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A Review of Efficient Power Converters in Electric Vehicle Charging

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Abstract Electrical Vehicles are better alternative to gasoline vehicles and EVs are greener mode of transport for people. The major aspect in EV is its charging. A charging station has different levels of power based on specification and in each charger a power converter is used. For each EV battery charger, a converter gives better result. In this paper some efficient power converters are analysed and discussed. The approximate efficiency and drawbacks are also discussed and finally suitability for EV is given for each converter.

***Index Terms*— Cuk Converter, DC-DC Converter, Electric Vehicle, Luo converter, SEPIC, Vienna Rectifier.**

INTRODUCTION

OWER electronic converters are one of the key components of applications which involve power storage and usage. Some of the Papplications include Switch Mode Power Supplies, Renewable Energy conversion, Electric Vehicle Charging, Machine motion control, LED optimization etc., In Power Electronics, we control the Electric Power flow using power switches with storage (passive) elements to obtain required levels of voltage and current demanded. With the evolution of modern convertor topologies the overall system efficiency has improved.

In EV charging a power converter is main link between power source and Battery. The design, cost and reliability of converter is very important in EV charging stations. In this context, we are going to discuss some contemporary converters in this paper. These converters are SEPIC, Luo, Zeta, Cuk converters and Vienna Rectifier. Many modern topologies involving these converters at present use suitable capacitor to store/supply energy to load.

II. POWER CONVERTERS

The basic purpose of each converter is to reduce line current THD and improve net power available to the battery for charging. The level of converters depends on storage elements (inductor & capacitor) present in the circuit of converter. In this paper we discuss four level converters with two inductors and two capacitors in converters. Depending on power level required these converters can be designed for single / three phase or for direct DC charging.

Buck, Boost & Buck-Boost Converters are primary/initial level of converters to be discussed. These converters are

used as switched mode regulators with suitable control. The circuits of Buck, Boost and Buck- Boost converters are shown in Fig. 1. In a Buck converter, the average output voltage is less than input voltage. In a Boost converter, the average output voltage is greater than input voltage. In a Buck-Boost converter, the average output voltage is less/greater than input voltage depending on duty ratio of switch.

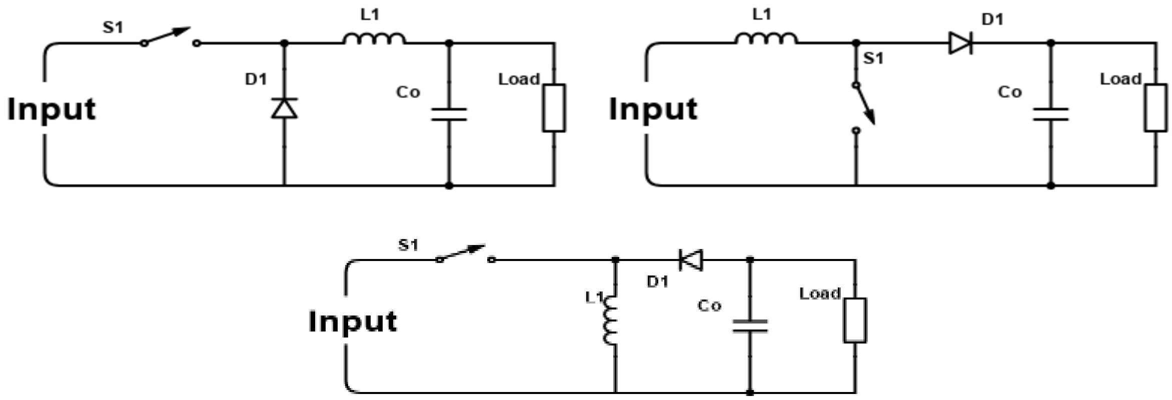

Fig. 1 Buck, Boost and Buck-Boost Converters

Buck Converter gives unidirectional output current, one polarity of voltage output and the efficiency will be greater than 90%. In Boost converter output is very sensitive to duty ratio; this requires large filter capacitance and inductor than those of Buck converter. Buck-Boost gives high efficiency as this converter has advantages of both Buck and Boost converters. Basic Buck-Boost topology provides reversal of output voltage polarity [1]. To improve output quality and to suit for applications like EV charging we need to use high level converters like these which we are going to discuss in this paper.

