Performance Evaluation of Two Switch Buck-Boost Converter with and without Input Voltage Feed Forward Compensation-A Comparative study

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Abstract— Renewable energy, which is clean, can be utilised as a replacement. Fuel-cell (FC) technology offers an efficient and effective alternative renewable energy source. Fuel cells become the main power source for fuel cell electric vehicles. Due to its soft characteristics, the output voltage of fuel cells cannot be directly connected to an inverter. So a DC-DC converter is inserted between them to make a match and improve the performance of traction motors. For the power converters of Fuel Cell Electric Vehicles, there is a great need for less component stress, smaller component size and higher efficiency. The main objective of this paper is to conduct a comparative study of Two switch buck-boost (TSBB) converter with and without input voltage feed forward compensation (IVFF) function with the inverting buck-boost converter to accomplish a performance evaluation of the same. In this comparative study, effectiveness of converter unit, power quality concern of the produced DC output and its operation reliability are taken into account. Some simulation results are provided to emphasis the comparison between converter topology with and without IVFF compensation.

Keywords— Input voltage feed forward technique, Two switch buck-boost converter, Two mode control scheme

I. INTRODUCTION

Renewable energy systems offer environmental and economic advantages in producing energy compared with the conventional fossil fuel systems. Among all types of green energy applications, fuel cells are the most popular because they can provide a continuous power supply throughout all seasons as long as fuel is provided. Today, fuel cell electric vehicles (FCEVs) have received much attention as an alternative to traditional vehicles powered by internal combustion engines with the advancement in battery technology and motor efficiency. The secondary batteries are the main energy sources of the EV. Thus, energy management is the most important key factor in EV or HEV design. Moreover, the electric capacity of the battery will influence the endurance of electric vehicles. Generally, an energy management mechanism is very important for improving system efficiency and extending endurance. FCs are a good choice for many applications, such as hybrid electric vehicles, uninterruptible power supply, telecom back-up facilities, utility AC sources and portable electronics.

Fig. 1 shows the block diagram of fuel cell electric vehicle (FCEV). Due to its soft characteristics, the output voltage of fuel cells cannot be directly connected to an inverter. So a DC-DC converter is inserted between them to make a match and improve the performance of motors loads.

With the development of fuel cell, the power provided by it is increasingly large; however, the output voltage changes in a wide range as the effect of the soft characteristics. Fuel cell output voltage fluctuate in the range of 250 V to 500 V. In order to raise the motor power rating, the dc link voltage of inverter is up to 400V, so a buck-boost converter is needed. The power demanded during a load transient is provided by the battery through a bi-directional DC-DC converter. For applications that require a stable DC bus voltage, step-down and step-up DC/DC converters are needed. For example, a DC/DC converter can be inserted between the FC and a motor. Several converter types are capable of providing both step-up and step-down voltage conversion for FCs, including the inverting buck–boost converter, the fly back converter, the Cuk converter and the single-ended primary-inductance converter (SEPIC). However, these converters greatly stress the switches. The Cuk and SEPIC converters utilise two pairs of inductors and capacitors to transform energy into the output, and are thus large and inefficient. Another disadvantage is that the output polarity is reversed in the inverting buck–boost and Cuk converters. The fly back converter has a high-leakage inductance and its efficiency is low. Compared with the basic converters, which have the ability of both voltage step-up and step-down, such as inverting buck-boost, Cuk, Zeta, and SEPIC converters, the TSBB converter presents lower voltage stress of the power devices, fewer passive components, and positive output voltage and efficiency.

The TSBB converter is a simplified cascade connection of buck and boost converters. It is suitable for wide input voltage applications. In order to achieve high efficiency over the entire input voltage range, the TSBB converter is operated in buck mode at high input voltage and boost mode at low input voltage. Such operation is called the two-mode control scheme.
Figure 2 shows the circuit diagram of TSBB converter. There are two active switches in the TSBB converter, which provides the possibility of obtaining various control methods for this converter. If Q1 and Q2 are switched ON and OFF simultaneously, the TSBB converter behaves the same as the single switch buck-boost converter. This control method is called one mode control scheme. If Q1 and Q2 are controlled independently, it is two mode control scheme.

![Fig- 2 Circuit Diagram of Two Switch Buck-Boost Converter](image)

Modes of operation can be explained in two stages, when switch Q1 is controlled and Q2 is off and when Q1 is continuously on and Q2 is controlled to regulate the output voltage.

a. When the input voltage is higher than the output voltage, Q2 is always kept OFF, and Q1 is controlled to regulate the output voltage, and as a result, the TSBB converter is equivalent to a buck converter, and is said to operate in *buck mode*.

b. When the input voltage is lower than the output voltage, Q1 is always kept ON, and Q2 is controlled to regulate the output voltage, and in this case, the TSBB converter is equivalent to a boost converter, and is said to operate in *boost mode*.

