Thyristor Converters

Chapter 6

- In some applications (battery charger, some ac/dc drives), the dc voltage has to be controllable
- Thyristor converters provide controlled conversion of ac into dc
- Primarily used in three-phase, high power application
- Being replaced by better controllable switches

Thyristors (Review Class)

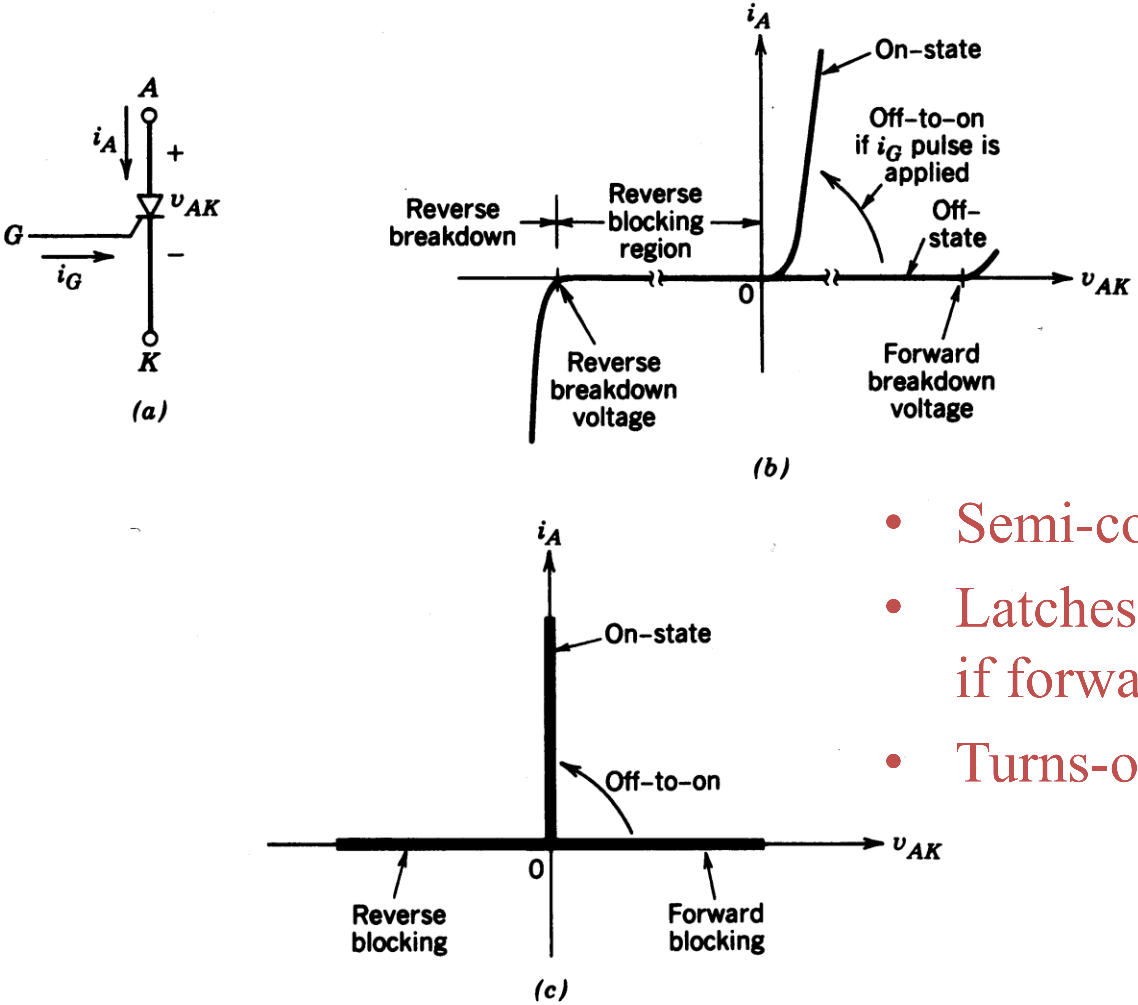
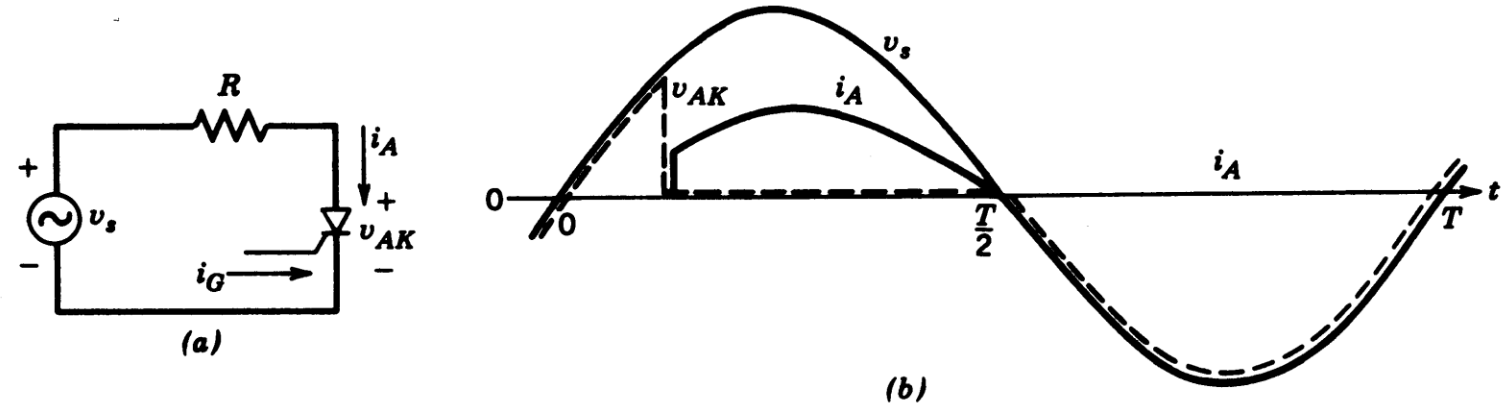


