Applied Industrial Electronics (COM 402)

Semester: Spring 2015 – 2016

Course Teacher: Prof. Dr. Fahmy El-Khouly

Scientific degrees:

B-sc 1982 , **M-sc** 1988 ,

Doctor 1995 (Academic channel system with university of New-Brunswick, CANDA),

Assistant Professor , 2001

Professor 2006 (in Power Electronics)

Prizes:

In 2005 he awarded the Encouraged Minoufiya University prize in engineering science

- **<u>Text Books and Reference Books</u>**

[1] Muhammad H. Rashid, **Power Electronics Circuits, Devices and Applications**, Second Edition or Third Edition, Prentice-Hall of India Private Limited

[2] B. K. Bose, “Modern Power Electronics and A.C. Drives”, Pearson Education, 2002.

- ***Weighting of assessments:***

-Quizzes	**20 (Degrees)**	**20 %**
Activities	**20 (degrees)**	**20 %**
-Mid-Term Exam	**20 (Degrees)**	**20 %**
- Final-Term Exam	**40 (Degrees)**	**40 %**
Total	**100 (Degrees)**	**100 %**

Intended Learning Outcomes (ILOs):

A. Knowledge and understanding:

On completing this course, students will be able to:

a1-Explain the importance of power electronic devices in electrical systems
a2-List the performance parameters of Rectifiers
a3-Describe the characteristics of power diode, transistor, thyristor and triacs
a4-Describe the operation of AC voltage control and inverters
a5-Identify the operation of DC chopper.

B-Intellectual Skills: مهارات ذهنية

b1-Select a suitable power electronics switch for certain operation
b2-Analyze the performance of rectifier circuit with different loads.
b3-Calculate the SCR current and voltage
b4-Analyze and test the performance of AC voltage control, DC choppers and inverters

C-Professional and Practical Skills مهارات مهنية وعملية

- c1- Design firing and commutation circuits to meet certain specifications
- c2- Design half and full-wave rectifiers, DC choppers, Inverters and motor speed controllers for specific needs.
- c3- Read datasheets of power diodes, transistors and thyristors

D- General and Transferable Skills مهارات عامة

- d1- Use IT effectively.
- d2- Work in a team or individually
- d3- Communicate effectively using written, oral, graphical, and presentational skills

COURSE OUTLINE

- Chapter1 : **Power Electronic Devices**
- Chapter 2 : **Rectifiers**
- Chapter 3 : **Dc to Dc converters**
- Chapter 4: **Inverter**

date	Title
15-2-2016	
22-2-2016	
29-2-2016	
7-3-2016	
14-3-2016	
21-3-2016	
28-3-2016	
4-4-2016	أسبوع امتحانات منتصف الفصل
11-4-2016	
18-4-2016	
25-4-2016	عطلة تحرير سيناء
2-5-2016	عطلة شم النسيم
9-5-2016	
16-5-2016	أسبوع امتحانات نهاية الفصل

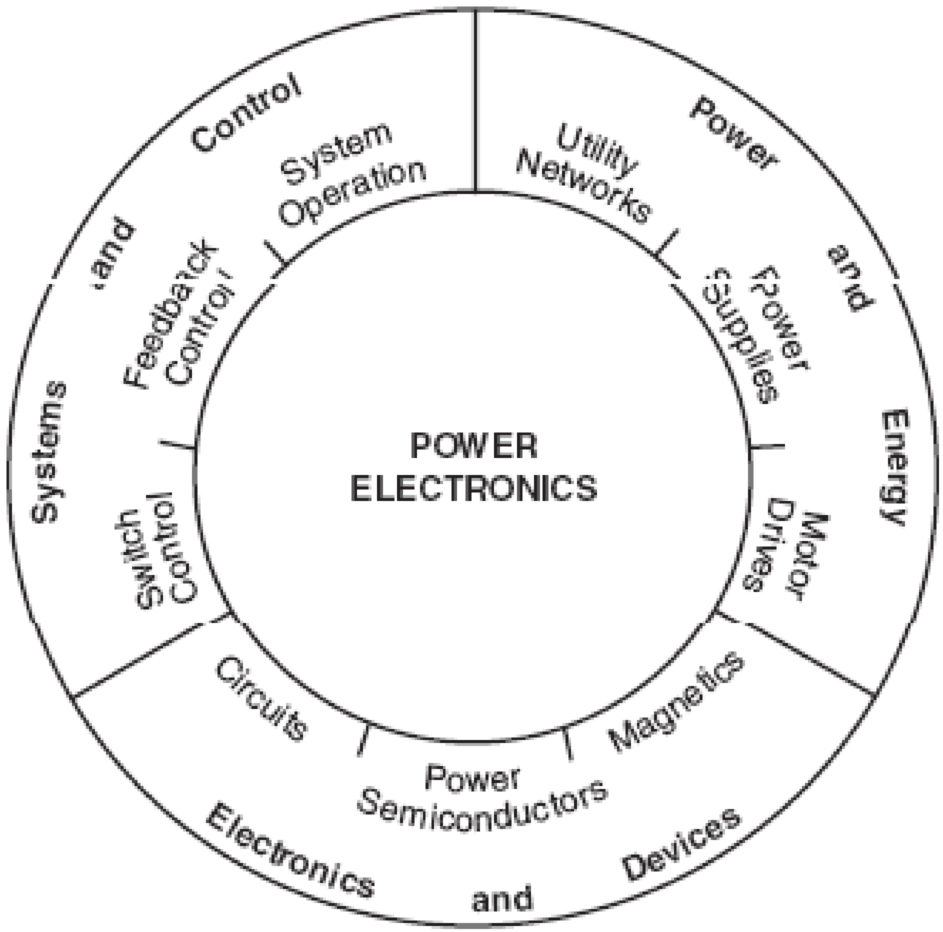
Industrial Electronics

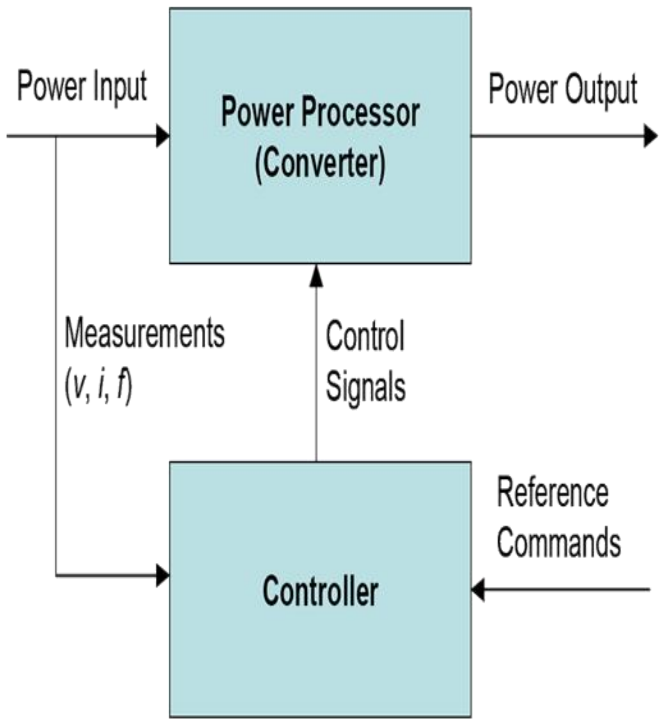
- Industrial electronics is a branch of electronics that deals with classical (analog or digital) electronic, power electronic, meters, sensors, analyzers, automatic test equipment, multimeters, data recorders, relays, resistors, waveguides, scopes, amplifiers, radio frequency (RF) circuit boards, timers, counters, etc.
- It covers all of the methods and facts of: control systems, instrumentation, mechanism and diagnosis, signal processing and automation of various industrial applications.
- The scope of industrial electronics ranges from the design and maintenance of simple electrical fuses to complicated programmable logic controllers (PLCs), solid-state devices and motor drives.
- Some of the specialty equipment used in industrial electronics includes: variable frequency converter and inverter drives, human machine interfaces, and computer or microprocessor controlled robotics.
- Industrial electronics are also used extensively in: chemical processing plants, oil/gas/petroleum plants, mining and metal processing units, electronics and semiconductor manufacturing.
- **The core area of industrial electronics is power electronics.**

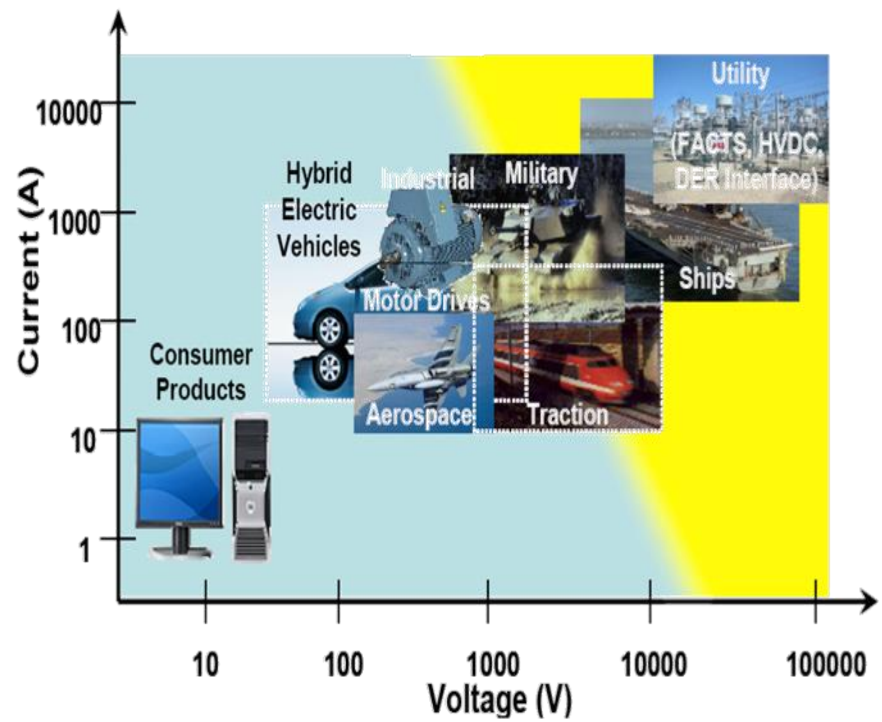
Power Electronics

- **Definition of Power Electronics:** **Power Electronics is used to change the characteristics (voltage and current magnitude and/or frequency) of electrical power to suit a particular application.**

