Bi Directional Power Flow Control with Low Voltage Duel Source Buck/Boost converter with Duel Battery Energy Storage for HEV

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Abstract: This study develops a newly designed, patented, bidirectional dc/dc converter (BDC) that interfaces a main energy storage (ES1), an auxiliary energy storage (ES2), and dc-bus of different voltage levels, for application in hybrid electric vehicle systems. The proposed converter can operate in a step-up mode (i.e., low-voltage dual-source-powering mode) and a step-down (i.e., high-voltage dc-link energy-regenerating mode), both with bidirectional power flow control. In addition, the model can independently control power flow between any two low-voltage sources (i.e., low-voltage dual-source buck/boost mode). Herein, the circuit configuration, operation, steady-state analysis, and closed-loop control of the proposed BDC are discussed according to its three modes of power transfer. Moreover, the fuzzy logic controller is used here to sampling the output with effectively and the simulation and experimental results for a 1 kW prototype system are provided to validate the proposed converter.

1. INTRODUCTION

Global climate change and energy supply is declining have stimulated changes in vehicular technology. Advanced technologies are currently being researched for application in future vehicles. Among such applications, fuel-cell hybrid electric vehicles (FCV/HEV) are efficient and promising candidates. In the past,. studied the vehicles' dynamics to look for an optimal torque-speed profile of the electric propulsion system [1].. discussed the operating properties of the topologies for different vehicles including HEV, FCV, and more electric vehicle.. also integrated power electronics intensive solutions in advanced vehicular power system to satisfy huge vehicular load.. sufficiently divide the load power among the fuel cell stack, the battery, and the ultra capacitors based on two proposed energy-management strategies.. studied the influence of fuel-cell (FC) performance and the advantages of hybridization for control strategies. Chan et al. reviewed electric, hybrid, and fuel-cell vehicles and focused on architectures and modeling for energy management presented energy-storage topologies for HEVs and plug-in HEVs (PHEVs). They also discussed and compared battery, UC, and FC technologies. Furthermore, they also addressed various hybrid ESSs that integrate two or more storage devices . Rajashekara reviewed the current status and the requirements of primary electric propulsion components-the battery, the electric motors, and the power electronics system. Lai et al. implemented a bidirectional dc/dc converter topology with two-phase and interleaved characteristics. For EV and dc-microgrid systems, the converter has an improved voltage conversion rati. Furthermore, Lai also studied a bidirectional dc to dc converter (BDC) topology which has a high voltage conversion ratio for EV batteries connected to a dc-microgrid system. In FCV systems, the main battery storage device is commonly used to start the FC and to supply power to the propulsion motor. The battery storage devices improve the inherently slow response time for the FC stack through supplying peak power during accelerating the vehicle .

Moreover, it contains a high power-density component such as super capacitors (SCs) eliminates peak power transients during accelerating and regenerative braking. In general, SCs can store regenerative energy during deceleration and release it during acceleration, thereby supplying additional power. The high power density of SCs prolong the life span of both FC stack and battery storage devices and enhances the overall efficiency of FCV systems.

A functional diagram for a typical (FCV/HEV) power system is illustrated in Fig. 1 The low-voltage FC stack is used as the main power source, and SCs directly connected in parallel with FCs. The dc/dc power converter is used to convert the FC stack voltage into a sufficient dc-bus voltage in the driving.

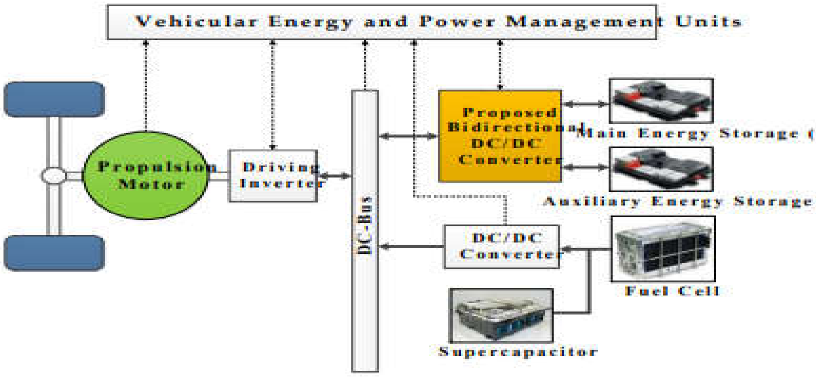

Fig. 1. Typical functional diagram for a FCV/HEV power system.

inverter for supplying power to the propulsion motor. Furthermore, ES1 with rather higher voltage is used as the main battery storage device for supplying peak power, and ES2 with rather lower voltage could be an auxiliary battery storage device to achieve the vehicle range extender concept The function of the bidirectional dc/dc converter (BDC) is to interface dual-battery energy storage with the dc-bus of the driving inverter.

