Electronics and Computer Science

ELEC2208 Power Electronics and Drives

Thyristor

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What is Thyristor?

Three terminal devices **invented in 1957** that can be used as a controlled switch to perform various functions such as rectification, inversion and regulation of power flow **(in low frequency operation).**

Thyristors are capable of **large currents and large blocking voltages** for use in **high-power applications**, but switching frequencies cannot be as high as when using other devices such as MOSFETs.

Classification

3 major types of thyristors

- **Silicon-controlled rectifier (SCR)**
- **TRIAC**
- **Gate turnoff thyristors (GTO)**

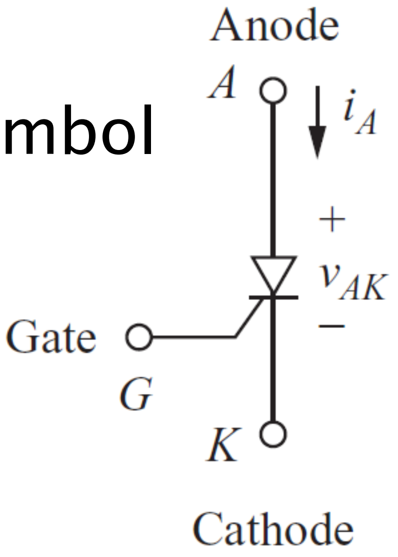
Other types: MOS-controlled thyristor (MCT), Emitter turn-off thyristor (ETO), Light activated SCR (LASCR) etc.

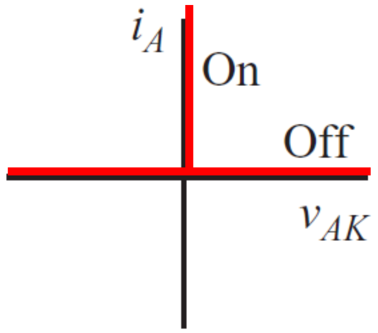
Thyristor

Silicon-controlled rectifier (SCR)