Figure 2-3 Thyristor: (*a*) symbol, (*b*) *i*–*v* characteristics, (*c*) idealized characteristics.

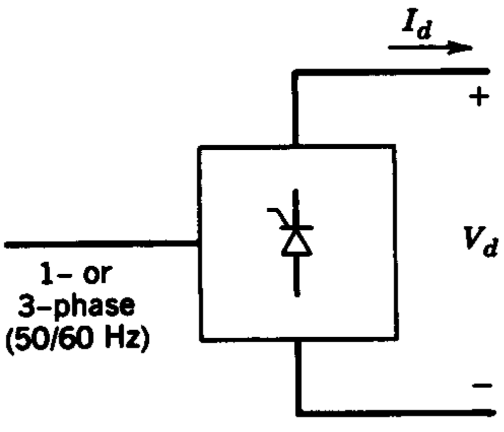
- Semi-controlled device
- Latches ON by a gate-current pulse if forward biased
- Turns-off if current tries to reverse

Thyristor in a Simple Circuit (Review Class)

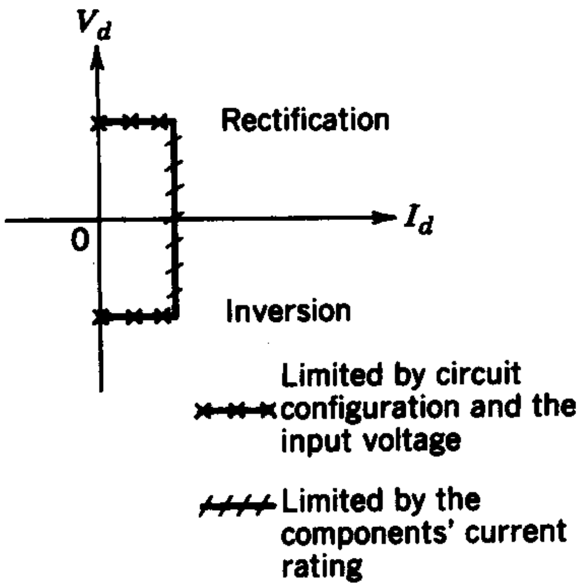


- For successful turn-off, reverse voltage required

Thyristor Converters

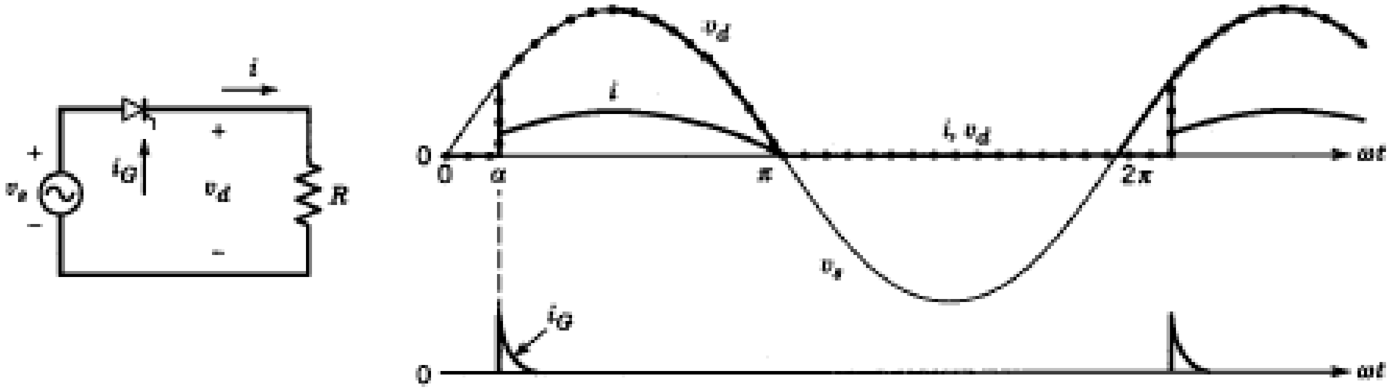


(a)

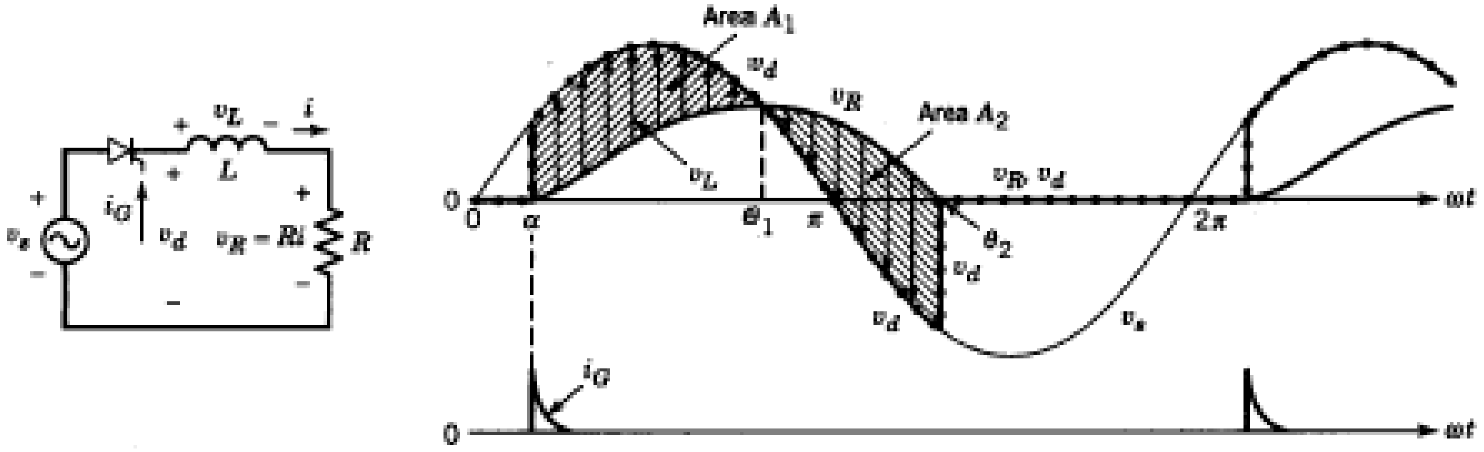


(b)

