A Novel Improved Resonant LLC Converter with Minimal Components

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Abstract: This paper presented a novel improved resonant LLC converter with minimal components compared with existing design. Conventional Full H-Bridge in converter replace with differential boost for improving the overall gain of the circuit and also able to operated buck, boost and buck-boost. As a result, the component size is significantly reduced and enhance the size and cost of the converter. Different modes of operations presented for understanding the new converter in terms of switching frequency and gain. An Experimental and simulation result confirms the effectiveness of the proposed inverter.

Key Words: Resonant tank, DC-DC converter, buck, boost, buck-boost, switching frequency, inverter, overall gain.

I. INTRODUCTION

Resonant DC-DC converter widely used in many applications like renewable energy, hybrid vehicles and other power conversion. For all applications, the preferable converter with controllable gain and minimal components [1]-[6]. The general structure of Resonant DC-DC converter is shown in Fig. 1. Overall operating gain of the converter customizable with first stage inverter circuit. By adjusting the gain, the overall performance of the converter is operated in wide range of operating mode.

The main objectives of this work is

• To design a converter which can able to operate in wide range of gain (buck, boost and buck-boost) results in enhanced performance.

• To utilize the frequency range within in the gain operating range improvise the component used in the tank circuit.

The contribution of the work is

• To involve the boost inverter in the circuit for improvise the gain.

• To incorporate a new PWM scheme for improving the EMI inference for same Resonant Circuit.

II. PROPOSED METHODOLOGY

A. Gain of LLC converter

General functional block diagram of Resonant LLC converter [1] is shown in Fig.1. The overall gain of LLC converter is product of inverter gain, tank gain and transformer turns ratio.

a. Degree of Freedom in Gain

Initially, the converter depends only on tank gain and transformer design are presented in 1, which is responsible for performance adjustment. But, Many research works not discuss the effect of inverter gain, it can be adjust by means of selection proper switching techniques. By selecting the proper inverter switching able to operate in gain and also feasibility in PWM and design. The degree of freedom in gain with respect to switching frequency in terms of resonant Q value in Fig.2.

b. Differential boost inverter with LLC converter

Differential boost inverter (DBI) (see Fig 3) able to operate in higher output voltage than input voltage, compared to conventional inverter. Additionally, DBI able to generate high frequency high quality sine wave output [7]-[13]. Hence the degree of freedom in this converter achieved with incorporating DBI with tank circuit and rectifier load.

Fig. 1. Block diagram of Resonant LLC converter

Fig. 2 General Configuration of Differential boost
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III. OPERATING MODES

Generally, the resonant tank circuit with transformer is controlled with different operating modes (Normal, Buck and Boost) depending on switching frequency and resonant frequency is shown in Table 1.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Voltage</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>$V_{in} = V_{in}$</td>
<td>$f_{sw} = f_{r}$</td>
</tr>
<tr>
<td></td>
<td>$V_{in} &gt; V_{in}$</td>
<td>$f_{sw} = f_{r}$</td>
</tr>
<tr>
<td></td>
<td>$V_{in} = V_{in}$</td>
<td>$f_{sw} &gt; f_{r}$</td>
</tr>
<tr>
<td>Buck</td>
<td>$V_{in} &gt; V_{in}$</td>
<td>$f_{sw} = f_{r}$</td>
</tr>
<tr>
<td></td>
<td>$V_{in} &gt; V_{in}$</td>
<td>$f_{sw} = f_{r}$</td>
</tr>
<tr>
<td></td>
<td>$V_{in} &gt; V_{in}$</td>
<td>$f_{sw} &gt; f_{r}$</td>
</tr>
</tbody>
</table>

Table IDB Based LLC Converter - Modes

A. Normal Mode

In this mode $f_{sw} = f_{r}$, same switching and resonant frequency of this converter. It depends on resonant capacitor and inductor. Technically, this scheme is preferred mode for ideal operation. Efficiency is achieved at max comparatively with other modes but with best perfect turn on and off operating period. On the other hand, $f_{sw} > f_{r}$, high switching than resonant frequency of this converter, indirectly operate with small resonant tank components. Efficiency is drastically reduced with non zero current but achieved zero voltage switching. Subsequently, $f_{sw} < f_{r}$, small switching than resonant frequency of this converter, indirectly operate with high resonant tank components. Efficiency is drastically reduced with non zero voltage but achieved zero current switching shown in Fig 4.