- Three-terminal devices
- Controllable diodes

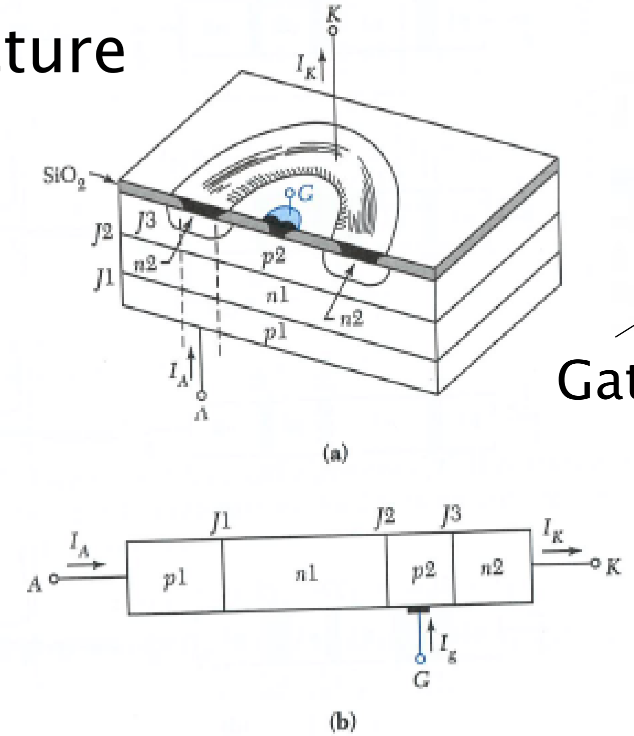
Symbol

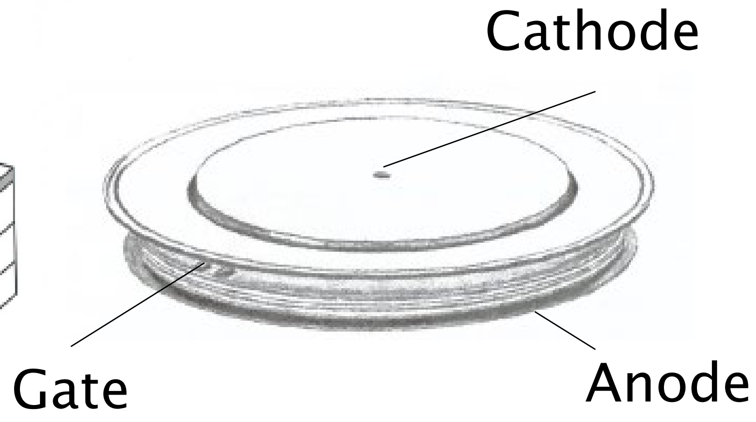




v_{AK} : Anode-Cathode voltage
i_A: Anode current

Structure



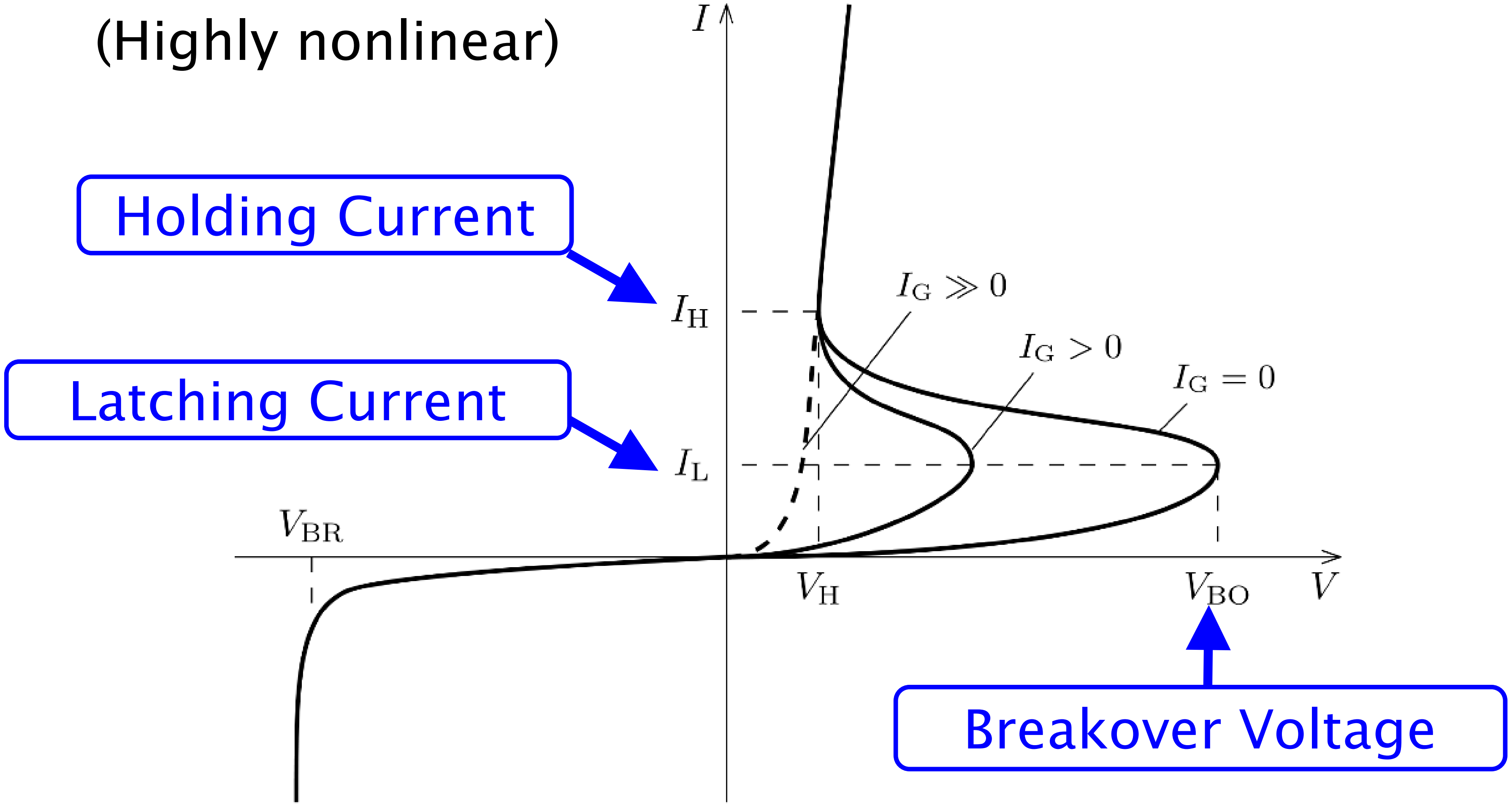


“Hockey puck” package

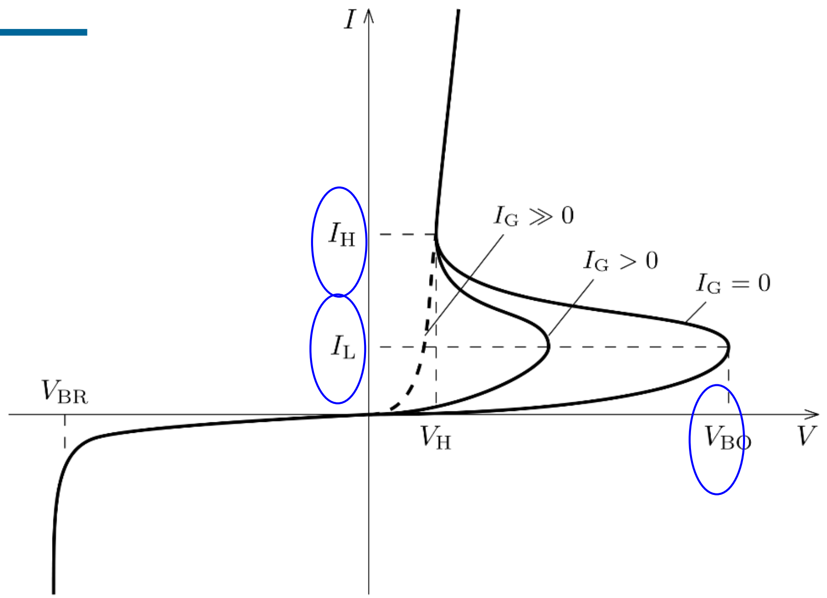
Semiconductor PNPN structure

Thyristor characteristics

***I* - *V* characteristics** (Highly nonlinear) — **Three key specifications**



Thyristor characteristics



Latching Current (I_L) Minimum principal current required to maintain the thyristor in the on state immediately after the switching from the off state, and the triggering gate signal has been removed.

⟶ Related to Switch ON

Holding Current (I_H) Minimum principal current required to maintain the thyristor in the on state.

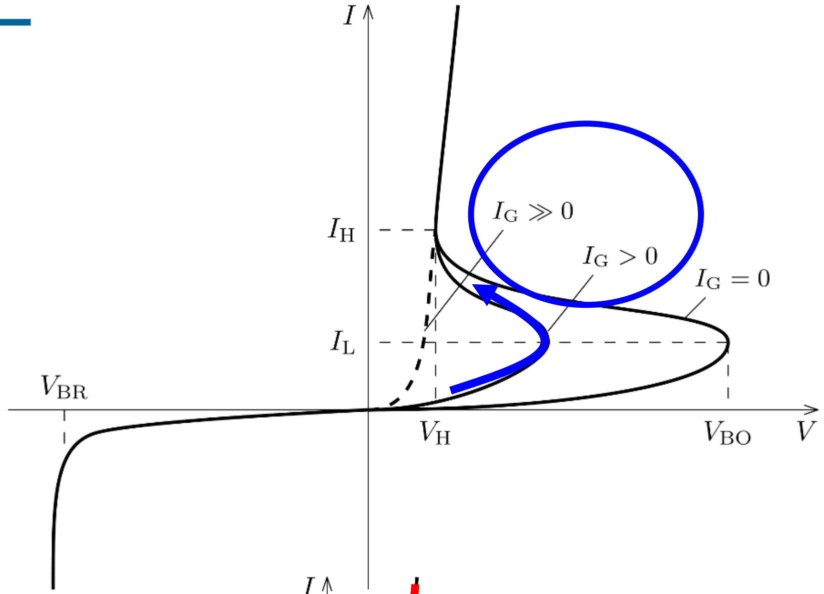
⟶ Related to Switch OFF

Breakover Voltage (V_{BO}) Principal voltage at the breakover point.

Triggering and Commutation

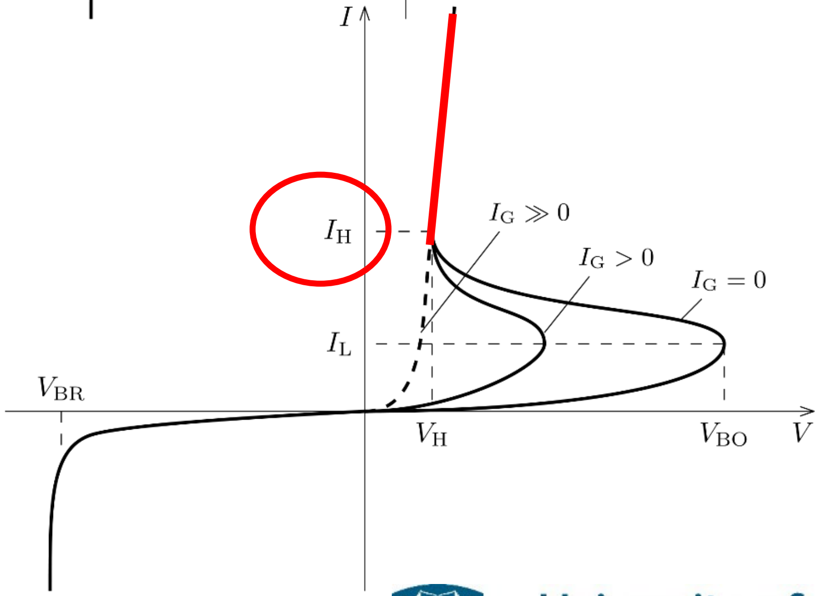
Triggering

- Under appropriate positive V_{AK}, a gate current is applied so that the thyristor is turned on.
- V_{AK} must be higher than specific threshold depending on magnitude of gate current.



