SEPIC CONVERTER

Prepared by
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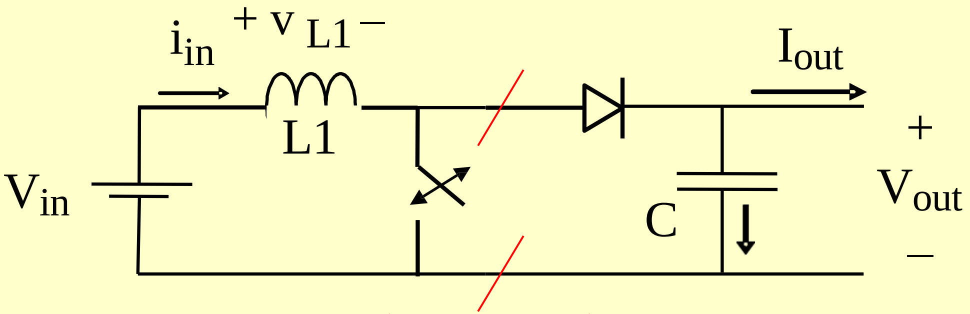
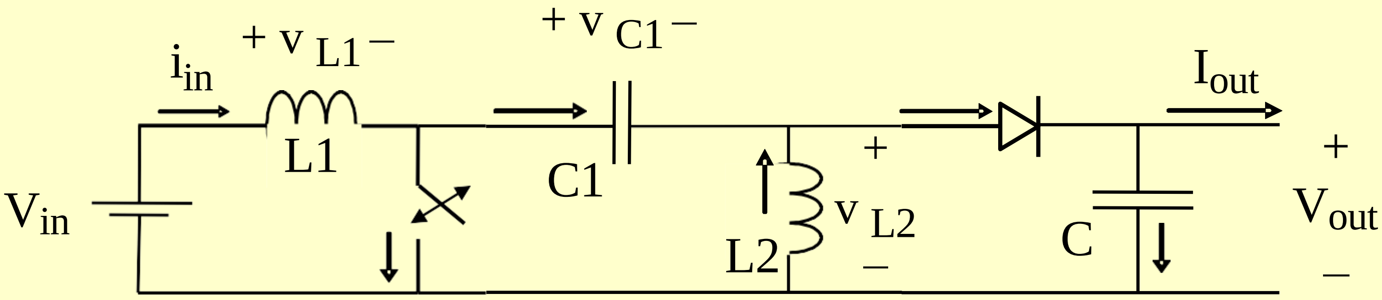
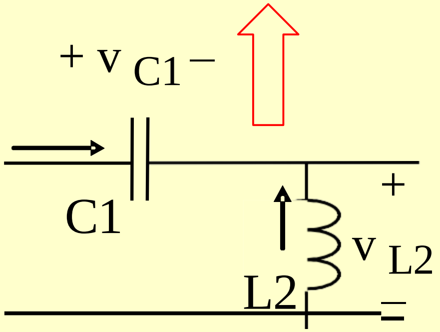
Boost converter

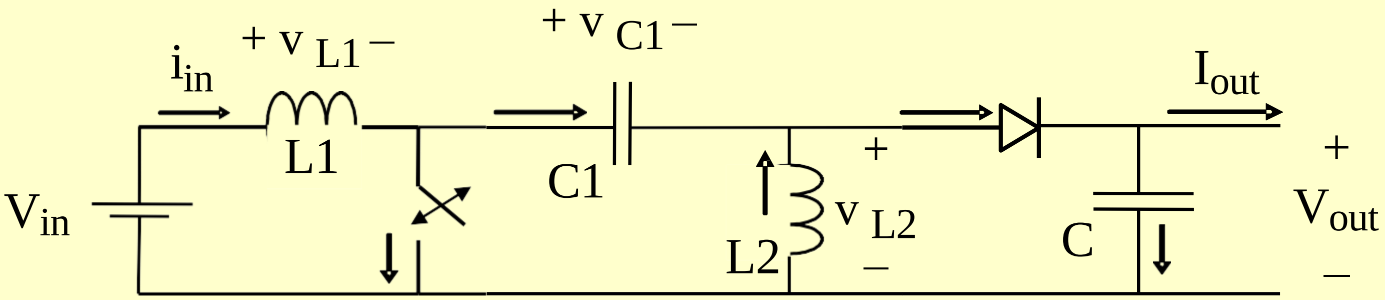


SEPIC converter





SEPIC converter

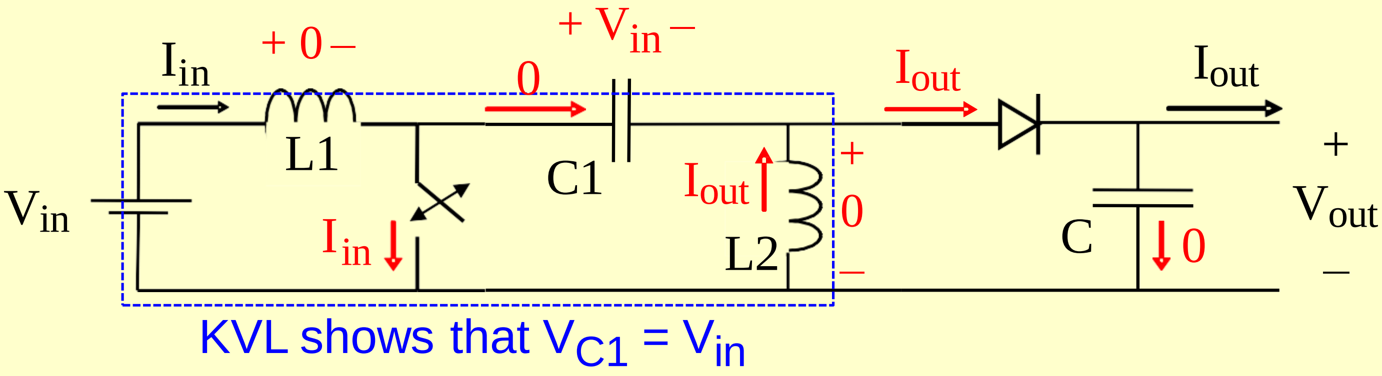


SEPIC = single ended primary inductor converter

This circuit is more unforgiving than the boost converter, because the MOSFET and diode voltages and currents are higher

- **Before applying power, make sure that your D is at the minimum, and that a load is solidly connected**
- **Limit your output voltage to 90V**

