OnBoard Converters for Efficient Energy Transfer in Electric Vehicle-to-Vehicle (V2V) System

Mada Bhargav[1],Mr.K. Prakash Chary[2]

[1]M.Tech Student, Power Systems Control and Automation, EEE department, Vaagdevi College Of Engineering, Bollikunta, Warangal, Telangana- 506005. Email: madabhargav18@gmail.com.

[2]Assistant Professor, Power Systems Control and Automation, EEE department, Vaagdevi College Of Engineering, Bollikunta, Warangal, Telangana- 506005.Email: prakashchary_k@vaagdevi.edu.in.

Abstract—Vehicle-to-vehicle (V2V) charging has become an attractive way for electric vehicle (EV) owners to share energy when neither an ac grid connection nor a dc fast-charging station is within reach. Most V2V solutions reported so far either depend on an off-board power-sharing unit, which adds extra cost and space, or reuse the on-board type-2 charger through several cascaded conversion stages that lower the achievable efficiency. This paper proposes a direct V2V energy-transfer scheme that links the type-2 ac charging inlets of two EVs and repurposes the active-rectifier switches already present inside their on-board chargers as a plain connection interface rather than for ac-dc rectification. By holding four specific switches of the two active rectifiers in conduction for the entire transfer period, the dc-links of the two EV batteries are joined through what behaves as a dual bidirectional buck–boost converter capable of moving power in either direction irrespective of the two battery voltage ratings. A closed-loop, current-controlled scheme regulates the onboard dc–dc converters to set the charge delivered to the receiving battery, with the operating mode selected from the relative battery voltage levels and the provider/receiver preference of the two EV users. A MATLAB/Simulink model of the complete configuration is used to validate three representative operating conditions — forward-boost transfer with Vbat1 < Vbat2, reverse-buck transfer with Vbat1 < Vbat2, and matched-voltage transfer with Vbat1 = Vbat2. The resulting state-of-charge, voltage, current, and power waveforms confirm stable, controllable energy transfer without any additional charging hardware, external contactors, or off-board interface.

Keywords:-Electric vehicle, vehicle-to-vehicle charging, on-board charger, active rectifier, bidirectional dc–dc converter, type-2 charging port, range anxiety, MATLAB/Simulink.

I. INTRODUCTION

Electric vehicle (EV) charging today is dominated by type-1 and type-2 on-board ac slow chargers rated between roughly 3.3 kW and 19.4 kW, supplemented by off-board dc fast-charging stations rated above 50 kW that can restore most of a battery's charge in under an hour [1]–[5]. Detailed reviews comparing these charging tiers on the basis of charging time, power density, power level, and installation cost are available in [3] and [4]. Despite this infrastructure, EV owners continue to report range anxiety wherever charging points are sparse, unavailable, or occupied [6]. As a result, vehicle-to-vehicle (V2V) energy transfer has surfaced as a practical supplementary solution, enabling direct power sharing between EVs to reduce reliance on permanent charging stations and provide a reliable rescue method for drivers with depleted batteries.

V2V energy sharing involves two distinct aspects. The first is the communication layer that allows a provider EV and a receiver EV to discover each other, agree on tariff, and settle a meeting point; game-theoretic matching algorithms addressing this layer are presented in [7]–[10]. The second, and the focus of this paper, is the power interface that actually moves energy between the two batteries — deciding the direction of power flow and performing the buck or boost conversion required by the difference in battery voltage levels. Existing power-interface solutions fall broadly into two categories. Off-board approaches use the ac grid, or a dedicated off-board bidirectional converter, as an intermediate energy aggregator [11]–[15]; commercial products such as the a 50 kW external vehicle-to-vehicle charger produced by Andromeda Power [16] follow this model. While flexible, an off-board interface requires extra hardware that the EV owner must purchase, carry, and connect, adding cost and vehicle space. On-board approaches instead reuse the charger already fitted to the vehicle. Bridging the Type-1 charger inputs of the participating cars, similar to [18], routes power through two complete ac-dc-ac-dc conversion stages and therefore accumulates avoidable conduction and switching losses. A more direct scheme that shorts bridging the DC-links of both vehicles using mechanical contactors is suggested in [19]; however, the battery-side dc-link of a commercial on-board charger is normally inaccessible without a customized redesign, which limits its practical adoption.