Commutation

- After conduction is triggered, the gate signal is no longer required.
- When anode current I_A becomes less than I_H, the system is turned off.



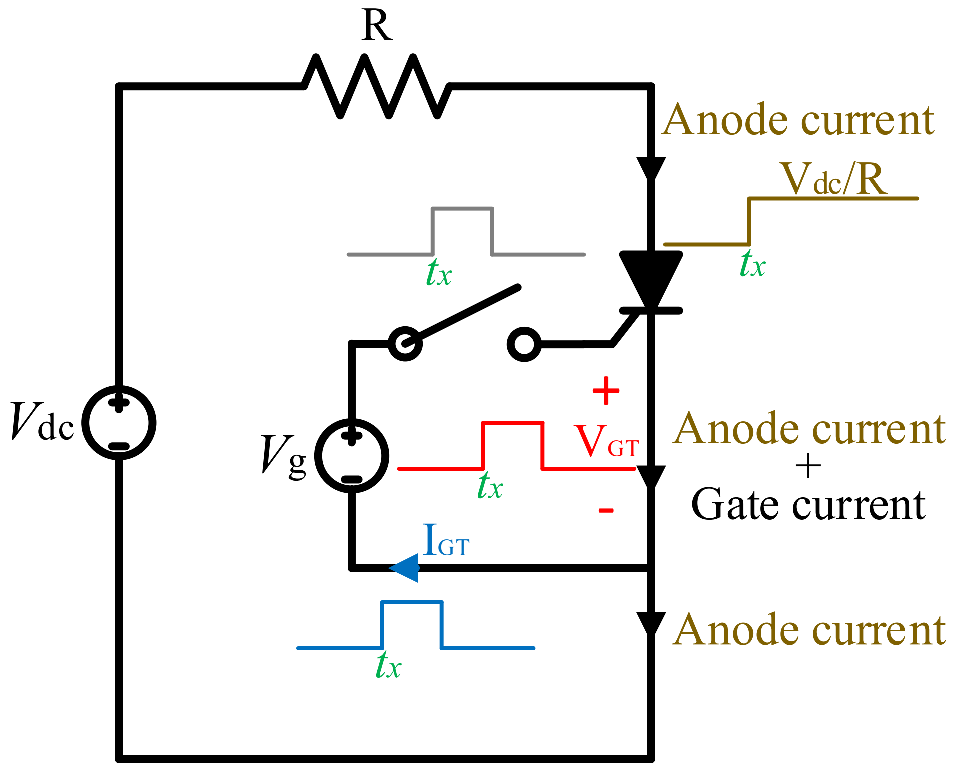
Thyristor triggering

- In order to turn on the SCR, the **gate voltage** V_G is increased up to a minimum value to initiate **triggering**. This minimum value of gate voltage at which SCR is turned on is called gate **triggering voltage** V_{GT}.

- The resulting gate current is called gate **triggering current** I_{GT}. Thus, to turn on an SCR, what we have to do is to apply positive gate voltage equal to V_{GT} or pass a gate current equal to I_{GT}. For most of the SCRs, **V_{GT} = 2 to 10 V and I_{GT} = 100 μA to 1500 mA.**

- Consideration of **triggering circuits or drive circuits** is very important in terms of **minimising power loss in switching**.

Thyristor gate triggering circuits



- Only a simple **voltage pulse** is needed to turn on a thyristor.
- Thyristor **conducts heavily after being turned on** and remains in this position indefinitely even if gate voltage is removed.
- If the circuit load has a large inductance, the anode current will rise slowly.
- To make sure load current **reaches latching current** and thyristor turn on successfully, triggering signal with long pulse width or a series of pulses can be used.

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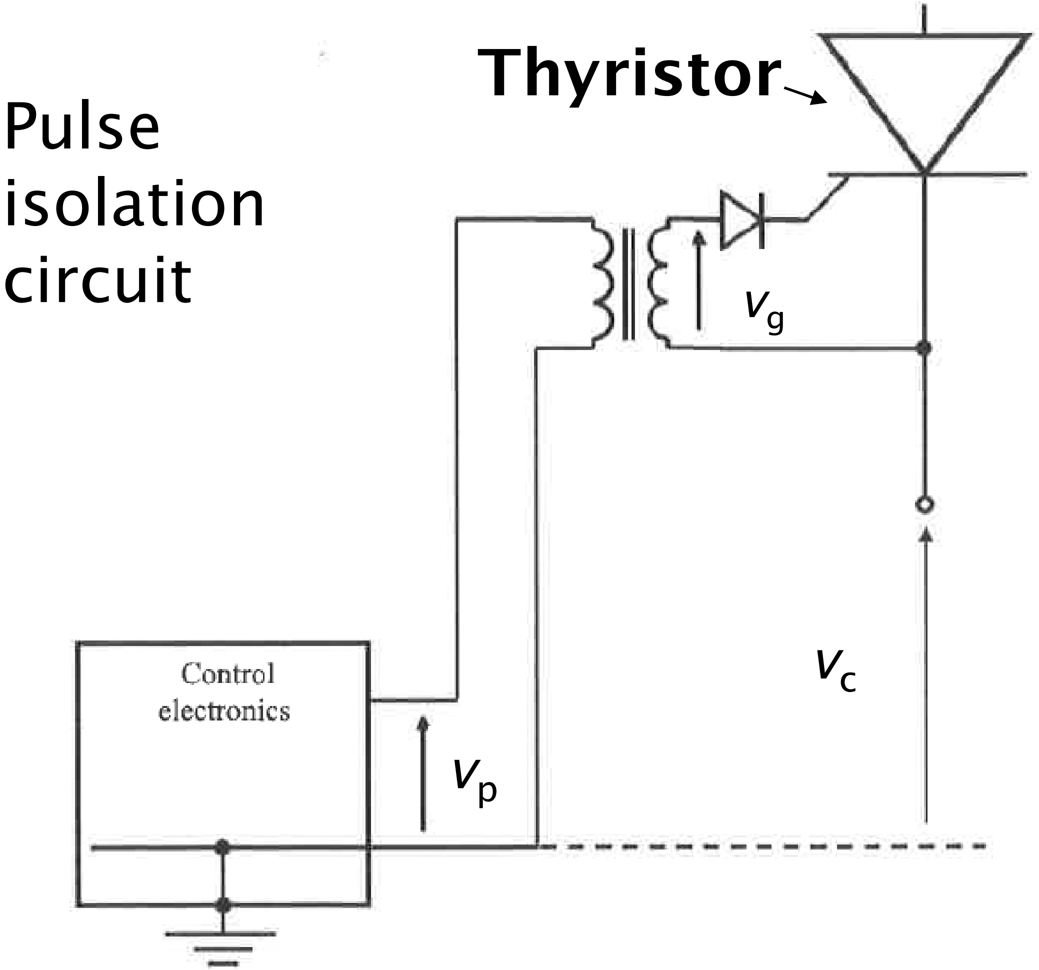
Thyristor gate triggering circuits



