Power Electronics

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Course Contents

- Power semiconductor devices
- Uncontrolled AC to DC converters
- Controlled AC to DC Converters
- DC to DC converters (Choppers)
- Inverters (DC to AC converters)
- AC to AC converter (Cyclo-converters)

Reference Books

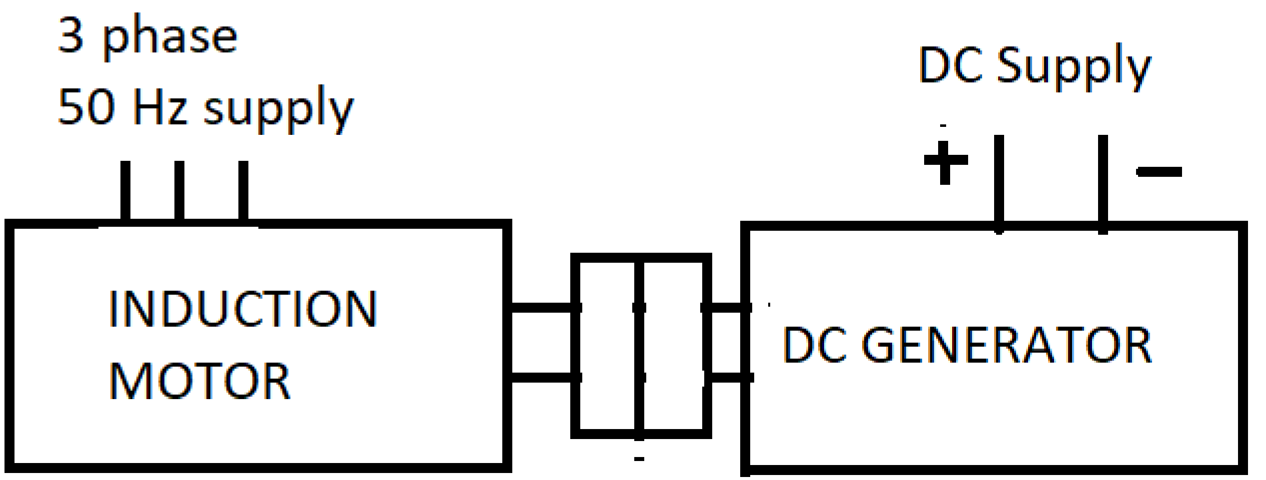
- M. H. Rashid “ Power electronics : Circuit devices and Applications” , Prentice Hall &co
- Ned Mohan and others “Power Electronics applications and design
- B. K. Bose “ Modern power Electronics and AC drives” Pearson education Inc
- P. S. Bhimra “ Power Electronics” third edition Khanna publishers

Importance of Power Electronics

- Power supply distribution
- Three phase 4 wire supply
- Line voltage 400 V and phase voltage =230V
- DC supply is required for various applications
- DC Motors
- Battery charging
- What are the possible options ?

Importance of Power Electronics

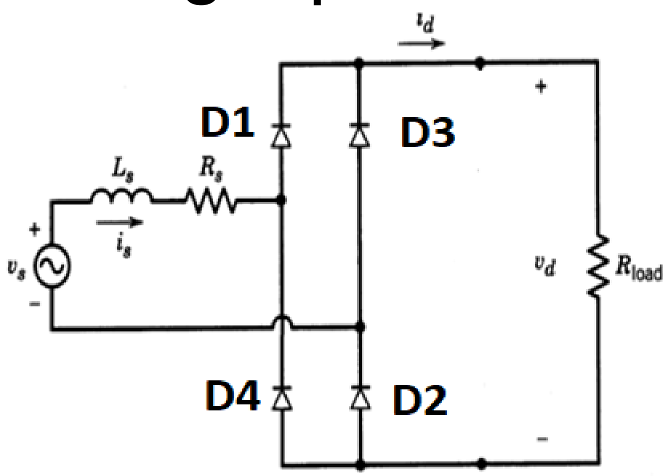
- Induction motor DC generator

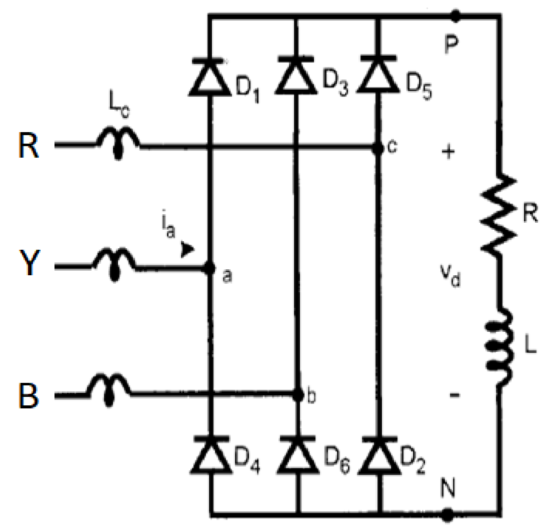


- Losses in the system
- Overall efficiency of energy conversion

Importance of power electronics

- Diode bridge rectifier / controlled converter
- Single phase three Phase





- Losses
- overall conversion efficiency

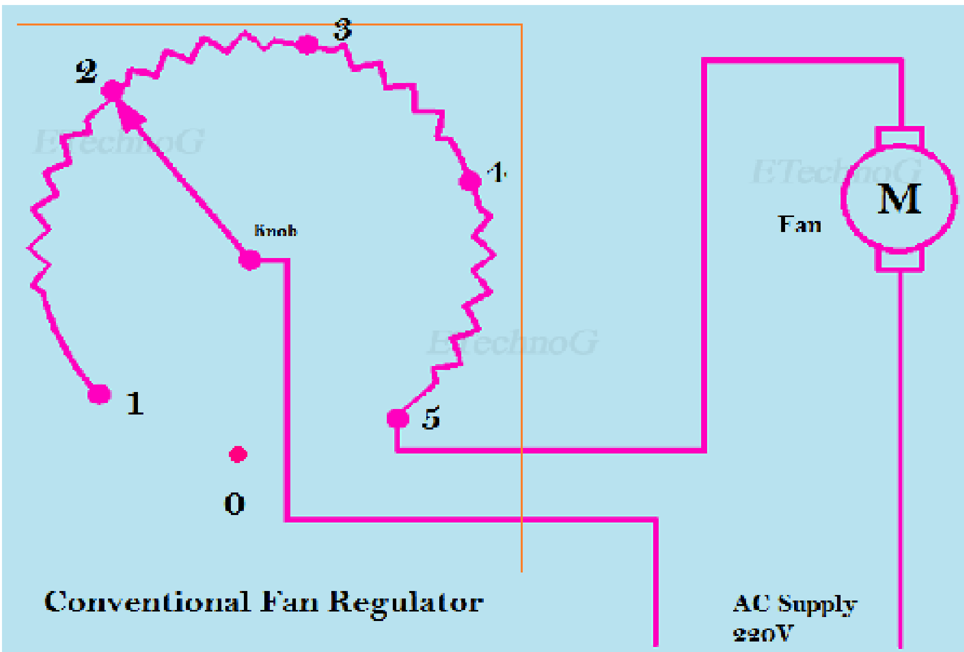
Importance of power electronics

- Incandescent lamp and LED lamp

- 100 W Incandescent lamp => 15 lumens/watt
- 25 W led lamp => 60 lumens/ Watt
- Energy efficiency

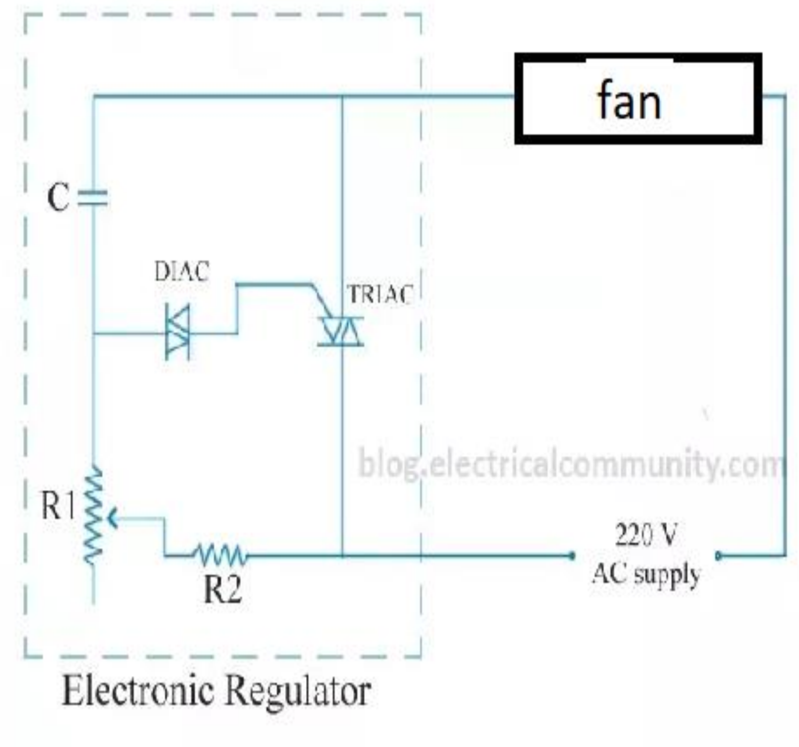
Importance of power electronics

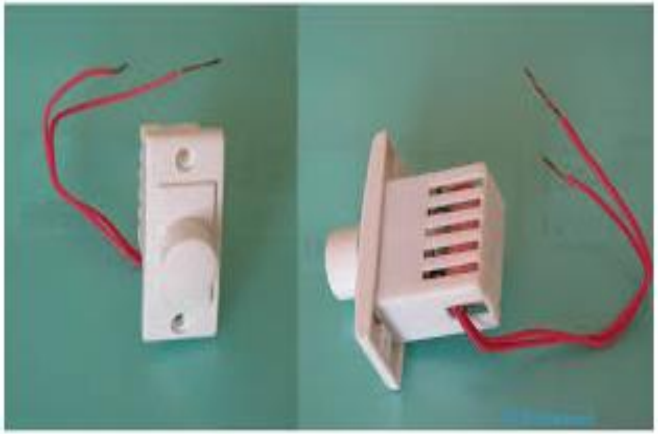
- Resistance type fan regulator



Importance of power electronics

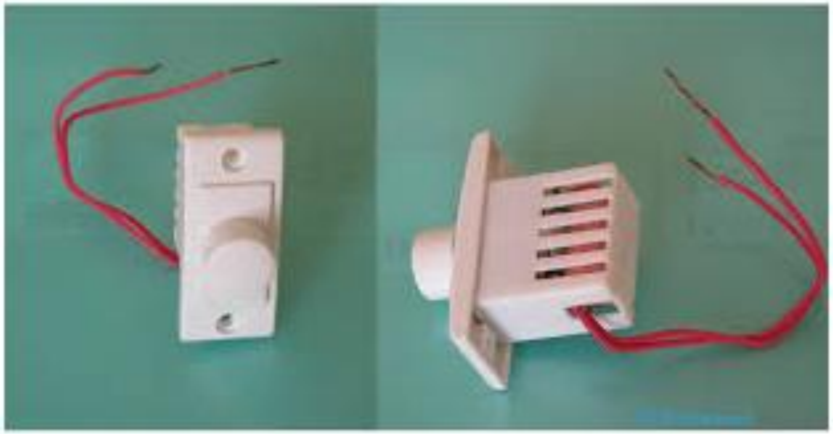
- Traic based fan regulator





Importance of power electronics

- Fan regulator
- Resistance type Traic based fan regulator



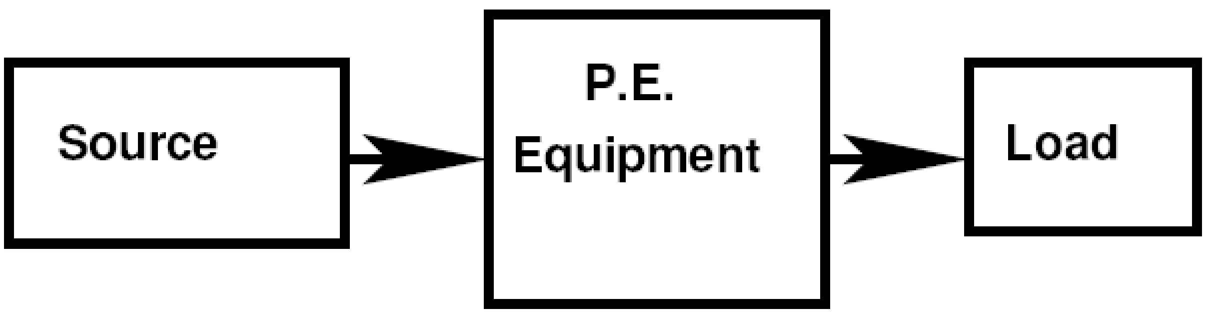
Applications of Power Electronics

- Variable speed drives
- Power supplies
- Lighting
- High frequency heating
- Electric Wielding
- Bulk power transmission
- Electric vehicles
- Active filters
- Process power from non conventional energy resources

