POWER CLASSIFICATION FOR POWER ELECTRONIC

Lower Power Level:	until 2 kW.
Sample applications	Domestic appliances
Power switches	MOSFET
Middle Power level:	2 - 500 kW.
	Electrical vehicles Solar Power Applications MOSFET, IGBT
Higher Power Level:	Over 500 kW.
	Renewable Energy Electric Distribution IGBT.

CLASSIFICATION OF POWER SWITCHES

1. Diodes: On and off states controlled by power circuit.
2. Thyristors: Latched on by a control signal but must be turned off by the power circuit
3. Controllable switches: Turned on and off by control signals.

Controllable switch category includes several device types including bipolar junction transistors (BJT), Metal oxide Semiconductor field effect transistors (MOSFETs), Gate turn off thyristors (GTOs) and Insulated Gate Bipolar Transistors (IGBTs)

There have been major advances in recent years...

DIODES

Conducting current = i_F

Reverse Breakdown voltge = V_{RB}

Treshold voltage = V_{FT} $V_F = V_{FT} + r_F \cdot i_F$

Internal resistance = r_F

Anod-cathode voltage = V_F

The Diode damages when the supplied voltage exceeds the V_{RB} breakdown voltage and so it is a conductor anymore.

When the diode is forward biased, it begins to conduct with only a small forward voltage across it.

When the diode is reverse biased, only a negligibly small leakage current flows through the device until the reverse breakdown voltage is reached.

Q_{RR} = Reverse recovery electrical charges

t_{rr} = Reverse recovery time = t_{OFF}

t_{rf} = Rising forward time = t_{ON}.

I_{RRM} = Reverse recovery maximum current

V_{AK} = Anod cathode voltage

V_{AKM} = Maximum anod cathode voltage.

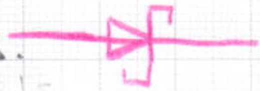
The reverse-recovery current can lead to overvaltages in inductive circuits.

But this reverse current does not affect the converter input / output characteristic, so the diode can also be considered as ideal during turn-off transients.

DIODE TYPES

Depending on the application requirements, various types of diodes are available.

1. Schottky diodes: In contrast with conventional p-n junction, a metal layer is added to on it. This means that on-state voltage drop is lower than conventional diodes. Also, breakdown voltage is lower than conventional diodes like 100 V. Max current value for on-state is 1-400 A. It is suggested for lower voltage and higher current applications.



2- Fast recovery diodes

These kind of diodes are designed to be used in high-frequency circuits. The recovery time is under 5μs. Their voltage ranges are from 50 V to 3 kV and current ranges are from 1 A to a few hundered ampere. Max voltage and current values are 6kV and 1100 A. The recovery time in these diodes is in nano second levels.

3.- Standart diodes

Their recovery time are higher than other types, 25μs. Voltage values might be between 50V and 5kV. Current values might be between 1A and a few thousand A.

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THYRISTORS

The main current flows from Anode (A) to the cathode (K). I_A: Thyristor current V_T: Anod-cathode voltage
I_G: Triggering current

In its off-state, the thyristor can block a forward polarity voltage and not conduct.

By applying a positive pulse of gate current for a short duration, the thyristor can be triggered in to the on-state.

Once the device begins to conduct, it is locked on and gate current can be removed.

The thyristor cannot be turned off by the gate
Thyristor conducts as a diode.

I_L = Locking current
I_H = Holding current.

If the main current decreases under holding current, thyristor is at off-state as long as 1) the time of supplied voltage is bigger than t_{OFF} time and 2) without supplying positive voltage during t_{OFF} time.

$$t_{ON} = t_d + t_s + t_r$$

t_d = Delaying time
t_s = spreading time
t_r = Raising time

$$\left.\frac{di_T}{dt}\right|_{max} < \frac{dI}{dt}_{critic}$$ must be

Otherwise the device damages due to the increased junction temprature.

The reasons for self On-state by itself

1) $\frac{dV_T}{dt} > \frac{dV_T}{dt}$ critic.

2) $V_T \gg U_{BO}$ ⇒ Zero breakdown voltage.

3) $t_N < t_q \rightarrow t_{OFF}$
↓
time for the supplied negative voltage

In any circumstances mentioned above, the device is turned on without any triggering current from gate terminal.

