EN 206: Power Electronics and Machines

Boost, Buck-Boost, Cuk Converters

Suryanarayana Doolla

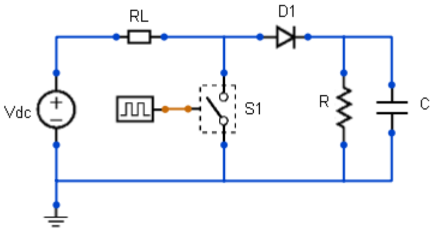
Department of Energy Science and Engineering
Indian Institute of Technology Bombay
email: suryad@iitb.ac.in

March 19, 2014

Lecture Organization - Modules

- Introduction and Power Semiconductor Switches
- Module 1: Transformers
- Module 2: AC/DC converter / Rectifier
- Module 3: DC machines and Drives
- Module 4: DC/DC converter
- Module 5: Induction Machine
- Module 6: DC/AC converter / Inverter
- Module 7: AC/AC converter / Cyclo converter
- Module 8: Synchronous Machine
- Module 9: Special Topics: Machines, HVDC, APF

Boost converter

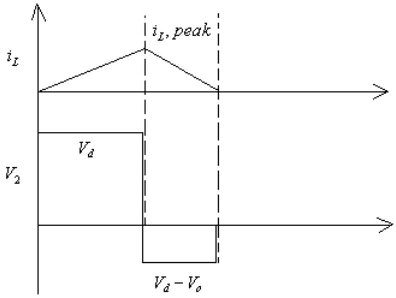


V_{dc}= Supply Voltage,
V_0= Output Voltage,
$V_{ind} = V_s - V_0$, (S1 is OFF)
$V_{ind} = V_s$, (S1 is ON)

- The average output voltage is more than the input voltage V_d
- The filter capacitor is assumed to be high so that the output voltage is more of less constant

Boost converter-CC Mode

Inductor Voltage and Current



Analysis

When the switch in ON, Inductor current is rising
When the switch in OFF, Inductor current is falling

$$V_L = \frac{1}{T_s}\int_0^{T_{on}} V_d.dt$$

$$+\frac{1}{T_s}\int_{T_{on}}^{T_s} -(V_d - V_0).dt$$

Boost converter-CC Mode

$$V_L = \frac{1}{T_s}\int_0^{T_{on}} (V_d).dt + \frac{1}{T_s}\int_{T_{on}}^{T_s} -(V_0 - V_d).dt$$

$$V_L = \frac{T_{on}}{T_s}(V_d) - \frac{V_0 - V_d}{T_s}(T_s - T_{on})$$

The average voltage across inductor in a cycle is zero.

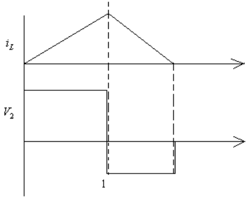
$$V_0 = \frac{T_s}{T_{off}} V_d$$

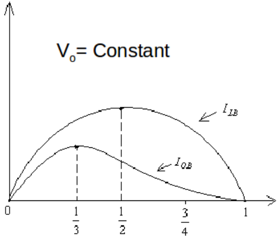
$$V_0 = \frac{1}{1-D} V_d$$

Assuming a lossless circuit,

$$\frac{I_d}{I_0} = \frac{V_0}{V_d} = \frac{1}{1-D}$$

Boundary Condition -CCM and DCM





Analysis

$$I_{LB} = \frac{1}{2} I_{L,peak}$$

$$\implies I_{LB} = \frac{1}{2} \frac{V_d}{L} T_{on}$$

$$\implies I_{LB} = \frac{V_0 T_s}{2L} D(1-D)$$

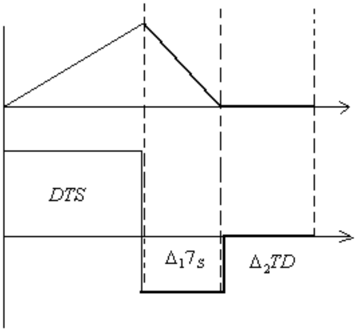
assuming lossless circuit,

$$I_{0B} = (1-D) I_{LB}$$

$$\implies I_{0B} = \frac{V_0 T_s}{2L} D(1-D)^2$$

Boost Converter - DCM

Inductor Current with duty cycle



Analysis

Average voltage across inductor in zero.

