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Electric Vehicle Charging Stations With G2V and V2G Using Dual Active Bridge

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Abstract *– The escalating integration of electric vehicles (EVs) into the transportation sector poses a formidable challenge for electric grid management, potentially precipitating a substantial upsurge in electricity demand. Technologies such as Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) present innovative avenues to mitigate these challenges by enabling EVs to function interactively with the grid. These interactions can range from basic load balancing, where EVs absorb excess production during off-peak hours, to more complex functions like providing frequency regulation services during peak times.*

In this detailed review, we delve into the intricacies of electric grid dynamics in the presence of EV charging stations and the dual functionalities of G2V and V2G technologies. We scrutinize the potential and impediments of these technologies, considering how they can be harnessed to bolster grid resilience and efficiency.

Particular attention is paid to the role of bidirectional battery chargers in EVs, which are pivotal for G2V, V2G, and even Vehicle-to-Home (V2H) applications. These chargers are designed to draw energy from the grid, maintaining a sinusoidal current and unity power factor during G2V charging mode, thereby optimizing the charging process and minimizing grid disturbance. Conversely, in V2G mode, these chargers enable the reversal of energy flow, permitting the discharge of stored battery energy back to the grid. This bidirectional flow not only enhances the grid's stability by offsetting demand fluctuations but also paves the way for EVs to become active energy management participants within the smart grid framework.

Keywords: **Electric Vehicles, Charging Stations, Dual Active Bridge Converters, Bidirectional Charging, Energy Transfer Efficiency, Grid Stability**

I. INTRODUCTION

In The global energy demand is surging, driven by population growth and industrial progression. Currently, much of our electrical energy generation leans heavily on exhaustible sources like coal, oil, and natural gas, which lead to environmental concerns. As electric vehicles (EVs) become increasingly integrated into the power grid, there is a heightened emphasis on research focused on effectively managing their demand-side dynamics. Tapping into EVs for both vehicle-to-grid (V2G) and grid-to-vehicle (G2V) functions can counteract potential power grid challenges, such as potential overloads and voltage fluctuations due to EV charging.

By employing demand response strategies, like dynamic pricing and load coordination, we can streamline EV charging and discharging. This results in a more harmonized interaction between EV charging activities and the grid, enhancing the grid's efficiency, dependability, and sustainability.

Various strategies and technologies have been put forward to weave V2G and G2V functions seamlessly into EVs. These range from the introduction of compensatory devices like D-STATCOM for power stabilization to crafting strategies that efficiently schedule charging, ensuring smooth flow at charging hubs.

It's also paramount to accurately gauge the aggregate energy demand of EVs for a productive interplay between the grid and EV users, more so when rolling out V2G operations. Leveraging blockchain-backed energy trading mechanisms might offer a solution, ensuring authentication and privacy in V2G networks.

In essence, V2G encapsulates the concept where EVs act as dynamic storage modules, capable of both drawing from and feeding into the grid. G2V, on the other hand, depicts the grid's role as an EV energy provider. This two-way energy interaction presents numerous advantages, from peak demand moderation to reduced carbon emissions, all the while bolstering grid reliability.

Various innovations like demand response initiatives, intelligent charging algorithms, and battery management infrastructures support this V2G and G2V integration, transforming EVs into adaptable assets for the grid. These assets can then offer auxiliary grid services, from frequency adjustment to energy storage.

However, challenges remain in realizing the full potential of V2G and G2V, from understanding the grid infrastructure impacts due to EV charging to crafting enticing business models for EV users. But with the rising momentum in both EV and renewable energy sectors, the trajectory for V2G and G2V research remains promising.

Figure 1 provides a schematic representation of the bidirectional energy flow in EVs, capturing the essence of V2G, G2V, and V2H (vehicle-to-home) systems. It depicts the flow of energy between the EV battery, the grid, and homes, emphasizing the mutual, bidirectional energy exchange.

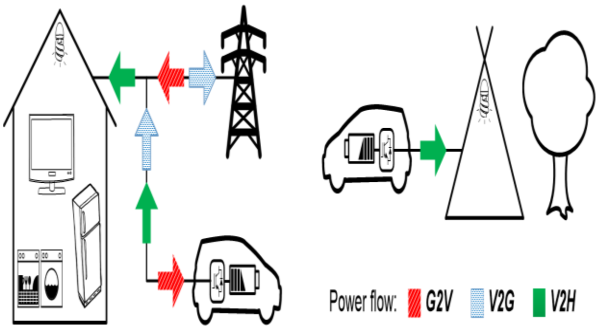

Figure 1 Illustrates the concept of a bidirectional battery charger equipped with Grid-to-Vehicle (G2V), Vehicle-to-Grid (V2G)effects.