- Often the triggering circuit with low power/voltage level should be isolated from thyristor gate (power circuit) for protection.

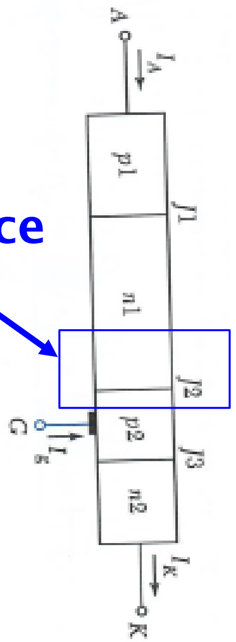
(via magnetic or optical coupling)

- Isolation between gate of thyristor and triggering circuit is mandatory if the cathode of thyristor in power circuit is floating (not earthed).

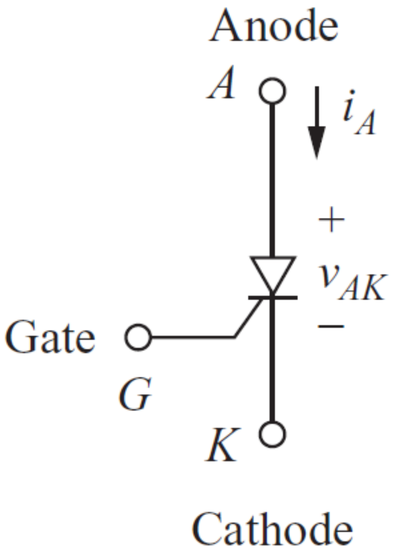
Thyristor snubber circuits

SCR

Capacitance



PNPN
junction



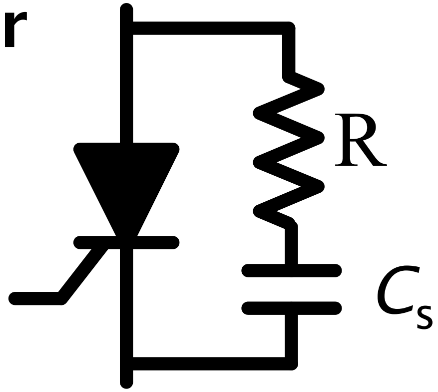
Sudden change of voltage v_{AK}

- Current is induced via internal capacitance.

$$i = C\frac{dv}{dt}$$

- Switch will be turned on if the induced current is larger than I_{GT}.

RC snubber



- By choosing C appropriately, this can limit transient voltage across the switch below **the maximum critical rate of rise of off-state voltage or Static *dv/dt*** (typically 1kV/μs).

$$\frac{dv}{dt} = \frac{i}{C_s}$$

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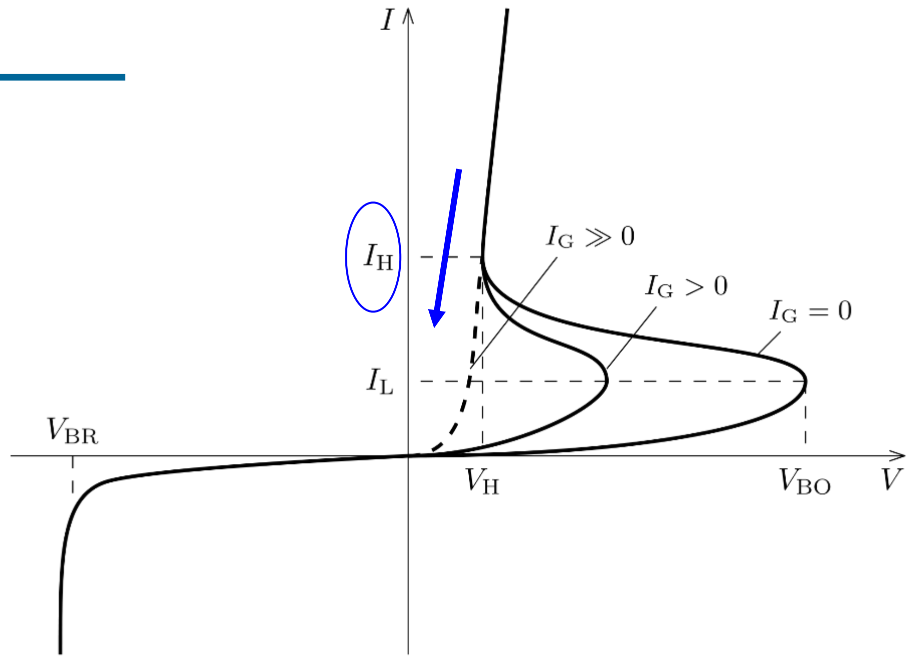
Commutation

- Thyristor turns off when the anode current falls below the holding current.



- Commutation is the process of turning off an electronic switch, which usually involves transferring the load current from one switch to another.

- Types of commutation
  - **Natural commutation** ——— **Common in SCR**
  - Forced commutation (Additional circuits, GTO)

Natural commutation

- Turning off occurs naturally due to the characteristics of power circuits.

