# A Combinatory AC and DC Charging Approach for Electric Vehicles

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## ABSTRACT

One of the most important things that may increase sales of electric cars is the capacity to charge their batteries more rapidly. Commercial off-board high power dc quick charging stations are costly to install and provide a big obstacle to entrance. Conventional on-board type-1 and type-2 ac chargers are notoriously sluggish, but they can manage loads between 3.3 kW and 19 kW. A method that combines alternating current and direct current is suggested in this paper as a means to accelerate the charging of electric car batteries. There are others who advocate for a dual-device charging system for EV batteries, with one device serving as an integrated DC charger for the powertrain and the other as a type-2 ac charger. The drivetrain inverter's negative rail (O) and the electric vehicle motor winding's neutral (N) are used to provide a direct current input port (N(−)) for integrated direct current charging of the drivetrain. You may charge your electric car's battery using rooftop solar panels, dc microgrids, or anything else that accepts DC power. By repurposing the motor windings as filter inductors, the electric car's drivetrain inverter may be managed as an integrated interleaved dc-dc converter (IDC). This paves the way for the car to run on direct current. This document details the procedure for managing the voltage on a shared dc-link that draws power from two sources: an inbuilt interleaved dc charger and a type-2 ac charger. Results from a combined simulation using Ansys Maxwell and Simplorer for Finite Element Methods (FEM) verified the study on the performance of the electric car motor and combination DC charger. In order to confirm the suggested method of combining ac and dc charging, a little experimental model is created.The index includes terms such as electric car chargers, hybrid ac/dc charging, dc input port, and integrated dc charging within the engine.

**Keywords:**Electric Vehicles (EVs), Combinatory AC/DC Charging, Type-2 AC Charger, DC Fast Charging, Interleaved DC-DC Converter, Drivetrain-Integrated Charging, DC-Link Voltage Regulation, d-q Control, Unity Power Factor, MATLAB/Simulink.

## I.INTRODUCTION

The rapid adoption of electric vehicles (EVs) has increased the demand for charging systems that can provide higher charging power, improved efficiency, and greater flexibility while reducing the dependence on expensive charging infrastructure. Conventional onboard AC chargers are generally limited in power capacity, whereas DC fast-charging systems can provide significantly higher charging rates but require dedicated high-power infrastructure. Recent research has therefore focused on integrated and advanced charging technologies that can improve charging performance by utilizing the existing power-electronic components of the EV powertrain [1], [3], [5].

Integrated onboard charging has emerged as an effective approach in which the traction motor, inverter, and other drivetrain components are reused during the charging process. Such architectures can reduce additional hardware requirements while increasing the utilization of existing high-power components. Reviews of integrated EV chargers have highlighted the development of different converter topologies and control techniques aimed at improving power density, efficiency, and charging capability [1]. Similarly, recent studies have investigated advanced onboard charging technologies and their future development for high-voltage EV powertrains [2], [20].

The charging capability of an EV can be further improved by integrating the onboard charger with the drivetrain inverter. Wang and Lehn proposed a three-phase integrated charger for dual-inverter drivetrain EVs, demonstrating the potential of using drivetrain components for charging applications [6]. Other research has investigated integrated fast-charging systems in which the motor windings are utilized as part of the charging converter. Lacroix et al. presented an integrated fast battery charger for EV applications [8], while Sharma et al. investigated the use of three-phase induction motor stator windings as filter components in an integrated battery charger [10]. These approaches demonstrate that existing motor and inverter components can contribute to increased charging power without requiring completely separate high-power charging hardware.

Multiphase and integrated motor-drive configurations have also received considerable attention because of their ability to support charging while making efficient use of the available drivetrain components. Subotic et al. investigated an onboard integrated battery charger based on an asymmetrical nine-phase machine [12], while other studies explored multiphase-machine-based onboard chargers and integrated charging configurations [17], [18]. Six-phase open-end winding machines have also been investigated for three-phase integrated EV battery chargers, providing additional possibilities for integrating charging functions with the electric drivetrain [9], [19].

