On-Board Converters for Electric Vehicle-to-Vehicle Energy Transfer

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ABSTRACT

A modern method of energy sharing among electric cars (EVs) is electric vehicle-to-vehicle (V2V) charging. For EV users, current V2V methods with an off-board power-sharing interface incur extra space and expense. Moreover, redundant conversion steps make the on-board type-2 chargers used for Vechile2Vechile energy transfer described in the literature inefficient. Automatically connected the two electric vehicle batteries to share energy via switches and type-2 ac charger input ports, this paper suggests a novel approach to V2V power transmission. In order to prevent redundant power conversion and related losses, the active rectifiers of on-board type-2 chargers are not utilized for rectification during V2V charging; rather, a small number of switches serve as interfaces to link the two EV batteries together, so improving the total efficiency of V2V. Through MATLAB/Simulink simulation research, the potential V2V charging scenarios of the suggested V2V technique are verified. Additionally, a scaled experimental prototype is created in order to actually evaluate the suggested V2V approach.

INTRODUCTION

Type-1 and -2 (single/three-phase) ac on-board slow chargers with a power range of 3.3–19.4 kW is typically used to charge HE electric vehicles (EVs). For on-board chargers in commercial EVs, a thorough analysis of bidirectional topologies with single/two stage rectification and power factor correction is included. Type-1, -2, and dc fast-charging stations are compared in detail in and with regard to charging time, power density, power level, cost, and a review of recent typologies for traditional and future charging techniques. Additionally, regardless of the difference in the voltage ratings of the two EV batteries, high power (>50 kW) external off-board dc fast charging stations are designed to charge EV batteries in less than an hour. EVs, when neither the dc fast charging stations nor the ac grid are available. With the least amount of infrastructure and expense, V2V charging enables EV users to share energy cooperatively and lessen range anxiety. There are primarily two components to V2V energy sharing: the first is communication, which gives EV users a way to communicate with one another in order to identify a match for energy sharing, choose a provider and a recipient, and choose a tariff. Game theory-based techniques to match the nearest meeting place, the supplier EV, the receiver EV, and the communication components of the V2V are provided .The power interface for the actual power transfer, or regulating the power flow direction according to the preferences of the receiver and provider and a buck or boost conversion dependent on the voltage level of the EV battery, is the second crucial component of V2V. One of the fundamental V2V methods described in and involves using the ac power grid as a common energy aggregator with off-board bidirectional power converters to achieve an indirect V2V energy transfer, where the conversion efficiency is low because of numerous redundant conversion stages. presents an off-board V2V charger that uses an off-board bidirectional interleaved dc–dc converter and has the potential to be integrated into the grid.

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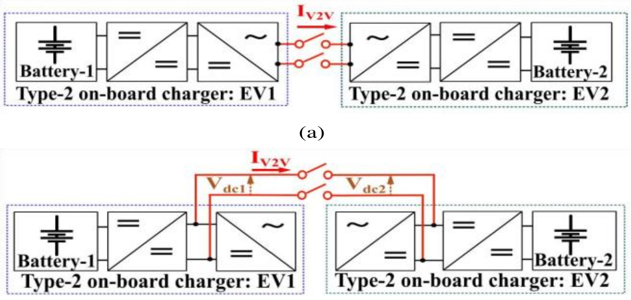


(a)

(b)

Fig. 1.V2V operations: (a) ac V2V operation and (b) dc V2V operation.

Conversely, V2V methods are introduced in by reusing the on-board type-1 and -2 chargers as power interfaces. The on-board type-1 and type-2 chargers essentially consist of a dc–dc converter [for constant current and constant voltage (CCCV) charge control] after an ac to dc converter (active rectifier) step. As seen in Fig. 1(a), a V2V charging method is described in by connecting the type-1 charger input ports of the two EVs, whereby the provider EV The bidirectional two-stage on-board type-1 ac charger is used to first convert the battery's dc output into single-phase ac. To charge the receiver EV battery, the two-stage onboard type-1 converter receives this ac power output from the provider EV. V2V charging efficiency is reduced in as a result of cascaded converter losses brought on by unnecessary conversion steps.

