Electric Vehicle to Vehicle (V2V) Power Transfer with On-board Network and Capacitor-link

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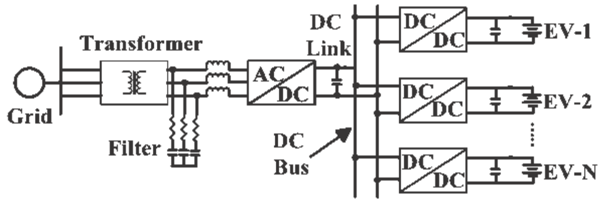
***Abstract*—This paper presents a new configuration and analysis to share energy between electric vehicle to vehicle (V2V). The proposed converter uses on-board equipment of the electric vehicle (EV) and an externally connected capacitor. This configuration is capable of transferring energy between EVs with either identical or non-identical battery ratings. Further, it uses only the DC-DC converter components of the on-board equipment. Thus, reduces the number of devices conduction during the V2V power transfer. The operation of the proposed arrangement is validated by using simulation studies and the results are presented for different battery charging conditions.**

***Keywords*—Vehicle to Vehicle, battery charging, electric vehicles.**

I. Introduction

Nowadays, every nation is considering electric vehicles (EVs) as one of the essential tools for sustainable transportation to achieve a carbon-neutral environment. The adoption of electric vehicles also brings about economic benefits such as creation of new job opportunities in manufacturing, research and development, decrease in oil imports and positively impacting a nation's trade balance. As the batteries are the only source of energy for a pure EV, it encounters a few challenges namely, low energy density, long battery charging time, inadequate charging infrastructure, battery cost and range anxiety. Recent times, research in battery technology progressing towards the development of batteries with low cost and high energy density. The EV battery gets charged either by using on-board or off-board grid to vehicle (G2V) chargers. The type of charger and number of EVs charging at a certain time influences the peak load of the power systems. The higher number of EVs charging at peak load hours of the power systems will affects the power quality and stability of the grid. To address these issues distribution companies increasing the distribution networks and also offering low tariff during off-peak hours. EVs with bi-directional chargers support the power grid by getting charged during off-peak load hours and transfer excessive energy from vehicle to grid (V2G) during peak load hours. However, EVs are suffering from range anxiety during the exploration of new places considering availability of charging infrastructure. To address this issue vehicle to vehicle (V2V) power transfer can be used during emergency situations. Further, V2V charging aids the extended range, grid support and peak load management, reduced infrastructure dependency and etc.

V2V charging topologies are classified as indirect V2V power transfer [1-2] and direct V2V [3-7] power transfer.



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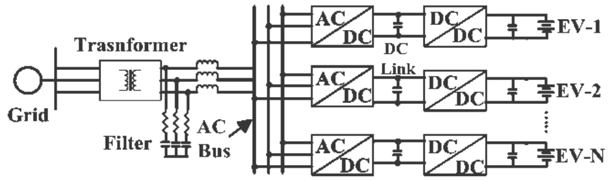

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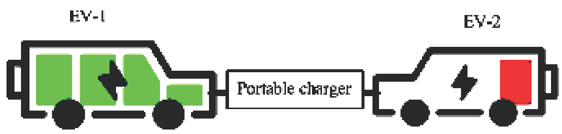
Fig. 1. Block diagram of indirect V2V power trasfer with (a) DC-grid [1] and (b) AC-grid [2].



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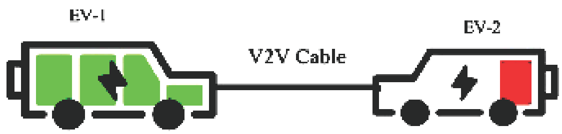

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Fig. 2. Block diagram of direct V2V power trasfer with (a) external charger [3-4] and (b) V2V cable [5-7].

The indirect V2V system is depicted in Fig. 1, which uses either a DC- or AC-grid as medium to transfer energy from one EV to another. In this system, the EV which requires energy gets charged from grid in G2V mode and the EV with excessive energy transfer the energy to the grid in V2G operation. Thus, provides independent operation of each EV either in charging or discharging operation and also helps in grid peak load management. However, the multiple power processing stages in V2V operation will reduce the overall efficiency.