- **Power Electronics combine: power, electronics and control.**
- **Power deals with the static and rotating power equipments for the generation, transmission and distribution of electrical energy.**
- **Electronics deals with the solid-state devices and circuits for signal processing to meet the desired control objectives.**
- **Control deals with the steady-state and dynamic characteristics of closed-loop systems for energy conversion to meet the desired of electrical load.**


POWER
ELECTRONICS
Control
Systems
and
Power
and
Energy
Electronics
and
Devices
System
Operation
Utility
Networks
Feedback
Control
Power
Supplies
Switch
Control
Motor
Drives
Circuits
Power
Semiconductors
Magnetics


Power Input
Power Processor
(Converter)
Power Output
Measurements
(v, i, f)
Control
Signals
Reference
Commands
Controller


Current (A)
10000
1000
100
10
1
10
100
1000
10000
100000
Voltage (V)
Utility
(FACTS, HVDC,
DER Interface)
Hybrid
Electric
Vehicles
Industrial
Military
Ships
Motor Drives
Consumer
Products
Aerospace
Traction

Classification of Power Semiconductor Switching Devices:

Power semiconductor devices are classified as follows:

1. **Power diodes**
2. **Power Transistors**
3. **Thyristors**

Classification of Power Diodes:

Power diodes are classified as follows:

1. **Standard or General-Purpose diodes**
2. **Fast-recovery or High-speed diodes**
3. **Schottky diodes**

Standard or General-Purpose Diodes

Switching Time: 50 to 100 μs
Operating Frequency: Up to 1 kHz
Current Rating: Less than 1 A to several thousands of amperes
Voltage Rating: 50 V to around 6 kV

Fast-Recovery or High Speed Diodes

Switching Time: Less than 5 to 10 μs
Operating Frequency: Up to 30 kHz
Current Rating: Less than 1 A to hundreds of amperes
Voltage Rating: 50 V to around 6 kV

Schottky Diodes

Switching Time: 0.2 μs
Operating Frequency: Up to 30 kHz
Current Rating: Less than 1 A to 400 A
Voltage Rating: up 150 V

Some Diode Packages

Axial Pack

Plastic Pack

Plastic Pack

Stud Type

Stud Type

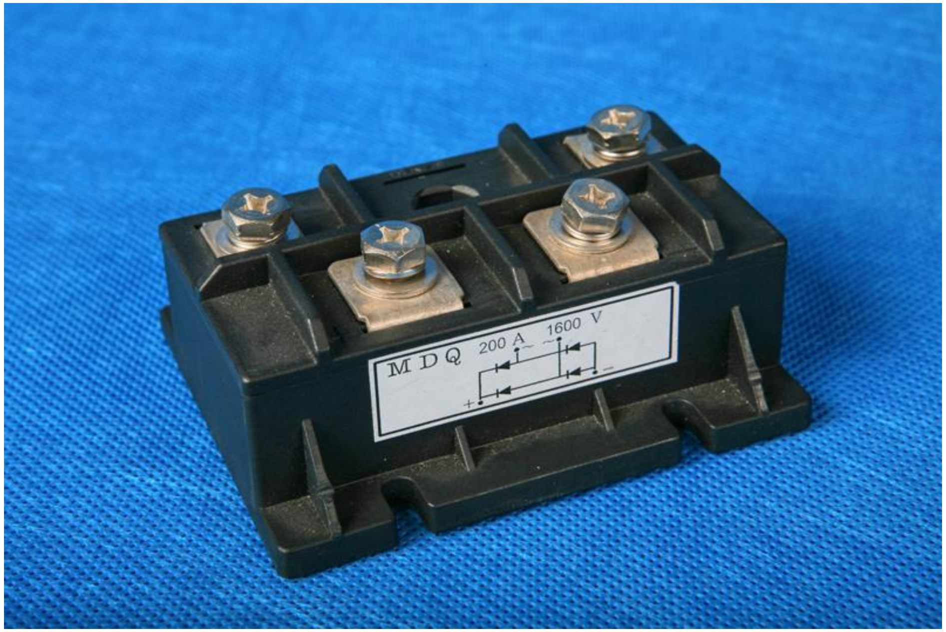
Disc Type

Some Diode Packages

Stud type diodes (Source: www.china-rectifier.com)

Disc type diodes (Source: www.china-rectifier.com)

Some Diode Rectifier Modules



Single-phase Diode Bridge Module

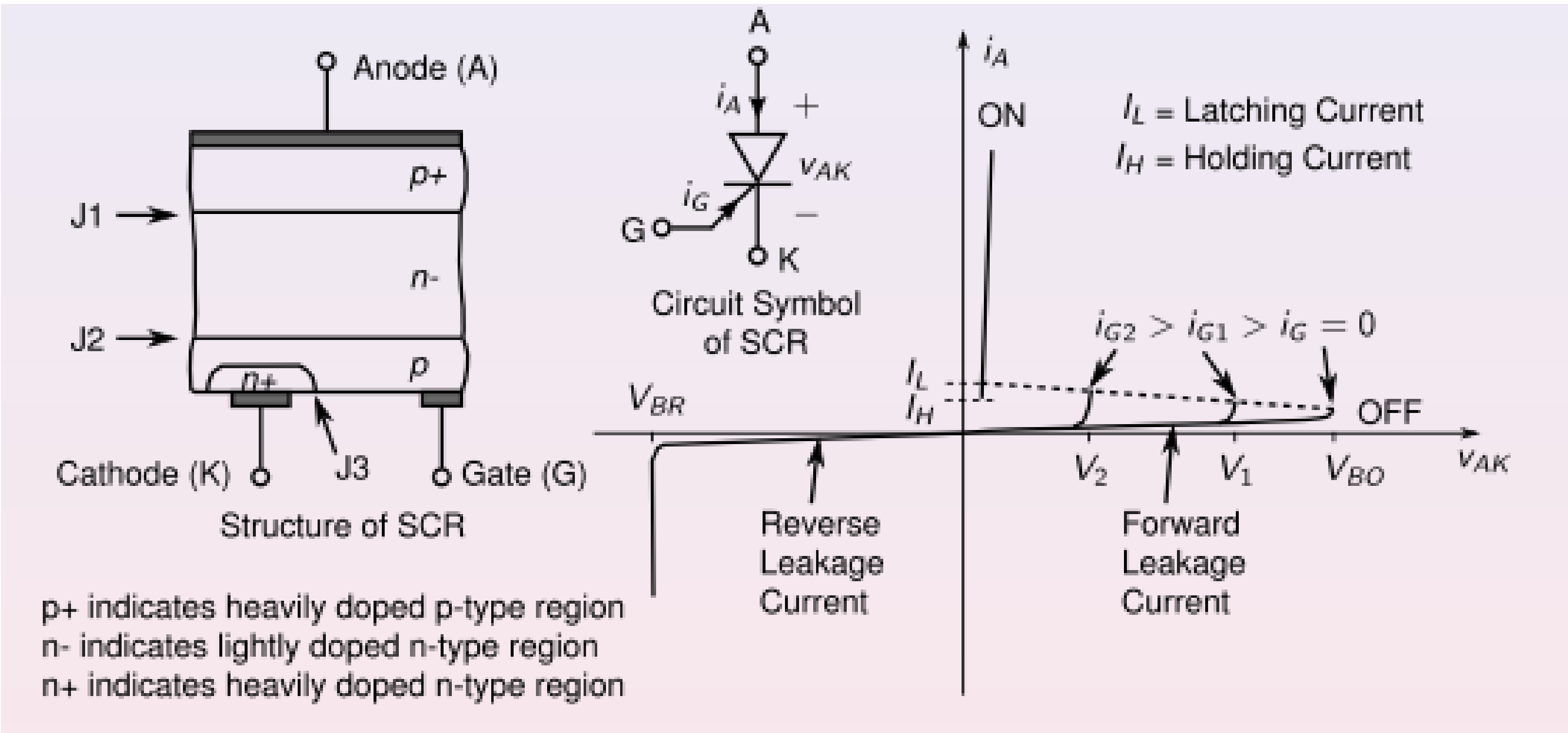
(Source: www.china-rectifier.com)

Some Diode Rectifier Modules

Three-phase Diode Bridge Module

(Source: www.china-rectifier.com)

Silicon Controlled Rectifier (SCR) ***(Thyristors):***



-The forward voltage at which the device turns on decreases with increase in gate current.

Latching Current: This is the minimum required current to turn on the SCR device and convert it from the *Forward Blocking State* to the *ON State*.

