ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Modeling, Design and Fault Analysis of Bidirectional DC-DC Converter for Hybrid Electric Vehicles

Sarab Jwaid Mousa Al-Chlaihawi
M.Tech Electrical and Electronic Engineering, Ph.D Student in Electrical Engineering,
Department of Electrical Engineering, Faculty of Electrical Engineering,
Polytechnic University of Bucharest, Independence Splaiul 313, 060042, EB225 Hall, Bucharest, Romania.

Abstract:

Modeling, design and analysis of a bidirectional half-bridge DC/DC converter suitable for power electronic interface between the main energy storage System and the electric traction drive in hybrid electric vehicles. Energy storage system composed of a battery unit and an ultra-capacitor pack is considered. A shunt dc-linked multiinput converter with a half-bridge bidirectional DC/DC cell topology is chosen to link the ultra capacitor storage unit with the dc-link. The paper focuses on modeling the proposed Converter for both dynamic and steady state analysis. Averaging and linearization techniques are applied to obtain the averaged state space models and small signal models of the converter in both boost and buck operation modes. The criterion for sizing the converter passive components based on the imposed design specifications and constraints is illustrated. Simulation results of the Step Down and Step Up converter during normal functioning and under faulty conditions are presented.

EXISTING SYSTEM:

The use of DC/DC converters is essential in hybridvehicles. Mainly, there exist two types of DC/DC converters onboard of a Hybrid Electric Vehicle (HEV).A low power bidirectional DC/DC converter which connects the high voltage dc-link with a low voltage battery used to supply low power loads. Secondly is for high power bidirectional DC/DC Converter used to connect the energy storage unit(ESU) with the electric traction drive system.

PROSED SYSTEM:

Project presents modeling, design and analysis of the later converter. A Hybrid Energy Storage System (HESS) composed of a battery unit and an UltraCapacitor (UC) pack is considered, a shunt dc-linked multi-input converter with half-bridge bidirectional DC/DC cells is chosen to link the ultra capacitor (UC) storage unit with the unidirectional-link. The DC/DC converter is used to provide a regulated dc voltage at higher level to the inverter and to control power flow to and from the electric drive during motoring and generating modes.Paper mainly focuses on modeling the proposed converter for bothsteady and dynamic state analysis.

TECHNOLOGY:

The following technology is used in the paper:

- Dynamic modeling.
- State space representation.
- Bidirectional DC/DC converter.
- Simulation.
- Hybrid electric vehicles.
- Fault analysis.
- Components sizing.

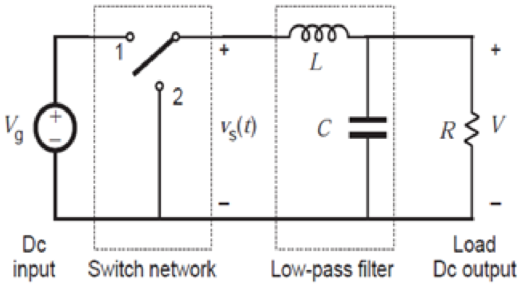
A shunt dc-linked multi-input converter with a half-bridge bidirectional DC/DC cell technology is chosen to link the ultracapacitor storage unit with the unidirectional-link.To determine the unidirectional-link voltage and the energy storage unit capacity at the DC/DC converter terminals, it is empirical to specify the electric vehicle hybridization level.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

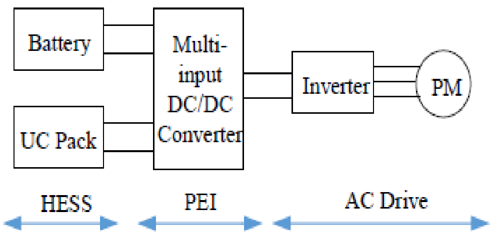
A full HEV is chosen with large traction drivers, high-capacity energy storage pack and main DC bus voltage around 200-300V.Dynamic modeling of power converter is necessary in order to study its sudden change in behavior and analyze variations in the input voltage, load current, and duty cycle e affect its output voltage. A switching power converter is a nonlinear time-varying system which is not possible to analyze due to its transient large signal nature. Small signal modeling is a commonly used to approach simplify the analysis, control and design of the converter nonlinear system by transforming it into a linear time-invariant system.