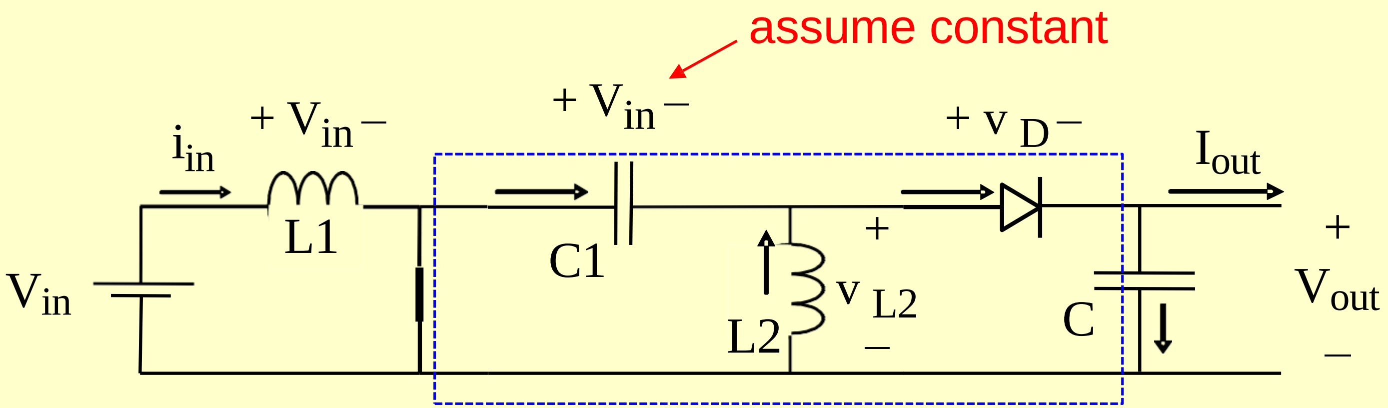
KVL and KCL in the average sense



KVL shows that $V_{C1} = V_{in}$

Interestingly, no average current passes from the source side, through C1, to the load side, and yet this is a “DC - DC” converter

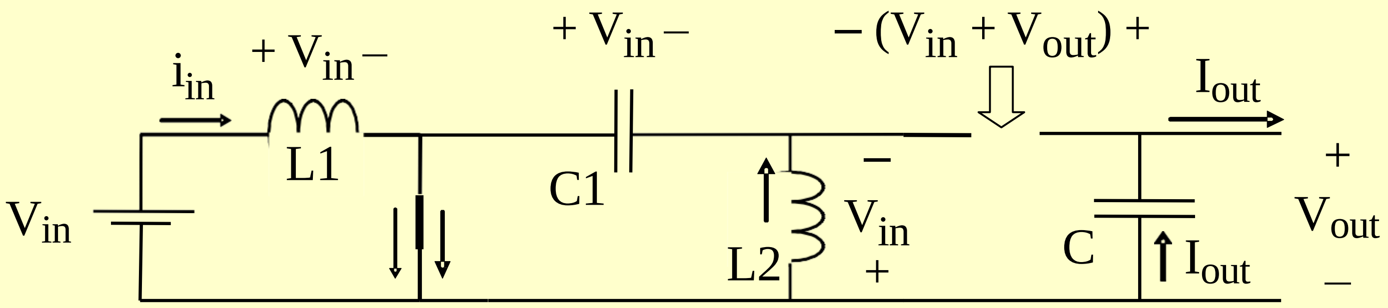
Switch closed



KVL shows that $v_D = -(V_{in} + V_{out})$,

so the diode is open

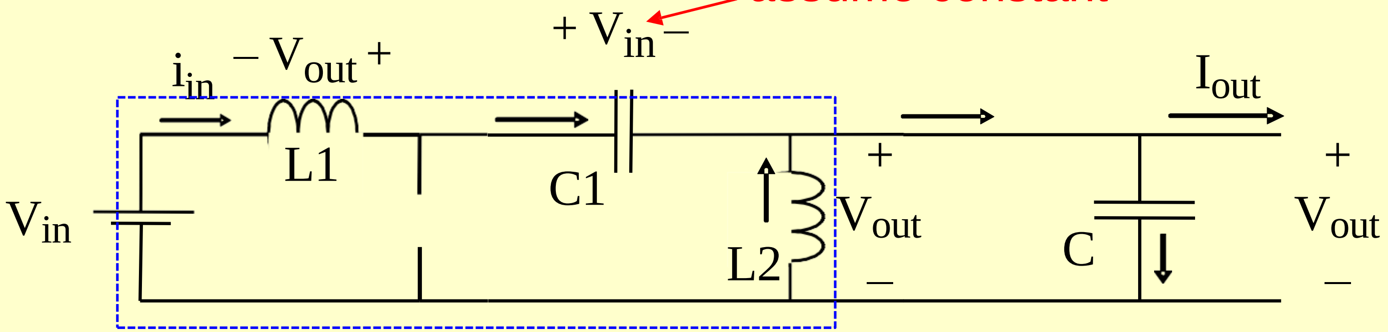
Thus, C is providing the load power when the switch is closed



i_{L1} and i_{L2} are ramping up (charging). C1 is charging L2

(so C1 is discharging). C is also discharging.

Switch open (assume the diode is conducting because, otherwise, the circuit cannot work)



assume constant

C1 and C are charging. L1 and L2 are discharging.

KVL shows that $V_{L1} = -V_{out}$

The input/output equation comes from recognizing that the average voltage across L1 is zero

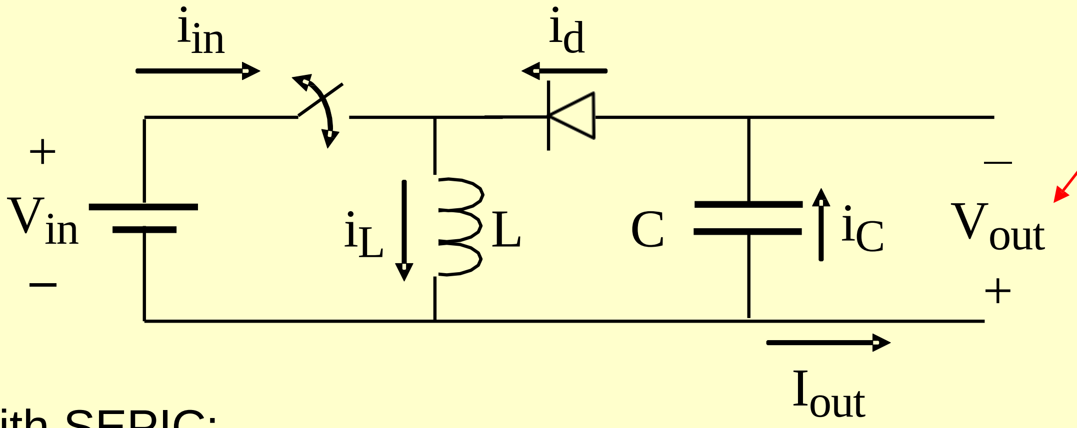
$$V_{L1avg} = D \bullet V_{in} + (1-D) \bullet (-V_{out}) = 0$$

$$V_{out} \bullet (1-D) = D \bullet V_{in}$$

$$\boxed{V_{out} = \frac{DV_{in}}{1-D}}$$

Voltage can be stepped-up or stepped-down

The buck-boost converter



Inverse polarity with respect to input

Compared with SEPIC:

+ Fewer energy storage components

+ Capacitor does not carry load current

+ In both converters isolation can be easily implemented

- Polarity is reversed

$$\boxed{V_{out} = \frac{DV_{in}}{1-D}}$$

Voltage can be stepped-up or stepped-down

Inductor L1 current rating

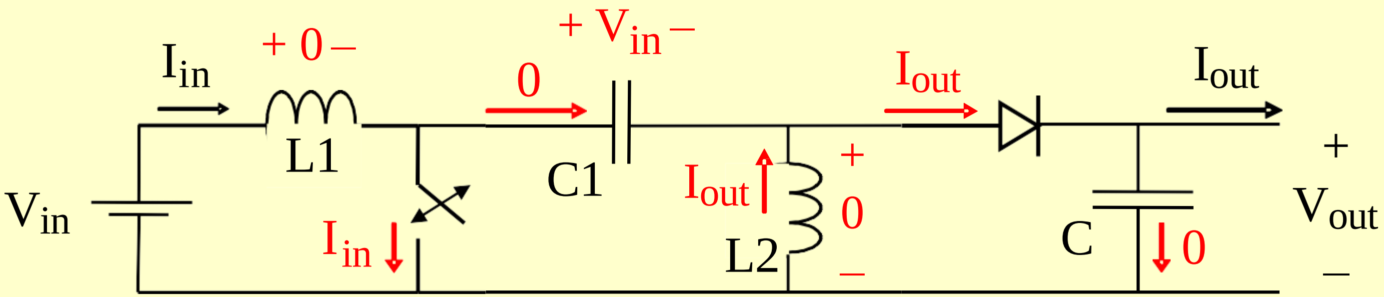
During the “on” state, L1 operates under the same conditions as the boost converter L, so the results are the same

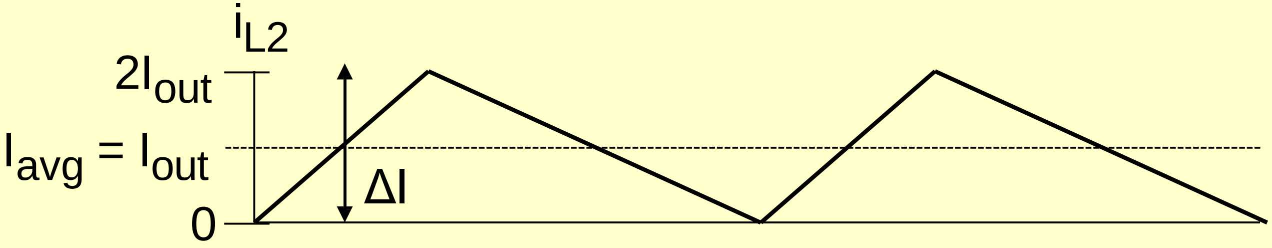
Use max

$$I_{L1rms} = \boxed{\frac{2}{\sqrt{3}} I_{in}}$$

Inductor L2 current rating

Average values



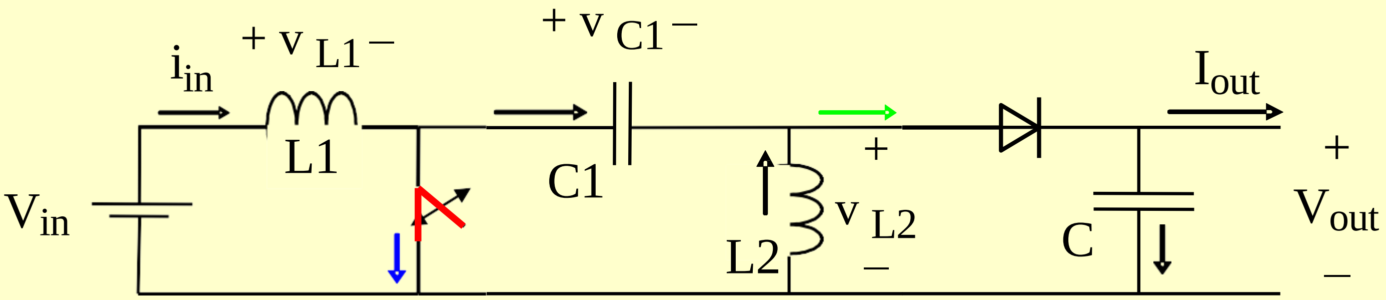


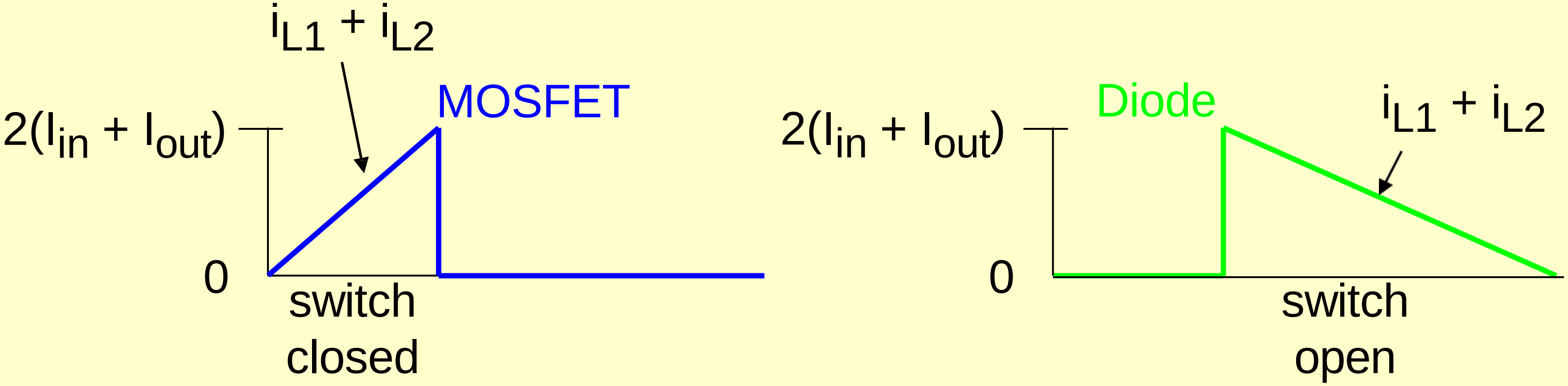
$$I_{L2rms}^2 = I_{out}^2 + \frac{1}{12}\left(2\Delta I_{out}\right)^2 = \frac{4}{3} I_{out}^2$$

