Electrical Vehicle Based Bidirectional DC-DC Converter Analysis

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Abstract- *The electric vehicle was created for the modern world due to fuel constraints. The interest in electric vehicle applications has substantially increased thanks to bidirectional DC to DC converters. The challenging domain in smart grid (SG) is interactions between electric vehicles and either the grid (V2G) or individual vehicles (G2V). Future generations of electric vehicles (EVs) will be developed with the integration of renewable energies, making a greater contribution to the environment and lowering CO2 emissions. The purpose of this work is to develop a bidirectional DC to DC converter for electric vehicles (EV) that can be used for both grid-to-vehicle and vehicle-to-grid connections. PWM (Pulse Width Modulation) is used in a traditional bidirectional converter to generate the triggering pulse for the switches.*

Keywords- Electric Vehicle, Bi-directional DC-DC Converters, V2G, G2V, Smart Grid.

I. INTRODUCTION

The power sector is currently showing increasing interest in smart grids (SG). A strong, bi-directional communications infrastructure with distributed computers is made possible by the integrated communication and power system known as SG. This system also allows for improved control, stability, and controllability of optimum power delivery. Electric Power Research Institute (EPRI) defines the SG as a power system that (a) consists of various automatic transmission and distribution (T&D) systems that operate in a reliable, effective, and coordinated manner, (b) manages crisis situations with "self-healing" responses and responds to needs of utility and energy-market, (c) obligates zillions of consumers, and includes an effective communications infrastructure that enables the timely, flexible delivery of energy.

Since the last decade, electric vehicles (EVs)1 have witnessed a considerable increase in popularity. The progressive depletion of fossil fuels such as crude oil, coal, natural gas, and heavy oils, which are sought by the expanding populations of industrialised and emerging nations, is driving up demand [2]. Electric cars have become a class that is further divided into Hybrid Electric Vehicles (HEVs)2 and Plug-in Hybrid Electric Vehicles (PHEVs)3 due to continual efforts and pioneering research initiatives in the Battery Management System (BMS) for applications in EVs.Although the majority of EVs currently on the market are both HEVs and PHEVs, the desire for PHEVs is clearly higher. This is owing to the fuel flexibility provided by these cars, which can run on both traditional fuels like petroleum and gas as well as electric power stored in a battery (energy storage device).
Advanced Power Electronics Converters (PECs) and motor drives have been increasingly important in recent breakthroughs in car technology [3-6]. PECs and electric motor drives in electric vehicles (EVs) regulate the flow of electrical energy within the car, as well as from the external charging station or grid to the vehicle and vice versa. This makes EVs less polluting, more efficient, have better performance, and are more durable [4,5].

6 V to 12 V is required to start and run additional electric components in a traditional ICE car [7]. An electrically powered system is replacing hydraulic systems like brakes and mechanically driven systems like steering, making it more efficient and safer [2]. Luxurious features like as motorised windows, high-powered headlights, and auto start-up are included in sophisticated automotive systems that require more electricity and various voltage ratings to function. As a result, power electronics converters are to blame for the growth of electric vehicles [8].

Different types of ESSs are coupled to various types of power electronic converters in EVs [9-11]. ESSs are charged in most cases by using AC-DC converters to obtain current and voltage from the grid or charging stations [12]. After afterwards, ESSs give the needed energy to the motor, which allows the car to accelerate. The electricity provided by ESSs, on the other hand, has unreliable characteristics and significant voltage dips [13-15]. As a result, DC-DC converters are critical for converting an uncontrolled power flow to a regulated one [16-18]. Zhang et al. [19] discussed the study progress of hybrid ESS development in EV applications, with an emphasis on size, DC/DC converter architecture, and an energy management method. A case study was used to verify the usefulness of the suggested topology, and the findings showed a 40% reduction in battery deterioration rate when compared to a battery-based storage system. Nonetheless, because input voltage, duty cycle, and load characteristics all affect DC-DC converter design, it's difficult to get it right [20-22]. Due to the switching operations, DC-DC converters also exhibit nonlinear behaviour and mildly damped dynamics [23,24]. The design of an efficient controller is critical for overcoming nonlinearity concerns, as well as achieving quick dynamics and the correct output voltage.