Another important research direction is drivetrain-integrated DC fast charging. Viana and Lehn investigated a drivetrain-integrated DC fast charger with buck and boost functionality and simultaneous drive/charge capability [13]. Such approaches can potentially utilize the high-power rating of the traction inverter and motor windings to achieve higher charging power than conventional onboard AC chargers. Reconfigurable and integrated converter structures have also been proposed to improve charging flexibility and reduce converter hardware requirements [11], [15].

Despite these developments, conventional charging systems generally operate AC and DC charging as separate charging modes. This restricts the simultaneous utilization of different available energy sources and can result in underutilization of the EV's onboard charger or drivetrain power electronics. The development of charging systems capable of combining AC and DC power can therefore provide a more flexible approach to EV charging. The combinatory AC/DC charging concept integrates the onboard Type-2 AC charger with drivetrain-integrated DC charging, allowing the available charging power to be increased through coordinated operation [3].

Advanced control strategies are essential for such integrated charging systems because multiple power converters must operate through a common DC-link without creating unwanted circulating currents or control conflicts. The use of synchronous reference-frame d-q control can provide independent control of active and reactive current components and can support unity power-factor operation during AC charging [3], [6]. Meanwhile, integrated DC-DC conversion can be controlled according to the available DC-source power and required charging current. Bidirectional onboard charger architectures further provide flexibility in managing energy flow between the battery, DC-link, and external sources [2], [20].

Therefore, the development of a combinatory AC and DC charging system for electric vehicles provides a promising approach for increasing charging power while making better use of existing EV powertrain components. By coordinating the Type-2 AC charger, drivetrain-integrated interleaved DC-DC converter, and battery-side DC-DC converter, the system can support flexible charging from AC and DC sources while maintaining DC-link stability and appropriate power control. The approach builds upon existing research in integrated onboard chargers, multiphase-machine charging, drivetrain-integrated DC charging, and advanced converter control [3], [6], [9], [10], [12], [13].

## II.LITERATURE SURVEY

**Metwly et al. (2020):** Metwly et al. presented a comprehensive review of integrated onboard EV battery chargers, focusing on advanced charging topologies and recent developments. The study examined different integrated charger configurations and highlighted the advantages of utilizing existing EV powertrain components for charging. The authors emphasized improved integration, efficiency, power capability, and reduced additional hardware requirements as important aspects of modern EV charging systems [1].

**Wang and Lehn (2019):** Wang and Lehn investigated the design and control of a three-phase integrated charger for dual-inverter drivetrain electric vehicles. Their work demonstrated how the existing drivetrain inverter and associated components can be utilized for battery charging. The study focused on converter control and integrated operation, showing the potential of drivetrain-based charging to improve charging capability while reducing the need for separate charging hardware [6].

**Lacroix et al. (2010):** Lacroix et al. proposed an integrated fast battery charger for electric vehicles. The research explored the reuse of electric-drive components during the charging process to achieve faster charging. The study demonstrated that integrating the charger with the vehicle's existing powertrain can reduce additional hardware requirements while supporting improved charging performance [8].

**Raherimihaja et al. (2020):** Raherimihaja et al. developed a three-phase integrated battery charger based on a six-phase open-end winding machine. The study utilized the multiphase machine structure to integrate charging functionality with the EV drivetrain. The research demonstrated the potential of multiphase machines for achieving integrated charging while providing suitable control of the charging process [9].

**Sharma et al. (2020):** Sharma et al. investigated an integrated EV battery charger that uses three-phase induction motor stator windings as filter components. By utilizing the existing motor windings, the proposed approach reduces the requirement for separate filter inductors. This research provides an important foundation for drivetrain-integrated charging in which motor windings are reused as part of the charging converter [10].

**Subotic et al. (2015):** Subotic et al. proposed an onboard integrated battery charger for EVs using an asymmetrical nine-phase machine. The study addressed the charging-torque problem associated with using traction motors during charging and investigated a multiphase-machine configuration to support torque-free charging. The work demonstrated that multiphase motor structures can provide additional flexibility for integrating charging and propulsion functions [12].

**Viana and Lehn (2019):** Viana and Lehn developed a drivetrain-integrated DC fast charger with buck and boost functionality and simultaneous drive/charge capability. The study focused on using the vehicle's drivetrain power electronics for high-power DC charging and supporting different DC voltage conditions. Their work demonstrated the potential of integrated DC charging to provide higher charging capability while making effective use of existing EV powertrain components [13].