- ***Holding Current***: This is the minimum forward current flowing through the thyristor in the absence of the gate triggering pulse.

- ***Forward Breakover** Voltage*: This is the forward voltage required to be applied across the thyristor to turn it *ON* without the gate signal application.

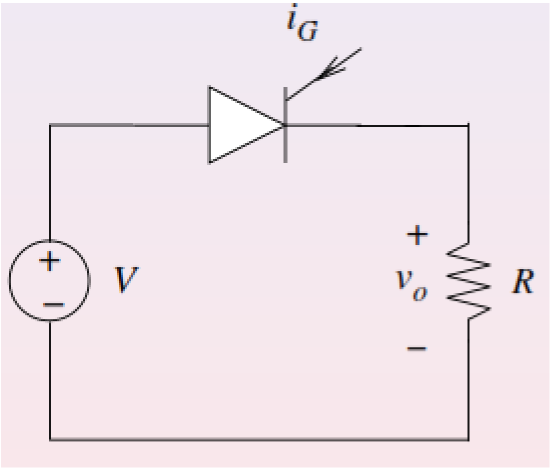
- ***Max Reverse Voltage***: This is the maximum reverse voltage to be applied across the thyristor before the reverse avalanche occurs.

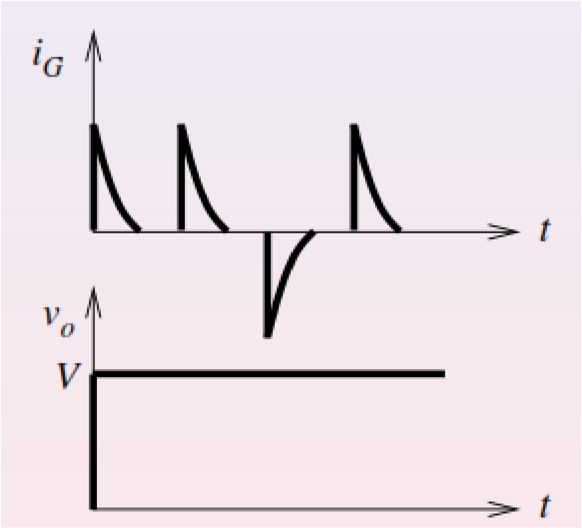
Classification of Thyristors:

Thyristors are classified as follows:

1. Phase-controlled thyristors [or Silicon-controlled rectifiers (SCRs)]
2. Fast switching thyristors (or SCRs)
3. Gate-turn off thyristors (GTOs)
4. Bidirectional triode thyristors (TRIACs)
5. Reverse-conduction thyristors (RCTs)
6. Static induction thyristors (SITHs)
7. Light-activated silicon-controlled rectifiers (LASCRs)
8. FET-controlled thyristors (FET-CTHs)
9. MOS-controlled Thyristors (MCTs)
10. MOS turn-off thyristors (MTOs)

Control Characteristics of SCR





SCR is semicontrolled and pulse triggered.

Factors Causing Turn ON of SCR

- Forward voltage $V_{AK} > V_{BO}$. This should be avoided since it may permanently damage the device.

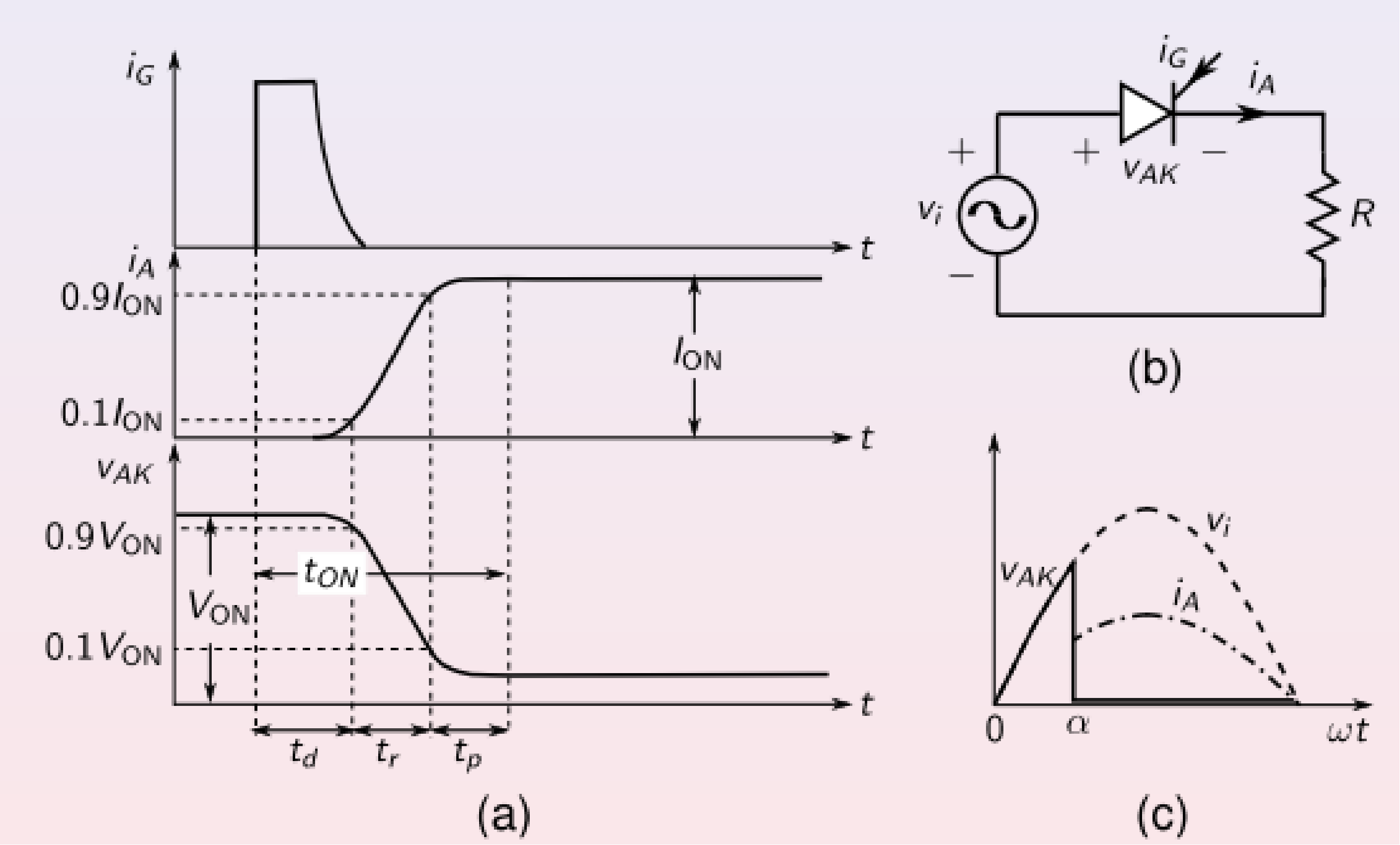
- Rise in device temperature can cause unwanted turn ON and hence should be avoided by cooling the device.

- By injecting positive gate current I_G until $I_A = I_L$ where I_L is the latching value. This is the preferred method of turning ON the device.

- Forward dv_{AK}/dt > rated value causes undesirable turn ON and should prevented by connecting a snubber circuit across the SCR.

- Light radiation of specific wavelength incident on junctions of SCR turns ON the device. LASCR’s are turned ON by this method.

SCR Turn ON Characteristics



t_{ON} increases with increase in the inductance of the load.

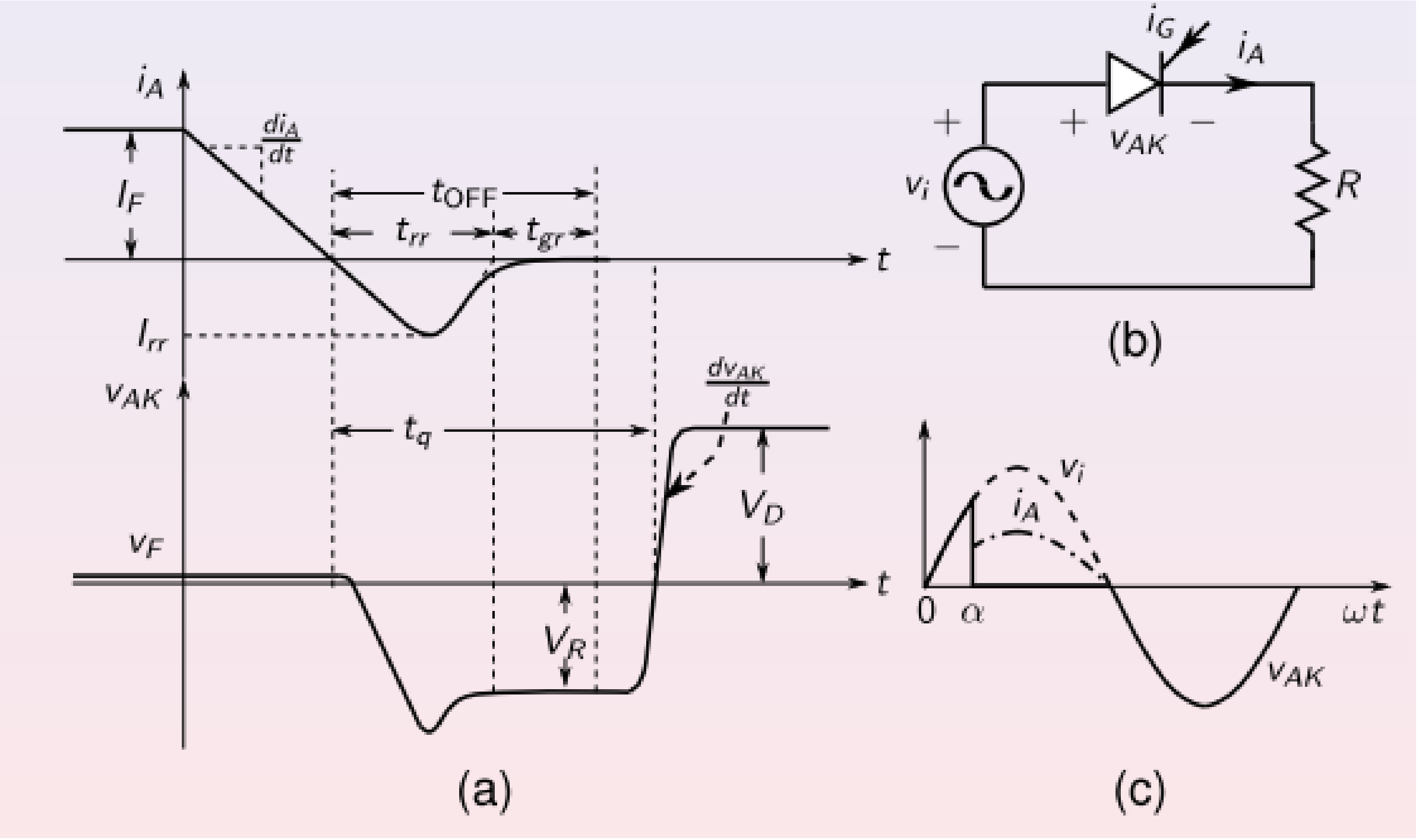
How to Turn Off SCR?