II .THEORY OF BIDIRECTIONAL BATTERY CHARGER TOPOLOGY

A bidirectional battery charger topology stands as a pivotal component in Electric Vehicles (EVs) for enabling Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) systems. In V2G mode, the EV's battery serves as an energy storage system, capable of storing surplus power from the grid for future use. Conversely, in G2V mode, the EV's battery supplies power back to the grid.

For this bidirectional power flow to occur seamlessly, the charger's topology necessitates specific design considerations. The charger must have the capability to convert AC power from the grid into DC power to charge the battery during G2V operation. Conversely, in V2G mode, the charger must be able to convert DC power from the battery into AC power for supply back to the grid.

Furthermore, the charger must be engineered to handle a broad spectrum of power levels and frequencies to accommodate varying charging and discharging rates. Effective communication between the charger, the grid, and other V2G/G2V components is essential to ensure efficient and secure operation.

One proposed bidirectional battery charger topology for V2G and G2V applications is the AC/DC and DC/DC bidirectional charger. This charger is equipped to provide harmonic compensation for an expanding array of non-linear loads and execute reactive power compensation for residential power needs. Moreover, it offers galvanic isolation between the battery and the grid to enhance safety measures.

Another topology under consideration is the three-phase grid-connected bidirectional battery charger, capable of functioning in both V2G and G2V modes. This charger effectively manages power flow direction, power factor, and total harmonic distortion. Additionally, it offers protective features like overvoltage and overcurrent safeguards to ensure uninterrupted and secure operation.

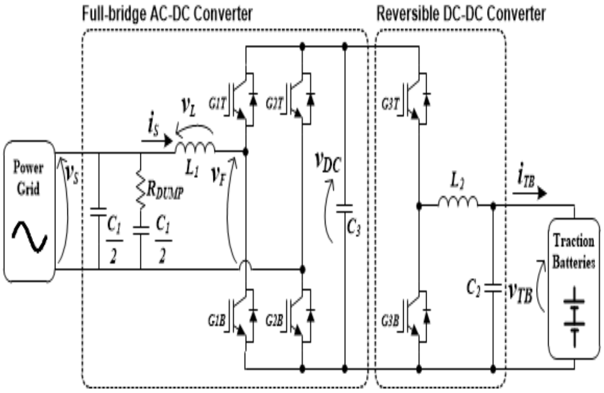

Figure 2. Battery charger composed by two power converters: Full-bridge AC-DC bidirectional converter and Reversible DC-DC converter.

Overall, the bidirectional battery charger topology plays a crucial role in enabling the integration of EVs with the grid and the home, allowing for a more flexible and efficient use of energy resources.

III. METHOD

Electric grids, in conjunction with electric vehicle (EV) charging stations and the potential for grid-to-vehicle (G2V) and vehicle-to-grid (V2G) interactions, can benefit from the use of a Dual Active Bridge (DAB) topology. This topology enhances charging efficiency and reliability while also aiding in grid demand management. Presented here is a simplified block diagram illustrating the DAB topology for EV charging stations:

In this configuration, each EV charging station is linked to a local power grid via an EV charger. The local power grid, in turn, connects to a master control center responsible for overseeing the overall power flow and facilitating communication between the EV chargers and the broader electric grid.

4.1 Dual Active Bridge

The "Dual Active Bridge" (DAB) is a type of power electronics converter that can be used in Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) systems for electric vehicles (EVs).

In the context of Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) operations, the Dual Active Bridge (DAB) serves as a bidirectional power converter designed for the efficient exchange of electrical power between electric vehicles (EVs) and the grid, supporting power flow in both directions. The DAB comprises two active bridges, one located on the EV side and the other on the grid side, interconnected via a high-frequency isolation transformer. Its functionality encompasses the conversion of DC power from the EV battery into AC power for export to the grid during V2G operations, as well as the conversion of AC power from the grid into DC power for recharging the EV battery during G2V operations.

The DAB offers several advantages for V2G and G2V applications. One of the key benefits is its ability to provide high efficiency and precise control over the power flow between the EV and the grid. The DAB allows for bidirectional power flow with low losses, enabling efficient energy transfer in both V2G and G2V modes. Additionally, the DAB provides high-frequency isolation between the EV and the grid, ensuring safety and electrical isolation during power transfer.