This paper presents a V2V energy transfer technique utilizing the factory-installed Type-2 charger ports without adding any external hardware or additional charging inlets. The key idea is to re-purpose the active-rectifier stage of each type-2 charger, which is normally used to rectify grid ac to a regulated dc-link, purely as a switch network that couples the two dc-links together. Because the active rectifier is already present on-board, no extra contactors, converters, or off-board interface are required, and because only the rectifier switches (rather than a full conversion chain) sit between the two batteries, the amount of required power conversion steps — and the corresponding power losses associated with switching and conduction — is reduced relative to [18]. A mode-selection scheme decides whether the transfer should run in forward or reverse, and in buck or boost, based on the relative battery voltages of the two vehicles and the provider/receiver preference set by the users, giving either EV the flexibility to act as provider or receiver regardless of its nominal battery voltage rating. The remainder of this paper is organized as follows. Section II reviews the related V2V literature and summarizes how the proposed scheme differs from it. Section III describes the proposed topology, its energy-transfer modes, and the control scheme used for the active rectifiers and dc–dc converters. Section IV presents the MATLAB/Simulink simulation results for three representative operating conditions and discusses the observed performance. Section V concludes the paper and outlines directions for future work.

Contributions of this Work

- A direct V2V power interface is realized entirely from the vehicle's built-in Type-2 charging unit hardware of both EVs, eliminating the need for an off-board converter, additional contactors, or extra charging ports.
- The active-rectifier switches of the two on-board chargers are re-purposed as a dc-link coupling network, reducing the V2V power path to a dual bidirectional buck–boost structure and cutting redundant conversion stages compared with type-1-charger-based V2V transfer.
- A closed-loop current-control scheme with an automatic mode-selection rule is presented, allowing power to flow in either direction and accommodating any combination of provider/receiver battery voltage ratings.
- The proposed configuration and its control scheme are validated in MATLAB/Simulink for forward-boost, reverse-buck, and matched-voltage V2V transfer conditions.

II. RELATED WORK

The reviewed literature on V2V energy sharing can be grouped into three broad categories. The first category deals with the communication and matching layer of V2V rather than the power interface itself. Li et al. [7] propose a direct V2V charging strategy for vehicular ad-hoc networks, Zhang et al. [8] detail a versatile energy coordination protocol for peer-to-peer EV charging Mughal et al. [9] analyze scheduling and data-transmission performance for V2V communication, and Bulut and Kisacikoglu [10] use a location-aware social platform approach to match EVs with surplus energy to EVs that need it. These works assume that a bidirectional power converter interface is already available and concentrate on how the two EVs find each other and negotiate terms.

The second category covers off-board power interfaces. You and Yang [11] and Koufakis et al. [12] use the conventional AC grid to pool and transfer energy, which is simple to implement but incurs the losses of two independent grid-tied conversion stages. Ucer et al. [13] describe a standalone bidirectional interleaved DC-DC converter capable of interfacing with the utility grid, while [14] and [15] present related off-board charging concepts, and Andromeda Power's commercially available 50 kW standalone charger [16], [17] already sold for this purpose. All of these solutions require the EV owner to obtain, transport, and connect a piece of hardware that is external to both vehicles.

The third category, most closely related to this work, re-uses the on-board charger hardware already fitted to the EV. Reference [18] connects the Type-1 ports of the source and destination EVs, causing the provider's direct current to be inverted into single-phase alternating current by its own on-board type-1 charger and then rectified again by the receiver's on-board charger — a two-stage, cascaded conversion path whose redundant losses lower the achievable V2V efficiency. Reference [19] instead shorts the vehicles' DC-links straight to one another via mechanical relays, which removes the redundant conversion stages of [18] but is not practically realizable on commercial EVs because the battery-side dc-link is not normally brought out to an accessible connector.