## III.EXISTING SYSTEM

The existing electric vehicle charging system mainly uses separate AC and DC charging methods. In conventional AC charging, the vehicle is connected to an AC power source through an onboard charger (OBC), which converts the supplied AC power into DC power suitable for charging the battery. Because the AC-to-DC conversion hardware is installed inside the vehicle, its size, weight, thermal limitations, and power rating restrict the achievable charging rate.

In the conventional DC fast-charging system, the AC-to-DC and DC-to-DC conversion stages are located outside the vehicle in the charging station. The regulated DC power is supplied directly to the EV battery, bypassing the onboard charger. This arrangement provides substantially higher charging power and shorter charging times, but it requires dedicated high-power charging infrastructure with higher installation cost, space requirements, and power-handling capability.

Existing integrated charging approaches attempt to overcome some of these limitations by reusing the traction inverter and motor windings as parts of the charging system. Such systems can reduce the number of additional components, converter size, weight, and cost. However, they introduce challenges such as charging torque, motor-winding limitations, current ripple, thermal management, control complexity, and the need to maintain appropriate power quality.

The document specifically identifies a major limitation in the existing approach: AC and DC charging are generally treated as independent charging modes. The onboard Type-2 AC charger is used when charging from the AC grid, while a separate DC fast charger is used for high-power DC charging. Consequently, the available AC and DC sources cannot be effectively utilized simultaneously. The document notes that previous approaches mainly concentrate on either AC or DC drivetrain-integrated charging rather than coordinated combined charging.

## IV.PROPOSED SYSTEM

The proposed system introduces a combinatory AC and DC charging architecture for electric vehicles, allowing the EV battery to be charged from an AC source, a DC source, or both sources simultaneously. The system combines the existing Type-2 onboard AC charger with a drivetrain-integrated interleaved DC-DC converter (IDC). A common DC-link connects the charging subsystems and the battery-side converter, enabling coordinated transfer of power from the available sources to the battery.

For DC charging, an additional DC input port N(+) and O(−) is incorporated into the EV. The motor winding neutral is connected to the positive DC input, while the negative rail of the drivetrain inverter acts as the negative terminal. This allows an external DC source, such as a DC charging station, DC microgrid, energy-storage system, solar-based DC source, or another EV battery, to supply power to the vehicle.

A key feature of the proposed system is the conversion of the drivetrain inverter into a three-legged interleaved DC-DC converter during DC charging. The stator windings of the traction motor are reused as the filter inductors of the converter. Interleaved operation provides phase-shifted current paths, helping to reduce input-current ripple while utilizing the high-power capability of the existing motor and inverter.

The proposed architecture supports three charging modes: AC-only charging through the Type-2 onboard charger, DC-only charging through the integrated DC input port and IDC, and combined AC/DC charging in which both sources supply power simultaneously. During combined charging, the Type-2 charger supplies controlled AC-derived power while the integrated DC-DC converter provides additional DC power according to the available external DC source.

The control architecture uses d-q control for the Type-2 AC charger to regulate active and reactive power and maintain unity power factor at the grid interface. The integrated DC-DC converter operates in current-control mode so that its charging contribution can be independently adjusted according to the external DC source. Meanwhile, the battery-side bidirectional DC-DC converter operates in voltage-control mode and maintains the common DC-link at approximately 600 V while absorbing the combined power from the AC and DC charging paths.

Overall, the proposed system provides a flexible, scalable, and high-power EV charging solution by reusing the vehicle's existing onboard charger, traction inverter, and motor windings. It reduces dependence on additional high-power charging hardware and enables available AC and DC energy sources to be utilized together. The document also considers applications involving renewable energy systems, DC microgrids, energy-storage systems, and vehicle-to-vehicle energy sharing.

