IJERST

International Journal of Engineering Research and Science & Technology

www.ijerst.org

ISSN : 2319-5991

Vol. 21 No. 4 (2025)

ijerst.editor@gmail.com
editor@ijerst.com

ISSN 2319-5991 www.ijerst.com
Vol. 21, No. 4, 2025

Research Paper

AN ENHANCED BIDIRECTIONAL LLC+C RESONANT CONVERTER WITH PARALLEL TRANSFORMERS FOR HIGH-EFFICIENCY EV CHARGING IN DC MICROGRIDS.

[1]**B LAKSHMANA NAYAK,** ASSOCIATE PROFESSOR, VIKAS COLLEGE OF ENGINEERING AND TECHNOLOGY
[2] **KANIGALPULA YASODA DEVI ,** EEE, VIKAS COLLEGE OF ENGINEERING AND TECHNOLOGY

ABSTRACT

This paper presents a High-Efficiency Bidirectional LLC+C Resonant Converter with Parallel Transformers designed for solar-charged electric vehicle (EV) applications. The proposed converter topology enables bidirectional power flow between the solar photovoltaic (PV) source, the battery storage system, and the EV drivetrain, ensuring optimal utilization of harvested solar energy. By integrating parallel-connected transformers, the system achieves reduced current stress, improved thermal performance, and enhanced power-handling capability. The inclusion of a hybrid LLC+C resonant tank allows zero-voltage switching (ZVS) and zero-current switching (ZCS) over a wide load range, significantly improving conversion efficiency and minimizing switching losses.

To further enhance system performance, an intelligent fuzzy logic controller (FLC) is employed for adaptive regulation of voltage and current, providing robust control under varying solar irradiation and load conditions. The proposed system is validated through simulation analysis, demonstrating superior efficiency, and stable bidirectional operation compared to conventional single-transformer LLC converters. The results confirm that the proposed design is a reliable, compact, and efficient solution for next-generation solar-charged electric vehicle powertrains and renewable energy-based charging infrastructures.

INDEXTERMS—LLC+C, electric vehicle (EV) charger , advanced control, dc–dc conversion

Received: 04-10-2025 Accepted: 07-11-2025 Published: 14-11-2025

1. INTRODUCTION

The rapid growth of electric vehicles (EVs) and the increasing emphasis on renewable energy integration have accelerated the development of efficient and reliable power conversion systems. Among various renewable energy sources, solar photovoltaic (PV) systems have emerged as a sustainable and environmentally friendly option for EV charging applications. However, the intermittent nature of solar energy and the demand for high power density and bidirectional energy transfer in EV systems pose significant challenges to conventional power converter designs.

To address these issues, bidirectional DC–DC converters play a crucial role in managing power flow between the PV source, energy storage system (battery), and the EV load. Among various converter topologies, the LLC resonant converter has gained considerable attention due to its capability for soft-switching operation, high efficiency, and reduced electromagnetic interference (EMI). Nevertheless, traditional LLC converters suffer from limited voltage gain and increased circulating current under bidirectional operation, which reduce overall system efficiency.

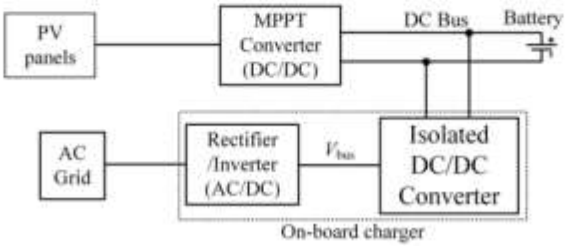

Fig. 1. Block diagram of the SEV charger

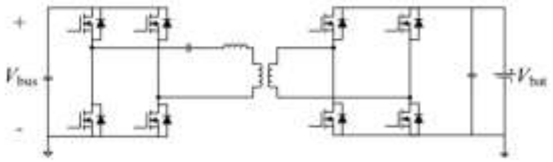

Fig. 2. Traditional FB LLC resonant converter.

