POWER ELECTRONICS TECHNOLOGY

As the technology for the power semiconductor devices and integrated circuit develops, the potential for applications of power electronics become wider. There are already many power semiconductor devices that are commercially available, however, the development in this direction is continuing.

The power semiconductor devices or power electronic converter fall generally into six categories :
- AC to DC Converter (Controlled Rectifier)
- DC to DC Converter (DC Chopper)
- AC to AC Converter (AC voltage regulator)
- DC to AC Converter (Inverter)
- Static Switches

The design of power electronics converter circuits requires design the power and control circuits.

The voltage and current harmonics that are generated by the power converters can be reduced or minimized with a proper choice of the control strategy.

Power Electronics Application

Power Electronics defined as the application of solid-state (devices) electronics for the control and conversion of electric power.

Power electronics have already found an important place in modern technology and are now used in a great variety of high-power product, including heat controls, light controls, electric motor control, power supplies, vehicle propulsion system and high voltage direct current (HVDC) systems.

Power Electronics Application

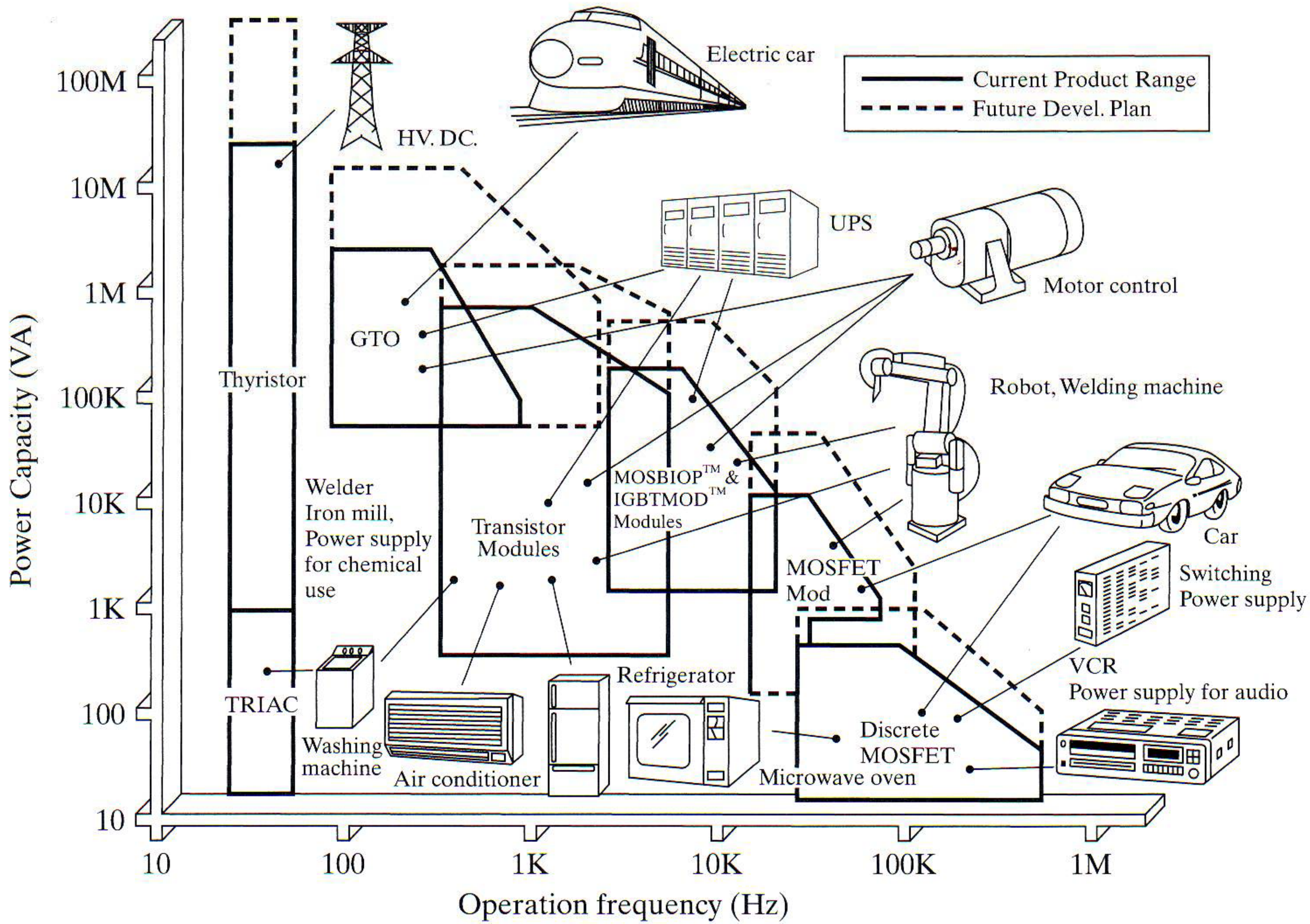


Figure of Power Electronic devices application

Sources of M. Rashid" Power Electronics Circuit, Device and Application, 2006

POWER ELECTRONIC SWITCHING DEVICES

1. Uncontrolled turn on and off (Power Diode)
2. Controlled turn on uncontrolled turn off (Thyristors)
3. Controlled turn on and off characteristic (Power Transistor, BJT, MOSFET, GTO, IGBT)
4. Continuous gate signal requirement (BJT, MOSFET, IGBT)
5. Pulse gate requirement (SCR, GTO)
6. Bipolar voltage-withstanding capability (SCR, GTO)
7. Unipolar voltage-withstanding capability (BJT, MOSFET, GTO, IGBT)
8. Bidirectional current capability (TRIAC)
9. Undirectional current capability (SCR, GTO, BJT, MOSFET, IGBT)

STATIC CONVERTERS

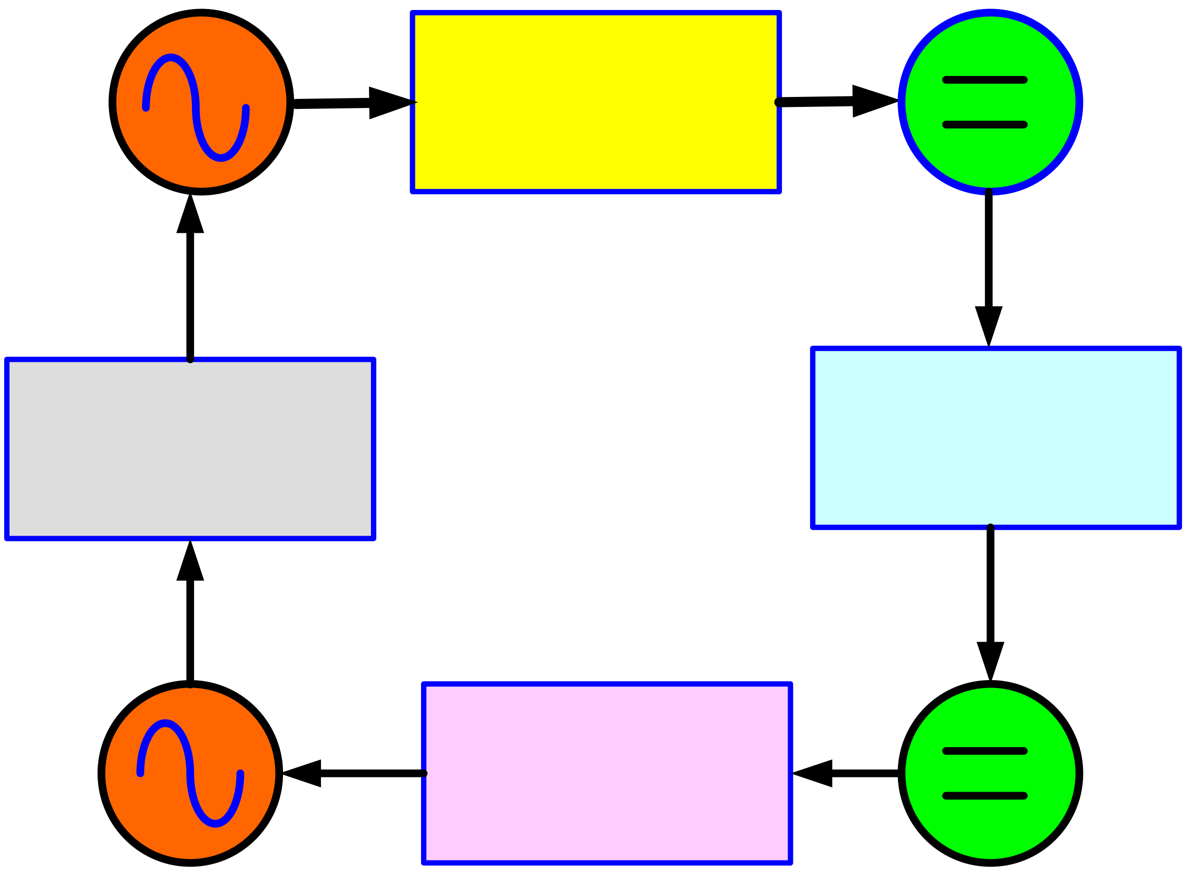
Static converter is a power electronic converter that can conversion of electric power from one to another.