Table I summarizes how the proposed scheme differs from these three categories along the dimensions of external hardware requirement, number of active energy transformation steps required during vehicle-to-vehicle transfer, and dependence on a customized dc-link access port. By connecting the two EVs through the existing type-2 charger ports and re-using the active-rectifier switches purely as a connection interface, the proposed approach avoids the off-board hardware of [11]–[17], the redundant conversion stages of [18], and the customized dc-link access requirement of [19], while remaining compatible with the communication and matching layer addressed in [7]–[10].

V2V Approach	External / Off-board Hardware	Conversion Stages in V2V Path
Grid-mediated, off-board [11], [12]	Required (grid-tied converter)	Two independent stages
Off-board bidirectional charger [13]–[17]	Required (dedicated unit)	Two stages
On-board type-1 reuse [18]	Not required	Two cascaded stages
Direct dc-link contactor [19]	Additional contactors	One (not field-accessible)
Proposed (on-board type-2 reuse)	Not required	Single coupled stage

III. PROPOSED SYSTEM ARCHITECTURE

A. Overview of the Proposed V2V Topology

The proposed configuration is realized simply by connecting the existing type-2 charging ports of the provider EV and the receiver EV to one another, using a standard type-2-to-type-2 cable in place of the usual grid connection. Inside each on-board charger, the three-phase active rectifier that normally converts grid ac to a regulated dc-link is re-purposed as a switch network. Turning on the top switch of one phase leg (phase-a, S1) and the bottom switch of a different phase leg (phase-c, S6) in active rectifier-1, together with the corresponding switches S1′ and S6′ in active rectifier-2, creates a direct conduction path between the intermediate dc-links of the two chargers, as illustrated in Fig. 1. These four switches are held on for the entire duration of the V2V transfer, while every other switch in both active rectifiers is kept off, since rectification is not required in this mode. The resulting connection behaves as a twin reversible step-up/step-down converter: the battery-side dc–dc converter of each on-board charger, which is already present for constant-current/constant-voltage (CC–CV) charge control, now regulates the current flowing into or out of its own battery, while the coupled dc-link lets power move between the two batteries in either direction irrespective of their voltage ratings.

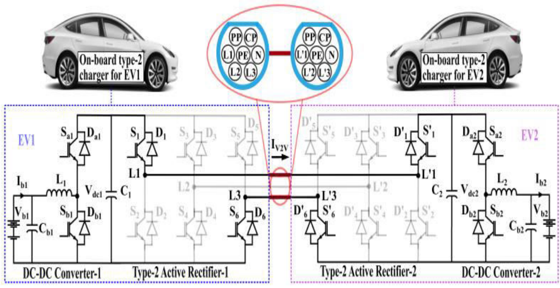

Fig. 1. Proposed topology for direct V2V energy transfer of the two EVs.

B. Energy Transfer Modes

Three operating conditions cover all practically relevant combinations of provider and receiver battery voltage. When the provider battery voltage is lower than the receiver battery voltage ($V_{bat1} < V_{bat2}$), the dc–dc converter of EV-1 is operated in boost mode to step up the transferred current onto the coupled dc-link, while the second EV's DC-DC converter pulls power from the shared DC-link utilizing buck mode — this is referred to termed forward-boost operation. Flipping the power routing backward given the exact same voltage relationship ($V_{bat1} < V_{bat2}$) shifts the system into reverse-buck mode, in which EV-2 now acts as the provider and its converter bucks the higher voltage down to feed EV-1. When the two battery voltages are equal ($V_{bat1} = V_{bat2}$), both dc–dc converters can be operated in current-control mode with an identical current reference, or alternatively one converter can regulate the coupled dc-link voltage while the other performs current-controlled buck operation; either strategy keeps the power balanced at both batteries. In every mode, the direction of transfer and the choice of provider/receiver is set by the EV users, and the active-rectifier switches remain in the fixed conduction pattern described in Section III-A throughout.