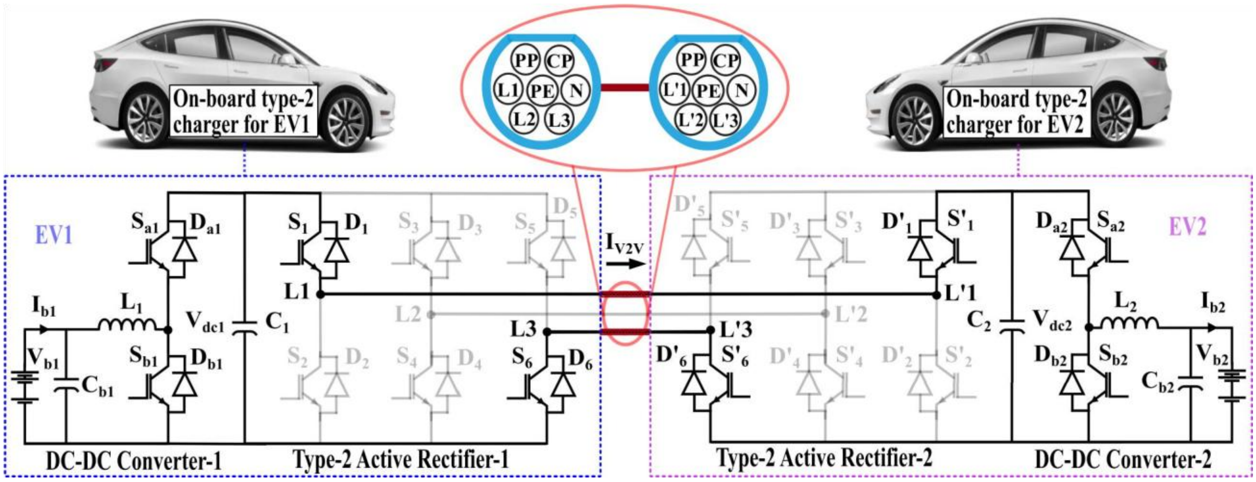
PROPOSED V2VAPPROACH

The receiver-EV and the provider-EV's current type-2 charging connectors are connected to create the suggested V2V setup. The three-phase active rectifier switches are used to connect the two EVs. The two EV batteries are directly connected through the intermediary dc-link of the provider and receiver EVs, as illustrated in Fig. 2, by turning on the top switch of one of the phases (phase-a, S1 here) and the bottom switch of the other phase (phase-c, S6 here) of the active rectifier-1 and the corresponding phase switches S1 and S6 of the active rectifier-2. During the V2V power transfer period, all four switches—S1, S6, S1, and S6— remain in the ON position.

A. V2V Scenario-1: $V_{bat1} < V_{bat2}$:

As detailed below, there are two conceivable situations of boost and buck functioning with power flowing in either the forward or backward direction, respectively, when the EV-1 battery voltage is lower than the EV-2 battery voltage and provider–receiver role.

1) Forward Boost Mode (EV1 as Provider and EV2 as Receiver): In this mode, battery-1 has a lower voltage than battery-2, and EV1 is the charge provider and EV2 is the charge receiver. The dc–dc converter-1 is used in boost mode to step up the EV-1 battery voltage to the EV-2 battery voltage after two EV batteries are directly connected using the suggested method (by turning on the switches S1, S6, S1, and S6). Inductor L1 holds energy from EV-1 while the switch Sb1 is turned on to use S1, S1, Sa2, and inductor L2 to transfer energy from EV-1 battery and inductor L1 to EV-2 battery. As illustrated in Fig. 3(b), switch Sa2 is kept on throughout this V2V mode in order to accept power from the dc-links, resulting in Vdc1 = Vdc2 = Vbat2, and switch Sb2



is complimentary switched to Sa2.

Fig 2: Proposed topology for V2V operation.

2)Reverse Buck Mode (EV1 as Receiver and EV2 as Provider):

Similar to the forward boost mode in this reverse buck mode, the EV batteries are connected by turning on the switches S_1, S_6, S_1 , and S_6 of the active rectifier-1 and 2. The dc–dc converter-1 is operated in buck mode to transfer power from EV-2 battery to EV-1

battery. The diode D_{a2} gets forward biased as Vbat1 < Vbat2 leading to Vbat2 = Vdc1 = Vdc2 and thus making EV-2 battery available for delivering power to EV-1 battery through the dc-link.

B. V2V Scenario-2: $V_{bat1} = V_{bat2}$

1) **Forward Boost Mode (EV1 as Provider and EV2 as Receiver):** power transfer from EV-1 to EV-2 battery is accomplished by running the dc-dc converter-1 in boost mode and the dc-dc converter-2 in buck mode with closed-loop current management. In this mode, Vbat1 = Vbat2. Inductor L1 stores energy from the EV-1 battery during the switch Sb1's turn-on period, and switch Sa1 is complimentary switched to Sb1. In order to freewheel the energy in inductor L2, the switch Sb2 of the dc–dc converter-2 is also turned on at the same time, and the switch Sa2 is complementary to Sb2.

