6.334 Power Electronics
Spring 2007

Chapter 4

Phase-controlled Rectifiers

Read Chapter 5 of "Principles of Power Electronics" (KSV) by J. G. Kassakian, M.

F. Schlecht, and G. C. Verghese, Addison-Wesley, 1991.

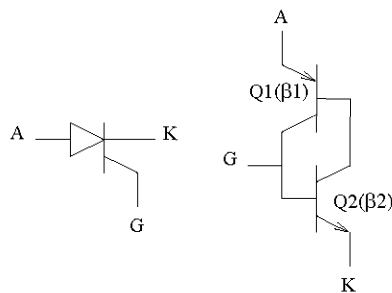**Thyristor Devices: SCR (Silicon Controlled Rectifier)**

Figure 4.1: Thyristor

SCR: Acts like a diode where you can select when conduction will start, but not when it stops.

- Stay off until a gate pulse is applied while $V_{AK} > 0$.

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- Once on, behaves like a diode and does not turn off until $i \to 0$.

- To stay off (after $V_{AK} > 0$ again) must have i stay at 0 for a short time t_q $(10 - 100\mu s)$

So the device is semi-controlled: we control the turn on point, but only turns off when circuit conditions force it to.
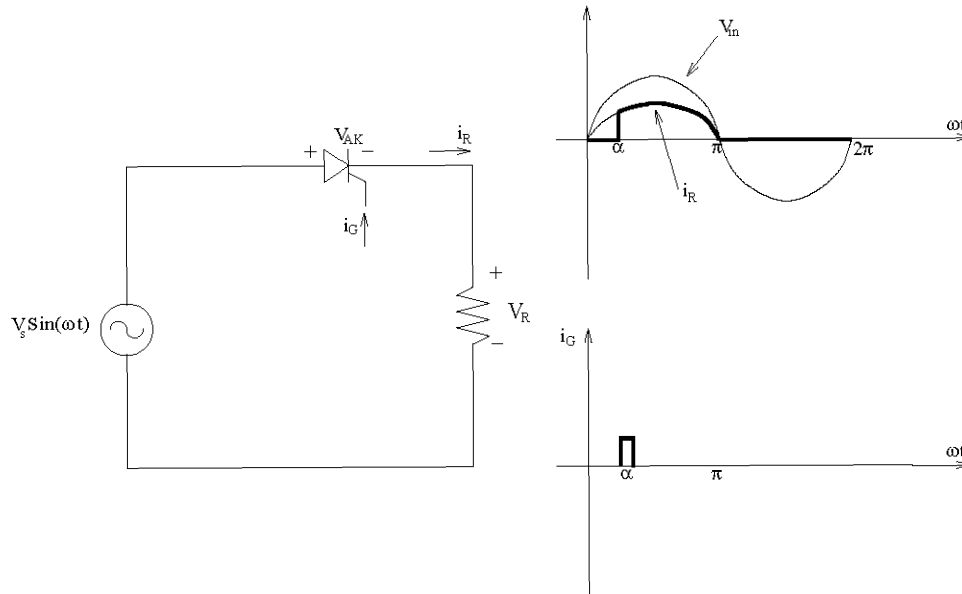
Simple example:

Figure 4.2: Example

Phase of thyristor turn on (with respect to line voltage) is termed firing angle α.

Consider a full-bridge converter (inductive/current load).

Diode version:

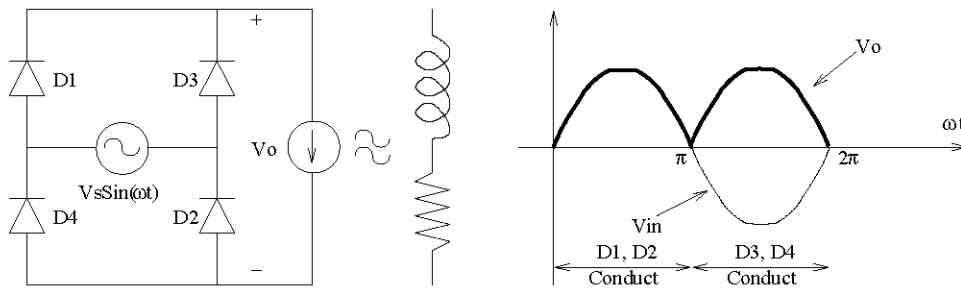$$< v_0 > \ = \ \frac{1}{\pi} \int_0^\pi V_s \sin \phi d\phi$$

