A Novel V2V Charging Method Addressing the Last Mile Connectivity

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Abstract: **One of the main drawbacks in adopting EV vehicles is the last mile connectivity issue. There is always a chance that the user/rider may get stranded without EV charge and no EV charging stations nearby. With the aim of solving such an exigency, this paper proposes a novel V2V charging technique which allows charge transfer between two EVs off the grid, and discusses its modes of operation. Non-isolated bidirectional DC-DC converters with average current control technique are simulated in a MATLAB/Simulink environment to verify and validate the efficiency and charging time for the proposed charging technique.**

Keywords: - V2V charging, Bi-directional converter, Pricing strategy.

I. INTRODUCTION

There has been a phenomenal growth in the adoption of Electric vehicles (EVs) in western countries and EVs are considered as an effective solution to curb carbon emissions and fight global warming. But the ever increasing use of EVs in turn increases the load on the grid network. **Vehicle-to-grid (V2G)** technology [1, 3 & 5] reduces the burden on the electric grid during peak loads and enables consumption of power during off peak hours. It also enables electric vehicles to feed excess power back to the power grid and to get paid in return for the energy transfer. Smart charging algorithms enable V2G charging stations to transfer energy in an efficient manner thus reducing energy loss and increasing vehicle Battery life.

Vehicle to Vehicle (V2V) technology provides additional support to the grid during peak hours through peak demand shifting. V2V technology supports demand shifting by enabling charge transfer between EV vehicles for emergencies, off the grid, thus reducing load on the grid during peak time. The V2V charging concept allows the Electric Vehicle owners to share their battery charge with other Electric Vehicle riders on price per KWh based pricing system [4]. Pricing slabs can also be derived based on the percentage of State of Charge at which the charge transfer is initiated.

In case of IC engine vehicles, if the vehicle halts due to lack of fuel, it can be refueled by getting fuel from the nearest fuel station or by carrying additional fuel in a container as a reserve. But if an electric vehicle stops due to lack of charge, it can be charged only at the nearest charging station. The proposed V2V charging technique can be used to charge an Electric Vehicle from another Electric Vehicle, when it is stranded far from the charging station. The main motive behind V2V charging concept is to meet the need for last mile connectivity to the charging stations. A pricing strategy can also be employed with different pricing slabs.

II. BLOCK DIAGRAM

Fig 1 depicts a block diagram of the proposed V2V charging technology which comprises of two vehicles fitted with bidirectional converters whose input sides are connected to respective batteries and outputs are connected with a cable. Each bidirectional converter is controlled by a controller in the each vehicle which takes inputs such as battery currents, converter output voltages, and initial SOC of the respective vehicle batteries, along with some user inputs which are mentioned in the flowchart, and generate pulses to respective switches in the corresponding bidirectional converters

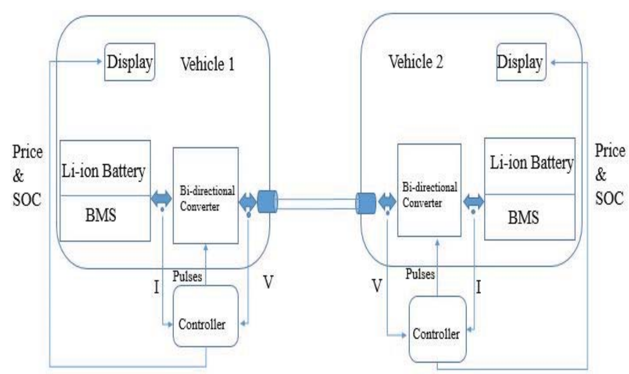

Figure 1: Block diagram of V2V technology

III. ALGORITHM

The V2V charging process begins by reading the initial SOC% of the corresponding EV. Before initiating charge transfers between EVs, it takes an input from the user/rider indicating whether it is in a state of charging or discharging. Another input provided is the desired SOC% while charging/discharging. The process then checks whether the difference between Initial SOC and the present

SOC (or vice-versa) matches the desired SOC% depending on whether the vehicle is charging or discharging. If they are equal, it blocks pulses to boost switch in case of discharging, or blocks buck switch in case of charging. If not, the controller will continue to provide pulses to the respective switches depending on the charging or discharging state. Once the pulses are blocked to the boost switch in the discharging process, energy transfer in the discharging process is read from the Battery Management System.