A. SEPIC

The SEPIC converter has an advantage of low output current ripple, which is good to improve life time of battery. The SEPIC conventional circuit [2] is presented in Fig. 2.

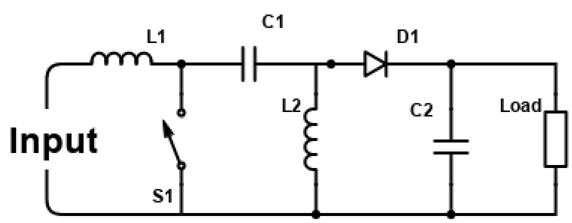

Fig. 2 Conventional SEPIC

The Switch S1 will be a MOSFET and by varying the duty cycle we get the Buck or Boost output from converter. If generated power level is low (like PV source) we use boost mode and if power level is high (like from High voltage Grid) we go for Buck mode to charge an electric vehicle. In literature we can find many modified topologies for PFC and high voltage gain. In [3] an improved and efficient SEPIC converter was simulated to reduce THD and in [4] a converter with more number of components than traditional one is presented to decrease overall losses of converter.

B. Cuk Converter

Cuk Converter has many advantages compared to other DC-DC converters. This can be used in low voltage vehicles like E-bikes (Hybrid Bicycle & Low CC Motor Bike), E-rickshaws etc. A Conventional Cuk Converter [5] is shown in Fig. 3.

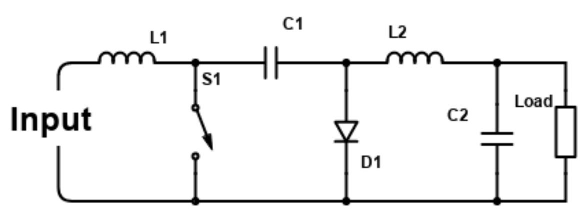

Fig. 3 Conventional Cuk Converter

For Solar energy charging stations we can use Cuk regulator for smooth flow of energy between PV and DC link. Different converters based on Cuk [6], [7] were present to improve power supply available to EV during charging.

C. Zeta Converter

The Zeta converter belongs to family of SEPIC converters. In Zeta converter the switch is placed on input unlike SEPIC where switch is on low voltage side. The Circuit diagram of a Zeta Converter [8] is shown in Fig.4.

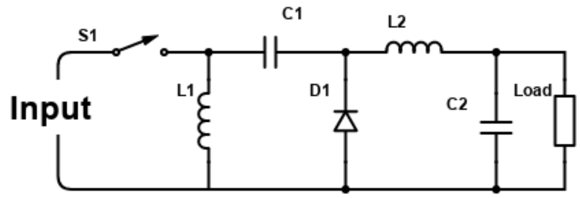

Fig. 4 Circuit Diagram of Zeta Converter

Zeta topology can be preferred when low ripple positive output voltage is required compared to basic SEPIC converter [9]. Using a Bidirectional Zeta converter, Low Frequency Ripple Current Charging of Li-ion Battery can be done as in [10] which improves charging time and transfer efficiency. Many modified Zeta-SEPIC topologies were under research for better charging performance of EV. Zeta can be used to use solar generated energy to feed an EV [11].

D.Luo Converter

Luo converters are derived from elementary Zeta/SEPIC circuits and named after its inventor. Luo converter is combination of Switched Capacitor, Voltage Lift and Impedance network. The Elementary circuit of Luo converter [12] is based on Fig. 4.