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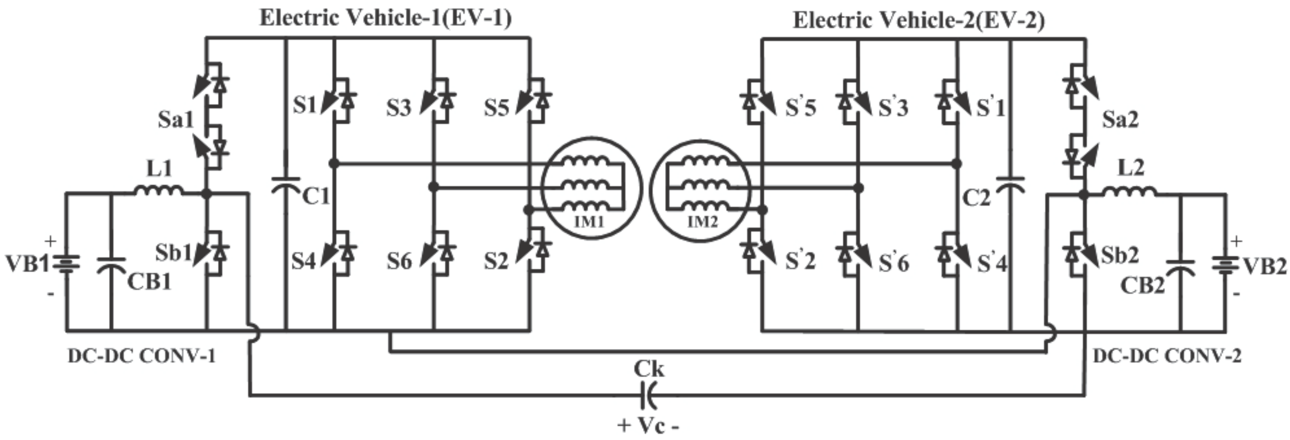


Fig. 3. Circuit diagram of the proposed V2V power trasfer.

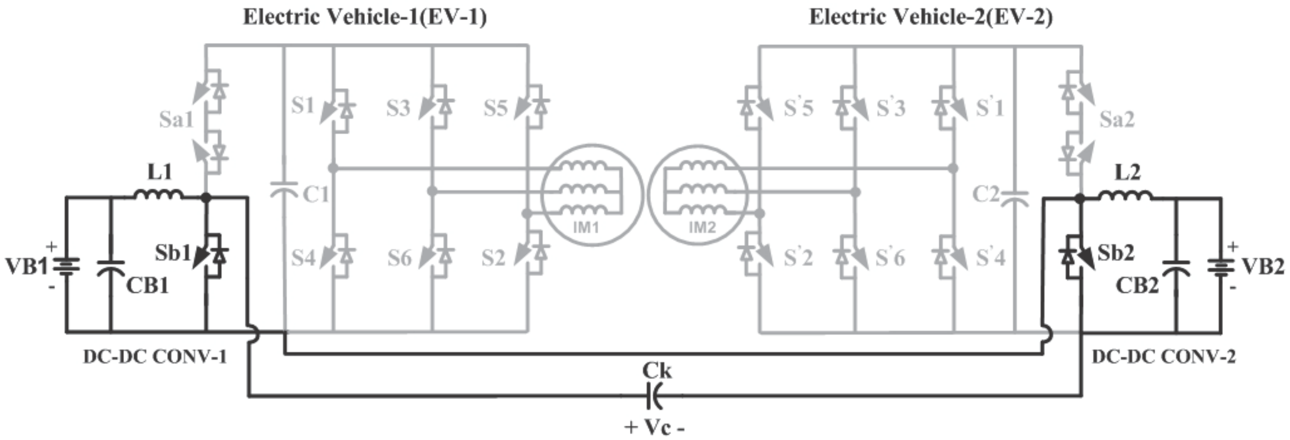


Fig. 4. Equivalent circuit diagram of the proposed configuration during V2V power transfer.