When a discharging process is initiated by the user, a pricing slab is chosen by the controller depending the initial SOC. Using the pricing slab value and the total energy transfer value, the price is calculated and is displayed on the vehicle's display unit. The algorithm is summarized as follows:

1) Read the initial SOC which is SOC(i)
2) Read the input from the user whether to CHARGE or DISCHARGE
3) If it is to "CHARGE"
   a) Read the desired SOC to be charged
   b) If the desired SOC = SOC(p)-SOC(i) then STOP pulses to the Buck switch, else continue to give pulses
4) If it is to "DISCHARGE"
   a) Read the desired SOC to be discharged
   b) If the desired SOC = SOC(i) – SOC(p) then STOP the pulses to the Boost switch, else continue to give pulses
   c) Select the pricing slab depending on the current SOC before discharging. Read the total energy transferred in the discharging process. Calculate the total price for the energy transfer on display on the Vehicle's display.

IV. BI-DIRECTIONAL DC-DC CONVERTER

Bidirectional DC-DC converters [2, 6, and 7] are widely deployed in the field of the energy storage systems for Electric Vehicles as they come in handy for regenerative braking during deceleration of an electric vehicle by converting the kinetic energy from the wheels back into electrical energy. Bi-directional DC-DC converters are also used in V2V technology for energy transfer between two electric vehicles.

Figure.2 shows the basic structure of the Non-Isolated Bidirectional DC-DC converter. Component design of the bi-directional converter parameters are carried out with equations (1) – (3).

Source side capacitor C_S,

$$C_s = \frac{I_{omax} * D}{f_s * \Delta V_o} \tag{1}$$

Load side capacitor C_1,

$$C_1 = \frac{V_o * (1-D)}{8 * \Delta V_o * f_s^{\,2}} \tag{2}$$

Magnetic field storage element L_{min},

$$L_{min} = \frac{V_s * D}{\Delta i_L * f_s} \tag{3}$$

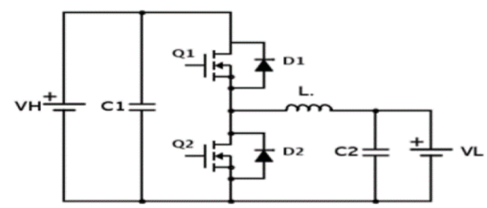

Figure 2: Non Isolated Bi-Directional Converter topology

V. MODES OF OPERATIONS

The circuit diagram of the V2V system (Fig.3) resembles two bidirectional converters connected back to back with batteries of the respective vehicles as their input.

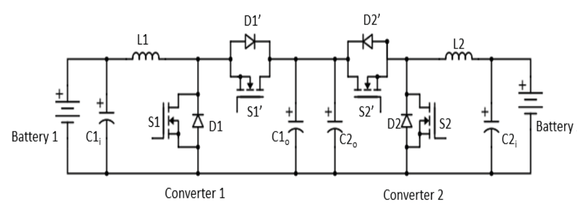

Figure 3: Circuit diagram of V2V technology with back to back non isolated converters connecting batteries

The modes of operation of the V2V circuit diagram shown in Fig.3 from the perspective of both the vehicles are explained below. In mode-1 and mode-2 Battery-1 is considered as discharging and Battery-2 is charging, and in Mode-1' and Mode-2' it is vice-versa.