- Gate current has no control over the SCR after it turns ON.

- I_A should be reduced below the holding value I_H in order to turn OFF the device.

- After I_A drops to zero, the device should be reverse biased for a duration t q > t_{OFF} where t_{OFF} is known as the device turn OFF time and t q is known as the circuit turn-off time.

SCR Turn OFF Characteristics



t_q should be > t_{OFF} and dv_{AK}/dt should be less than rated value for proper turn off of SCR.

Letter Symbols used to Specify Ratings of SCR

A – Anode, ambient
(AV) – Average
(BO) – Breakover
(BR) – Breakdown
D – Off state or non-trigger
d – Delay time
F, f – Forward, falltime
H – Holding
G, g – Gate terminal

J – Junction
K – Cathode
M, m – Maximum
Q, q – Turn off
R, r – Reverse, repetitive
(RMS) – RMS value
rr – Reverse recovery
S – surge, nonrepetitive
T, t – On-state, trigger

Examples:
V_{RRM} – Reverse repetitive maximum voltage.
I_{TSM} – On-state maximum surge current
V_{GT} – Gate voltage required for triggering
$I_{(RMS)}$ – On-state RMS current.

Specifications of BT145 Thyristor Series

Philips Semiconductors | Product specification

Thyristors | BT145 series

GENERAL DESCRIPTION

Glass passivated thyristors in a plastic envelope, intended for use in applications requiring high bidirectional blocking voltage capability and high thermal cycling performance. Typical applications include motor control, industrial and domestic lighting, heating and static switching.

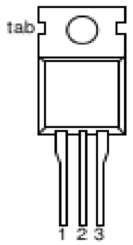
QUICK REFERENCE DATA

SYMBOL	PARAMETER	MAX.	MAX.	MAX.	UNIT
	BT145-	500R	600R	800R	
V_{DRM}, V_{RRM}	Repetitive peak off-state voltages	500	600	800	V
$I_{T(AV)}$	Average on-state current	16	16	16	A
$I_{T(RMS)}$	RMS on-state current	25	25	25	A
I_{TSM}	Non-repetitive peak on-state current	300	300	300	A

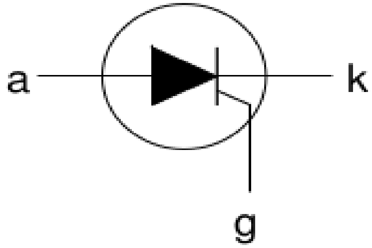
PINNING - TO220AB

PIN	DESCRIPTION
1	cathode
2	anode
3	gate
tab	anode

PIN CONFIGURATION



SYMBOL



LIMITING VALUES

Limiting values in accordance with the Absolute Maximum System (IEC 134).

SYMBOL	PARAMETER	CONDITIONS	MIN.	MAX.			UNIT
				-500R	-600R	-800R	
V_{DRM}, V_{RRM}	Repetitive peak off-state voltages		-	500[1]	600[1]	800	V
$I_{T(AV)}$	Average on-state current	half sine wave; $T_{mb} \leq 101$ ˚C	-	16			A
$I_{T(RMS)}$	RMS on-state current	all conduction angles	-	25			A
I_{TSM}	Non-repetitive peak on-state current	half sine wave; $T_j = 25$ ˚C prior to surge					
		t = 10 ms	-	300			A
		t = 8.3 ms	-	330			A
I^2t	I^2t for fusing	t = 10 ms	-	450			A^2s
dI_T/dt	Repetitive rate of rise of on-state current after triggering	$I_{TM} = 50$ A; $I_G = 0.2$ A; $dI_G/dt = 0.2$ A/µs	-	200			A/µs
I_{GM}	Peak gate current		-	5			A
V_{GM}	Peak gate voltage		-	5			V
V_{RGM}	Peak reverse gate voltage		-	5			V
P_{GM}	Peak gate power		-	20			W
$P_{G(AV)}$	Average gate power	over any 20 ms period	-	0.5			W
T_{stg}	Storage temperature		-40	150			˚C
T_j	Operating junction temperature		-	125			˚C

1 Although not recommended, off-state voltages up to 800V may be applied without damage, but the thyristor may switch to the on-state. The rate of rise of current should not exceed 15 A/µs.

THERMAL RESISTANCES

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
$R_{th\ j\text{-}mb}$	Thermal resistance junction to mounting base		-	-	1.0	K/W
$R_{th\ j\text{-}a}$	Thermal resistance junction to ambient	in free air	-	60	-	K/W

STATIC CHARACTERISTICS

T_j = 25 ˚C unless otherwise stated

SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
I_{GT}	Gate trigger current	V_D = 12 V; I_T = 0.1 A	-	5	35	mA
I_L	Latching current	V_D = 12 V; I_{GT} = 0.1 A	-	25	80	mA
I_H	Holding current	V_D = 12 V; I_{GT} = 0.1 A	-	20	60	mA
V_T	On-state voltage	I_T = 30 A	-	1.1	1.5	V
V_{GT}	Gate trigger voltage	V_D = 12 V; I_T = 0.1 A	-	0.6	1.0	V
		$V_D = V_{DRM(max)}$; I_T = 0.1 A; T_j = 125 ˚C	0.25	0.4	-	V
I_D, I_R	Off-state leakage current	$V_D = V_{DRM(max)}$; $V_R = V_{RRM(max)}$; T_j = 125 ˚C	-	0.2	1.0	mA