## V.BLOCK DIAGRAM

The proposed combinatory AC/DC charging system integrates both AC and DC charging paths to provide flexible and high-power charging for an electric vehicle. In the AC path, power from the AC grid is supplied through a Type-2 connector to the onboard AC charger, which converts AC power into DC and feeds the common DC link maintained at approximately 600 V. In parallel, the DC charging path accepts power from an external DC source such as a DC fast charger, DC microgrid, energy-storage system, solar source, or another EV battery through the N(+) and O(−) DC input terminals. The drivetrain inverter operates as an integrated interleaved DC-DC converter, with the traction motor windings serving as filter inductors, allowing additional DC charging power while reducing current ripple. The combined power from both sources is delivered through the common DC link to the bidirectional battery-side DC-DC converter, which regulates the voltage and charging current supplied to the EV battery. The control architecture independently manages the Type-2 AC charger using d-q control, the integrated DC-DC converter using current control, and the battery-side converter using voltage control, enabling stable DC-link operation and coordinated AC/DC charging.

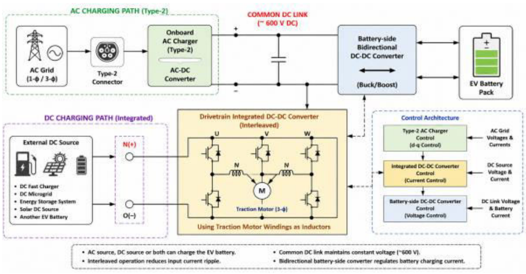

Fig 5.1 Block diagram

## VI.IMPLEMENTATION

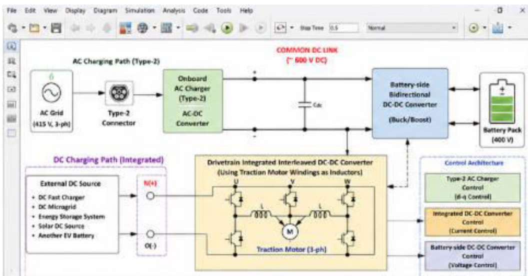

Fig 6.1 MATLAB/Simulink Model of the Proposed Combinatory AC/DC Charging System

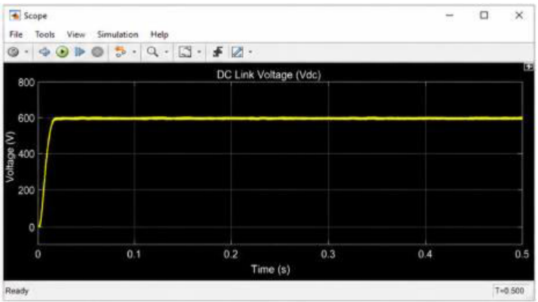


Fig 6.2 DC-Link Voltage Regulation at Approximately 600 V

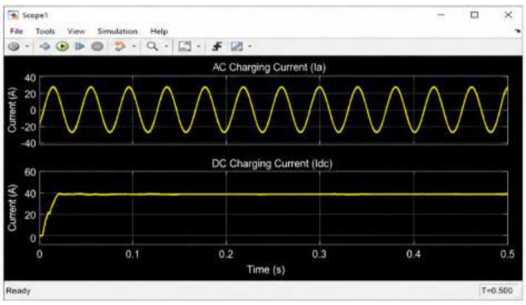

Fig 6.3 AC and DC Charging Current Waveforms

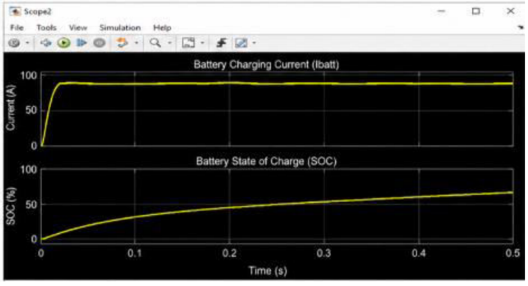


Fig 6.4 Battery Charging Current and State of Charge (SoC) Analysis

## VII.CONCLUSION

In this paper a combined ac and dc charging approach is proposed to increase the charging rate of EV batteries. The complex part of combined ac and dc charging is controlling the ac to dc converter of the OBC and the drivetrain integrated dc-dc converter in a co-ordination with the right control mode. The proposed approach integrates dc charging by controlling the drivetrain inverter as interleaved dc-dc converter in current control mode with the onboard type-2 ac charging in constant power mode, with common dc-link voltage controlled from battery side dc-dc converter in voltage control mode to provide relatively faster charging rates. The charging rate of the EV battery is increased proportional to the power rating of the dc source connected to the dc input port. The proposed drive train integrated dc charging can accommodate high power dc sources by virtue of high-power rating of the drivetrain and EV motor. The experimental and simulation results demonstrate an increase in rate of charge up to 2C rate with the proposed combined ac and dc charging. The performance analysis is presented demonstrating the efficiency of ac charging at a constant power and dc charging at 30kW, 60kW and 90kW with a range of dc input voltage from 250V to 450V and for the combined operation of ac and dc. In the proposed work the ac charging is limited to power rating of the on-board charger (19 kW), the future direction to enhance the ac charging rate is to explore multiphase EV motors and drivetrain configurations to support drivetrain integrated high power ac charging in addition to the drivetrain integrated high power dc charging