2) **Reverse Boost Mode (EV1 as Receiver and EV2 as Provider**): Operating the dc-dc converter-2 in boost mode and the dc-dc converter-1 in buck mode with closed-loop current control reverses the power flow. This mode is comparable to the forward boost mode with Vbat1 = Vbat2. The power flow in this mode could also be managed using the voltage control mode.

C. Scenario 3 for V2V:

Vbat1>Vbat2 With the direction of power flow inverted, the converter functions similarly to Scenario 1. **1) Reverse Boost Mode (EV1 as Provider and EV2 as Receiver):** This mode is comparable to the forward boost mode with Vbat1 < Vbat2, but using EV-2's dc-dc converter-2 in boost mode and maintaining EV-1's dc-dc converter-1's Sa1 always ON reverses the power flow.

2) Forward Buck Mode (EV1 as Provider and EV2 as Receiver): This mode is comparable to the reverse buck mode with Vbat1 < Vbat2, but the power flow is inverted by running EV-2's dc-dc converter-2 in buck mode while maintaining Sa1 of EV1's dc-dc converter-1 constantly ON.

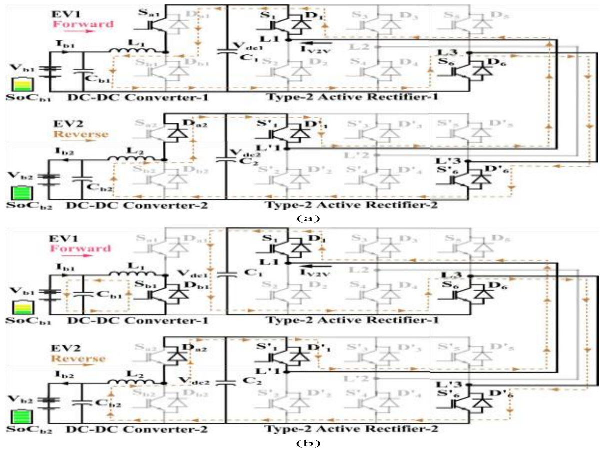
CONTROL SCHEME FOR THE PROPOSED V2V APPROACH A.

Active Rectifier Control via V2V Interface

In order to convert three-phase ac to DC with unity power factor operating at the grid terminals, the active rectifier is usually regulated in d-q control mode during standard three-phase ac charging with a type-2 charger. The active rectifier is repurposed as an interface to connect and access the two EVs' batteries during the suggested V2V charging. The gating pulse for the switches S1 and S6 of the active rectifier-1 of the EV-1 and the switches S1 and S6 of the active rectifier-2 are maintained high during the V2V charging for all modes once the type-2 charger ports are connected for V2V charging.

B. DC-DC Converter Control

The type-2 chargers' dc–dc converters are closed-loop current-controlled for the suggested V2V charging method that makes use of the onboard chargers. For management of the forward boost and backward buck modes (Vbat1 < Vbat2): In these modes, the forward or reverse inductor current (IL1) of the dc–dc converter-1 is regulated in With Vbat1 < Vbat2, forward boost V2V mode is used. (a) The EV-1 battery's energy is stored in L1. (b) Energy is sent to EV2 via the dc-link. closed-loop, where Sb1 is complimentarily switched to Sa1 by feeding a PI controller the error between the reference current (IL*) and the real inductor current (IL1) to generate the duty ratio for switch Sa1. During this mode, the gating signal to the switch Sa2 is maintained at a high level.



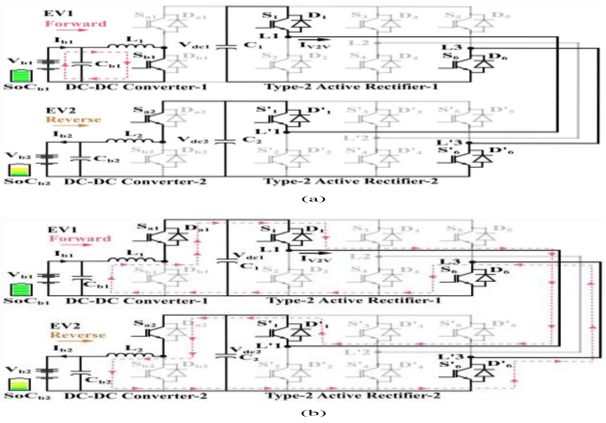


Fig. 3. Forward boost V2V mode with $V_{bat1} < V_{bat2}$.
(a) L1 stores energy from EV-1 battery.