Compared with one-mode control scheme, two-mode control scheme can reduce the conduction loss and switching loss effectively, leading to a high efficiency over a wide input voltage range, as explained in [4]. Besides, in order to achieve automatic switching between buck and boost modes, the two-mode control scheme based on two modulation signals with one carrier signal is used. For the converter in the applications with wide input voltage variation, input voltage feed-forward (IVFF) compensation is an attractive approach for improving the transient response of the converter, for it can eliminate the effect of the input voltage disturbance on the output voltage. The IVFF of the buck or boost converter can be implemented in several methods.

a. Vary either the amplitude of the carrier signal or the value of the modulation signal according to the input voltage. However, the variations of the carrier signal for the IVFF of the boost converter and the modulation signal for IVFF of the buck converter are both inversely proportional to the input voltage, which imply that the implementation of this IVFF method is complicated relatively for the TSBB converter.

b. Calculating the duty ratio. Since the duty ratio for the buck converter is inversely proportional to the input voltage results in complicated design.

c. Deriving IVFF functions in both buck and boost modes of operation which is easy to implement.

II. TWO MODE CONTROL SCHEME FOR TSBB CONVERTER

Voltage conversion ratio for TSBB converter in continuous current mode is,

\[ V_o = \frac{d_1}{1 - d_2} V_{in} \]

In the two-mode control scheme, d1 and d2 are controlled independently. When the input voltage is higher than the output voltage, the TSBB converter operates in *buck mode*, where \( d_2 = 0 \) and \( d_1 \) is controlled to regulate the output voltage. When the input voltage is lower than the output voltage, the TSBB converter operates in *boost mode*, where \( d_1 = 1 \) and \( d_2 \) is controlled to regulate the output voltage.

\[ V_o = \begin{cases} d_1 V_{in}, & d_2 = 0 \quad (V_{in} \geq V_o) \\ \frac{V_{in}}{1 - d_2}, & d_1 = 1 \quad (V_{in} < V_o) \end{cases} \]

The TSBB converter under the two-mode control scheme based on two modulation signals and one carrier which is shown in Fig- 3.

![Fig- 3 Two mode control scheme](image)

In two mode control scheme, \( v_{e ,\text{buck}} \) and \( v_{e ,\text{boost}} \) are the modulation signals for switches Q1 and Q2, and \( v_{saw} \) is the carrier. The maximum and minimum values of carrier are \( V_L \) and \( V_H \). To achieve two mode control scheme only one of the modulation signals can intersect with carrier \( v_{saw} \) at any time.

a. When \( V_{in} > V_{out} \), \( v_{e ,\text{buck}} \) will be within \([V_L, VH]\), and it intersects \( v_{saw} \) and thus determines \( d_1 \) and \( v_{e ,\text{boost}} < V_L \) and thus \( d_2 = 0 \), which is corresponds to the buck mode of the TSBB converter.

b. When \( V_{in} < V_{out} \), \( v_{e ,\text{boost}} \) will be within \([V_L, VH]\), and it intersects \( v_{saw} \) and thus determines \( d_2 \) and \( v_{e ,\text{buck}} > VH \) and thus \( d_1 = 1 \), which is corresponds to the buck mode of the TSBB converter.

III. IVFF FOR TWO-MODE CONTROL SCHEME

Schematic diagram of the two-mode control scheme with IVFF is shown in Fig- 4. From this schematic diagram control block diagram of TSBB converter with IVFF is in Fig- 5.

![Fig- 4 Schematic Diagram of TSBB Converter with IVFF](image)
being changed to $G_{ff}(s)$. The path from $v_{in}$ to $v_{ff}$ is called the IVFF path and the IVFF function is

\[
G_{ff}(s) = \frac{V_{o}}{V_{in}} - \frac{G_{PWM}(s)}{G_{rd}(s)}
\]

IVFF transfer function in buck mode,

\[
G_{ff,buck}(s) = -\frac{V_{o}}{V_{in}}V_{sw}
\]

IVFF transfer function in boost mode,

\[
G_{ff,boost}(s) = -\frac{1}{V_{o}}V_{sw}
\]

The output signals of the IVFF path under different operating modes are,

\[
u_{ff,buck} = G_{ff,buck}v_{in} = -\frac{V_{o}}{V_{in}}V_{sw}v_{in}
\]

\[
u_{ff,boost} = G_{ff,boost}v_{in} = -\frac{1}{V_{o}}V_{sw}v_{in}
\]