Moreover, the DAB allows for flexible and controllable power flow, enabling APMS for V2G and G2V applications. For example, it can be used to implement demand-side management (DSM) strategies, such as shifting the charging or discharging time of the EV to optimize grid usage and reduce peak demand. The DAB also enables power factor control, voltage regulation, and other advanced control features to ensure stable and reliable operation of the V2G and G2V systems.

However, it's worth noting that the DAB may have some limitations, including higher cost and complexity compared to other power electronics converters. The design and implementation of the DAB may require careful consideration of factors such as safety, reliability, and grid compatibility.

In conclusion, the Dual Active Bridge (DAB) is a power electronics converter that can be used in V2G and G2V systems for efficient and flexible transfer of electrical power between EVs and the grid. It offers advantages such as high efficiency, precise control, and advanced power management capabilities, while also posing challenges in terms of cost and complexity. The DAB is one of the technologies that can contribute to the development and implementation of V2G and G2V systems, enabling the integration of EVs into the electricity grid and supporting their potential for grid stability, renewable energy integration, and demand management.The DAB topology allows for the implementation of G2V and V2G capabilities, which enable electric vehicles to receive power from and send power back to the electric grid. This is achieved through bidirectional communication between the EV chargers and the master control center.

The use of a DAB topology also helps to manage the demand on the electric grid by distributing the load across multiple EV charging stations. This can prevent overloading of any one station and improve the overall efficiency and reliability of the charging process.

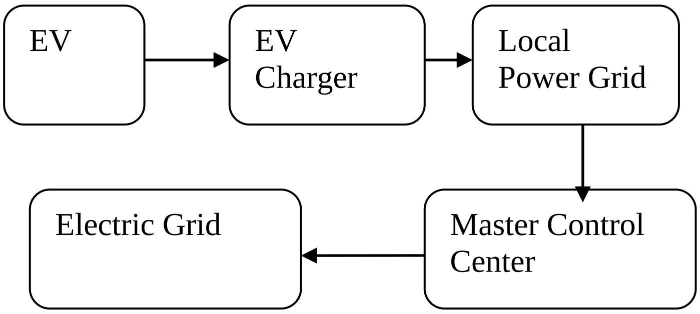

Figure 3 Block diagram of DAB

IV. RESULT

In this setup, the DAB converter was deployed in a V2G and G2V system, enabling bidirectional power flow, allowing the electric vehicle battery to either supply power to the grid or receive power from it. The experimentation employed a hardware-in-the-loop (HIL) simulator to mimic the behavior of the electric vehicle and the grid. The HIL simulator was interconnected with the DAB converter via a digital signal processor (DSP) and a real-time controller.

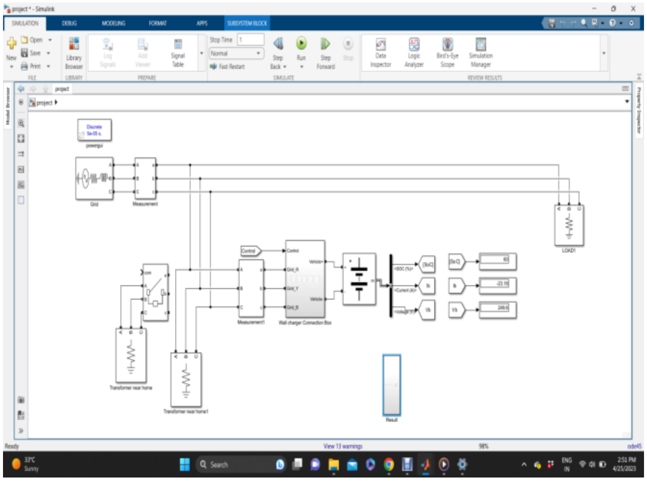

Figure 4 Proposed Model

The proposed model of the Dual Active Bridge (DAB) converter for Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) power conversion comprises several components meticulously designed to ensure efficient and dependable power conversion in both directions. As depicted in Figure 4, the model is divided into various sections:

The initial section is the grid architecture, which interfaces with another section containing the Wall charger or the DAB component of the proposed model before linking to the third section, the battery. The DAB model encompasses several key blocks:

The first block within the model is the DC link, which incorporates a bidirectional DC-DC converter responsible for delivering a stable DC voltage essential for the DAB converter's operation. Additionally, the DC link features a capacitor bank, serving to filter high-frequency noise and maintain a consistent power flow between the battery and the DAB converter.