(b) Energy is transferred through dc-link to EV2.

Fig. 4. Reverse buck V2V mode with $V_{bat1} < V_{bat2}$.
(a) L1 stores energy from EV-2 battery through dc-link.

(b) Energy is stored from L1 to EV-1 battery through freewheeling.

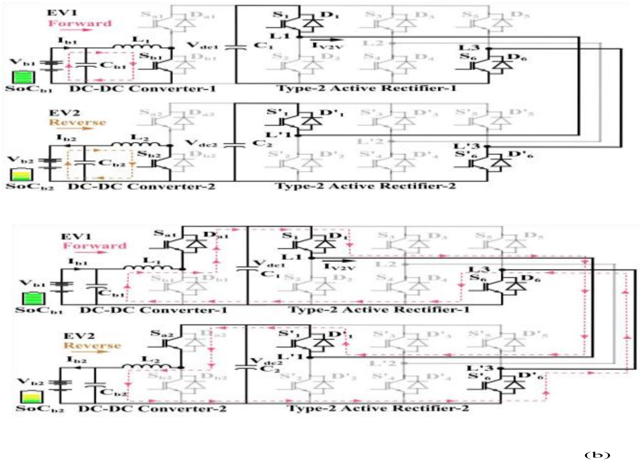


Fig. 5. Forward boost V2V mode with $V_{bat1} = V_{bat2}$.
(a) L_1 and L_2 store energy from the batteries.
(b) Energy is transferred through dc-link to EV2.

To keep power balance at the two EV batteries, IL∗ should be the same for both dc–dc converters. An alternate method of controlling this mode is to operate one of the dc-dc converters-1 in voltage-controlled boost mode and the other in current-controlled buck mode, which will regulate the dc link at a greater voltage. The proposed V2V solution is more realistically applicable among EV users due to the increased efficiency, lower losses, and convenience of connecting two EVs through the current on-board type-2 charger ports. Access to the provider and receiver EVs' onboard instrumentation sensors and BMS controllers is typically necessary for the effective execution of any V2V strategy in order to initiate communication between the two EVs and get the necessary

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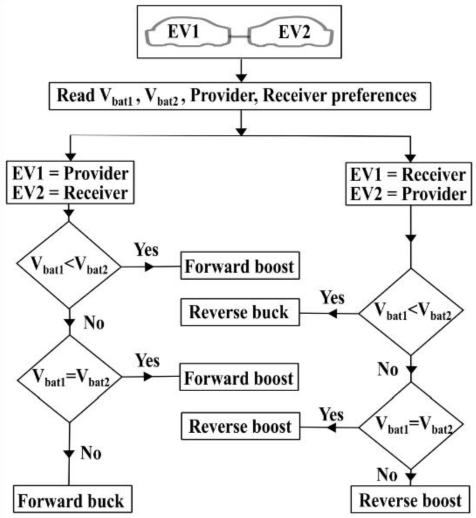

Fig. 6.Proposed V2V power transfer control flow.

SIMULATION PARAMETERS OF THE PROPOSED V2V APPROACH

Parameter	**Value**
Battery-1 capacity (E_{bat1})	40 kWh
Battery-2 capacity (E_{bat2})	100 kWh
Battery-1 nominal voltage (V_{bat1})	350 V
Battery-2 nominal voltage (V_{bat2})	450 V
Switching frequency (f_{sw})	20 kHz
Filter inductor (L_1)	0.5 mH
Filter inductor (L_2)	0.005 Ω
L_1 Internal resistance (R_1)	0.6 mH
L_2 Internal resistance (R_2)	0.005 Ω

DC-link capacitor (C_1)	1000 uF
DC-link capacitor (C_2)	1100 uF
DC-DC converter-1 capacitor (C_{b1})	5.6 nF
DC-DC converter-2 capacitor (C_{b2})	5.8 nF