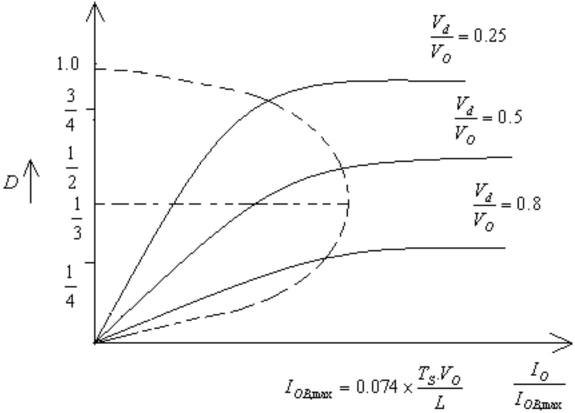
$(V_d)DT_s + (V_d - V_0)\Delta_1 T_s = 0$

$\implies \frac{V_d}{V_0} = \frac{\Delta_1}{\Delta_1 + D}$

The general practise is to keep V_0 constant and vary V_d.

Δ_1 can be derived in terms of known parameters (home work).

Boost Converter - Boundary Condition



Boost Converter - Output ripple

$$\Delta V_0 = \frac{\Delta Q}{C}$$

$$\implies \Delta V_0 = \frac{I_0 D T_s}{C} = \frac{V_0}{R} \times \frac{D T_s}{C}$$

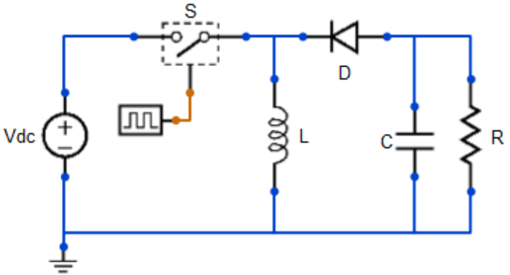
$$\implies \frac{\Delta V_0}{V_0} = \frac{D T_s}{RC}$$

Problem

In a step-up converter, the duty ratio is adjusted to regulate the output voltage at 48V. The input voltage varies in a wide range from 12 to 36V. The maximum power output is 120W. For stability reasons, it is required to operate the converter in discontinuous current conduction mode. The swtiching frequency is 50 kHz. Assuming ideal components and C is very large, Calculate the maximum value of L that can be used.

- The output is to be regulate at 48V for varying input, calculate the range of duty cycle.
- Determine the value of the inductor at which the current is at the border of CCM and DCM
- For the range of duty cycles we get different values of inductor, which one to choose?
- For solution using equations and graphs, please refer to text book[1], page, 176.?

Buck-Boost Converter



- Cascading of Buck and Boost circuits
- The output voltage polarity is negative
- The output voltage is higher (boost, $D > 0.5$) or lower (buck, $D < 0.5$) than input voltage.

Buck-Boost Converter - CCM

Integral of inductor voltage over one time period is zero:

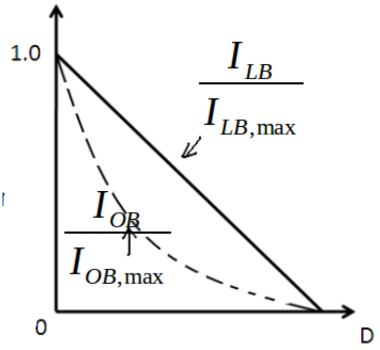
$$V_d(T_{on}) + (-V_0)T_{off} = 0$$

$$V_d(D.T_s) - V_0(1 - D)T_s = 0$$

$$\frac{V_0}{V_d} = \frac{D}{1 - D}$$

Boundary Condition

Inductor Current with duty cycle



Analysis

$$I_{LB} = \frac{1}{2} I_{L,peak}$$

$$\implies I_{LB} = \frac{1}{2} \frac{V_d}{L} T_{on}$$

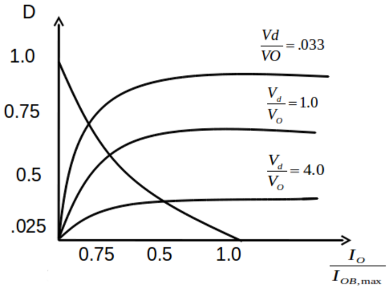
$$\implies I_{LB} = \frac{V_0 T_s}{2L}(1 - D)$$