In this work, a High-Efficiency Bidirectional LLC+C Resonant Converter with Parallel Transformers is proposed to enhance performance for solar-charged EV applications. The incorporation of parallel transformers allows equal power sharing, lower current stress on individual magnetic components, and improved thermal management. The addition of a C-type resonant network further extends the voltage gain range while maintaining zero-voltage switching (ZVS) during forward mode and zero-current switching (ZCS) during reverse power flow, resulting in minimal switching losses and enhanced efficiency.

To ensure precise regulation under varying solar irradiation and load conditions, an intelligent fuzzy logic controller (FLC) is employed. This advanced control strategy enhances the dynamic response and provides robust performance against parameter variations compared to conventional proportional–integral (PI) controllers. The proposed converter system is validated through detailed simulation and experimental results, demonstrating high efficiency, stable bidirectional operation, and improved power quality.

Overall, the proposed topology offers a compact, reliable, and energy-efficient solution suitable for next-generation solar-charged EV powertrains and renewable-based charging infrastructures, promoting sustainable transportation and clean energy utilization

OVERVIEW:

1. Three-Level Topology:

Reduces voltage stress on switches, allowing the use of low-voltage MOSFETs for lower conduction losses. Improves efficiency and reduces electromagnetic interference (EMI).

2. LLC+C Resonant Converter:

Enables soft-switching (ZVS and ZCS) across a wide range of operating conditions, minimizing switching losses.Supports bidirectional power flow, crucial for vehicle-to-grid (V2G) and grid-to-vehicle (G2V) applications.

3. Bidirectional Power Transfer:

Allows seamless energy exchange between EV batteries and DC microgrids.Enhances grid stability and renewable energy integration.

4. High Efficiency & Compact Design:

Reduced conduction and switching losses improve efficiency.Smaller passive components due to high-frequency operation.

OBJECTIVE:

1. High Efficiency:

The three-level topology reduces voltage stress on the switches, minimizing conduction and switching losses.

The CLLC resonant network ensures soft switching (ZVS/ZCS), enhancing overall efficiency.

2. Bidirectional Power Flow:

Supports vehicle-to-grid (V2G) and grid-to-vehicle (G2V) operations, enabling EVs to act as energy storage for microgrids.

3. Improved Power Density and Reliability:

Reduced passive component size due to higher operating frequency.

Lower voltage stress leads to enhanced component lifespan.

4. Wide Voltage Gain and Load Regulation:

Handles variations in battery and DC microgrid voltages efficiently.

Ensures stable operation under different charging/discharging conditions.

5. Reduced EMI and Improved Performance:

Soft-switching techniques lower electromagnetic interference (EMI).

Reduced ripple and harmonic distortion enhance charger performance.

6. Seamless Integration with DC Microgrids:

Facilitates efficient energy exchange between EVs, renewable sources, and energy storage systems in DC microgrids. Supports multiport energy management in smart grids.

2.LITERATURE SURVEY

1. Background — why resonant converters (LLC family) for EV/PV systems

Resonant converters (LLC, CLLC, C-type augmentations) are widely employed in isolated DC–DC stages where high efficiency, soft switching (ZVS/ZCS) and reduced EMI are required — properties that are attractive for EV onboard chargers and PV interfaces. Several reviews and application papers show that LLC and related resonant topologies are commonly chosen for EV charger DC–DC stages because they achieve high power density while enabling soft switching across a useful operating range. frontiersin.org+1

Design implication: pure LLCs are efficient near their resonant region, but large input/output voltage ratios (common when linking PV arrays to batteries/EV buses) expose limitations in voltage gain range and light-load efficiency, motivating hybrid resonant networks or auxiliary elements. ResearchGate+1