II. DESIGN OF PROPOSED CONVERTER

Fig.1depicts the suggested converter's configuration. Eight MOSFET switches, seven inductors, and four capacitors make up the converter. Both the grid and the battery are connected to the converter's ports A and B, respectively. The suggested converter functions as a boost converter while operating forward and as a buck converter when operating backward. Based on the converter's duty cycle for a specific output voltage, the Gating signals are delivered.

For the analysis of the suggested converter design, some assumptions were made,

i. Initial charging of all capacitors and inductors
ii. All capacitors and inductors are the same.
iii. MOSFETS' ON state resistance is disregarded.

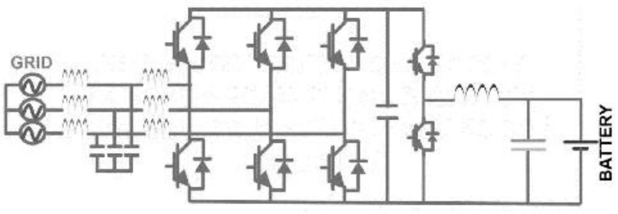

Figure 1: Proposed Bidirectional DC-DC Converter

2.1 Forward Operation:

With regard to the inductor current iL, the dc-dc converters can work in two different modes. The CCM with an inductor current that is always greater than zero is shown in Figure 1. The converter may transition into discontinuous conduction mode when the average output current is low (high R) or when the switching frequency is low (f) (DCM). During a portion of the switching time in the DCM, the inductor current is zero. The CCM is preferred for its great efficiency and effective use of passive parts and semiconductor switches.Because the dynamic order of the converter is minimised, the DCM can be employed in applications with unique control needs (the energy stored in the inductor is zero at the beginning and at the end of each switching period). Due to the various control algorithms, it is uncommon to combine these two working modes.

2.2 Backward Operation:

A buck-boost converter pair that is anti-parallel. Q1 will not operate in stepdown mode whereas Q2 will operate in accordance with the duty cycle. Between each operation, there is a brief dead period to prevent cross-conduction. The topology in question is a non-isolated half-bridge BDC topology that was created by connecting a buck converter in parallel with a boost converter. This topology is more effective and straightforward.

III. DESIGN OF CIRCUIT PARAMETERS

Three phase filter on the grid side and inductor and capacitor of the battery side can be calculated as follows:

Consider basic L-C-L filter,

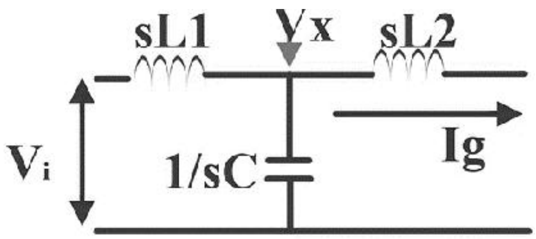

Figure 2: Basic LCL filter

$$\frac{Vi-Vx}{sL1} = Ig + \frac{Vx}{\frac{1}{sC}} \quad (1)$$

$$Vx = Ig\ sL2 \quad (2)$$

$$\frac{Ig}{Vi} = \frac{1}{S^3 L1L2C + s(L1+L2)} \quad (3)$$

Let,

L1 + L2 = L and Lp = $\frac{L1L2}{L1+L2}$

$$\frac{Ig}{V} = \frac{1}{sL\,(1+S^2\,C\,Lp)} \quad (4)$$

$$\omega res = \frac{1}{\sqrt{CLp}} \quad (5)$$

Switching frequency Fsw is selected to be 10 kHz.
Resonant frequency Fres is given by,

$$Fres = \frac{Fsw}{10} = 1000\ Hz \quad (6)$$

Reactive power requirement is assumed to be 5% of rated power.