Definition of Power Electronics

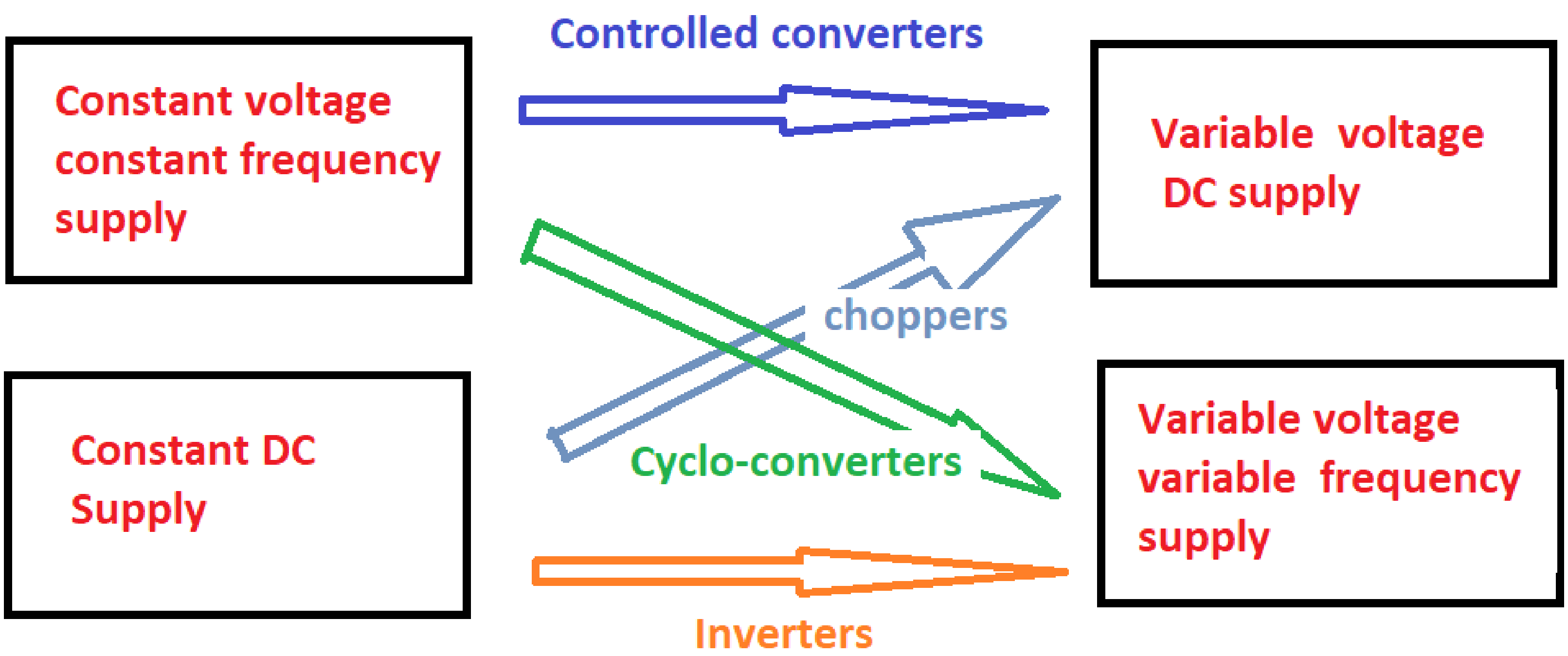
- Power electronics is technology associated with efficient conversion and control of electric power with the help of power semiconductor devices

- Goal of Power Electronics : control the flow of power from source to load



Electrical Energy conversion

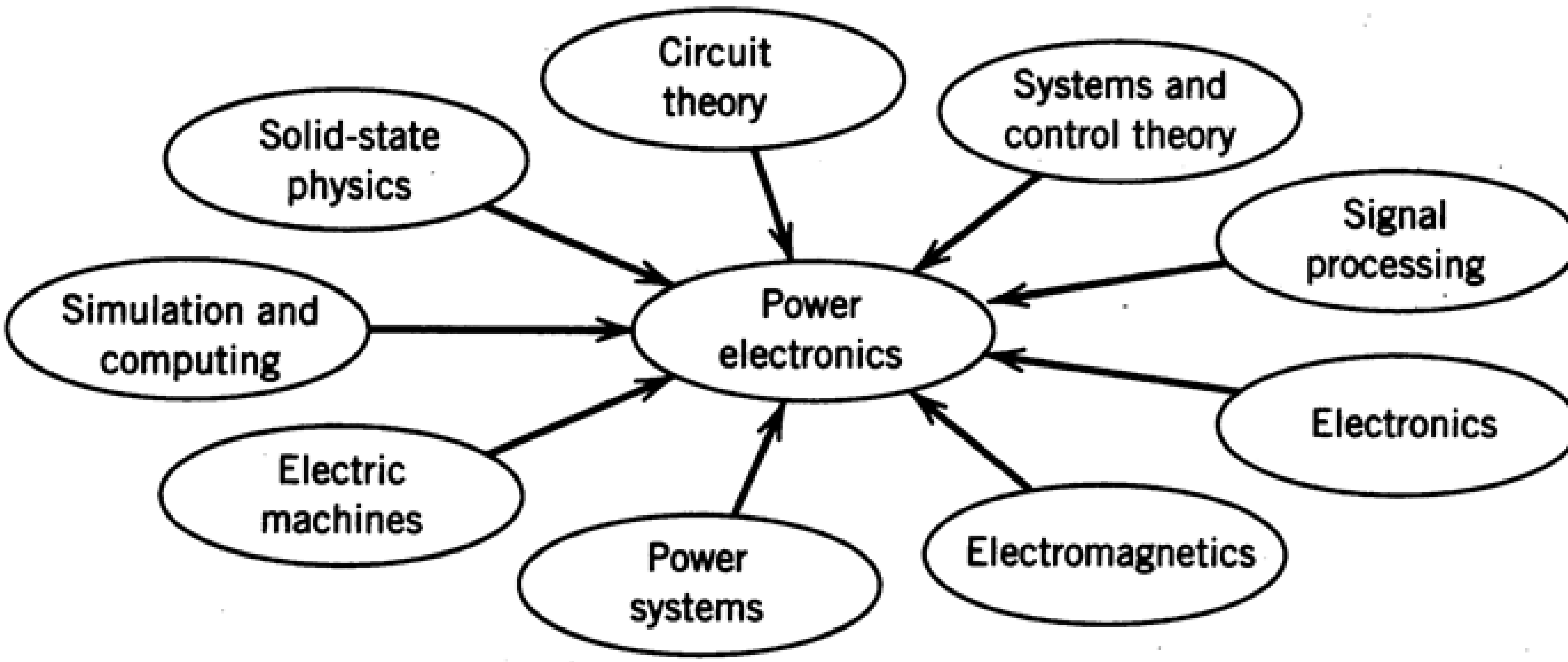
- Efficient conversion of electric power from one from to other form



Development in PE

- Progress in PE is primarily due to
- Advances in power semiconductor devices
- Fast processors
- Dedicated chips
- Circuit configurations
- Control and estimation techniques

Interdisciplinary Nature of PE



Power Electronics course contents

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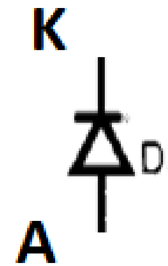
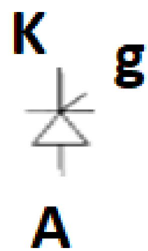
Semiconductor Switches

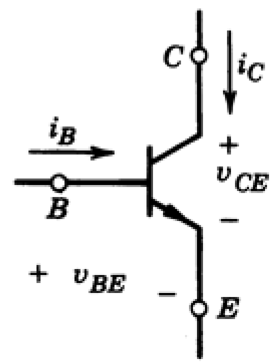
- Diode



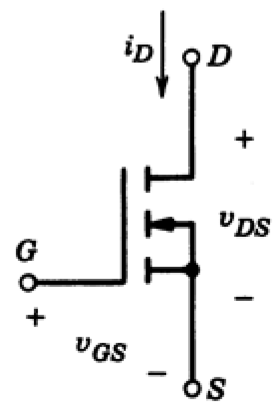
- Thyristor



- Power transistor

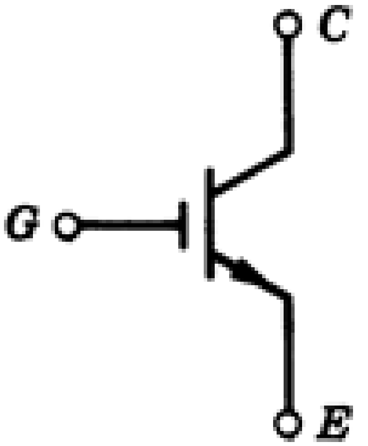


- MOSFET

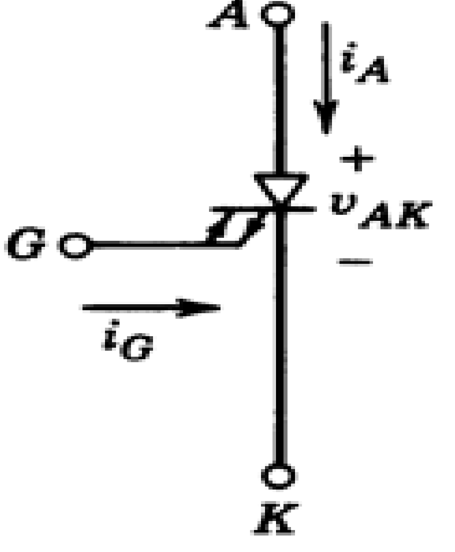


Semiconductor Switches

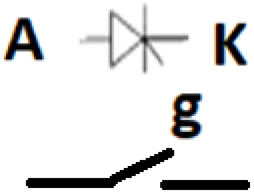
- IGBT
- Insulated gate
  bipolar transistor



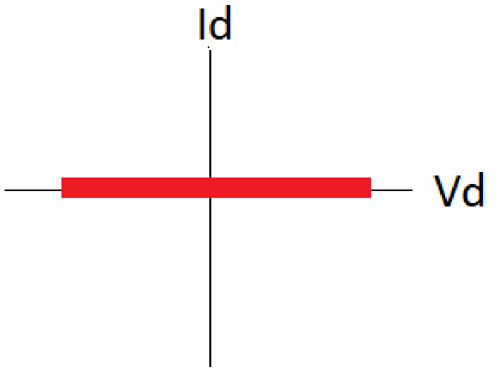
- GTO
- Gate turn off thyristor



V-I characteristics Ideal Semiconductor Switch

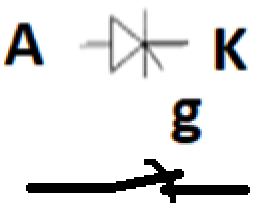


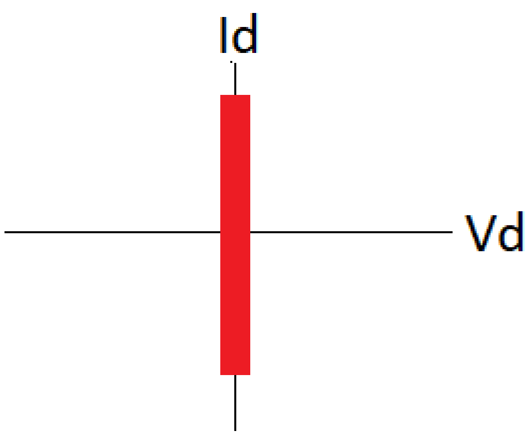
- When switch is off



- It should block large forward and reverse voltage

Current through device =0





- When switch is on
- It allows large current
- And drop across device =0

Properties of an ideal Switch

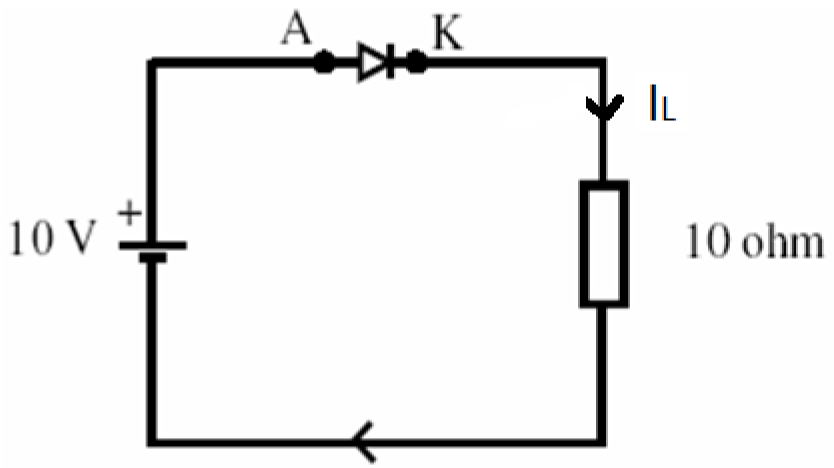
- Power loss in the device when on =0
- Power loss in the device when off = 0
- Time required to turn on (t_{on})=0
- Time required to turn off (t_{off})=0
- Power required to turn on =0
- Power required to turn off =0
- It can block large voltage during turn off
- It can carry large current during turn on