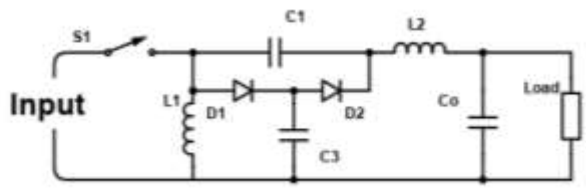

Fig. 5 Self-Lift Luo Converter

Voltage lift can be done by adding shunt elements to capacitor C1 (replacing Diode D1 with capacitor and diodes) and the voltage lift can be self lift, re-lift, triple or even quadruple as in [12]. For Battery electric car, Luo converters are suitable as they provide high power density with simple structure due to voltage lift capability. It is also a better choice for using Solar Energy to charge EV in off-grid areas [13]. A Modified Bridgeless Luo Converter as in [14] can be used in high power EV charger which offers high precision, high power density and low cost in a single switching cycle.

E. Vienna Rectifier

Vienna rectifier has proven application in non-conventional renewable energy production. This rectifier provides active power factor correction with simple control.

In a charging station with hybrid smart grid for medium / high power applications with non-isolated input Vienna rectifier gives better result. This rectifier in three phases gives high power density which can be used for a large Electric Vehicle [15]. High Power to weight ratio, low THD, Small filter size needed makes it suitable for EV applications [16]. Different control strategies are present to improve efficiency and in turn which are used for EV applications. This can be used in high power (DC fast) charging stations [17]. The Uni-directional nature as this is a rectifier is only point to be considered while considering the converter to use.

III. SOME RECENT CONVERTERS IN EVs

Power converters used in Charging have minimum effect on Supply (either AC or DC), Reduced Switching Losses, simple & smaller size and less distortion in the output [23].

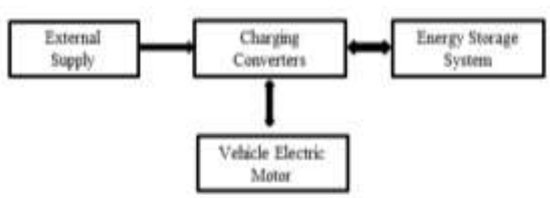

Fig. 6: Block Diagram of Converter Usage

The Block diagram of converter usage is presented in Figure 6. The converters takes power from supply and stores it in energy storage system and these converters supply the power from storage to run the motor. At times of regenerative breaking power s returned to battery bank through these converters. Some of such converters are discussed in this paper.

A. ZVS Interleaved AC-DC BOOST PFC Converter

This Converter is used for front-end conversion followed by a DC-DC Buck Converter. The converter consists of switches probably MOSFETs, series inductance and shunt capacitance. The voltage switching happens at the instant of Zero Voltage and this is achieved by introducing a very small Dead time between MOSFET switching. The parasitic capacitance of MOSFET gets charged and discharged before this dead time. Series Inductor acts as Boost Inductor and its value [23] is given by

$$Boost\ PFC\ Inductor(L) = \frac{V_{Bus} \times D(1-D)}{f_s \times \Delta I_L} \ldots (1)$$

This configuration has numerous advantages like near unity PF, Soft switching, near zero losses in switching and efficient in Battery charging. As EVs need charging in range of 48V to 400V, the desired voltage can be supplied by this converter. The disadvantage of this converter is limited control of duty ratio and control is to be done by an auxiliary circuit for Zero Voltage Switching to get wide range of output Voltage and universal input voltage (86 – 265 RMS) [24].

B. Partial Power DC-DC Converter

Only a fraction of power is converted using converter and the rest is bypassed directly to the load, hence the name Partial Power converter. As intermediate conversion takes place only for partial time the losses like magnetic, switching, conduction losses gets decreased. This makes the converter attractive for usage in DC fast charging stations. This converter can be used in grid connected fast charging and the efficiency of this partial Converter is 3% more compared to full converter [25].