The second block is the DAB converter itself, characterized by two sets of switches that respond to Pulse Width Modulation (PWM) signals. This DAB converter is engineered to facilitate bidirectional power flow, permitting the electric vehicle battery to either supply power to the grid or receive power from it. The DAB converter is further equipped with a transformer that ensures galvanic isolation between the DC link and the AC grid.

The third block, the control system, assumes responsibility for regulating power flow and preserving stable grid voltage and frequency. This control system employs a feedback loop that monitors the voltage and current within the DC link and the AC grid, adjusting the PWM signal as necessary to sustain the desired power flow.

The proposed model also includes a communication block that enables the DAB converter to communicate with the electric vehicle and the grid. The communication block uses a wireless network to exchange information about the state of the battery, the power demand, and the grid conditions. All block show on figure no 5.2

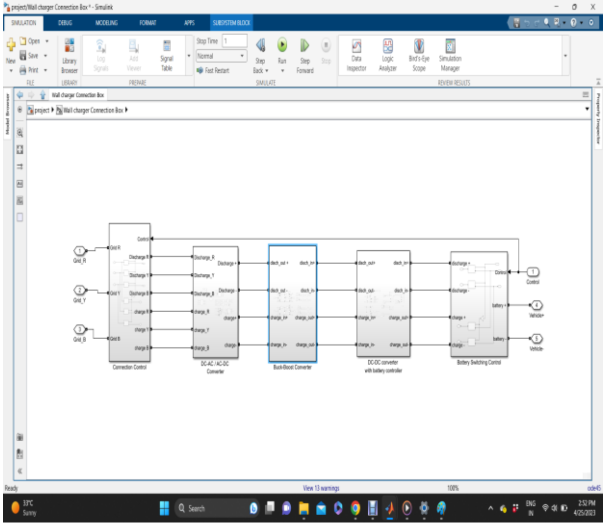

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Figure 5. DAB Control Operation and Control Block

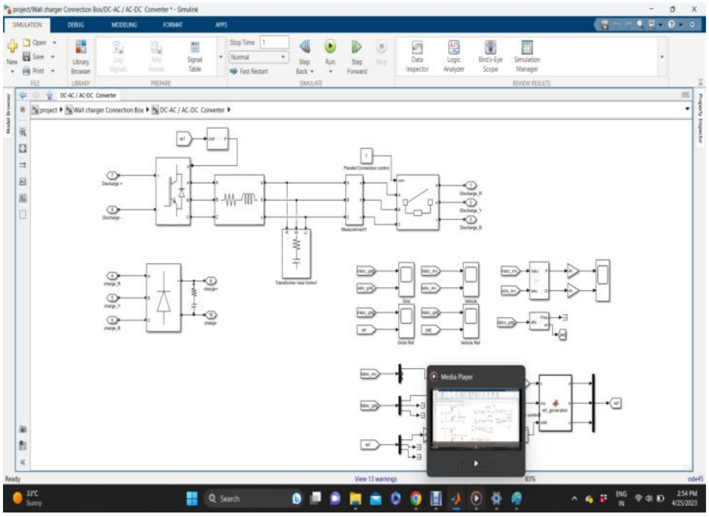

Figure 6 AC-DC,DC-AC Converter

AC-DC and DC-AC converters serve as foundational components within power electronic systems, facilitating the efficient and adaptable transformation of electrical power between DC and AC formats. These converters find extensive application and play a pivotal role in enabling the seamless integration of RES, EV, and grid-connected systems into modern power grids. Effective modeling and control of these converters are crucial for achieving the desired performance and efficiency, and ongoing research and development endeavors continue to propel progress in these domains. In Figure 5.3, we observe the proposed AC-DC and DC-AC converter, which comprises three primary blocks:

Universal Bridge: This component serves as the workhorse for power conversion.

RLC Circuit: It plays a pivotal role in managing voltage and current.

Transformer: Utilizing the DAB (Dual Active Bridge) method.

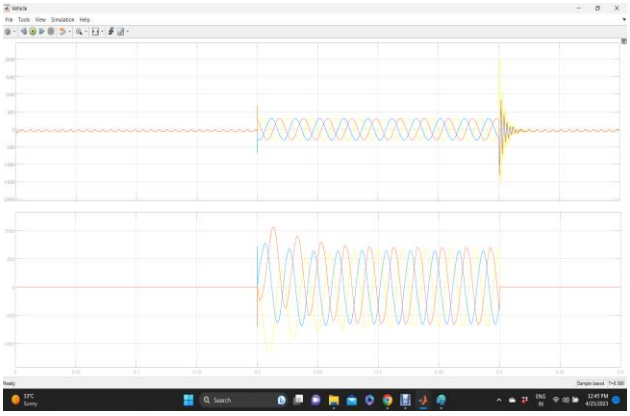

Figure 7 Vehicle Voltage

In Figure 7 vehicle voltage in Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) conversion refers to the voltage level of the electrical energy that is transferred between a vehicle and the power grid during the V2G or G2V operation.