DYNAMIC CHARACTERISTICS

T_j = 25 ˚C unless otherwise stated

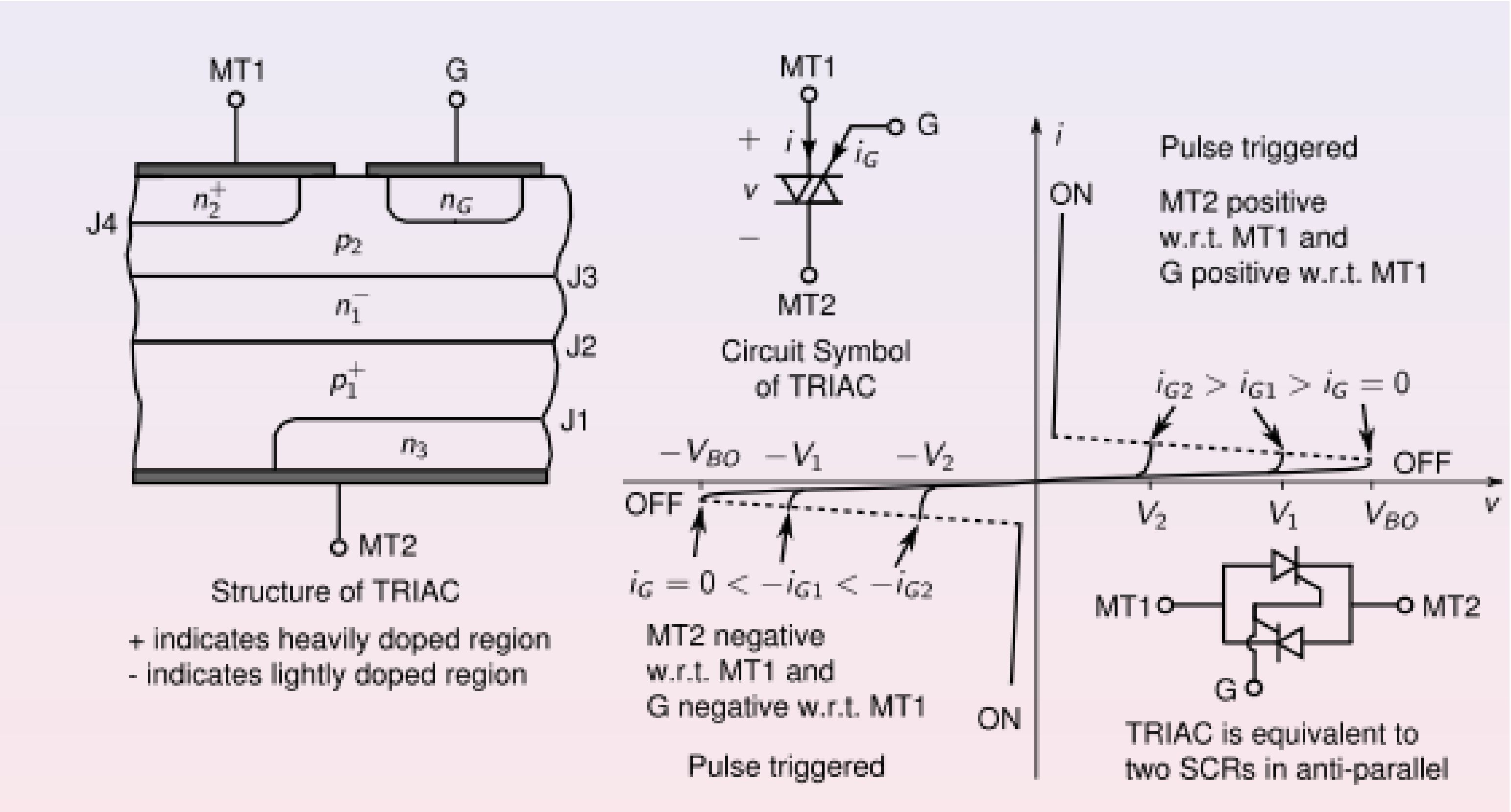
SYMBOL	PARAMETER	CONDITIONS	MIN.	TYP.	MAX.	UNIT
dV_D/dt	Critical rate of rise of off-state voltage	V_{DM} = 67% $V_{DRM(max)}$; T_j = 125 ˚C; exponential waveform; gate open circuit	200	500	-	V/µs
t_{gt}	Gate controlled turn-on time	I_{TM} = 40 A; $V_D = V_{DRM(max)}$; I_G = 0.1 A; dI_G/dt = 5 A/µs	-	2	-	µs
t_q	Circuit commutated turn-off time	V_D = 67% $V_{DRM(max)}$; T_j = 125 ˚C; I_{TM} = 50 A; V_R = 25 V; dI_{TM}/dt = 30 A/µs; dV_D/dt = 50 V/µs	-	70	-	µs

Disc Type of SCRs

Stud Type of SCRs

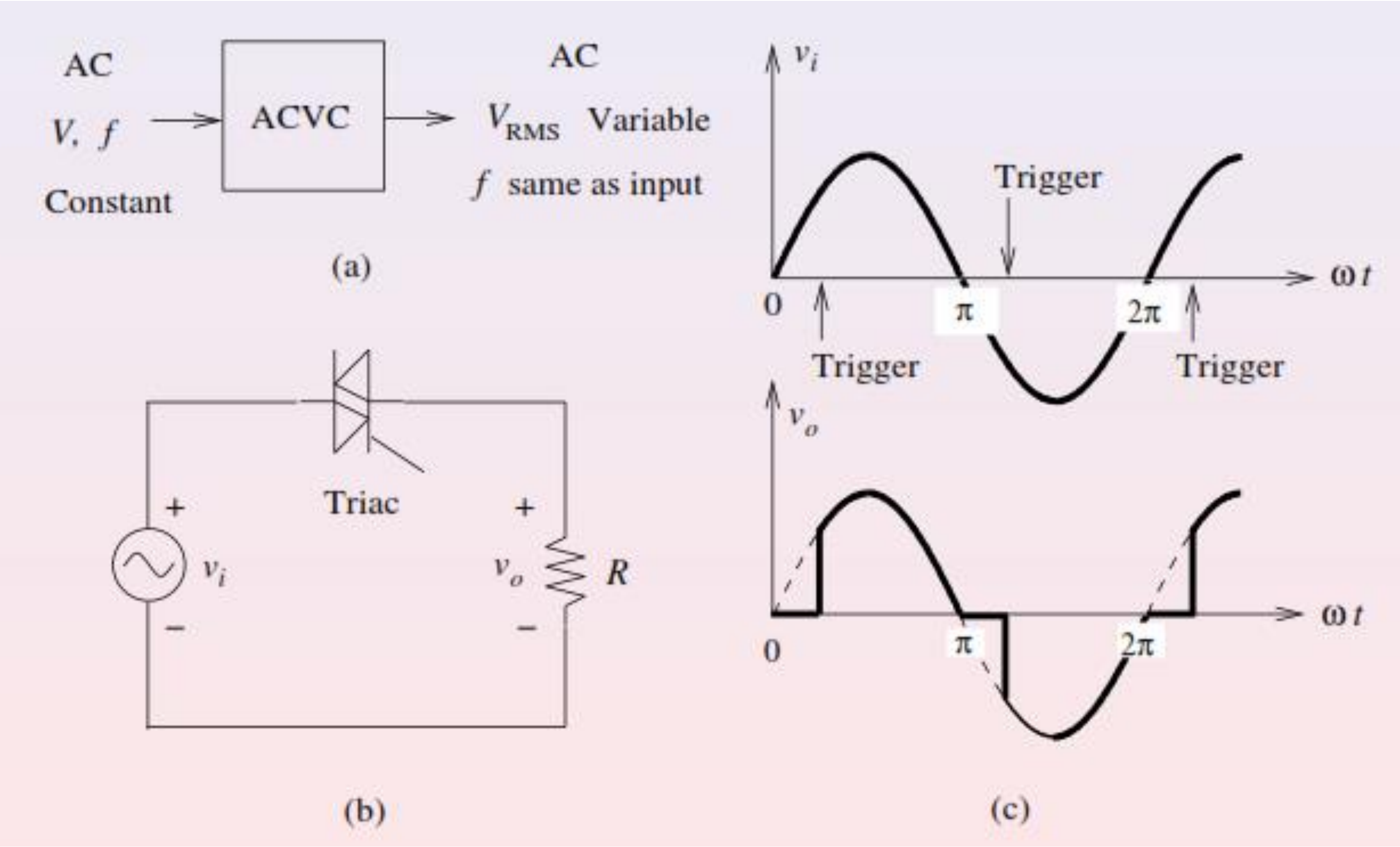
SCR Power Module

TRIAC



Shorting of p_1 region to n_3 region due to MT2 metal contact, and the p_2 region to the n_2 region due to MT1 metal contact results in two anti-parallel SCR structures: $p_1n_1p_2n_2$ and $p_2n_1p_1n_3$

