

Designing and Implementing Artificial Neural Network-Based Controllers for Transferring Energy from Electric Vehicles to Electric Vehicles by using Onboard Chargers

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Abstract—The work discusses the ANN-based controller design and implementation of Electric Vehicle-to-Electric Vehicle (EV-to-EV) energy transferring through On-Board Chargers (OBCs). The aim is to enhance efficiency and reliability of electric vehicle-to-electric vehicle energy transfer. The work emphasizes the design and integration of ANN controllers to realize the maximum flow of power and the regulation of the transferring process in the optimal manner. Large-scale performance analysis is conducted for comparison of efficiency of implemented controllers to increase the overall efficiency and reliability of EV-to-VV energy transfer. The result of the work is an input to the electric vehicle technology design and optimization of the energy transfer mechanism for green transportation systems, as validated in a MATLAB/Simulink simulation study.

Index Terms: Electric vehicle (EV), On-board type2 AC charger, Vehicle-to-Vehicle (V2V) charging, ANN controllers, energy transfer optimization, power management.

I. INTRODUCTION

Typically, ac on-board slow chargers of type-1 and type-2 (single/three-phase) with a scale in Wattage from 3.3 kilowatt to 19.4 kilowatt are used to charge Electric Vehicles (EVs). “A comprehensive review of reversible designs with single/two stage correction with power factor adjustment is provided by [1], [2], and [3].” “Type 1, type 2, and dc quick-charging stations are contrasted in depth with charging duration, power density, power level, price, & an overview of latest types for conventional and future charging strategies in [4] and [5].” “Moreover, large powered (more than 50 kW) outside off-board dc quick recharging facilities can recharge EV battery packs in less than an hour [6].” Due to a lack of adequate charging infrastructure, EV consumers are still suffering from range anxiety despite these traditional EV charging techniques [7].

When dc quick-charging stations and the ac grid are unavailable, to transfer energy from vehicle-to-vehicle charging has emerged as a viable alternative for energy sharing between two EVs. Vehicle-to-vehicle charging reduces range anxiety and allows EV users to share energy cooperatively with the least amount of infrastructure and cost. The two main components of vehicle-to-vehicle energy sharing are the communication component, which gives EV users a platform to communicate with one another in order to discover a match for energy sharing, determine tariffs, and choose Sender and receiver preferences. “Game theory-based techniques to match the nearest meeting location, the supplier EV, the receiver EV, and the communication

components of the vehicle-to-vehicle are provided in [8], [9], [10], and [11].”

The power interface, the second essential part of vehicle-to-vehicle, executes a boost or buck conversion depending on the electric vehicle's battery voltage rating and controls the direction of power flow based on the preferences of the Sender and the receiver. However, due to the large number of redundant conversion stages, the conversion efficiency is low. An extra vehicle-to-vehicle interface is required for this off-board vehicle-to-vehicle technique, which could increase the cost and space requirements for EV customers.

“Vehicle-to-vehicle charging is demonstrated by directly connecting the two EV's dc-links using mechanical switches, as seen in Fig. 1(a), Fig. 1(b) [12].”

In actuality, the recommended direct connection cannot be making by directly accessing the battery-side dc-dc converters dc-link. “The vehicle-to-vehicle method outlined is not a feasible solution without additional charging ports and specific design modifications to bring out the two EVs' dc-link terminals in [12].”

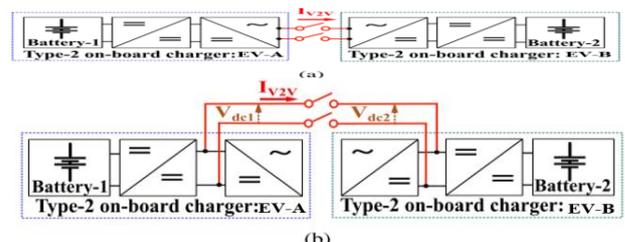


Fig 1: Vehicle to Vehicle operations:

- a. ac connection between vehicle-to-vehicle operation.
- b. dc connection between vehicle-to-vehicle operation.

For EV charging, this article suggests a direct connection between the onboard type-2 power input ports and vehicle to vehicle on-board type-2 chargers. More power inlet ports or external hardware are not requiring for this response to function. Because fewer active switches result in switching and conduction losses, efficiency is significantly increased by reducing transformation phases. According to the EV user's preference, the suggested vehicle to vehicle approach uses logic for selecting a state to determine the buck/boost functioning states according to the direction of power flow and battery voltage levels. Regardless of the difference in the two EV battery voltage ratings, control over power flow in either direction gives EV users more flexibility to act as either a Sender or a receiver. Instead of using, "additional contactor switches as in [12]", Considering associated losses, the recommended technique of using on-board active rectifier switches to connect the two EV battery packs improves the overall vehicle-to-vehicle efficiency along with using ANN controlling.

II. LITERATURE SURVEY

J. Yuan, et al. [2] conducted a survey of "Bidirectional on-board chargers (OBCs) with an emphasis on their use in EV energy management. Their contribution highlighted the advantages of power-dense compact structures, bidirectional power transfer, and grid integration. The paper provided insights into smart operating states, component efficiency, and industry standards, along with wide bandgap semiconductor technologies and wireless charging advancements[2]."

M. Y. Metwly, et al. [3] researched on "Integrated OBCs, where existing propulsion arrangements are used in charging, which reduces additional components and infrastructure cost. The study categorized OBCs as three-phase and single-phase, where focus was put on their compatibility with induction motors and permanent magnet motors. Research also identified FSCW topologies, whose efficiency during charging is increased by sacrificing induced magnet losses. Comparison analysis found most suitable slot/pole numbers to achieve optimal performance in propulsion as well as in charging state[3]."

