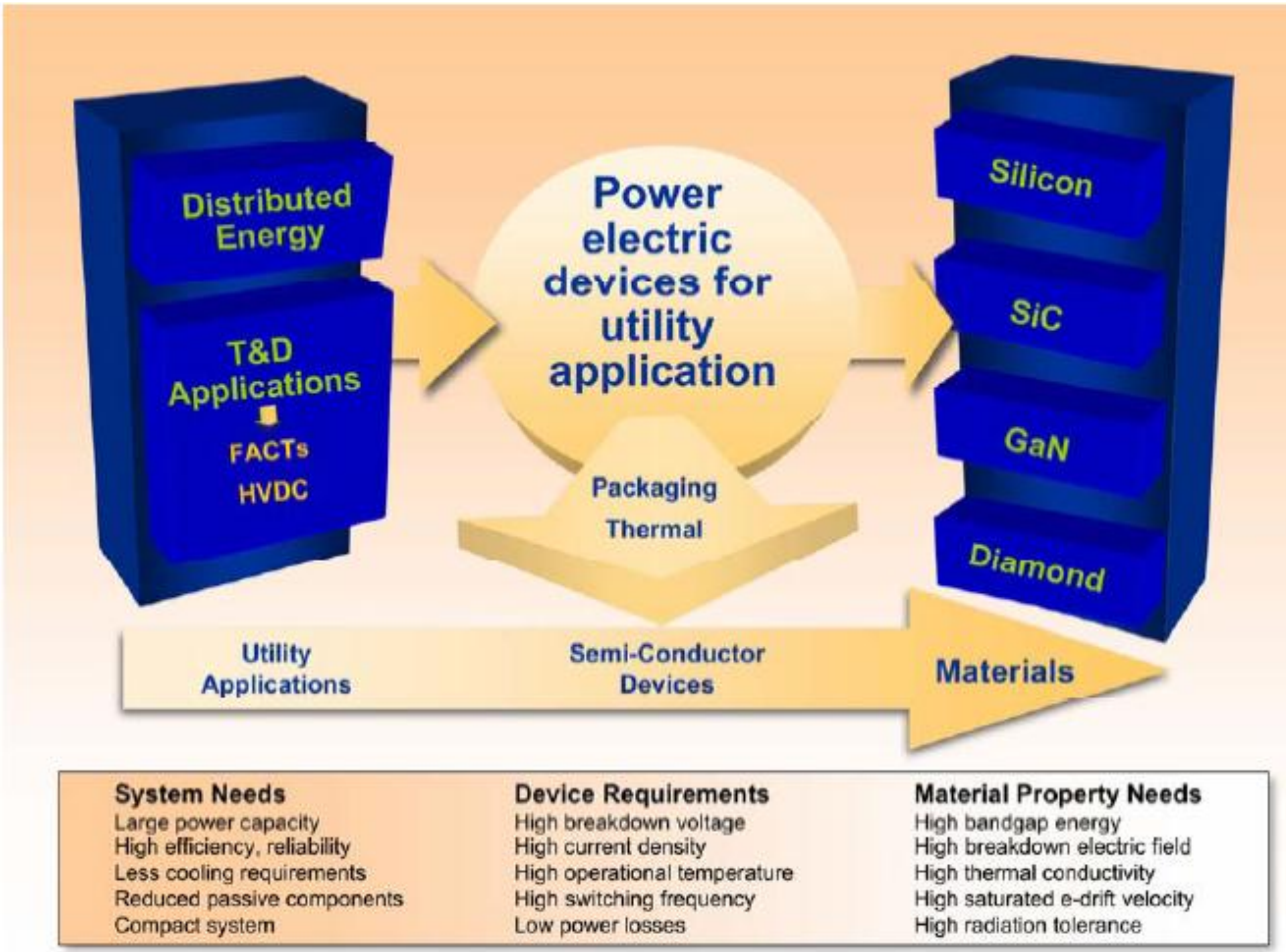
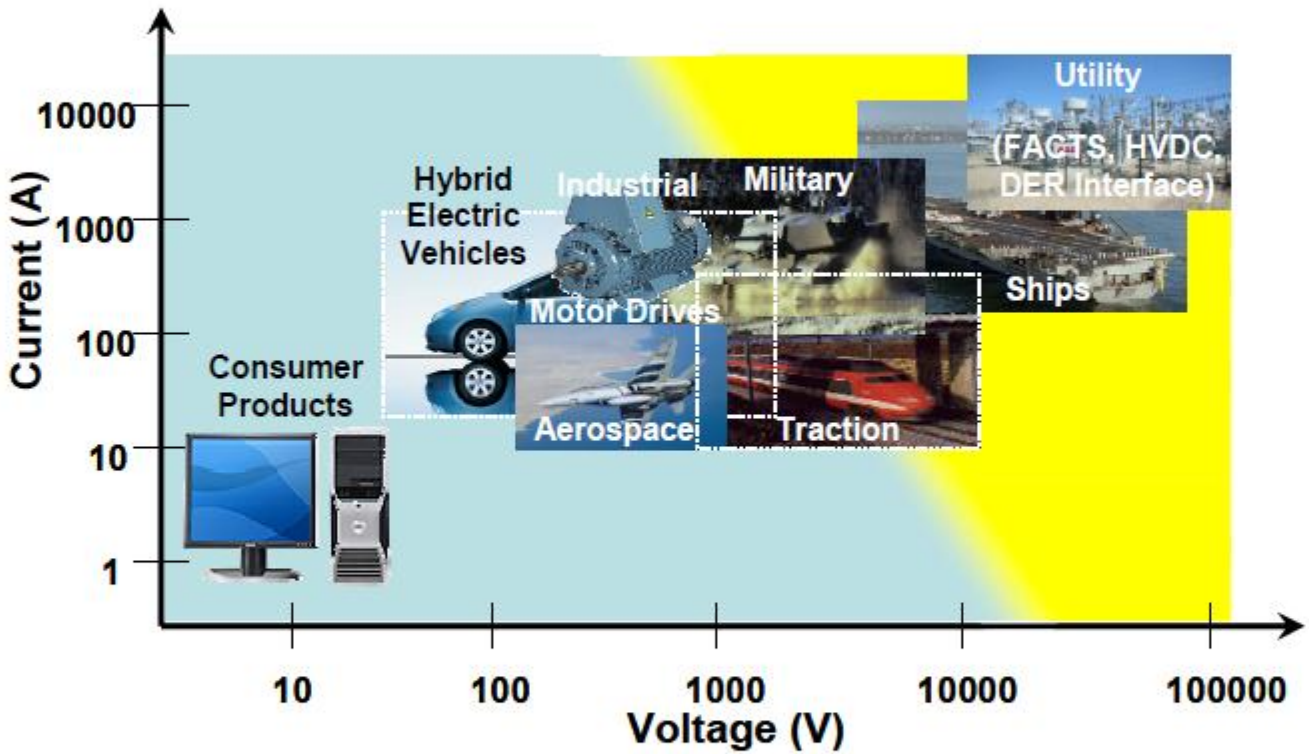
Utility Applications of Power Electronics



