Mathematical Modeling of DC DC Converters

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Abstract: The 3 Basic DC-DC converters that is the BUCK converter, BOOST converter and the BUCK-BOOST converter have been studied and the mathematical model of the same have been represented. The component values have been individually designed and the frequency of operation has been verified for the range of 20-50 KHz for an input voltage range of 10-30V. All the mathematical models have been implemented using an open source software Scilab X-cos. The schematic simulations have been done in pspice student edition. And the results of schematic and mathematical model have been verified.

I. INTRODUCTION

DC DC converters play vital role in VLSI circuits as well as HVDC transmission systems. DC DC converters are the AC transformer equivalents. They are used to step up and step down the DC voltages at minimal or no power loss. The BUCK converter is used to step down the input DC voltage. The BOOST converter is used to step up the given input voltage. And the BUCK-BOOST has the capability to perform both the operations with inverted output. The DC DC converters like CUK converter, SEPIC converter and SWITCH CAPACITOR converters also exist. They are used depending upon the application required.

II. PROPOSED MODELS

1. Design a Buck converter to produce an output of 15V from a 24V source. The load is 2A. Design for continuous inductor current. Output voltage ripple and inductor current ripple must be no greater than 0.5%.

Solution: Given: \( V_{in} = 24V; V_o = 15V \)

- \( V_o \leq 0.5\% \)
- \( V_o \)

Design assumptions:

- The switching frequency is assumed to be 40KHz
- Inductor current is assumed to be continuous

\[
\frac{V_o}{V_{in}} = D
\]

\[
D = \frac{15}{24} = 0.625
\]

\[
R = \frac{V_o}{I_o} = \frac{15}{2} = 7.5 \Omega
\]

\[
L_{min} = (1 - D) \frac{R}{2f}
\]

\[
L_{min} = 35 \mu H
\]

Let

\[
L = 175\% \text{ of } L_{min} = 1.75 \times 35 = 61.25 \mu H.
\]

\[
C \geq \frac{1-D}{8+L_{min}} \frac{V_o}{f^2}
\]

\[
C \geq 96 \mu F
\]

Let \( C = 120 \mu F \)

MATHEMATICAL MODELS
SIMULATION RESULTS

Table 1:

<table>
<thead>
<tr>
<th>Sl no</th>
<th>Quantity</th>
<th>Theoretical values</th>
<th>Simulation result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VOUT</td>
<td>15 V</td>
<td>14.3 V</td>
</tr>
<tr>
<td>2</td>
<td>Iload</td>
<td>2 A</td>
<td>1.92 A</td>
</tr>
</tbody>
</table>

2. Design a Boost converter to provide an output of 18V from a 12V source. The load is 20W. The voltage and current ripple must be less than 0.5%. Specify the duty ratio, switching frequency, values and ratings of each of the components. Design for a continuous current. Assume ideal components.

Solution:
Given:
$V_{in} = 12V$
$V_o = 18V$
$\delta V_o \leq 0.5\%$

$V_o$

Design assumptions:
- The switching frequency is assumed to be 25KHz
- Inductor current is assumed to be continuous

$I_o = \frac{P_o}{V_o} = \frac{20}{18} = 1.11;$
$V_o = \frac{V_{in}}{1 - D}$

$D = 0.33$

$L_{min} = \frac{D(1 - D)}{2f} \times R$
$L_{min} = 48\mu H$

Let $L = 50\%$ of $L_{min} = 1.5*48=72\mu H$

$C \geq \frac{D}{R \times \frac{V_o}{V_{in}} f} \geq 163\mu F$

$C = 165\mu F$

MATHEMATICAL MODELS

Table 2:

<table>
<thead>
<tr>
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<th>Quantity</th>
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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>VOUT</td>
<td>18 V</td>
<td>16 V</td>
</tr>
<tr>
<td>2</td>
<td>Iload</td>
<td>0.92 A</td>
<td>1.2 A</td>
</tr>
</tbody>
</table>

3. Design a Buck-Boost convertor that has a source that varies from 10 to 14V. The output is regulated at -12V. The load varies from 10 to 15W. The voltage and current ripple must be less than 1% for any operating condition. Specify the range of duty ratios, switching frequency, values and ratings of each of the component. Assume ideal components.

Solution:
a. Given:

\[ V_{in} = 10\text{V} \]
\[ V_0 = 12\text{V} \]
\[ V_0 \leq 1\% \]
\[ V_0 \]
\[ P_o = 10\text{W} \]

Design assumptions:

- The switching frequency is assumed to be 100KHz
- Inductor current is assumed to be continuous
- \[ \frac{V_0}{V_{in}} = -\frac{D}{1-D} \quad D = 0.545 \]

\[ R = \frac{V^2}{P_o} = 14.4\Omega \]

\[ C \geq \frac{D}{R \cdot (\frac{1}{f})} \geq 37\mu F \]

\[ C = 50\mu F \]

\[ L_{min} = (1 - D)^2 \cdot \frac{R}{2f} = 15\mu H \]

Let \( L = 75\% \) of \( L_{min} = 27\mu H \)

b. Given:

\[ V_{in} = 14\text{V} \]
\[ V_0 = 12\text{V} \]
\[ V_0 \leq 1\% \]
\[ V_0 \]
\[ P_o = 15\text{W} \]

Design assumptions:

- The switching frequency is assumed to be 100KHz
- \[ \frac{V_0}{V_{in}} = -\frac{D}{1-D} \]
- \[ D = 0.4615 \]

\[ R = \frac{V^2}{P_o} = 9.6\Omega \]

\[ C \geq \frac{D}{R \cdot (\frac{1}{f})} \geq 48\mu F \]

\[ C = 72\mu F \]

\[ L_{min} = (1 - D)^2 \cdot \frac{R}{2f} = 14\mu H \]

Let \( L = 75\% \) of \( L_{min} = 25\mu H \)

<table>
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<th>Simulation result</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>VOUT</td>
<td>-12 V</td>
<td>-11.3 V</td>
</tr>
<tr>
<td>2</td>
<td>IL</td>
<td>1 A</td>
<td>8 A</td>
</tr>
</tbody>
</table>

Table 3:

CONCLUSION

The mathematical models of BUCK, BOOST and BUCK-BOOST converter have been simulated and are
verified theoretically. All the simulations were done in Scilab-Xcos tool®.

REFERENCES

[1] Power Electronics, Dr. P.S. BIMBHRA

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