Rectifiers in Power Electronics

Read Chapter 3 of "Principles of Power Electronics" (KSV) by J. G. Kassakian, M. F. Schlecht, and G. C. Verghese, Addison-Wesley, 1991.

Start with simple half-wave rectifier (full-bridge rectifier directly follows).

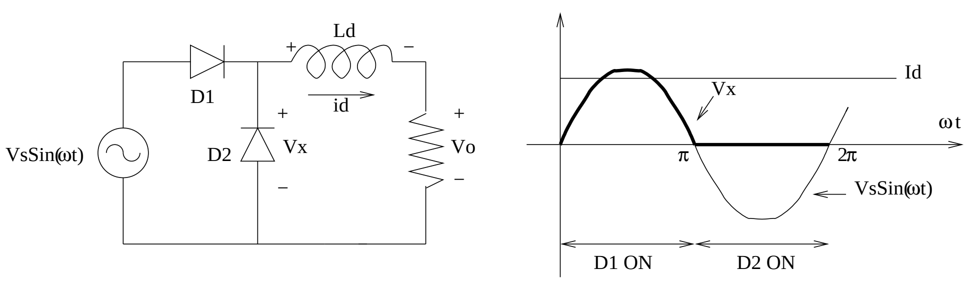

Figure 2.1: Simple Half-wave Rectifier

In P.S.S.:

$$
\begin{aligned}
< v_o > &= < v_x > \\
&= \frac{v_s}{\pi} \qquad (2.1)
\end{aligned}
$$

$$If\ L_d\ Big \rightarrow i_d \simeq I_d = \frac{v_s}{\pi R} \tag{2.2}$$

If $\frac{L_d}{R} \gg \frac{2\pi}{\omega} \Rightarrow$ we can approximate load as a constant current.

2.1 Load Regulation

Now consider adding some ac-side inductance L_c (reactance $X_c \doteq \omega L_c$).

- Common situation: Transformer leakage or line inductance, machine winding inductance, etc.
- L_c is typically $\ll L_d$ (filter inductance) as it is a parasitic element.

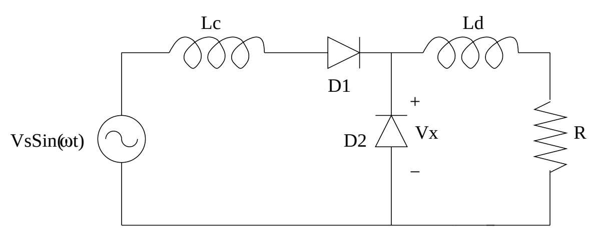

Figure 2.2: Adding Some AC-Side Inductance

Assume $L_d \sim \infty$ (so ripple current is small). Therefore, we can approximate load as a "special" current source.

$$\text{“Special” since } < v_L >= 0 \text{ in P.S.S. } \Rightarrow I_d =< \frac{v_x}{R} > \tag{2.3}$$

Assume we start with D_2 conducting, D_1 off ($V \sin(\omega t) < 0$). What happens when $V \sin(\omega t)$ crosses zero?

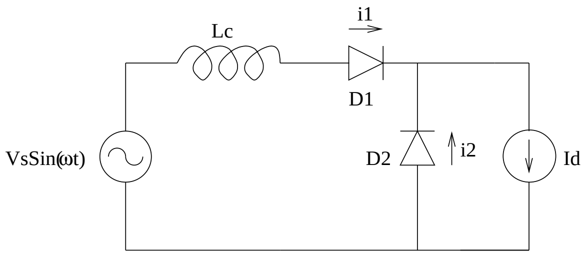

Figure 2.3: Special Current

- D_1 off no longer valid.
- But just after turn on i_1 still $= 0$.

Therefore, D_1 and D_2 are both on during a commutation period, where current switches from D_2 to D_1.

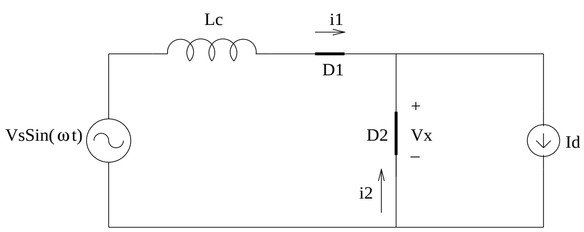

Figure 2.4: Commutation Period

D_2 will stay on as long as $i_2 > 0$ $(i_1 < I_d)$.

Analyze:

$$
\begin{aligned}
\frac{di_1}{dt} &= \frac{1}{L_c} V_s \sin(\omega t) \\
i_1(t) &= \int_0^{\omega t} \frac{V_s}{\omega L_c} \sin(\omega t) d(\omega t) \\
&= \frac{V_s}{\omega L_c} \cos(\Phi)|_{\omega t}^{0} \\
&= \frac{V_s}{\omega L_c} [1 - \cos(\omega t)]
\end{aligned}
\tag{2.4}
$$

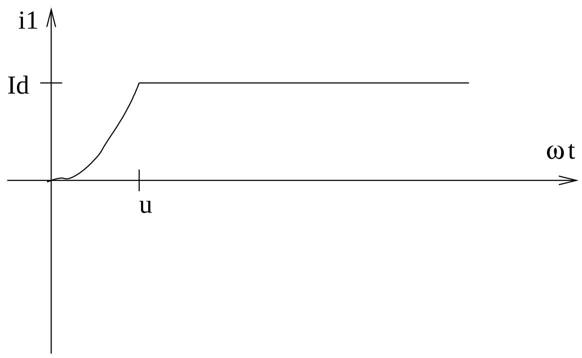

Figure 2.5: Analyze Waveform

Commutation ends at $\omega t = u$, when $i_1 = I_d$.