The modulation signals of the TSBB converter under the two-mode control scheme with IVFF compensation are,

\[
v_{c,buck} = \nu_{c,buck} + v_{en} + v_{bias} = -\frac{V_{o}}{V_{in}}V_{sw}v_{in} + v_{en} + v_{bias}
\]

\[
v_{c,boost} = \nu_{c,boost} + v_{en} = -\frac{V_{o}}{V_{in}}V_{sw}v_{in} + v_{en}
\]

IV. COMPARATIVE STUDY

A. Output signal of Voltage Regulator

The modulation signals under the two-mode control scheme are the functions of only input voltage. The output signal of the voltage regulator under the two-mode control scheme with IVFF compensation is

\[
v_{en}^* = \left\{ \begin{array}{ll} V_{sw} \left( \frac{V_{o}}{V_{in}} + \frac{V_{o}}{V_{in,min}}v_{in} + \frac{V_{o}V_{bias}}{V_{in,min}V_{in}} - \frac{V_{o}V_{bias}}{V_{in,min}} - 1 \right) \\ + V_{L} (V_{in} < V_{o}) \\ V_{H} (V_{in} > V_{o}) \end{array} \right.
\]

The output signal of the voltage regulator under the two-mode control scheme without IVFF compensation is,

\[
v_{en} = \left\{ \begin{array}{ll} \frac{V_{o}}{V_{in}} - 1 \ V_{sw} + V_{L} (V_{in} > V_{o}) \\ 1 - \frac{V_{in}}{V_{o}} \ V_{sw} + V_{L} (V_{in} < V_{o}) \end{array} \right.
\]

Features of IVFF compensation are,

a. Voltage variation of $v_{en}$ under the two-mode control scheme with IVFF compensation is much smaller than that without IVFF compensation over the entire input voltage range.

b. IVFF mainly regulated the output voltage, extremely alleviating the task of the voltage regulator and improving the transient response on the disturbance of the input voltage.

c. $v_{en}$ has a small leap at the mode-switching point when the IVFF compensation is incorporated.

d. Automatic and smooth switching of modulation signal is possible with IVFF compensation.

B. Comparison of Two Mode Control Scheme with and without IVFF Compensation

<table>
<thead>
<tr>
<th>Comparison between with and without IVFF</th>
<th>With IVFF</th>
<th>Without IVFF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Variation</td>
<td>$v_{en}$ is much smaller</td>
<td>$v_{en}$ has large value</td>
</tr>
<tr>
<td>Transient Response</td>
<td>Improved transient response on the disturbance of input voltage.</td>
<td>Transient response is poor.</td>
</tr>
<tr>
<td>Voltage Regulation</td>
<td>Effectively regulated the output voltage</td>
<td>Voltage regulation is not efficient.</td>
</tr>
<tr>
<td>Mode Switching</td>
<td>Automatic and smooth switching of modulation signal at mode switching point</td>
<td>Switching of modulation signal is not smooth.</td>
</tr>
</tbody>
</table>

V. SIMULATION AND RESULTS

Simulation is done with the same design conditions in Matlab 2012a and simulation results obtained are given below.

TABLE II Design Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage</td>
<td>250 V-500 V</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>360 V</td>
</tr>
<tr>
<td>Output Power</td>
<td>6 KW</td>
</tr>
<tr>
<td>Switching Frequency</td>
<td>100 KHz</td>
</tr>
<tr>
<td>Output Voltage Ripple</td>
<td>2 % output voltage</td>
</tr>
<tr>
<td>Current Ripple</td>
<td>20 % output current</td>
</tr>
</tbody>
</table>

Design equations for TSBB converter is given in [2].

Components of TSBB Converter | Specification |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Filter Capacitor</td>
<td>4080µF</td>
</tr>
<tr>
<td>Inductor</td>
<td>320µH</td>
</tr>
<tr>
<td>Full Load Resistor</td>
<td>21.6Ω</td>
</tr>
</tbody>
</table>

A. Simulation Models

(a)
Transient response on the disturbance of input voltage is improved with IVFF compensation. Also output voltage is effectively regulated over wide range of input voltage. But without IVFF, transient response is poor and voltage regulation is not efficient.

VI. CONCLUSION

Through this comparative study, performance of TSBB converter under two mode control scheme is evaluated with and without IVFF compensation. The superiority of IVFF compensation in voltage regulation, variation of error signal, switching of modulation signal and transient response also evaluated using simulation results. The variation of $v_{ea}$ under the two-mode control scheme with IVFF compensation is much smaller which implies that the IVFF mainly regulated the output voltage, extremely alleviating the task of the voltage regulator and improving the transient response on the disturbance of the input voltage. Automatic and smooth switching is also achieved with IVFF.

REFERENCES