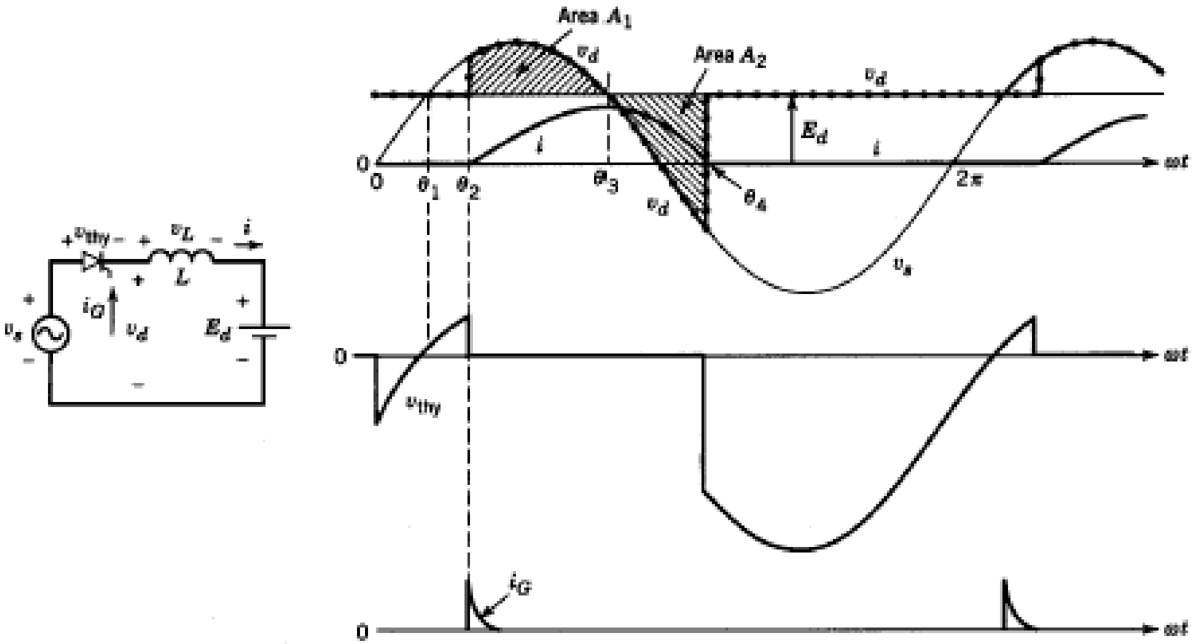
- Fully controlled converter shown in Fig. 6-1a
- Average dc voltage V_d can be controlled from a positive maximum to a negative minimum on a continuous basis
- The converter dc current I_d can not change direction
- Two-quadrant operation
- Rectification mode (power flow is from the ac to the dc side): $+V_d$ & $+I_d$
- Inverter mode (power flow is from the dc to the ac side): : $-V_d$ & $+I_d$
- Inverter mode of operation on a sustained basis is only possible if a source of power, such as batteries, is present on the dc side.



- Basic thyristor circuits: Line-frequency voltage source connected to a load resistance
- In the positive half cycle of v_s, the current is zero until ωt=α, at which a gate pulse of a short duration is applied
- With the thyristor conducting, $v_d = v_s$
- v_d becomes zero at $\omega t = \pi$
- By adjusting the firing angle α, the average dc voltage V_d and current I_d can be controlled



- Basic thyristor circuits: Line-frequency voltage source connected to a *RL* load
- Initially, the current is zero until $\omega t = \alpha$, at which the thyristor is fired during the positive half cycle of v_s
- With the thyristor conducting, current begins to flow, $v_d = v_s$
- Voltage across the inductor: $v_L = v_s - v_R$
- During α to θ_1, v_L is positive, and the current increases
- Beyond θ_1, v_L is negative, and the current begins to decline
- θ_2 is the instant at which current becomes zero and stays at zero until $2\pi + \alpha$ at which the thyristor is fired again