Characteristics of practical Switch

- Practical switches characteristics
- During off state $I \neq 0$ and $V \neq$ infinity .
- $V_{(sw\ on)} \neq 0$ on state current carrying capacity is limited
- P_{loss} in off state (blocking loss) and on state (conduction loss) $\neq 0$
- $t_{on} \neq 0$ and $t_{off} \neq 0$

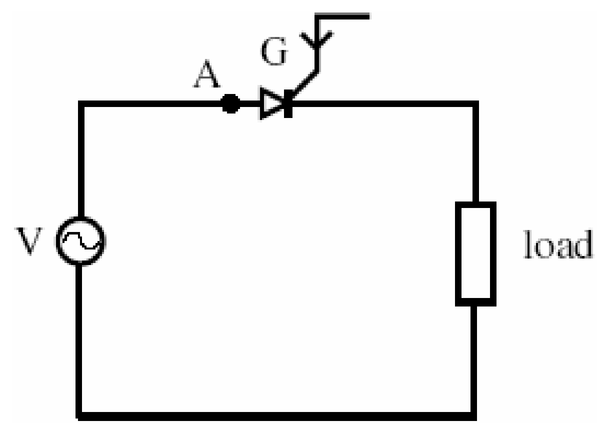
Classification of Switches

- Uncontrolled switched => Diode
- Only two terminals device
- On and off of the device is determined by circuit conditions where it is connected
- When D is ON
- $I_L = (10-0.7)/10 = 0.93A$



Classification of Switches

- Semi controlled switch =>Thyristor
- It is a three terminal device
- Device turns on when it is forward biased
- (anode is +Ve wrt cathode) and positive gate current Ig is applied
- Turn off is not possible with gate
- Turns off when Ia = 0 and reverse bias is applied across the device.

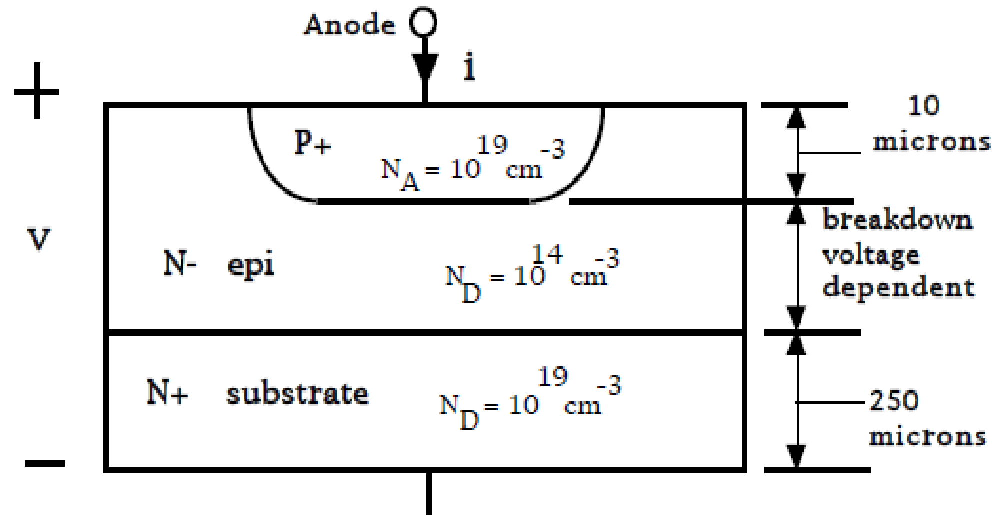


Classification of Switches

- Fully controlled switches = (3 terminal device)
- Power transistor, MOSFET , IGBT & GTO
- Device can be made ON or OFF by applying control signal to control terminal
- Turn on and turn off by current signal => current controlled switch => BJT and GTO
- Turn on and turn off by voltage signal => voltage controlled switch=> MOSFET &IGBT

Power Diode

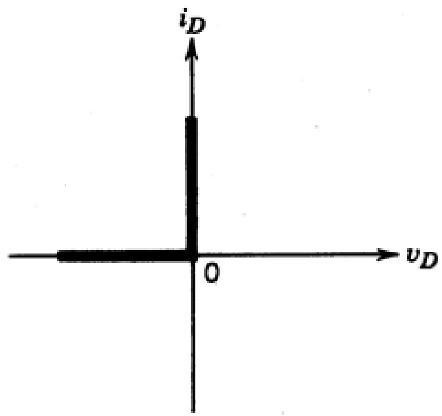
- Constructional details
- It is a pn junction
- Impurities concentration (impurities/cm^3)
- N^+ or $P^+ = 10^{19}$
- N or P = 10^{17}
- N^- or $N^- = 10^{14}$
- Thickness of N- determines the voltage rating of the diode

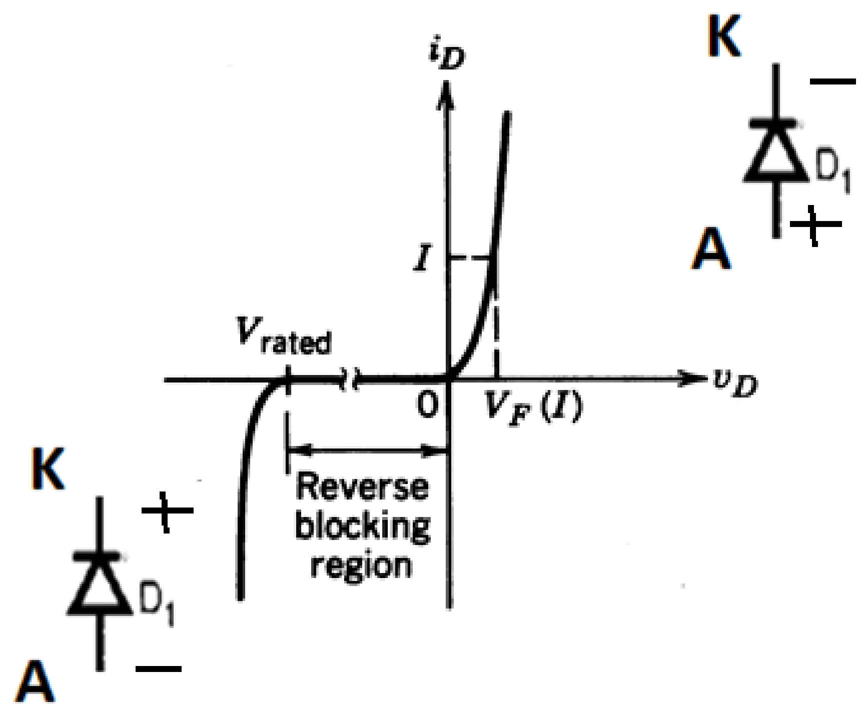


Cross sectional area determines the current rating

Power Diode

- V-I characteristics
- Ideal   Actual





- Operating Mode
- Forward conduction
- Reverse blocking

Power Diode

- Forward biased Vak >0
- Voltage drop = 0.7 V for low power rating
- Voltage drop = 1.5 V for high power rating
- Current in the ON mode is limited by load resistance
- When reverse biased => small leakage current will flow
- Avalanche breakdown when applied voltage> Vbo

Power Diode

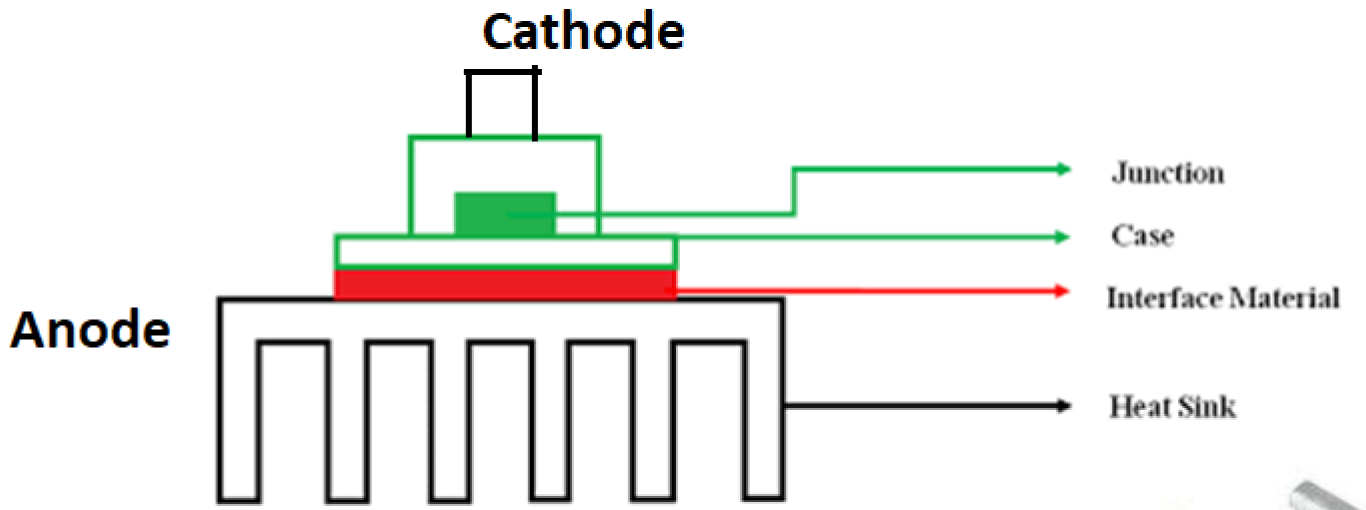
- Conduction loss = $V_f * I_d$
- Vf= forward voltage drop across the device
- Id = diode current (average)
- As loss increases, to dissipate the heat generated to atmosphere we have to use heatsink

Heat sinks


Types of Heat Sinks
Extruded
Folded Fin
Bonded Fin
Active Fan
Stampings
Cross-cut