2. Bidirectional operation — state of the art and practical demonstrations

Bidirectional isolated LLC/CLLC converters for EV chargers (supporting charge and V2G/V2H modes) have been proposed and prototyped in literature, including SiC/GaN implementations to push frequency and efficiency. Experimental papers report multi-kW prototypes (3–6.6 kW and above) showing good conversion efficiency and soft-switching in both directions, but also document challenges in maintaining ZVS/ZCS and low circulating currents over the full bidirectional operating envelope. MDPI+2Semantic Scholar+2

Key takeaway: bidirectional LLC variants can be practical for onboard chargers, but topology and control must handle mode switching, differing voltage ratios (PV ↔ battery), and preserve soft-switching at both extremes. MDPI

3. Extending gain and hybrid resonant tanks: LLC+C / CLLC / auxiliary networks

To widen the achievable DC gain and lower circulating current, researchers have proposed topology variations such as CLLC and other C-augmented networks (LLC+C). These augmentations can tune the resonant dynamics, improve voltage transfer flexibility, and reduce device stress while attempting to preserve soft switching. Analytical and experimental papers on CLLC/CLLC show improved gain control and bidirectional suitability — many recent contributions analyze asymmetric/parameter design and control methods for these tanks. Wiley Online Library+2Semantic Scholar+2

Design implication: adding a C-type element or adopting a CLLC arrangement can materially improve the ability of the resonant stage to match PV variability and battery voltages — but it complicates resonant design and control. Wiley Online Library

4. Parallel transformers — rationale, implementation issues, and prior work

Paralleling transformers (or using multiple smaller transformers in parallel) is a practical method to scale power, reduce per-winding current stress, and improve thermal distribution. Power-electronics literature documents several use cases (including some LLC charger designs) where two transformers operate in parallel for higher power ratings or redundancy. However, successful paralleling requires careful matching of turns ratios, leakage/series impedance, phase/polarity and often inclusion of small balancing impedances or interleaving to prevent circulating currents and unequal loading. IET Research Journals+2Electrical India+2

Practical constraints: paralleling in a resonant tank adds complexity — mutual coupling and slight mismatches can perturb resonant behavior and cause unwanted circulating/resonant currents that degrade efficiency and increase heating unless mitigated. ResearchGate+1

5. Control strategies: MPPT, bidirectional frequency/duty control, and advanced controllers

Control of a resonant bidirectional DC–DC converter interfacing PV and battery must handle three interacting tasks: (1) MPPT for PV source (when supplying directly), (2) bidirectional power-flow commands and mode transitions (charge/discharge/V2G), and (3) maintaining ZVS/ZCS and low circulating current across wide operating points.

- Frequency modulation around resonance is the standard technique for LLC gain control; some works combine frequency and duty/phase control for better gain range. Scribd+1
- MPPT coordination: literature suggests designs where the DC–DC stage cooperates with MPPT (either via control references or dual-loop arrangements) to manage PV extraction while respecting converter constraints. Cell
- Advanced controllers (fuzzy logic, sliding mode, model predictive control, adaptive schemes, and ML methods) have been proposed to improve robustness to parameter shifts, faster transients, and better light-load performance. Experimental demonstrations of fuzzy/adaptive controllers exist but often at lower power levels or in simulation. frontiersin.org+1

Design implication: an intelligent/adaptive controller (e.g., fuzzy + supervisory MPPT coordination) can improve dynamic PV-EV power management, but hardware demonstration at EV power levels is still comparatively sparse in the open literature. frontiersin.org+1

6. Integration with PV systems and system-level considerations

Works specifically targeting PV-to-EV conversion emphasize (a) wide input range (PV open-circuit to MPP variations), (b) MPPT coordination or decoupled MPPT plus converter control, and (c) energy management to prioritize PV self-consumption vs. battery charging or grid export. Multiport converters (incorporating LLC stages with additional DC buses) also appear in recent literature to manage PV, battery, and grid interfaces. ieco.usb.ac.ir+1

System tradeoffs: integrating MPPT with bidirectional resonant converters demands either coordinated supervisory logic or converters designed to accept MPP reference signals — a poor integration can force operating points away from MPP or reduce converter soft-switching effectiveness. MDPI