Use max

$$I_{L2rms} = \boxed{\frac{2}{\sqrt{3}} I_{out}}$$

MOSFET and diode currents and current ratings



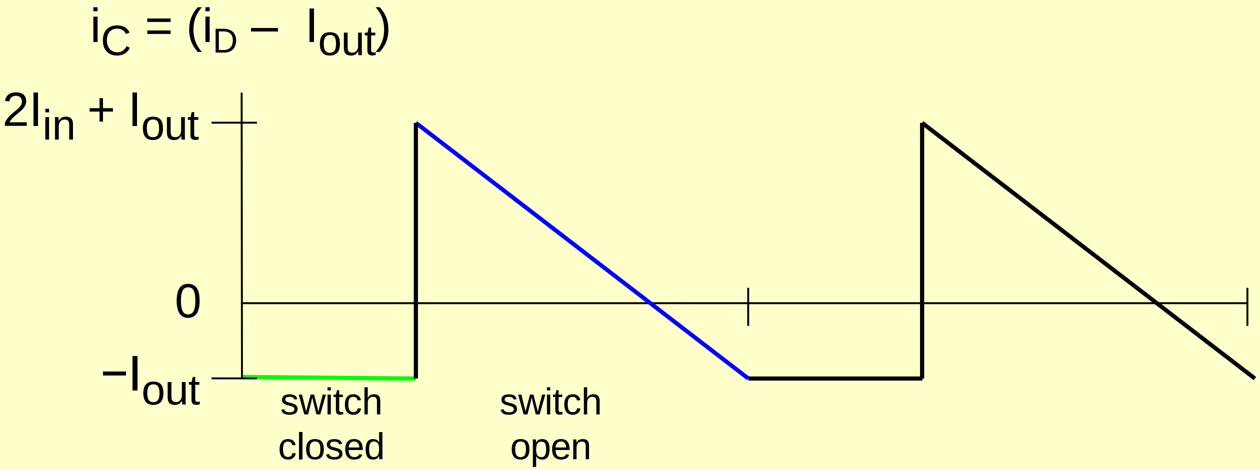


Take worst case D for each

Use max

$$\boxed{I_{rms} = \frac{2}{\sqrt{3}}\left(I_{in} + I_{out}\right)}$$

Output capacitor C current and current rating



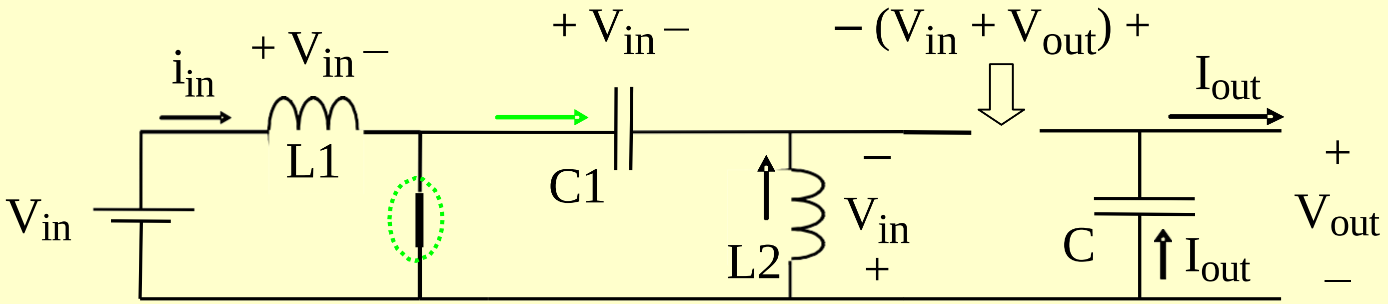
$$I_{in} = \frac{DI_{out}}{1-D},\ I_{out} = \frac{(1-D)I_{in}}{D}$$

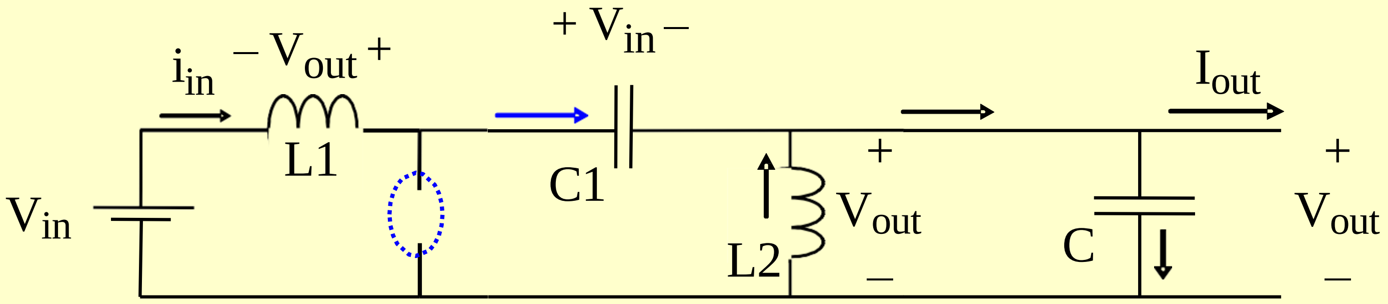
As D → 1, $I_{in} >> I_{out}$, so $I_{Crms} = \frac{2}{\sqrt{3}} I_{in}$