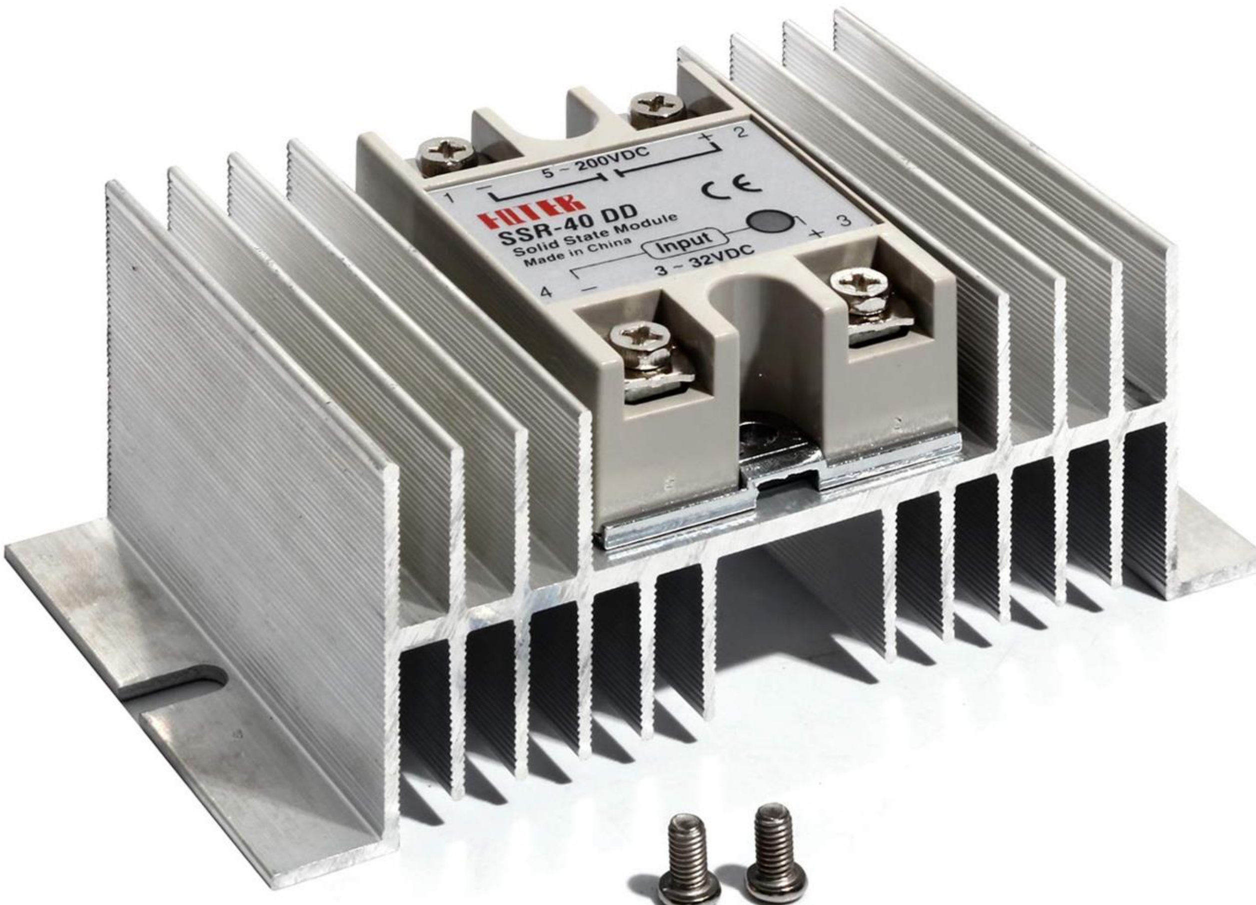
Heat sinks

- Mounting of devices on heat sink



Heat sink

- Heat sink with device mounted on it

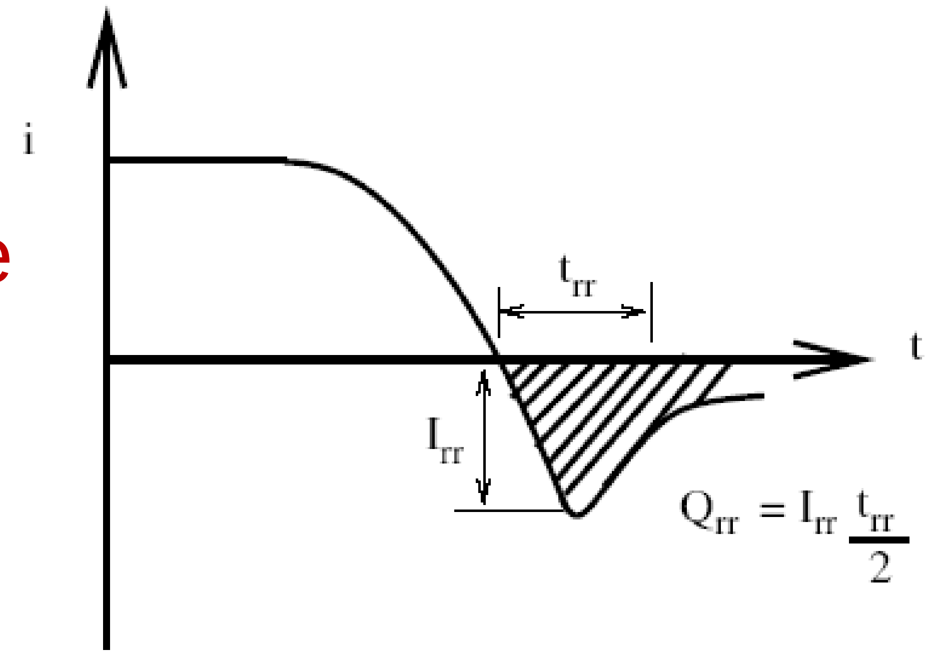


Cooling

- Natural air cooled
- Forced air cool
- Water cooling => heat sink is cooled by circulating the cold water through it.

Turn off of diode

- Diode goes to turn off state after t_{rr} when forward current becomes zero and reverse bias is applied
- Minority carriers requires certain time to recombine with opposite polarity and get neutralized



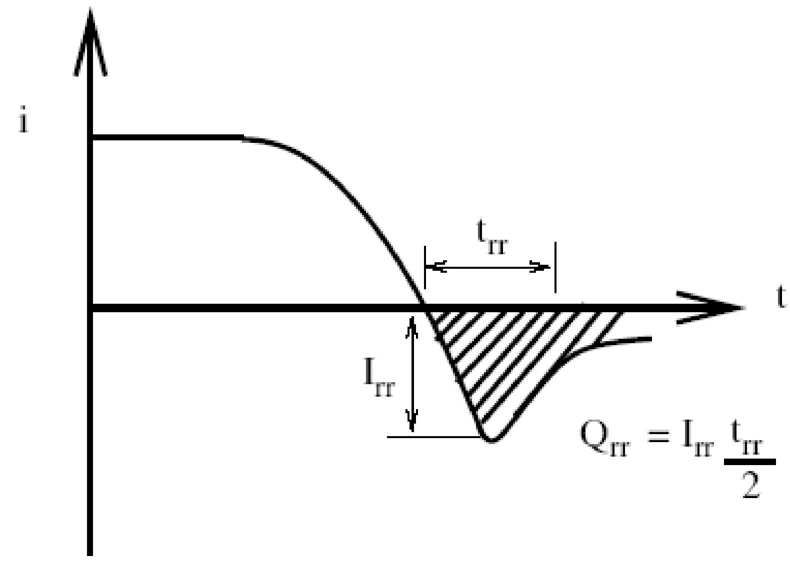
Q_{rr}=> Reverse recovery charge

Turn off of diode

- Reverse recovery time(t_{rr}) : is the time duration from 1st initial zero crossing of diode current to 25% of maximum reverse recovery current

- During t_{rr} negative I flows through the device

- t_{rr} decided maximum switching frequency of the device



Data sheet of power diode

150U/150UR

SILICON POWER DIODE

NSL NAINA

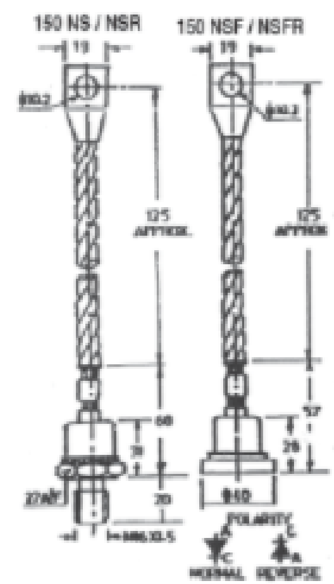
DO - 8

FEATURES

- Diffused Series
- Available in Normal & Reverse Polarity
- Industrial Grade
- Available In Avalanche Characteristic

ELECTRICAL SPECIFICATIONS

I_F	Maximum Average Forward Current Te=125^{0}C	150A
V_{FM}	Maximum peak forward voltage drop @ Rated IF(AV)	1.4V
I_{FSM}	Maximum peak one cycle (non-rep) surge current 10 m sec	3000A
I_{FRM}	Maximum peak repetitive surge current	750A
I^2t	Maximum I^2t rating (non-rep.) for 5 to 10 msec.	45,000 A2 Sec



Data sheet of power diode

THERMAL MECHANICAL SPECIFICATIONS

θ_{JC}	Maximum thermal resistance Junction to case	0.25^0C/W
Tj	Operating Junction Temp.	-65^0C to 150^0C
Tstg	Storage temperature	-65^0C to 200^0C
	Mounting torque (Non-lubricated threads)	2.0 M-kg min, 3.0 M-kg max
W	Approx, weight	150 gms.

ELECTRICAL RATINGS

TYPE	150U/150UR	10	20	40	60	80	100	120	140	160
V_{RRM}	Max. repetitive peak reverse voltage (v)	100	200	400	600	800	1000	1200	1400	1600
V_R(RMS)	Max. R.M.S. reverse voltage (V)	70	140	280	420	560	700	840	980	1120
V_R	Max. D.C. Blocking Voltage (V)	100	200	400	600	800	1000	1200	1400	1600
	Recommended R.M.S. working Voltage(v)	40	80	160	240	320	400	480	560	640
I_R(AV)	Max. Average reverse leakage current @ VRRM Tc 25^0C (uA)	200	200	200	200	200	200	200	200	200

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D-95,SECTOR 63, NOIDA(INDIA)
e-mail:sales@nainasemi.com, web site: www.nainasemi.com

Important specifications

- Average Forward current= to access suitability with power circuit
- Reverse blocking voltage
- On state voltage => to determine conduction loss
- t_{rr} => to access high frequency switching capability.
- I^2t rating => coordinate fuse with device
- Short time surge energy that diode can withstand

Types of diode

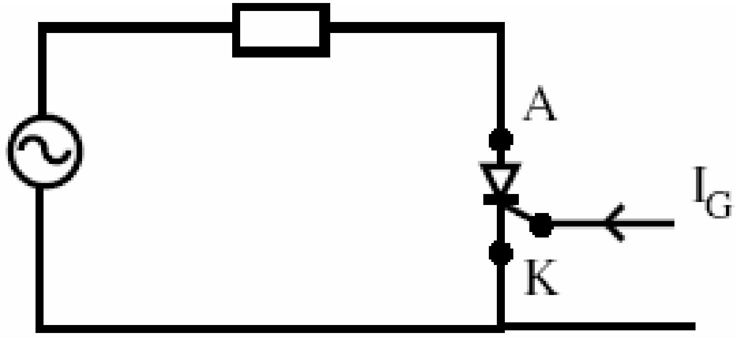
- Line frequency diode or rectifier diode
- Suitable for line frequency applications
- Recovery time is not specified or > 25 micro seconds
- 6 KV, 4.5 KA rating are available
- Fast recovery diodes
- High frequency switching applications
- 6.0KV &1.1KA are available
- t_{rr} could be less than 0.5 micro seconds

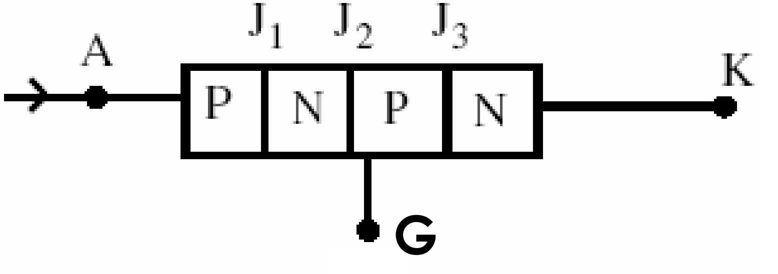
Types of diode

- Schottky diode
- They have low on state voltage drop = 0.3 V
- Rating :100 V and current = 300 A
- Low voltage high current rectifiers
- Silicon carbide diode
- Ultra low power loss
- Ultra fast switching behavior
- Highly reliable (no temperature influence on the switching behavior)

Thyristor or Silicon Controlled Rectifier (SCR)

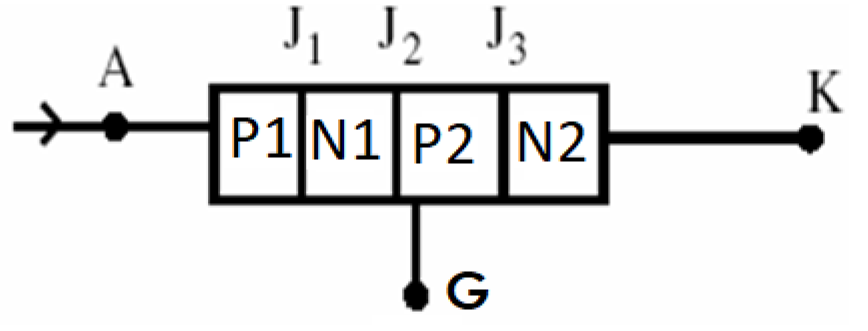
- Three terminal device
- Anode (A), Cathode (C)
- & Gate (G)
- A&K are power terminal
- Control signal is applied to gate wrt Cathode





