Bidirectional Dc to DC Converter with Ann Controller for Hybrid Electric Vehicle

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Abstract—A bidirectional chopper (BDC) is the one which can interface main source (HVS), auxiliary source (LVS) and a DC-Bus voltage at different levels which is implemented in Hybrid Electric Vehicle (HEV). This converter operation is of two modes namely dual source powering mode and energy regeneration mode along with power flow control in both the directions. And also the independent power flow control across two sources (i.e. the dual source buck-boost mode). The operation, closed loop control of artificial neural network (ANN) and the comparison between PI and ANN control are provided in simulation results.

I. INTRODUCTION
The emission of harmful gases from the internal combustion engines (ICE) and the merits of hybrid electric vehicles and electric vehicles are discussed in [1]. The energy control and management of driving cycles of charge and discharge of battery, which impacts on the life time battery is verified, in different operating stations like urban and sub urban areas in [2].The importance of optimal energy management controllers and future driving conditions are discussed [3].The dynamic response of bidirectional DC converter with minimal phase for buck and boost modes for different load changing conditions are validated [4]. A bidirectional DC/DC converter for electric vehicle (EV) and DC-microgrid with interleaved charge-pump topology and increased two phase voltage ratio [6]. A novel BDC offering with less current ripples and greater voltage conversion ratio has been implemented [7]. The analyses of power transmission of IBDC under control of DPS have been conducted for wide range of power transmission than SPS control , the designing steps along with detailed operating principal and modes of a non-isolated BDC with soft switching was achieved with ZVC is verified [8-9]. The development of a seven phase voltage source inverter with ANN based SVPWM with the advantage of real time DSP implementation and increased computational efficiency[10]. Stability analysis of voltage with ANN based back propagation algorithm with Global Stability Voltage[11]. The schedule of charging and discharging of a battery in electric vehicle using artificial neural network is proposed along with the weight adjustment process (training or learning), performance measurement, evaluation, of network[12]. Application of neural networks for estimation of power levels in the battery of electric vehicle and the behaviour of battery at different temperatures is proposed and verified by Ala A. Hussein [13]. A newly proposed BDC in Fig.1 with two voltage sources, operational configuration with step up and step down modes and a prototype of 1KW is done and proven in simulation [5].

Fig.1 The Functional Block Diagram Of BDC

The main properties of the proposed circuit are it interfaces two DC energy sources with different voltages. The independent control of power flow between two energy sources as well as power flow control from dc bus to voltage sources.

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II. MODES OF OPERATION

A present bidirectional dc to dc converter with dual-battery voltage sources is given in Fig. 2, where \( V_{BUS} \), \( V_{HVE} \), and \( V_{LVE} \) represent the DC-Bus voltage, main source (HVS) and auxiliary source (LVS) respectively. The power switch \( S_{HVS} \) used to switch on and the \( S_{LVS} \) is used to switch off the converters current loops of \( V_{HVE} \) and \( V_{LVE} \), respectively. A pump capacitor \( (C_P) \) is introduced as voltage divider for four active switches \( (S_1, S_2, S_3, S_4) \) and two inductors \( (L_A, L_B) \) to increases the voltage gain between low-voltage sources \( V_{HVE} \), and \( V_{LVE} \). \( C_P \) decreases the voltage stress across the switches and eliminates the need of extreme duty. The four-quadrant operation of circuit is possible by the bidirectional switches \( (S, S_{HVS}, S_{LVS}) \), and allows the power flow control between two low voltage sources \( V_{HVE} \), and \( V_{LVE} \), and also helps in blocking positive and negative voltages. The bidirectional switches \( (S, S_{HVS}, S_{LVS}) \) are MOSFETS connected back to back as shown in fig.2 the concept and modes are given in detail in the table 1.