As D → 0, $I_{in} << I_{out}$, so $I_{Crms} = I_{out}$

$$\boxed{I_{Crms} = \max\left(\frac{2}{\sqrt{3}} I_{in}, I_{out}\right)}$$

Series capacitor C1 current and current rating

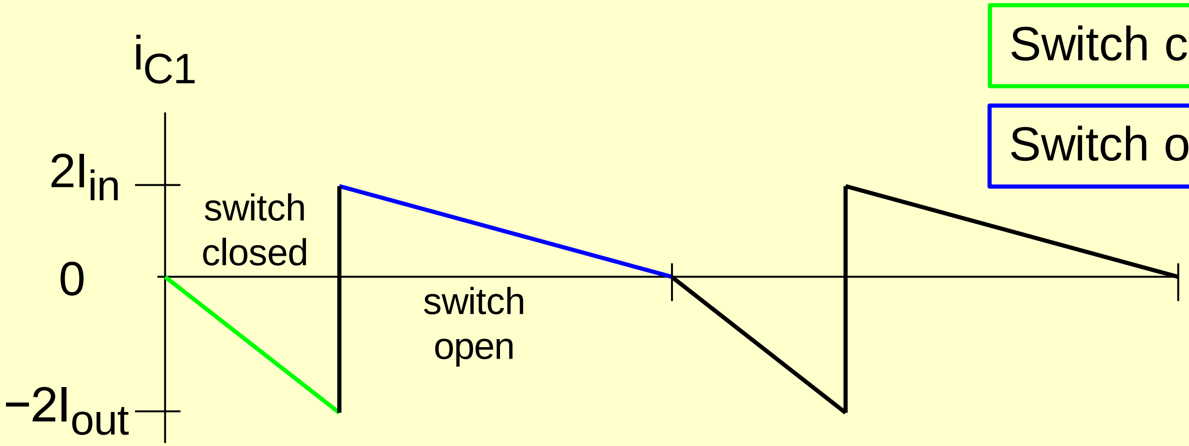




Switch closed, $I_{C1} = -I_{L2}$

Switch open, $I_{C1} = I_{L1}$

Series capacitor C1 current and current rating



Switch closed, $I_{C1} = -I_{L2}$

Switch open, $I_{C1} = I_{L1}$

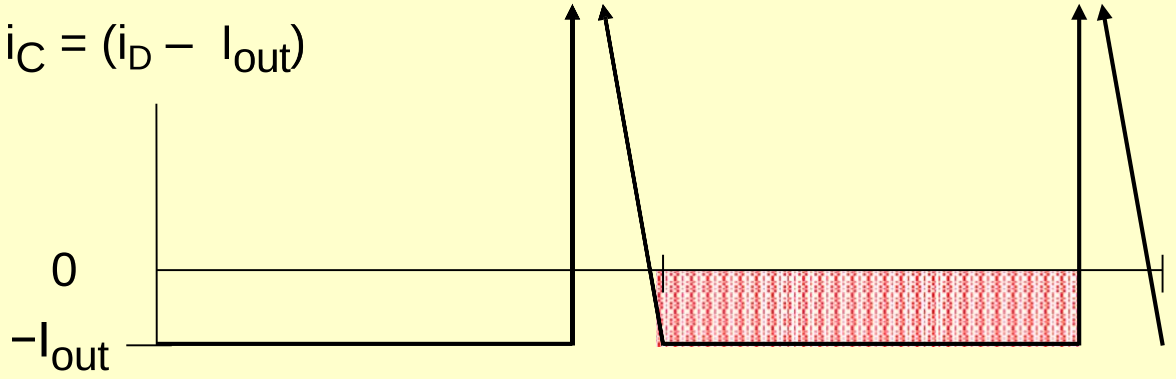
As D → 1, $I_{in} >> I_{out}$, so $I_{C1rms} = \frac{2}{\sqrt{3}} I_{in}$

As D → 0, $I_{in} << I_{out}$, so $I_{C1rms} = \frac{2}{\sqrt{3}} I_{out}$

$$I_{C1rms} = \max\left(\frac{2}{\sqrt{3}} I_{in}, \frac{2}{\sqrt{3}} I_{out}\right)$$

The high capacitor current rating is a disadvantage of this converter

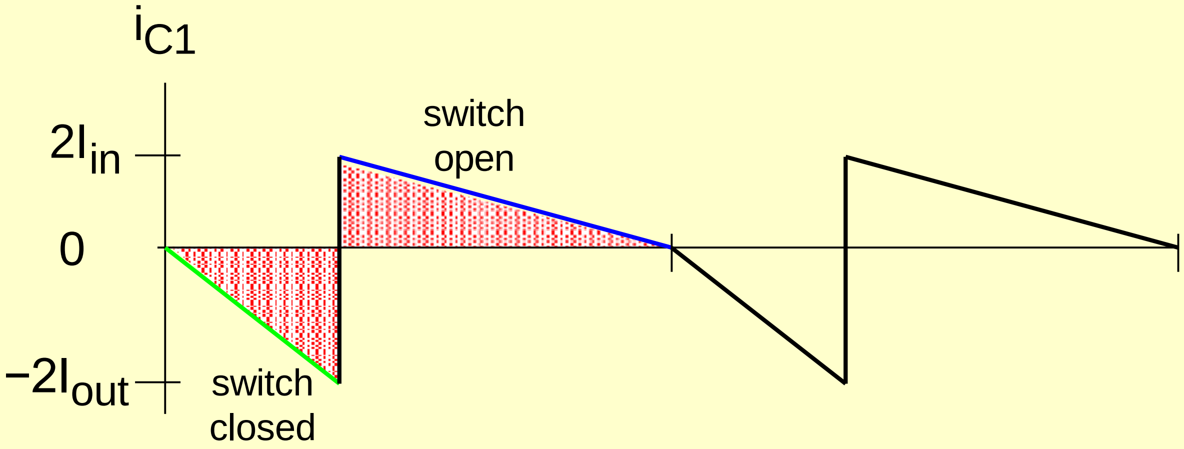
Worst-case load ripple voltage



The worst case is where D → 1, where output capacitor C provides I_{out} for most of the period. Then,

$$\Delta V = \frac{\Delta Q}{C} = \frac{I_{out} \bullet T}{C} = \frac{I_{out}}{Cf}$$