Generally, the FC stack and battery storage devices have different voltage levels. Several multiport BDCs have been developed to provide specific voltages for loads and control power flow between different sources, thus reducing overall cost, mass, and power consumption [These BDCs can be categorized into isolated and nonisolated types.

II. LITERATURE REVIEW

1.Propulsion system design of electric and hybrid vehicles

There is a growing interest in electric and hybrid-electric vehicles due to environmental concerns. Efforts are directed toward developing an improved propulsion system for electric and hybrid-electric vehicles applications. This paper is aimed at developing the system design philosophies of electric and hybrid vehicle propulsion systems. The vehicles' dynamics are studied in an attempt to find an optimal torque-speed profile for the electric propulsion system. This study reveals that the vehicles' operational constraints, such as initial acceleration and grade, can be met with minimum power rating if the power train can be operated mostly in the constant power region. Several examples are presented to demonstrate the importance of the constant power operation. Operation of several candidate motors in the constant power region are also examined. Their behaviors are compared and conclusions are made.

2.Topological overview of hybrid electric and fuel cell vehicular power system architectures and configurations

This paper discusses the operational characteristics of the topologies for hybrid electric vehicles (HEV), fuel cell vehicles (FCV), and more electric vehicles (MEV). A brief description of series hybrid, parallel hybrid, and fuel cell-based propulsion systems are presented. The paper also presents fuel cell propulsion applications, more specific to light-duty passenger cars as well as heavy-duty buses. Finally, some of the major fundamental issues that currently face these advanced vehicular technologies including the challenges for market penetration are highlighted.

3."Power electronics intensive solutions for advanced electric, hybrid electric, and fuel cell vehicular power systems

There is a clear trend in the automotive industry to use more electrical systems in order to satisfy the ever-growing vehicular load demands. Thus, it is imperative that automotive electrical power systems will obviously undergo a drastic change in the next 10-20 years. Currently, the situation in the automotive industry is such that the demands for higher fuel economy and more electric power are driving advanced vehicular power system voltages to higher levels. For example, the projected increase in total power demand is estimated to be about three to four times that of the current value. This means that the total future power demand of a typical advanced vehicle could roughly reach a value as high as 10 kW.

4."**Influence of battery/ultra capacitor energy-storage sizing on battery lifetime in a fuel cell hybrid electric vehicle**

Combining high-energy-density batteries and high-power-density ultra capacitors in fuel cell hybrid electric vehicles (FCHEVs) results in a high-performance, highly efficient, low-size, and light system. Often, the battery is rated with respect to its energy requirement to reduce its volume and mass. This does not prevent deep discharges of the battery, which are critical to the lifetime of the battery. In this paper, the ratings of the battery and ultra capacitors are investigated. Comparisons of the system volume, the system mass, and the lifetime of the battery due to the rating of the energy storage devices are presented. It is concluded that not only should the energy storage devices of a FCHEV be sized by their power and energy requirements, but the battery lifetime should also be considered. Two energy-management strategies, which sufficiently divide the load power between the fuel cell stack, the battery, and the ultra capacitors, are proposed. A charging strategy, which charges the energy-storage devices due to the conditions of the FCHEV, is also proposed. The analysis provides recommendations on the design of the battery and the ultra capacitor energy-storage systems for FCHEVs.

5."Comparative study of fuel-cell vehicle hybridization with battery or supercapacitor storage device

This paper deals with the conception and the achievement of a hybrid power source using a fuel cell combined with a battery or a supercapacitor. In which, the fuel cell supplies the main power to the drive system; while the battery or the supercapacitor is used as an auxiliary power source. This gives the benefit that the regenerative energy is stored in battery or supercapacitor during the deceleration and it is transferred back to the drive system during the acceleration when compared to electric vehicles solely powered by a fuel cell. Different energy storage devices, such as fuel cell, battery, and supercapacitor are compared., and then several structures of fuel cell-based electric vehicles are analyzed in the paper. Following that a conventional topology based on fuel cell and battery using a DC/DC converter with the connection between the fuel cell and the inverter, and a floating voltage topology powered by fuel cell and supercapacitor without any DC/DC converters are chosen for the simulation analysis.

III. MODEL CASE STUDY

TOPOLOGY AND OPERATION MODES

The proposed BDC topology with dual-battery energy storage is illustrated in Fig. 2, where VH, VES1, and VES2 represent the high-voltage dc-bus voltage, the main energy storage (ES1), and the auxiliary energy storage (ES2) of the system, respectively. Two bidirectional power switches (SES1 and SES2) in the converter structure, are used to switch on or switch off the current loops of ES1 and ES2, respectively. A charge-pump capacitor (CB) is integrated as a voltage divider with four active switches (Q1, Q2, Q3, Q4) and two phase inductors (L1, L2) to improve the static voltage gain between the two low-voltage dual sources (VES1, VES2) and the high-voltage dc bus (VH) in the proposed converter. Furthermore, the additional CB reduces the switch voltage stress of active switches and eliminates the need to operate at an extreme duty ratio. Furthermore, the three bidirectional power switches (S, SES1, SES2) displayed in Fig. 2 exhibit four-quadrant operation and are adopted to control the power flow between two low-voltage dual sources (VES1, VES2)