Figure 4.3: Diode Version

$$= \frac{2V_s}{\pi} \tag{4.1}$$

Thyristor (phase-controlled) version (firing angle α):
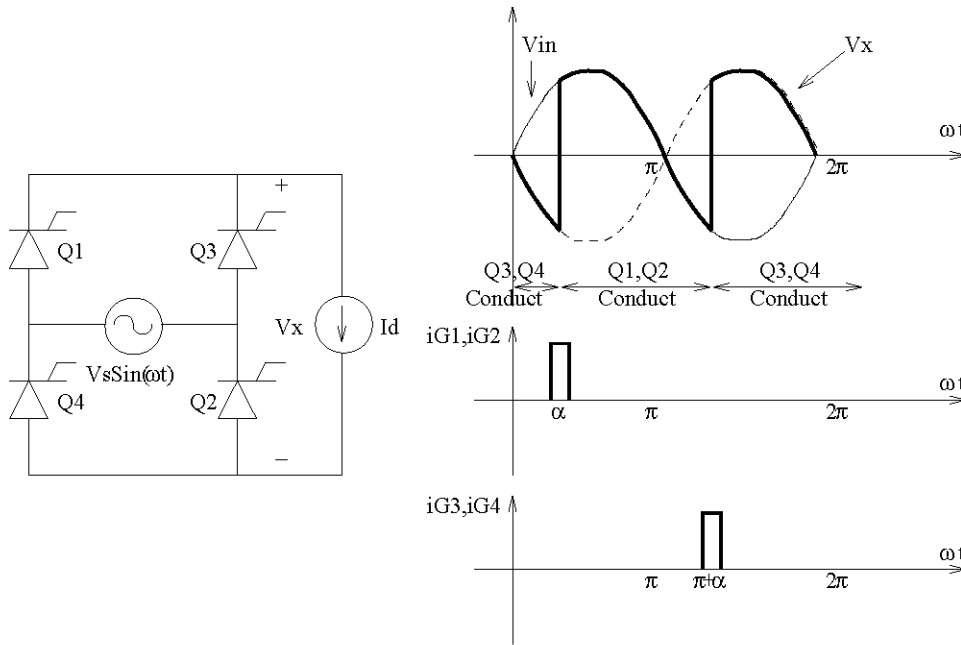

Figure 4.4: Thyristor Version

Lets analyze the output voltage $< v_x >$:

$$< X_x > = \frac{1}{\pi} \int_{\alpha}^{\pi+\alpha} V_s \sin(\phi) d\phi$$

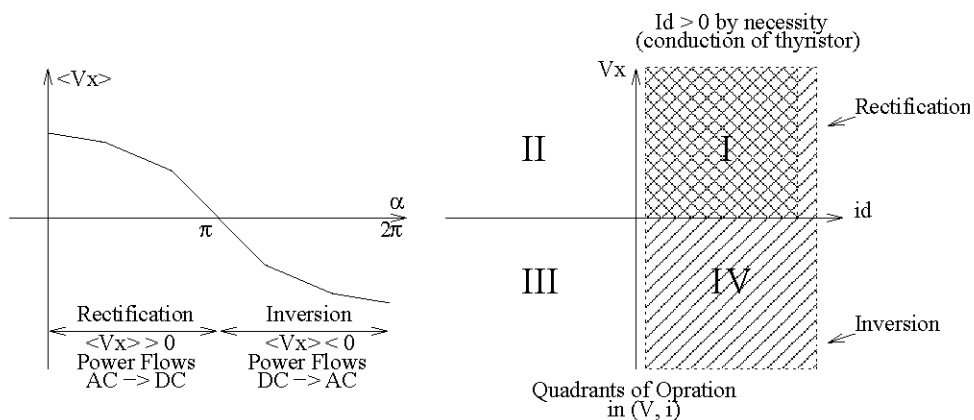$$= \frac{2V_s}{\pi} \cos \alpha \qquad (4.2)$$

Figure 4.5: Output Voltage

So with a phase controlled converter, we can regulate the output voltage by varying

firing angle α. We can even cause power flow from dc-side to ac-side as long as $I_d > 0$

(e.g., pull power out of inductor and put into line).