Worst case ripple voltage on series capacitor C1

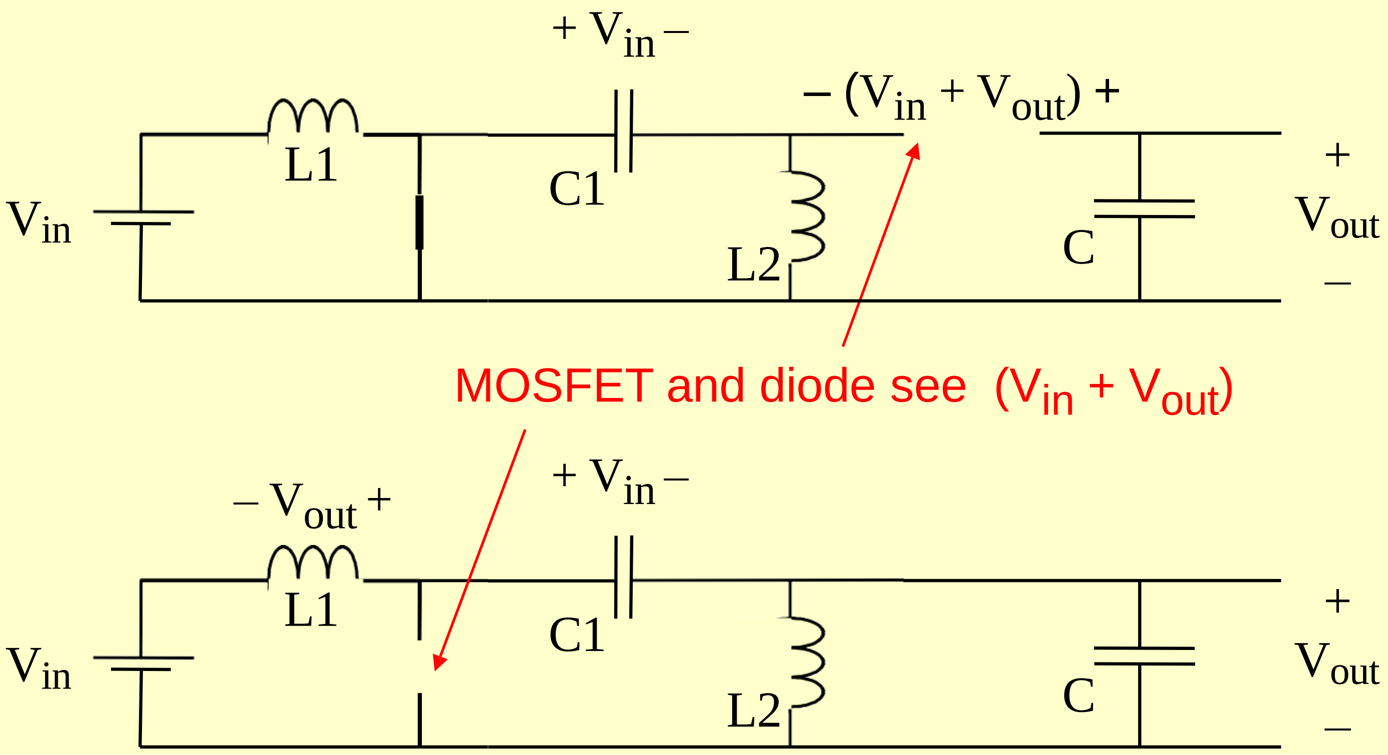


$$\Delta V = \frac{\Delta Q}{C1} = \frac{I_{out} \bullet DT}{C1} = \frac{I_{in} \bullet (1-D)T}{C1}$$

Then, considering the worst case (i.e., D = 1)

$$\boxed{\Delta V = \frac{I_{out}}{C1 \bullet f}}$$

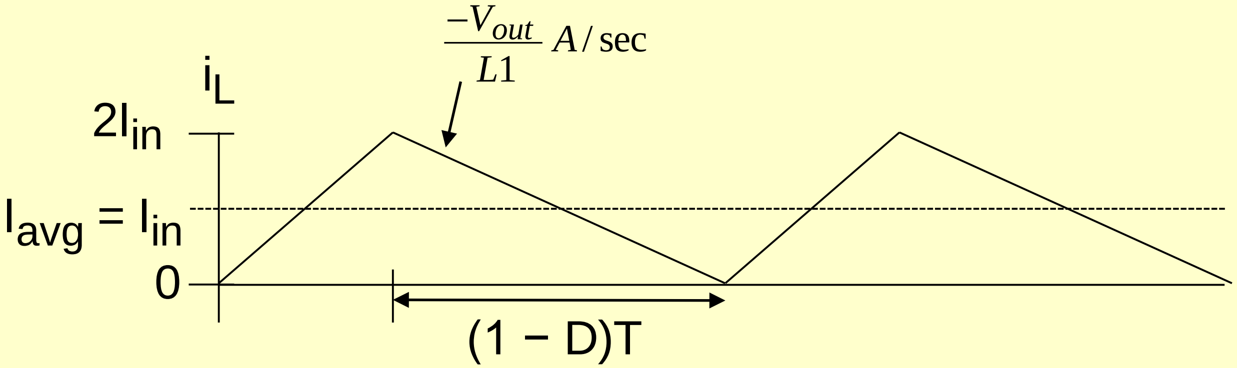
Voltage ratings



MOSFET and diode see (V_{in} + V_{out})

- Diode and MOSFET, use 2(V_{in} + V_{out})
- Capacitor C1, use 1.5V_{in}
- Capacitor C, use 1.5V_{out}

Continuous current in L1



$$2I_{in} = \frac{V_{out}}{L1_{boundary}} \bullet (1-D)T = \frac{\frac{DV_{in}}{1-D}}{L1_{boundary}} \bullet (1-D)T = \frac{V_{in}D}{L1_{boundary} f}$$

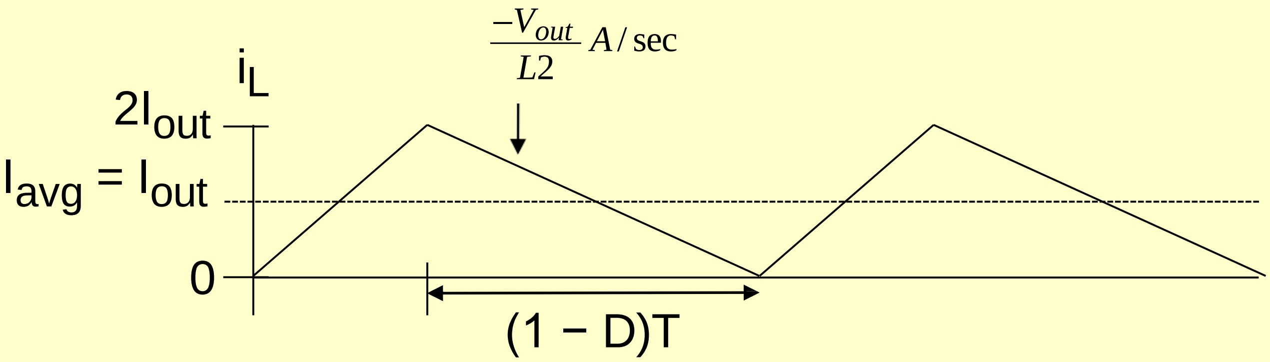
$$L1_{boundary} = \frac{V_{in}D}{2I_{in} f}$$

Then, considering the worst case (i.e., D → 1),

$$L1 > \frac{\overset{\text{use max}}{V_{in}}}{\underset{\text{use min}}{2I_{in} f}}$$

guarantees continuous conduction

Continuous current in L2



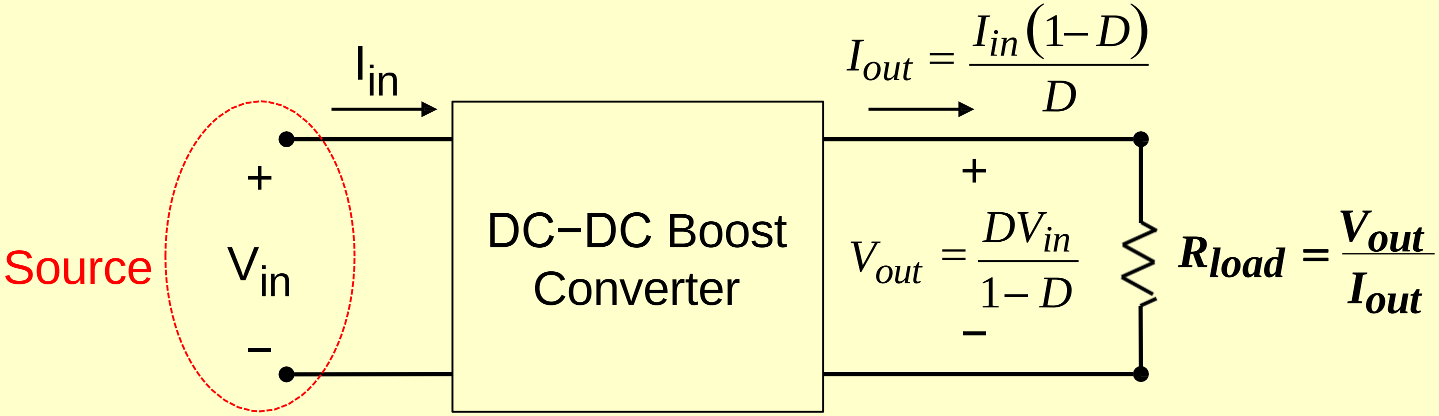
$$2I_{out} = \frac{V_{out}}{L2_{boundary}} \bullet (1-D)T = \frac{V_{out}(1-D)}{L2_{boundary}\, f}$$