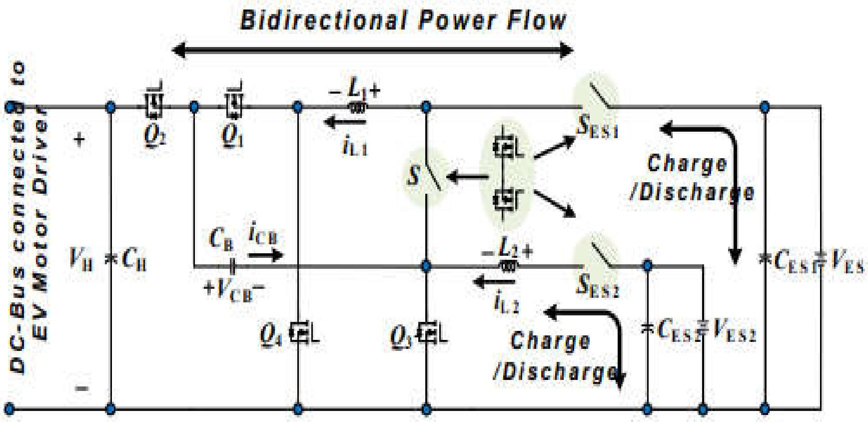

Fig. 2. Proposed BDC topology with dual-battery energy storage

TABLE I.
CONDUCTION STATUS OF DEVICES FOR DIFFERENT OPERATING MODES

Operating Modes	ON	OFF	Control Switch	Synchronous Rectifier (SR)
Low-voltage dual-source-powering mode (Accelerating, x_1=1, x_2=1)	S_{ES1}, S_{ES2}	S	Q_3, Q_4	Q_1, Q_2
High-voltage dc-bus energy-regenerating mode (Braking, x_1=1, x_2=1)	S_{ES1}, S_{ES2}	S	Q_1, Q_2	Q_3, Q_4
Low-voltage dual-source buck mode (ES1 to ES2, x_1=0, x_2=0)	S_{ES1}, S_{ES2}	Q_1, Q_2, Q_4	S	Q_3
Low-voltage dual-source boost mode (ES2 to ES1, x_1=0, x_2=0)	S_{ES1}, S_{ES2}	Q_1, Q_2, Q_4	Q_3	S
System shutdown	--	S_{ES1}, S_{ES2} Q_1, Q_2, Q_3, Q_4	--	--

and to block either positive or negative voltage. This bidirectional power switch is implemented via two metal-oxide-semiconductor field-effect transistors (MOSFETs), pointing in opposite directions, in series connection. To explain the concept for the proposed converter, all the conduction statuses of the power devices involved in each operation mode are displayed in Table I. Accordingly, the four operating modes are illustrated as follows to enhance understanding.

A. Low-Voltage Dual-Source-Powering Mode

Fig. 3(a) depicts the circuit schematic and steady-state waveforms for the converter under the low-voltage dual-source-powering mode. Therein, the switch S is turned off, and the switches (SES1, SES2) are turned on, and the two low-voltage dual sources (VES1, VES2) are supplying the energy to the dc-bus and loads. In this mode, the low-side switches Q3 and Q4 are actively switching at a phase-shift angle of 180°, and the high-side switches Q1 and Q2 function as the synchronous rectifier (SR).

Based on the typical waveforms shown in Fig. 3(b), when the duty ratio is larger than 50%, four circuit states are possible (Fig. 4). In the light of the on/off status of the active switches and the operating principle of the BDC in low-voltage dual-source-powering mode, the operation can be explained briefly as follows.

a) State 1 [t0 < t < t1]

During this state, the interval time is (1-Du)Tsw, switches Q1, Q3 are turned on, and switches Q2, Q4 are turned off. The voltage across L1 is the difference between the low-side voltage VES1 and the charge-pump voltage (VCB), and hence iL1 decreases linearly from the initial value. In addition, inductor L2 is charged by the energy source VES2.

