The average current flows through the inductor.

However, the inductor current will vary about this average based on:

\[ V_{dov} \cdot DT_s \cdot Ts = D \]

We can rewrite this to also produce

\[ Volt-second balance \]

\[ V_{dov} - V_{ave} \]

\[ D \]

This implies that equal and opposite areas for the two parts of the conduction period

\[ \left( V_{dov} - V_{ave} \right) \cdot D \cdot Ts = -V_{ave} \cdot \left( Ts - D \cdot Ts \right) \]

\[ Volt-second balance \]

We can rewrite this to also produce

\[ \frac{V_{ave}}{V_d} = \frac{D \cdot Ts}{Ts} = D \]

The average current flows through the inductor.

However, the inductor current will vary about this average based on:

**Exam #2**
- Friday in class
- Will review to prepare for it on Wednesday
- Sample exam will be posted

**Homework #7**
- Due in class on Wednesday

**Buck Converter:**

Continuous Conduction Mode

- Inductor current
  1. In this case, inductor current is the same as the output current
  2. Input current is discontinuous.

\[ i_L = I_0 + \frac{1}{L} \left( \int_0^{t_{on}} v_L \, dt + \int_{t_{on}}^{Ts} v_L \, dt \right) = I_0 + \left[ \int_0^{D \cdot Ts} \left( V_d - V_o \right) \, dt + \int_{D \cdot Ts}^{Ts} \left( 0 - V_o \right) \, dt \right] \]

- Note that for a duty ratio of 0.5, the 2 slopes
- For a large duty ratio, Vo is closer to Vd, so the rising slope is more gradual and the falling slope is steeper.

- Average voltage across the inductor needs to be zero.

\[ \int_0^{Ts} v_L \, dt = \int_0^{t_{on}} v_L \, dt + \int_{t_{on}}^{Ts} v_L \, dt = \int_0^{D \cdot Ts} \left( V_d - V_o \right) \, dt + \int_{D \cdot Ts}^{Ts} \left( 0 - V_o \right) \, dt = 0 \]

- This implies that equal and opposite areas for the two parts of the conduction period

\[ \left( V_{dov} - V_{ave} \right) \cdot D \cdot Ts = -V_{ave} \cdot \left( Ts - D \cdot Ts \right) \]

- We can rewrite this to also produce

\[ \frac{V_{ave}}{V_d} = \frac{D \cdot Ts}{Ts} = D \]
\[ \int_{0}^{D \cdot T_s} (V_d - V_o) \, dt + \int_{0}^{T_s} (0 - V_o) \, dt = 0 \]

- This variable part of the current will flow into the filter capacitor. Only the average part will to the load.
- This variation in the current is called the current ripple. Peak to peak current ripple is usually specified item.
- The variation depends on the size of the L.
- Input current will have a large ripple, since current is zero while the switch is open.

**Boundary Between Continuous and Discontinuous Conduction**

- It is possible to create an operating condition where the inductor current goes to zero before the next time the switch would turn on.
- In many cases it is desirable to operate this at or above this level, so it is important to determine boundary of this zone.
- At this boundary, the instantaneous current will be zero at the instant the switch turns on.
- The average current at this boundary will be:

\[ I_{LB} = I_{OB} = \frac{1}{2} I_{L\text{peak}} = \frac{t_{on} \cdot (V_d - V_o)}{2L} = D \cdot T_s \cdot \frac{(V_d - V_o)}{2L} \]

- Note that this boundary depends on the following:
  1. Input voltage
  2. Duty ratio
  3. L

- The duty ratio usually depends on values of \( V_d \) and \( V_o \).
- Need to consider allowable variation of input voltage and limits of output variation.
- The circuit designer needs to find the minimum value of the inductance to maintain continuous conduction for all allowable values of input voltage and D.

Example: Let's say that the input voltage varies between 50 and 100V, and the output voltage is regulated at 40V. The converter switches at 10kHz, and we have an inductor of 0.5 mH

\[
\begin{align*}
V_{d\text{min}} &:= 50V \\
V_{d\text{max}} &:= 100V \\
V_o &:= 40V \\
L_{\text{filt}} &:= 0.5\text{mH}
\end{align*}
\]

\[
\begin{align*}
D_{\text{max}} &:= \frac{V_o}{V_{d\text{min}}} & D_{\text{max}} = 0.8 \\
D_{\text{min}} &:= \frac{V_o}{V_{d\text{max}}} & D_{\text{min}} = 0.4
\end{align*}
\]
fs := 10kHz \quad Ts := \frac{1}{fs} \quad Ts = 1 \times 10^{-4} s

ILB1 := \frac{D_{\text{min}} \cdot Ts}{2 \cdot L_{\text{filt}}} \cdot (V_{\text{dmax}} - V_o) \quad \text{ILB1} = 2.4 \, \text{A}

ILB2 := \frac{D_{\text{max}} \cdot Ts}{2 \cdot L_{\text{filt}}} \cdot (V_{\text{dmin}} - V_o) \quad \text{ILB2} = 0.8 \, \text{A}

- So the minimum current at the boundary is 2.4A to guarantee that it is always in continuous conduction for all values of input current.
- However, in many cases, the output current is known, and instead we want to find the minimum inductance.