$$Q = \frac{V^2}{(\frac{1}{2}*pi*f*C)} \quad (7)$$

Specification of the converter is 100 kVA, 230 V, 50 Hz.

$$C = \frac{0.05*S}{V^2*2*pi*f} = 100.28uF \quad (8)$$

$$\frac{Ig}{Vi} = \frac{1}{sL(1+S^2CLp)} \quad (9)$$

Since, $\omega res = \frac{1}{\sqrt{CLp}}$

$$\frac{Ig}{Vi} = \frac{1}{sL(1+\frac{S^2}{\omega res^2})} \quad (10)$$

$$\frac{Ig(s\omega)}{Vi(s\omega)} = \frac{1}{j\omega sw\ L(1+\frac{j\omega sw^2}{\omega res^2})} \quad (11)$$

L = 76.68uH

V_L = 20% of Vgrid

$$Lmax = \frac{0.2*Vgrid}{2*pi*50*I} = 1mH \quad (12)$$

L1 = L2 = 500 uH

Now, we are going to calculate the battery side parameters. Specifications of the converter for battery side capacitors and inductors are:

Vin = 800 V

Vout = 360 V

Fsw = 5kHz

Vripple = 0.36 V

Iripple = 3A

$$L = \frac{Vout*(Vin-Vout)}{Iripple*Fsw*Vin} \quad (13)$$

$$L = \frac{360*(800-360)}{3*5000*800} = 13mH$$

$$C = \frac{Iripple}{(8*Fsw*Vripple)} \quad (14)$$

$$C = \frac{3}{8*5000*0.36} = 20uF$$

IV. SIMULATED SYSTEM

Following table shows the values of all the parameters of the proposed system.

Table 1: Circuit Parameters for proposed system

Parameter	**Value**
Grid Side Voltage	400 V
Battery Side Voltage	360 V
Grid Side Inductor	5 mH
Grid Side Capacitor	30 uF
Battery Side Inductor	20 mH
Battery Side Capacitor	0.625 uF
Switching Frequency	10 kHz
Resonant Frequency	1000 Haz
Converter Power Rating	10 kW
Voltage Ripple	10%
Current Ripple	3%