The static power converters perform these function of power conversion.

The Power Electronic Converter can be classified into six types:

1. **Diode Rectifier**
2. **AC to DC Converter (Controlled Rectifier)**
3. **DC to DC Converter (DC Chopper)**
4. **AC to AC Converter (AC voltage regulator)**
5. **DC to AC Converter (Inverter)**
6. **Static Switches**

Diagram Block of Converters



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Diode Rectifiers. A diode rectifier circuit converts AC voltage into a fixed DC voltage. The input voltage to rectifier could be either single phase or three phase.

AC to DC Converters. An AC to DC converter circuit can convert AC voltage into a DC voltage. The DC output voltage can be controlled by varying the firing angle of the thyristors. The AC input voltage could be a single phase or three phase.

AC to AC Converters. This converters can convert from a fixed ac input voltage into variable AC output voltage. The output voltage is controlled by varying firing angle of TRIAC. These type converters are known as AC voltage regulator.

DC to DC Converters. These converters can converter a fixed DC input voltage into variable DC voltage or vice versa. The DC output voltage is controlled by varying of duty cycle.

Static Switch. Because the power devices can be operated as static switches or contactors, the supply to these switches could be either AC or DC and the switches are called as AC static switches or DC static switches.

Example of type of converter

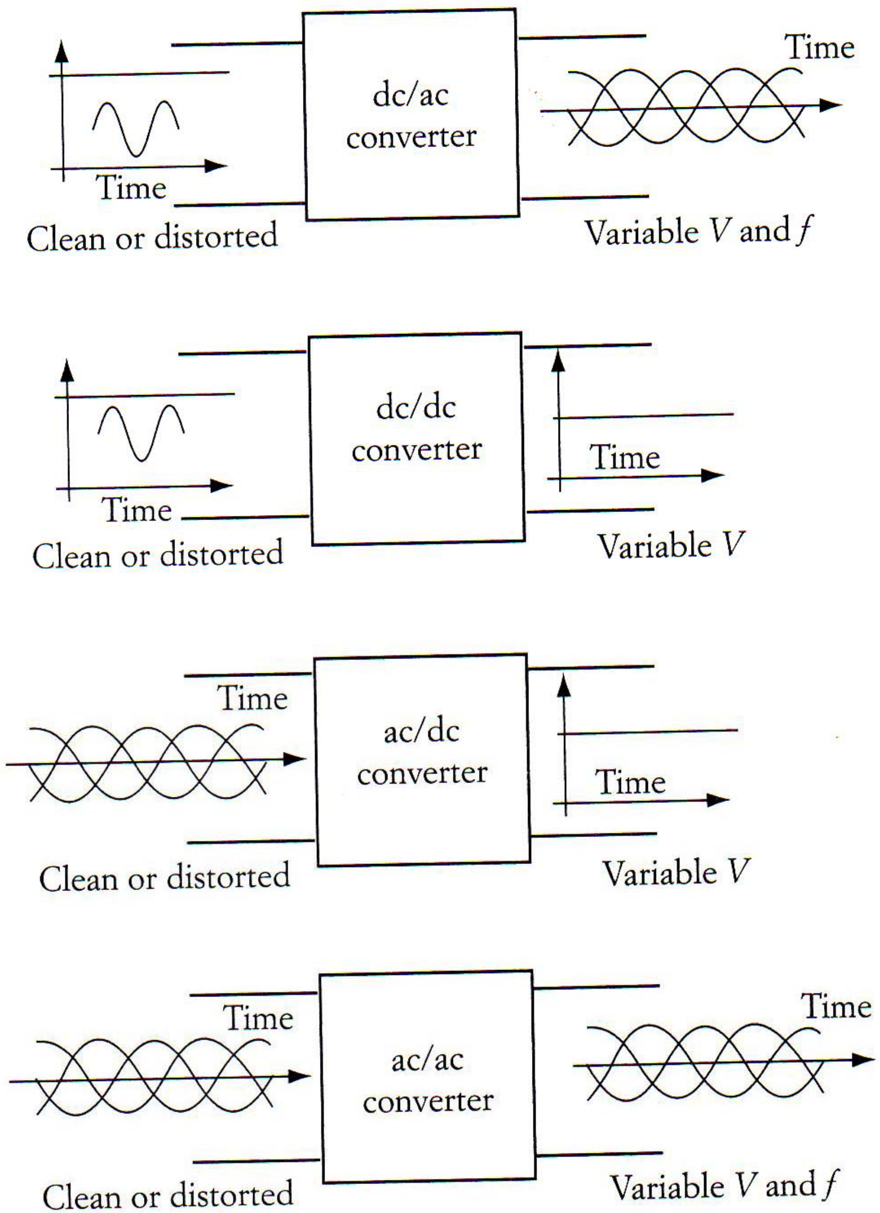


Table of Characteristic and Symbol of Power Electronic Devices

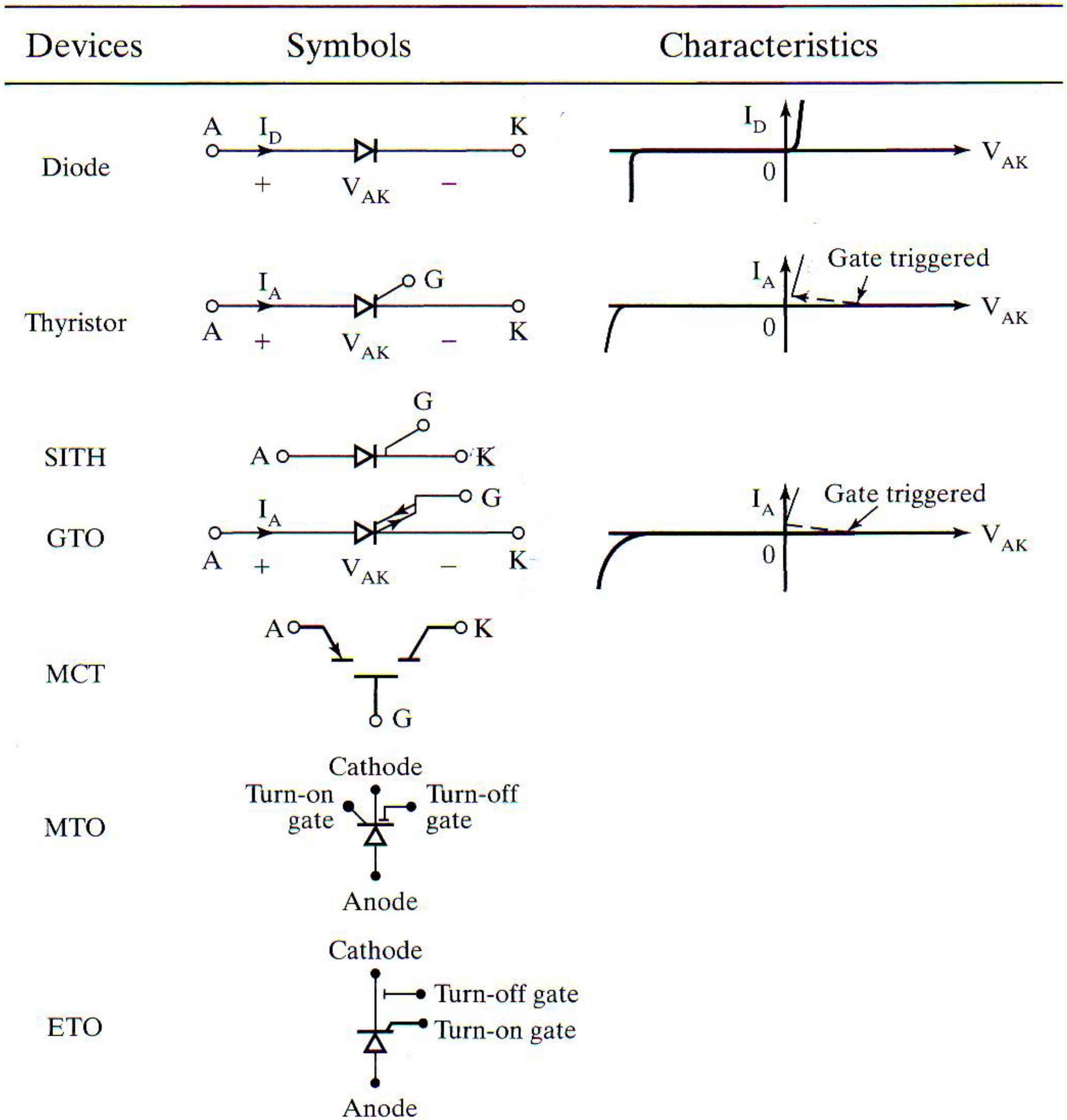
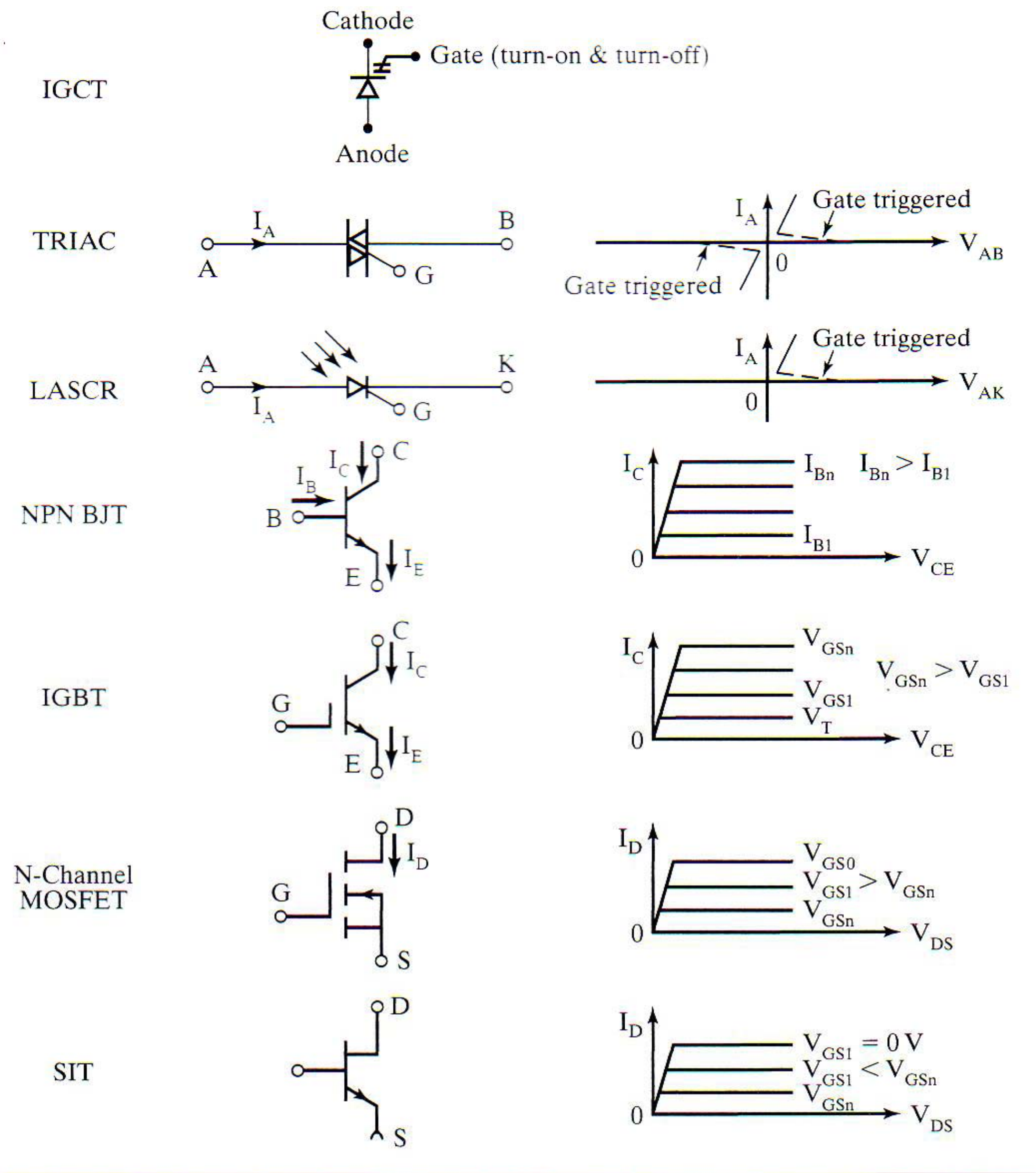
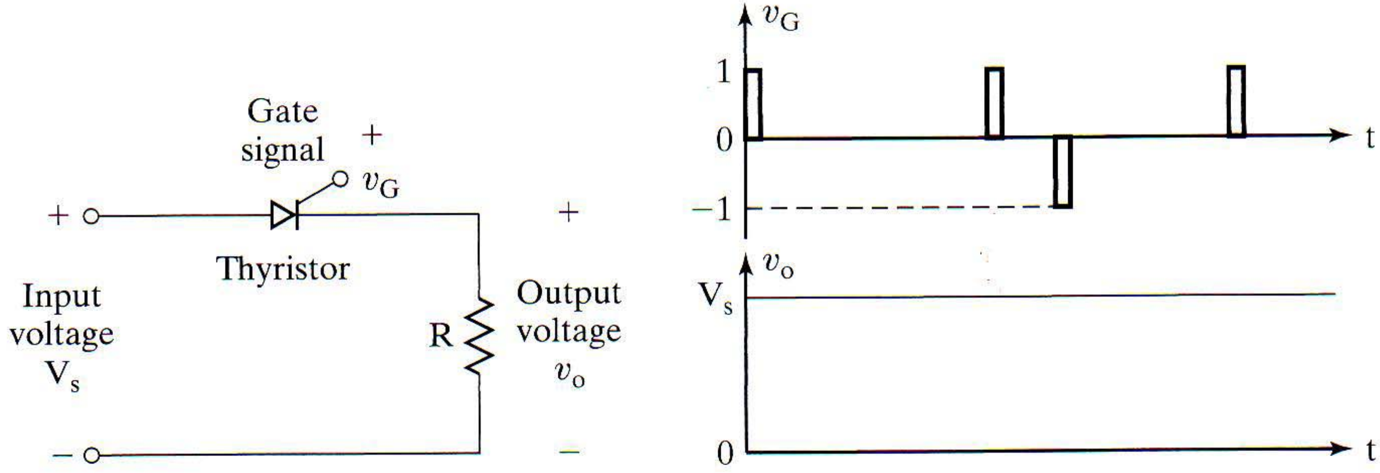


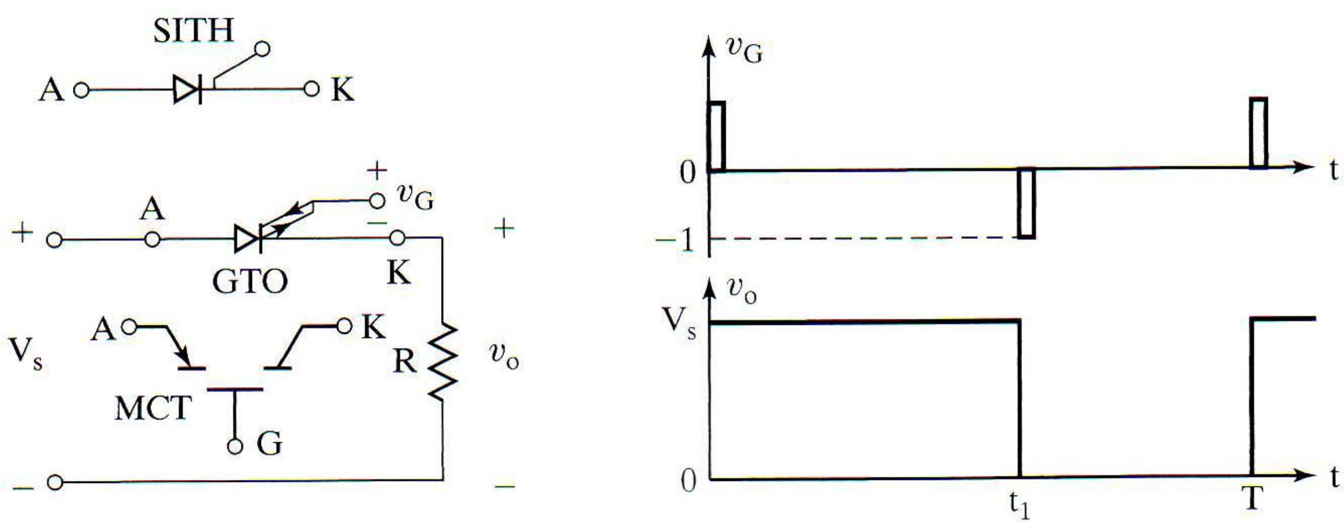
Table of Characteristic and Symbol of Power Electronic Devices