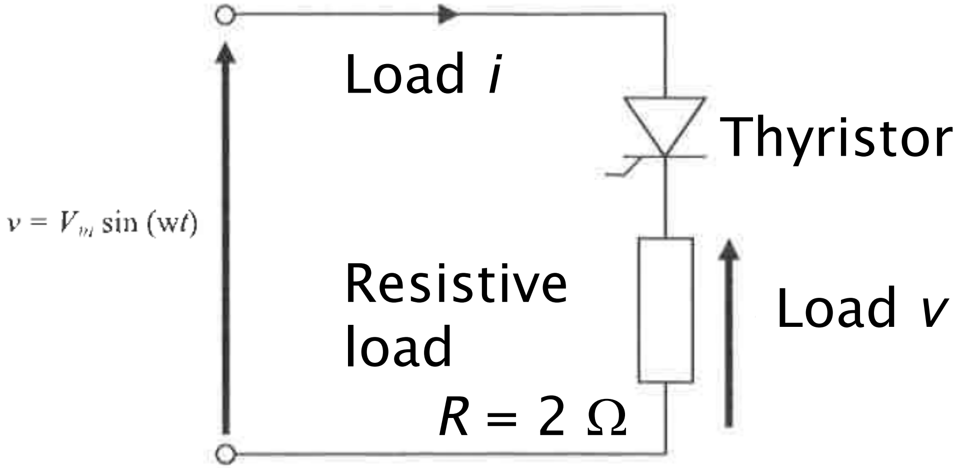
- Current flowing through a resistor supplied by an AC voltage falls and crosses zero naturally every half a cycle.

- The thyristor turns off by 'itself' due to current falls to zero naturally.

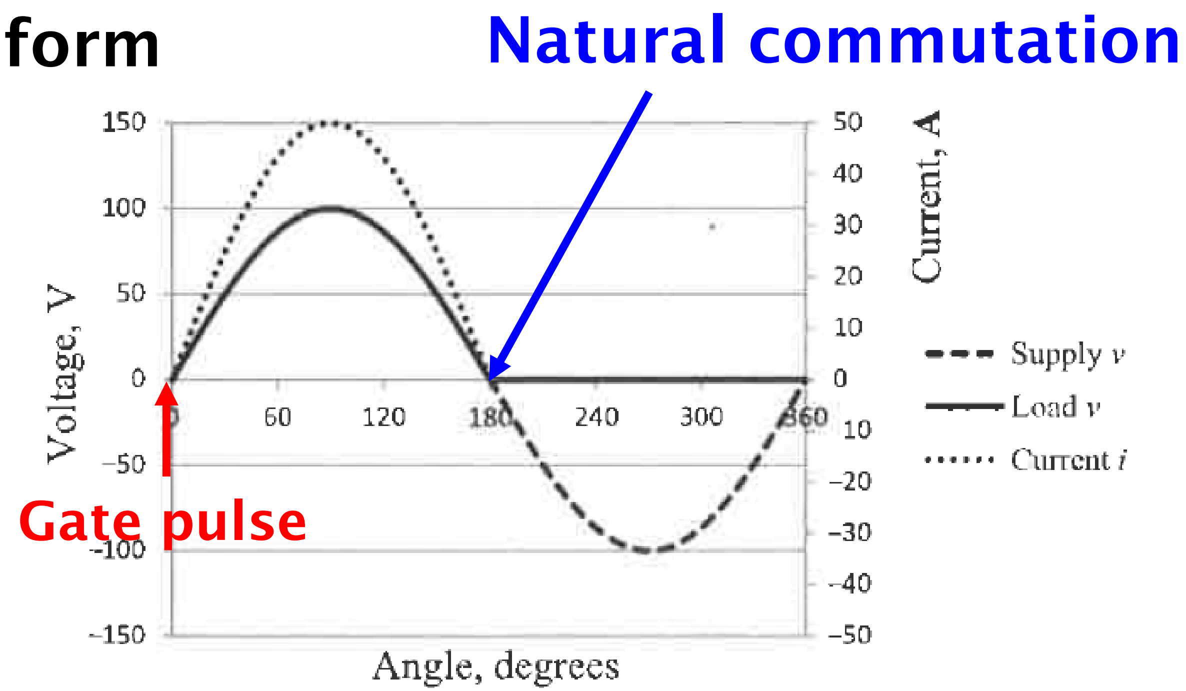
- This is called **Natural commutation.**

Natural commutation – Resistive load

In a circuit with a thyristor and resistive load,



Waveform



- Triggered via single gate pulse
- Anode current starts flowing at the instant when the thyristor has been triggered.
- Due to resistive load, anode current is in phase with supply voltage.
- Anode current falls to zero naturally at π and hence the thyristor turned off naturally.

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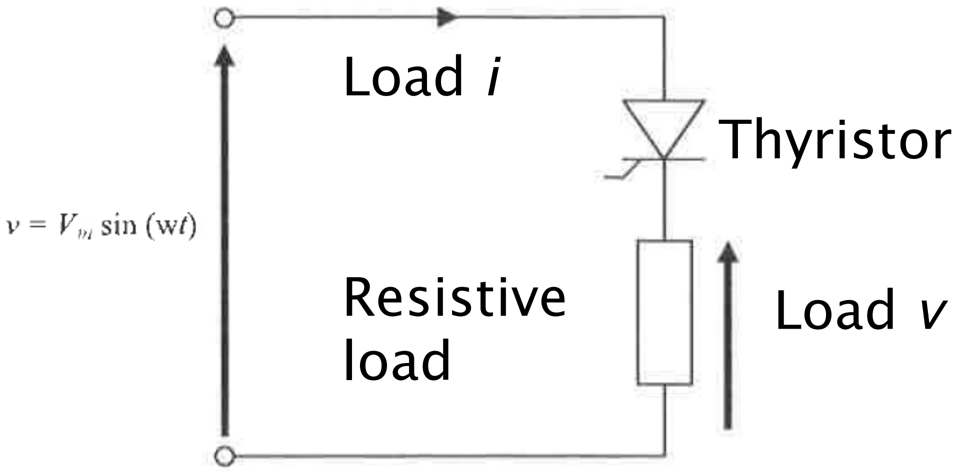
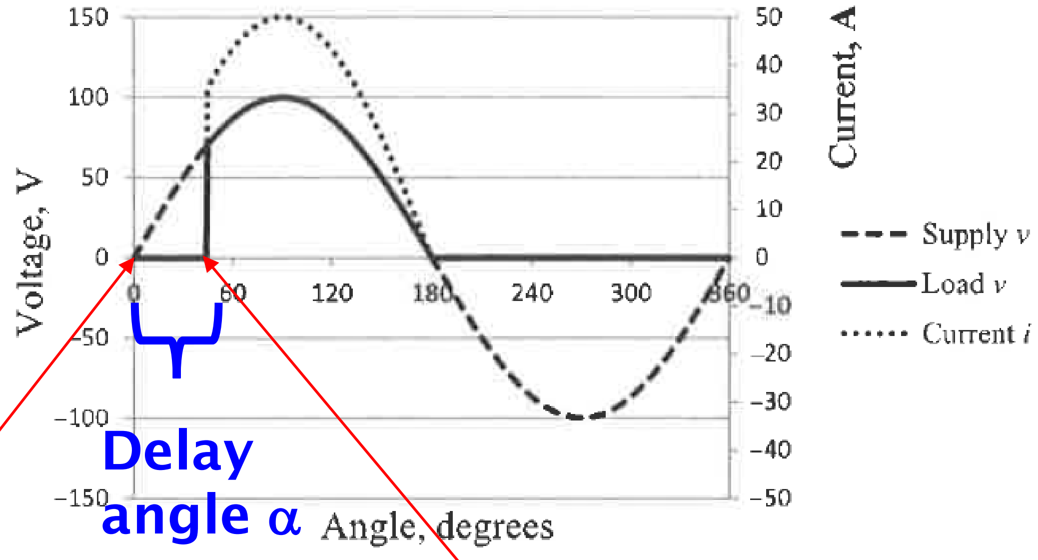
Delay angle in triggering

Angle $\theta = \omega t$

Waveform





- Triggered via single gate pulse with a **delay angle**

- Zero crossing point can be detected and time delay created.
- The delay angle a can be adjusted to control the waveform.