Khaligh and M. D'Antonio [4] explored "High-power conductive OBCs, discussing trends in integrated and non-integrated topologies. They discussed unidirectional vs. bidirectional OBCs, including energy transfer efficiency, weight, and power density compromises. Their work also explored wireless charging systems, including the viability of integrating them with EV auxiliary power modules to provide charging solutions[4]."

V. T. Tran, et al. [5] characterized "EV battery (EVB) chargers depending on control methods and power ratings (Level 1, 2, and 3). Their work was particularly interested

in bidirectional Level 3 chargers for both grid-to-vehicle (G2V) and vehicle-to-grid (V2G) energy transfer to enable EVs as active participants in smart grid networks. Their findings suggested that bidirectional fast charging could be a potential enabler of grid stability and reducing the charging time of EVs[5]."

M. R. Khalid, et al. [6] addressed pertinent challenges in the "Deployment of EVs, which encompassed cost of vehicles, range anxiety, and inadequate charging stations. Electric vehicle supply equipment (EVSE), energy storage systems (ESS), and charger topologies that incorporated low- and high-frequency transformer-based chargers were what their paper highlighted. The Inductive Power Transfer (IPT) technology was also highlighted as among the available alternatives for evading range anxiety by enabling wireless transfer of power[6]."

M. Yilmaz and P. T. Krein [7] offered a thorough examination of "EV charging infrastructure, contrasting on-board vs. off-board chargers and their implications on charging speed, hardware complexity, and power constraints. Their work introduced roadbed charging concepts, which would enable constant charging of EVs on the move. The paper contrasted different charging configurations, evaluating them based on charging time, cost, location suitability, and compatibility with renewable energy sources[7]."

III. PROPOSED METHOD

The type-2 charging connectors of the supplier and receiver EVs are connected to setup the recommended vehicle-to-vehicle arrangement. The 3phase active rectifier switches are using to connect the two EVs the two battery packs for electric vehicles can be directly connecting through the connecting dc-link of the Sender and receiver EVs as in Fig. 2. All four switches - S1, S6, S1, and S6 remain in the ON position during the vehicle-to-vehicle power transfer period. Since the other switches on both type-2 charger active rectifiers are used as a gateway to connect two dc-links rather than for their original rectification function, they remain off during the vehicle-to-vehicle operation. According to the battery voltage of two EVs, the arrangement may operate in one of the several energy transfer states, as detailed below.

A. SYSTEM DESCRIPTION

The 3phase active rectifier switches are used in the suggested vehicle-to-vehicle setup to link the receiving EV's and supplier EV's current type-2 charging connections. The technology creates dc-links for both EV's active rectifiers by turning on the upper switch (S1) of phase-a and the lower switch (S6) of phase-c. Any variation in battery voltage levels, this configuration permits energy transmission in either way. Since the active rectifiers are repurposed for vehicle-to-vehicle transfer rather than rectification, all other switches remain OFF. The technology uses the battery voltages of both EVs to dynamically choose the best energy transfer state. Fig. 2 illustrates this configuration.

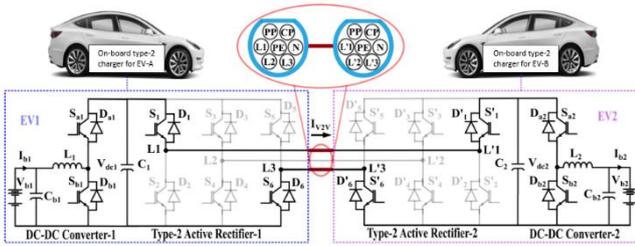


Fig 2:SDN Network Architecture

B. ARTIFICIAL NEURAL NETWORK (ANN)

A controller that employs an artificial neural network (ANN) to regulate a system or process is known as an ANN controller. Comprising interconnected artificial neurons with the ability to learn and adjust to changing circumstances, the ANN controller is a computational state intended to mimic the behavior of the human brain. Sensors that measure the temperature, pressure, and speed of the system under control provide input signals to the ANN controller. After processing these inputs, the ANN produces an output signal that is transmitting to an actuator or other control device to modify the behavior of the system.

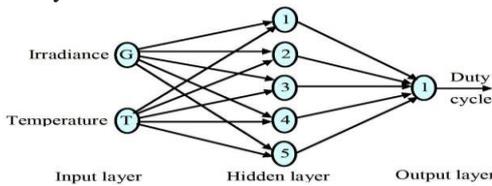


Fig 3: structure of ANN controller

It eliminates conversion losses, enhances efficiency and reliability, and ensures safety standards are meeting via the passive elimination of thermal failures and voltage imbalances. The knowledge and application of the ANN system improve continuously by learning, bringing improvements in decision-making and expediting processes for energy sharing. Hence, ANN control is the next-generation EV charging that allows for self-sufficient, seamless, and green travel. With technological advancement in AI, ANN-based controllers will turn into future intelligent mobility solutions, doing away with charging stations while enabling smooth energy continuance transfer between EVs as shown in Fig 3.

C. STATES OF OPERATION

(A) Vehicle-To-Vehicle, Condition-1:

$V_{bat1} < V_{bat2}$, because the voltage value of the EV-A battery is lesser than that of the voltage value of EV-B battery and the sender and receiver role,

1) Forward Boost State (EV-A (Sender)&EV-B

(Receiver)): In this operation, battery1 has a lower voltage than battery2, and EV-A is the charge sender and EV-B is the charge receiver. The dc-dc cvt-1 operates in a boosting state to increase the voltage value of EV-A battery to the voltage value EV-B battery after two EV batteries have been electrically coupled using the specified method (by switching on switches $S_1, S_6, S_1,$ and S_6). As seen in Fig.