Natural Commutation: There is no need any additional circuit

Forced-Commutation: There is need additional circuit

BIPOLAR JUNCTION TRANSISTOR (BJT)

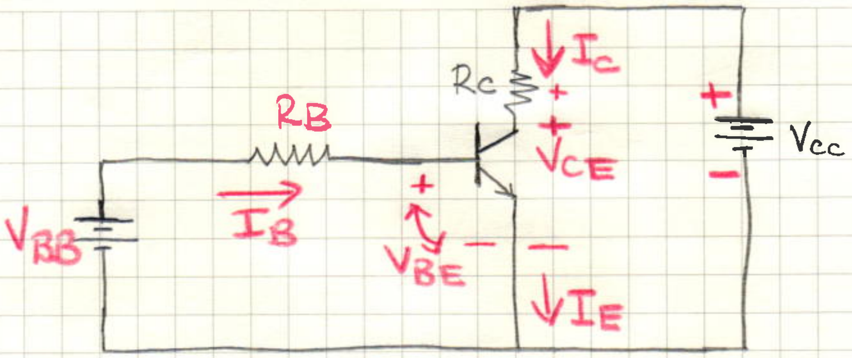
A sufficiently large base current (dependent on Ic collector current) results in the device fully on state.

$I_B > \frac{I_C}{\beta_F}$ → dc current gain of the device.

The on state voltage $V_{CE(sat)}$ of the BJT is usually 1-2 V range in order to obtain the lower conduction power losses.

BJT is a current-controlled device. Input and output current

The Base current must be supplied to keep BJT in onstate



I_B = Base Current
I_E = Emiter current
I_C = Collector current

V_{BE} = Base-Emiter Voltage
V_{CE} = Collector-Emiter Vol.
V_{CC} = Supply voltage
V_{BB} = Voltage for I_B.

$V_{BE} \approx 0.7\ V$

$$V_{BB} = I_B \cdot R_B + V_{BE} \Rightarrow I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

$$\frac{I_C}{I_B} = \beta \rightarrow \text{Gain} \qquad I_E = I_C + I_B$$

$$V_{R_C} = I_C \cdot R_C$$

$$V_{CC} = I_C \cdot R_C + V_{CE} \Rightarrow V_{CE} = V_{CC} - I_C \cdot R_C$$

Turn-off Region: When $I_B = 0$, I_C will be equal to zero value. The collecter-emiter resister is so high for this reason does not permit to current flow.

Saturation Region: For this region, When I_B increases, I_C increases as well, as result V_{CE} diminishes. In case $V_{CE} = V_{CE_{saturation}}$, even if I_B increases, I_C does not increase due to saturation. The transistor is operated only a switch.

Active Region: If a transistor will be used as an amplifier, V_{BE} must be biased positively and V_{CE} must be biased negatively. The output current of transistor is dependent on I_B and V_{CE} in a small quantity

DESIRED CHARACTERISTCS IN CONTROLLABLE SWITCHES

1. Small leakage current in the off state.

2. Small on-state voltage Von to minimize on-state power losses

3. Short turn-on and turn-off times. This will permit the the device to be used at high switching frequencies.

4. Large forward and reverse-voltage blocking capability. This will minimize the need for series connection of several devices. Otherwise, that need complicates the control and protection of the switches

5. High on-state current rating. This will minimize the need to connect several devices in paralled.

6. Small control power required to switch the device This will simplify the control circuit design.

7. Capability to withstand rated voltage and current simultaneously while switching. This will eleminate the need for external protection like snubber circuits.

8. Large dv/dt and di/dt ratings. This will minimize the need for external circuits to limit dv/dt and di/dt so that it is not damaged

During analyzing we assume that the power devices have ideal characteristics

But in applications power devices will dissipate power depending on their operating mode.

If they dissipate too much power, the devices can fail and in doing so, will destroy themselves. Furthermore they may damage the other system components

There are four type of losses according to the instantaneous state of power switch

* 1. Triggering/Controlling Losses

$$P_G = \frac{1}{T} \int u_G \cdot i_G \cdot dt$$

2. Switching losses

$$P_S = P_{ON} + P_{OFF}$$

While the power device switches on or off states switching operation causes to power losses highly.

* 3. OFF-state Losses

$$P_B = P_P + P_N$$

These are the losses due to leakage currents during positive and negative blockage.

4. ON-state Losses

$$P_T = \frac{1}{T} \int u_T \cdot i_T \cdot dt$$

When the power switch is on-state, due to the value of nominal current, it dissipates power.

For the types of losses, Triggering/controlling and off-state losses are negligible.
In other words, on-state and switching losses are much more intensive compared to the others.

Switching losses are defined as the energy losses per switching operation in data sheets
We obtain the power losses per one second if we multiply those energy losses with operational frequency.

$$W_S = W_{ON} + W_{OFF}$$
$$P_S = f_p \cdot W_S$$

ON-state Power Losses For The Types of power switches

For Transistors

$$P_T = \frac{1}{T} \int u_{CE} \cdot i_C \cdot dt$$

For Mosfet

$$P_T = \frac{1}{T} \int u_{DS} \cdot i_D \cdot dt = \frac{1}{T} \int r_{DS} \cdot i_D^2 \, dt = r_{DS} \int i_D^2 \, dt$$

For Thyristor/Diod

$$P_T = \frac{1}{T} \int u_T \cdot i_T \cdot dt = \frac{1}{T} \int (u_{TO} + r_T \cdot i_T) \, i_T \cdot dt$$

THE THERMAL EQUIVALENT CIRCUIT OF POWER SWITCH.