A Partial Power Converter is analysed in [26] by scaling down as two prototypes. It is concluded that this type of converters do not require galvanic isolation and the size of converter also gets reduced in Partial Power method.

C. Quadratic Double Boost Converter

In Renewable Sources like solar, the voltage output is small and a Boost is required, to use this power directly to charge an EV a double Boost converter is best suited [27]. By using principle of superposition Double Boost can be obtained by overlapping the supply with capacitance discharge to charge an EV battery. This Double boost improves the overall solar efficiency to 80% but the control is complex as more number of diodes is used for superimposing the voltage [28].

D. Bi-Directional DC-DC Converter

A three level Bi-directional converter can be used for storage of energy in battery and retrieval for supplying to motor. This can be used efficiently for different modes of driving. In [29] a converter is proposed, here battery gets charged in buck mode and gets discharged in Boost mode. Passive Elements L and C act as filters in conversion.

Pulse Width Modulated strategies are used in this type of converters. This technique compares reference current with battery input current and controls the on and off process of switching. In charging control Phase locked loop extracts the required current for sinusoidal signal generation [30].

E. Multi Level Converters

In Interleaved converter the conversion takes place with the help of passive elements but in multi-level converter the conversion happens by dividing the voltage into n levels by proper switching elements. The number of switches used is less compared to conventional interleaved converter, component stress; cost of converter is also less in multilevel converters [31].

The Battery of EV is under usage for several cycles, so voltage stress is high on it. When variable charge profile is needed multilevel inverters are suitable, the chargers with this converters also has reduced voltage stress [32]. Due to lesser passive storage elements the conversion efficiency of multi-level converters is also superior compared to interleaved converters.

IV. COMPARISON OF CONVERTERS

The converters studied are compared and shown in Tabular form. In Table 1 the mode of operation, approximate THD and efficiency are shown. In Table 2 the
drawbacks of each converter are given along with remarks on usability of converters. The advantages of the power converters reviewed include low current ripple, high power output, reliable efficiency and Current THD less than 5% as per IEC Standard 61000-3-2.

A Cuk and SEPIC can be fused together. This design produces power continuously and efficiently from available renewable energy. In turn the power produced from this fused converter can be used to charge an EV [22]. Luo Converters with ultra lift technique provides high power output with given input compared to other converters. A number of researchers have been studying to implement Vienna Rectifier in on-board chargers as in [15] and research is being carried out to use Vienna rectifier off-board as this gives high power density per charging cycle.

In the studied converters and the multi-level converters are very efficient for usage in the Electric Vehicle compared to other converters. The converters are useful based on the application like for Solar Power Double Boost converter gives overall system efficiency as 80%.

Table 1: Comparison of THD and Efficiency of Converters

Converter	Reference	Mode of operation	Current THD (%)	Efficiency (%)
SEPIC	[2-4][18]	Buck-Boost	~ 3	~ 90
Cuk	[5-7][19]	Buck-Boost	~ 4.8	~ 95
Zeta	[8-11][20]	Buck-Boost	~ 2	~ 94
Luo	[12-14] [21]	Advanced Buck-Boost with voltage lift	~ 3.5	~ 92
Vienna	[15-17]	Boost	~ 3	> 95
ZVS AC-DC	[23][24]	Boost-Buck	~ 2	~ 95
Partial Power DC-DC	[25][26]	Boost	~ 1.5	~ 96
Quadratic Double Boost	[27][28]	Double Boost	~ 3.5	~ > 80
Bi-directional DC-DC	[29][30]	Buck in charging, Boost in discharging	~ 2.5	High
Multi- Level	[31-33]	Multi-level Boost	~ 2	~ 97