MODE 1:

In mode-1, Switch S1 is given pulses and hence Inductor L1 and Capacitor $C1_i$ of converter-1 are charged from Battery-1. If the output capacitors of both the converters are considered as initially charged, or charged in the previous cycle, they will discharge in this mode as switch S2' is given pulses. These capacitors will charge the inductor L2 and Capacitor $C2_i$ of the converter-2 through the switch S2' as shown in Fig.4.

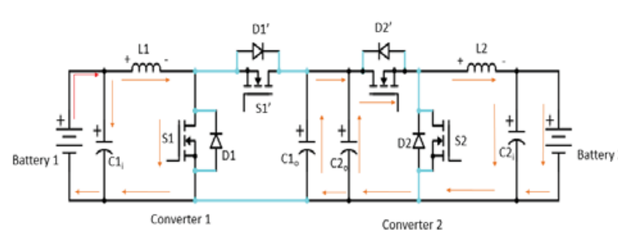

Figure 4: Mode 1 Operation

MODE 2: In this mode as shown in Fig.5 pulses are blocked to both the switches S1 and S2'. Now the energy stored in the form of magnetic field in the inductor L1 and in the form of electric field in the capacitor $C1_i$ is discharged into output capacitors of both the converters (i.e.) $C1_o$ and $C2_o$. The stored energy in the form of magnetic field in inductor L2 and in the form of electric field in capacitor $C2_i$ from the previous mode is discharged into the Battery-2.

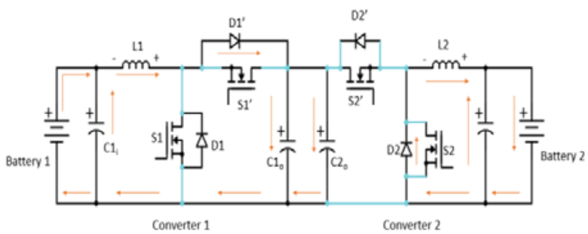

Figure 5: Mode 2 Operation

MODE 1':

In this mode Switch S2 is given pulses, therefore inductor L2 and Capacitor $C2_i$ of the converter-2 gets charged from Battery-2. If the output capacitors of both the converters are considered as initially charged or charged in the previous cycle, they will discharge in this mode as switch S1' is given pulses. These capacitors will charge inductor L1 and Capacitor $C1_i$ of converter-1 through switch S1' as detailed in Fig.6.

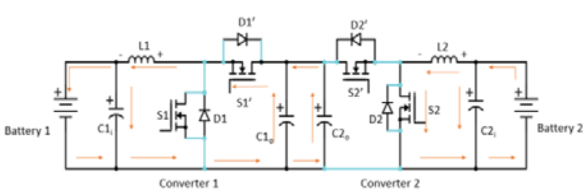

Figure 6: Mode 1' Operation

MODE 2':

In this mode shown in Fig.7, pulses are blocked to both the switches S2 and S1'. Now the energy stored in the form of magnetic field in the inductor L2 and in the form of electric field in the capacitor $C2_i$ is discharged into output capacitors $C1_o$ and $C2_o$ of both the converters. The stored energy in the magnetic field form in the inductor L1 and in the form of electric field form in the capacitor $C1_i$ from the previous mode is discharged into the Battery-1.

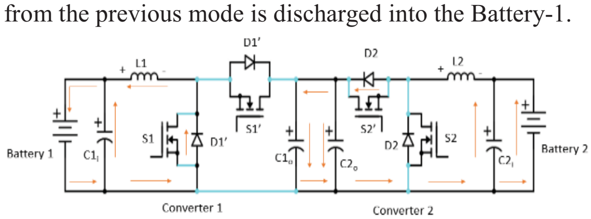

Figure 7: Mode 2' Operation

VI. BATTERY AND BIDIRECTIONAL CONVERTER SPECIFICATIONS

The battery and bidirectional converter specifications considered for the analysis are as listed in table. I.