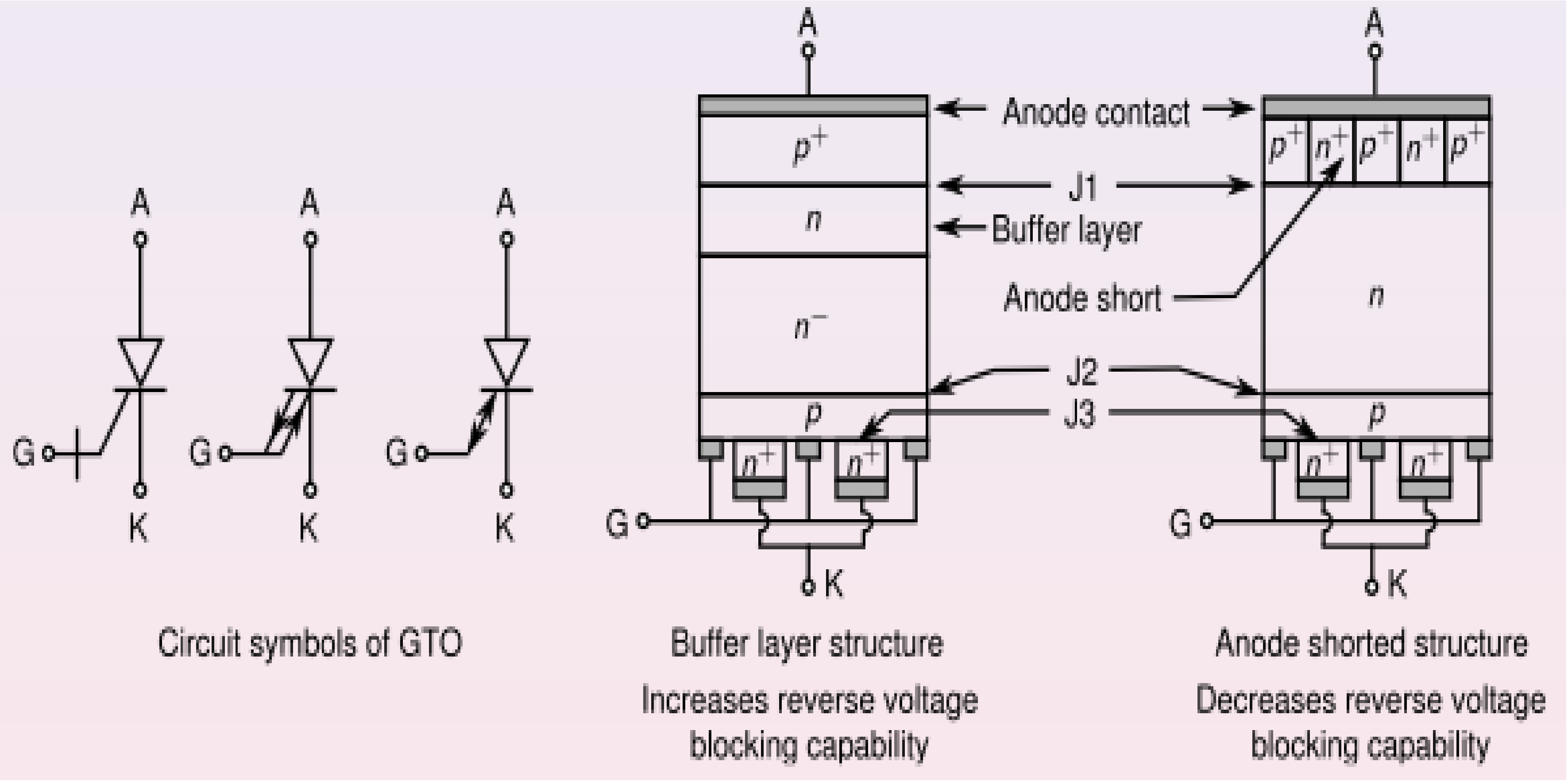
TRIAC used in ACVC



Limitations of TRIAC as Compared to SCRs

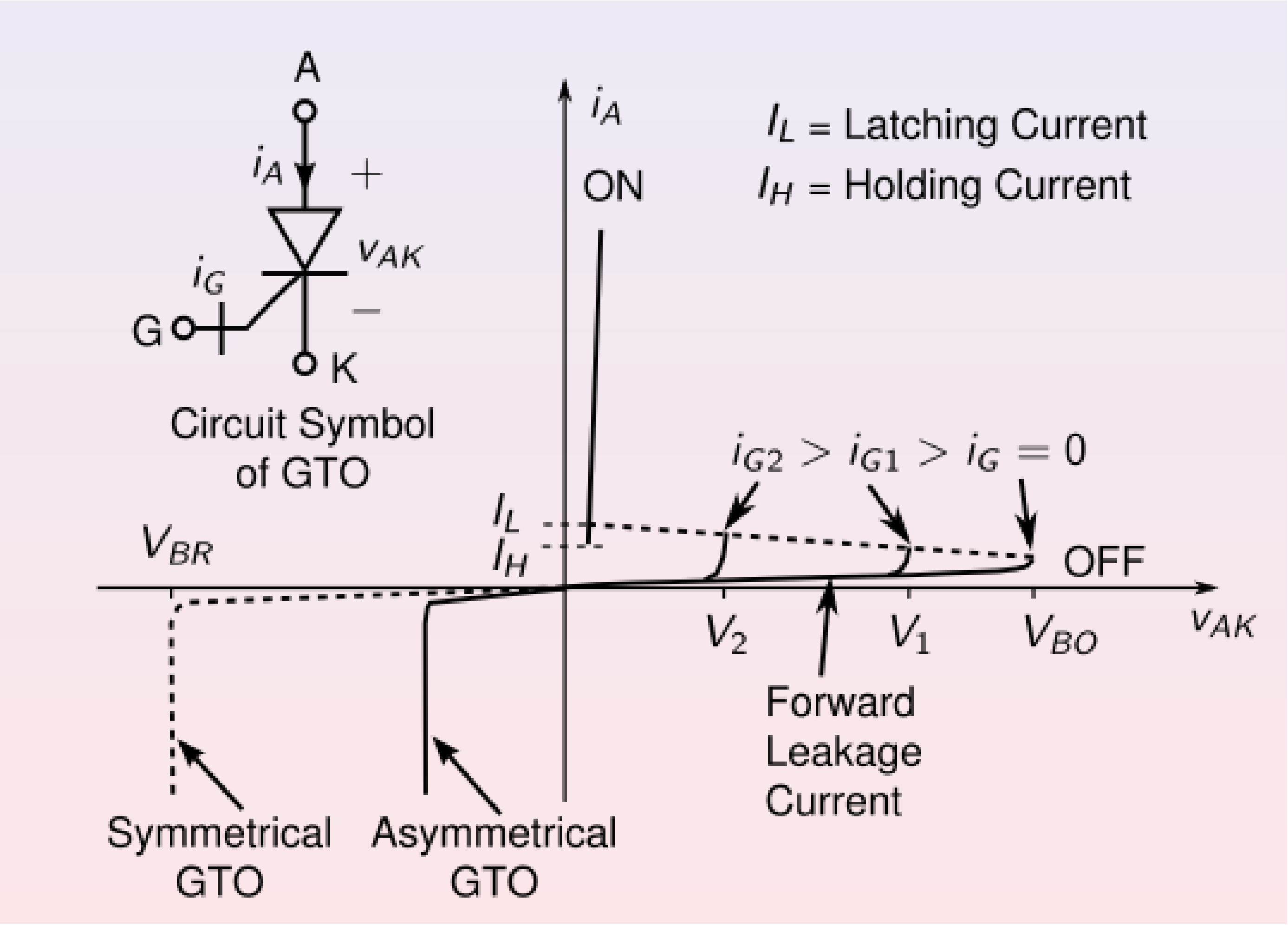
- Has lower dv/dt rating.
- Has longer turn-off time.
- Requires well designed R-C snubber connected across it to limit dv/dt.
- Has lower power handling capability.
- Typically used in small motor speed regulators, temperature control, illumination control, liquid level control, phase control circuits, power switches.
- Cannot be used in A.C. systems of frequency more than 400 Hz.

Gate Turn Off Thyristor (GTO)

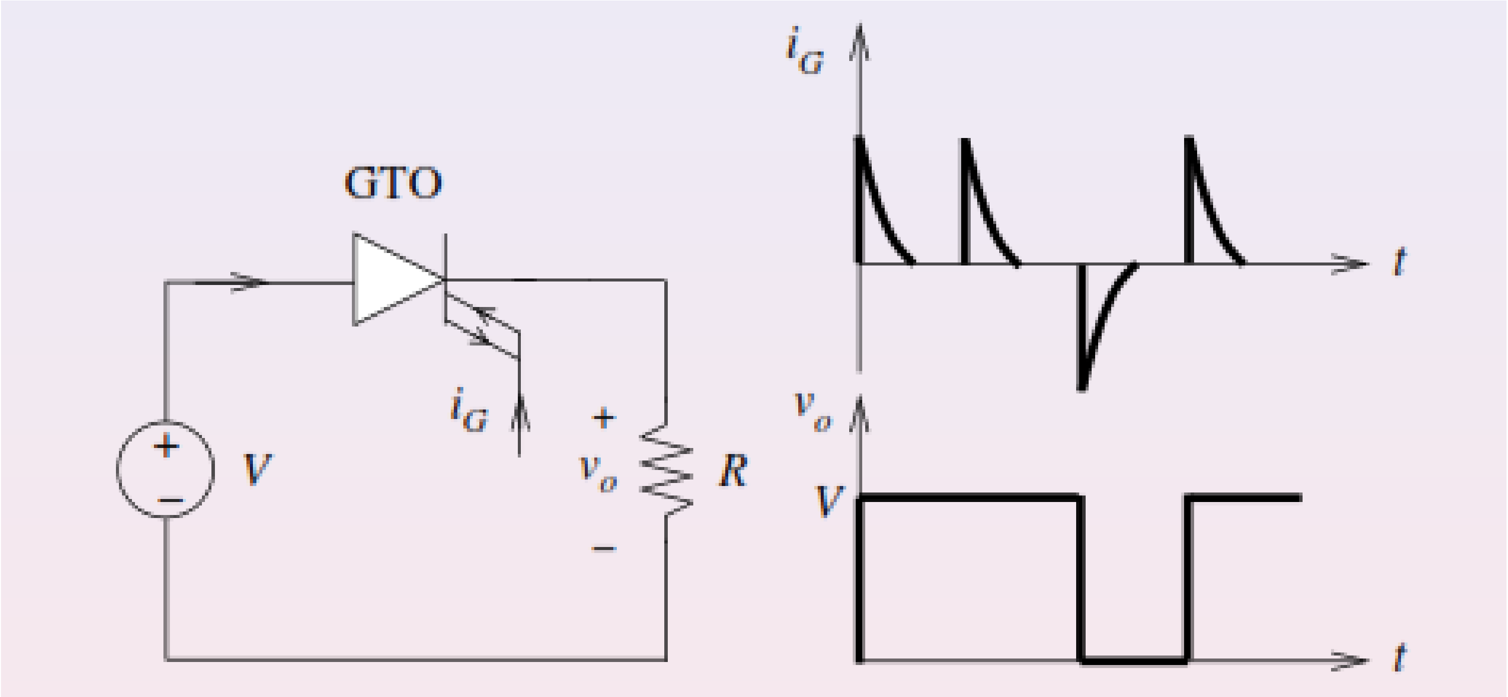


Inter digitized gate-cathode structure increases di/dt rating of the device and also improves turn-off performance of the device.

Static Characteristic of GTO



Control Characteristics of GTO



- GTO can be turned on by applying a positive gate current pulse and turned off by applying a negative gate current pulse.
- To prevent unwanted turn-off during transients, it is recommended to apply a low value of continuous positive gate current as long as GTO has to be kept on.