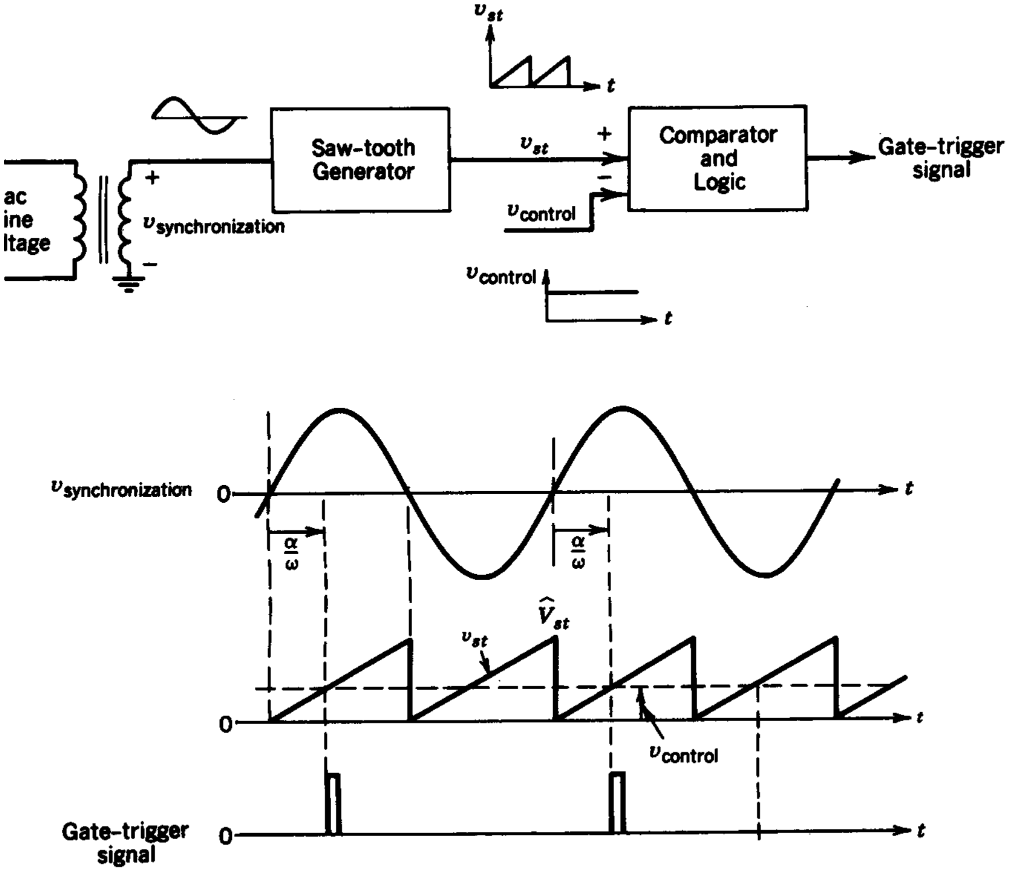


- Basic thyristor circuits: The load consists of L and a dc voltage E_d
- The thyristor is reverse biased until θ_1
- The thyristor conduction is further delayed until θ_2 at which the thyristor is fired
- With the thyristor conducting, $v_d = v_s$
- Between θ_2 to θ_3, v_L is positive, and the current increases
- Beyond θ_3, v_L is negative, and the current begins to decline
- When A_1 is equal to A_2, current goes to zero at θ_4

Thyristor Gate Triggering

- Generation of the firing signal
- The sawtooth waveform (synchronized to the ac input) is compared with the control signal $v_{control}$, and the delay angle α with respect to the positive zero crossing of the ac line voltage is obtained in terms of $v_{control}$ and the peak of the sawtooth waveform V_{st}.

$$\alpha^o = 180^o\left(\frac{v_{control}}{V_{st}}\right)$$



gure 6-3 Gate trigger control circuit.