TABLE. I. SIMULATION PARAMETERS

Parameters	Values
Energy	7.34 kWh
Nominal Voltage	48 V
Amp-hour	150 Ah
V_{bat}	V_{imin} = 47 V V_{imax}= 51 V
$V_{dc\text{-}bus}$	V_{omin} = 140 V V_{omax} = 150 V
Inductance	L_{min} = 30mH
DC-Bus side Capacitance Battery-side Capacitance	C_{min} =10 mF C_{min} =10 uF
Switching Frequency	F_s = 10kHz

VII. OPEN LOOP OBSERVATIONS

a. If duty ratio is greater than 50%, there occurs a shoot through condition which prevents the battery from charging as depicted in Fig.8.

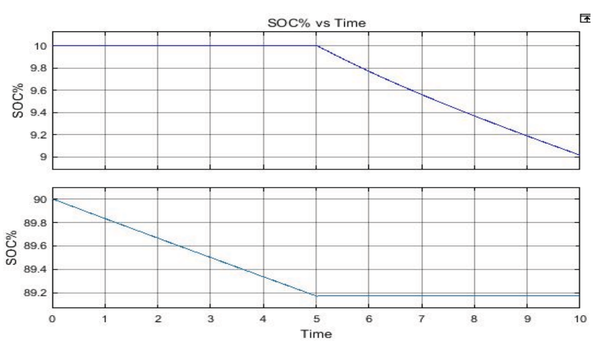

Figure 8: Plot between SOC% and Time

b. If SOC of one of the batteries is less than the other, it discharges less and charges more, and a high SOC battery charges less and discharges more for a given amount of time as represented in Fig.9.

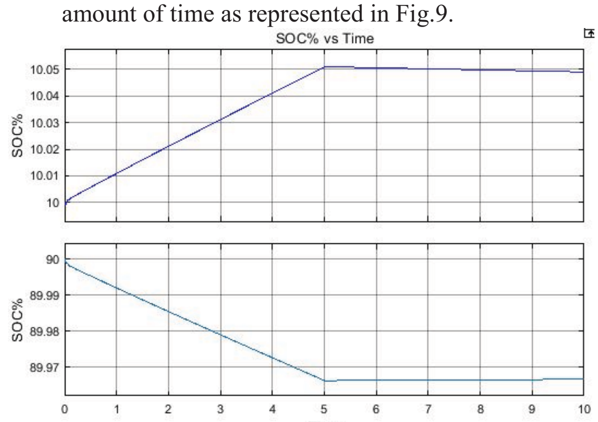

Figure 9: Plot between SOC% and Time

c. If a high SOC battery is charged with a low SOC battery, it results in low efficiency as listed in Table II.

TABLE. II. CONVERTER EFFICIENCY

Battery 1 (SOC%)	Battery 2 (SOC%)	Converter 1 (η%)	Converter 2 (η%)
90	10	56	60
20	10	53	63

d. If a low SOC battery is charged with high SOC battery, the resulting efficiency is very high Amp-hour doesn't have much effect on the efficiency or charging and discharging rates. From Table III it's clear that, SOC difference decides the level of efficiency of the power transfer. If SOC difference is very less, efficiency will also be low. The main drawback of open loop control is the charging time required and the converter efficiency.

TABLE. III. EFFICIENCY TABLE FOR DIFFERENT SOC DIFFERENCE

Battery 1 (SOC%) & (Ah)	Battery 2 (SOC%) & (Ah)	Converter 1 (η%)	Converter 2 (η%)
90%, 150Ah	10%, 150Ah	93.7	88.4
90%, 50Ah	10%, 150Ah	94	88.3
20%, 150Ah	10%, 150Ah	89.4	86.12
20% , 50Ah	10%, 150Ah	88.64	85.4