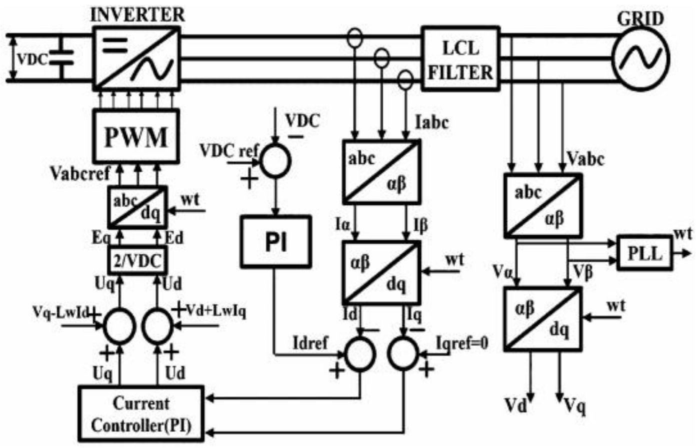

Figure3: Control System for Grid-side Inverter

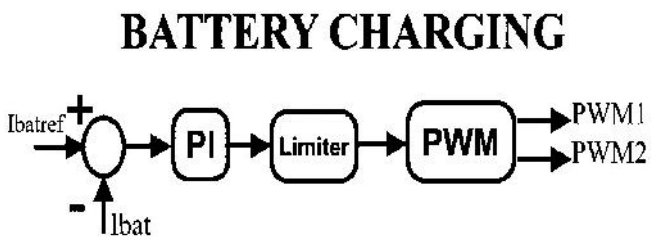

Figure 4: Control System for Battery Charging

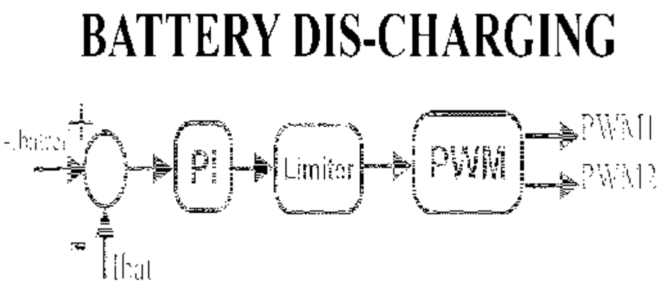

Figure5:ControlSystem for Battery Dis-charging

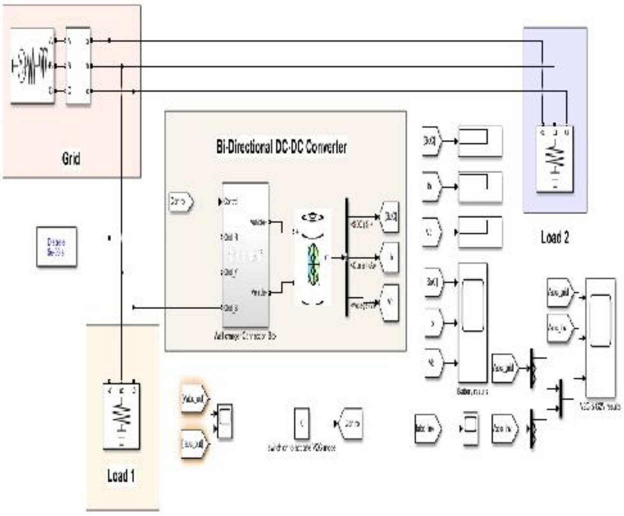

Figure6: Simulink Model of thewhole system

IV. RESULTS AND DISCUSSION

The simulation presented us the bi-direction power flow of Grid and EV. From the results, we summarized that EV can be operated in both mode i.e. V2G or G2V.

Moreover, voltage profile in both mode is same while current and apparent are different**.**

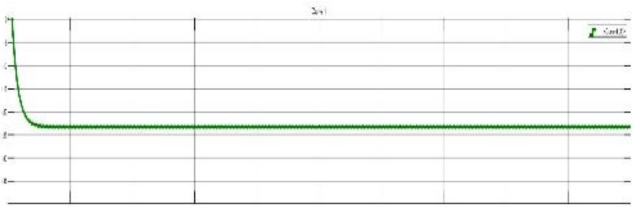

Figure 7: Battery Current in G2V mode

Figure 7 shows the graph of battery current in grid to vehicle mode that time current flows from grid to battery and from battery to vehicle current that time current is leaving from battery terminal therefore battery current will be negative in grid to vehicle mode.

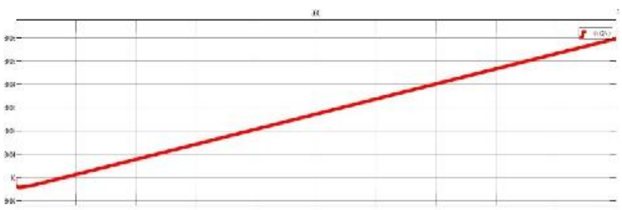

Figure 8: Battery SoC in G2V mode

Figure 8 shows the graph of battery state of charging(SoC) in grid to vehicle powerflow battery willcharge.

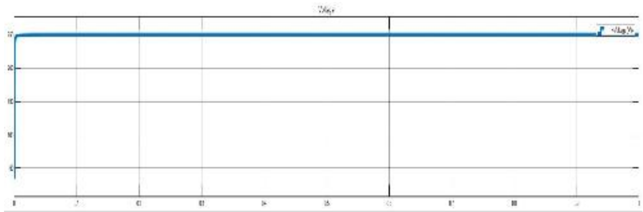

Figure 9: Battery Voltage in G2V mode

Figure 9 shows the graph of battery voltage this is DC voltage it will be maintained in grid to vehicle or vehicle to grid power flow.