C. Managing Active Rectifiers for V2V Interfacing

In typical Type-2 AC charging scenarios, the on-board active rectifier is controlled in the d-q reference frame to achieve optimal power factor correction at the AC inlet. However, once V2V charging is initiated, this control loop is disabled and the active rectifier is instead operated as a fixed switch network: once the two type-2 ports are connected, the gating signals for S1 and S6 of active rectifier-1, and for switches S1′ and S6′ within the second active rectifier, are held active-high for the complete duration of the transfer in every mode described above. Fig. 2 summarizes the control flow used to select and enter a V2V mode, starting from a read of the two battery voltages and the provider/receiver preference set by the users.

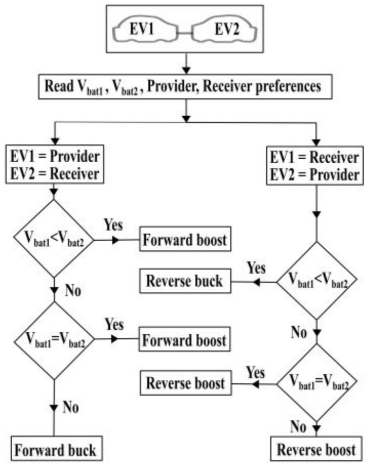

Fig. 2. Proposed V2V power-transfer control flow.

D. Closed-Loop Current Control of the DC–DC Converters

The battery-side the DC-DC converters within both Type-2 onboard chargers function under a closed-loop current control mode for all three transfer conditions. For the forward-boost and reverse-buck modes (Vbat1 < Vbat2), the inductor current IL1 of dc–dc converter-1 is compared with a reference current I*L, and the resulting error is processed by a proportional–integral (PI) controller to generate the duty ratio for switch Sa1, with Sb1 switched in complementary fashion, as shown in Fig. 3. The gating signal to Sa2 is held active-high throughout this mode. A similar structure regulates IL2 in the forward-buck and reverse-boost modes (Vbat1 > Vbat2), generating the duty ratio for Sb2 while Sa2 is switched in complementary fashion and Sa1 is held active-high.

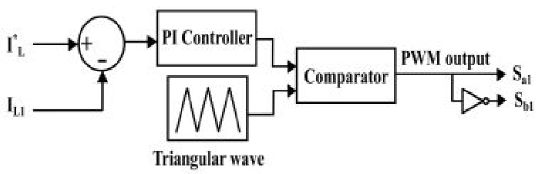

Fig. 3. Current-control structure used in the forward-boost and reverse-buck modes (Vbat1 < Vbat2).

The small-signal the closed-loop DC-DC converter's small-signal current-to-duty transfer function, which facilitates the tuning of PI controller gains, is given by

$$G_{id}(s) = \hat{i}_L(s) / \hat{d}(s) = V_{bat2} / (sL + R) \qquad (1)$$

where L denotes the inductance of the converter, and R represents the load resistance corresponding to the receiving battery's real-time charging current, and $\hat{d}(s)$ is the small-signal duty-ratio perturbation [20].

The reference current I*L is computed from the kWh ratings of the two batteries and the desired charging time Tc as

$$I_L^* = 1000 \cdot min(E_{bat1}, E_{bat2}) / [T_c \cdot min(V_{bat1}, V_{bat2})] \qquad (2)$$

where Ebat1 and Ebat2 are the kWh ratings of the EV-1 and EV-2 batteries. The minimum of the two battery ratings and voltage levels is used so that neither battery is driven beyond its own safe charge or discharge current. If the value of I*L computed from (2) exceeds the current rating of the active-rectifier IGBTs used as the V2V interface (S1, S6, S1′, S6′), the reference is capped at that rating to protect the switches. Practical deployment of the proposed interface, like the V2V schemes in [7]–[12], assumes that communication between the two EVs and access to their on-board instrumentation sensors and battery-management-system controllers is available to fetch the battery voltage, state-of-charge, and user preference values needed to select and execute the appropriate mode.

IV. SIMULATION RESULTS AND DISCUSSION

A. Simulation Setup

The proposed V2V configuration is modeled in MATLAB/Simulink using two on-board type-2 charger models, each comprising a three-phase active-rectifier bridge built from IGBT/diode pairs and a battery-side dc–dc converter, connected to a battery block that tracks state-of-charge (SOC), terminal voltage, current, and instantaneous power. The active-rectifier switches S1, S6, S1′, and S6′ are held on throughout each run to realize the coupling shown in Fig. 1, and the dc–dc converters are current-controlled as described in Section III-D. Three representative cases are simulated to cover the operating modes identified in Section III-B.