Full-Bridge (Single- and Three-Phase) Thyristor Converters

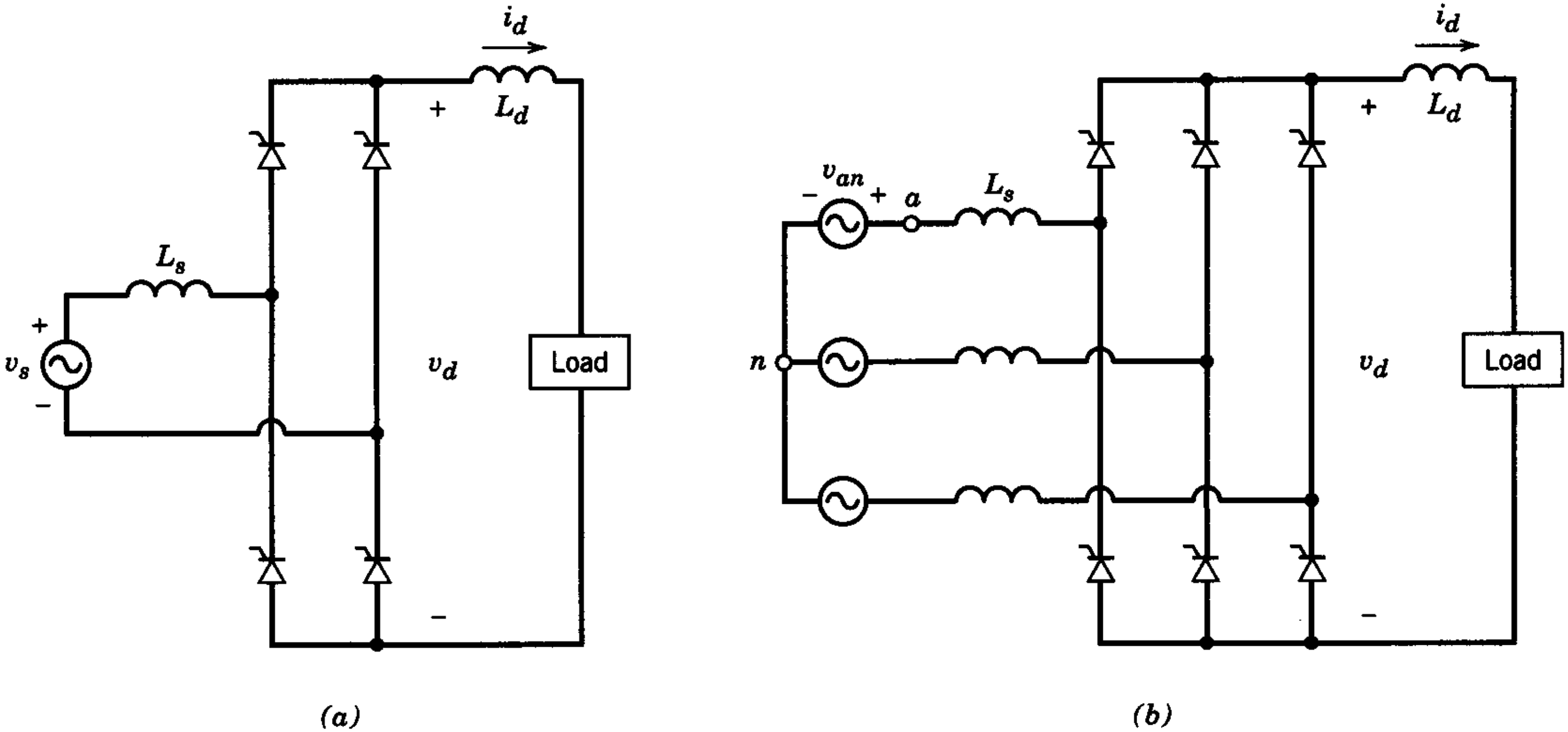


Figure 6-4 Practical thyristor converters.

Single-Phase Thyristor Converters