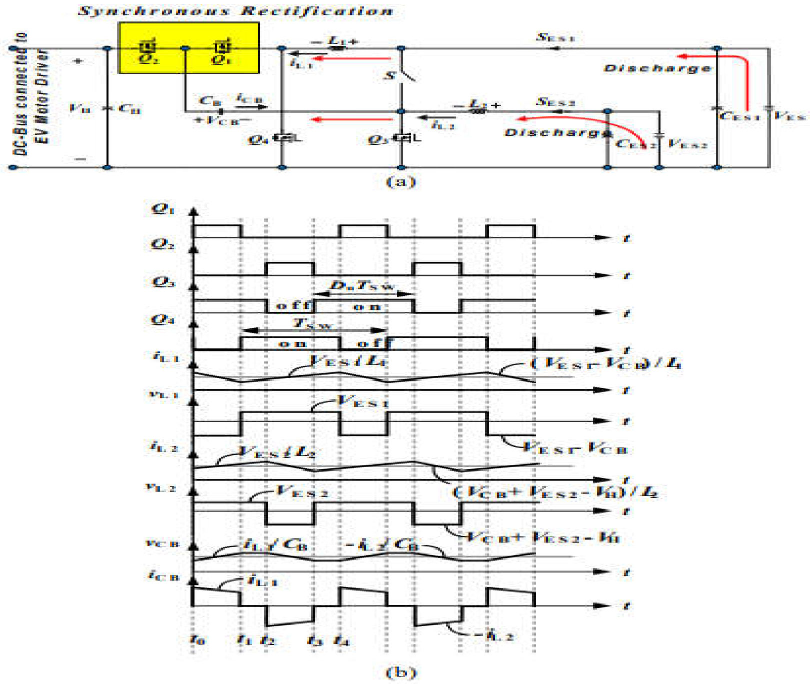

Fig. 3. Low-voltage dual-source-powering mode of the proposed BDC: (a) circuit schematic and (b) steady-state waveforms

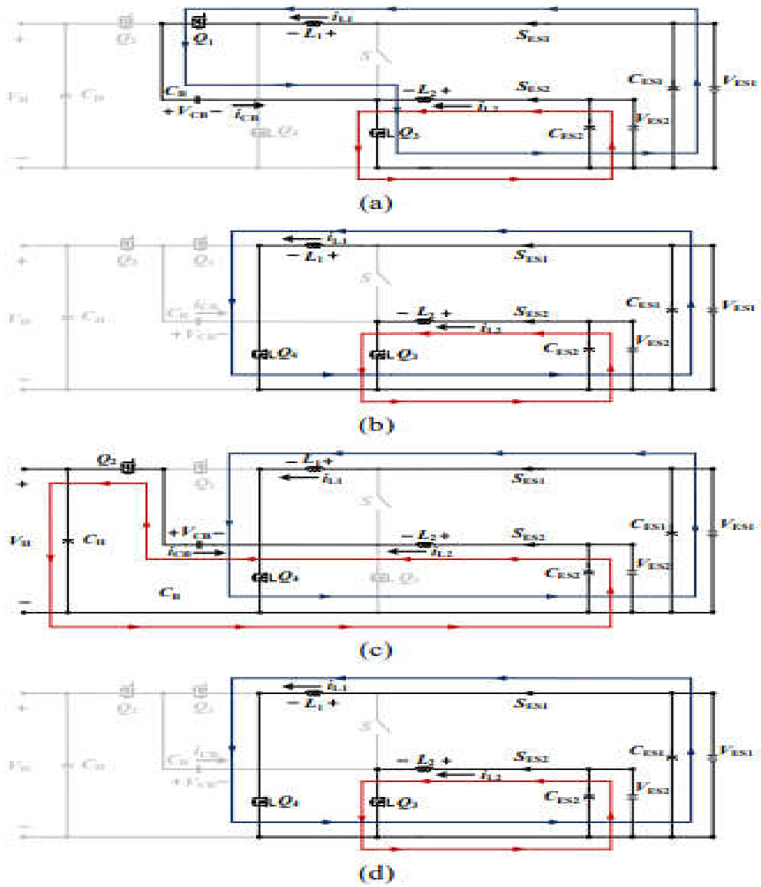

Fig. 4. Circuit states of the proposed BDC for the low-voltage dual-source-powering mode. (a) State 1. (b) State 2. (c) State 3. (d) State 4.

b) State 2 [t1 < t < t2]:

During this state, the interval time is (Du-0.5)Tsw; switches Q3 and Q4 are turned on; and switches Q1 and Q2 are turned off. The low-side voltages VES1 and VES2 are located between inductors L1 and L2, respectively, thereby linearly increasing the inductor currents, and initiating energy to storage. The voltages across inductors L1 and L2 under state 2 can be denoted.

c) State 3 [t2 < t < t3]:

During this state, the interval time is (1-Du)Tsw; switches Q1 and Q3 are turned on, whereas switches Q2 and Q4 are turned off. The voltages across inductors L1 and L2 can be denoted as

d) State 4 [t3< t]

During this state, the interval time is (Du-0.5)Tsw; switches Q3 and Q4 are turned on, and switches Q1 and Q2 are turned off. The voltages across inductors L1 and L2 can be denoted.

B**. High-Voltage DC-Bus Energy-Regenerating Mode In this mode**

the kinetic energy stored in the motor drive is fed back to the source during regenerative braking operation. The regenerative power can be much higher than what the battery can absorb. Consequently, the excess energy is used to charge the energy storage device. The circuit schematic and the steady-state waveforms of the BDC under the high-voltage dc bus energy-regenerating mode are illustrated in Fig. 5.