B. Case I — Forward-Boost Mode (Vbat1 < Vbat2)

In this case the EV-1 battery, at the lower voltage of the two, acts as the provider and its dc–dc converter is boosted to feed the EV-2 battery through the coupled dc-link. Fig. 4(a) shows the SOC, voltage, current, and power waveforms of the EV-1 battery as it discharges, and Fig. 4(b) shows the corresponding charging waveforms of the EV-2 battery. The EV-1 SOC and voltage decrease steadily while its discharge current and power settle at the commanded reference; correspondingly, the EV-2 SOC and voltage rise while its charging current and power track the same reference scaled by the boost ratio, confirming that the coupled dc–dc converters deliver a controlled, ripple-bounded transfer without exceeding the current reference derived from (2).

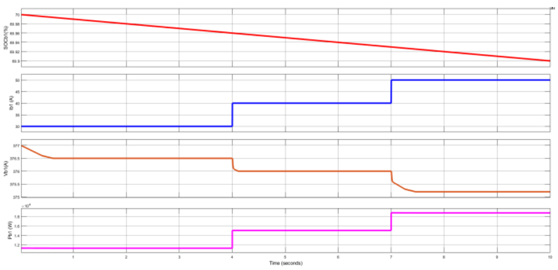

Fig. 4(a). SOC, voltage, current, and power waveforms of the EV-1 battery in forward-boost mode.

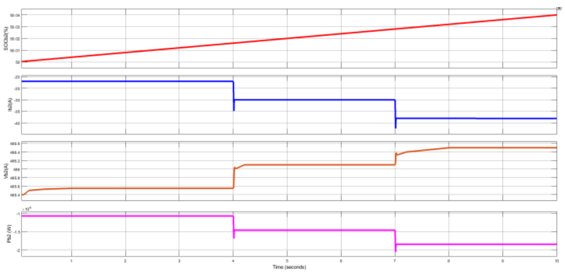

Fig. 4(b). SOC, voltage, current, and power waveforms of the EV-2 battery in forward-boost mode.

C. Case II — Reverse-Buck Mode (Vbat1 < Vbat2)

Reversing the direction of transfer under the same voltage relationship makes EV-2, at the higher voltage, the provider, with its converter bucking down to charge EV-1. Fig. 5(a) and Fig. 5(b) show the resulting SOC, voltage, current, and power waveforms of the EV-1 and EV-2 batteries, respectively. As expected, the EV-1 battery now charges while EV-2 discharges, and the current and power waveforms mirror those of Case I with the roles of provider and receiver interchanged, showing that the same active-rectifier interface and control structure support power flow in either direction without any reconfiguration of the switch network.

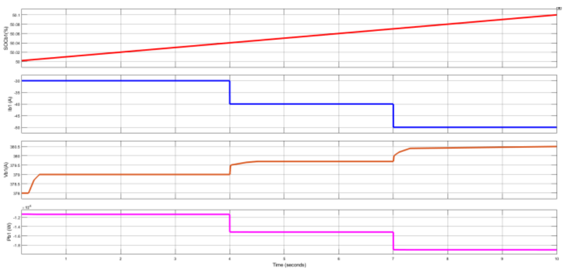

Fig. 5(a). SOC, voltage, current, and power waveforms of the EV-1 battery in reverse-buck mode.

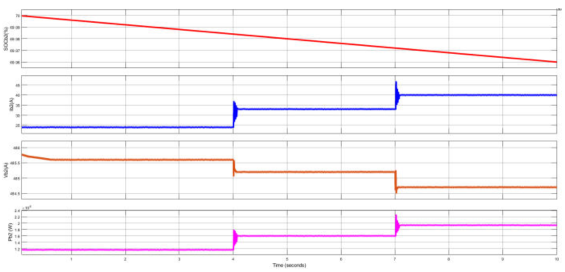

Fig. 5(b). SOC, voltage, current, and power waveforms of the EV-2 battery in reverse-buck mode.