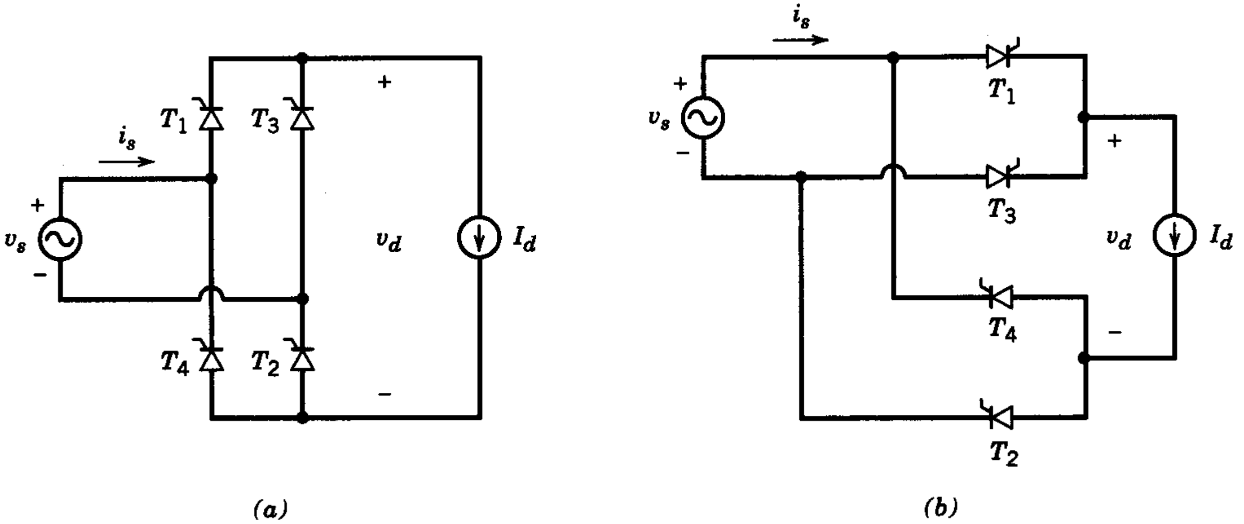
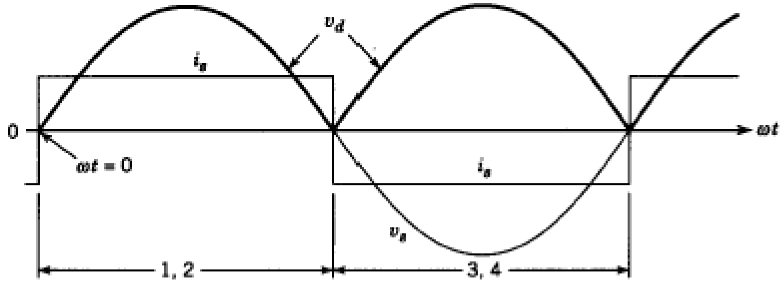


Figure 6-5 Single-phase thyristor converter with $L_s = 0$ and a constant dc current.