Commutation Period:

$$I_d = \frac{V_s}{\omega L_c}[1 - \cos u] \Rightarrow \cos u = 1 - \frac{\omega L_c I_d}{V_s} \tag{2.5}$$

As compared to the case of no commutating inductance, we lose a piece of output voltage during commutation. We can calculate the average output voltage in P.S.S. from $< V_x >$:

$$\begin{aligned}
< V_x > &= \frac{1}{2\pi}\int_u^\pi V_s \sin(\Phi) d\Phi \\
&= \frac{V_s}{2\pi}[\cos(u) + 1] \\
from\ before\ \cos(u) &= 1 - \frac{\omega L_c I_d}{V_s} \\
&= 1 - \frac{X_c I_d}{V_s} \\
< V_x > &= \frac{V_s}{\pi}[1 - \frac{\omega L_c I_d}{V_s}] \qquad (2.6)
\end{aligned}$$

So average output voltage drops with:

1. Increased current

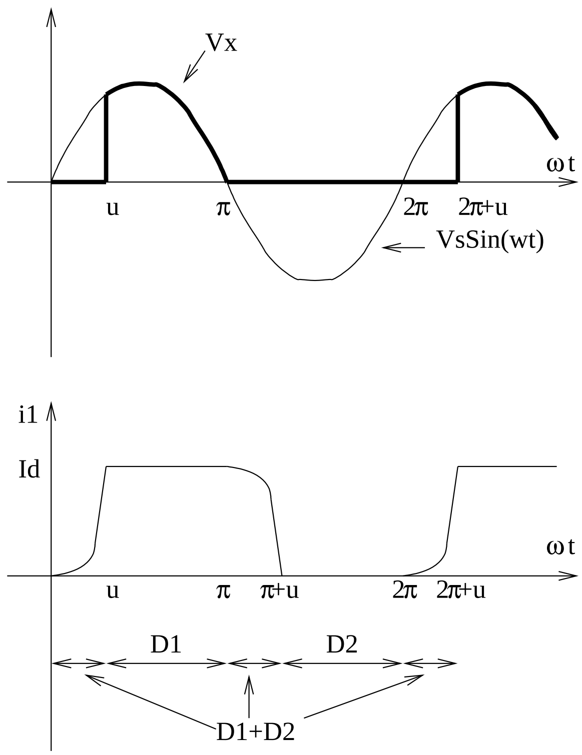

Figure 2.6: Commutation Period

2. Increased frequency

3. Decreased source voltage

We get the "Ideal" no L_c case at no load.

We can make a dc-side thevenin model for such a system as shown in Figure 2.7.

No actual dissipation in box: "resistance" appears because output voltage drops when current increases.

This Load Regulation is a major consideration in most rectifier systems.

- Voltage changes with load.

- Max output power limitation

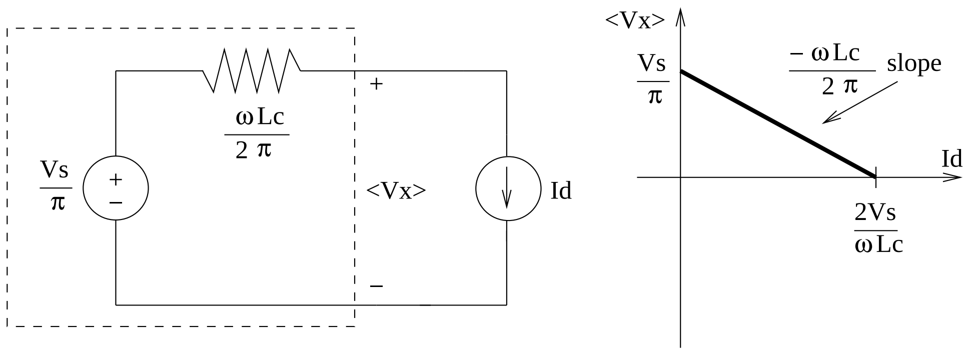

Figure 2.7: DC-Side Thevenin Model

All due to non-zero commutation time because of ac-side reactance. This effect occurs in most rectifier types (full-wave, multi-phase, thyristor, etc.). Full-bridge rectifier has similar problem (similar analysis).

Read Chapter 4 of KSV.

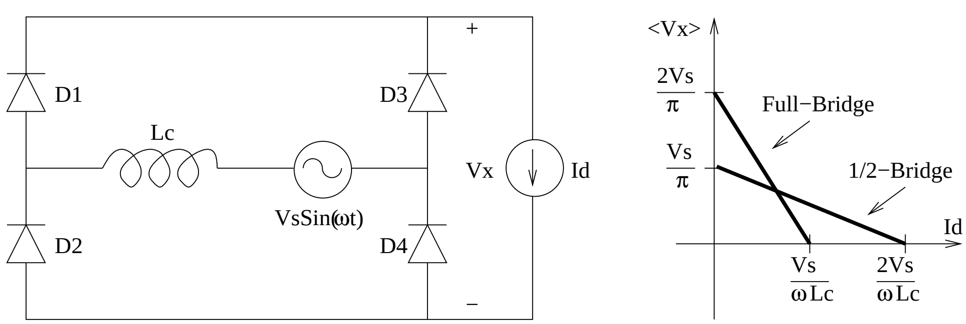

Figure 2.8: Full-Bridge Rectifier