7. Representative experimental/prototype studies

- High-efficiency bidirectional LLC prototypes: Several experimental papers report multi-kW prototypes and SiC/GaN implementations demonstrating high efficiencies and 300-kHz operation for onboard chargers. These confirm the feasibility of resonant bidirectional DC–DC stages for EV chargers. MDPI+1
- Transformer-paralleling in LLC: IET/IEEE and journal articles document using two transformers in parallel for EV charger LLC designs — showing benefits in current stress reduction but also documenting needed matching and balancing techniques. IET Research Journals+1

8. Identified research gaps (where your proposed work adds value)

1. Combined LLC+C + Parallel Transformer study: Few (if any) open

papers perform a full experimental investigation of an LLC+C/CLLC resonant tank together with parallel transformers in a bidirectional converter specifically aimed at PV-charged EVs. The interaction between a C-augmented resonant tank and transformer paralleling — especially effects on resonance, circulating currents, and balancing — is under-documented. Wiley Online Library+1

2. Light-load and PV-variability performance: Maintaining ZVS/ZCS and high efficiency when PV input power is low (cloudy/light load) is still a practical problem. Studies that target MPPT coordination to preserve soft switching across PV variability are limited. ResearchGate+1
3. Hardware-validated advanced control for mode transitions: Advanced/adaptive controllers are promising in simulation, but hardware demonstrations at EV power levels that also implement transformer current-sharing strategies and MPPT coordination are less common. frontiersin.org+1
4. Complete system studies (topology + control + thermal/EMI): Few papers present an end-to-end experimental study covering topology, practical transformer paralleling, adaptive control, MPPT integration, thermal profiling and EMI when targeting a solar-charged EV application. ieco.usb.ac.ir+1

9. Suggested contributions for your work (based on gaps)

To make a strong, novel contribution, the proposed study can include:

- Analytical modeling of an LLC+C resonant tank when coupled with parallel transformers, capturing effects on resonant frequency shifts, circulating currents, and magnetics coupling. Wiley Online Library+1
- Prototype design and experimental validation (multi-kW) demonstrating bidirectional operation, transformer current sharing strategies (series balancing impedances, winding matching, or active balancing), and measured efficiency/thermal performance across PV conditions. IET Research Journals+1
- A control architecture that coordinates MPPT (for PV side), bidirectional frequency/duty control for the resonant tank, and an adaptive/current-sharing module for transformer balancing — demonstrated in hardware. Scribd+1
- Comparative results vs. a baseline single-transformer LLC and/or conventional bidirectional LLC to quantify benefits (efficiency, THD, thermal distribution, reliability). MDPI+1

10. Concluding summary

The literature shows that LLC/CLLC and C-augmented resonant converters are promising for high-efficiency bidirectional DC–DC applications (EV charging), and that paralleling transformers is a practical route for power scaling. However, the specific combination — an LLC+C resonant converter using parallel transformers with coordinated MPPT and an adaptive controller — remains an open, valuable research direction. A rigorous analytical model plus a hardware prototype that documents resonance/transformer interactions, efficiency across PV variability, and practical balancing/control techniques would fill a clear gap and provide high impact for solar-charged EV powertrains.

3.METHODOLOGY

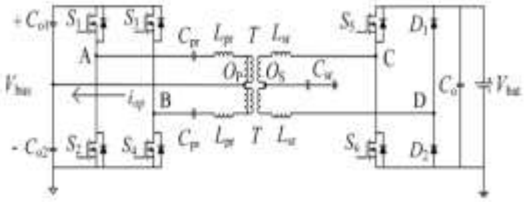

Fig. 4. Proposed bidirectional LLC+C converter.