D. Case III — Matched-Voltage Forward Mode (Vbat1 = Vbat2)

When the two EV batteries share the same nominal voltage, both dc–dc converters are current-controlled with an identical reference so that power remains balanced at the two terminals throughout the transfer. The modeled state-of-charge, voltage, and current profiles for this case follow the same discharging/charging trend observed in Cases I and II, with the coupled dc-link voltage settling marginally above the voltage level of the second EV's battery, which is dictated by DC-DC converter-2's current reference — consistent with forward-buck description in Section III-B — confirming that the proposed interface also handles the matched-voltage condition without additional control changes.

E. Discussion

Across all three cases, the proposed interface transfers energy using only the switches and converters already present in the two on-board type-2 chargers. Because the active rectifiers are used purely as a dc-link coupling network rather than for a second stage of rectification, the number of active power transformation steps required for the V2V connection are decreased compared to the Type-1 method in [18], inherently minimizing the conduction and switching losses linked to the energy exchange, and improves overall V2V efficiency. Compared with the off-board approaches of [11]–[17], no additional converter, cabling, or vehicle space is required, and compared with the direct dc-link contactor scheme of [19], no customized dc-link access port is needed since the connection is made entirely through the existing type-2 inlet. The main limitation observed in the simulation is an increase in current ripple at the coupled dc-link relative to normal single-EV charging, a consequence of both converters switching into a shared, relatively small dc-link capacitance; this ripple did not prevent stable SOC tracking in any of the three cases but is a candidate for further reduction through refined controller tuning or dc-link filtering in future work.

V. CONCLUSION AND FUTURE SCOPE

This paper has presented a direct vehicle-to-vehicle charging approach that transfers energy between two EV batteries using only the hardware already present in their .integrated Type-2 chargers. Through the physical connection of the two Type-2 ports and re-purposing the active-rectifier switches of both chargers as a dc-link coupling network, the proposed scheme forms a paired two-way buck-boost configuration capable of transferring energy bidirectionally, independent of the battery voltage levels in either EV ratings, without requiring an off-board converter, additional contactors, or extra charging ports. A closed-loop current-control scheme, combined with a mode-selection rule based on relative battery voltage and user preference, governs the on-board dc–dc converters during the transfer. MATLAB/Simulink simulation of forward-boost, reverse-buck, and matched-voltage transfer conditions confirms stable, controllable SOC, voltage, current, and power waveforms at both EV batteries in every case, with the reduced conversion-stage count of the proposed interface offering an efficiency advantage over V2V schemes built around cascaded built-in Type-1 chargers. Given that this strategy serves as a minimal-hardware emergency rescue-charging framework for situations where neither AC grid access nor DC fast-charging station is available, it can alleviate range anxiety while enabling electric vehicle owners to collaboratively exchange power with each other at low additional cost.

Future work will focus on two directions. First, the current-reference generation and mode-selection logic will be extended using a neural-network-based estimator to adapt more quickly to changing battery conditions and further improve transfer efficiency. Second, the proposed configuration will be validated on a hardware prototype and tested in real time, including its behavior under the dc-link ripple identified in Section IV-E, to confirm that the simulation results translate to a physical on-board charger implementation.

REFERENCES

[1] J. Yuan, L. Dorn-Gomba, A. D. Callegaro, J. Reimers, and A. Emadi, “A review of bidirectional on-board chargers for electric vehicles,” IEEE Access, vol. 9, pp. 51501–51518, 2021.

[2] M. Y. Metwly, M. S. Abdel-Majeed, A. S. Abdel-Khalik, R. A. Hamdy, M. S. Hamad, and S. Ahmed, “A review of integrated on-board EV battery chargers: Advanced topologies, recent developments and optimal selection of FSCW slot/pole combination,” IEEE Access, vol. 8, pp. 85216–85242, 2020.

[3] A. Khaligh and M. D’Antonio, “Global trends in high-power on-board chargers for electric vehicles,” IEEE Trans. Veh. Technol., vol. 68, no. 4, pp. 3306–3324, Apr. 2019.