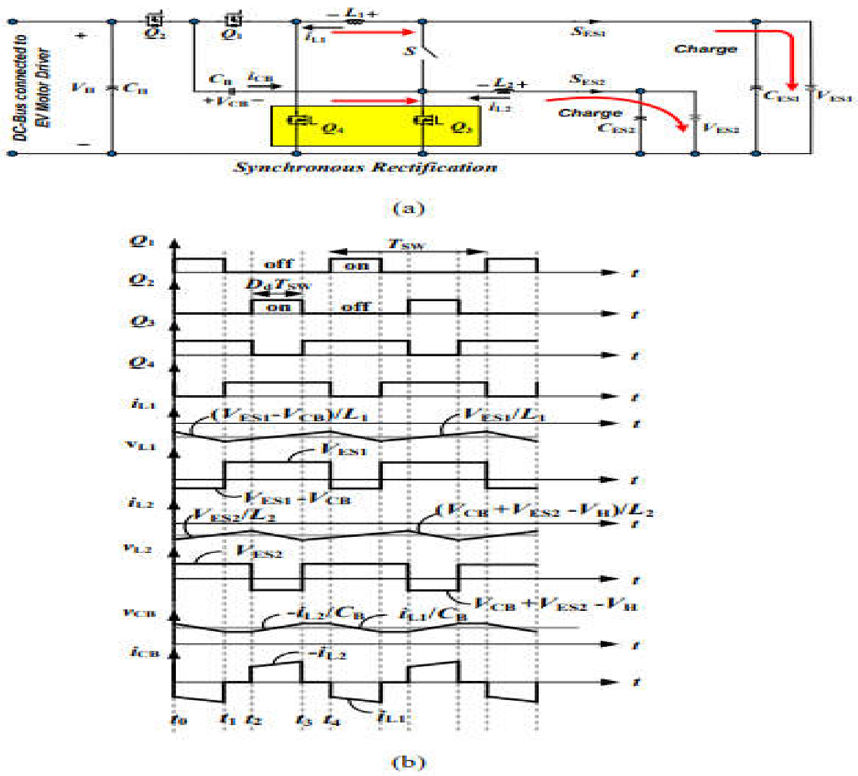

Fig. 5. High-voltage dc-bus energy-regenerating mode of the proposed BDC: (a) circuit schematic and (b) steady-state waveforms

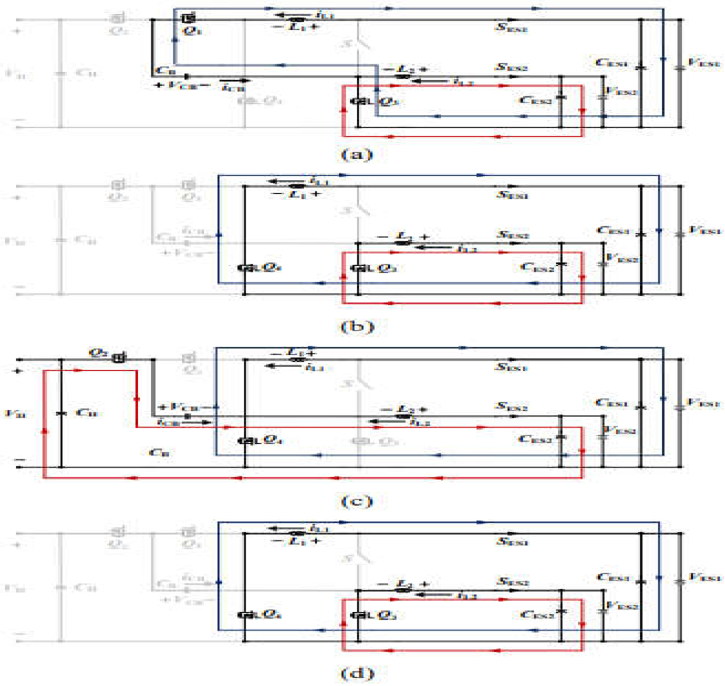

Fig. 6. Circuit states of the proposed BDC for the high-voltage dc-bus energy-regenerating mode. (a) State 1. (b) State 2. (c) State 3. (d) State 4

Therein, the current in the inductors is controlled by the active switches Q1 and Q2, which have a phase-shift angle of 180° and thereby direct the flow away from the dc-bus and toward the dual energy storage devices; the switches Q3 and Q4 function as the SR to improve the conversion efficiency.