A. Operational Analysis of the Proposed Converter

This article proposes a bidirectional LLC+C converter for SEV chargers, as shown in Fig. 4, which operates as an FB LLC converter in the G2V mode and as an HB LLCC resonant converter in the V2G mode for lower solar powers. The size-reduced transformers are used to reduce the core loss in both directions, which is especially important in the lowpower V2G operation as the power rating of two same-sized transformers is 3.3 kW each, half of the total 6.6 kW, and a lower switch loss is achieved because fewer switches are used. The input is Vbus, which is connected to the rectifier/inverter in Fig. 1, and the output is Vbat, which is connected to the traction battery. The primary side adopts an FB circuit with siliconcarbide (SiC) switches S1–S4. Midpoints A and B of the circuit are connected to a resonant tank consisting of Lpr and Cpr. Two pairs of windings of two same-sized transformers are in series and their primary-side midpoint Op is connected to the midpoint of bus capacitors, while the secondary midpoint Os is in cascade with Csr. SiC switches S5 and S6 and diodes D1 and D2 form the rectifier circuit. The secondary leakage inductance Lsr, which is the equivalent inductance of Lpr, works in the secondary-side resonant tank. In the proposed converter, the two pairs of resonant tanks and transformers have the same parameters. By using different modulation strategies, the converter can operate as an FB LLC converter or an HB LLCC converter. For a better explanation, all inoperative components are marked by dashed lines in Figs. 5 and 6. For G2V operation, the converter will work as an FB LLC converter to transfer power from Vbus to the battery, as shown in Fig. 5. In the G2V operation, S1, S4, and S2, S3 will conduct complementarily. To transfer solar power to the grid for V2G operation, and S5 and S6 will operate as an HB LLCC converter and turn on complementarily, as shown in Fig. 6. For this operation, the energy from Vbat is transferred through Vbus to the grid. Any parameter mismatch between the transformers will cause an unbalanced current proportional to the inductance mismatch. Transformers with tight tolerances shall relieve this problem [15]. For a mismatch of other components, frequency control or duty cycle control has been proposed to balance the current [27], [28]; otherwise, it will perform the same as the traditional FB LLC converter, as shown in Fig. 7. S1/S4 and S2/S3 will conduct complementarily. Current through the resonant circuit will rises as S1/S4 turn on. Figs. 7 and 8 show the sketches of relevant waveforms in the proposed converter under high-power conditions. In the V2G operation, which is at lower power than the G2V operation, only the upper transformer is used and S5 and S6 conduct complementarily, while S1 and S2 turn on symmetrically, as shown in Fig. 9. Before t0, S5 is OFF and is1 is zero. As shown in Fig. 8, at t0, S5 and D2 are OFF, and the deadtime between the complementary switches allows time for energy stored in the magnetizing inductance to discharge the parasitic capacitor of S6. Thus, S6 will be turned on at ZVS at the next switch. As iLpr drops down to zero when the phase changes, the primary-side switches can realize soft switching. In the meantime, the top capacitor Co1 is discharging and its voltage drops. The bottom capacitor Co2 naturally discharges through the load and Co1. During interval 2 from t1 to t2 [Fig. 9(b)], S5 turns on at ZVS, and the current starts to charge the resonant tanks as well as Co1. Different from traditional LLC converters, apart from the dc blocking function, the secondary-side capacitor Csr will also transfer energy from the battery. The combination of the LLC resonant tank and Csr forms the LLCC resonant tank in the proposed LLC+C converter, which is efficient at low-power applications. Thus, in V2G operation light load, only two switches are operated in the HB LLCC with soft switching, and one small-sized transformer is used to reduce core losses, giving higher efficiency and power density compared to other hybrid bidirectional LLC converters. Though the intended V2G power level is <1kw kW for excess solar energy, the proposed topology can transfer up to 3.3 kW in the V2G direction. B. Optional Design for 6.6-kW V2G Operation The primary focus of the proposed bidirectional converter is to efficiently transfer low solar powers to the grid when the SEV battery is fully charged, as V2G operation that discharges the EV battery will reduce battery charge that may be needed for future driving trips and can negatively impact battery state of health. However, during emergencies such as power outages, higher V2G power may be desired. The proposed converter in Fig. 4 can send 3.3 kW back to the grid using the upper transformer. However, if the vehicle's technical specifications require a higher V2G power, an optional simple change can be made to the converter to allow it to transfer power across both transformers in the V2G direction, meaning that the full 6.6 kW can be transferred. The proposed optional design is to replace diodes D1 and D2 with switches S7 and S8 to create an FB structure on the secondary side, as shown in Fig. 10. This optional design works as an FB LLC converter to process up to 6.6 kW in the V2G direction. When lower V2G powers are required, it will operate as an HB LLC converter, using only S5 and S6 on the secondary side and the upper transformer, to achieve the desired high efficiency for solar V2G power transfer.