a. Buck Mode

In this mode the output voltage is less than output voltage $f_{sw} = f_{r}$, same switching and resonant frequency of this converter. It depends on resonant capacitor and inductor. Technically, this scheme is preferred mode for light load operation. On the other hand, $f_{sw} > f_{r}$, high switching than resonant frequency of this converter, indirectly operate with small resonant tank components. Subsequently, $f_{sw} < f_{r}$, small switching than resonant frequency of this converter. Efficiency is drastically reduced with non zero current but achieved zero voltage switching shown in Fig 5.

b. Boost Mode

In this mode the output voltage is less than output voltage $f_{sw} = f_{r}$, same switching and resonant frequency of this converter. It depends on resonant capacitor and inductor. Technically, this scheme is preferred mode for
heavy load operation. On the other hand, $f_{sw} > f_r$, high switching than resonant frequency of this converter indirectly operate with small resonant tank components. Subsequently, $f_{sw} < f_r$, small switching than resonant frequency of this converter indirectly operate with high resonant tank components. It includes non zero voltage but achieved zero current switching shown in Fig 6.

c. Selection of Modes

Among nine possible operating modes, each one has its own advantage. In order to select the suitable method for wide range of load variations, the inverter output voltage and switching frequencies make huge impact within the range shown in Fig 7.

![Figure 6 Operating Mode with $f_{sw} > f_r$](image1)

![Figure 7 Selection of operating modes](image2)

IV. RESULTS AND DISCUSSION

A. Impact on inductance ratio ($m$)

The entire resonant tank circuit with transformer highly impact on the inductance ratio ($m$). As the value of $m$ increases, the overall gain and regulation improved with small switching frequency range. In other side of high $m$ value, increase the magnetizing inductance along with over al efficiency and reduce the magnetizing current. To utilize the both side advantage the selection of switching frequency with inverter gain (mode selection) make impact on designing the tank circuit.

B. Design Aspects

Table 2 show the comparison of the component size used in resonant tank with transformer. There resonant tank circuit

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Existing</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Voltage</td>
<td>400 V</td>
<td></td>
</tr>
<tr>
<td>Input Voltage</td>
<td>18 V</td>
<td></td>
</tr>
<tr>
<td>Output Power</td>
<td>125 W</td>
<td></td>
</tr>
<tr>
<td>Resonant frequency</td>
<td>100 kHz</td>
<td>10-250 kHz</td>
</tr>
<tr>
<td>Switching frequency</td>
<td>50 kHz</td>
<td>25-125 kHz</td>
</tr>
<tr>
<td>Resonant Capacitor</td>
<td>940 pF</td>
<td>520 pF</td>
</tr>
<tr>
<td>Resonant Inductor</td>
<td>2.2 µH</td>
<td>1 µH</td>
</tr>
<tr>
<td>Magnetizing Inductor</td>
<td>12.2 µH</td>
<td>7 µH</td>
</tr>
</tbody>
</table>

Table II Comparison Of DB Based LLC Converter Design Aspect With Conventional LLC Converter Component values reduced by half and reduced the cost in significantly for same output power and input/output voltages without any losses.

C. Results

Fig 10 and Fig 11 shows the resonant tank voltage and current of existing scheme with proposed scheme. The new scheme shows the smooth ZVS and ZCS compare with Existing design. This new design is most preferable of conventional and enhance the size and cost of the converter. Different modes of operations presented for understanding the new converter in terms of switching frequency and gain.

![Figure 8 Experimental results of Existing Scheme](image3)

V. CONCLUSION

A novel improved resonant LLC converter was designed with minimal components compared with existing system. This new converter able to operate in wide range of gain (buck, boost and buck, boost) results in enhanced performance. Here Conventional Full H-Bridge in converter replace with differential boost for improving the overall gain of the circuit and also able to operated buck, boost and buck-boost. Experimental and simulation results confirmed the effectiveness of the proposed inverter. As a result, the component size is significantly reduced.

REFERENCES