Thyristor

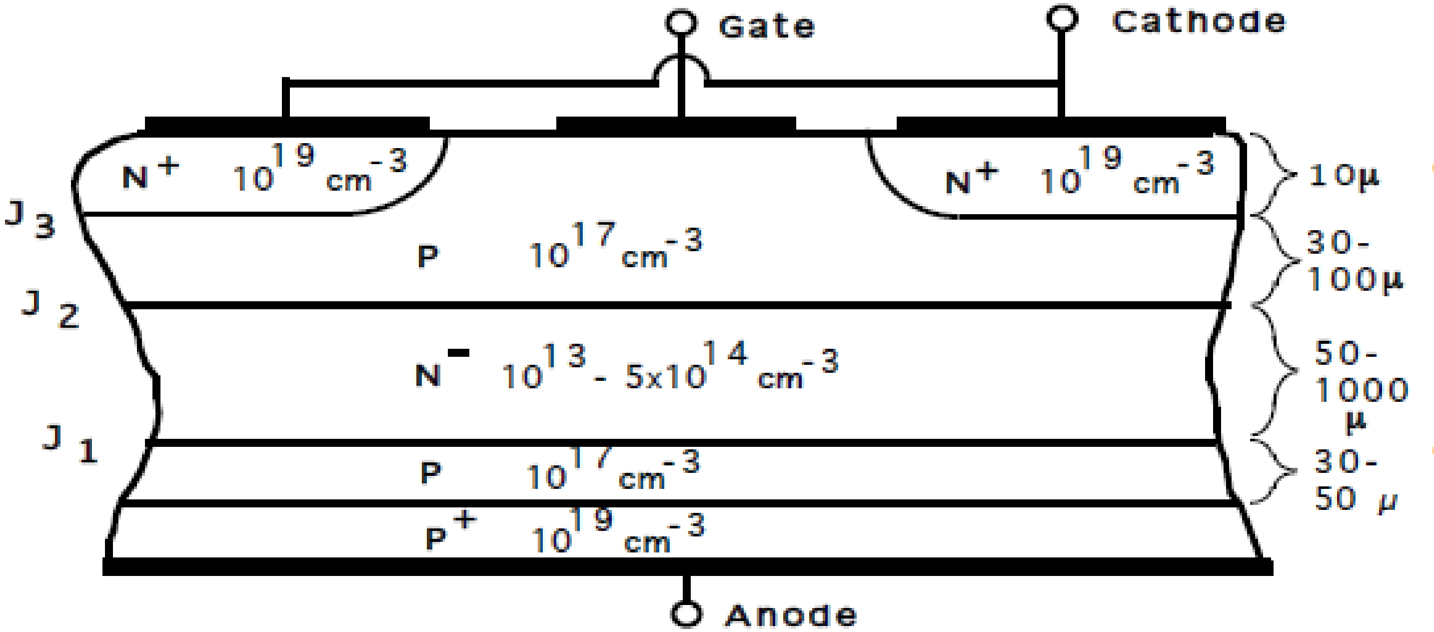
- Constructional details



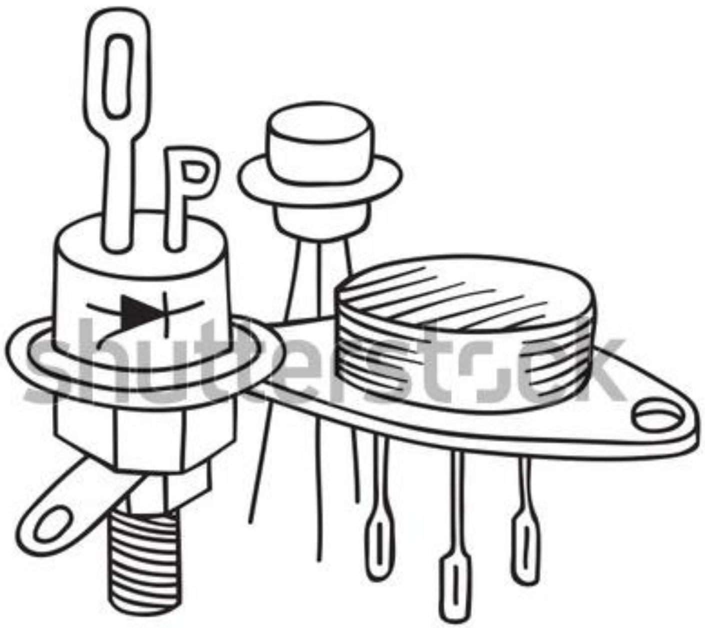
- N2 => Layer is very thin & highly doped.
- P2 => layer is thicker & less highly doped
- N1 => blocking layer is thickest & less doped
- P1 => has having highly doped & less doped
- Junction J3 has low breakdown voltage in either direction
- J3 can not support reverse voltage

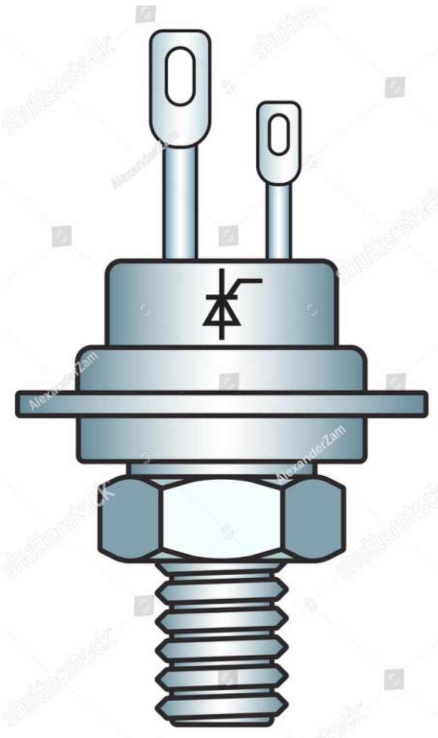
Thyristor

- Constructional details



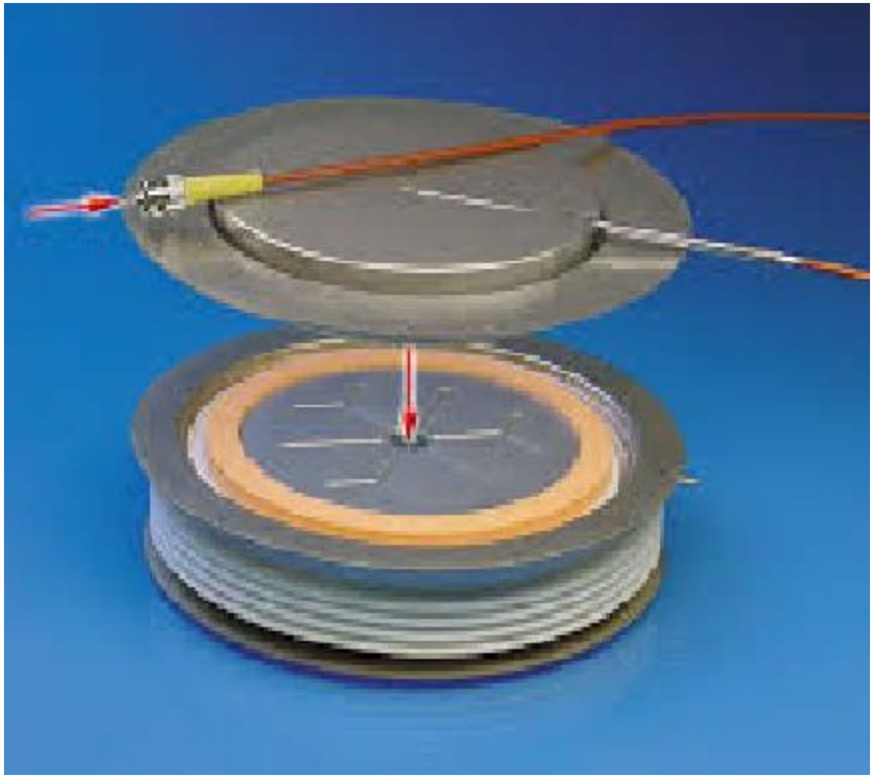
Various Case configurations



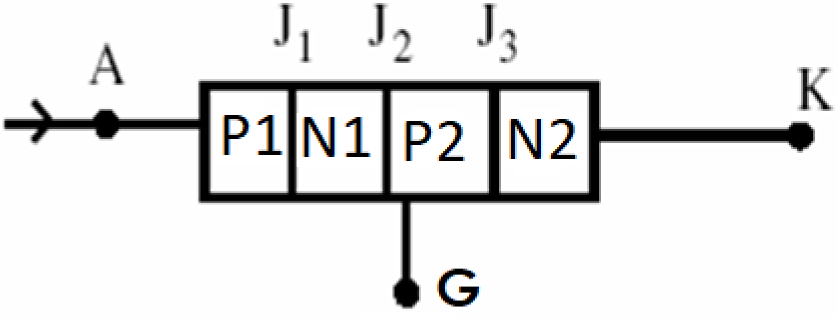


Various Case configurations

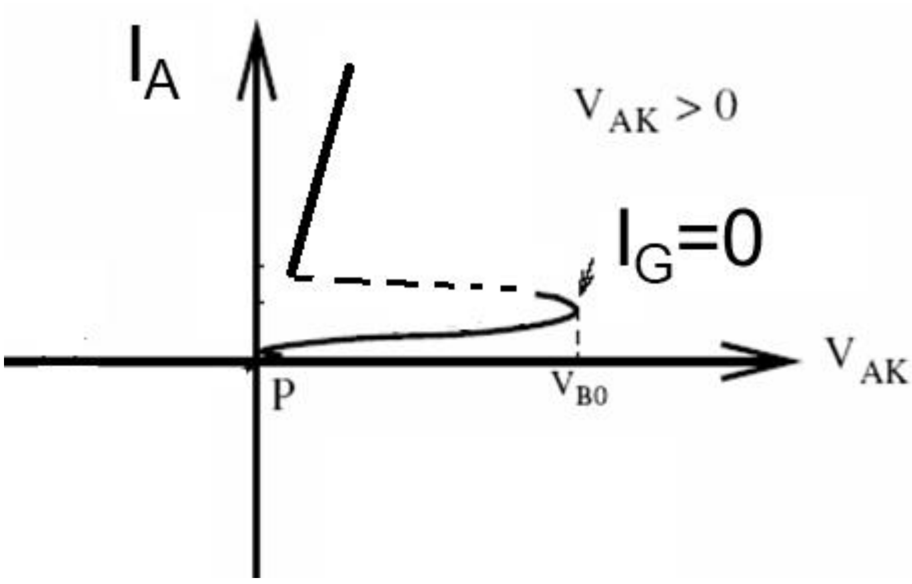
LASCR



Thyristor

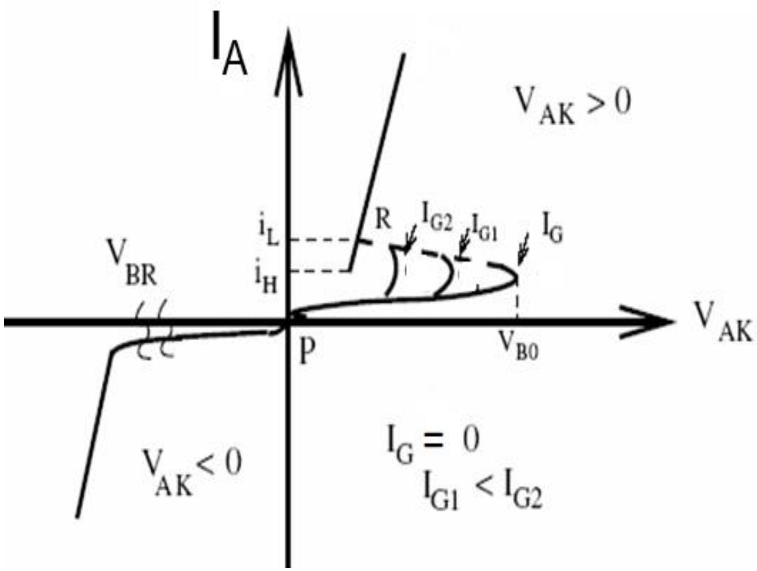


- Forward blocking mode
- VAK > 0, Ig=0 device is off
- Forward voltage is blocked by J2
- Junctions J1 and J3 are forward biased
- As V_{AK} goes on increasing , leakage Current goes on Increasing.
- At V_{BO} junction J2 break downs and device turns on



Thyristor

- Forward conduction => Gate triggering
- As value of gate current increases blocking voltage decrease and device goes into conduction
- Once device turns on gate will loose the control

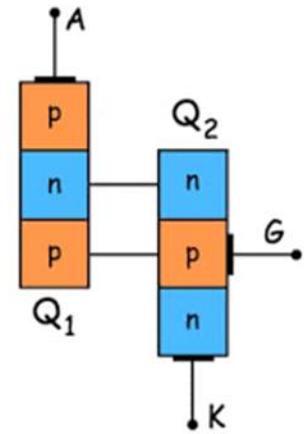


- Thyristor is latching device
- Thyristors can have blocking voltage 5KV - 8KV

Thyristor

- Forward conduction
- Current to several kiloamps for V(on) of 2- 4 volts.
- Blocking voltages to 5-8 kilovolts.
- VBO = breakover voltage ;
- I_H = holding current
- I_L = Latching current
- Maximum junction temperature = 125 °C
- Forward blocking voltage depends upon capacity of junction J2

Two transistor Analogy



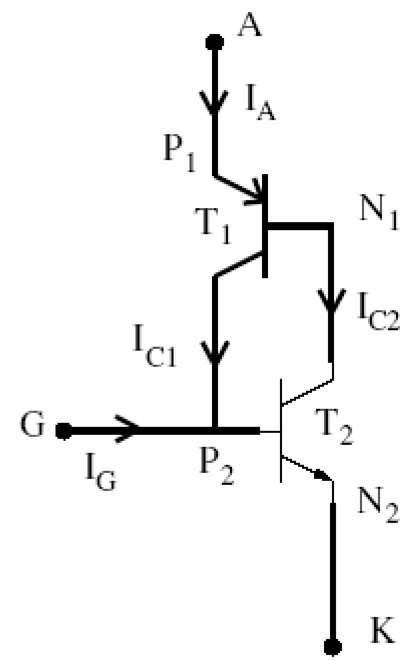
For any transistor

$I_C = \alpha I_E + I_{CBO}$

$\alpha \rightarrow$ common base current gai

$\alpha = \frac{I_C}{I_E}$,

$I_{CB0} \rightarrow$ leakage current of the C-B junction.