4(a), Inductor L_1 charges energy from the EV-A battery during the switch ON time of S_{b1} , and the switch S_{a1} is switching complementary to S_{b1} . In order to transfer energy from the EV-A battery and inductor L_1 to the EV-B battery via S_{a1}, S_{a2} , and inductor L_2, S_{a1} turns on when S_{b1} turns off. Switch S_{b2} is switched complimentary to switch S_{a2} in order to draw power from the dc-links, as illustrated in Fig. 4(b), and switch S_{a2} is keeping on during this vehicle-to-vehicle state, making $V_{dc1} = V_{dc2} = V_{bat2}$.

2) Backward Buck State (EV-A(Receiver)&EV-B

(Sender): Same as the forward boost state, activate the switches $S_1, S_6, S_1,$ and S_6 of active rectifiers 1 and 2 to link the EV batteries. Power is transferring from the battery of EV-B to the battery of EV-A using the dc-dc cvt-1 in buck state. Then $V_{bat1} < V_{bat2}$, diode D_{a2} is forward biased, meaning that $V_{bat2} = V_{dc1} = V_{dc2}$, which prepares the EV-B battery to power the EV-A battery through the dc-link. As in Fig. 5(a), energy from the EV-B battery gets transmitted to the EV-A battery through inductor $L_1, D_{a2}, S_1,$ and L_2 during the time that switch S_{a1} turn-on period. The energy stored in an inductor L_1 freewheels through complementary switched S_{b1} to S_{a1} during S_{a1} turn OFF time, as illustrated in Fig. 5(b).

(B) Vehicle-To-Vehicle, Condition-2:

$V_{bat1} = V_{bat2}$ in this case, the dc-dc converters must be regulating, boost& buck state is both available, since the voltages of the two EV batteries are equal to each other.

1) Forward Boost State (EV-A (Sender) &EV-B

(Receiver): Forward boost operation with $V_{bat1} = V_{bat2}$ involves powering EV-A battery with EV-B battery using dc-dc cvt-1dc-dc cvt-2 performed in buck state and in boost state. At S_{b1} switch ON time, energy from EV-A battery charge inductor L_1 and switch S_{a1} is temporary switching to S_{b2} in Fig. 6(a). Simultaneous activation of the dc-dc cvt-2 is switch S_{b2} and parallel activation of switch S_{a2} freewheel the energy stored in an inductor L_2 . When S_{b1} and S_{b2} are turned off, switches S_{a1} and S_{a2} activate, sending power from the EV-A battery to the EV-B battery in Fig 6(b).

2) Backward Boost State (EV-A(Receiver)&EV-B

(Sender): This state of operation is the same as the forward boost state, with $V_{bat1} = V_{bat2}$, but the power flow direction is backward by using closed-loop current control to run the dc-dc cvt-1 in buck state and the dc-dc cvt-2 in boost state.

(C) Vehicle-To-Vehicle, Conditon-3:

V_{bat1} outperformed V_{bat2} . The converter operates in the same way as in condition 1, but flowing of power in backward.

1) Backward Boost State (EV-A(Receiver)&EV-B

(Sender): By running the dc-dc cvt-2 of EV-B in boost state and leaving the S_{a1} of EV-A on continuously, the power flow direction is backward, similarly to forward boost state with $V_{bat1} < V_{bat2}$.

2) Forward Buck State (EV-A (Receiver) &EV-B

(Sender): By running the dc-dc cvt-2 of EV-B in the buck state and keeping the S_{a1} of the dc-dc cvt-1 of EV-A constantly ON, the backward buck state is achieved with the exception that V_{bat1}

D. CONTROL SCHEME FOR THE SUGGESTED VEHICLE-TO-VEHICLE APPROACH

Controlling the on-board converters regulates the charging rate and energy supply in the proposed vehicle-to-vehicle process. Figure 7 depicts the state selector flow that controls the vehicle-to-vehicle state based on the EV-A and EV-B battery levels as well as the Sender receiver information. Furthermore, the on-board charger converters are adjusted based on the operation state to achieve the desired vehicle-to-vehicle, as stated in the following paragraph of this section.

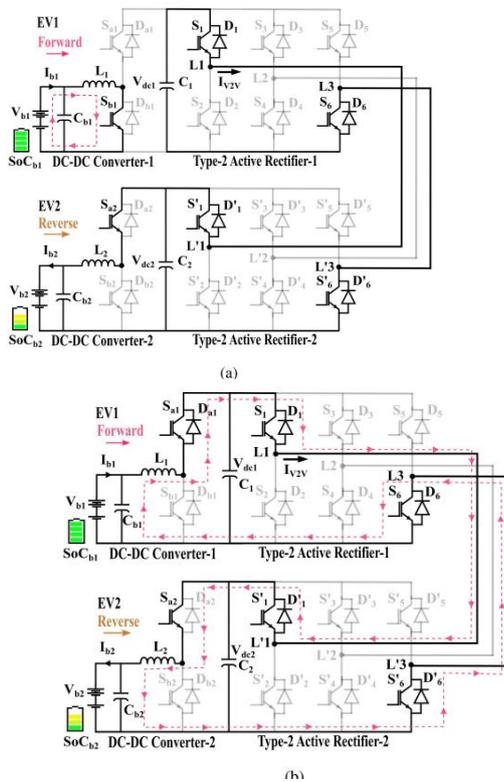


Fig4: Forward boost vehicle-to-vehicle state with battery1(V)<battery2(V).

- a. Energy from the EV-A is stored in the inductor (L_1).
- b. Energy is transmitting to EV-B via a direct current link.