VIII. SYNCHRONIZATION OF SWITCHING PATTERN OF THE TWO CASCADED CONVERTERS

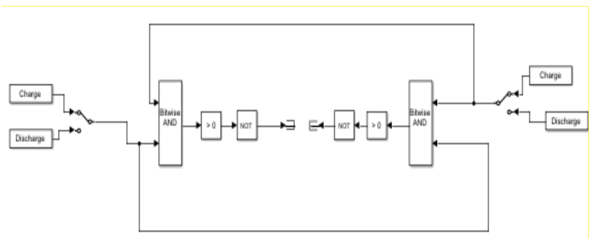

Figure 10: Logic for Synchronizing switching pattern

In the algorithm discussed above, there is an issue about synchronization of switching pattern. If there is a delay in selecting charge and discharge options, the delay is propagated throughout the V2V charging process which might result in misfiring of switches. To solve this problem, along with the charging cable, two wires parallel to cable are added to transmit the selected modes of one vehicle to other and providing pulses to the switches accordingly. Thereby, any delay in switching is accommodated and the pulses won't trigger the switches unless the other user selects the mode of V2V charging.

As shown in Figure 10, each selected mode information is transmitted to the other vehicle and the respective decimal Id's are bit wise AND- ed and compared with zero. If both the modes are the same, then it yields a '1' as output and its negation can be used to block pulses as the modes are supposed to be different. By using this logic, misfiring of switches is avoided.

IX. CLOSED LOOP SIMULATION

Average current control method is used for closed loop simulation. In closed loop simulation as shown in Fig.11, Battery-1 side Bi-directional DC-DC converter is switched as Buck converter and the Bi-directional DC-DC converter on the Battery-2 side is switched as Boost converter. Figure 12 and 13 presents the simulation output for the battery with high SOC charging and discharging conditions.

V2V charging technique implemented in closed loop control by opting for "Average Current Control" method resulted in an efficiency of **85%** with a charging time of **1 min 8 seconds** for **1%** increase in SOC%.

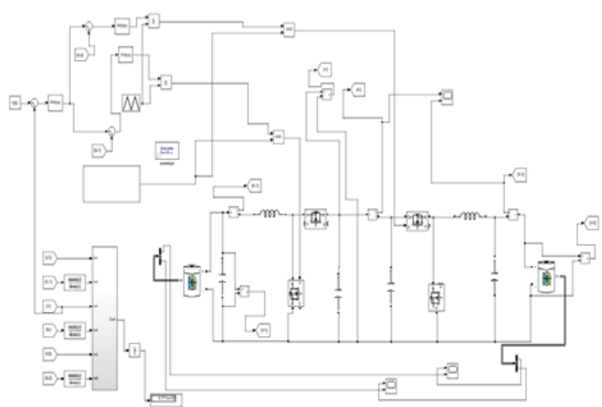

Figure 11: Closed loop simulation model for V2V charging

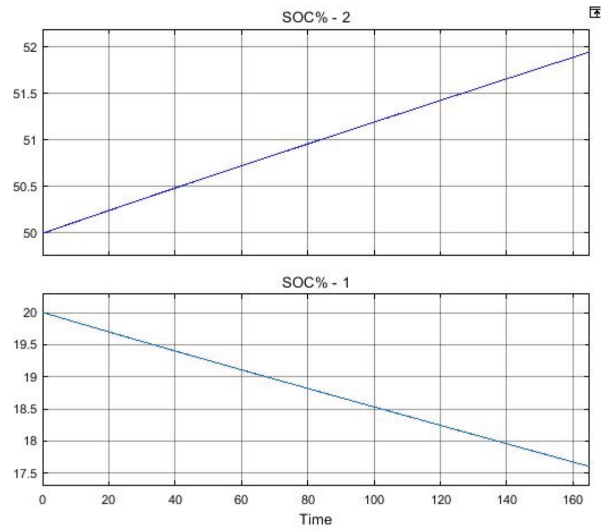

Figure 12: SOC% plots where higher SOC battery is charging and lower SOC battery is discharging

In the above figure higher SOC battery which is battery-2 is charging while the lower SOC battery which is battery - 1 is discharging which depicts the energy transfer from lower SOC battery to higher SOC battery.