$\therefore$ for T_1, $I_E = I_A$ $\quad I_{C1} = \alpha_1 I_A + I_{CBO1}$

for T_2, $I_E = I_K$ $\quad \therefore I_{C2} = \alpha_2 I_K + I_{CBO2}$

Two transistor Analogy

Now, $I_E = I_C + I_B$

$I_{E1} = I_A$ and $I_{B1} = I_{C2}$

$\therefore\ I_{C1} + I_{C2} = I_A = \alpha_1 I_A + I_{CBO1} + \alpha_2 I_K + I_{CBO2}$

$I_K = I_{B2} + I_{C2}$

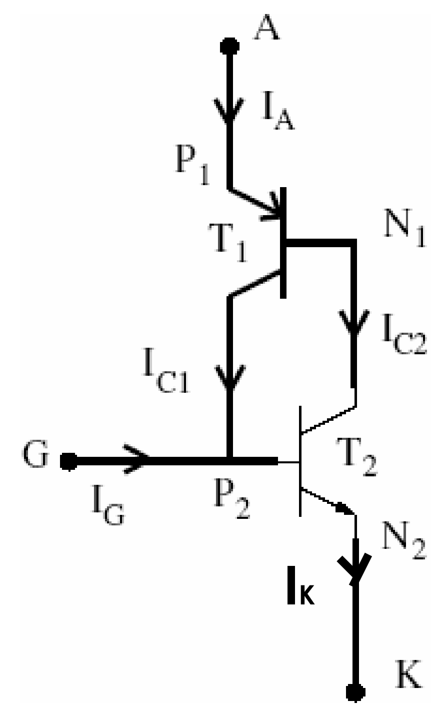
for finite I_G,

$I_K = I_{C1} + I_G + I_{C2}$

$= I_A + I_G$

$$\therefore\ I_A = \frac{\alpha_2 I_G + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)}$$

$\alpha \uparrow$ with I_E



Two transistor Analogy

α increases with I_E

$\therefore\ \alpha_1$ also increases with $I_A \ \because\ I_{E1} = I_A$

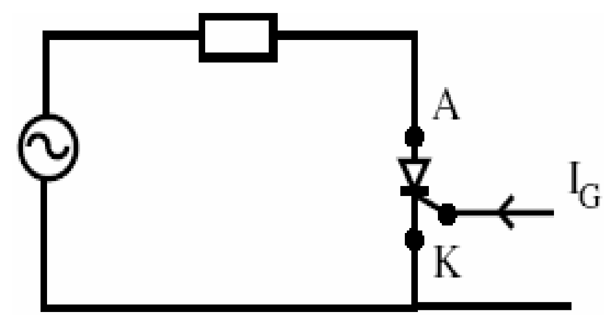
Similarly α_2 varies with $I_K \ \because\ I_{E2}=I_K=I_A + I_G$

If I_G is suddenly $\uparrow$, $I_A \uparrow \ \because\ I_A = \dfrac{\alpha_2 I_G + I_{CBO1} + I_{CBO2}}{1 - (\alpha_1 + \alpha_2)}$

As $I_A \uparrow$, $\alpha_1 \uparrow$ and $\therefore\ \alpha_2 \uparrow$.

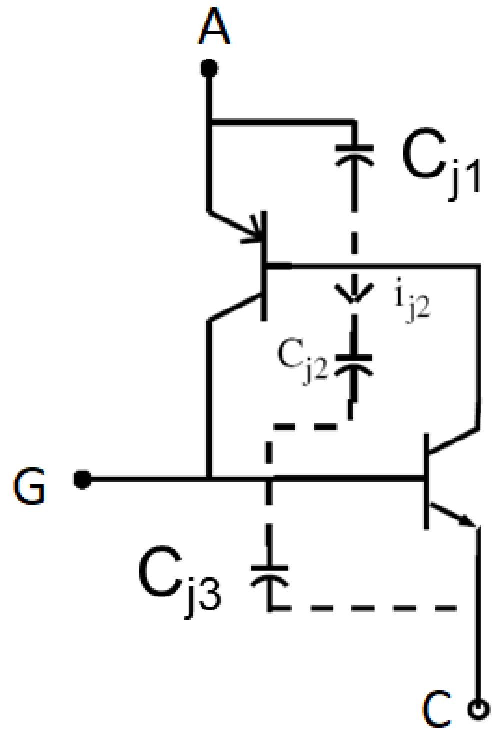
$\Rightarrow\ \uparrow$ in α_1 and α_2 further increases I_A

$\Rightarrow$ +ve feedback.



Un-scheduled turn on

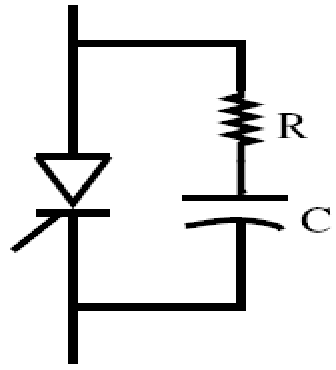
- Junction capacitance C_{j1} C_{j2} & C_{j3}
- forward blocking J_1 and J_3 F B
- Junction J_2 blocks forward voltage
- If rate of change of voltage is very fast

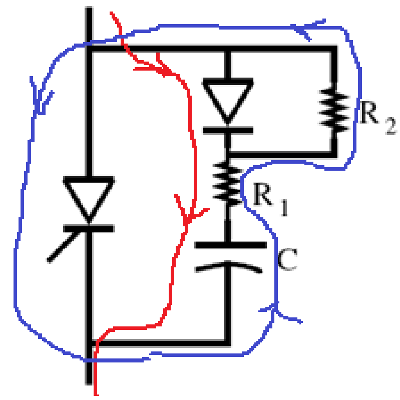


- Because of that charging current
- Of C_{j2} (I_{j2}) acts as a virtual gate
- current and device turns on without gate pulse

dv/dt protection

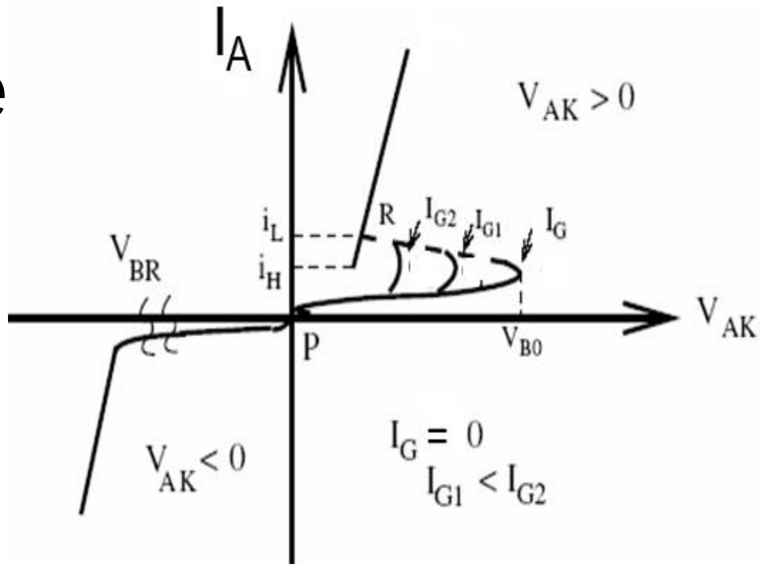
- At higher value of dv/dt , thyristor turns on without gate pulse current
- Protection from dv/dt
- Snubber circuit (RC) is used
- R is selected such that discharge current is controlled during turn on
- RCD snubber , charging & discharging
- Currents are controlled separately





Turn on Methods

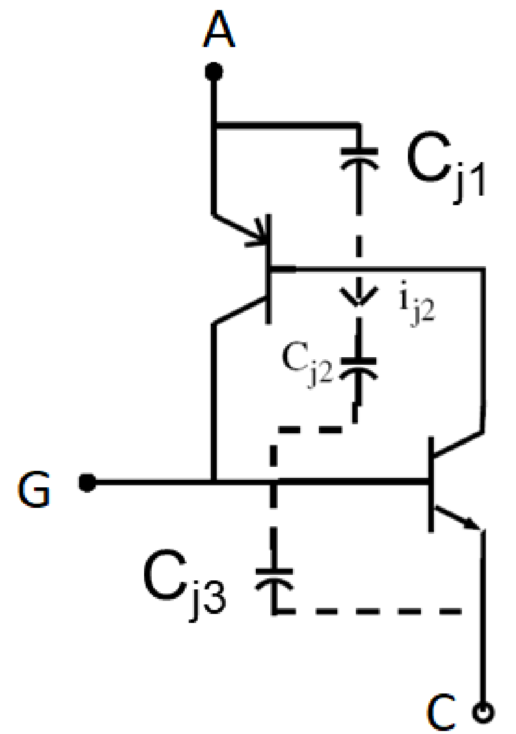
- For turn on device should be forward biased
- 1) V applied > V_{BO}
- 2) Applying +ve I_G, I_G should be maintained till $I_A > I_{latching\ current}$
- Once device turns on gate will loose its control
- Device turns off when $I_A < I_{holding}$ and reverse bias is applied

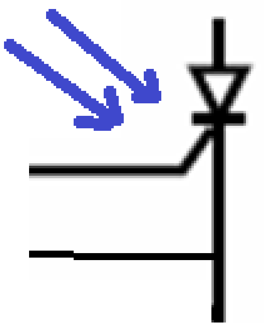


Turn on Methods

- 3) dV/dt turn on

  normally it is not used.
- 4) Use of light radiations
- LASCR
- LASCR used in high voltage applications



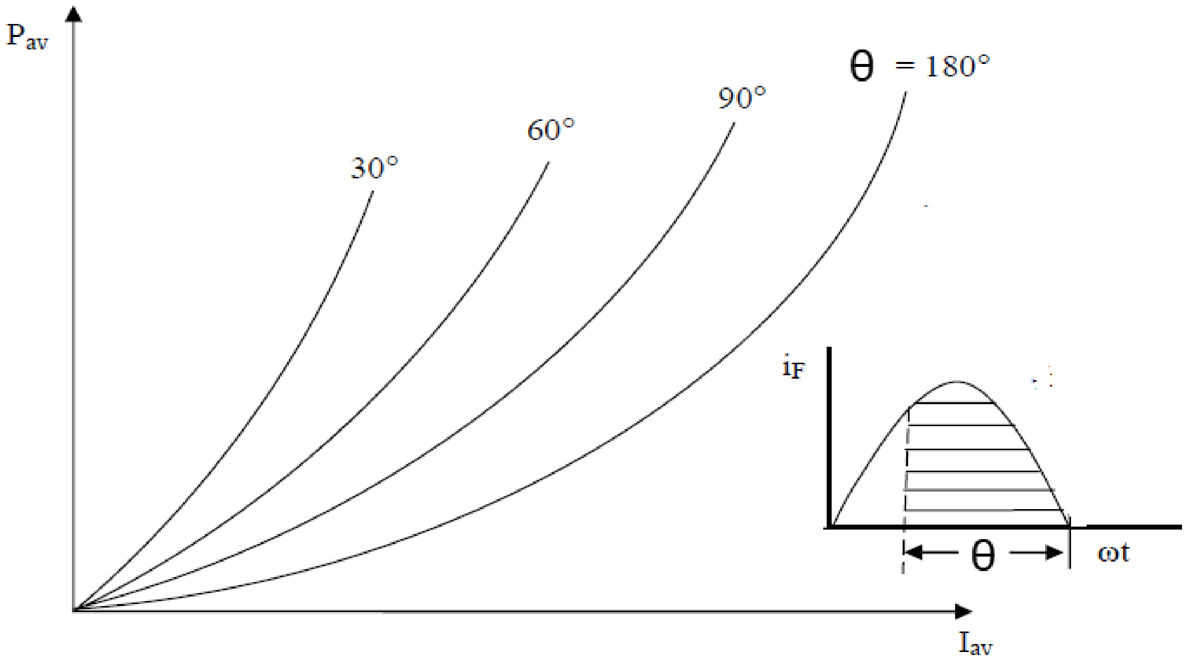


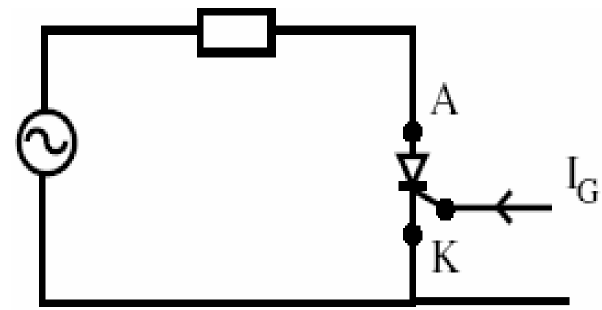
Current Ratings

- Thyristor has following current Rating
- Average current
- RMS current
- Surge current rating
- di/dt current
- I^2t current
- Whereas machines has only RMS current rating
- Thermal time constant comparison of machines and semiconductor devices