On the basis of the steady-state waveforms shown in Fig. 5(b), when the duty ratio is below 50%, four different circuit states are possible, as shown in Fig. 6. In the light of the on-off status of the active switches and the operating principle of the BDC in high-voltage dc-bus energy-regenerating mode, the operation can be depicted briefly as follows.

a) **State 1 [t0 < t < t1]:** During this state, the interval time is DdTsw; switches Q1 and Q3 are turned on, and switches Q2 and Q4 are turned off. The voltage across L1 is the difference between the low-side voltage VES1 and the charge-pump voltage VCB; hence, the inductor current iL1 decreases linearly from the initial value. In addition, inductor L2 is charged by the energy source VES2, which also contributes to the linear increase in the inductor current. The voltages across inductors L1 and L2 can be denoted

b) **State 2 [t1 < t < t2]:** During this state, the interval time is (0.5-Dd)Tsw; switches Q3 and Q4 are turned on, and switches Q1 and Q2 are turned off. The voltages across inductors L1 and L2 are the positive the low-side voltages VES1 and VES2, respectively; hence, inductor currents iL1 and iL2 increase linearly. These voltages can be denoted.

c) **State 3 [t2 < t < t3]:** During this state, the interval time is DdTsw; switches Q1 and Q3 are turned off, and switches Q2 and Q4 are turned on. The voltage across L1 is the positive low-side voltage VES1 and hence iL1 increases linearly from the initial value. Moreover, the voltage across L2 is the difference of the high-side voltage VH, the charge-pump voltage VCB, and the low-side voltage VES2, and its level is negative. The voltages across inductors L1 and L2 can be denoted

d) **State 4 [t3 < t < t4]:** During this state, the interval time is (0.5-Dd)Tsw; switches Q3 and Q4 are turned on, and switches Q1 and Q2 are turned off. The voltages across inductors L1 and L2 can be denoted.

IV.SIMULATION MODEL AND RESULTS

4.1 SIMULATION MODLE

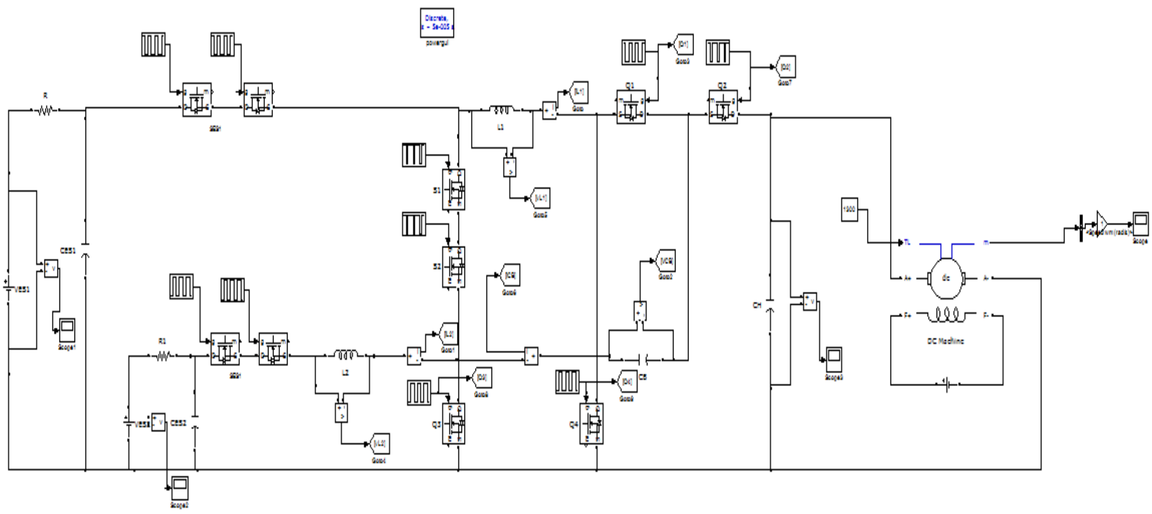

Fig 1 MATLAB/SIMULINK circuit diagram of extended fuzzy controlled bidirectional DC/DC converter

