How to construct a dc-dc converter?

Assume the following:

\[ V_g = 100 \text{V}, \quad V_{load} = 50 \text{V} \]

1) The voltage divider by a variable resistor, whose value is adjusted such that the required output voltage is obtained.

\[ P_{in} = 1000 \text{W} \]

\[ P_{loss} = 500 \text{W} \]

\[ \Rightarrow \text{conversion loss is high} \Rightarrow \text{efficiency is low} \]

\[ \eta = \frac{P_{out}}{P_{in}} = \frac{500 \text{W}}{1000 \text{W}} = 50\% \]

2) Using a linear-mode power transistor.

\[ P_{in} = 1000 \text{W} \]

\[ P_{loss} = 500 \text{W} \]

This series-pass linear regulator generally find more application at low power level.
Assume the switch position is varied periodically, as illustrated by $v_s(t)$.

$V_g$  
\[ \begin{array}{c}
\text{DTs} \quad (1-D)T_s \\
\text{switch in position 1} \quad \text{switch in position 2}
\end{array} \]

$D' = 1 - D$

The duty cycle is defined as a fraction of time the switch is in position 1.

\[ 0 \leq D \leq 1 \]

\[ T_s = \frac{1}{f_s} \]

\[ \Rightarrow \frac{\langle v_s(t) \rangle}{T_s} = V_s = \frac{1}{T_s} \int_0^{T_s} v_s(t) \, dt = D V_g \]

The switch changes the dc voltage, by a factor of equal to the duty cycle. To convert the voltage $V_g = 600 \, V$ into desired output voltage of $V = 50 \, V$, a duty cycle of $D = 0.5$ is required.
The power dissipated by the switch is zero when the switch

Switch in position 1: \[ \text{Position 1} = 0 \]
\[ \text{Position 2} = 0 \]

Switch in position 2: \[ \text{Position 1} = 0 \]
\[ \text{Position 2} = 0 \]

\[ \Rightarrow \text{we succeed in DC-DC conversion by using an ideal lossless switch.} \]

\[ \text{Note: in addition to the desired DC component} \ V_s, \ \text{the switch output voltage waveform} \ V_s(t) \ \text{also contains undesirable harmonics of the switching frequency.} \Rightarrow \text{these harmonics must be removed, such that the output voltage} \ V(t) \ \text{is essentially equal to the DC component} \ V = V_s. \Rightarrow \text{A low-pass filter can be inserted to remove the harmonics.} \]

\[ \text{L & C are ideally lossless elements} \Rightarrow \text{efficiency is 100%.} \]
\[ v \approx Dv_g \]

\[ 0 \leq (1-D) \Rightarrow 0 < v = Dv_g \leq v_g \]

we want to develop a general analytical approach for the analysis of any DC-DC converter.

- Three principles
  - Inductor Volt-sec. Balance
  - Capacitor charge balance
  - Small ripple approximation

Let's examine the inductor and capacitor waveforms in the buck converter.

\[ V_g \]

It is impossible to build a perfect low-pass filter that allows the dc component to pass but completely removes the component at the switching frequency and its harmonics.
Hence, in practice the output voltage $v_{ct}$ appears as:

$$v_{ct} = V + \text{Vripple}(t)$$

$\text{Vripple}(t)$ arises from the incomplete attenuation of the switching harmonics by the low-pass filter.

In a well-designed converter, output voltage switching ripple should be small: $|\text{Vripple}| \ll V \Rightarrow v_{ct} \approx V$

This approximation is known as small ripple approximation.

Now let us analyze the inductor current waveform.

Switch in position 1:

$$v_{ct}(t) = V - v_{ct} \approx V - V$$

Small ripple approximation

Switch in position 2:

$$v_{ct}(t) = \frac{\text{d}i(t)}{\text{d}t} = -v_{ct}$$

$$\frac{\text{d}v_{ct}(t)}{\text{d}t} = v_{ct}(t) \approx -V$$