WORKING PRINCIPLE:

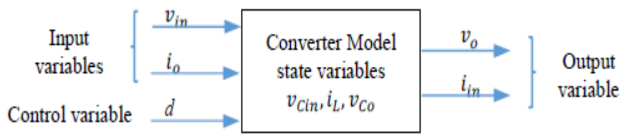
The designing a bidirectional DC/DC converter well suitable for Power Electronic Interface (PEI) between the EnergyStorage System (ESS) and the electric traction motors.It is important to indicate the note down specifications of the electric traction system. Those specifications include identity's the level of hybridization of the electrical vehicle; As well as the choice of hybrid drive train configuration, HESS, electric AC drive system, and DC/DC PEI selection.



Block Diagram



Electric drive subsystem:

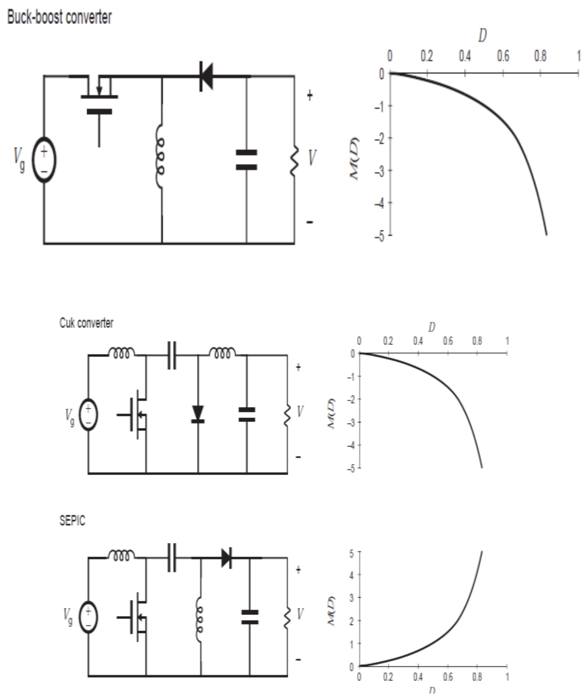


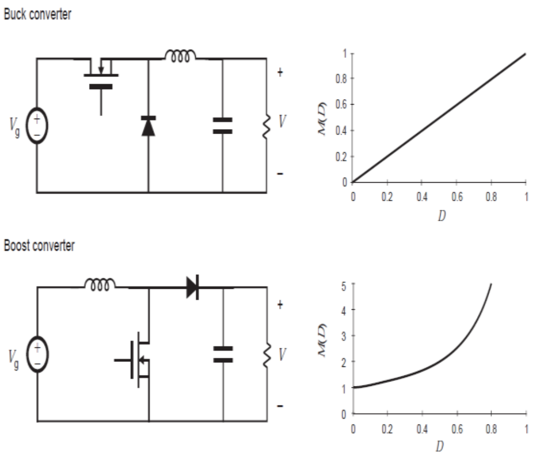
Power switching converter model:

Converter circuit topologies:

A large number of dc-dc converter circuits are known that can increase or decrease the magnitude of the dc voltage or invert its polarity.In example shows, the switch is realized using a power MOSFET and diode, Other semiconductor switches such as IGBTs, BJTs, or thyristores can be replaced if desired.The first converter is the step up converter, which reduces the dc voltage and has conversion ratio $M(D) = D$. In a similar topology known as the boost converter, the positions of the switch and inductor are interchanged. This converter produces an output voltage V that is greater in magnitude than the input voltage Vg. Its conversion ratio is $M(D) = 1/(1 – D)$.