### Table 1 Modes Of Operation

<table>
<thead>
<tr>
<th>Modes of operation</th>
<th>On Switch</th>
<th>Off Switch</th>
<th>Controlling Switch</th>
<th>Synchronous Rectifier (SR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual-Source Low Voltage Powering Mode (Accelerating)</td>
<td>( S_{HVS}, S_{LVS} )</td>
<td>( S )</td>
<td>( S_3, S_4 )</td>
<td>( S_1, S_2 )</td>
</tr>
<tr>
<td>Dc-Bus High-voltage Energy-Regenerating Mode (Braking)</td>
<td>( S_{HVS}, S_{LVS} )</td>
<td>( S )</td>
<td>( S_1, S_2 )</td>
<td>( S_3, S_4 )</td>
</tr>
<tr>
<td>Dual-Source Low Voltage Buck Mode</td>
<td>( S_{HVS}, S_{LVS} )</td>
<td>( S_1, S_3, S_4 )</td>
<td>( S )</td>
<td>( S )</td>
</tr>
<tr>
<td>Dual-Source Low Voltage Boost Mode</td>
<td>( S_{HVS}, S_{LVS} )</td>
<td>( S_1, S_2, S_4 )</td>
<td>( S )</td>
<td>( S )</td>
</tr>
<tr>
<td>Shutdown</td>
<td>--</td>
<td>( S_{HVS}, S_{LVS} )</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

The switches \( S_3, S_4 \) are used as control switches and operates at 180 degree phase shift, and \( S_1, S_2 \) acts as the synchronous rectifiers.
During the state $S_1, S_3$ are ON and $S_2, S_4$ are off then voltage across the inductor is given by

$$L_A \frac{di_A}{dt} = V_{LVS} - V_{CP}$$  

$$L_B \frac{di_B}{dt} = V_{LV}$$  

where $V_{CP}$ is voltage across the capacitor $C_p$.

During the state $S_3, S_4$ are ON and $S_1, S_2$ are off then voltage across the inductor is given by

$$L_A \frac{di_A}{dt} = V_{HVS}$$  

$$L_B \frac{di_B}{dt} = V_{LV}$$

\[\text{b. DC-Bus High-voltage Energy Regenerating Mode}\]

During regenerating mode the kinetic energy from the motor is fed back to the storage devices regenerating power may be higher than the storage capacity of the battery so, the excess energy is stored in the capacitors connected in the parallel to storage devices. The schematic circuit shown in Fig.5.

\[\text{III. CONVERTER CONTROL}\]

The schematic control circuit shown in fig.8 consist of operating mode selector energy management unit and electrical load demand estimator. The management unit increases the use of voltage sources that fulfills the load requirement. The inductor currents $I_{LA}$ and $I_{LB}$ are measured and compared with the reference converter currents.

The mode of operation of the controller depends on the power demand by the load/HEV then it selects the appropriate $I_{LA\text{Ref}}$ and $I_{LB\text{Ref}}$ and then the triggering of the switches $S_1, S_3, S_2, S_4$ takes place with the help of Artificial Neural Network. The switch selector $Y_1$ and $Y_2$ of BDC controller are responsible for selection of operating modes, the pulse width modulation (PWM) switching scheme is employed to trigger the gate switches.

During Low voltage and high voltage dual sources DC bus the $I_{LA\text{Ref}}$ is taken as the reference to control the power flow. During Buck/Boost mode the $I_{LB\text{Ref}}$ is taken as reference to control the power flow between high voltage source and low voltage source and vice versa.
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On average inductor current $I_{LA}$ and $I_{LB}$ are equal due to the uniform current sharing of sources, depending on the power demand of Load/HVE the operating mode changes this mode selection is discussed in the Table 2.

<table>
<thead>
<tr>
<th>Modes of operation</th>
<th>$Y_1$</th>
<th>$Y_2$</th>
<th>Relation/condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual Source Low Voltage Powering Mode</td>
<td>1</td>
<td>1</td>
<td>$P_{Demand} &gt; 0$ $I_{LA}Ref &gt; 0$</td>
</tr>
<tr>
<td>Dc Bus High voltage Energy Regenerating Mode</td>
<td>1</td>
<td>1</td>
<td>$P_{Demand} &gt; 0$ $I_{LA}Ref &lt; 0$</td>
</tr>
<tr>
<td>Dual-Source Low Voltage Buck Mode</td>
<td>0</td>
<td>0</td>
<td>$P_{Demand} &lt; 0$ $V_{HS} &lt; 48$ $I_{LB}Ref &lt; 0$</td>
</tr>
<tr>
<td>Dual-Source Low Voltage Boost Mode</td>
<td>0</td>
<td>0</td>
<td>$P_{Demand} &lt; 0$ $V_{HS} &lt; 96$ $I_{LB}Ref &gt; 0$</td>
</tr>
</tbody>
</table>