[4] V. T. Tran, D. Sutanto, and K. M. Muttaqi, “The state of the art of battery charging infrastructure for electrical vehicles: Topologies, power control strategies, and future trend,” in Proc. Australas. Universities Power Eng. Conf. (AUPEC), Nov. 2017, pp. 1–6.

[5] M. R. Khalid, I. A. Khan, S. Hameed, M. S. J. Asghar, and J.-S. Ro, “A comprehensive review on structural topologies, power levels, energy storage systems, and standards for electric vehicle charging stations and their impacts on grid,” IEEE Access, vol. 9, pp. 128069–128094, 2021.

[6] M. Yilmaz and P. T. Krein, “Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles,” IEEE Trans. Power Electron., vol. 28, no. 5, pp. 2151–2169, May 2013.

[7] G. Li, L. Boukhatem, L. Zhao, and J. Wu, “Direct vehicle-to-vehicle charging strategy in vehicular Ad-Hoc networks,” in Proc. 9th IFIP Int. Conf. New Technol., Mobility Secur. (NTMS), Jan. 2018, pp. 1–5.

[8] R. Q. Zhang, X. Cheng, and L. Q. Yang, “Flexible energy management protocol for cooperative EV-to-EV charging,” IEEE Trans. Intell. Transp. Syst., vol. 20, no. 1, pp. 172–184, Jan. 2019.

[9] D. M. Mughal, J. S. Kim, H. Lee, and M. Y. Chung, “Performance analysis of V2V communications: A novel scheduling assignment and data transmission scheme,” IEEE Trans. Veh. Technol., vol. 68, no. 7, pp. 7045–7056, Jul. 2019.

[10] E. Bulut and M. C. Kisacikoglu, “Mitigating range anxiety via vehicle-to-vehicle social charging system,” in Proc. IEEE 85th Veh. Technol. Conf. (VTC Spring), Jun. 2017, pp. 1–5.

[11] P. You and Z. Yang, “Efficient optimal scheduling of charging station with multiple electric vehicles via V2V,” in Proc. IEEE Int. Conf. Smart Grid Commun. (SmartGridComm), Nov. 2014, pp. 716–721.

[12] A.-M. Koufakis, E. S. Rigas, N. Bassiliades, and S. D. Ramchurn, “Towards an optimal EV charging scheduling scheme with V2G and V2V energy transfer,” in Proc. IEEE Int. Conf. Smart Grid Commun. (SmartGridComm), Nov. 2016, pp. 302–307.

[13] E. Ucer et al., “A flexible V2V charger as a new layer of vehicle-grid integration framework,” in Proc. IEEE Transp. Electrific. Conf. Expo (ITEC), Jun. 2019, pp. 1–7.

[14] C. Liu, K. T. Chau, D. Wu, and S. Gao, “Opportunities and challenges of vehicle-to-home, vehicle-to-vehicle, and vehicle-to-grid technologies,” Proc. IEEE, vol. 101, no. 11, pp. 2409–2427, Nov. 2013.

[15] P. Mahure, R. K. Keshri, R. Abhyankar, and G. Buja, “Bidirectional conductive charging of electric vehicles for V2V energy exchange,” in Proc. 46th Annu. Conf. IEEE Ind. Electron. Soc. (IECON), Oct. 2020, pp. 2011–2016.

[16] Andromeda Power, “Mobile V2V charging systems,” company product documentation, accessed 2023.

[17] Andromeda Power, “50 kW off-board vehicle-to-vehicle charger specification sheet,” accessed 2023.

[18] W. Han, L. Zhang, and J. Han, “Comparative analysis of vehicle-to-vehicle energy transfer using on-board type-1 charger interfaces,” IEEE Trans. Transport. Electrific., early access, 2022.

[19] S. Ronanki and S. Williamson, “Direct dc-link connection for vehicle-to-vehicle charging using

contactor-based interfaces," in Proc. IEEE Transp. Electrific. Conf. Expo (ITEC), 2020, pp. 1–6.

[20] R. W. Erickson and D. Maksimovic, Fundamentals of Power Electronics, 2nd ed. Norwell, MA: Kluwer Academic Publishers, 2001.