Control circuits:





Hybrid Energy Storage System:

HEVs rely on the capability of their energy storage unit not only to store large amounts of energy but also to discharge e according to load. Alarge power, high energy, and high efficiency ESS can be obtained by utilizing a hybrid battery combination.The UltraCapacitor will increase the ESS power handling capability and reserve the amount of regenerative energy dissipated in the friction brakes because to the low power handling capability of the battery. Battery is used during transient peak power demands and to capture regenerative energy which greatly reduces the voltage variations and stresses across the battery terminals

Electric AC Drive System:

AC drive is a classic Permanent Magnet Synchronous Motor (PMSM) drive which consists of a PMSM, a three-phase bridge voltage source inverter and a power electronic controller. Voltage source inverters are commonly used in HEV applications, where the source delivers a stiff voltage. PMSMs exhibit higher efficiency, higher power density and higher torque-to-inertia ratio when compared to induction motors. This advantages as well as the fast torque response make PMSMs good response for use in HEVs.

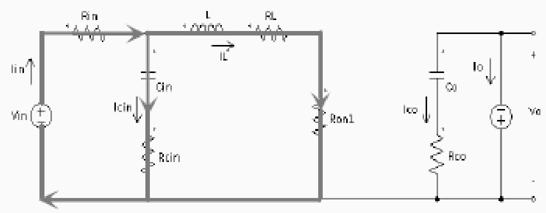
State Space Representation:

A analytic model of the converter during boost and buck operations can be obtained by applying Kirchhoff's voltage and current equations for each of the commutation modes shown in below figure respectively.The resistances of all power inductors and capacitors, the transistors ON resistances and the storage unit ESR are included. During step-down operation.The converter averaged state space equations are obtained by taking a linearly weighted average of the equations in both modes of switching using the duty cycle as control variable with

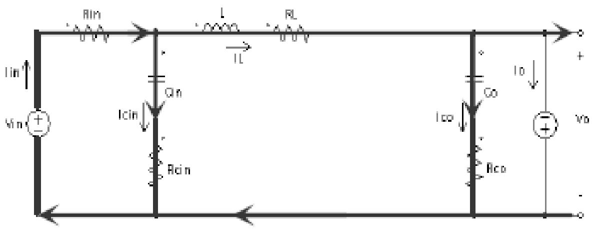
$$\dot{x} = \mathrm{A}x + \mathrm{B}u$$

$$y = \mathrm{C}x + \mathrm{E}\dot{x} + \mathrm{F}u$$

Where x= $\begin{bmatrix} v_{Cin} \\ i_L \\ v_{Co} \end{bmatrix}$ is the state space vector, $u = \begin{bmatrix} v_{in} \\ i_o \end{bmatrix}$ is the input or control vector $y = [v_o]$ is the output vector for the capacitor fedConverter.