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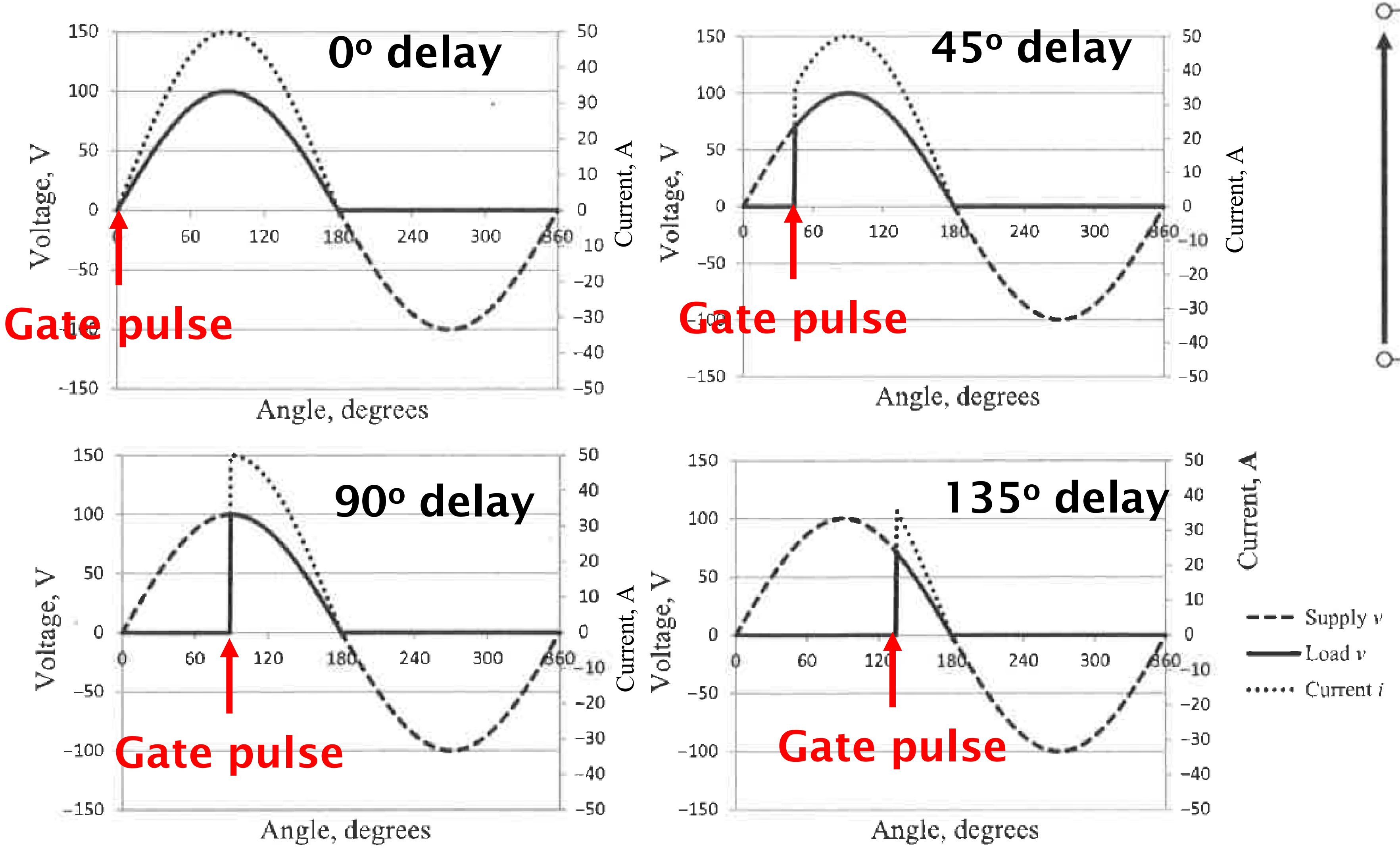
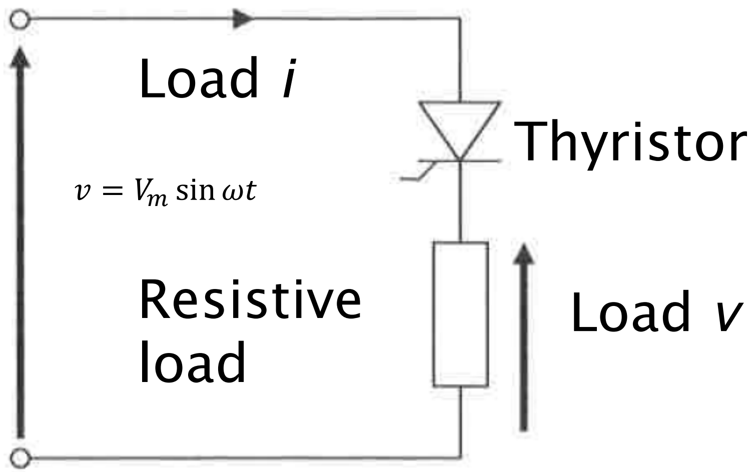
Waveform with changing delay angle