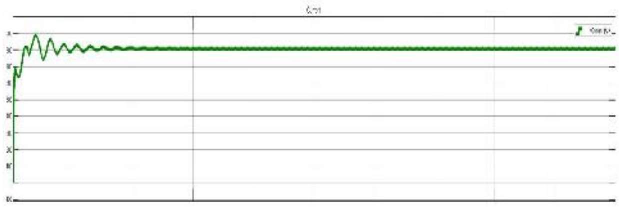

Figure 10: Battery Current in V2G mode

Figure 10 shows the graph of battery current in vehicle to grid mode that time current flows from vehicle to battery and from battery to bidirectional converterthat time current is enteringin the battery terminal therefore battery current will be positive in grid to vehicle mode and at starting there is transient state because of change of mode from G2V to V2G.

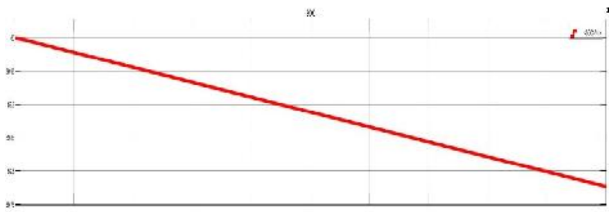

Figure 11: Battery SoC in V2G mode

Figure 11 shows the graph of battery state of charging(SoC) in vehicle to grid powerflow battery will discharge.

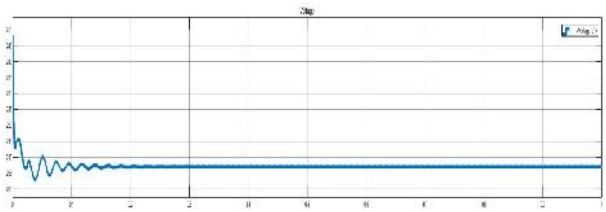

Figure 12: Battery Voltage in V2G mode

Figure 12 shows the graph of battery voltage this is DC voltage it will be maintained in grid to vehicle or vehicle to grid power flow but in vehicle to grid modeat starting there is transient state because of change of mode from G2V to V2G.

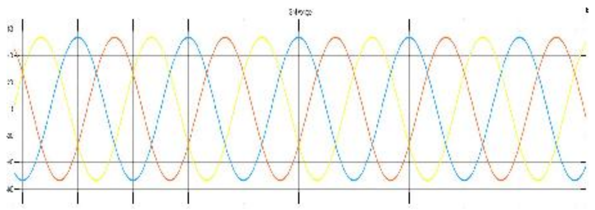

Figure 13: Grid Voltage in V2G mode

Figure 13 shows the graph of grid voltage in vehicle to grid power flow it is the three phase AC voltage and it will remain same in grid to vehicle power flow.

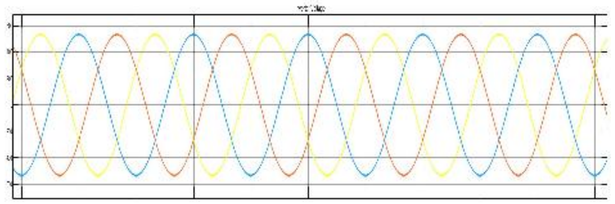

Figure 14: Inverter Voltage in V2G mode

Figure 14 shows the graph of Inverter Voltage in vehicle to grid power flow inverter will only required in vehicle to grid power flow to converter DC bidirectional converter voltage to AC voltage for grid.

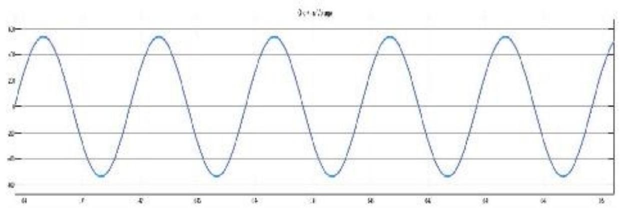

Figure 15: Grid and Inverter Voltage in V2G mode

Figure 15 show the graph of grid or inverter single phase voltage in voltage to grid power flow.