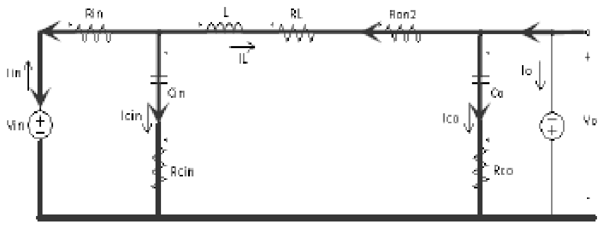
(a) boost mode 1



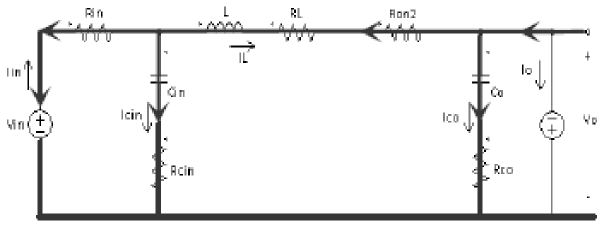
(b) boost mode 2

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

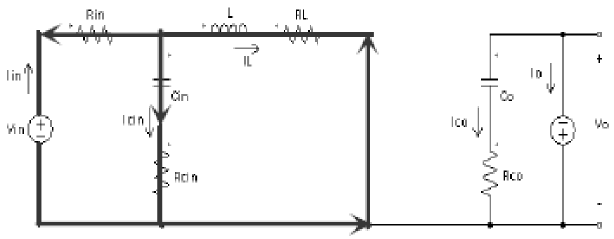
Boost converter normal operation modes



(a) buck mode 1



(a) buck mode 1



(b) buck mode 2

Buck converter normal operation modes:
Steady State Equations:

During steady state, the averaged inductor voltage over one switching period is zero; therefore, at steady state $\langle v_L \rangle_{avg} = 0$ and $\langle \frac{di_L}{dt} \rangle_{avg} = 0$. This is known as the principle of inductor volt second balance.

The principle of capacitor charge balance states that the steady state averaged capacitor current over one switching period is zero, so

$$\langle i_{Co} \rangle_{avg} = \langle i_{Cin} \rangle_{avg} = 0 \text{ and } \langle \frac{dv_{Co}}{dt} \rangle_{avg} = \langle \frac{dv_{Cin}}{dt} \rangle_{avg} = 0$$

$$A_{1boost} = \begin{bmatrix} -\frac{1}{C_{in}R_{iCin}} & -\frac{R_{in}}{C_{in}R_{iCin}} & 0 \\ \frac{R_{in}}{LR_{iCin}} & -\frac{(R_{in}R_{Cin}+R_L R_{iCin}+R_{ON1}R_{iCin})}{LR_{iCin}} & 0 \\ 0 & 0 & 0 \end{bmatrix},$$

$$A_{2boost} = \begin{bmatrix} -\frac{1}{C_{in}R_{iCin}} & -\frac{R_{in}}{C_{in}R_{iCin}} & 0 \\ \frac{R_{in}}{LR_{iCin}} & -\frac{(R_{in}R_{Cin}+R_L R_{iCin}+R_{Co}R_{iCin})i_L}{LR_{iCin}} & -\frac{1}{L} \\ 0 & \frac{1}{C_o} & 0 \end{bmatrix},$$

$$B_{1boost} = \begin{bmatrix} \frac{1}{C_{in}R_{iCin}} & 0 \\ \frac{R_{Cin}}{LR_{iCin}} & 0 \\ 0 & -\frac{1}{C_o} \end{bmatrix}, \text{ and } B_{2boost} = \begin{bmatrix} \frac{1}{C_{in}R_{iCin}} & 0 \\ \frac{R_{Cin}}{LR_{iCin}} & \frac{R_{Co}}{L} \\ 0 & -\frac{1}{C_o} \end{bmatrix}.$$

$$A_{1buck} = \begin{bmatrix} -\frac{1}{C_{in}R_{iCin}} & -\frac{R_{in}}{C_{in}R_{iCin}} & 0 \\ \frac{R_{in}}{LR_{iCin}} & -\frac{(R_{in}R_{Cin}+R_L R_{iCin}+R_{ON2}R_{iCin}+R_{Co}R_{iCin})}{LR_{iCin}} & -\frac{1}{L} \\ 0 & \frac{1}{C_o} & 0 \end{bmatrix},$$

$$A_{2buck} = \begin{bmatrix} -\frac{1}{C_{in}R_{iCin}} & -\frac{R_{in}}{C_{in}R_{iCin}} & 0 \\ \frac{R_{in}}{LR_{iCin}} & -\frac{(R_{in}R_{Cin}+R_L R_{iCin})}{LR_{iCin}} & 0 \\ 0 & 0 & 0 \end{bmatrix},$$