also,

$$\implies I_{0B} = \frac{V_0 T_s}{2L}(1 - D)^2$$

Boundary Condition

Conv characteristics keeping V_0 constant



Analysis

For discontinuous current conduction mode,

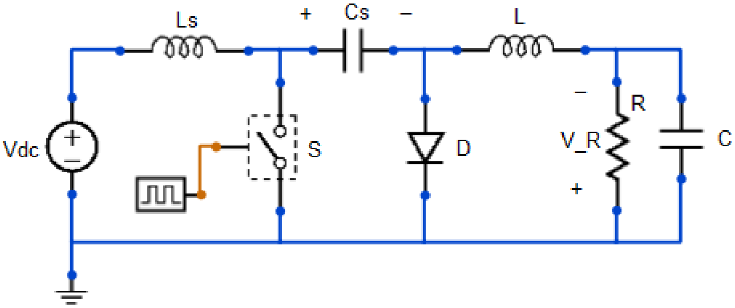
$$D = \frac{V_0}{V_d}\sqrt{\frac{I_0}{I_{0B,max}}}$$

Problem

In a buck-boost converter operating at 20kHz, L=0.05mH. The output capacitor is sufficiently large and $V_d = 15V$. The output is to be regulated at 10V and the converter is supplying a load of 10W. Calculate the duty ratio D.

- If the conduction mode (DCM/CCM) is known then the solution is straight forward, choose appropriate equation.
- It is also difficult to do the analysis using graphs.
- Assume that the system is at border of CCM, initially and compute D
- At this value of D, computer, I_{0B}, compare this with I_0 actual.
- Now determine the actual value of D

Cuk Converter



- Average voltage across inductors is zero
- C_s is sufficiently large and hence at steady state V_{c1} can be assumed to be neglibly larger V_d, $V_0 + V_d = V_{cs}$

Cuk Converter

Switch Off state:

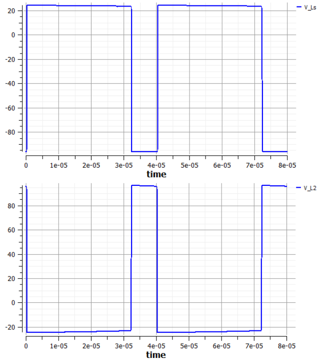
- The inductor currents flow through the diode.
- Capacitor C_s is charged through the diode by energy from both the input and L_1.
- The current I_{L1} decreases, because V_{c1} is larger than V_d.
- Energy stored in L_2 feeds output and therefore I_{L2} decreases

Switch ON state:

- V_{C1} reverse biases the diode.
- I_{L1} and I_{L2} flows through the switch.
- As $V_{C1} > V_0$, C_1 discharges through the switch, transferring energy to the output and L_2 and therefore I_{L2} increases.
- The input feeds energy to L_1 causing i_{L1} to increase

Cuk Converter - Analysis

Votlage across inductors



Analysis

$$V_d D T_s + (V_d - V_{c1})(1-D) T_s = 0$$

$$\Longrightarrow \quad V_{c1} = \frac{1}{1-D} V_d$$

$$(V_{c1} - V_0) D T_s + (-V_0)(1-D) T_s = 0$$

$$\Longrightarrow \quad V_{c1} = \frac{1}{D} V_d$$

therefore

$$\Longrightarrow \quad V_0 = \frac{D}{1-D} V_d$$

Summary

- DC/DC Converters
  - DC/DC Converter - Boost, Buck-Boost Converter, Cuk Converter Analysis

  Next Class

  - DC/DC Converter - Flyback and Forward Converters

For Further Reading:

- Power Electronics: Converters, Applications, and Design: N. Mohan, T. M. Undeland, W. P. Robbins, John Wiley and Sons.
- Power electronics and motor drives: advances and trends: Bimal K Bose. Pearson Education.