Within the context of Vehicle-to-Grid (V2G), a vehicle equipped with an electric drivetrain, such as an electric vehicle (EV) or a plug-in hybrid electric vehicle (PHEV), possesses the capability to release electrical energy stored in its battery back into the grid when it is not in use for transportation purposes. This transformative capacity endows the vehicle with the role of a mobile energy storage system, enabling it to supply electricity to the grid during periods of heightened demand or to bolster grid stability. The term "resultant vehicle voltage" in the V2G conversion pertains to the voltage level of the electrical energy discharged from the vehicle's battery and returned to the grid.

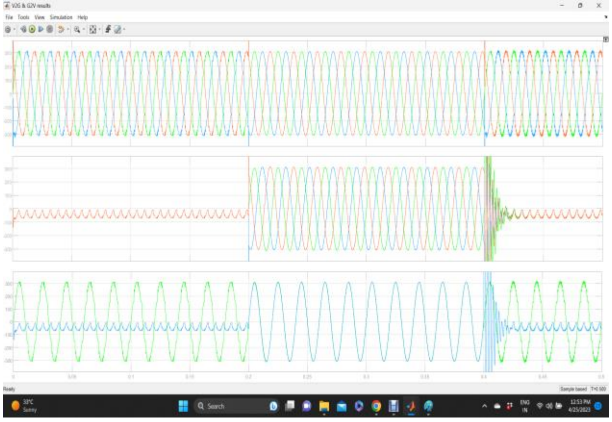

Figure 8 Grid ,Vehicle and Combine Voltage

Figure 8 show Grid, Vehicle voltage, and combine voltage during the DAB operation of the proposed model. In Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) conversion refers to the voltage level of the electrical energy that is transferred between a vehicle and the power grid during the V2G or G2V operation.

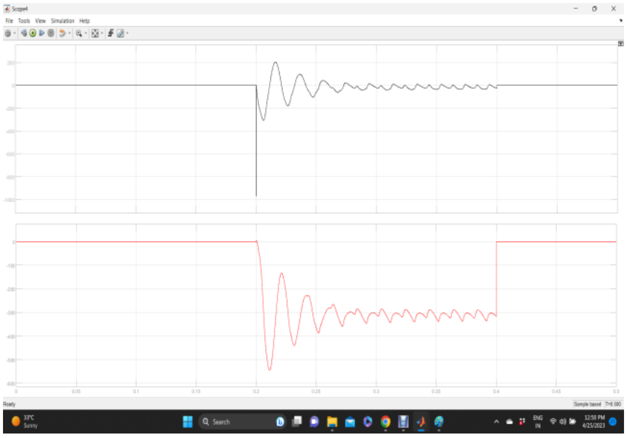

Figure 9 PQ Active and Reactive Power

Figure 9 show the active power (P) and reactive power (Q) components of the electrical energy being converted. n AC-DC conversion, such as in rectifiers or power supplies, the P-Q control refers to the management of both the active power (P) and reactive power (Q) components of the input AC power to achieve the desired output DC voltage and current.
in power network.

V. CONCLUSION

The Dual Active Bridge (DAB) converter has recently emerged as a highly promising solution for applications in Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) power conversion. This converter presents several key advantages, including remarkable efficiency, the capability for bidirectional power flow, and its flexibility in regulating voltage and frequency. These attributes render it exceptionally suitable for both V2G and G2V operations.

A comprehensive review of the existing literature and a detailed analysis of the AC-DC and DC-AC conversion equations relevant to V2G and G2V operations using the DAB converter underscore its effectiveness. It becomes apparent that this converter proficiently transforms AC power from the grid into DC power for V2G applications and performs the reverse operation for G2V scenarios. These equations elucidate the intricate relationship between AC and DC voltages, frequency, inductance, and phase angle. These parameters can be skillfully managed through Pulse-Width Modulation (PWM) techniques to achieve the desired power conversion. Additionally, a Proportional-Integral-Derivative (PID) controller is employed for precise control of the bidirectional operation.

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