Control Characteristic of Power Electronic Devices



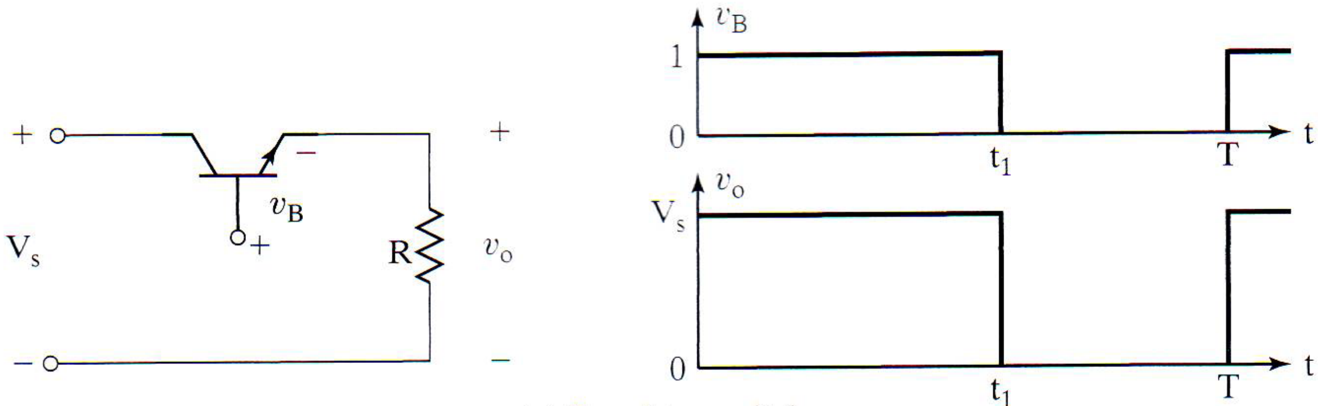
(a) Thyristor switch



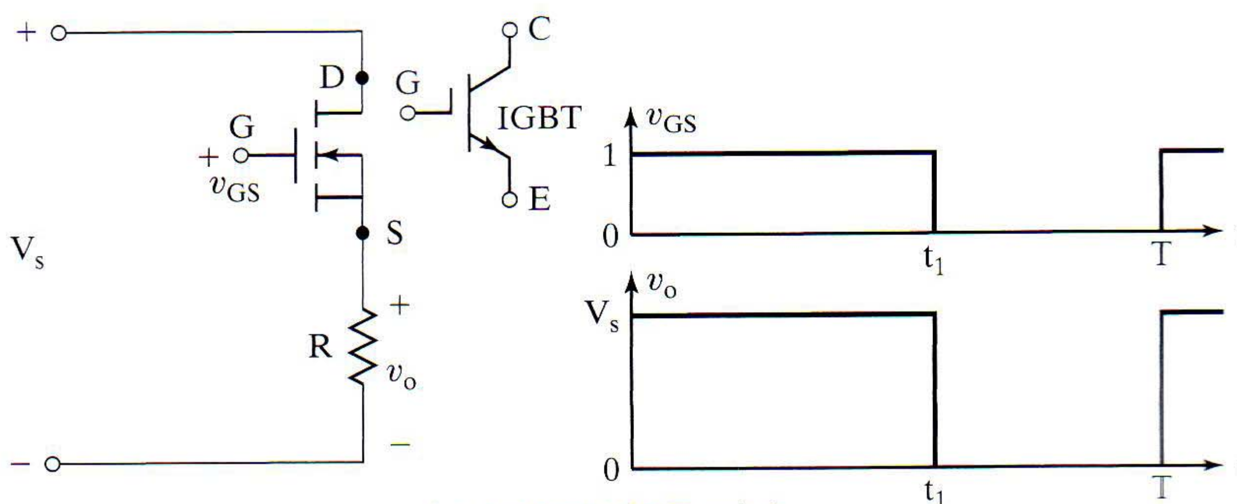
(b) GTO/MTO/ETO/IGCT/MCT/SITH switch (For MCT. the polarity of V_G is reversed as shown)

Control Characteristic of Power Electronic Devices

(b) GTO/MTO/ETO/IGCT/MCT/SITH switch (For MCT, the polarity of V_G is reversed as shown)



(c) Transistor switch

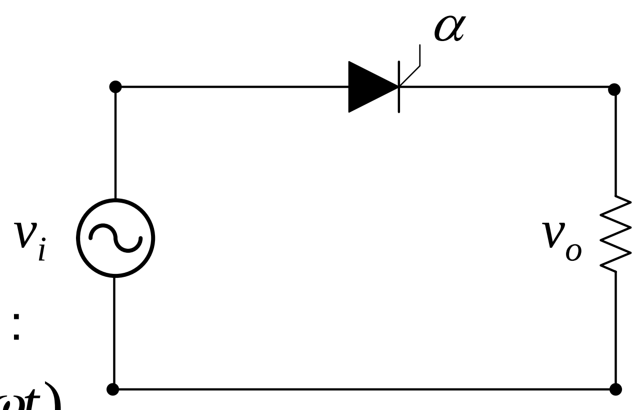


(d) MOSFET/IGBT switch

CONVERTERS

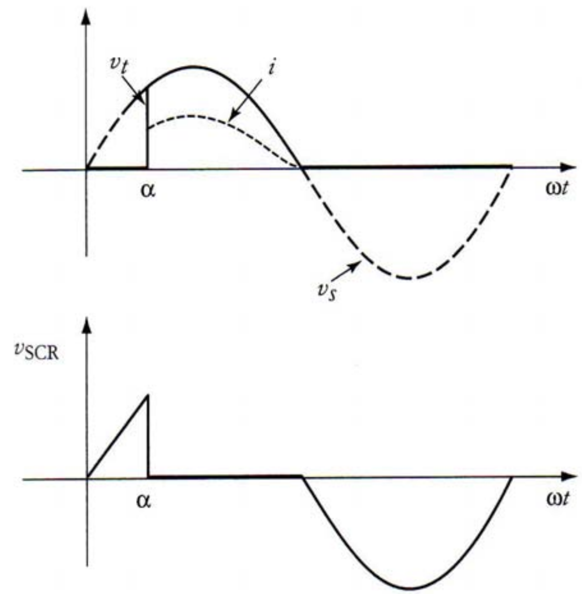
1. AC to DC Converters

- Single phase, half wave AC to DC converter



Input voltage :

$$v_i = V_m \sin(\omega t)$$



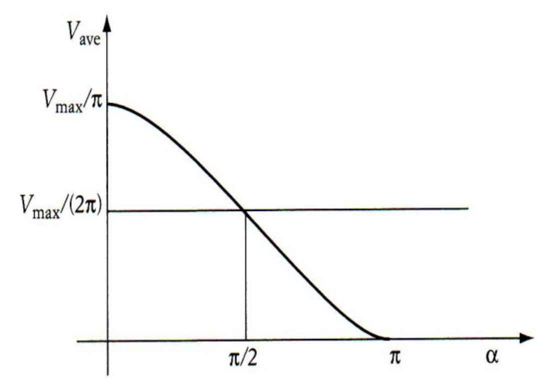
Waveform of single-phase, half wave AC to DC converter