$$L2_{boundary} = \frac{V_{out}(1-D)}{2I_{out}\, f}$$

Then, considering the worst case (i.e., D → 0),

$$L2 > \frac{\overset{\text{use max}}{V_{out}}}{\underset{\text{use min}}{2I_{out}\, f}}$$ guarantees continuous conduction

Impedance matching



Source

V_{in}

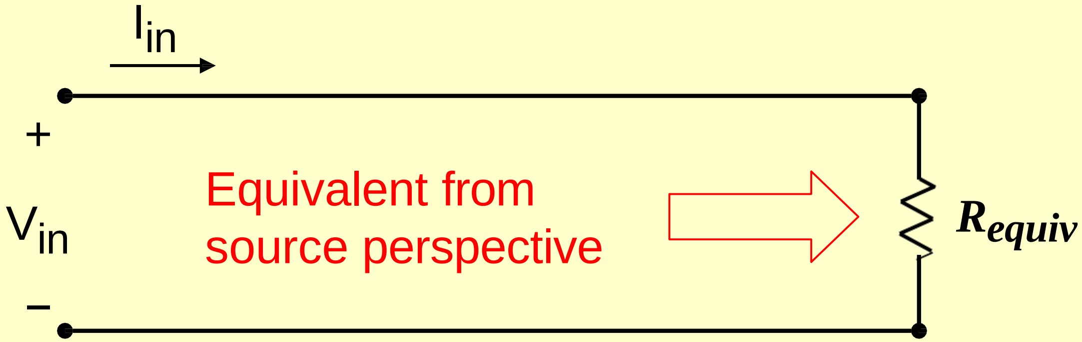
I_{in}

DC−DC Boost Converter

$$I_{out} = \frac{I_{in}(1-D)}{D}$$

$$V_{out} = \frac{DV_{in}}{1-D}$$

$$R_{load} = \frac{V_{out}}{I_{out}}$$



V_{in}

I_{in}

Equivalent from source perspective

R_{equiv}

$$R_{equiv} = \frac{V_{in}}{I_{in}} = \frac{\frac{(1-D)V_{out}}{D}}{\frac{DI_{out}}{(1-D)}} = \left(\frac{1-D}{D}\right)^2 \bullet \frac{V_{out}}{I_{out}} = \left(\frac{1-D}{D}\right)^2 R_{load}$$

Impedance matching

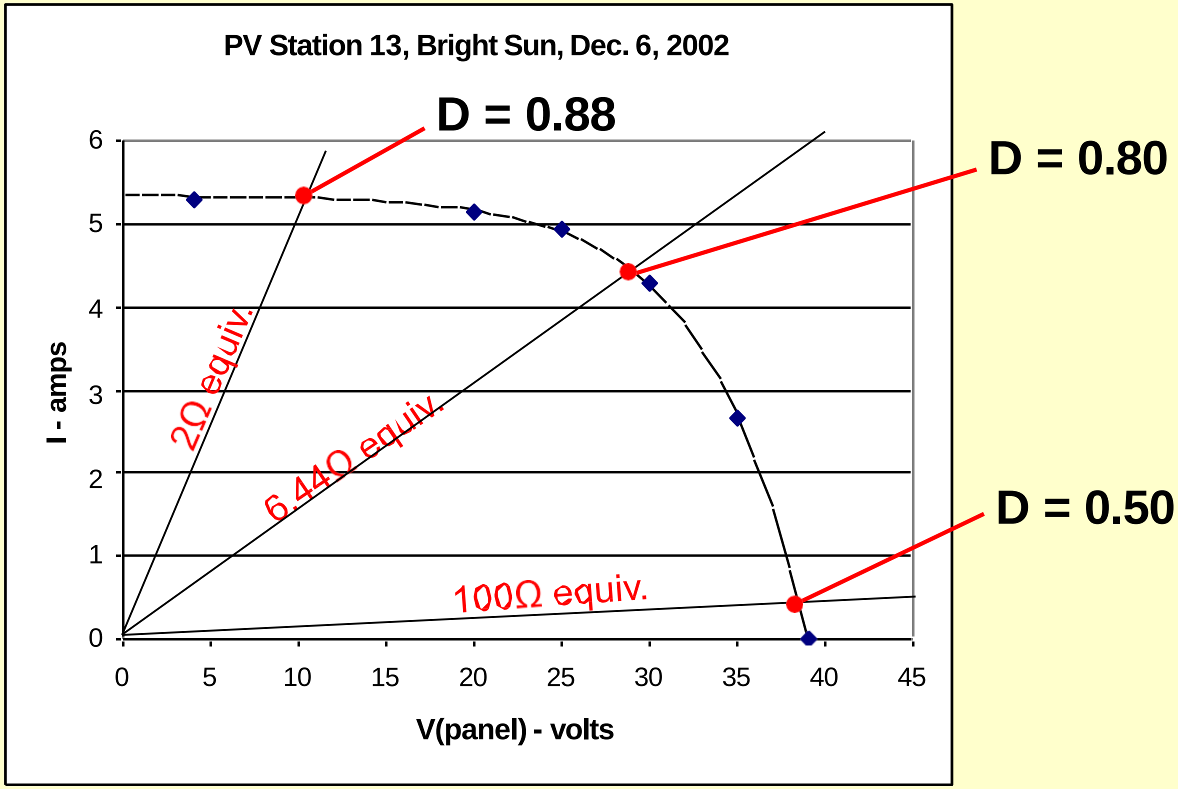
$$R_{equiv} = \frac{V_{in}}{I_{in}} = \frac{\dfrac{(1-D)V_{out}}{D}}{\dfrac{DI_{out}}{(1-D)}} = \left(\frac{1-D}{D}\right)^2 \bullet \frac{V_{out}}{I_{out}} = \left(\frac{1-D}{D}\right)^2 R_{load}$$