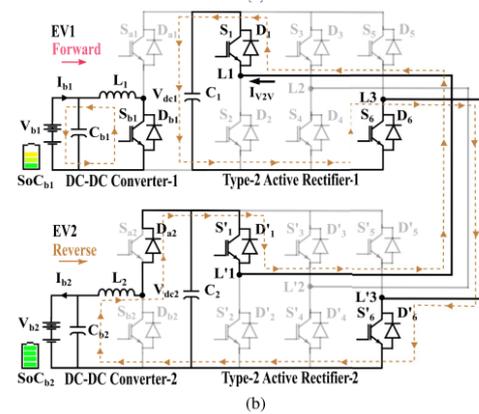
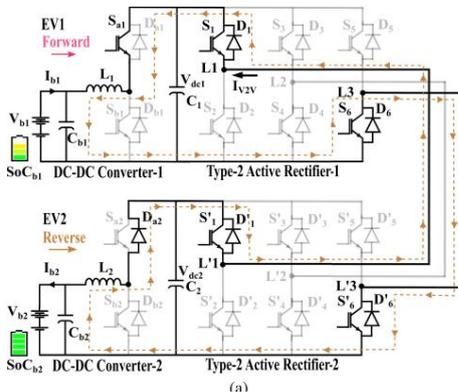


Fig5: Backward buck vehicle-to-vehicle state with battery1(V)< battery2(V).

- a. Through a dc link, the inductor (L_1) retains energy from the EV-B.
- b. Energy is transmitting from L_1 to the EV-A battery via freewheeling.

A. Control of active rectifiers using vehicle-to-vehicle interface in order to achieve three-phase ac to dc conversion it is often necessary to manage the active rectifier in d-q control state when using a type-2 charger for normal three-phase ac charging. The active rectifier will once more work as a connection to read and link the batteries of both EVs in the planned vehicle-to-vehicle charging. The switching pulses S_1 & S_6 of the EV-A rectifier-1 and S_1 & S_6 of the rectifier-2 stay active high during the vehicle-to-vehicle charging process in all states after the type-2 charger ports are connecting for vehicle-to-vehicle charging.

B. DC-DC Conversion The dc-dc converters of the type-2 chargers are current-controlled, closed-loop, and the charging process is regulated to be carried out over vehicle-to-vehicle using the onboard chargers. When using the backward buck state control ($V_{bat1} < V_{bat2}$) and forward boost states. For those states, error pumping between reference current I_L and actual inductor current I_{L1} to a PI controller generates duty ratio for switch S_{a1} , and S_{b1} is switched in addition with S_{a1} as illustrated in Fig. 8. This allows the dc-dc cvt-1 to regulate its inductor current I_{L1} in a closed-loop manner, either forwards or backwards. Switching signal to S_{a2} is large during this state. The following equation describes the transfer function for controlling dc-dc cvt-1 utilized in PI controller tuning.

$$\frac{\widehat{I}_{L1}(s)}{\widehat{d}(s)} = \frac{(C_1 V_{b1})s + 2(1 - D)L_1}{(L_1 C_1)s^2 + \frac{L_1}{R_2}s + (1 - D)^2} \quad 1$$

The reference current I is computed using in following equation, where E_{bat1} and E_{bat2} are the EV-A and EV-B battery kWh ratings, and T_c is the charging time necessary.

$$I_L^* = \frac{\min(E_{bat1}, E_{bat2})}{\min(V_{bat1}, V_{bat2}) * T_c}$$

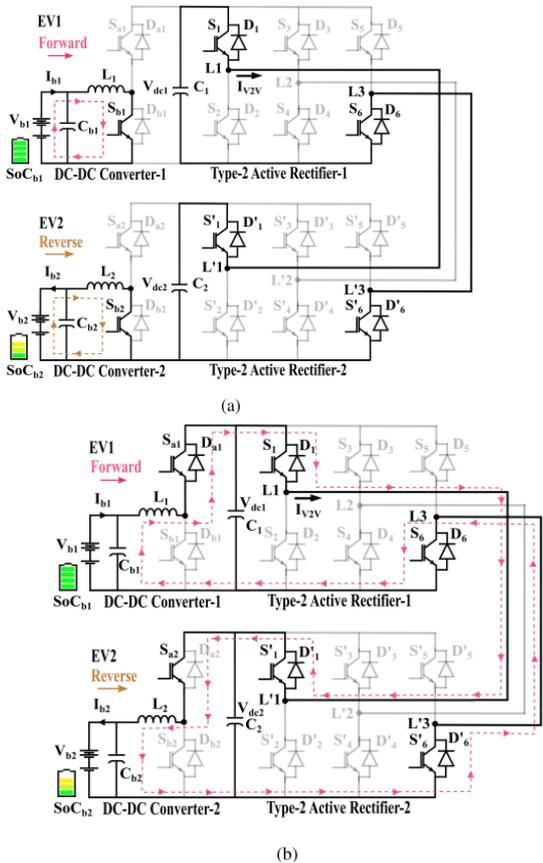


Fig 6: Forward boost vehicle-to-vehicle state with battery1(V) = battery2(V).
 a. The energy from the batteries is stored in L₁ and L₂
 b Energy is transmitting through dc-link to EV-B.

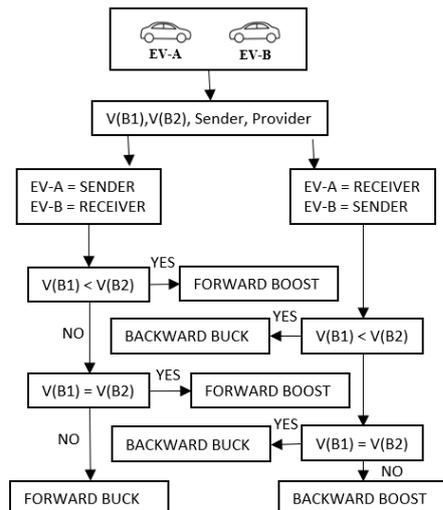


Fig 7: The proposed control flow chart for power transfer between vehicles.