When vehicle is in running state then $P_{Demand} > 0$ and $I_{LA}Ref > 0$ then the control is over $I_{LA}$ and control loop change $Y_1 = 1$ and the vehicle will operating accelerating mode or braking if $I_{LA}Ref < 0$ if none of the condition gets satisfied then the controller checks for $P_{Demand} < 0$ then the controller if $I_{LB}Ref$ control loop change $Y_1 = 0$ in this condition the switching controller checks for $V_{HS}$ and $V_{LV}$ and if $V_{HS} < 96$ then the control changes the boost mode and changes $I_{LB}Ref > 0$ and the circuit operates in boost mode and the voltage is boosted from $V_{LV}$ to $V_{HS}$ if $V_{LV} < 48$ then the control changes the buck mode and changes $I_{LB}Ref < 0$ and the circuit operates in buck mode and the voltage is chopped from $V_{HS}$ to $V_{LV}$.

![Fig. 8: ANN Based Control Circuit](image)

Table 2: Mode Selection

The power demand estimation/calculation of load/HEV and the decision making control unit is shown in the fig. 10.

![Fig. 9: Implemented ANN Controller](image)

The buck and boost modes, the controller unit for decision making to trigger the switch accordingly is shown in the fig. 11.

![Fig. 10: Power Demand Estimation](image)
IV. SIMULATION RESULTS

A MATLAB simulation is performed to verify the converter performance and the simulation circuit Fig.12 Dual Source low voltage powering mode shown in Fig.12(a), that both sources powerup the dc bus for electric motor and sufficiently maintains the dc bus voltage.

Fig.12(B) Output Dc-Bus Voltage And Inductor Currents Dual Source Low Voltage Powering Mode

Fig.12 (A) is the gate pulses given to the switches $S_1, S_2, S_3, S_4$ respectively and the Fig.12(B) is the Output Dc-Bus voltage and inductor currents of $L_A$ and $L_B$. 
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DC bus high voltage regenerating mode Fig.13 (A) is the gate pulses given to the switches $S_1, S_2, S_3, S_4$ and the Fig.13(B) is the Output source voltages and inductor currents of $L_A$ and $L_B$ respectively.

Dual-Source High Voltage Boost Mode Fig.14(A) is the gate pulses given to the switches $S_3, S$ and Output source voltages and inductor currents of $L_B$.

Dual-Source Low Voltage Buck Mode Fig.14(B) is the gate pulses given to the switches $S_3, S$ and Output source voltages and inductor currents of $L_B$.

The fig.16 represents the controlled step change in current in DC Bus High Voltage Regenerating Mode.

The fig.17 represents the controlled step change in current of High voltage source in Dual-Source High Voltage Boost Mode.

The fig.18 Controlled Step Change In Current Of High Voltage Source In Dual-Source Low Voltage Buck Mode
The fig.18 represents the controlled step change in current of high voltage source in Dual-Source Low Voltage Buck Mode.

V. CONCLUSION

A bidirectional DC to DC converter (BDC) is presented interface main source (HVS), auxiliary source (LVS) and a DC-Bus with different voltage levels which is implemented in Hybrid Electric Vehicle (HEV). The circuit operating principle and modes of operation of bidirectional dc to dc converter were discussed and Simulation waveforms of Dual Source Low Voltage Powering Mode, DC Bus High Voltage Regenerating Mode, Dual-Source High Voltage Boost/Buck Mode and the comparison between PI and ANN are demonstrated that it can be successfully implemented for the hybrid electric vehicle.

REFERENCES

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AUTHORS PROFILE

Received his B Tech Degree in Electrical and Electronics Engineering From AEC Engineering College Jawaharlal Nehru Technological University Hyderabad, India 2016. He worked as lecturer in Polytechnic for a period of 8 Months, He worked for Regal Beloit Corporation (Marathon Electric India Pvt Ltd) as a trainee during his academics of his master’s degree for a period of 8months, He is currently a MTech Sophomore in Anurag Group of Institutions (Autonomous) (Formerly CVSR College of Engineering), Hyderabad, India in Power Electronics and Electrical Drives and likely to graduate in 2019. He has published a few National Journals and Conferences. His area of interest is Power Electronics, Network Analysis and Motor Drives.
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