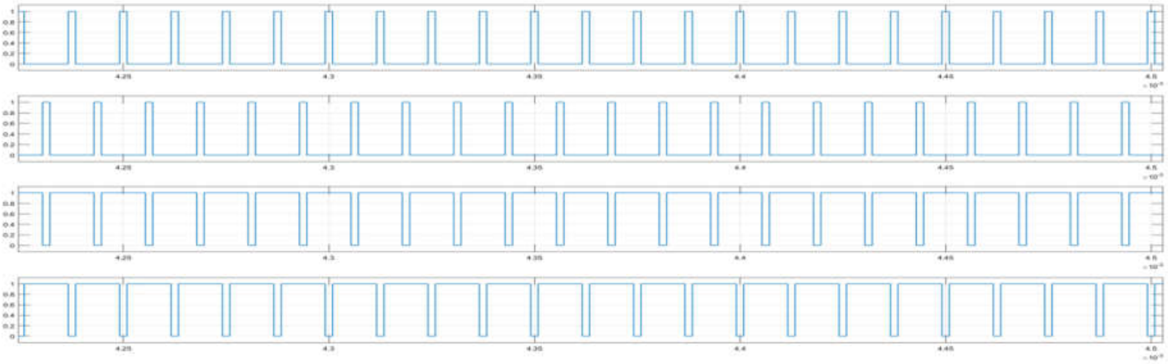

FIG2. X- axis as time, y-axis as Switching gate signals of Q1,Q2,Q3,Q4

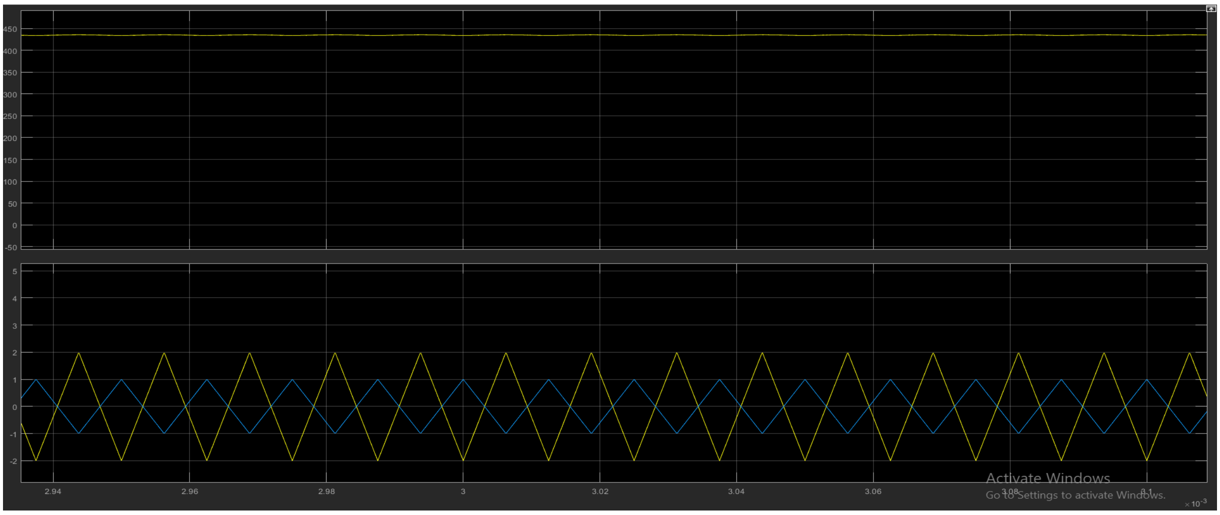

FIG 3. X- axis as time, Y- axis as output voltage and inductor currents Inductor currents IL1, IL2

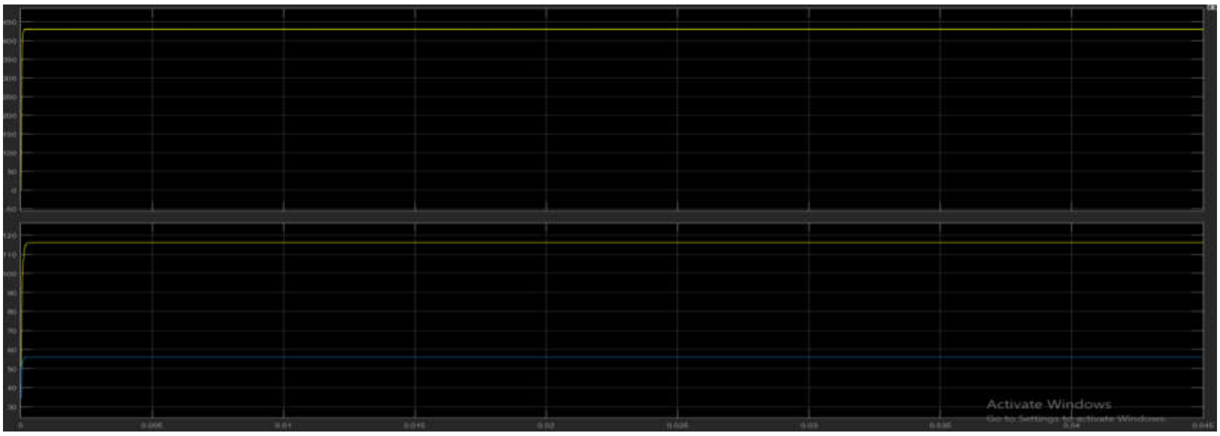

FIG 4. X- axis as time, Y- axis as Energy storage VES1, VES2 (voltage)