Table 2: Drawbacks of Converters

Converter	Drawbacks	Remarks
SEPIC	• Switching Stress is high but less than Cuk Converter • A compromise between capacitors and power density happens	Low current ripple which improves efficiency.
Cuk	• Negative power output of this converter makes sensing circuit complex. • High Switch voltage stress for same output compared to SEPIC	Higher Power Output and low pulsating current compared to SEPIC. Can be used to charge low power EVs like Bike & Rickshaw.
Zeta	• Requirement of high-input voltage ripple • Larger flying capacitor at input [21]	Compensation is easier in Zeta compared to SEPIC. Can be used for Solar powered charging station.
Luo	• Care has to be taken with voltage-lift (Super-lift & Ultra-lift) as it may lead to EMI/EMC issues	Luo converter with Ultra-lift technique is used at present for better efficiency
Vienna	• Unidirectional operation and restricted reactive power control	Suitable to use in Off-board vehicle charging applications in off-grid areas as charging is unidirectional.
ZVS AC-DC	• Limited Control of Duty Ratio and need of auxiliary circuit for control	Soft switching, near unity PF
Partial Power DC-DC	• Need accurate control timings for partial power processing	Do not need galvanic isolation, size of converter is also less
Quadratic Double Boost	• Number of diodes get increased in the circuit	Suitable for efficient Solar Energy operations
Bi-directional DC-DC	• Need extra elements like Phase Locked Loop in the control process and more passive elements compared to other converters	These are useful particularly in on-board chargers and motor drive trains
Multi-Level	• Commutation control is more complex as power switches are more	Lesser passive storage elements compared to interleaved converters

V. CONCLUSIONS

In this paper, comparison of some converters which can be used in EV Charging Station is done. It is understood from literature that the SEPIC, Cuk converters can be used for low power EVs, Zeta can be used for Solar Powered EV charging, Luo converter can be used for high power EVs and Vienna can be used for On-board and Off-board Off-grid EV charging stations. There is a future scope to design novel topologies / adding extra filter elements to further improve Power converter quality. The improvement of Power converters makes EV charging cheaper and reliable which in turn increase number of EV charging stations.

REFERENCES

[1] Rashid, Muhammad H. "Power Electronics Circuits, Devices and Applications", 4th Ed. Pearson education, 2014

[2] G. Mohanty, "SEPIC Based Multi Input Dc-Dc Converter," 2019 IEEE 5th International Conference for Convergence in Technology (I2CT), 2019, pp. 1-4, doi: 10.1109/I2CT45611.2019.9033886.

[3] Golam Sarowar et al, "Simulation of High Efficiency Switched Capacitor AC to DC SEPIC Converter for Improved Power Quality", International Journal of Computer Science and Network Security, Vol. 16 No. 10 pp. 9-15.

[4] R. Kushwaha and B. Singh, "An Improved SEPIC PFC Converter for Electric Vehicle Battery Charger," 2019 IEEE Industry Applications Society Annual Meeting, 2019, pp. 1-8, doi: 10.1109/IAS.2019.8912344.

[5] Wenzheng Xu, K. W. E. Cheng and K. W. Chan, "Application of Cuk converter together with battery technologies on the low voltage DC supply for electric vehicles," 2015 6th International Conference on Power Electronics Systems and Applications (PESA), 2015, pp. 1-5, doi: 10.1109/PESA.2015.7398944.

[6] A. Kumar and B. Singh, "Solar Fed Cuk Converter Based SRM Drive Control of E-Rikshaw," 2020 3rd International Conference on Energy, Power and Environment: Towards Clean Energy Technologies, 2021, pp. 1-6, doi: 10.1109/ICEPE50861.2021.9404389.

[7] Wenzheng Xu, K. W. E. Cheng and K. W. Chan, "Application of Cuk converter together with battery technologies on the low voltage DC supply for electric vehicles," 2015 6th International Conference on Power Electronics Systems and Applications (PESA), 2015, pp. 1-5, doi: 10.1109/PESA.2015.7398944.