For any R_{load}, as D → 0, then $R_{equiv} \rightarrow \infty$ (i.e., an open circuit)

For any R_{load}, as D → 1, then $R_{equiv} \rightarrow 0$ (i.e., a short circuit)

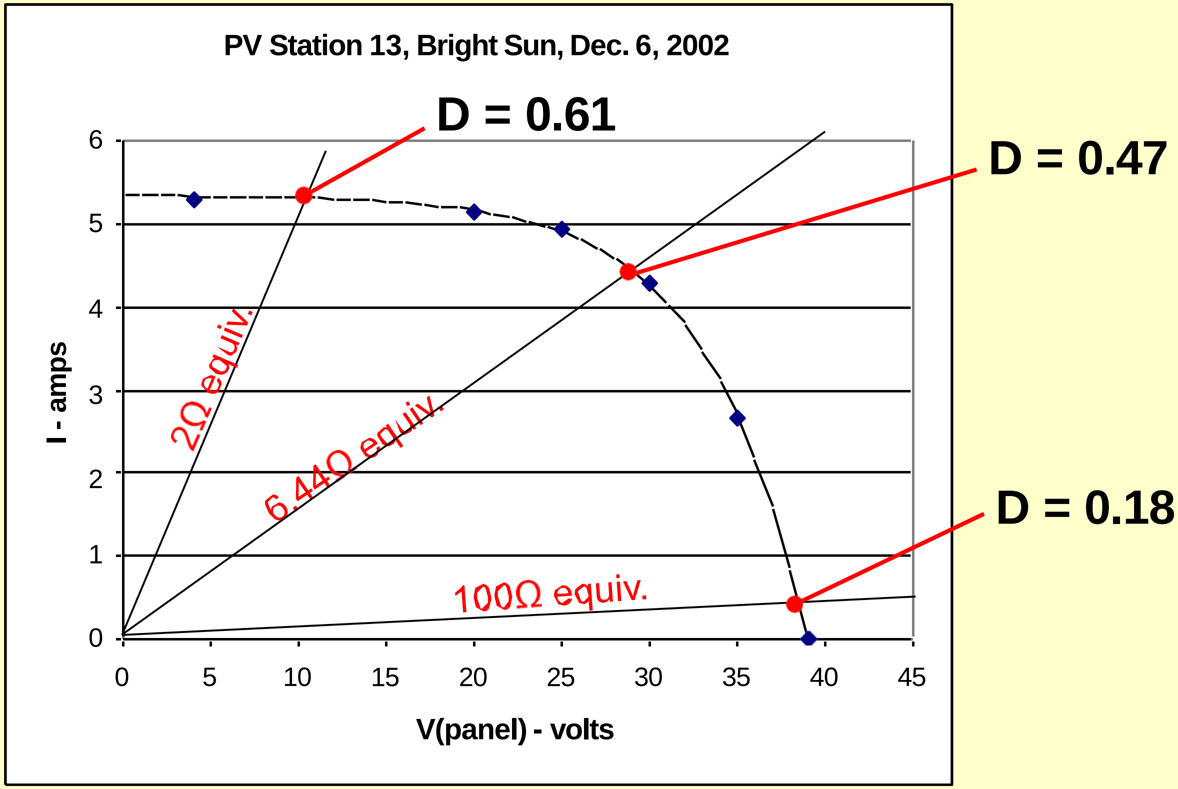
Thus, the SEPIC converter can sweep the entire I-V curve of a solar panel

Example - connect a 100Ω load resistor



With a 100Ω load resistor attached, raising D from 0 to 1 moves the solar panel load from the open circuit condition to the short circuit condition

Example - connect a 5Ω load resistor



SEPIC DESIGN

Worst-Case Component Ratings Comparisons for DC-DC Converters

Our components

9A   250V   5.66A p-p   200V, 250V   16A, 20A

Converter Type	Input Inductor Current (Arms)	Output Capacitor Voltage	Output Capacitor Current (Arms)	Diode and MOSFET Voltage	Diode and MOSFET Current (Arms)
Buck/Boost	$\frac{2}{\sqrt{3}} I_{in}$	$1.5V_{out}$	$\max\left(\frac{2}{\sqrt{3}} I_{in}, I_{out}\right)$	$2(V_{in}+V_{out})$	$\frac{2}{\sqrt{3}}\left(I_{in}+I_{out}\right)$

10A   90V   10A, 5A   40V, 90V   10A, 5A

Likely worst-case SEPIC situation

L1. 100µH, 9A

C. 1500µF, 250V, 5.66A p-p

Diode D. 200V, 16A

MOSFET M. 250V, 20A

L2. 100µH, 9A

C1. 33µF, 50V, 14A p-p

SEPIC DESIGN

Comparisons of Output Capacitor Ripple Voltage

Converter Type	Volts (peak-to-peak)
Buck/Boost	0.067V $\frac{I_{out}}{Cf}$ 5A

1500µF 50kHz

L1. 100µH, 9A

C. 1500µF, 250V, 5.66A p-p

Diode D. 200V, 16A

MOSFET M. 250V, 20A

L2. 100µH, 9A

C1. 33µF, 50V, 14A p-p

SEPIC DESIGN

Minimum Inductance Values Needed to Guarantee Continuous Current

Converter Type	For Continuous Current in the Input Inductor	For Continuous Current in L2
Buck/Boost	$L_1 > \frac{V_{in}}{2I_{in} f}$ 40V 200µH 2A 50kHz	$L_2 > \frac{V_{out}}{2I_{out} f}$ 90V 450µH 2A 50kHz

L1. 100µH, 9A

C. 1500µF, 250V, 5.66A p-p

Diode D. 200V, 16A

MOSFET M. 250V, 20A

L2. 100µH, 9A

C1. 33µF, 50V, 14A p-p

SEPIC DESIGN

Additional Components for SEPIC converter

50V 14A p-p Our components 9A

Series Capacitor Voltage	Series Capacitor (C_1) Current (Arms)	Series Capacitor (C_1) Ripple Voltage (peak-to-peak)	Second Inductor (L_2) Current (Arms)
$1.5V_{in}$	$\max\left(\frac{2}{\sqrt{3}}I_{in}, \frac{2}{\sqrt{3}}I_{out}\right)$	$\frac{I_{out}}{C_1 f}$	$\frac{2}{\sqrt{3}}I_{out}$

5A

3.0V

40V 10A 5A 33µF 50kHz 5A

Likely worst-case SEPIC situation

L1. 100µH, 9A

C. 1500µF, 250V, 5.66A p-p

Diode D. 200V, 16A

MOSFET M. 250V, 20A

L2. 100µH, 9A

C1. 33µF, 50V, 14A p-p

Conclusion - 50kHz may be too low for SEPIC converter