## VIII.FUTURE SCOPE

The proposed combinatory AC/DC charging system provides several opportunities for future development. One important direction is the development of higher-power charging configurations by increasing the power contribution from the drivetrain-integrated interleaved DC-DC converter while maintaining stable operation of the common DC-link. The charging system can also be further developed to support a wider range of external DC sources, including solar photovoltaic systems, DC microgrids, battery energy-storage systems, and other EV batteries. The document specifically identifies these sources as potential applications of the proposed DC charging interface.

Future work can also focus on improving the coordinated control strategy for simultaneous AC and DC charging. More advanced control methods can be investigated to dynamically distribute charging power between the Type-2 AC charger and the integrated DC-DC converter according to source availability, battery requirements, and converter operating conditions. Maintaining the DC-link voltage while avoiding circulating currents and control conflicts will remain an important area of development.

Another important area is the optimization of converter efficiency and power quality. Future implementations can investigate reductions in switching losses, conduction losses, current ripple, and harmonic distortion while improving the overall charging efficiency. The interleaved structure can be further optimized to obtain better current sharing and dynamic performance during high-power charging.

The proposed system can also be extended toward renewable-energy-based and smart charging applications. Integration with rooftop solar systems, DC microgrids, energy-storage units, and vehicle-to-vehicle energy transfer can enable more flexible utilization of available DC energy. The system can therefore be developed as part of future smart charging and distributed-energy infrastructures.

Finally, future research should concentrate on hardware prototype development and real-world validation. The proposed architecture can be tested under different AC/DC source combinations, charging power levels, battery states of charge, and transient operating conditions. Further investigation of thermal performance, electromagnetic compatibility, battery aging, protection mechanisms, and long-term reliability would help move the proposed combinatory AC/DC charging concept toward practical EV deployment.

## IX.REFERENCES

[1] 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, doi: 10.1109/ACCESS.2020.2992741.

[2] H. Wouters and W. Martinez, "Bidirectional onboard chargers for electric vehicles: State-of-the-art and future trends," IEEE Transactions on Power Electronics, vol. 39, no. 1, pp. 693–716, 2024, doi: 10.1109/TPEL.2023.3319996.

[3] B. S. Umesh, V. Khadkikar, H. Zeineldin, S. Singh, H. Otrok, R. Mizouni, and A. Rathore, "A combinatory AC and DC charging approach for electric vehicles," IEEE Transactions on Intelligent Transportation Systems, vol. 25, no. 11, pp. 15467–15476, 2024, doi: 10.1109/TITS.2024.3464591.

[4] R. Baharom and M. H. Hayroman, "A comprehensive review on advancements in battery charger technologies for electric vehicles," in Proc. IEEE Industrial Electronics and Applications Conference (IEACon), 2024, pp. 190–195, doi: 10.1109/IEACon61321.2024.10797305.

[5] S. A. Q. Mohammed and J. Jung, "A comprehensive state-of-the-art review of wired/wireless charging technologies for battery electric vehicles: Classification, common topologies, and future research issues," IEEE Access, vol. 9, pp. 19572–19585, 2021, doi: 10.1109/ACCESS.2021.3055027.