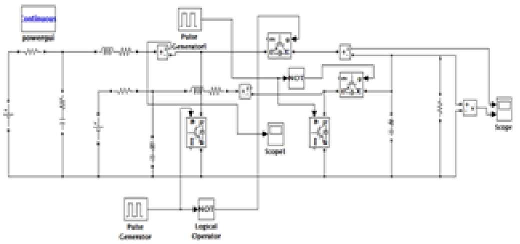
$$B_{1buck} = \begin{bmatrix} \frac{1}{C_{in}R_{iCin}} & 0 \\ \frac{R_{Cin}}{LR_{iCin}} & \frac{R_{Co}}{L} \\ 0 & -\frac{1}{C_o} \end{bmatrix}, \text{ and } B_{2buck} = \begin{bmatrix} \frac{1}{C_{in}R_{iCin}} & 0 \\ \frac{R_{Cin}}{LR_{iCin}} & 0 \\ 0 & -\frac{1}{C_o} \end{bmatrix}.$$

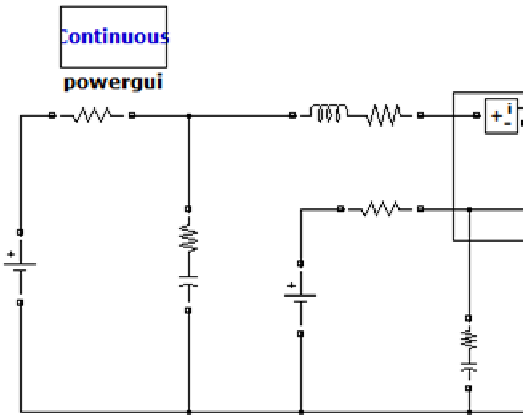
CONVERTER DESIGN:

To convey the electric traction power demand to a fullHEV, the converter is rated at 30kW output power. Voltage, current and power ratings are based on the requirements of an HEV with 300V-30kW unidirectional-link.

Practical switching frequencies for power switching converters used in HEVs fall in the range of 15-20 kHz. An energy source of 200V is considered at the input of the DC/DC converter.

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal





bidirectional half-bridge DC/DC converter

SOFTWARE TOOLS:

(Matlab Simulation)

- **Simulink**
- It is a commercial tool for modeling, simulating and analyzing multidomain dynamic systems.
- Its primary interface is a graphical block diagramming tool and a customizable set of block libraries.
- Simulink is widely used in controltheory and digital signal processing for multi domain simulation and Model based design.

- **APPLICATIONS**

1.Technical computing
2.Engineering and sciences applications

- **Other Features**

- 2-D and 3-D graphics functions for visualizing data
- Tools for building custom graphical user interfaces
- Functions for integrating MATLAB based algorithms with external applications and languages, such as C, C++, Fortran, Java, COM, and Microsoft Excel .

ADVANTAGES:

A parallel dc-linked multiinput converter with a half-bridge bidirectional DC/DC cell topology is chosen to link the battery/ultra capacitor storage unit with the dc-link.

- Electrical Engineering
- DSP and DIP
- Automation
- Communication purpose
- Aeronautical
- Pharmaceutical
- Financial services.
- These advantages as well as the fast torque response make PMSMs good candidates for use in HEVs. The main disadvantage is the use of permanent magnets which are not only expensive but also sensitive to load and temperature.

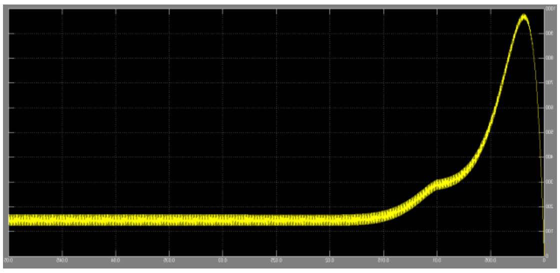
- **APPLICATION:**

- A Hybrid Energy Storage System (HESS) composed of a battery unit and an UltraCapacitor (UC) pack is considered.
- IGBTs are chosen since they are suitable for low frequency, high power applications such as the full hybrid vehicle considered.