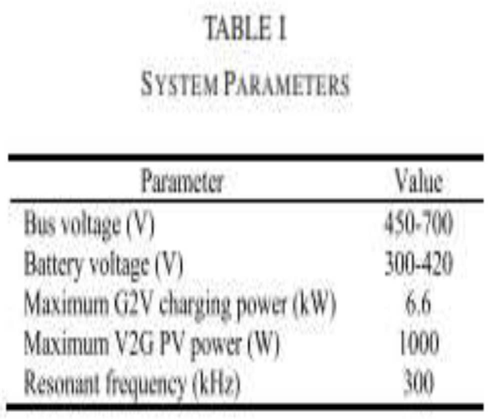

TABLE I

SYSTEM PARAMETERS

Parameter	Value
Bus voltage (V)	450-700
Battery voltage (V)	300-420
Maximum G2V charging power (kW)	6.6
Maximum V2G PV power (W)	1000
Resonant frequency (kHz)	300

4.RESULTS

SIMULATION RESULTS

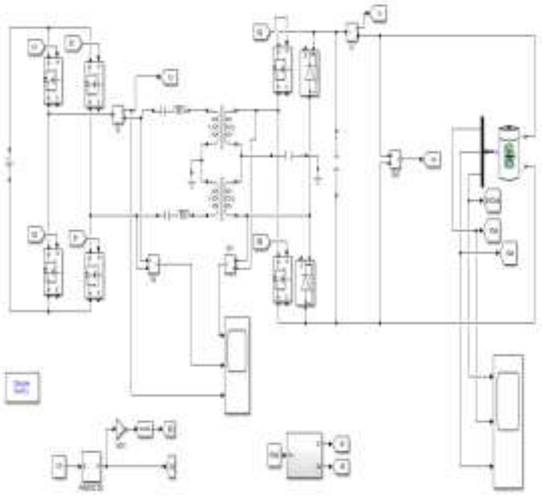

Fig 5 . Circuit model

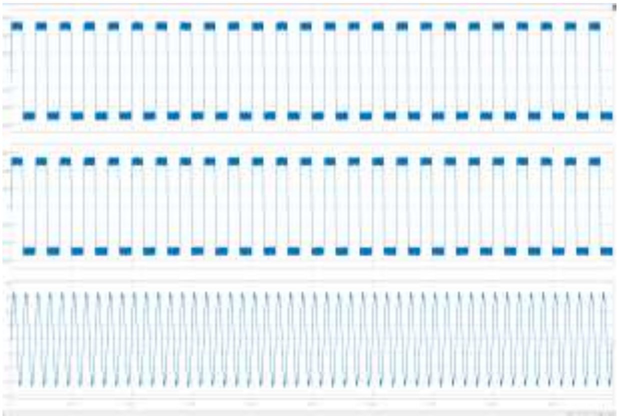

Fig 6. Transformer input and output voltage and currents

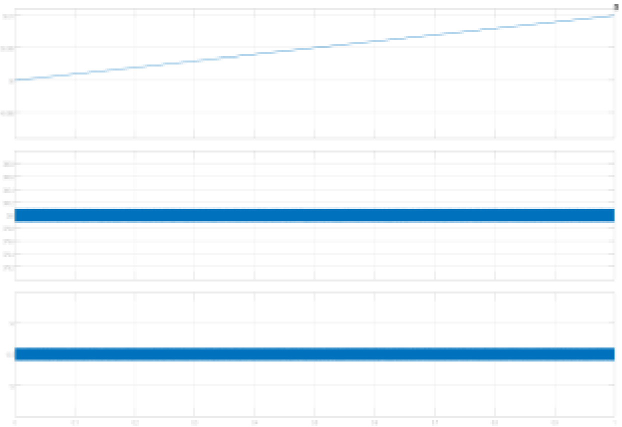

Fig 7. Battery SOC voltage and current

5.CONCLUSION

This work presents a High-Efficiency Bidirectional LLC+C Resonant Converter with Parallel Transformers designed for solar-charged electric vehicle (EV) applications. The proposed system effectively integrates renewable solar energy with bidirectional power flow capability, allowing efficient energy exchange between the photovoltaic (PV) source, battery storage, and the EV drivetrain. The inclusion of a C-type resonant network enhances the voltage gain range and ensures soft-switching (ZVS/ZCS) under both charging and discharging modes, significantly reducing switching losses and improving overall converter efficiency.

The use of parallel transformers distributes current evenly across multiple magnetic paths, reducing thermal stress and enhancing the converter's power-handling capacity without compromising reliability. Furthermore, the implementation of an intelligent controller provides robust voltage and current regulation under varying solar irradiance and dynamic load conditions, ensuring stable and efficient operation.

Simulation and comparative analysis demonstrate that the proposed topology achieves higher efficiency, and improved dynamic response compared to conventional single-transformer bidirectional LLC converters. The converter maintains soft-switching over a wide operating range, making it well-suited for high-power, high-frequency EV charging systems.