Output average voltage :

$$v_{o\,av} = v_{dcav} = \frac{V_m}{2\pi}\left(1 + \cos\alpha\right)$$

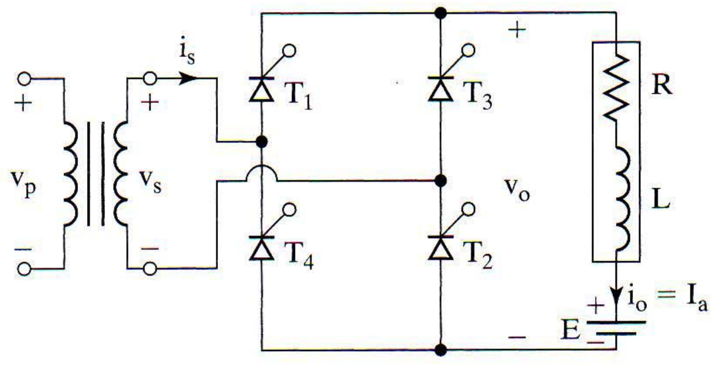
rms value of Output voltage :

$$V_{o\,rms} = V_{dc\,rms} = \frac{V_m}{2}\sqrt{\left[1 - \frac{\alpha}{\pi} + \frac{\sin(2\alpha)}{2\pi}\right]}$$

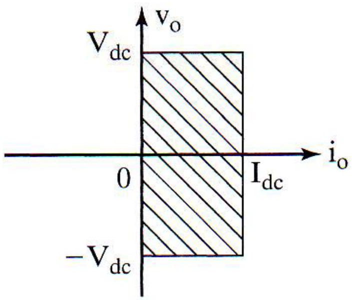


1. AC to DC Converters

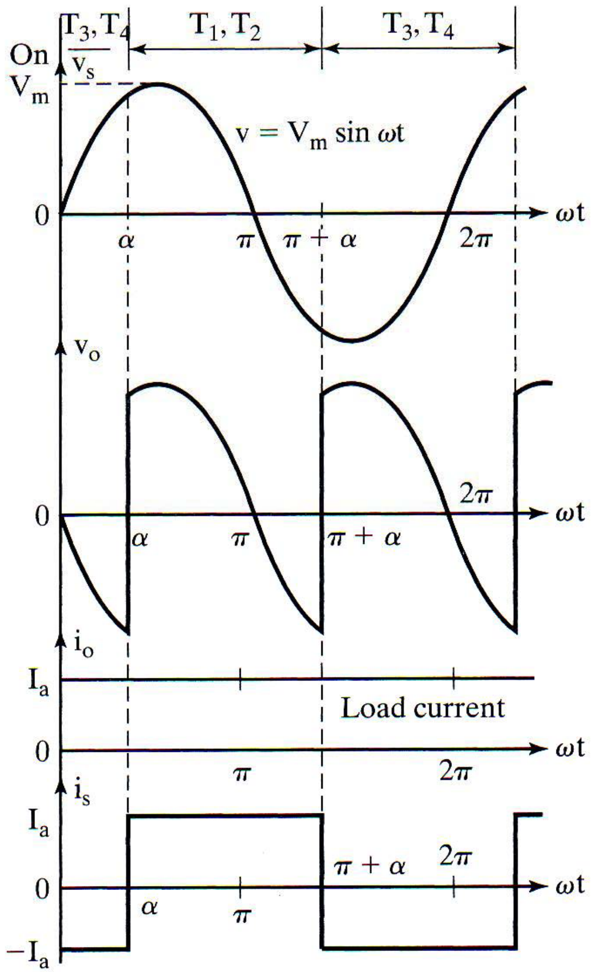
- Single phase, Full wave AC to DC converter



(a) Circuit



(b) Quadrant



(c) Waveforms

The average output voltage can be found from :

$$V_{dc} = \frac{2}{2\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin \omega t \, d(\omega t) = \frac{2V_m}{2\pi}\left[-\cos \omega t\right]_{\alpha}^{\pi+\alpha}$$

$$= \frac{2V_m}{\pi} \cos \alpha$$

1. AC to DC Converters (cont)

- Single phase, Full wave AC to DC converter

The rms value of the output voltage is given by

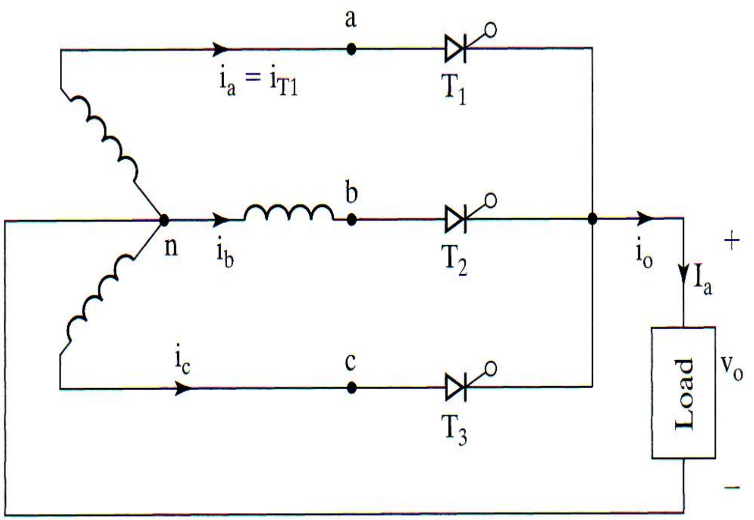
$$V_{rms} = \left[\frac{2}{2\pi}\int_{\alpha}^{\pi+\alpha} V_m^2 \sin^2 \omega t \, d(\omega t)\right]^{1/2} = \left[\frac{V_m^2}{2\pi}\int_{\alpha}^{\pi+\alpha} (1 - \cos 2\omega t)\, d(\omega t)\right]^{1/2}$$

$$= \frac{V_m}{\sqrt{2}} = V_s$$

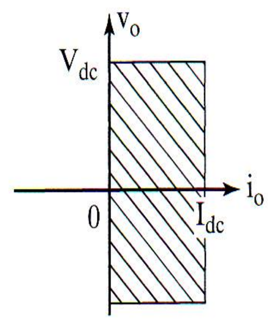
With a purely resistive load, thyristors T_1 and T_2 can conduct from α to π, and thyristors T_3 and T_4 can conduct from $\alpha + \pi$ to 2π.

1. AC to DC Converters

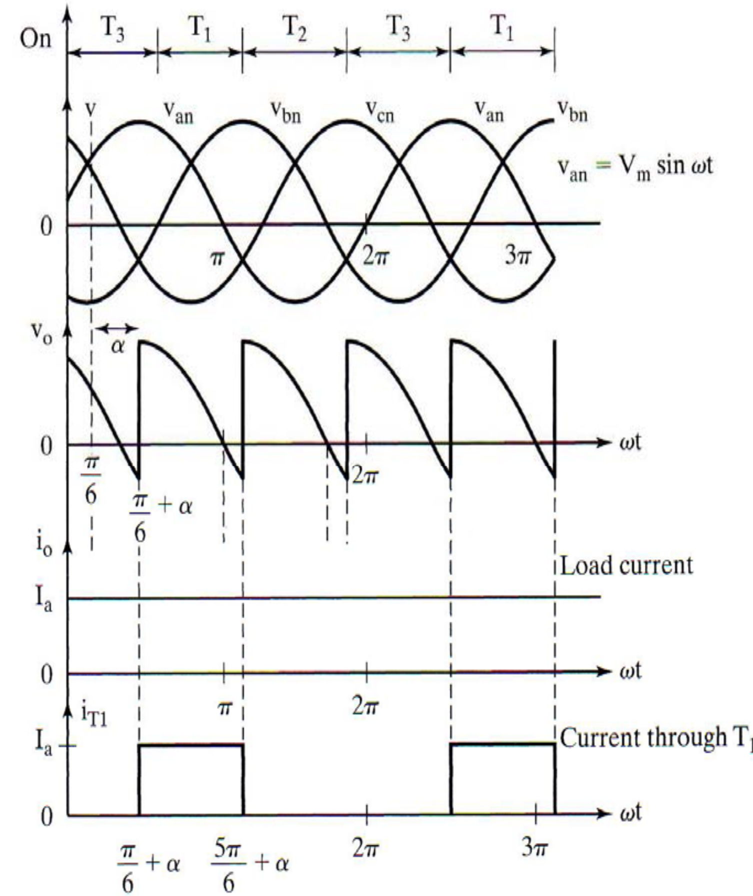
- Three-phase, Half wave AC to DC converter