I Grid to Vehicle Mode

Table 2: Grid to Vehicle results summary

Sr. No	Parameter	Value
1	Grid Voltage	380 V rms
2	Grid Current	450 A rms
3	Battery Voltage	250 V
4	Battery Current	-23.2 A (due to charging)
5	Battery SOC	0.01% increase / sec

II Vehicle to Grid mode

Table 3: Vehicle to Grid results summary

Sr. No	Parameter	Value
1	Grid Voltage	380 V rms
2	Grid Current	450 A rms
3	Battery Voltage	210 V
4	Battery Current	800 A (due to discharging)
5	Battery SOC	0.22% decrease / sec

Above results show that in G2V mode, the battery is getting charged through the grid. In this mode, our converter operates in buck mode for stepping down the voltage. SoC graph clearly shows that the battery SoC is increasing.

In V2G mode, the battery feeds the supply to the grid. In this mode, our converter operates in boost mode in order to step up the voltage to match the grid voltage. SoC graph shows the corresponding result. Moreover. Grid voltage and inverter voltage can be seen overlapping which indicates proper synchronisation.

IV. CONCLUSION

As part of smart grid, electric vehicles are supposed to be energy storage devices. To store excess amount of energy generated in the smart grid has to be stored in the EV battery. This stored energy can be utilised in future as per demand. To perform this two-way operation, a bi-directional dc-dc converter is presented in this paperand applied for an electric vehicle application. The proposed converter found to be working perfectly in both G2V and V2G mode. Digital simulation results show that operation is stable in each operating mode and a smooth transition between the step-up and step-down regimes can be achieved using a simple hysteresis current controller.

REFERENCES

[1] Larry Sollecito GE Digitial Energy, Smart Grid: The Road Ahead Available: http://www.gegridsolutions.com/multilin/journals/issues/Spring09/Smart_Grid_The_Road_Ahead.pdf

[2] C. Gan, J. Wu, Y. Hu, S. Yang, W. Cao and J. M. Guerrero, "New Integrated Multilevel Converter for Switched Reluctance Motor Drives in Plug-in Hybrid Electric Vehicles With Flexible Energy Conversion," in *IEEE Transactions on Power Electronics*, vol. 32, no. 5, pp. 3754-3766, May 2017.

[3] Baha, M. A. A. ,& Thomas, H. B. (2013). Review of hybrid, plug-in hybrid, and electric ve- hicle market modeling Studies. Renewable and Sustainable Energy Reviews, 21 , 190–203 MaPages .

[4] Bhaskar, M. S. , Ben-Brahim, L. , Iqbal, A. , Padmanaban, S. ,Meraj,M. , & Rah- man, S. (2019a). Hardware implementation of a new single input double output L-l converter for high voltage auxiliary loads in fuel-cell vehicles. In IEEE applied power electronics conference and exposition (APEC) (pp. 1595–1600). Mar. .

[5] Krishna, M., Daya, F., Sanjeevikumar, P. ,& Mihet-Popa, L. (2017). Real-time analysis of a modified state observer for sensorless induction motor drive used in electric vehicle applications. Energies, MDPI, Open Access Journal, 10 (8), 1–23 pagesJuly.

[6] Un-Noor, F., Padmanaban, S. , Mihet-Popa, L. , Mollah, M. N. , & Hossain, E. (2017). A com- prehensive study of key electric vehicle (EV) components, technologies, challenges, impacts, and future direction of development. Energie, 10, 1217.

[7] Miller, J. F., Webster, C. E. , Tummillo, A. F. , et al. (1997). Testing and evaluation of batteries for a fuel cell powered hybrid bus. In Proceedings of the energy conversion engineering conference: 2 (pp. 894–898). 27 July–1 August.

[8] Chan, C. C. (2002). The state of the art of electric and hybrid vehicles. In Proceedings of the IEEE: 90 (pp. 247–275). Feb.

[9] Hannan, M.A.; Lipu, M.S.H.; Ker, P.J.; Begum, R.A.; Agelidis, V.G.; Blaabjerg, F. Power electronics contribution to renewable energy conversion addressing emission reduction: Applications, issues, and recommendations. Appl. Energy 2019, 251, 113404.