Whereas in the direct V2V system, the energy between the EVs will be shared either by using an external charger circuit or with a simple V2V cable as shown in Fig. 2. Dual active bridge (DAB) base external charger [3-4] is presented for direct V2V charging, which provides isolation between the EVs and higher efficiency due to soft switching operation. However, it [3-4] requires additional hardware and complex control. Three-phase direct V2V charger [5] by using on board switches and external inductors with interleaving operation is presented to provide less ripple current. Direct V2V charger [6] by using on-board switches and EV motor windings eliminates the need of external components. However, in case of over currents the expensive EV motors can be damaged which adversely affects EV in terms of repair cost and time. To avoid this issue direct V2V charger [7] with inter connection of inverter outputs of EVs is presented. However, these topologies utilize higher number of devices during V2V power transfer.

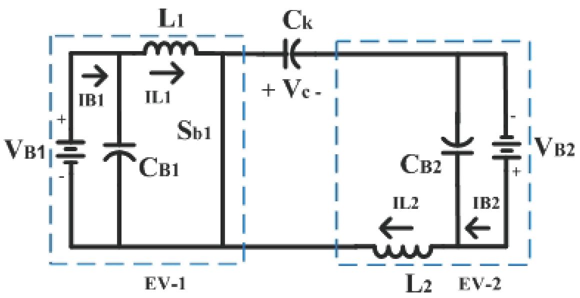
Hence, in this paper a direct V2V charging configuration is proposed by using on-board DC converter and external capacitor. It involves a smaller number of switching components and provides simple operation. The proposed V2V charging configuration is validated using simulation study and results.

II. Proposed Direct V2V Charger

Proposed direct V2V charging configuration is depicted in Fig. 3. It uses on-board battery voltage V_{B1}, inductor L_{B1} and switch S_{b1} of EV1, battery voltage V_{B2}, inductor L_{B2} and switch S_{b2} of EV2 and an external capacitor C_k for power transfer between EVs. Its equivalent circuit during V2V power transfer is presented in Fig. 4. The I_{B1} and I_{B2} are the battery currents of V_{B1} and V_{B2}. The I_{L1} and I_{L2} are the inductor currents of L_1 and L_2. The V_C is voltage of the capacitor C_k. The switches S_{b1} and S_{b2} operation is complimentary to each other.

When S_{b1} is turned ON for the DT_s period, the inductor L_1 gets charged and the C_k discharges to transfer the energy to V_{B2} as depicted in Fig. 5(a). Whereas the D is the duty cycle and T_s is the time period. The ripple currents of I_{L1} and I_{L2} are ΔI_{L1} and ΔI_{L2}, which are expressed as follows

$$\Delta I_{L1} = \frac{V_{B1} D T_s}{L_1} \tag{1}$$



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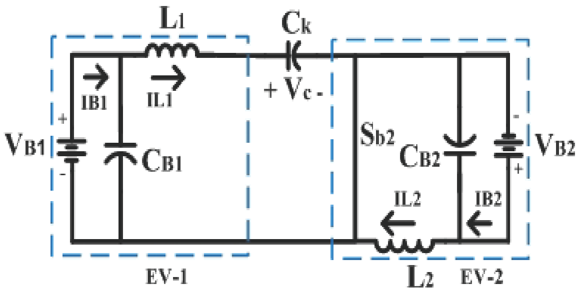

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Fig. 5. Equivalent circuits of the proposed configuration when (a) S_{b1} is ON and (b) S_{b2} is ON.

$$\Delta I_{L2} = \frac{(V_{B2} - V_C)DT_s}{L_2} \tag{2}$$

When S_{b2} is turned ON for the (1-D)T_s period, the inductor L_1 gets discharged and the C_k gets charged as depicted in Fig. 5(b). The ΔI_{L1} and ΔI_{L2}, which are as follows