GTO Compared with SCR

GTO	SCR
Fully-controlled	Semi-controlled
$V_{ON} = 3\text{-}4$ V	$V_{ON} = 1.5\text{-}2$ V
Higher I_L and I_H	I_L and I_H very low compared to GTO
Assymetric GTO has very low V_{BR}	Has $V_{BR} \approx V_{BO}$
Typically $dv/dt = 1000$ V/μs	Typically $dv/dt = 200\text{-}500$ V/μs
Turn-off Current Gain: 6-15	Not applicable
Max. operating frequency: 1-4 kHz	Typcally operated at 50 or 60 Hz

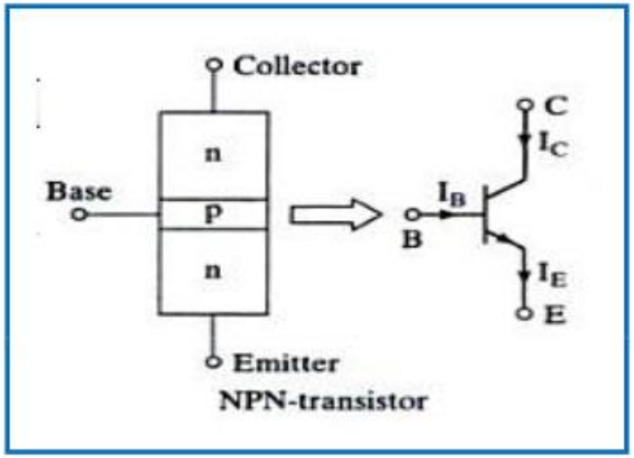
Power Transistors:
Comparison of Thyristor and Transistor

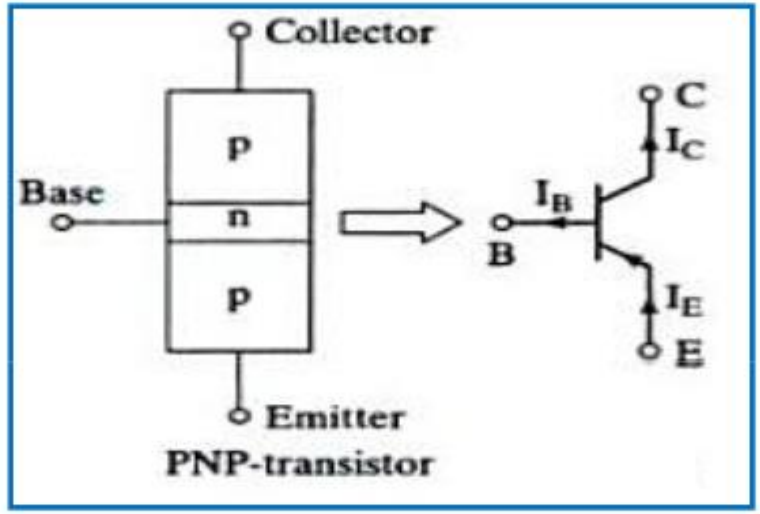
- Have controlled turn-on and turn-off characteristics
-- Switching speed of modern transistors is much higher than that of thyristors.
- Voltage and current ratings of transistors are lower than those of thyristors
- A thyristor needs only a pulse to make it conducting and thereafter it remains conducting. On the other hand a transistor needs a continuous current for keeping it in a conducting state.
-Thyristors need turn-off circuit but transistors no need turn-off circuit.
- Thyristors have higher voltage drop while transistors have smaller voltage drop.

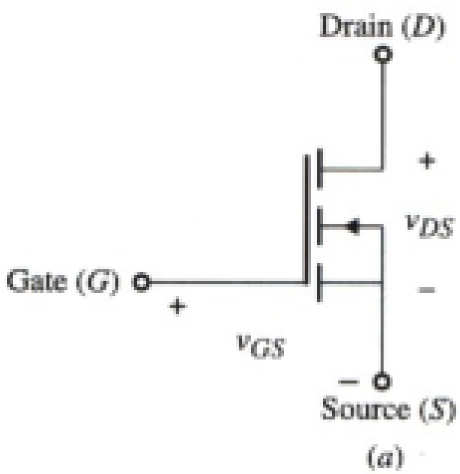
Classification of Power Transistors:

Power Transistors are classified as follows:

1. **Bipolar Junction Transistors (BJTs)**
2. **Metal-Oxide-Semiconductor Field Effect Transistors(MOSFETs)**
3. **Static Induction Transistors (SITs)**
4. **Insulated Gate Bipolar Transistors (IGBTs)**







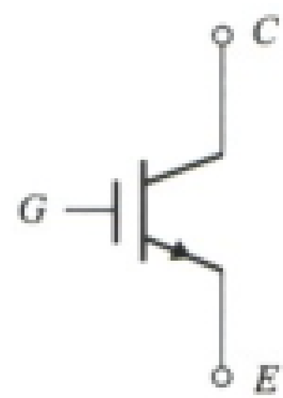


Fig. 4 MOSFET: a) symbol :

Fig. 5 IGBT symbol [1]

POWER BJT	POWER MOSFET	POWER IGBT
It is current controlled device.	It is voltage controlled device.	It is voltage controlled device.
It is minority-carrier as well as majority carrier device.	It is majority-carrier device.	It is minority-carrier device.
Its switching speed is comparatively lower than that of the power MOSFET.	Its switching speed is high.	Its switching speed is very high.
It needs an appropriate value of control current for keeping it in the ON-state.	A negligible current is required at its control terminal to maintain it in the ON-state.	A small current is required at its control terminal to maintain it in the ON-state.
The current and voltage ratings are higher than those of the power MOSFETs.	The current and voltage ratings are LOW.	The current and voltage ratings are well above those of the power MOSFETs.
On state voltage drop is comparatively higher than that of power MOSFETs.	On state voltage drop is lower than that of power BJTs.	On state voltage drop is minimum.
Input resistance is low.	Input resistance is high.	Input resistance is high.

Table 1 Power semiconductor devices ratings comparison [1]

Device type	Year made available	Rated voltage	Rated current	Rated frequency	Rated power	Forward voltage
Thyristor (SCR)	1957	6 kV	3.5 kA	500 Hz	100s MW	1.5–2.5 V
Triac	1958	1 kV	100 A	500 Hz	100s kW	1.5–2 V
GTO	1962	4.5 kV	3 kA	2 kHz	10s MW	3–4 V
BJT (Darlington)	1960s	1.2 kV	800 A	10 kHz	1 MW	1.5–3 V
MOSFET	1976	500 V	50 A	1 MHz	100 kW	3–4 V
IGBT	1983	1.2 kV	400 A	20 kHz	100s kW	3–4 V
SIT	1987	4 kV	600 A	100 kHz	10s kW	10–20 V
SITH	1975	4 kV	600 A	10 kHz	10s kW	2–4 V
MCT	1988	3 kV	2 kV	20–100 kHz	10s MW	1–2 V

Classification of power semiconductor switching devices:

The power semiconductor switching devices can be classified on the basis of:

1. **Uncontrolled turn on and off (e.g. diode)**
2. **Controlled turn on and uncontrolled turn off (e.g. SCR)**
3. **Controlled turn on and off characteristics (e.g. BJT, MOSFET, GTO, SITH, IGBT, SIT, MCT)**
4. **Continuous gate signal requirement (e.g. BJT, MOSFET, IGBT, SIT)**
5. **Pulse gate requirement (e.g. SCR, GTO, MCT)**
6. **Bidirectional current capability (e.g. TRIAC, RCT)**
7. **Unidirectional current capability (e.g. SCR, GTO, BJT, MOSFET, MCT, IGBT, SITH, SIT, diode)**

Power Electronics Circuits:

The power electronic circuits can be classified into five types:

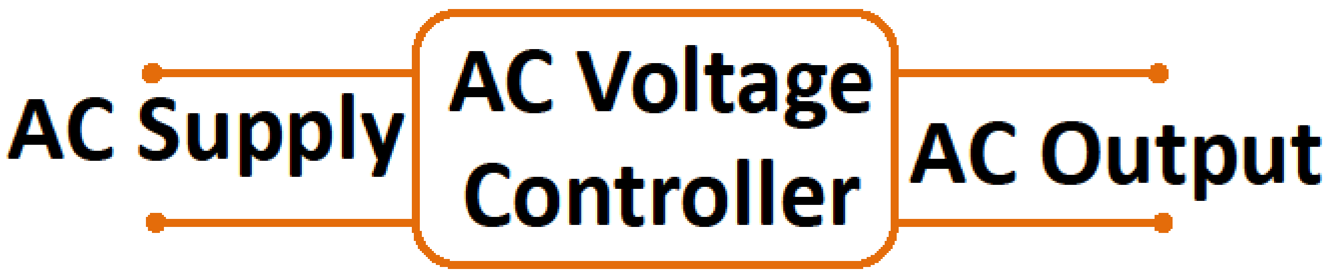
1. **Diode rectifiers (uncontrolled ac-dc converter)**
2. **AC-DC converters (controlled rectifier)**
3. **AC-AC converters (ac voltage controllers)**
4. **DC-DC converters (dc choppers)**
5. **DC-AC converters (inverters)**