[8] A. M. Khatab, M. I. Marei and H. M. Elhelw, "An Electric Vehicle Battery Charger Based on Zeta Converter Fed from a PV Array," 2018 IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), 2018, pp. 1-5, doi: 10.1109/EEEIC.2018.8494541.

[9] https://www.analog.com/en/technical-articles/the-low-output-voltage-ripple-zeta-dc-dc-converter-topology.html

[10] J. S. Goud, K. R., K. R. and B. Singh, "Low Frequency Ripple Charging of Li-Ion Battery using Bidirectional Zeta DC-DC Converter to Improve Charge Transfer Efficiency," 2018 IEEE 7th International Conference on Power and Energy (PECon), 2018, pp. 62-66, doi: 10.1109/PECON.2018.8684089.

[11] B. Saha and B. Singh, "Sensor less PMBLDC Motor Driven Solar-PV Battery Fed EV System with Regenerative Braking Employing Zeta Converter," 2021 International Conference on Sustainable Energy and Future Electric Transportation (SEFET), 2021, pp. 1-6, doi: 10.1109/SeFet48154.2021.9375728.

[12] Fang Lin Luo, "Luo-Converters, a series of new DC-DC step-up (boost) conversion circuits," Proceedings of Second International Conference on Power Electronics and Drive Systems, 1997, pp. 882-888 vol.2, doi: 10.1109/PEDS.1997.627511.

[13] A.Manikandan , N.Vadivel. "Design And Implementation Of Luo Converter For Electric Vehicle Applications". International Journal of Engineering Trends and Technology (IJETT). V4(10):4437-4441 Oct 2013. Pp. 4437-4441.

[14] U. Muthuraman and R. Kabilan, "A High Power EV Charger based on Modified Bridgeless LUO Converter for Electric Vehicle," 2021 Third International Conference on Intelligent Communication Technologies and Virtual Mobile Networks (ICICV), 2021, pp. 512-515, doi: 10.1109/ICICV50876.2021.9388385.

[15] H. Vahedi, P. Labbe and K. Al-Haddad, "Single-Phase Single-Switch Vienna Rectifier as Electric Vehicle PFC Battery Charger," 2015 IEEE Vehicle Power and Propulsion Conference (VPPC), 2015, pp. 1-6, doi: 10.1109/VPPC.2015.7353019.

[16] G. Rajendran, C. A. Vaithilingam, N. Misron, K. Naidu and M. R. Ahmed, "Voltage Oriented Controller Based Vienna Rectifier for Electric Vehicle Charging Stations," in IEEE Access, vol. 9, pp. 50798-50809, 2021, doi: 10.1109/ACCESS.2021.3068653.

[17] Thandapani, T. & Karpagam, R. & Paramasivam, S.. (2015). Comparative study of VIENNA rectifier topologies. International Journal of Power Electronics. 7. 147. 10.1504/IJPELEC.2015.075420.

[18] M. Muntasir Nishat, M. A. Moin Oninda, F. Faisal and M. A. Hoque, "Modeling, Simulation and Performance Analysis of SEPIC Converter Using Hysteresis Current Control and PI Control Method," 2018 International Conference on Innovations in Science, Engineering and Technology (ICISET), 2018, pp. 7-12, doi: 10.1109/ICISET.2018.8745619.

[19] B. R. Ananthapadmanabha, R. Maurya and S. R. Arya, "Improved Power Quality Switched Inductor Cuk Converter for Battery Charging Applications," in IEEE Transactions on Power Electronics, vol. 33, no. 11, pp. 9412-9423, Nov. 2018, doi: 10.1109/TPEL.2018.2797005.

[20] S. Rezazade, M. Salehi, M. Changizian and E. Afjei, "Analysis of PFC Improvement and THD Reduction Achieved by PFC-based Zeta Converter and PWM-Rectifier," 2019 International Power System Conference (PSC), 2019, pp. 441-446, doi: 10.1109/PSC49016.2019.9081524.