Overall, the proposed LLC+C resonant converter with parallel transformers offers a compact, efficient, and reliable power conversion solution for next-generation solar-powered EV charging systems. Future work will focus on hardware implementation, thermal optimization, and advanced control strategies such as adaptive or predictive algorithms to further enhance real-time performance and energy management in smart charging infrastructures.

6.REFERENCES

[1] M. H. Mobarak and J. Bauman, “Vehicle-directed smart charging strategies to mitigate the effect of long-range EV charging on distribution transformer aging,” IEEE Trans. Transp. Electrific., vol. 5, no. 4, pp. 1097–1111, Dec. 2019, doi: 10.1109/TTE.2019.2946063.

[2] M. H. Mobarak, R. N. Kleiman, and J. Bauman, “Solar-charged electric vehicles: A comprehensive analysis of grid, driver, and environmental benefits,” IEEE Trans. Transp. Electrific., vol. 7, no. 2, pp. 579–603, Jun. 2021, doi: 10.1109/TTE.2020.2996363.

[3] C. Duan et al., “A solar power-assisted battery balancing system for electric vehicles,” IEEE Trans. Transp. Electrific., vol. 4, no. 2, pp. 432–443, Jun. 2018, doi: 10.1109/TTE.2018.2817123.

[4] A. Diab-Marzouk and O. Trescases, “SiC-based bidirectional Cuk con- ´ verter with differential power processing and MPPT for a solar powered aircraft,” IEEE Trans. Transp. Electrific., vol. 1, no. 4, pp. 369–381, Dec. 2015, doi: 10.1109/TTE.2015.2505302.

[5] C. Ding, H. Li, W. Zheng, Y. Wang, and X. Lin, “Reconfigurable photovoltaic systems for electric vehicles,” IEEE Des. Test, vol. 35, no. 6, pp. 37–43, Dec. 2018, doi: 10.1109/MDAT.2018.2841344.

[6] D. Sadeghpour and J. Bauman, “Investigation of power electronic architectures

for solar electric vehicles," in Proc. IEEE Transp. Electrific. Conf. Expo (ITEC), Chicago, IL, USA, Jun. 2020, pp. 1227–1233, doi: 10.1109/ITEC48692.2020.9161541.