Average current rating

- Conduction loss is determined from I_{AV}

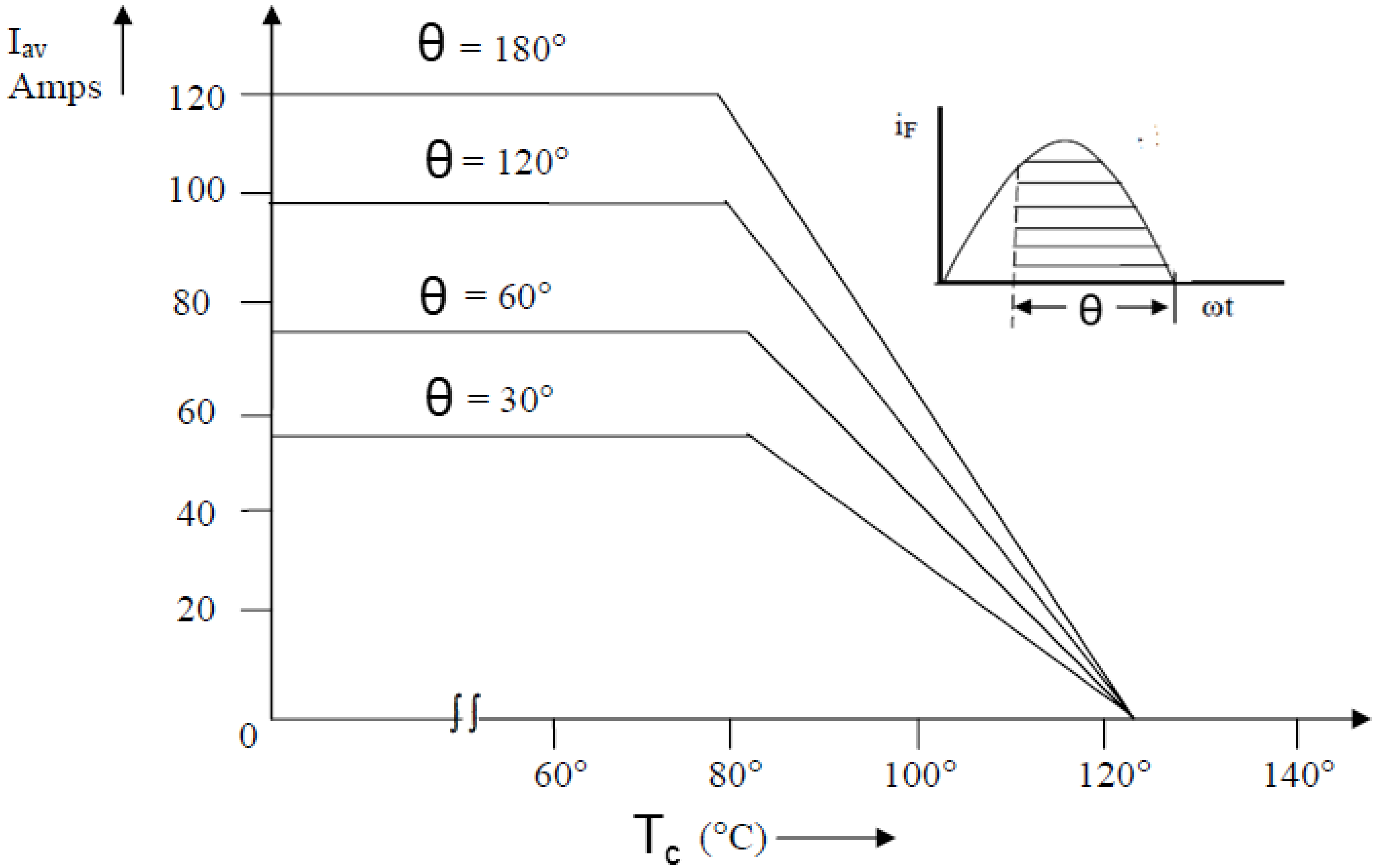




- Power loss Vs conduction angle

Average current rating

- Average forward current derating characteristics



Average current rating

- Power loss depend upon I_{AV} and conduction angle.
- Suitability of the device depends on T_j
- Power loss is used to calculate T_j

- To access the suitability with power circuit average current rating is used
- Device suitability is finally decided by junction temp.

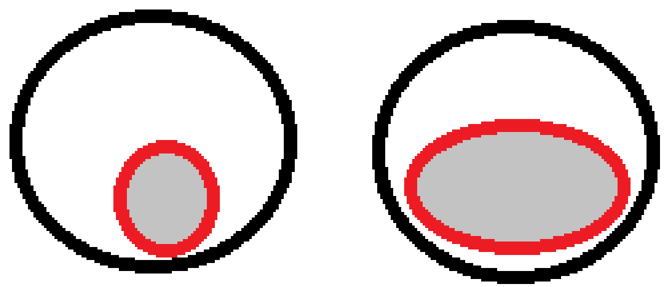
Thyristor Current Rating

- I_{rms} => Heating of surface metal joints, Leads and interfaces depends upon RMS current

- Surge current rating=> Maximum allowable non repetitive current device can withstand
- Following the surge, device can be disconnected and allowed to cool down
- I_{sm} = 3000A for ½ cycle
- I_{sm} = 2100A for 3 cycle
- I_{sm} = 1800A for 5 cycle

Thyristor Current Rating

- di/dt rating
- di/dt during turn on is high =>
- rate of spreading of conduction in the device < di/dt of current during turn on =>
- then result into high current density into device
- Hot spot temp will be high
- Failure of the device

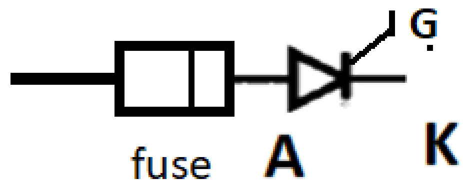


Thyristor Current Rating

- I^2t rating => it is defined as amount energy device can absorb.
- I^2t rating is used for coordination of fuse with device.
- Device can be protected from short circuit with the help of semiconductor fuses.
- I^2t of device > I^2t of semi-conductor fuse

Semiconductor fuses

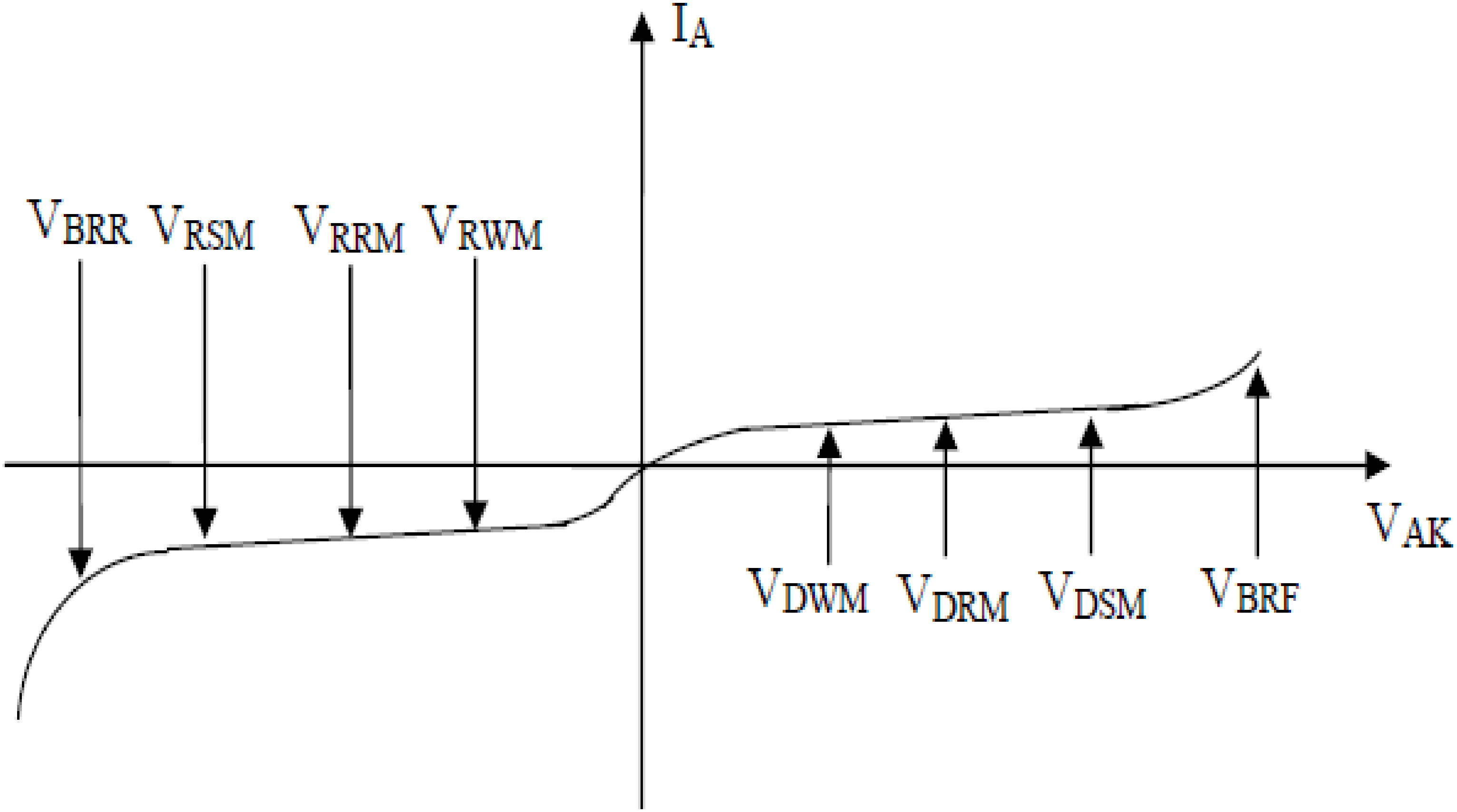
- Photograph



Voltage Rating

- Peak Working Forward OFF state voltage (V_{DWM}):
- Maximum forward voltage device can withstand during working
- Peak repetitive off state forward voltage (V_{DRM}):
- Peak forward transient voltage device can block during off state
- Peak non-repetitive off state forward voltage (V_{DSM})
- Allowable peak forward transient voltage that does not repeat