(a) Circuit



(b) Quadrant



(c) For inductive load

If the phase voltage is : $v_{an} = V_m \sin\alpha$ **the average output voltage for a continuous load current is :**

$$V_{dc} = \frac{3}{2\pi}\int_{\pi/6+\alpha}^{5\pi/6+\alpha} V_m \sin \omega t \, d(\omega t) = \frac{3\sqrt{3}\,V_m}{2\pi}\cos\alpha$$

1. AC to DC Converters (cont)

- Three-phase, Half wave AC to DC converter

The rms output voltage is found from

$$V_{\text{rms}} = \left[\frac{3}{2\pi}\left[\int_{\pi/6+\alpha}^{5\pi/6+\alpha} V_m^2 \sin^2\omega t \, d(\omega t)\right]\right]^{1/2}$$

$$= \sqrt{3}V_m\left(\frac{1}{6} + \frac{\sqrt{3}}{8\pi}\cos 2\alpha\right)^{1/2}$$

For a resistive load and $\alpha \geq \pi/6$:

$$V_{\text{dc}} = \frac{3}{2\pi}\int_{\pi/6+\alpha}^{\pi} V_m \sin \omega t \, d(\omega t) = \frac{3V_m}{2\pi}\left[1 + \cos\left(\frac{\pi}{6} + \alpha\right)\right]$$

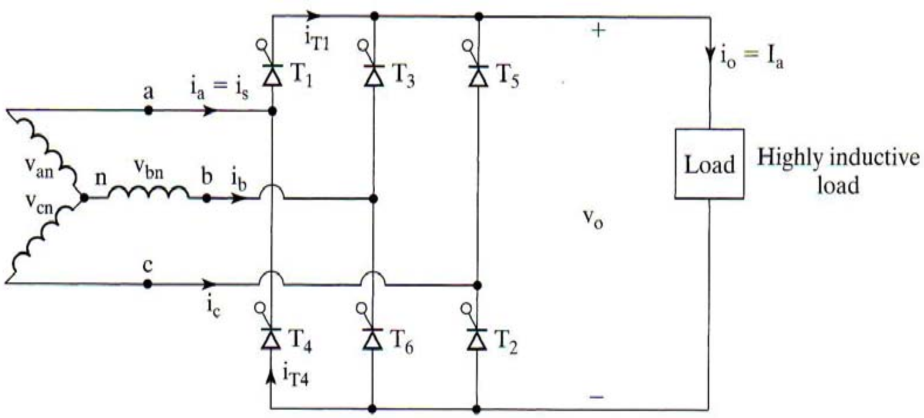
$$V_n = \frac{V_{\text{dc}}}{V_{dm}} = \frac{1}{\sqrt{3}}\left[1 + \cos\left(\frac{\pi}{6} + \alpha\right)\right]$$

$$V_{\text{rms}} = \left[\frac{3}{2\pi}\int_{\pi/6+\alpha}^{\pi} V_m^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$$

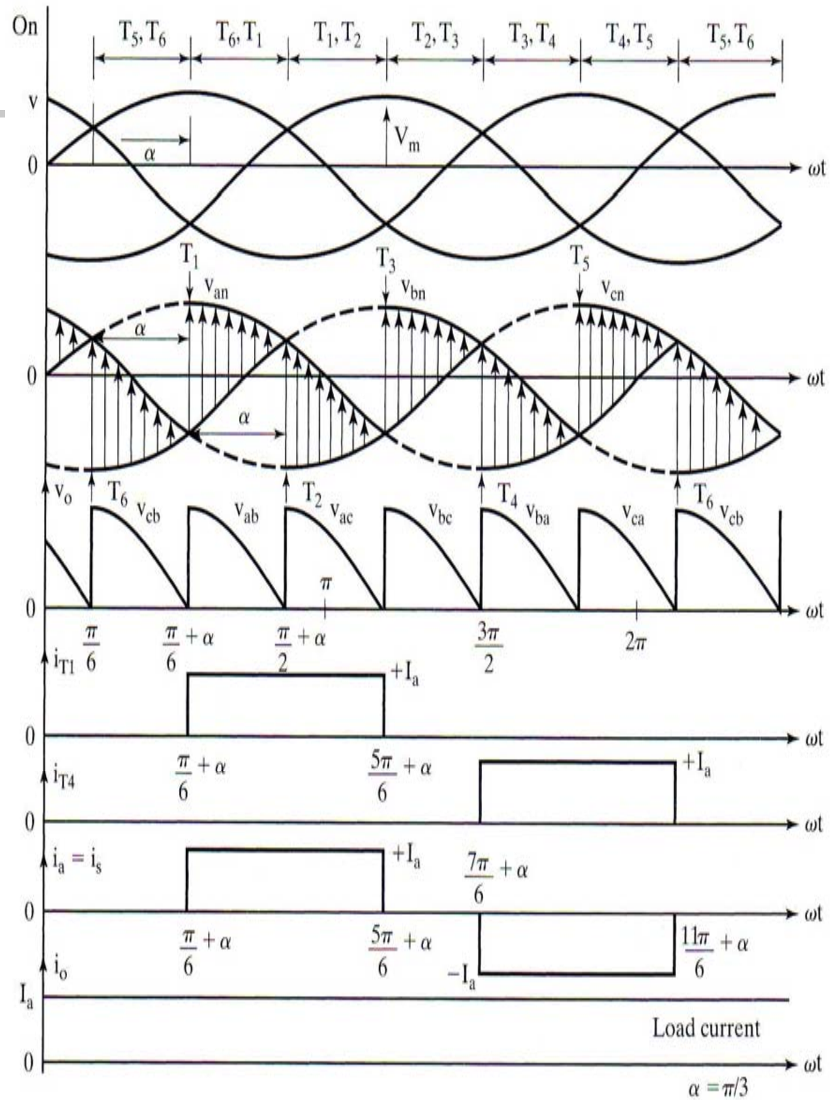
$$= \sqrt{3}\,V_m\left[\frac{5}{24} - \frac{\alpha}{4\pi} + \frac{1}{8\pi}\sin\left(\frac{\pi}{3} + 2\alpha\right)\right]^{1/2}$$

1. AC to DC Converters (cont)

- Three-phase, Full Wave AC to DC converter



(a) Circuit



(b) Waveforms

If the line-to-neutral voltages are defined as

$$v_{an} = V_m \sin \omega t$$

$$v_{bn} = V_m \sin\left(\omega t - \frac{2\pi}{3}\right)$$

$$v_{cn} = V_m \sin\left(\omega t + \frac{2\pi}{3}\right)$$

the corresponding line-to-line voltages are

$$v_{ab} = v_{an} - v_{bn} = \sqrt{3}\, V_m \sin\left(\omega t + \frac{\pi}{6}\right)$$

$$v_{bc} = v_{bn} - v_{cn} = \sqrt{3}\, V_m \sin\left(\omega t - \frac{\pi}{2}\right)$$

$$v_{ca} = v_{cn} - v_{an} = \sqrt{3}\, V_m \sin\left(\omega t + \frac{\pi}{2}\right)$$

The average output voltage is found from

$$V_{dc} = \frac{3}{\pi}\int_{\pi/6+\alpha}^{\pi/2+\alpha} v_{ab}\, d(\omega t) = \frac{3}{\pi}\int_{\pi/6+\alpha}^{\pi/2+\alpha} \sqrt{3}\, V_m \sin\left(\omega t + \frac{\pi}{6}\right) d(\omega t)$$

$$= \frac{3\sqrt{3}\, V_m}{\pi} \cos \alpha$$

2. DC-DC CONVERTER (DC Chopper)

In many industrial application , DC-DC converter is required to convert a fixed-voltage DC source into a variable-voltage DC source. Like a transformer, DC-DC converter can be used to step down or step up a DC voltage source.