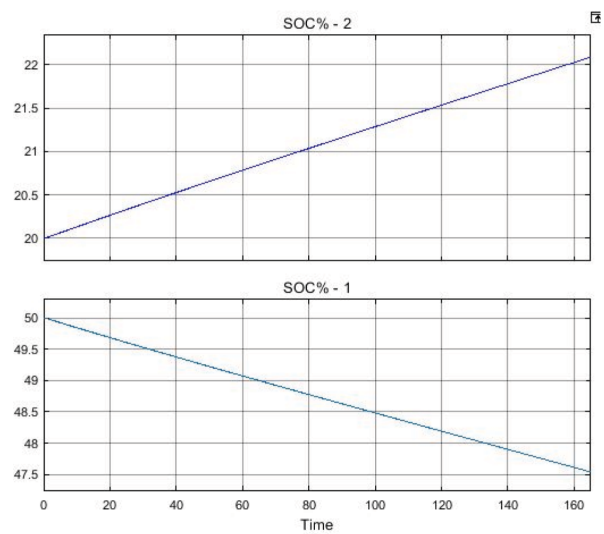

Figure 13: SOC% plots where higher SOC battery is discharging and lower SOC battery is charging

In the above figure higher SOC battery which is battery-1 is discharging while the lower SOC battery which is battery-2 is charging which depicts the energy transfer from higher SOC battery to lower SOC battery.

X. SCOPE

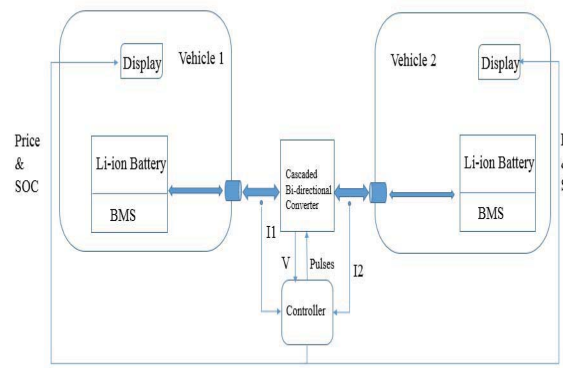

Figure 14: OFF-Board configuration

Implementation of OFF-board Configuration can make the EV more compact and reduce its overall weight as represented in Fig.14. The OFF-board configuration which uses a common Cascaded converter for both EVs is more compact, and the length of the cable carrying high current is also reduced, which in turn reduces the I^2R losses and thereby increasing the efficiency of the whole converter setup.

XI. CONCLUSION

A V2V charging scheme is proposed to synchronize the charging between two electric vehicles. This is particularly needed when an EV user is left stranded without battery charge and with no access to EV charging station. In this scenario, the proposed model allows another EV user to assist the stranded EV by charging from his EV thus solving last mile connectivity issues. The proposed model consists of a dual converter in the electric vehicle which enables fast DC charging or discharging. Extensive MATLAB simulation results on the model proves that the proposed work is capable of charging an EV from another under average current control method. The efficiency, SOC status and charging time for the proposed method is also analyzed. From the analysis it is evident that as the SOC difference increases the efficiency obtained also increases. To reduce the charging time and to enhance the efficiency average current control method is simulated and analyzed. The results obtained are presented and the results confirm the effectiveness of the proposed work.

V2V energy transfers which were reported in the earlier literature uses the concept of connected ad-hoc networks present in parking lots etc., where the vehicles parked in the parking lot are used for energy transfer through a connected bus in the parking lot itself. The term ‘novel’ has been used here as the issue of EV being left stranded without battery charge and with no access to charging station is not addressed anywhere in the literature and also the technique of using cascaded bi-directional converters for charging one vehicle from the other vehicle adds novelty to the V2V energy transfer. Cascaded Bi-directional converters can even facilitate the charge transfer when the electric vehicles battery voltage levels are different, that’s why cascaded converters has been employed.

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