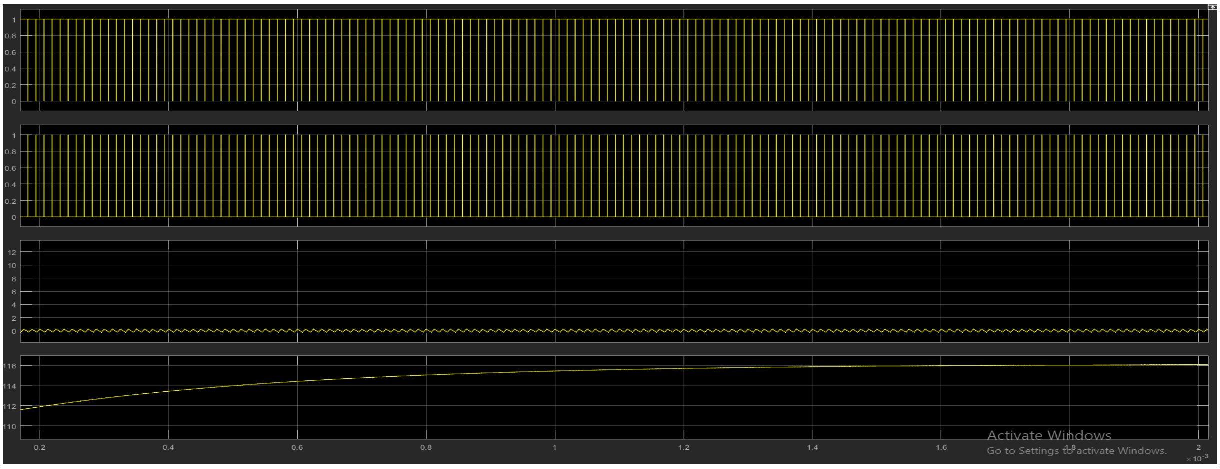

Fig 5. X- axis as time, Y- axis as switching pulse (Q3), Inductor current(IL2),and voltage VES1

V. CONCLUSION

A new BDC topology was presented to interface dual battery energy sources and high-voltage dc bus of different voltage levels. The circuit configuration, operation principles, analyses, and static voltage gains of the proposed BDC were discussed on the basis of different modes of power transfer. Simulation and experimental waveforms for a 1 kW prototype system highlighted the performance and feasibility of this proposed BDC topology. The highest conversion efficiencies were 97.25%, 95.32%, 95.76%, and 92.67% for the high-voltage dc-bus energy-regenerative buck mode, low-voltage dual-source-powering mode, low-voltage dual-source boost mode (ES2 to ES1), and low-voltage dual-source buck mode (ES1 to ES2), respectively. The results demonstrate that the proposed BDC can be successfully applied in FC/HEV systems to produce hybrid power architecture (has been patented.

REFERENCES

[1] M. Ehsani, K. M. Rahman, and H. A. Toliyat, "Propulsion system design of electric and hybrid vehicles," IEEE Transactions on industrial electronics, vol. 44, no. 1, pp. 19-27, 1997.

[2] A. Emadi, K. Rajashekara, S. S. Williamson, and S. M. Lukic, "Topological overview of hybrid electric and fuel cell vehicular power system architectures and configurations," IEEE Transactions on Vehicular Technology, vol. 54, no. 3, pp. 763-770, 2005.

[3] A. Emadi, S. S. Williamson, and A. Khaligh, "Power electronics intensive solutions for advanced electric, hybrid electric, and fuel cell vehicular power systems," IEEE Transactions on Power Electronics, vol. 21, no. 3, pp. 567-577, 2006.

[4] E. Schaltz, A. Khaligh, and P. O. Rasmussen, "Influence of battery/ultracapacitor energy-storage sizing on battery lifetime in a fuel cell hybrid electric vehicle," IEEE Transactions on Vehicular Technology, vol. 58, no. 8, pp. 3882-3891, 2009.

[5] P. Thounthong, V. Chunkag, P. Sethakul, B. Davat, and M. Hinaje, "Comparative study of fuel-cell vehicle hybridization with battery or supercapacitor storage device," IEEE transactions on vehicular technology, vol. 58, no. 8, pp. 3892-3904, 2009.

[6] C. C. Chan, A. Bouscayrol, and K. Chen, "Electric, hybrid, and fuel-cell vehicles: Architectures and modeling," IEEE transactions on vehicular technology, vol. 59, no. 2, pp. 589-598, 2010.

[7] A. Khaligh and Z. Li, "Battery, ultracapacitor, fuel cell, and hybrid energy storage systems for electric, hybrid electric, fuel cell, and plug-in hybrid electric vehicles: State of the art," IEEE transactions on Vehicular Technology, vol. 59, no. 6, pp. 2806-2814, 2010.

[8] K. Rajashekara, "Present status and future trends in electric vehicle propulsion technologies," IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 1, no. 1, pp. 3-10, 2013.

[8] K. Rajashekara, "Present status and future trends in electric vehicle propulsion technologies," IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 1, no. 1, pp. 3-10, 2013.

[9] C.-M. Lai, Y.-C. Lin, and D. Lee, "Study and implementation of a two-phase interleaved bidirectional DC/DC converter for vehicle and dc-microgrid systems," Energies, vol. 8, no. 9, pp. 9969-9991, 2015.

[10] C.-M. Lai, "Development of a novel bidirectional DC/DC converter topology with high voltage conversion ratio for electric vehicles and DC-microgrids," Energies, vol. 9, no. 6, p. 410, 2016.