Application :

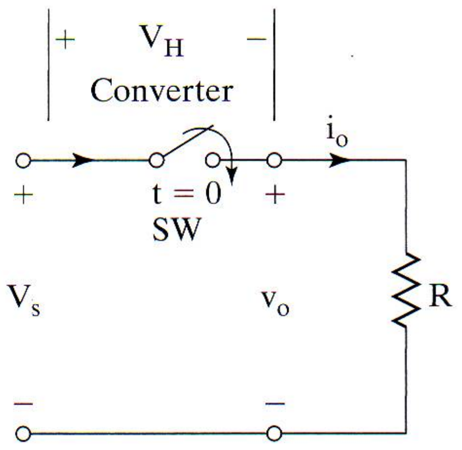
Traction motor control in electric automobiles, trolley cars, marine hoists, forklift trucks, mine haulers, etc

Advantages :

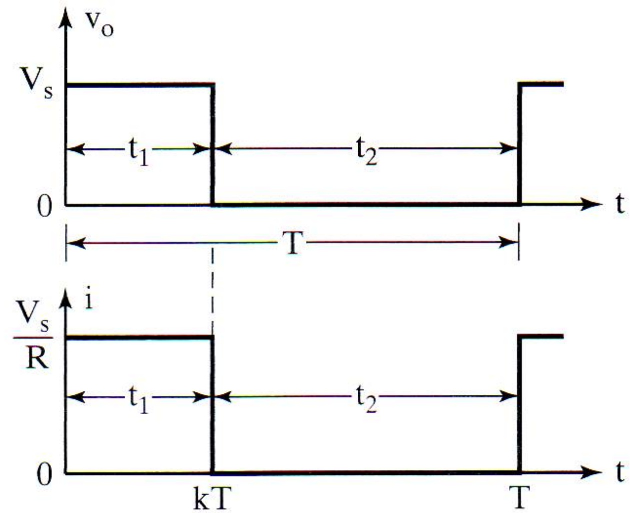
High Efficiency and fast dynamic response

2. DC-DC CONVERTER (DC Chopper)

Principle Of Step-Down Operation



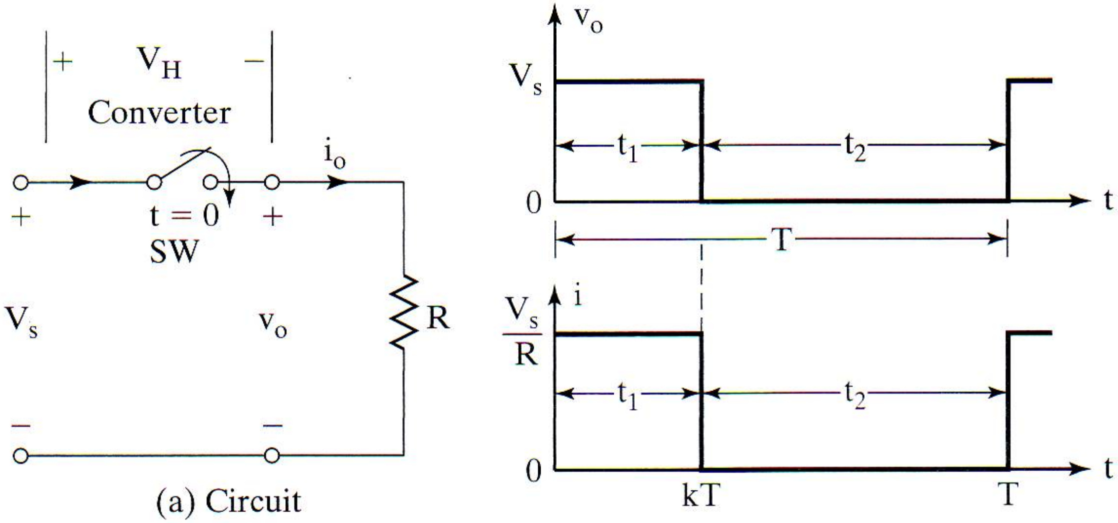
(a) Circuit



(b) Waveforms

When the switch SW is closed for a time t_1, the input voltage V_s appears across the load $V_o = V_s$. If the switch remains off a time t_2, the voltage across the load is zero, $V_o = 0$.

The converter switch SW can be implemented by using Transistor, MOSFET, GTO, IGBT, BJT, etc.



(a) Circuit

(b) Waveforms

The average output voltage is given by :

$$V_o = \frac{1}{T}\int_0^{t_1} v_o \, dt = \frac{t_1}{T} V_S = f\, t_1 V_S = k V_S$$

The average output current is given by :

$$I_o = \frac{V_o}{R} = k \frac{V_S}{R}$$

The average output voltage is given by :

$$V_{orms} = \left(\frac{1}{T}\int_o^{t_1} v_o^2 \, dt \right)^{1/2} = \sqrt{k} \;\; V_s$$

The input power :

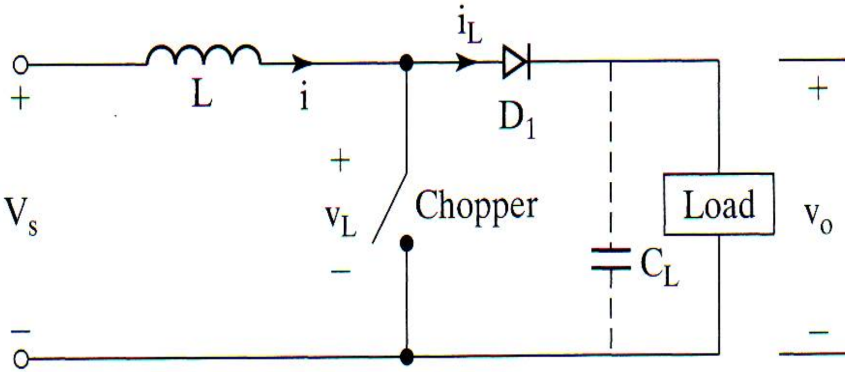
$$P_i = \frac{1}{T}\int_o^{t_1 = kT} v_o \, i \, dt = \frac{1}{T}\int_o^{t_1 = kT} \frac{v_o^2}{R} \, dt = k \frac{V_S^2}{R}$$

Where : T is the chopping period

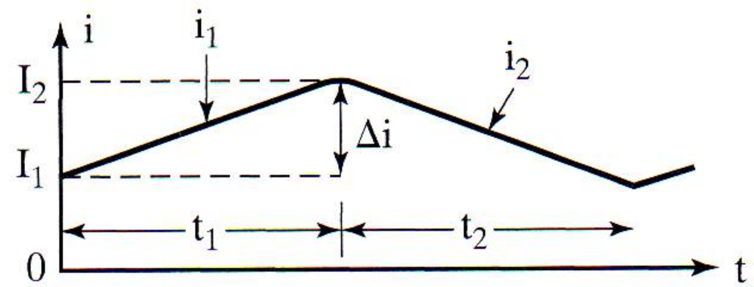
$k = t_1/T$ is the duty cycle

$f = 1/T$ is chopping frequency

STEP-UP DC to DC CONVERTER

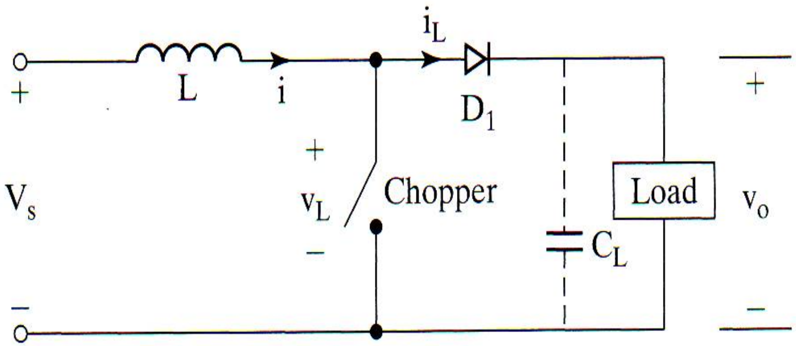


(a) Step-up arrangement

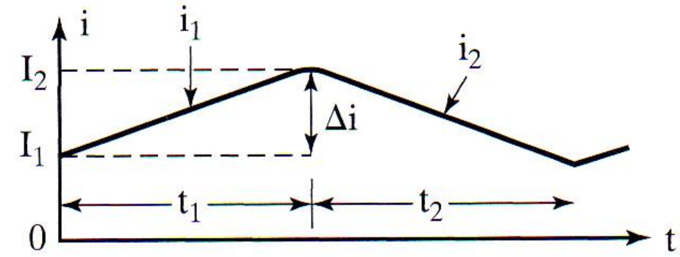


(b) Current waveform

When switch SW is closed for t_1, the inductor current rises and energy is stored in the inductor L. If the switch SW is opened for time t_2, the energy stored in the inductor is transferred to load through diode D_1 and the inductor current falls.