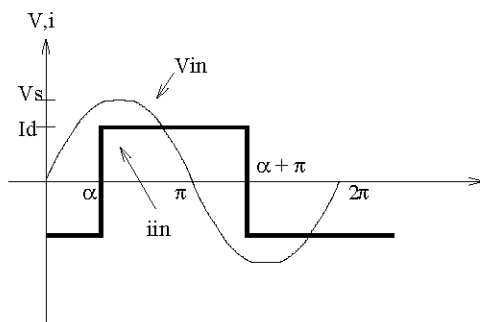Consider the power factor of a phase-controlled converter:

Figure 4.6: Power Factor

$$k_p = k_d K_\theta$$

$$
\begin{aligned}
&= \frac{I_{1,RMS}}{I_{RMS}} \cos \phi_1 \\
&= \frac{\frac{4}{\pi\sqrt{2}}I_d}{I_d} \cos \phi_1 \\
&= \frac{4}{\pi\sqrt{2}} \cos \alpha \\
&\simeq 0.9 \cos \alpha
\end{aligned}
\tag{4.3}
$$

Phase shift of fundamental of square wave in phase with square wave, therefore, $\phi_1 = \alpha$. So the power factor of a phase-controlled converter varies with firing angle α.

Consider the effect of ac-side reactance:

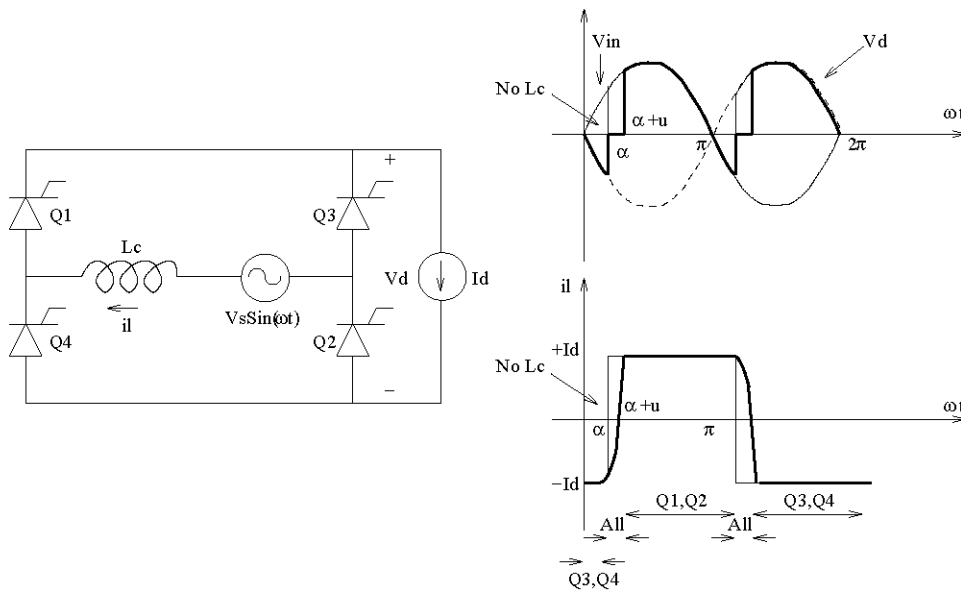
Figure 4.7: AC-Side Reactance

Similar to the diode rectifier case, a commutation period exists during which all devices are on, while current in L_C switches between $+I_d$ and $-I_d$ (between Q_1/Q_2 and Q_3/Q_4.

A similar analyze to the diode case shows that for the full-bridge thyristor converter:

$$< v_x >= \frac{2V_s}{\pi}[\cos\alpha - \frac{X_C I_d}{V_s}] \tag{4.4}$$

Note that the need to commutate devices places a limit on how negative the output voltage can be made as a function of $\frac{X_C I - d}{V_s}$ and α. This is analyzed in KSV, Chapter 5. (require $\alpha + u < \pi$).
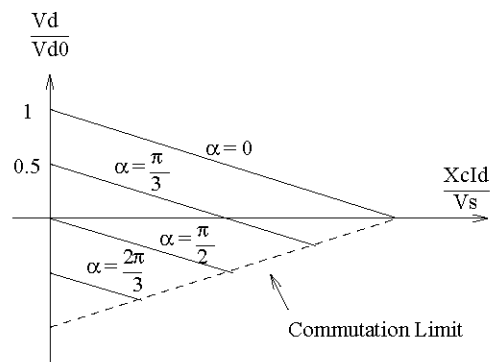
Summary:

Figure 4.8: Summary