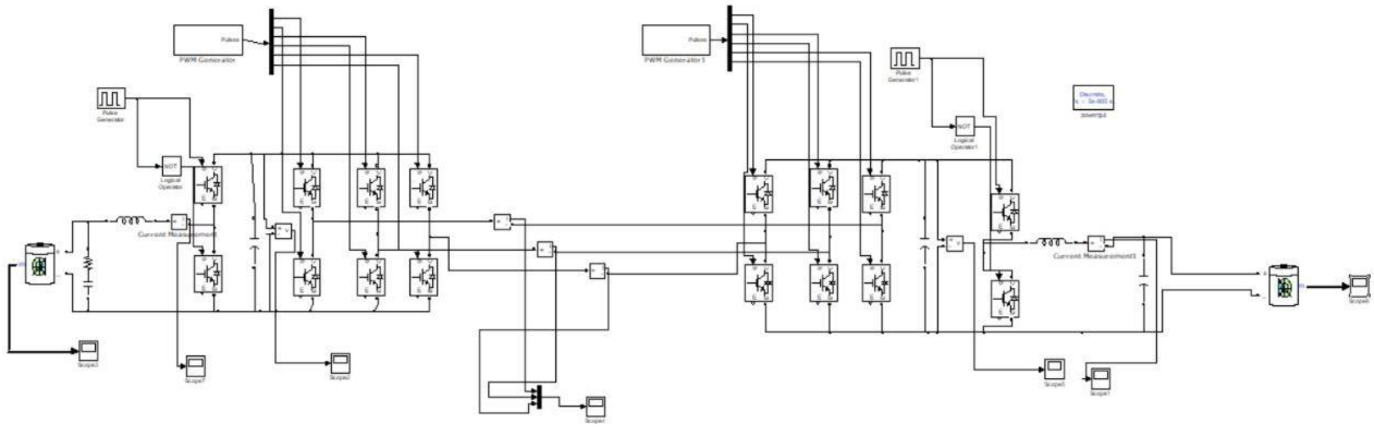

Fig.7. Simulation of Electric Vehicle-to-Vehicle Energy Transfer Using On-Board Converters

OUTPUT WAVEFORMS:

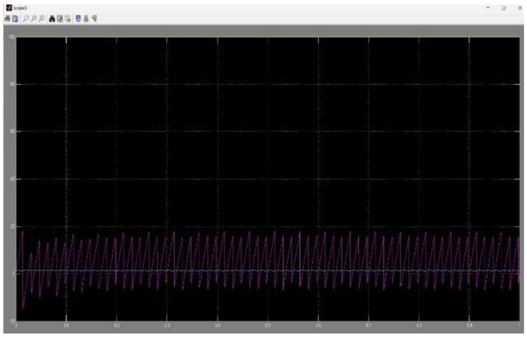

Fig. 7.Source voltage current and % of current

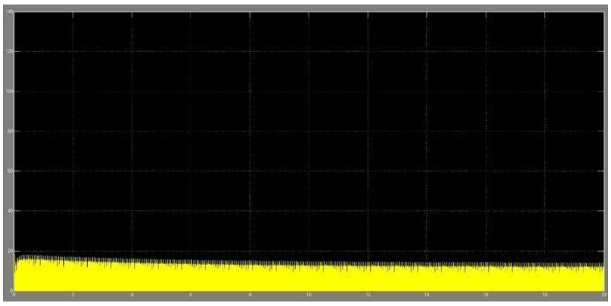

Fig. 8. current waveform at EV1

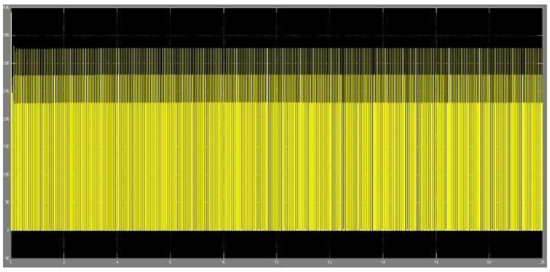

Fig. 9. Voltage waveform of EV1

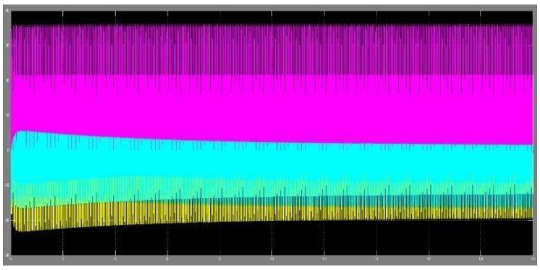

Fig. 10. Current Waveform of of EV2

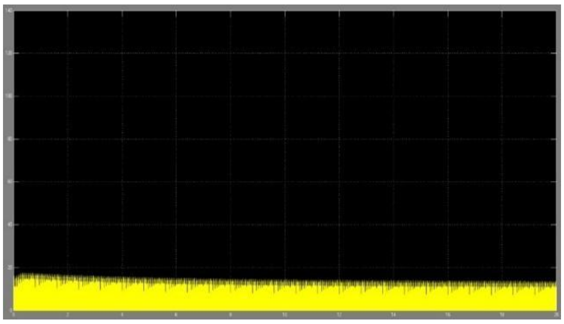

Fig. 11. Voltage waveform of EV2

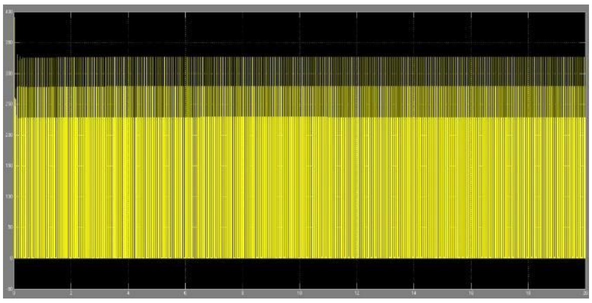

Fig. 12.output current waveform

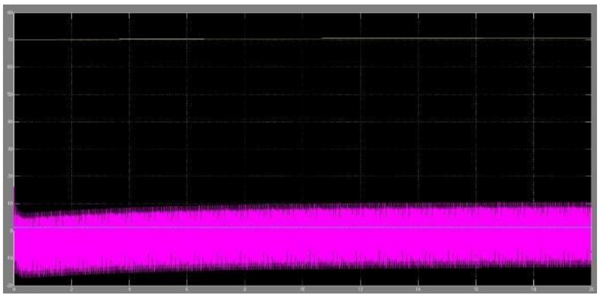

Fig.13. Output voltage, current and % of Charging

EXPERIMENTAL RESULTS

MATLAB/Simulink simulation studies for the forward boost and reverse buck modes using Vbat1 < Vbat2 and Vbat1 = Vbat2 confirm the suggested V2V strategy.

A. Mode of Forward Boost (Vbat1 < Vbat2) :

In this mode, the inductor current IL1 is controlled to transfer energy from the EV-1 battery to the EV-2 battery. To regulate the EV-1 battery discharge current Ib1, the reference inductor current IL* for the forward boost mode is first maintained at 30 A and then progressively raised in increments of 10 A to 50 A.

B. Mode Reverse Buck Mode ($V_{bat1} < V_{bat2}$):

This mode reverses the power flow while maintaining the same battery voltage levels for EV-1 and EV-2 as the forward boost mode. how the charging current Ib1 charges the receiver EV-1 battery and how the voltage and state of charge increase in tandem with the charging power level. the EV-2 battery Ib2's discharging current along with the matching SOC and voltage with the EV2 battery discharge power.

C. **Boost Mode Forward (Vbat1=Vbat2):**

The energy transfer between two EVs of the same model with identical voltage instances is represented by this mode. In the forward direction, the same current reference is used to control the currents IL1 and IL2. the charging current and the corresponding changes in EV-2 battery SOC and voltage with variations in the dc-link voltages. The dc-link voltage will be marginally greater than the EV-2 battery voltage, contingent on the dc–dc converter-2's current reference value.

D. Evaluation of Performance

This section includes loss calculations at various output power levels as well as the effectiveness of the suggested V2V technique Ohmic losses in filter inductors and the switching and conduction losses of the on-board charger's switches are examples of transfer operations.

THE ANALYSIS

This paper presents a new configuration and **analysis** to share **energy** between **electric vehicle to vehicle** (V2V). The proposed **converter** uses **on-board** equipment of the **electric vehicle** (EV) and an externally connected capacitor.

APPLICATIONS

- Battery-to-Battery Charging.
- Emergency Power Source.
- Shared Energy Networks.
- Ener-generative Braking Integration

CONCLUSION

In order to transfer electricity between two EVs without the use of extra charging ports or external hardware, the article suggests a direct V2V charging method. When ac grid and dc fast-charging outlets are unavailable, it serves as an emergency rescue charging alternative. There are major hardware infrastructure savings when two EV batteries are connected directly through the on-board charging connectors. The performance analysis shows that the suggested V2V solution was more efficient overall since redundant power conversion stages were omitted. With the least amount of infrastructure and expense, the suggested V2V method cooperatively exchanges energy between EV users and reduces range anxiety. Through MATLAB/Simulink simulation and experimental findings, the suggested V2V approach is verified for practical efficacy without altering the EV power architecture.

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