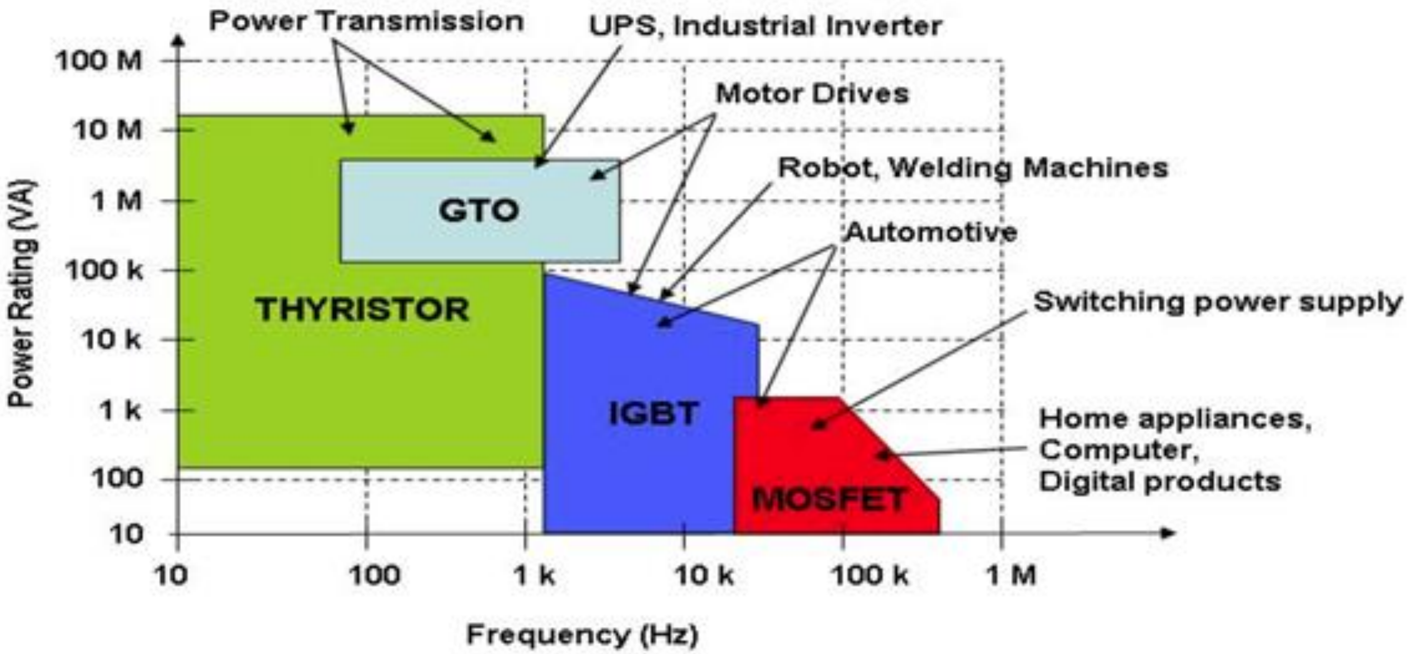
AC to DC Converter

DC to AC Converter

DC to DC Converter

AC to AC Converter




Power Transmission
UPS, Industrial Inverter
Motor Drives
Robot, Welding Machines
Automotive
Switching power supply
Home appliances,
Computer,
Digital products
GTO
THYRISTOR
IGBT
MOSFET
100 M
10 M
1 M
100 k
10 k
1 k
100
10
Power Rating (VA)
10
100
1 k
10 k
100 k
1 M
Frequency (Hz)

Applications of Power Converters

DC-DC converters - Switched Mode Power Supplies (SMPS) - Makes up about 75% of power electronics industry.

- Power Supplies for Electronic Equipment
- Robotics
- Automotive/Transportation
- Switching Power Amplifiers
- Photovoltaic System

DC-AC - Inverter

- **AC Machine Drive (permanent magnet, switched reluctance, or induction machine)**
- **Uninterruptible Power Supply (UPS)**
- **Machine Tools**
- **Induction Heating — Steel Mills**
- **Locomotive Traction**
- **Static Var Generation (Power Factor Correction)**
- **Photovoltaic or Fuel Cell Interface with Utility**

AC-DC - rectifier

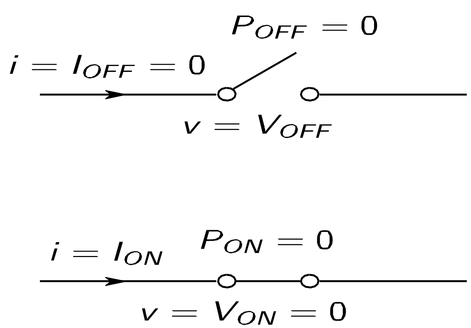
- **DC Machine Drive**
- **Input Stage to DC/DC or DC/AC Converter**
- **Energy Storage Systems**
- **Battery Chargers**
- **Aerospace Power Systems**
- **Subways, Trolleys**
- **High Voltage DC (HVDC) Transmission**

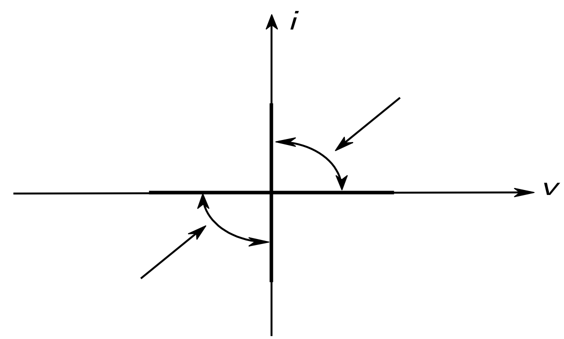
AC-AC Converters - Voltage Controller 1Φ to 3Φ Converters

- **Lighting /Heating Controls**
- **Large Machine Drives**

Switching Characteristics

Ideal Switch

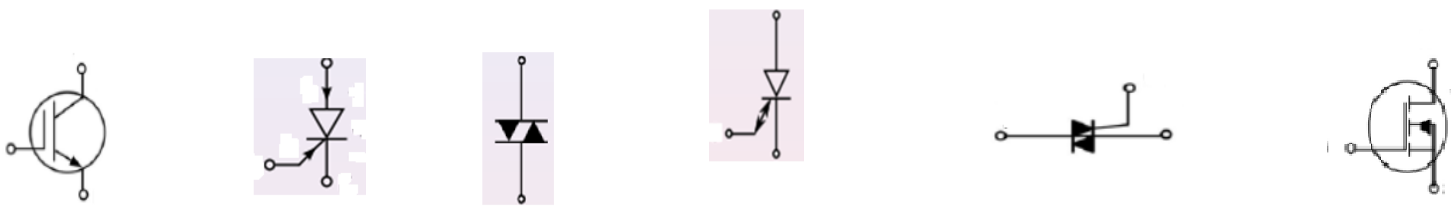




Switch closed: *v**(t) = 0***
Switch open: *i**(t) = 0***
In either event: *p**(t)*** **= *v(t) i(t)* = *0***
Ideal switch consumes zero power

questions

1- In the figures shown write the name of each device and the label of its terminals



2- Mark right or wrong (√ or ×) for the following:

The shotckky diode has lower rated voltage than that of fast recovery diode

Standard power diode has switching time greater than that of the shotcky diode

The fast recovery diode has rated power greater than that of shotcky diode

The shotcky diode has switching time lower than the fast recovery diode

GTO can be turned on by applying a positive gate current pulse and turned off by applying a negative current pulse.

SCR maximum operating frequency is smaller than that of GTO
SCR has dv/dt lower than GTO
To turn off SCR, the device should be reverse biased for a duration t q > t_{OFF} after I_A drops to zero,
dv_{AK}/dt should be less than rated value for proper turn off of SCR.
Power Transistors Have controlled turn-on and turn-off characteristics
Switching speed of modern transistors is much higher than that of thyristors
Voltage and current ratings of transistors are lower than those of thyristors
A thyristor needs only a pulse to make it conducting and thereafter it remains conducting
Transistor needs a continuous current for keeping it in a conducting state.
Thyristors need turn-off circuit but transistors no need turn-off circuit
Thyristors have higher voltage drop while transistors have smaller voltage drop.
The switching speed of BJT is comparatively lower than that of MOSFET
The switching speed of IGBT is comparatively higher than that of MOSFET
The current and voltage ratings of BJT are higher than those of MOSFET
The current and voltage ratings of IGBT are well above those of MOSFET
On state voltage drop of BJT is higher than that of MOSFET
On state voltage drop of MOSFET is higher than that of IGBT
The current required at control terminal for BJT is higher than that of MOSFET

The current required at control terminal for IGBT is higher than that of MOSFET
The switching speed of BJT is comparatively higher than that of MOSFET
The switching speed of IGBT is comparatively lower than that of MOSFET
The current and voltage ratings of BJT are lower than those of MOSFET
The current and voltage ratings of IGBT are well blew those of MOSFET
On state voltage drop of BJT is lower than that of MOSFET
On state voltage drop of MOSFET is lower than that of IGBT
Power Transistors operate as a switch in the linear operating region
The current required at control terminal for BJT is lower than that of MOSFET
The current required at control terminal for IGBT is lower than that of MOSFET
Transistors have higher voltage drop while Thyristors have smaller voltage drop.
Transistors need turn-off circuit but Thyristors no need turn-off circuit
SCR needs a continuous current for keeping it in a conducting state.
Power Transistors needs only a pulse to make it conducting and thereafter it remains conducting
The maximum operating frequency of SCR is greater than that of GTO
Voltage and current ratings of thyristors are lower than those of transistors
Switching speed of thyristors is much higher than that of modern transistors
SCR turned off by applying a negative gate current pulse.
SCR operating frequency is higher than that of GOT
SCR has dv/dt higher than GTO
The shotckky diode is lower rated voltage than fast recovery diode
The standard power diode has switching time lower than the shotcky diode
The fast recovery diode has rated power lower than shotcky diode

3- Write the full name for the following

SCR - GTO - RCT - SITH - LASCR - BJT - MOSFET - SIT - IGBT