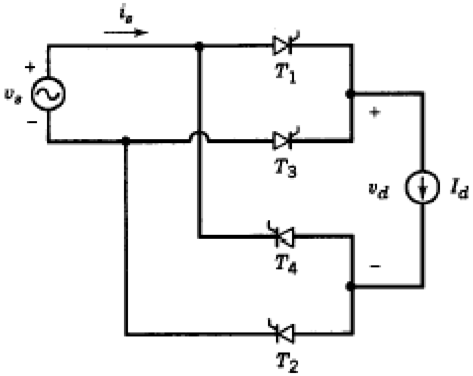
- One thyristor of the top group and one of the bottom group will conduct
- If a continuous gate pulse is applied then this circuit will act like a full bridge diode rectifier and the web forms are as shown below

☐ $\alpha=0$ for 1 and 2 and $\alpha=\pi$ for thyristors 3 and 4

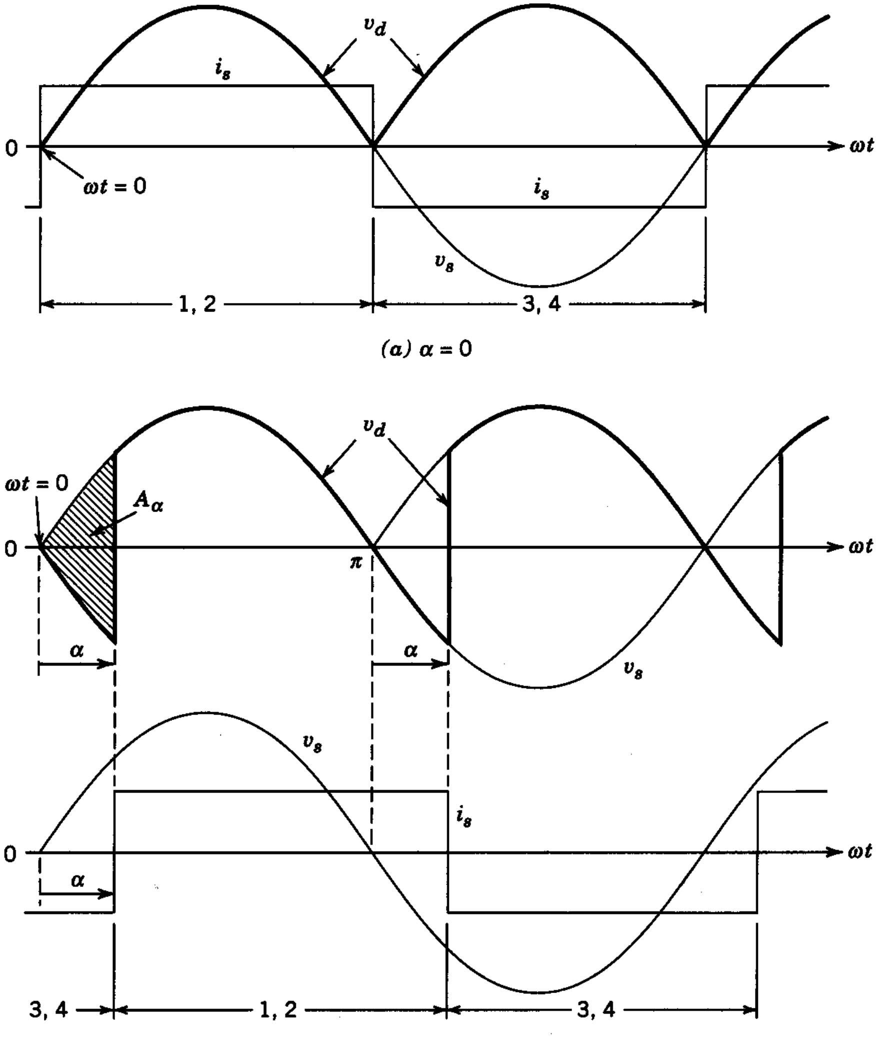


(a) $\alpha = 0$

1-Phase Thyristor Converter Waveforms



- Assumptions: L_s=0 and purely dc current I_d
- α: delay angle or firing angle
- Prior to ω*t*=0, current is flowing through 3 and 4, and $v_d = -v_s$
- Beyond ω*t*=0, thyristors 1 and 2 become forward biased, but cannot conduct until α.
- v_d becomes negative between 0 and α as a consequence of the delay angle
- At ωt=α, gate pulse applied and current commutation from thyristors 3 and 4 to 1 and 2 is instantaneous ($L_s = 0$), and $v_d = v_s$
- Thyristors 1 and 2 will keep conducting until 3 and 4 are fired



(a) α = 0

(b) α = finite

Figure 6-6 Waveforms in the converter of Fig. 6-5.

Average dc Voltage as a Function of the Delay Angle

The expression for the average voltage V_d:

$$V_{d\alpha} = \frac{1}{\pi} \int_{\alpha}^{\alpha+\pi} \sqrt{2} V_s \sin \omega t \, d(\omega t) = 0.9 V_s \cos \alpha$$

Let V_{d0} be the average dc voltage with α=0,

$$V_{d0} = \frac{1}{\pi} \int_{0}^{\pi} \sqrt{2} V_s \sin \omega t \, d(\omega t) = 0.9 V_s$$

Then, drop in average voltage due to α,

$$\Delta V_{d\alpha} = V_{d0} - V_{d\alpha} = 0.9 V_s (1 - \cos \alpha)$$

The average power through the converter,

$$P = \frac{1}{T} \int_{0}^{T} p(t) dt = \frac{1}{T} \int_{0}^{T} v_d i_d \, dt$$

With a constant dc current ($i_d = I_d$),

$$P = I_d \left[\frac{1}{T} \int_{0}^{T} v_d \, dt \right] = I_d V_d = 0.9 V_s I_d \cos \alpha$$

Average dc Output Voltage

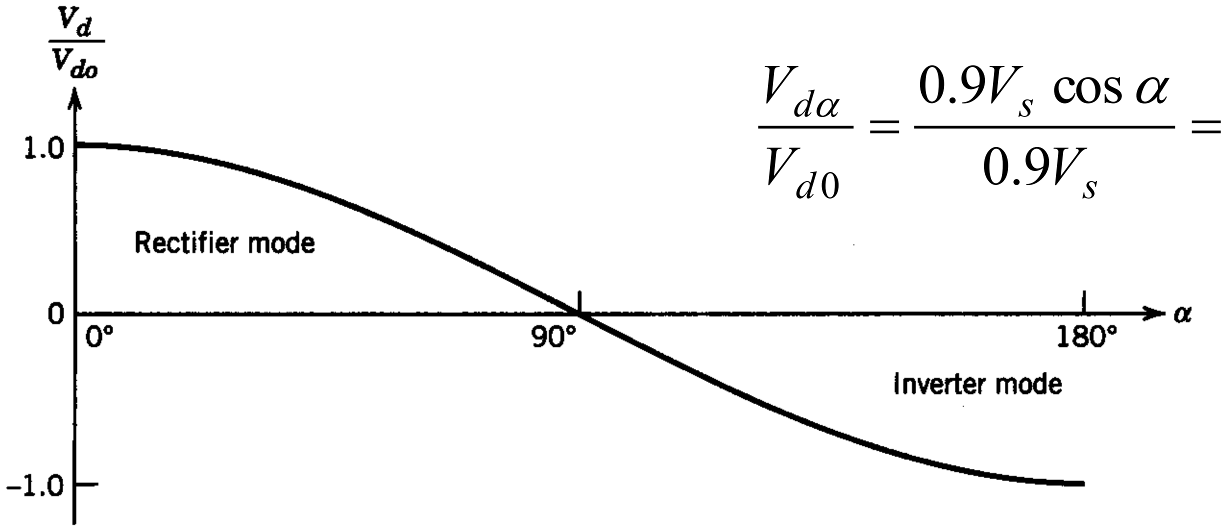


Figure 6-7 Normalized V_d as a function of α.

$$\frac{V_{d\alpha}}{V_{d0}} = \frac{0.9V_s \cos\alpha}{0.9V_s} = \cos\alpha$$

The variation of V_d as a function of α:

Average dc voltage is positive until α=90°: this region is called the rectifier mode of operation

Average dc voltage becomes negative beyond α=90°: this region is called the inverter mode of operation