[10] Miri, I.; Fotouhi, A.; Ewin, N. Electric vehicle energy consumption modelling and estimation—A case study. Int. J. Energy Res. 2020, 5700.

[11] Javorski Eckert, J.; Corrêa de Alkmin e Silva, L.; MazzariolSanticiolli, F.; dos Santos Costa, E.; Corrêa, F.C.; Giuseppe Dedini, F. Energy storage and control optimization for an electric vehicle. Int. J. Energy Res. 2018, 42, 3506–3523.

[12] Wu, J.; Wu, Z.; Wu, F.; Mao, X. A power balancing method of distributed generation and electric vehicle charging for minimizing operation cost of distribution systems with uncertainties. Energy Sci. Eng. 2017, 5, 167–179.

[13] Manzetti, S.; Mariasiu, F. Electric vehicle battery technologies: From present state to future systems. Renew. Sustain. Energy Rev. 2015, 51, 1004–1012.

[14] Pollet, B.G.; Staffell, I.; Shang, J.L. Current status of hybrid, battery and fuel cell electric vehicles: From electrochemistry to market prospects. Electrochim. Acta 2012, 84, 235–249.

[15] Moura, S.J.; Fathy, H.K.; Callaway, D.S.; Stein, J.L. A stochastic optimal control approach for power management in plug-in hybrid electric vehicles. IEEE Trans. Control. Syst. Technol. 2011, 19, 545–555.

[16] Zhai, L.; Hu, G.; Lv, M.; Zhang, T.; Hou, R. Comparison of Two Design Methods of EMI Filter for High Voltage Power Supply in DC-DC Converter of Electric Vehicle. IEEE Access 2020, 8, 66564–66577.

[17] Gomez Navarro, F.J.; Yebra, L.J.; Gomez Medina, F.J.; Gimenez-Fernandez, A. DC-DC Linearized Converter Model for Faster Simulation of Lightweight Urban Electric Vehicles. IEEE Access 2020, 8, 85380–85394.

[18] Elsayad, N.; Moradisizkoohi, H.; Mohammed, O.A. A New Hybrid Structure of a Bidirectional DC-DC Converter with High Conversion Ratios for Electric Vehicles. IEEE Trans. Veh. Technol. 2020, 69, 194–206.

[19] Zhang, L.; Hu, X.; Wang, Z.; Ruan, J.; Ma, C.; Song, Z.; Dorrell, D.G.; Pecht, M.G. Hybrid electrochemical energy storage systems: An overview for smart grid and electrified vehicle applications. Renew. Sustain. Energy Rev. 2020, 110581.

[20] Lai, C.M.; Cheng, Y.H.; Hsieh, M.H.; Lin, Y.C. Development of a Bidirectional DC/DC Converter with Dual-Battery Energy Storage for Hybrid Electric Vehicle System. IEEE Trans. Veh. Technol. 2018, 67, 1036–1052.

[21] Kanamarlapudi, V.R.K.;Wang, B.; Kandasamy, N.K.; So, P.L. A New ZVS Full-Bridge DC-DC Converter for Battery Charging with Reduced Losses Over Full-Load Range. IEEE Trans. Ind. Appl. 2018, 54, 571–579.

[22] Fardahar, S.M.; Sabahi, M. New Expandable Switched-Capacitor/Switched-Inductor High-Voltage Conversion Ratio Bidirectional DC-DC Converter. IEEE Trans. Power Electron. 2020, 35, 2480–2487.

[23] Sayed, K. Zero-voltage soft-switching DC-DC converter based charger for LV battery in hybrid electric vehicles. IET Power Electron. 2019, 12, 3389–3396.

[24] Moradisizkoohi, H.; Elsayad, N.; Mohammed, O.A. Experimental Verification of a Double-Input Soft-Switched DC-DC Converter for Fuel Cell Electric Vehicle with Hybrid Energy Storage System. IEEE Trans. Ind. Appl. 2019, 55, 6451–6465.