Simulation of Fully-Directional Universal DC-DC Converter for Electric Vehicle Applications

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ABSTRACT
This paper proposes a converter that interfaces the energy storage of the vehicle with its motor drive and external charger. In the converter, the circuitry of both Buck and Boost modes are interfaced. This converter applies to Electric Vehicles, Hybrid Electric Vehicles, and Plug-In Hybrid Electric Vehicles.

Keywords— Universal converter; Electric Vehicle; Battery; MatLab.

1. INTRODUCTION
The gap between the supply and demand of fossil fuels continues to grow today. This has helped in the development of the electric and hybrid vehicular industries. In a hybrid electric vehicle, a bidirectional dc-dc converter is placed between the battery and the high voltage dc bus. In acceleration or cruising mode, the converter should deliver power from the battery to the dc link [1]. In regenerative or braking mode, the converter delivers power from the dc link to the battery. In an electric vehicle, along with the above operation, the bidirectional dc-dc converter also interfaces the battery with the ac-dc converter during charging/discharging from/to the grid. Hence, the bidirectional dc-dc converter should interface the battery with charging converter as well [2]-[7].

Fig. 1 shows the power electronic interface in an electric vehicle. In this assembly, the bidirectional dc/dc converter should convert the output voltage of the ac/dc converter into a voltage that can recharge the batteries, and vice versa while injecting back to the grid [8]-[18]. The above is known as grid connected mode. In driving mode, the dc/dc converter regulates the dc link (grid) voltage.

![Diagram of a bidirectional dc-dc converter interface in an electric vehicle](image)

Fig. 1. Block diagram of the bidirectional dc-dc converter interface in electric vehicle

In the condition that $V_{dc} > V_{batt}$, the battery voltage is stepped up during acceleration and dc link voltage is stepped down during braking [10]. In the condition that $V_{dc} < V_{batt}$, the battery voltage is stepped down during acceleration and dc link voltage is stepped up during regenerative braking. Considering the need for bi directional flow of power, the proposed dc-dc converter, can meet the needs of the auto industry. It has stepping up and stepping down functionalities that operate in all four quadrants.

In this paper, a fully directional universal dc-dc converter is analyzed for electric vehicle applications. The analysis has been carried out using MatLab-Simulink and results are presented.
II. DESCRIPTION OF THE UNIVERSAL DC-DC CONVERTER

Fig. 2 shows the circuit of a universal dc-dc converter. It consists of 5 MOSFETs, T1-T5 and 5 power diodes, D1-D5.

These power devices are properly combined to select buck and boost modes of operation. V_{dc} represents the motor drive nominal input voltage during the driving mode or the rectified ac voltage at the output of the grid interface during plug-in mode. The nominal voltage of the vehicle's energy storage system (ESS) is represented by V_{batt} [12].

The different modes of operation of the converter are V_{dc} to V_{batt} (buck and boost Operations) and V_{batt} to V_{dc} (buck and boost Operations). In all of the modes, one switch is operated in PWM mode, and the other switches are either ON or OFF. The reasons for which the universal converter is preferred over a conventional converter are; it allows bidirectional power flow and the output is non-inverted with respect to the input, excluding the need for an inverting transformer, thus reducing the overall size and cost [15]. However, the controls of this converter and conventional converter are the same [17].

III. MODES OF OPERATION OF THE UNIVERSAL DC-DC CONVERTER

In this section, the different modes of operation of the universal converter are explained with pulse generation.

In the bidirectional power flow there are two modes in each direction of power flow. This is explained with the help of the flowchart shown in Fig. 3.

The modes of operation in each direction are explained below:

Mode 1: V_{dc} < V_{batt}, Boost mode

T1 and T4 are switched ON, T2 and T3 are switched OFF and T5 is in PWM switching mode. During this mode, V_{dc} and V_{batt} sequentially become the input and output voltages, also inductor current is a state variable in this operation and can be controlled, so the charging power delivered can be controlled.
Mode 2: $V_{dc} < V_{batt}$. Buck mode

$T_2$ is switched ON, $T_1$, $T_4$ and $T_5$ are switched OFF and $T_3$ is in PWM switching mode. During this mode, $V_{batt}$ and $V_{dc}$ sequentially become the input and output voltages, while delivering power from the battery to the dc link the inductor is at the output and the current is a state variable. Therefore the DC link voltage and the current delivered to the dc link can be controlled.

Mode 3: $V_{dc} > V_{batt}$. Buck mode

$T_4$ is switched ON, $T_2$, $T_3$ and $T_5$ are switched OFF and $T_1$ is in PWM switching mode. During this mode, $V_{dc}$ and $V_{batt}$ sequentially become the input and output voltages, the dc link voltage can be regulated by controlling the current delivered to the battery during driving mode. In Plug-In mode the current delivered can also be controlled.

Mode 4: $V_{dc} > V_{batt}$. Boost mode

$T_1$ and $T_4$ are switched OFF, $T_3$ and $T_2$ are switched ON and $T_5$ is in PWM switching mode. During this mode, $V_{batt}$ and $V_{dc}$ sequentially become the input and output voltages; the current drawn to the battery is controllable thereby regulating the dc link voltage.

IV. PULSE GENERATION USING MATLAB – M FILE

Based on the logic explained in the previous section, gating pulses for the switches have been generated using M-file coding [19]. The generated pulse pattern is shown in Fig. 4.

![Fig. 4. Logic used for generating pulses using MatLab- M-file](image)

V. SIMULATION OF THE BIDIRECTIONAL CONVERTER

The schematic shown in Fig. 2 has been implemented using MatLab and shown in Fig. 5.

![Fig. 5. MatLab Schematic of Fig. 2](image)

The parameters used for simulation is listed in Table 1.
TABLE I
Simulation Parameters for Universal Converter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC link voltage, V_{dc}</td>
<td>24 V / 42 V</td>
</tr>
<tr>
<td>Battery voltage, V_{batt}</td>
<td>42 V / 24 V</td>
</tr>
<tr>
<td>Switching frequency, f_s</td>
<td>20 kHz</td>
</tr>
<tr>
<td>Capacitance, C_{dc}</td>
<td>2200 µF</td>
</tr>
<tr>
<td>Inductance</td>
<td>3 mH</td>
</tr>
</tbody>
</table>

The pulses for the switches T_1 to T_5 are generated as explained in Section IV and the pulses for different modes are shown vide Fig. 6 to Fig. 9.

![Fig. 6. Pulses for switches in Mode 1](image1)

![Fig. 7. Pulses for switches in Mode 2](image2)
The simulation results are presented vide Fig. 10 to Fig. 13.
Fig. 10. Waveforms for Mode 1

Fig. 11. Waveforms for Mode 2
The load is kept the same for all the modes. In Fig.10, power is fed from dc link to battery by boost action. In mode 2 (Fig. 11), battery is delivering power to dc link by buck operation. The operation of mode 3 and mode 4 are vice-versa.
mode 2 and mode 1 respectively, that is battery and dc link are changed with voltage levels. In mode 1 and mode 3, load current is negative. In all the modes the universal dc-dc converter performs the satisfactory with respect to regulator operation.

VI. CONCLUSION

In this paper, the simulation of universal dc-dc converter has been done using MatLab software. The proper firing pulses have been generated and the working of the converter has been explained in different modes. The simulation of universal dc-dc converter has proved its capabilities of being used in a wide range of application areas. The topology uses less number of switches compared to that of dc-dc converters required for conventional electric vehicles. Bidirectional power flow capability has been verified through simulation. This work can be extended to interface renewable energy sources for hybrid vehicle applications.

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REFERENCES