[21] R. Kushwaha and B. Singh, "A Modified Luo Converter-Based Electric Vehicle Battery Charger With Power Quality Improvement," in IEEE Transactions on Transportation Electrification, vol. 5, no. 4, pp. 1087-1096, Dec. 2019, doi: 10.1109/TTE.2019.2952089.

[22] Jeff Falin, “Designing DC/DC Converters based o ZETA topology”, Texas Instruments Incorporated available at: https://www.ti.com/lit/an/slyt372/slyt372.pdf?ts=1620794793514&ref_url=https%253A%252F%252Fwww.google.com%252F

[23] M. Pahlevaninezhad, P. Das, J. Drobnik, P. K. Jain and A. Bakhshai, "A ZVS Interleaved Boost AC/DC Converter Used in Plug-in Electric Vehicles," in IEEE Transactions on Power Electronics, vol. 27, no. 8, pp. 3513-3529, Aug. 2012, doi: 10.1109/TPEL.2012.2186320.

[24] S. S. Indalkar and A. Sabnis, "An OFF Board Electric Vehicle Charger Based On ZVS Interleaved AC-DC Boost PFC Converter," 2019 8th International Conference on Power Systems (ICPS), 2019, pp. 1-6, doi: 10.1109/ICPS48983.2019.9067544.

[25] J. Rojas, H. Renaudineau, S. Kouro and S. Rivera, "Partial power DC-DC converter for electric vehicle fast charging stations," IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society, 2017, pp. 5274-5279, doi: 10.1109/IECON.2017.8216913.

[26] Anzola, J.; Aizpuru, I.; Arruti, A. Partial Power Processing Based Converter for Electric Vehicle Fast Charging Stations. Electronics 2021, 10, 260. https://doi.org/10.3390/electronics10030260

[27] Y. Raghunandan, Shivateja Manala, “Modelling of Double Boost DC-DC converter for Solar Based Electric Vehicle”, International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 10, 2018, pp. 61-67.

[28] Pires, Vitor & Foito, Daniel & Cordeiro, Armando. (2017). A DC–DC Converter With Quadratic Gain and Bidirectional Capability for Batteries/Supercapacitors. IEEE Transactions on Industry Applications. PP. 1-1. 10.1109/TIA.2017.2748926.

[29] V. K. Singh, Y. Sahu, P. K. Mishra, P. Tiwari and R. Maurya, "Charging of Electric Vehicles Battery Using Bidirectional Converter," 2020 International Conference on Electrical and Electronics Engineering (ICE3), 2020, pp. 82-88, doi: 10.1109/ICE348803.2020.9122843.

[30] A. H. AlMarzoogee and A. H. Mohammed, "Design a Bidirectional DC/DC Converter for Second-Level Electric Vehicle Bidirectional Charger," 2020 4th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT), 2020, pp. 1-3, doi: 10.1109/ISMSIT50672.2020.9254306.

[31] M. Abdel Monem et al., "Influence of selective harmonic elimination technique of Multi-Level DC/DC converter on second-life battery performances," 2013 International Conference on Renewable Energy Research and Applications (ICRERA), 2013, pp. 1107-1111, doi: 10.1109/ICRERA.2013.6749918.

[32] W. V. Wang, D. J. Thirmawithana, B. Riar and R. Zane, "A Novel Integrated Boost Modular Multilevel Converter for High Power Wireless EV Charging," 2018 IEEE Energy Conversion Congress and Exposition (ECCE), 2018, pp. 81-88, doi: 10.1109/ECCE.2018.8557404.

[33] F. Bento and A. J. Marques Cardoso, "Performance Assessment of Two Alternative DC-DC Converter Topologies for EV Charging Applications," 2020 Fifteenth International Conference on Ecological Vehicles and Renewable Energies (EVER), 2020, pp. 1-6, doi: 10.1109/EVER48776.2020.9243075.