(a) Step-up arrangement



(b) Current waveform

When this DC to DC converter is turned on " switch SW is closed, the voltage across the inductor L is :

$$v_L = L\frac{di}{dt}$$

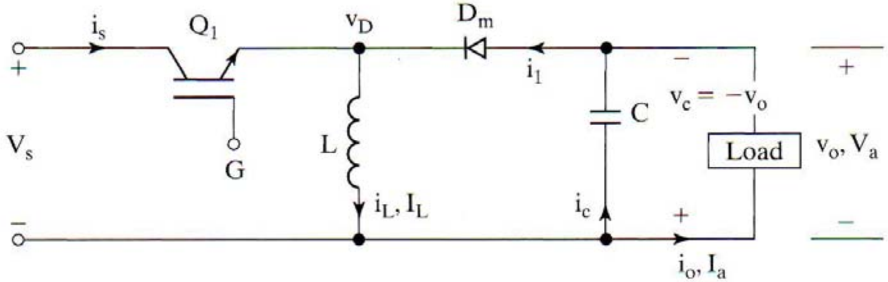
And this gives the peak-to-peak ripple current in inductor as : $\Delta I = \frac{V_s}{L} t_1$

The average output voltage is : $v_o = V_s + L\frac{\Delta I}{t_2} = V_s\left(1 + \frac{t_1}{t_2}\right) = V_s\frac{1}{1-k}$

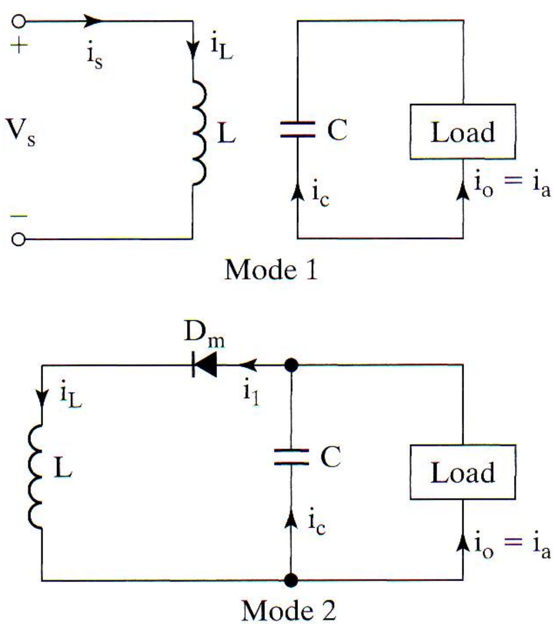
Buck–Boost Regulators

A buck–boost regulator provides an output voltage that may be less than or greater than the input voltage—hence the name "buck–boost"; the output voltage polarity is opposite to that of the input voltage. This regulator is also known as an *inverting regulator*. The circuit arrangement of a buck–boost regulator is shown in Figure

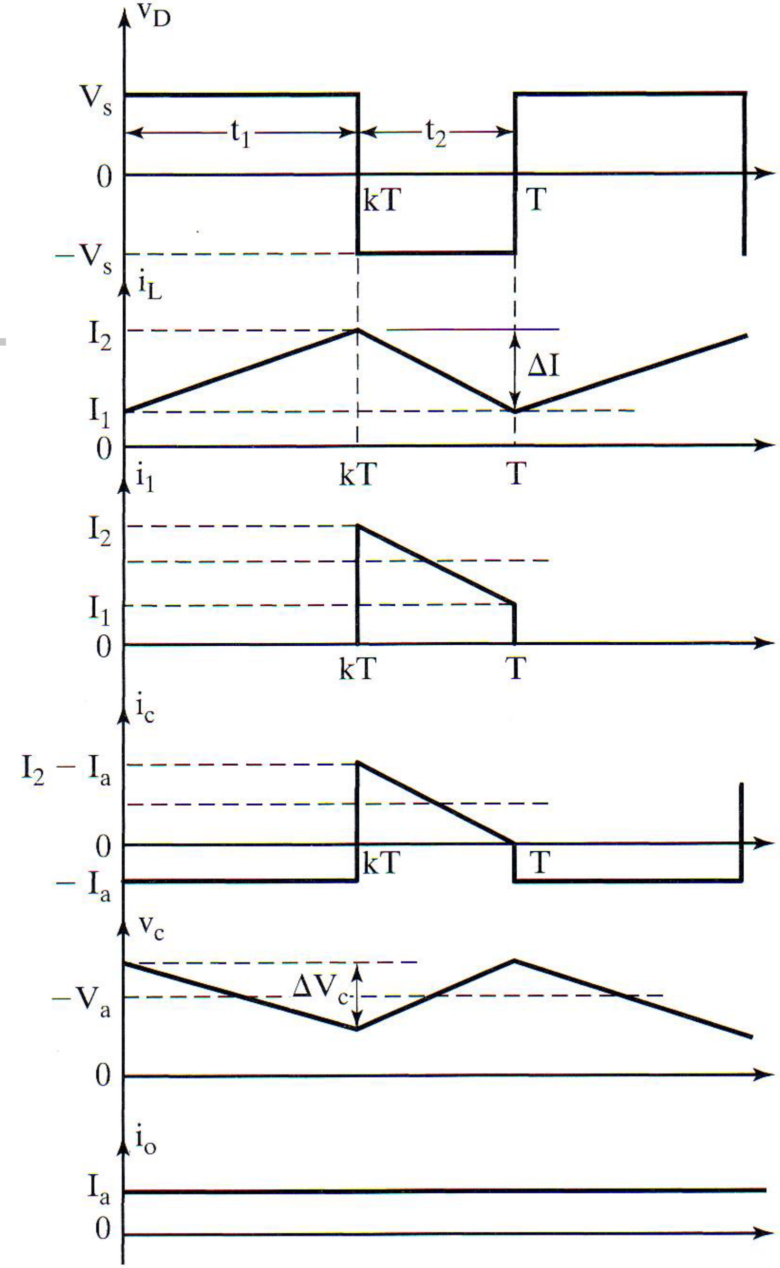
The circuit operation can be divided into two modes. During mode 1, transistor Q_1 is turned on and diode D_m is reversed biased. The input current, which rises, flows through inductor L and transistor Q_1. During mode 2, transistor Q_1 is switched off and the current, which was flowing through inductor L, would flow through L, C, D_m, and the load. The energy stored in inductor L would be transferred to the load and the inductor current would fall until transistor Q_1 is switched on again in the next cycle. The equivalent circuits for the modes are shown in Figure 5.18b. The waveforms for steady-state voltages and currents of the buck–boost regulator are shown in Figure 5.18c for a continuous load current.



(a) Circuit diagram



(b) Equivalent circuits



(c) Waveforms

Assuming that the inductor current rises linearly from I_1 to I_2 in time t_1,

$$V_s = L\frac{I_2 - I_1}{t_1} = L\frac{\Delta I}{t_1}$$

or

$$t_1 = \frac{\Delta I L}{V_s}$$

and the inductor current falls linearly from I_2 to I_1 in time t_2,

$$V_a = -L\frac{\Delta I}{t_2}$$

or

$$t_2 = \frac{-\Delta I L}{V_a}$$

where $\Delta I = I_2 - I_1$ is the peak-to-peak ripple current of inductor L. From Eqs.

$$\Delta I = \frac{V_s t_1}{L} = \frac{-V_a t_2}{L}$$

Substituting $t_1 = kT$ and $t_2 = (1 - k)T$, the average output voltage is

$$V_a = -\frac{V_s k}{1 - k}$$

Substituting $t_1 = kT$ and $t_2 = (1 - k)T$ into Eq. (5.78) yields

$$(1 - k) = \frac{-V_S}{V_a - V_S}$$

Substituting $t_2 = (1 - k)T$, and $(1 - k)$ from Eq. (5.79) into Eq. (5.78) yields

$$t_1 = \frac{V_a}{(V_a - V_S)f}$$

Assuming a lossless circuit, $V_s I_s = -V_a I_a = V_s I_a k/(1 - k)$ and the average input current I_s is related to the average output current I_a by

$$I_s = \frac{I_a k}{1 - k}$$