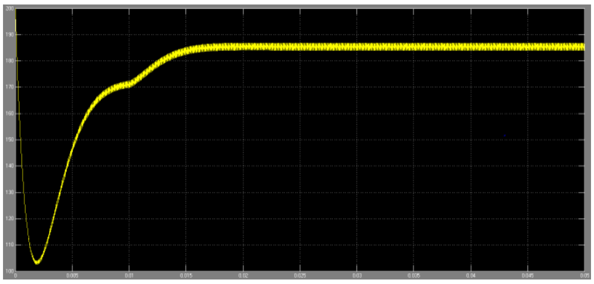
SIMULATION RESULTS:

INPUT GRAPH:

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

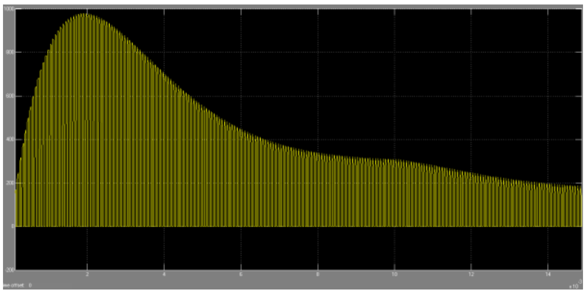


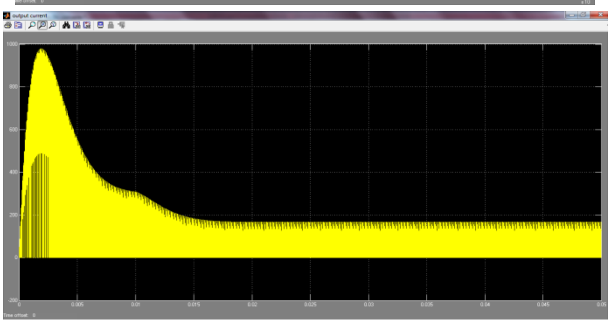
Simulation of the input side current waveform with load.



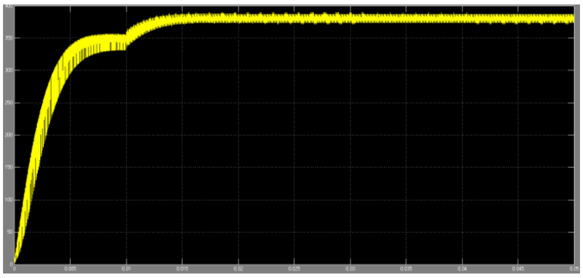
Simulation of the input side VOLTAGE waveform with load.

Output graph:



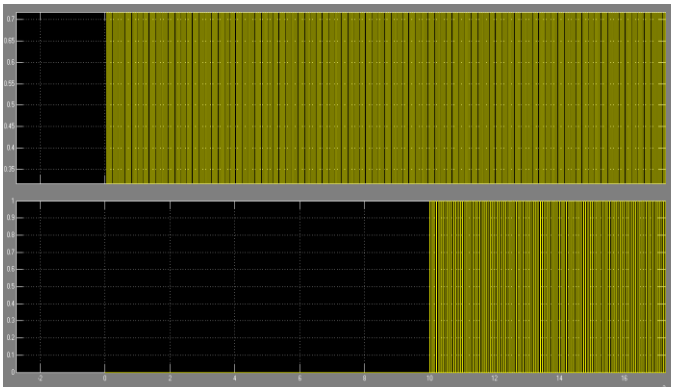


Simulation of the output side CURRENT waveform with load



Simulation of the output side VOLTAGE waveform with load

Pulse Generator WAVEFORMS:



Simulation of the IGBT GATE PULSE waveform with load.