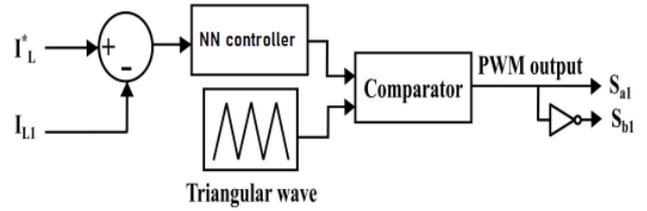


Fig 8: Controlling of current technique for forward boost and backward buck states (V_{bat1} < V_{bat2}).

The vehicle-to-vehicle bidirectional power converter interface allows for direct energy transfer between commercial EVs using on-board type-2 chargers. This solution implies the availability of EV communication, controller access, and instrumentation sensors, as described in [10], [11], [12]. The Sender and receiver EVs communicate via their on-board type-2 charging connectors, with battery voltage levels and user choices determining the vehicle-to-vehicle state (e.g., forward boost), as illustrated in Fig. 7.

Depending on the state selected, on-board DSP controllers manage power direction and energy transfer. Active rectifiers for each charger function as an interface, with each pair of switches activated to connect the two EV's dc-links. Following connection, to guarantee that the amount of charge transferred to the receiver EV is effective, the Sender EV's battery-side DC-DC converter controls the current flow. This design maximizes vehicle-to-vehicle power sharing with existing EV hardware.

TABLE I

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)	0.6 mH
L ₁ Internal resistance (R ₁)	0.005 Ω
L ₂ Internal resistance (R ₂)	0.006 Ω
DC-link capacitor (C ₁)	1000 μF
DC-link capacitor (C ₂)	1100 μF
DC-DC converter-1 capacitor (C _{b1})	5.6 nF
DC-DC converter-2 capacitor (C _{b2})	5.8 nF

IV. SIMULATION RESULTS

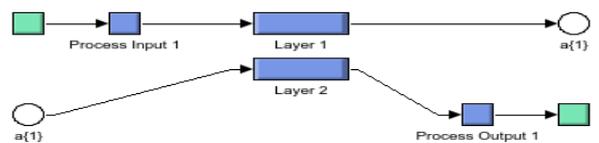


Fig 9: Internal Structure of ANN

CASE-1:

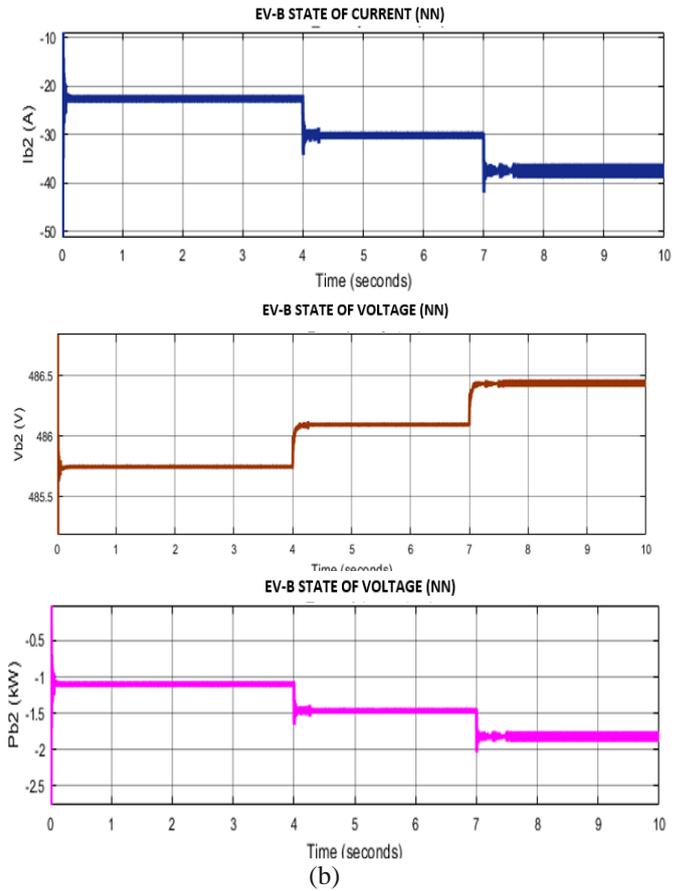
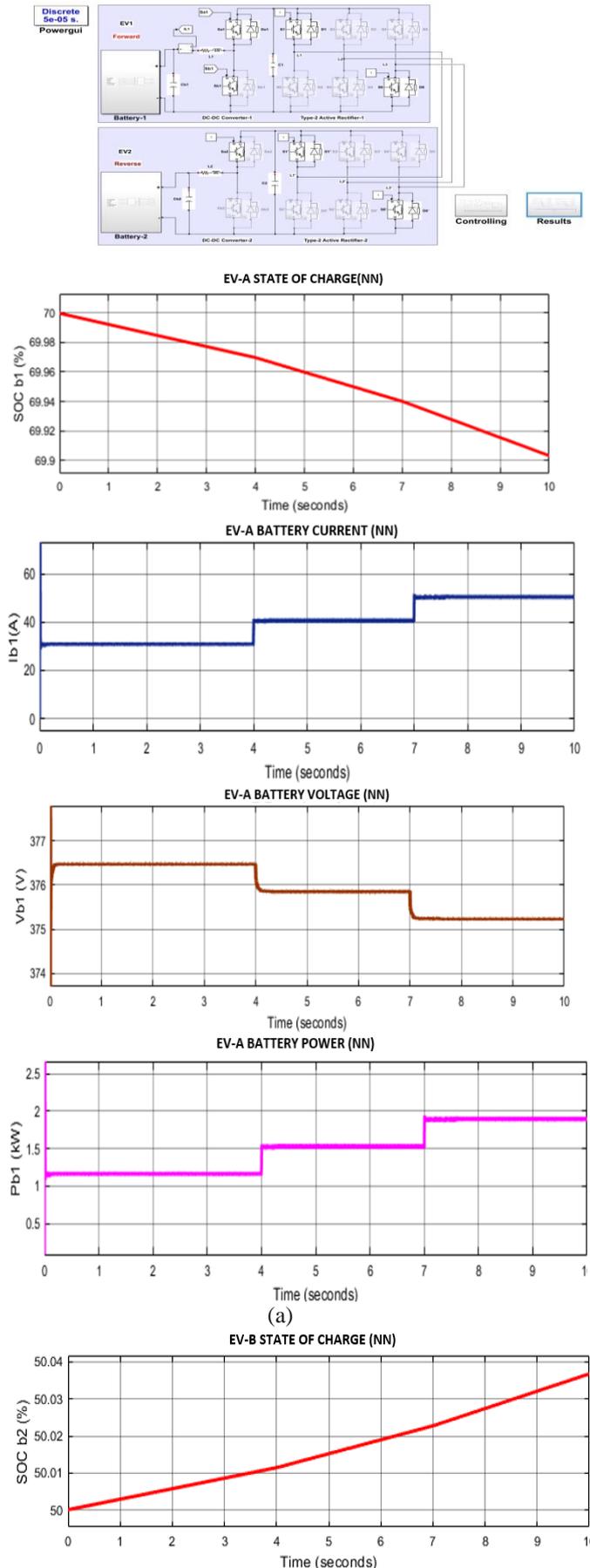
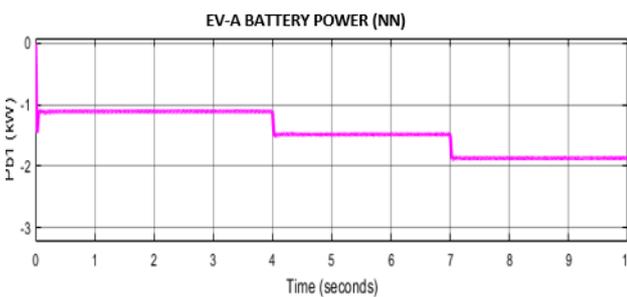
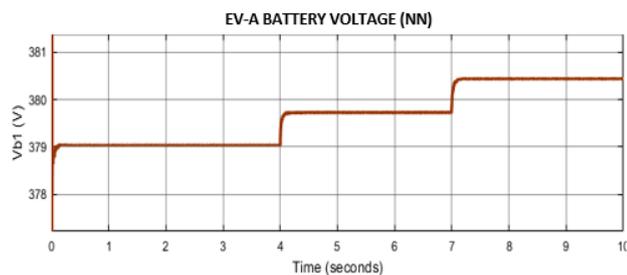
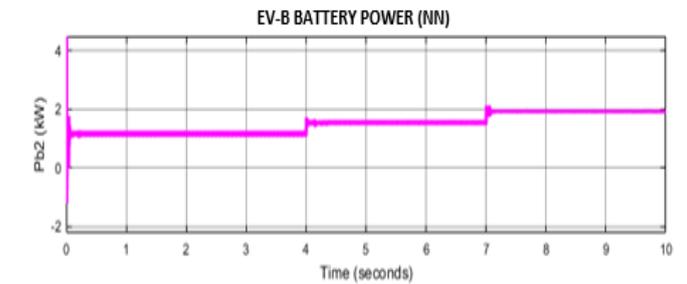
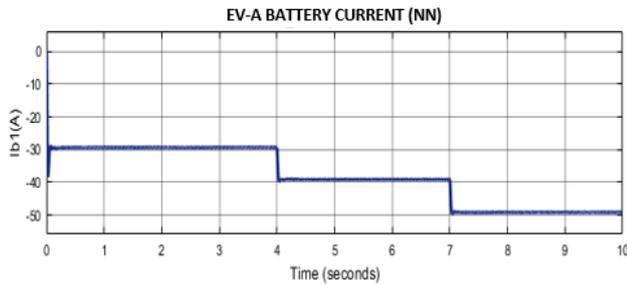
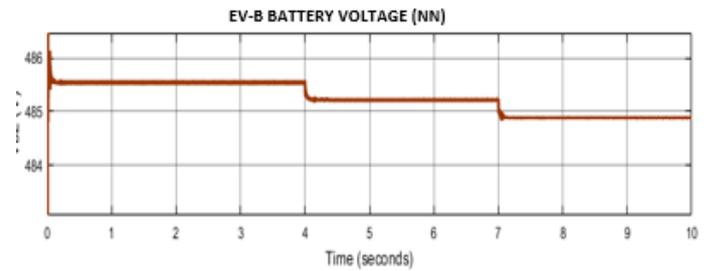
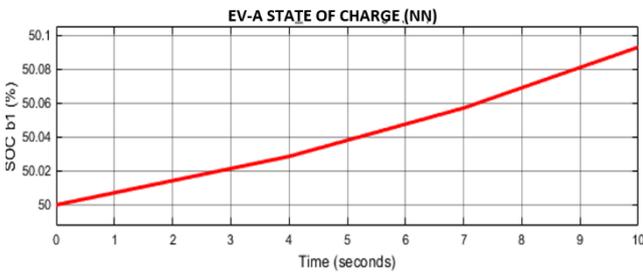
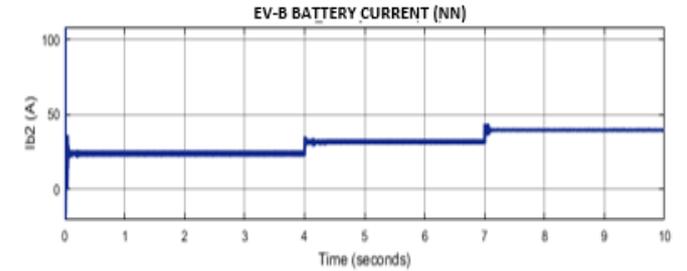
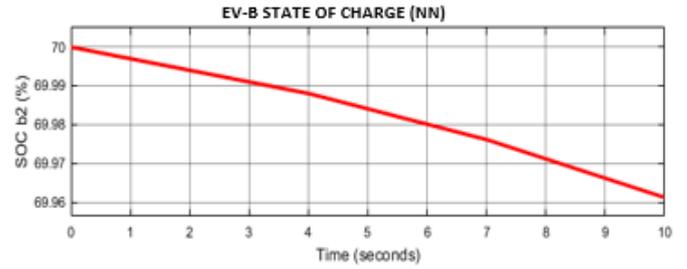
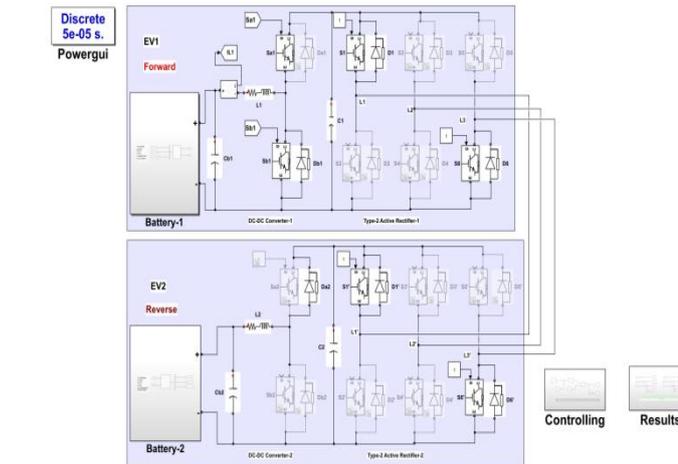