$$\Delta I_{L1} = \frac{(V_{B1} - V_C)(1-D)T_s}{L_1} \tag{3}$$

$$\Delta I_{L2} = \frac{V_{B2}(1-D)T_s}{L_2} \tag{4}$$

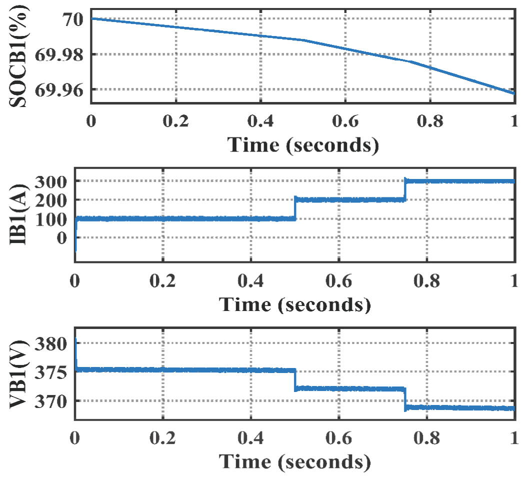
From (1) – (4), the relation between V_{B1} and V_{B2} are expressed as

$$\frac{V_{B2}}{V_{B1}} = \frac{D}{(1-D)} \tag{5}$$

III. Simulation Study

To verify the operation of proposed configuration, SIMULINK model is developed with L_1=500µF, L_2=600µF and C_k=1000µF. The switching frequency f_s is considered as 20kHz.

To verify the forward buck-boost operation, V_{B1} and V_{B2} are taken as 350V. In this mode the power will be transferred from EV1 to EV2. The state of charge (SOC), battery current and voltage at different charging rates of EV1 and EV2 are depicted in Fig. 6(a) and 6(b) respectively. In Fig. 6(a), from 0 to 0.5 seconds, battery-1 is discharging at a rate of 1C, i.e., 100A discharge current; from 0.5 to 0.75 seconds, it is discharging at a rate of 2C, i.e., 200A discharge current; and from 0.75 to 1 seconds, it is discharging at a rate of 3C, i.e., 300A discharge current. Similarly, in forward boost and reverse buck modes, operations are carried out at different charging rates.



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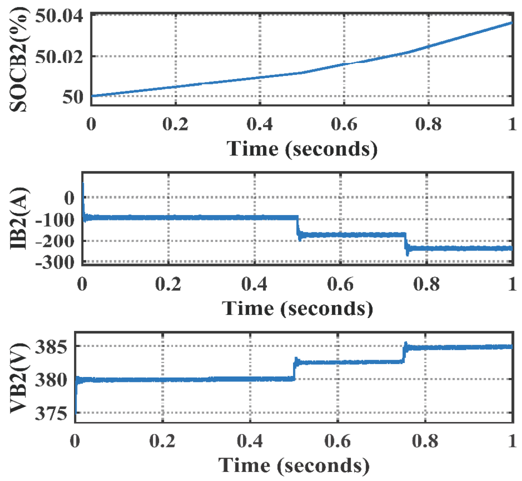

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Fig. 6. Simulation waveforms of battery SOC, current and voltage during forward buck-boost operation with VB1=VB2 of (a) EV1 and (b) EV2.

To verify the forward boost operation, V_{B1} and V_{B2} are taken as 350V and 450V respectively. In this mode the power will be transferred from EV1 to EV2. The SOC, battery current and voltage of EV1 and EV2 are depicted in Fig. 7(a) and 7(b) respectively.

To verify the reverse buck operation, V_{B1} and V_{B2} are taken as 350V and 450V respectively. In this mode the power will be transferred from EV2 to EV1. The SOC, battery current and voltage of EV1 and EV2 are depicted in Fig. 8(a) and 8(b) respectively.

From the Figs. 6-8, the power flow between EV1 and EV2 is verified for different charging currents under forward boost, forward buck-boost and reverse buck operation. With the closed loop control, the reference current value reached in all three modes of operation.