CONCLUSION:

This paper presents modeling, design and analysis of a halfbridge bidirectional DC/DC converter as a PEI between aHESS and the main DC bus in HEVs. The converter components are sized based on the design requirements of a full HEV. To verify the converter operation, the proposed design is simulated using Matlab/Simulink. Table V summarizes the converter simulation results under normal and faulty conditions for boost and buck operations. The effect of power switching device faults resulting from SC and OC diodes and transistors is analyzed. In summary, fault modes 1, 2, 3, 5, 6, and 7 can damage the power converter; whereas, OC transistor faults do not damage the power converter. When T2 is OC, the energy storage unit is directly to the dc-link; the PEI continues operation but not as a boost converter.When T1 is OC, the energy storage unit is completely disconnected

ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

from the dc-link; the converter behaves as if it is shut down. On the other hand, OC diode faults result in high voltage spikes across the converter power switching components which could damage the power device.

REFERENCES:

[1]H. Al-Sheikh, O. Bennouna, G. Hoblos, and N. Moubayed, "Study on power converters used in hybrid vehicles with monitoring and diagnostics techniques", in Proc. IEEE MELECON 2014, in press.

[2]L. Solero, A. Lidozzi, and J.A. Pomilio, "Design of multiple-input power converter for hybrid vehicles", IEEE Trans. on Power Electronics, vol. 20, no. 5, pp. 1007-1016, Sept. 2005.

[3]A. Lidozzi and L. Solero, "Power balance control of multiple-input DCDC converter for hybrid vehicles", in Proc. IEEE ISIE 2004, vol. 2, pp. 1467-1472.

[4]M. B. Camara, H. Gualous, F. Gustin, and A. Berthon, "Design and new control of DC/DC converters to share energy between supercapacitors and batteries in hybrid vehicles", IEEE Trans. on Vehicular Technology, vol. 57, no. 5, pp. 2721-2735, 2008.

[5]A. Di Napoli, F. Crescimbini, L. Solero, and F. Caricchi, "Multipleinput DC-DC power converter for power-flow management in hybrid vehicles" in Proc. IAS 2002, vol. 3, pp. 1578-1585.

[6]L.A. Tendillo, E.V. Idiarte, J.M. Altés, J.M. Moncusí, and H.V. Blaví, "Design and control of a bidirectional DC/DC converter for an Electric Vehicle", EPE/PEMC 2012, pp. LS4d.2-1 - LS4d.2-5.

[7]A.J. Forsyth and S.V. Mollov, "Modelling and control of DC-DC converters", Power Engineering Journal, vol. 12, no. 5, pp. 229-236,Oct. 1998.

[8]P. Pany, R.K. Singh, and R.K. Tripathi, "Bidirectional DC-DC converter fed drive for electric vehicle system", International Journal ofEngineering, Science and Technology, vol. 3, no. 3, pp. 101-110.

[9] W. Jianhua, Z. Fanghua, G. Chunying, and C. Ran, "Modeling and analysis of a buck/boost bidirectional converter with developed PWM switch model", in Proc. IEEE ICPE & ECCE 2011, pp. 705-711.

[10]Hiba Al-Sheikh, Ouadie Bennouna, Ghaleb Hoblos, IRSEEM, ESIGELEC, Nazih Moubayed, "Modeling, Design and Fault Analysis of Bidirectional DC-DC Converter for Hybrid Electric Vehicles"

Author's profile:

Sarab Jwaid Mousa Al-Chlaihawi, Assistant teacher in najaf technical institute , al-furatal-awsat technical university my bachelor degree in electrical engineering and education from Baghdad university of technology/ Baghdad, Iraq.i finished my master of technology in power electronics engineering ,collage of engineering , Jawaharlal Nehru technological university, hyderabad, india. Know Ph.D student in electrical engineering, department of electrical engineering, faculty of electrical electrical engineering, polytechnic university of Bucharest, Romania .