[6] S. Wang and P. W. Lehn, "Design and control of 3-phase integrated charger for dual-inverter drivetrain electric vehicles," in Proc. IEEE Transportation Electrification Conference and Expo (ITEC), Detroit, MI, USA, 2019, pp. 1–6, doi: 10.1109/ITEC.2019.8790589.

[7] F. Lacressonniere and B. Cassoret, "Converter used as a battery charger and a motor speed controller in an industrial truck," in Proc. European Conference on Power Electronics and Applications, 2005, p. 7.

[8] S. Lacroix, E. Laboure, and M. Hilairet, "An integrated fast battery charger for electric vehicle," in Proc. IEEE Vehicle Power and Propulsion Conference (VPPC), 2010, pp. 1–6, doi: 10.1109/VPPC.2010.5729063.

[9] H. J. Raherimihaja, Q. Zhang, T. Na, M. Shao, and J. Wang, "A three-phase integrated battery charger for EVs based on six-phase open-end winding machine," IEEE Transactions on Power Electronics, vol. 35, no. 11, pp. 12122–12132, 2020, doi: 10.1109/TPEL.2020.2986798.

[10] S. Sharma, M. V. Aware, and A. Bhowate, "Integrated battery charger for EV by using three-phase induction motor stator windings as filter," IEEE Transactions on Transportation Electrification, vol. 6, no. 1, pp. 83–94, 2020.

[11] S. Ranjith, V. Vidya, and R. S. Kaarthik, "An integrated EV battery charger with retrofit capability," IEEE Transactions on Transportation Electrification, vol. 6, no. 3, pp. 985–994, 2020, doi: 10.1109/TTE.2020.2980147.

[12] I. Subotic, N. Bodo, E. Levi, and M. Jones, "Onboard integrated battery charger for EVs using an asymmetrical nine-phase machine," IEEE Transactions on Industrial Electronics, vol. 62, no. 5, pp. 3285–3295, 2015, doi: 10.1109/TIE.2014.2345341.

[13] C. Viana and P. W. Lehn, "A drivetrain integrated DC fast charger with buck and boost functionality and simultaneous drive/charge capability," IEEE Transactions on Transportation Electrification, vol. 5, no.

4, pp. 903–911, 2019, doi: 10.1109/TTE.2019.2925211.
[14] S. Loudot, B. Briane, L. Ploix, and A. Villeneuve, “Fast charging device for an electric vehicle,” U.S. Patent 20 120 286 740 A1, Nov. 15, 2012.
[15] S. R. Meher, S. Banerjee, B. T. Vankayalapati, and R. K. Singh, “A reconfigurable on-board power converter for electric vehicle with reduced switch count,” IEEE Transactions on Vehicular Technology, vol. 69, no. 4, pp. 3760–3772, 2020, doi: 10.1109/TVT.2020.2973316.
[16] S. Ranjith, V. Vidya, and R. S. Kaarthik, “An integrated EV battery charger with retrofit capability,” IEEE Transactions on Transportation Electrification, vol. 6, no. 3, pp. 985–994, 2020, doi: 10.1109/TTE.2020.2980147.
[17] I. Subotic, N. Bodo, E. Levi, and M. Jones, “Single-phase on-board integrated battery chargers for EVs based on multiphase machines,” IEEE Transactions on Power Electronics, vol. 31, no. 9, pp. 6511–6523, 2016, doi: 10.1109/TPEL.2015.2504400.
[18] M. Singh, S. P. Das, and S. Samanta, “An on-board integrated fast charger based on multiphase machine,” in Proc. IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES), Jaipur, India, 2022, pp. 1–6, doi: 10.1109/PEDES56012.2022.10079952.
[19] P. Pescetto and G. Pellegrino, “Isolated semi integrated on-board charger for EVs equipped with 6-phase traction drives,” in Proc. IEEE IECON, Toronto, ON, Canada, 2021, pp. 1–6, doi: 10.1109/IECON48115.2021.9589656.
[20] R. Pradhan, N. Keshmiri, and A. Emadi, “On-board chargers for high-voltage electric vehicle powertrains: Future trends and challenges,” IEEE Open Journal of Power Electronics, vol. 4, pp. 189–207, 2023, doi: 10.1109/OJPEL.2023.3251992.