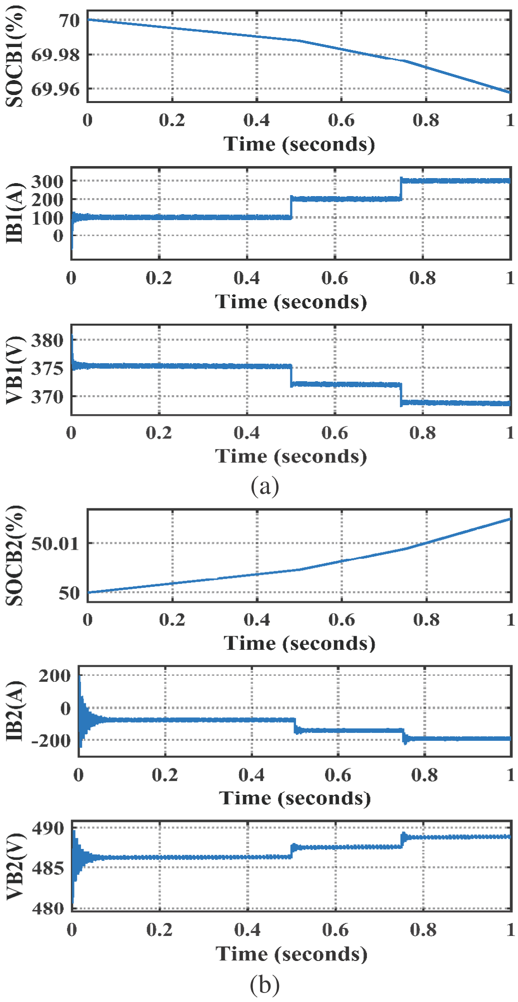

Fig. 7. Simulation waveforms of battery SOC, current and voltage during forward boost operation with VB1<VB2 of (a) EV1 and (b) EV2.

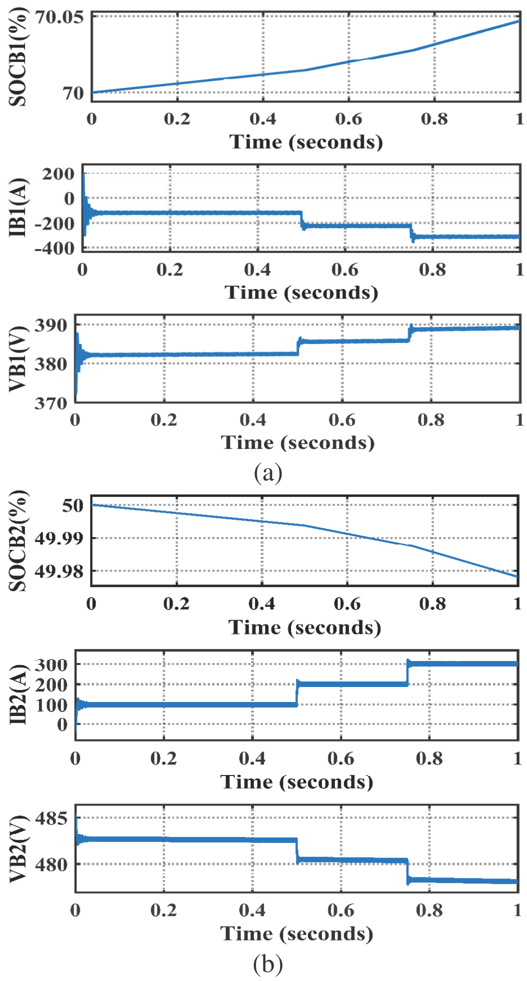

Fig. 8. Simulation waveforms of battery SOC, current and voltage during reverse buck operation with VB1<VB2 of (a) EV1 and (b) EV2.

Table I
Detailed Comparison Among The Suggested And Demonstrated V2V Strategies

Specifications	[6]	[7]	Proposed
Power conversion steps	2	2	1
Total Components quantity	22	12	5
Switches quantity	16	8	2
Inductors quantity	2	2	2

From Table I , since the suggested method uses a lower overall component quantity. As a result, this approach offers low losses and excellent efficiency.

IV. Conclusion

In this paper a new direct bi-directional V2V charger with on-board DC converter and external capacitor is presented. Its operation is verified with simulation study under forward boost, forward buck-boost and reverse buck condition. Also, its dynamic operation verified with different battery current conditions. The proposed configuration only used two switches for V2V charging operation compared to the other existing V2V configurations.

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