There are two types of cooling system as natural and forced ones.

T_a = Temperature of Ambient
T_s = " of heat sink
T_c = Temperature of Case
T_j = Junction Temperature

R_{ThJC} = Internal thermal resistance °C/W
R_{ThCA} = External " " °C/W = $R_{ThCS} + R_{ThSA}$

$$T_c = T_a + P \cdot R_{ThCA}$$
$$T_j = T_c + P \cdot R_{ThJC}$$

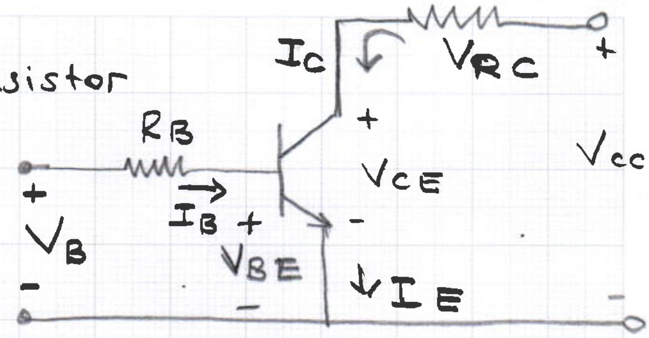
P = total power loss

$$P = P_S + P_T + P_G$$

Device manufacturers will guarantee the max. values of device parameters such as conduction voltage, switching losses... at a specified max. temprature. This is a worst-case junction temperature.
It is at 125 °C approximately. It may differs in from one type to other.

A system intended to have high reliability, that value would be 20-40° below 125 °C
If power switch is operated above that value, lifetime would be low and performance characteristic may be poor.

Some special applications will require operating in extremely high ambient temperature. All devices should be tested for that ambient temperature



The related data for a BJT transistor is given as following:

$V_{cc} = 250$ V., $V_B = 5$V.

$R_c = 20\Omega$, $V_{CES} = 0.5$ V.(sat)

$V_{BES\,(sat)} = 1.5$ V $\beta = 100$

a) By taking $R_B = 80\Omega$ and $V_{BE} = 1$ V., calculate base current (I_B), collector current (I_c), Load voltage (V_{Rc}) and transistor Voltage (V_{CE}).

b) For the saturation mode, determine transistor voltage (V_{CES}), collector current (I_{cs}) and base current (I_{BS})

c) For both operation mode, compare the load power (P_{Rc}) and power loses for transistor (P_{BJT}). Comment the results.

a) From Kirchhoff voltage equation,

$0 = R_B \cdot I_B + V_{BE} - V_B$ from here,

$$I_B = \frac{V_B - V_{BE}}{R_B} = 50 \text{ mA}$$

$I_c = \beta \cdot I_B$ with β dc gain of the BJT.

$I_c = 100 \cdot 50 \cdot 10^{-3} = 5$ A

$V_{Rc} = I_c \cdot R_c = 20 \cdot 5 = 100$ V.

$V_{CE} + V_{Rc} = V_{cc}$ from Kirchhoff equation,

$V_{CE} = V_{cc} - V_{Rc} = 250 - 100 = 150$ V.

b) For Saturation mode;

$V_{CE} = V_{CES} = 0.5$ V

with a similar approach;

$$I_{CS} = \frac{V_{CC} - V_{CES}}{R_C} = \frac{250 - 0,5}{20} = 12.475 \text{ A}.$$

$$I_{BS} = \frac{I_{CS}}{\beta} = 124.75 \text{ mA}.$$

c) For (a) option

$P_{RC} = R_C \cdot I_C^2 = 20 \cdot 5^2 = 500$ W. Load power

$P_{BJT} = V_{CE} \cdot I_C = 150 \cdot 5 = 750$ W BJT power loses

For (b) option

$P_{RC} = R_C \cdot I_C^2 = 20 \cdot 12.475 = 3113$ W.

$P_{BJT} = V_{CES} \cdot I_{CS} = 0.5 \cdot 12.475 = 6.24$ W.

Because of lower power losses, the saturation mode is the best option for the BJT.

2. $V_T = 1000 \cdot \sin(62800t)$ V. voltage is supplied to the tyristor. To prevent the self turn-on condition; Find,

a) V_{BO} (zero breakdown voltage)

b) $(dV/dt)_{critic}$ (critic speed of voltage)

a) $V_T < V_{BO}$

$V_T = 1000$ V V_{BO} must be bigger than 1000V.