- AC to DC
- Voltage adjusted

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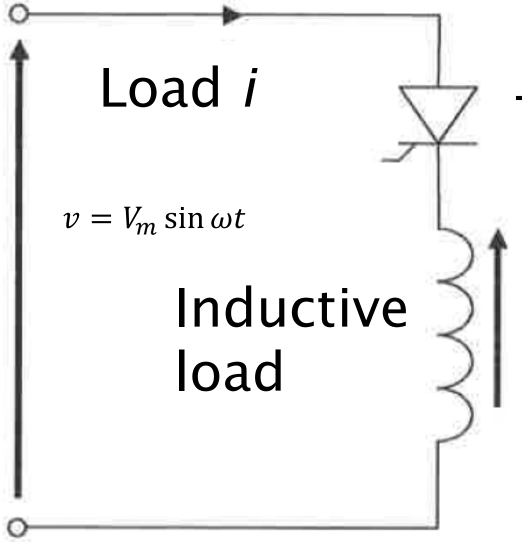
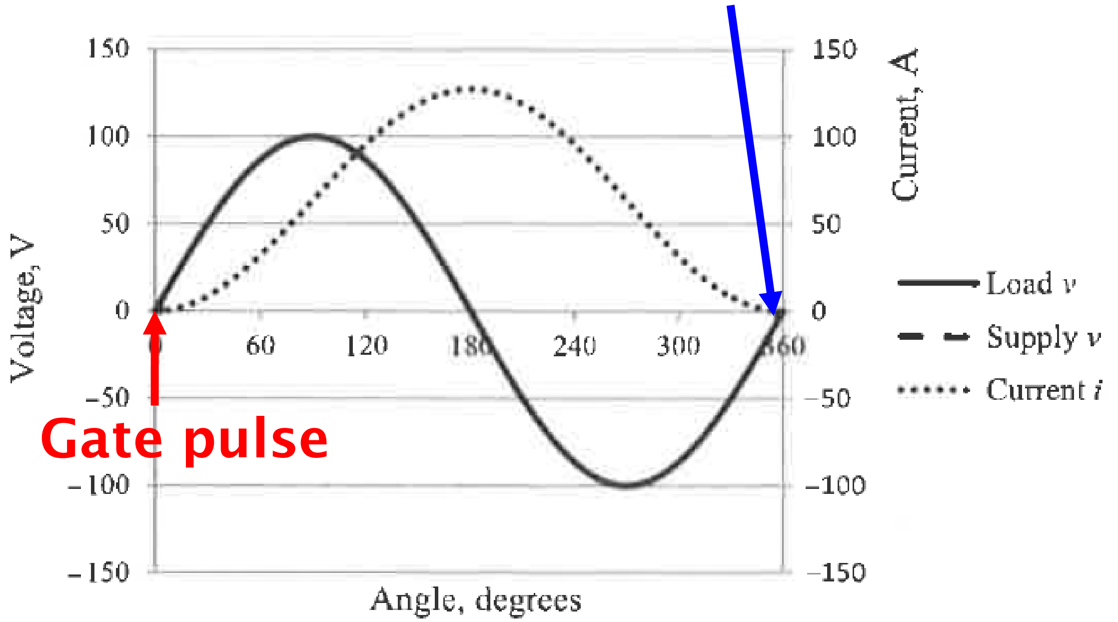
Natural commutation – Inductive load

In a circuit with a thyristor and inductive load,



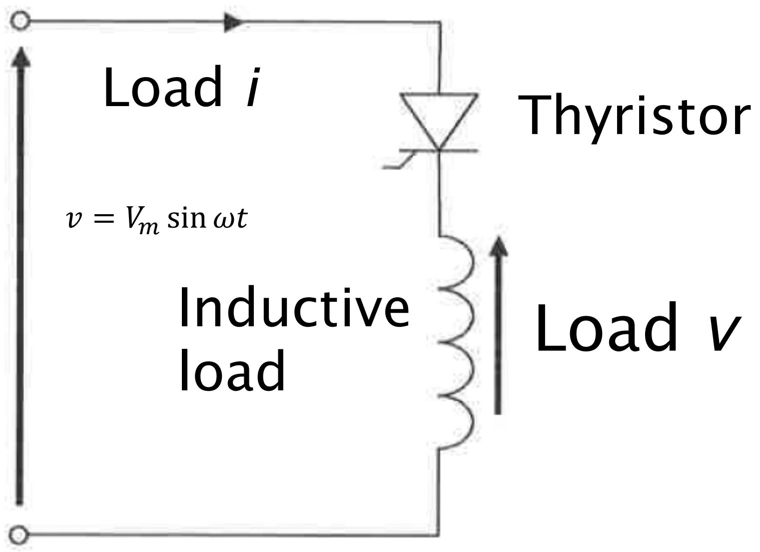
Waveform

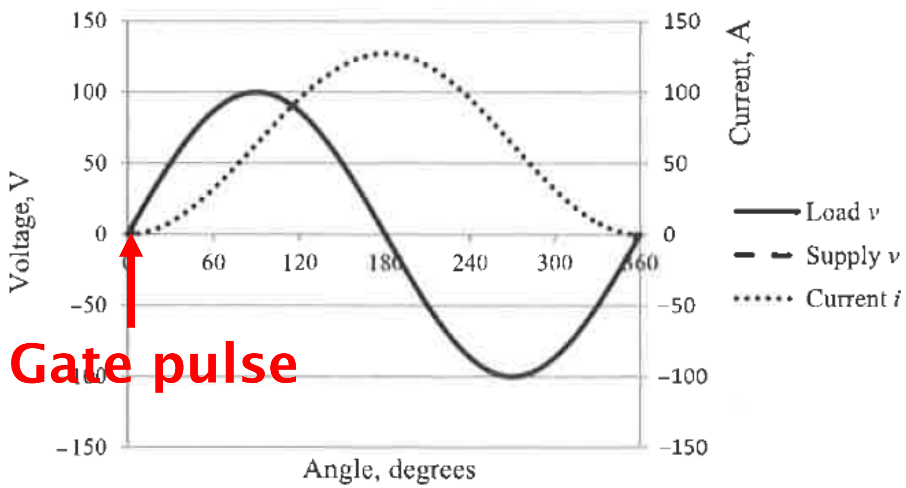


- Triggered via single gate pulse
- Due to inductive load, anode current is **not** in phase with supply voltage.

- The anode current can be determined by referring to $v = L(di/dt)$.
- Anode current starts flowing at the instant when the thyristor has been triggered.