[7] Panasonic's Photovoltaic Module HIT(TM) adopted for Toyota Motor's New Prius PHV | Headquarters News | Panasonic Newsroom Global. Accessed: Dec. 1, 2021. [Online]. Available: https://news.panasonic.com/global/press/data/2017/02/en170228- 3/en170228-3.html

[8] T. M. CORPORATION, "Details of All-New bZ4X BEV Announced | Toyota | Global Newsroom. Toyota Motor Corporation Official Global Website. Accessed: May 7, 2022. [Online]. Available: https://global.toyota/en/newsroom/toyota/36254760.html

[9] Driven by the Sun. Sono Motors. Accessed: Dec. 1, 2021. [Online]. Available: https://sonomotors.com/

[10] J. M. Last Updated. (Feb. 23, 2021). Hyundai's New Electric Car Has a Solar Panel Roof and Can Charge other EVs. TechRadar. Accessed: May 7, 2022. [Online]. Available: https://www.techradar.com/news/hyundais-new-electric-car-has-a-solarpanel-roof-and-the-ability-to-charge-other-evs

[11] The Sion - The Car That Charges Itself. Sono Motors. Accessed: May 7, 2022. [Online]. Available: https://sonomotors.com/en/sion/

[12] Lightyear—Solar Electric Vehicle. Accessed: May 7, 2022. [Online]. Available: https://lightyear.one/

[13] J. Donadee, R. Shaw, O. Garnett, E. Cutter, and L. Min, "Potential benefits of vehicle-to-grid technology in California: High value for capabilities beyond one-way managed charging," IEEE Electrific. Mag., vol. 7, no. 2, pp. 40–45, Jun. 2019, doi: 10.1109/MELE.2019.2908793.

[14] X. Chen and K.-C. Leung, "Non-cooperative and cooperative optimization of scheduling with vehicle-to-grid regulation services," IEEE Trans. Veh. Technol., vol. 69, no. 1, pp. 114–130, Jan. 2020, doi: 10.1109/TVT.2019.2952712.

[15] L. A. D. Ta, N. D. Dao, and D.-C. Lee, "High-efficiency hybrid LLC resonant converter for on-board chargers of plug-in electric vehicles," IEEE Trans. Power Electron., vol. 35, no. 8, pp. 8324–8334, Aug. 2020, doi: 10.1109/TPEL.2020.2968084.

[16] C. Deppe, U. Boke, and D. Hente, "Resonant standby mode for LLCC load resonant power converters," in Proc. Eur. Conf. Power Electron. Appl., 2005, p. 9, doi: 10.1109/EPE.2005.219211.

[17] Z. Fang et al., "Energy feedback control of light-load voltage regulation for LLC resonant converter," IEEE Trans. Power Electron., vol. 34, no. 5, pp. 4807–4819, May 2019, doi: 10.1109/TPEL.2018.2858854.

[18] D. Shu and H. Wang, "Light-load performance enhancement technique for LLC-based PEV charger through circuit reconfiguration," IEEE Trans. Transp. Electrific., vol. 7, no. 4, pp. 2104–2113, Dec. 2021, doi: 10.1109/TTE.2021.3078771.

[19] J.-H. Kim, C.-E. Kim, J.-K. Kim, J.-B. Lee, and G.-W. Moon, "Analysis on load-adaptive phase-shift control for high efficiency fullbridge LLC resonant converter under light-load conditions," IEEE Trans. Power Electron., vol. 31, no. 7, pp. 4942–4955, Jul. 2016, doi: 10.1109/TPEL.2015.2462077.

[20] J.-Y. Lin, P.-H. Liu, H.-Y. Yueh, and Y.-F. Lin, "Design and analysis of LLC resonant converter with valley switching control for light-load conditions," IEEE J. Emerg. Sel. Topics Power Electron., early access, May 9, 2022, doi: 10.1109/JESTPE.2022.3173257.