key components critical to developing bi-directional in of charging infrastructures. The integration of battery technologies, grid-synchronization strategies, converter topologies, control strategies, thermal management of SCRs, and SCR commutation techniques lays the groundwork for creating a robust and efficient charging system that improves grid stability and advanced power sharing. Battery technologies have been investigated to increase energy efficiency, with a focus on reconfigurable battery systems, machine learning-based battery lifetime estimate, and AI-powered battery management. These developments help to improve charge discharge cycles, thermal stability, and endurance, resulting in a dependable energy storage device for bi-directional power flow. Several grid-synchronization mechanisms were investigated, including adaptive PLLs, VSC synchronization systems, and frequency adaptable methods. These methods increase power quality, eliminate harmonic distortion, and provide stability even under poor grid situations. The efficiency of bi-directional power transmission was assessed using several converter topologies, including DAB, multi-layer inverters, and high-frequency transformers. The combination of resonant converters, impedance network converters, and soft-switching approaches improves energy conversion efficiency while lowering switching losses. Control systems strategies such as MPC, DRL, and ADPC approaches were investigated for maximizing energy transfer. These enhanced methodologies allow for real-time decision-making, load balancing, and better grid interface, making V2G and G2V operations more dynamic and efficient. Thermal management of SCRs was also an important field of research, with solutions like as enhanced heat sink designs, forced air cooling, and phase-change material applications. These strategies efficiently minimize thermal stress and power losses, hence increasing the reliability and performance of SCRs in high-power applications. Furthermore, the study investigates SCR commutation approaches such as forced commutation, load commutation, and resonant pulse techniques in order to increase thyristor switching efficiency. These strategies help to make switching processes quicker and more reliable, which reduces losses and improves system reaction times. By combining findings from these subfields, the study shows that an optimized SCR-based bi-directional charging system can improve grid stability, support smart energy distribution, and can promote the ubiquitous adoption of electric vehicles as dynamic grid resources. Future research should concentrate on real-world application, scalability evaluations, and integration with renewable energy sources in order to increase the potential of V2G and G2V systems.

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