Voltage Rating

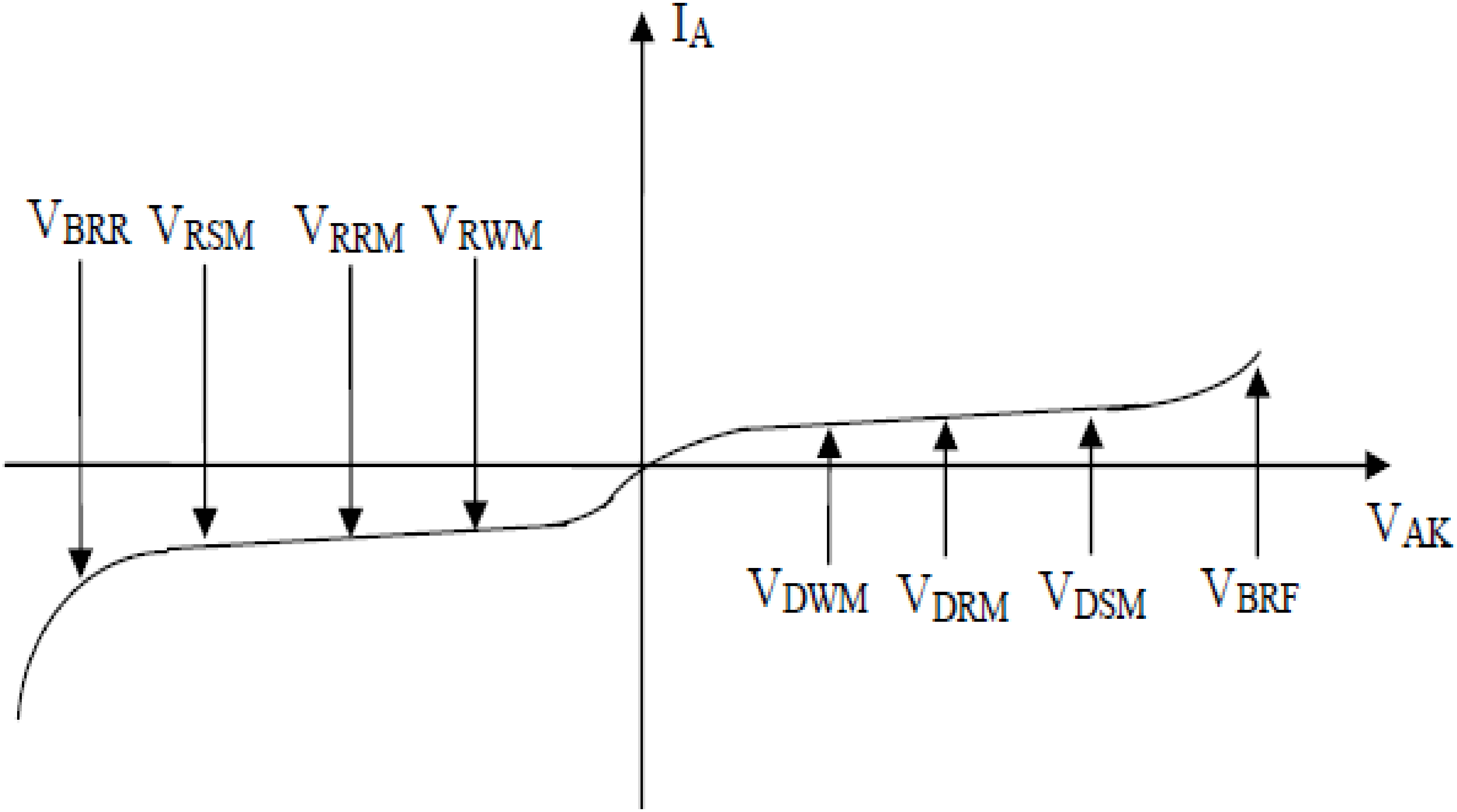


Voltage Rating

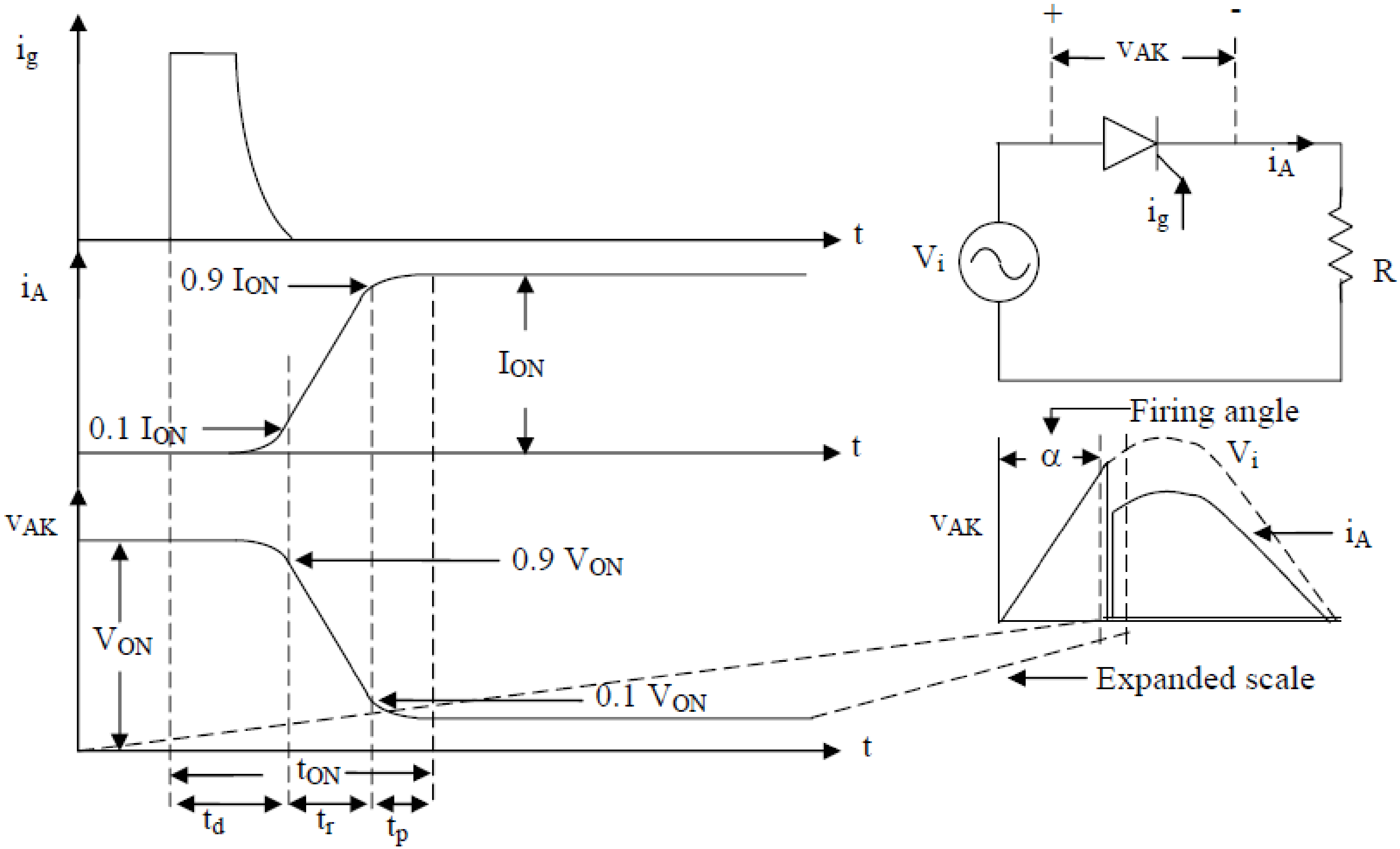
- Peak working reverse voltage (V_{DWM}):
- Maximum reverse voltage device can withstand during working
- Peak repetitive reverse voltage (V_{RRM}):
- Peak reverse transient voltage device can block during reverse bias condition

- Peak non-repetitive reverse voltage (V_{RSM}):
- Allowable peak reverse transient voltage that does not repeat

Voltage Rating



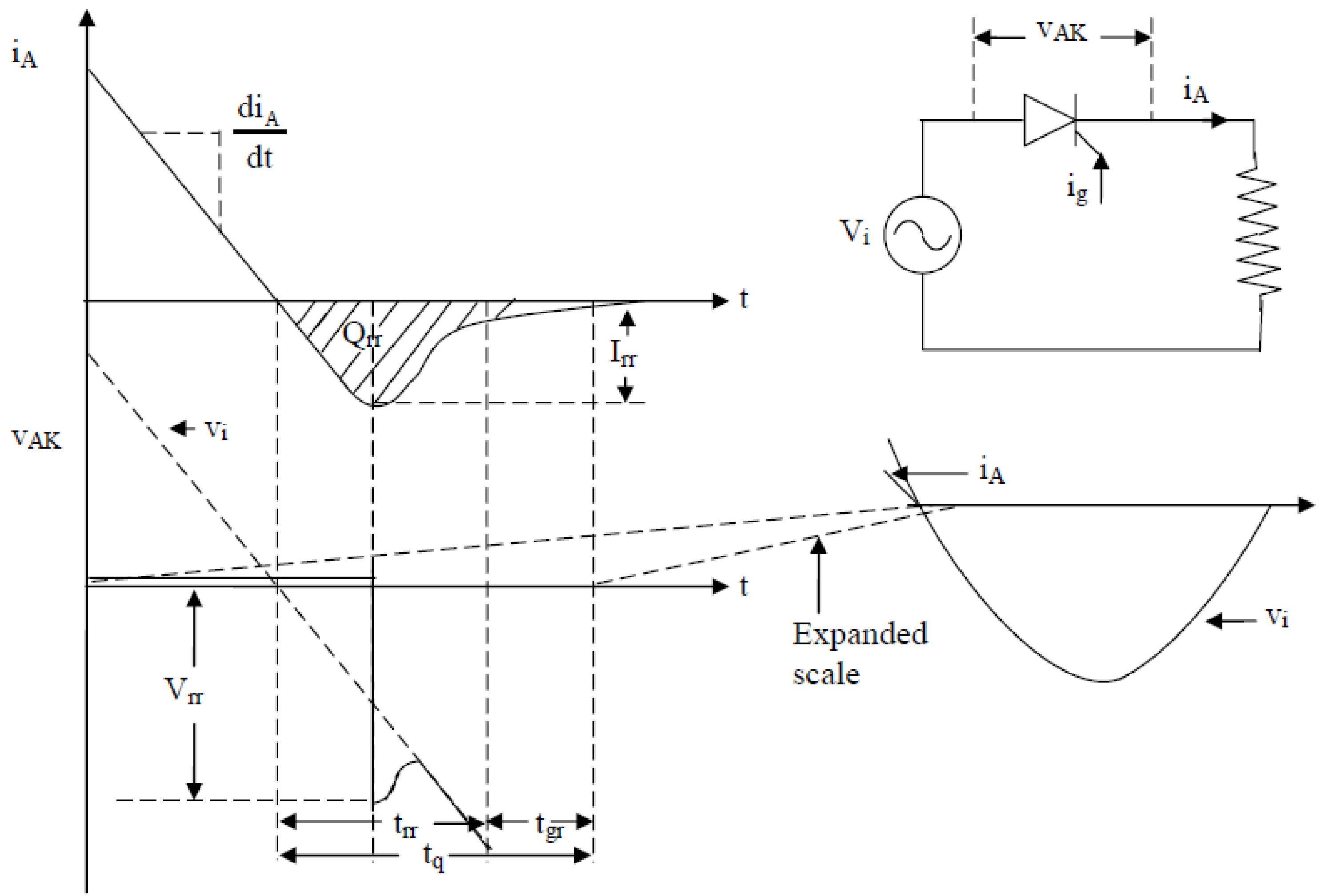
Turn on characteristics



Turn on characteristics

- Turn on time consists of delay time, rise time and spread time
- Delay time (t_d)=> application of gate pulse to I_A rises 10% of its steady state value (few µsec)
- Rise time (t_r) => time required for I_A to rise from 10% to 90% of its steady state value
- Spread time (t_p) => time required for I_A to 90% to 100%

Turn off characteristics



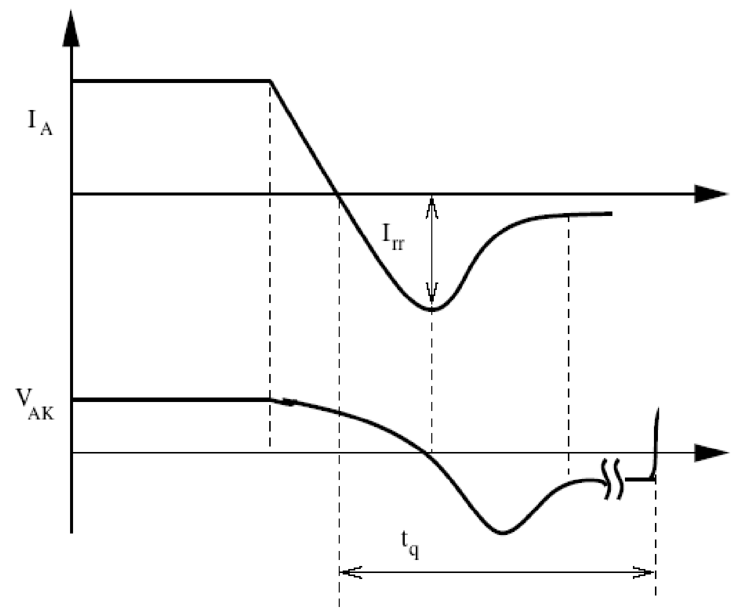
Turn off characteristics

- Turn off time consists of reverse recovery time (t_{rr}) and gate recovery time (t_{gr})
- The negative current removes excess carriers from junctions J_1 & J_3
- Charge carriers at J_2 will be removed by the process of recombination and for that reverse voltage has to be maintained
- Once the charge carriers are removed the gate will regain its control

$$t_q = t_{rr} + t_{gr}$$

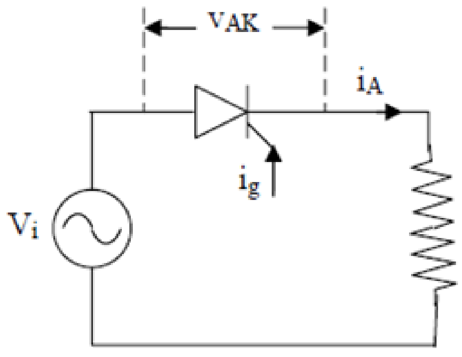
Turn off characteristics

- t_q => 50-100µsec=> Converter grade thyristor
- t_q => 5-50µsec=> Inverter grade thyristor
- Turn off time determines the switching frequency
- Inverter grade thyristors are costlier compared to converter grade thyristor



Turn off characteristics

- thyristor Turn -off in AC circuit



- thyristor Turn -off in DC circuit