Fig10: The outcomes of the simulation for the suggested vehicle-to-vehicle a forward boost state functioning using V_{bat1}
 a. SOC, V, I and P waveforms for the EV-A battery.
 b. SOC, V, I and P waveforms for the EV-B battery.

In this operating state, the inductor current I_{L1} is adjusted for transferring energy from EV-A to EV-B batteries. Starting with an initial reference inductor current I_{L1}^* of 30A, it is gradually increased in 10A steps up to 50A, controlling the discharge current I_{b1} of the EV-A battery. This control affects fluctuations in the EV-A's state of charge (S_{oc1}), voltage (V_{b1}), and discharged power (P_{b1}), as shown in Fig. 10a. Concurrently, the EV-B battery experiences a charging current I_{b2} , which causes an increase in S_{ocb2} , V_{b2} , and charged power (P_{b2}), as seen in Fig. 10b. Positive battery currents indicate discharge, while negative values indicate charging, with both currents remaining within the active rectifier switches the current rating.

CASE-2:



(a)

(b)

Fig11: The outcomes of the simulation for the suggested vehicle-to-vehicle a backward buck state functioning, with $V_{bat1} < V_{bat2}$.

- a. SOC, V, I and P waveforms for the EV-A battery.
- b. SOC, V, I and P waveforms for the EV-B battery.

In this operational state, power flow is backward compared to forward boost state, while maintaining the same voltage levels for EV-A& EV-B batteries. Where EV-A battery undergoes charging with current I_{b1} , leading to an increase in state of charge (SOC) and voltage, as depicted Fig. 11a. Simultaneously, EV-B battery experiences a discharging current I_{b2} , resulting in the changes of SOC and voltage, alongside of discharge power from the EV-B battery, as illustrated in Fig. 11b.

CASE 3:

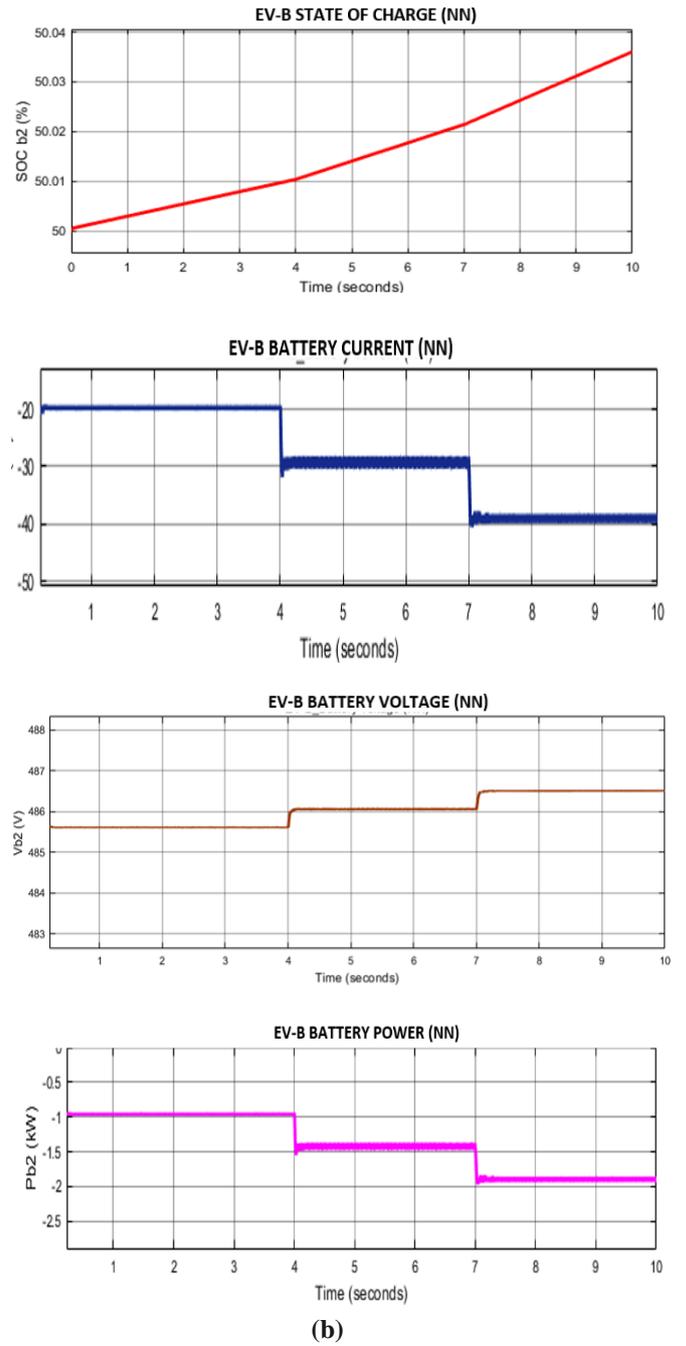
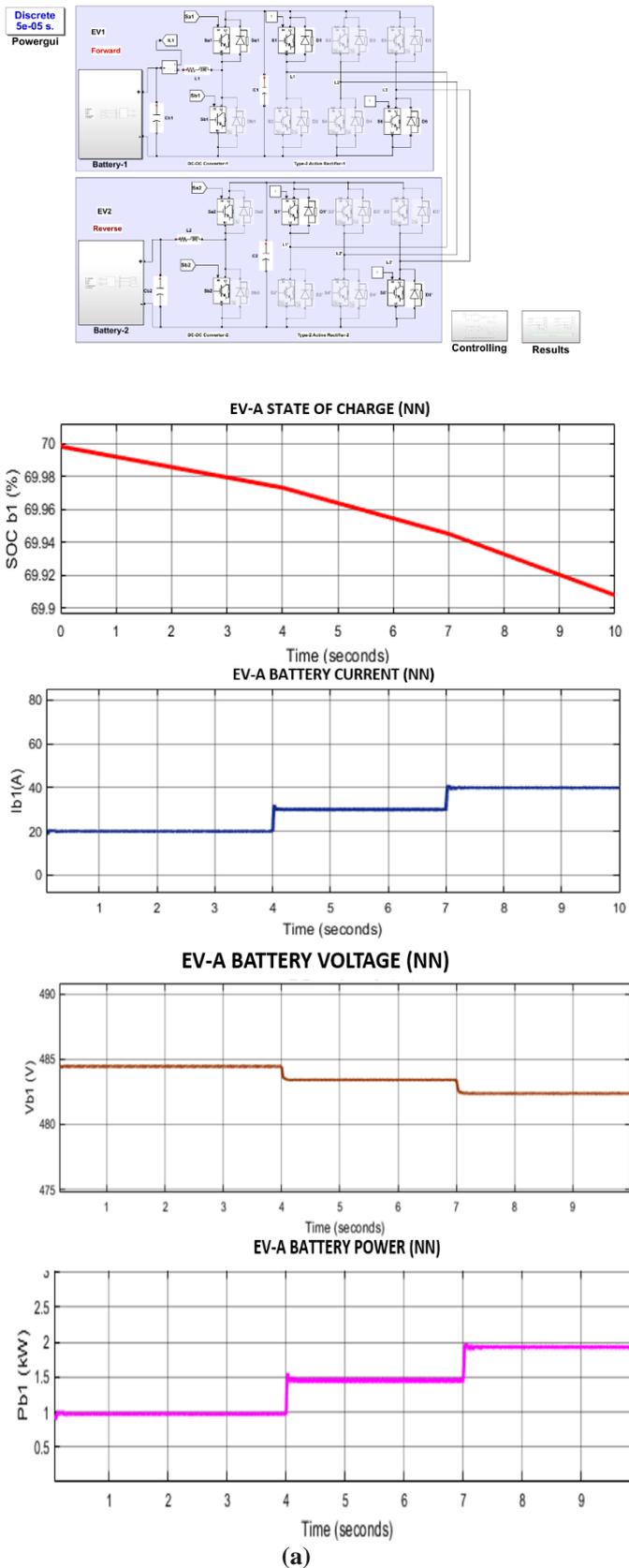


Fig12: The outcomes of the simulation for the suggested vehicle-to-vehicle a backward buck state functioning, with $V_{bat1} = V_{bat2}$.

- a. SOC, V, I and P waveforms for the EV-A battery.
- b. SOC, V, I from the EV-B battery, and DC-link voltage.

In this state, energy exchange occurs between two identical electric vehicles with matching voltage levels. Common current reference regulates forward currents I_{L1} and I_{L2} . Fig 12a illustrates EV-A battery discharge current, showcasing variations in voltage, power, and SOC, while Fig. 12b depicts charging current and associated variations in SOC and voltage for EV-B batteries.

V. CONCLUSION

In conclusion, the implementation of ANN-controlled EV-to-V energy transfer through onboard converters has proven to be highly effective. The MATLAB Simulink simulation demonstrated the controller's ability to efficiently manage power flow optimization, ensuring seamless energy transfer while significantly enhancing overall system efficiency. High adaptability, resilience, and flexibility were demonstrated by the ANN controller, which made it ideal for managing a variety of operating situations and practical difficulties in the electric vehicle (EV) energy transfer. By leveraging artificial intelligence, the system intelligently adjusts voltage levels, current flow, and energy distribution, thereby minimizing conversion losses and maximizing power utilization between EVs. This capability makes ANN-controlled energy transfer a reliable and scalable alternative to traditional power-sharing mechanisms. The dynamic learning nature of ANN ensures that the system continuously improves performance over time, adapting to varying battery states, vehicle loads, and environmental conditions.

VI. FUTURE SCOPE

With its many potential uses, this technology will support advancements in electric vehicles (EV's), artificial intelligence, and smart energy management systems. As EV adoption increases, effective energy transfer between vehicles will become crucial for optimizing energy consumption and enhancing battery longevity. Artificial neural networks (ANNs) can significantly improve power distribution in energy management because they enable real-time energy flow prediction and optimization. By guaranteeing efficient and seamless energy sharing between EV's, this can reduce dependency on charging stations.

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