Waveform features – Inductive load

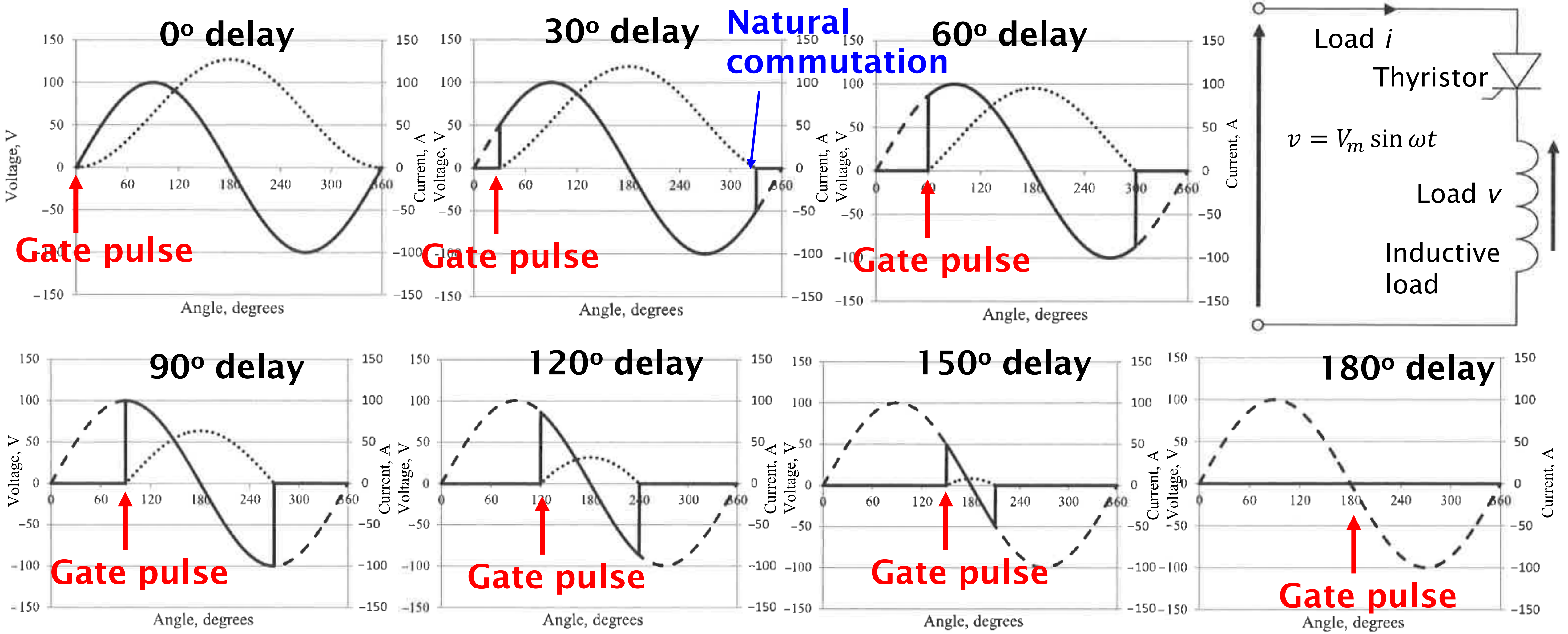




- Inductor stores energy (increasing current) for angle less than π, then discharging for angle beyond π (decreasing current). Anode current falls to zero naturally at angle between π and 2π and thyristor is turned off.

- Due to inductance load, positive current remain conducting (thyristor remain on) beyond π before it falls to zero, and negative load voltage is observed. When load voltage is negative, energy stored in inductor is transferred back to ac supply.

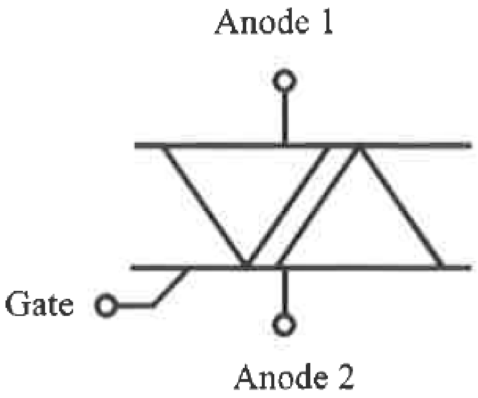
Waveform with changing delay angle



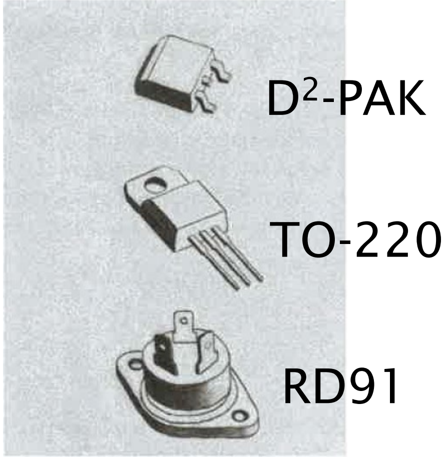
Symmetric current waveform due to gate trigger and natural commutation.

Other Thyristors - TRIAC

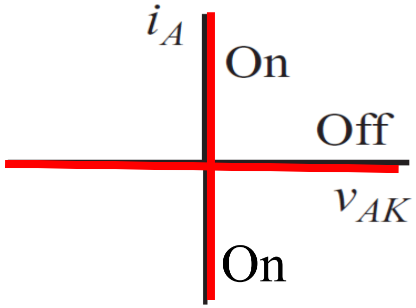
TRIAC



Symbol



I-V characteristics

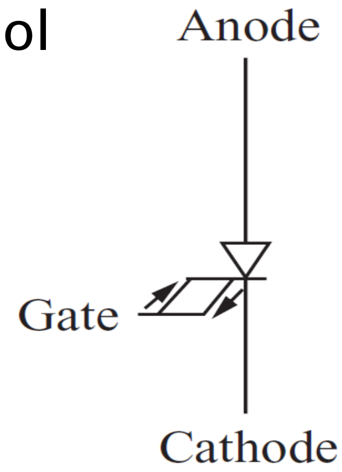


- Consists of thyristors that are connected back to back to allow bi-directional flow of current.
- One thyristor conduct during positive half cycle while the other conduct during negative half cycle (after being triggered).
- It has one gate input.
- Widely used in ac-ac voltage controllers for phase control applications such as light dimmer and conventional motor speed controller.

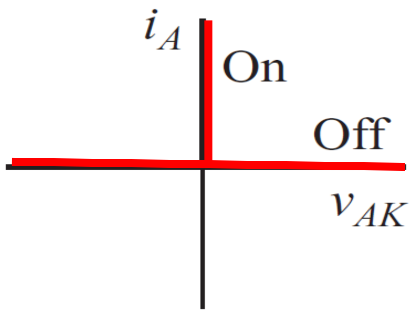
Other Thyristors - GTO

Gate turnoff thyristors (GTO)

Symbol



I-V characteristics



- Like the SCR, GTO is turned on by a short-duration gate current if the anode-to-cathode voltage is positive.
- **GTO can be turned off with a negative gate current.**
- Suitable for some applications where control of both turn-on and turn off of a switch is required.
- The negative gate turnoff current can be of brief duration (a few microseconds), but its magnitude must be very large compared to the turn-on current.

Summary - Thyristor

- A three terminal device, thyristor is a key element in power electronics, and particularly capable of large currents and large blocking voltages for use in high-power applications with relatively low switching speed.

- Three key specifications for SCR are Latching Current, Holding Current, and Breakover Voltage.

- Triggering is required for turn on and commutation needs to be considered for turn off.

- A variety of thyristors, SCR, TRIAC, GTO can be chosen depending on applications.