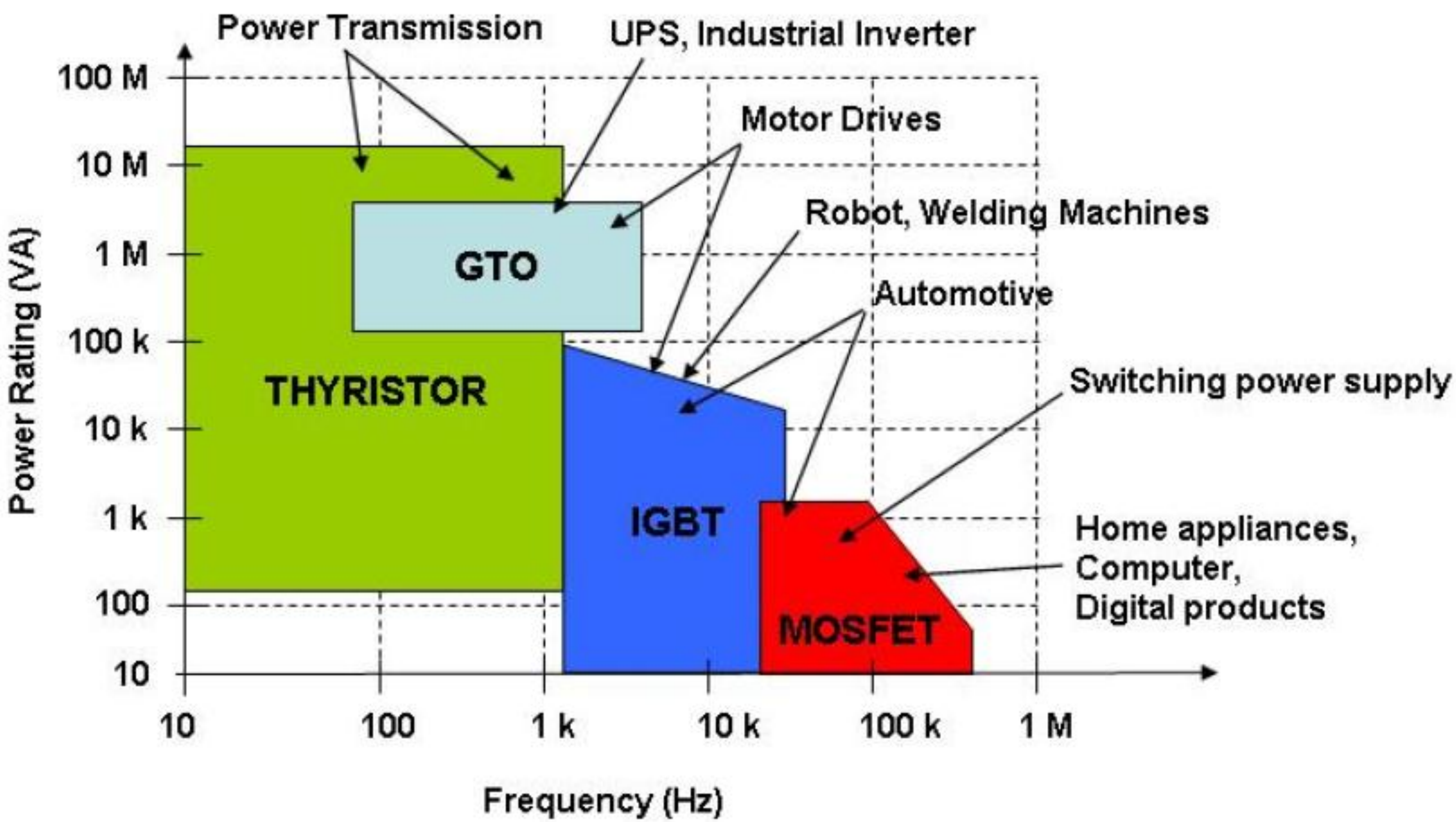
Utility Applications of Power Electronics

- The applications of power electronics exist in many forms within the electric power system including:
  - High-Voltage Direct Current (HVDC) converter stations.
  - Flexible AC Transmission System (FACTS) devices.
- The above systems are used to control and regulate AC power grids, to variable-speed drives for motors; interfaces with storage devices of several types, interfacing of distributed energy resources (DER) with the grid, electric drives in transportation systems, fault current–limiting devices, solid-state distribution transformers, and transfer switches.

Required Power for Power Electronics



Typical Applications of Power Electronics Switches



Switches for Power Electronics
Thyristors

GTO and ICGT

The GTO, makes it possible to build efficient converters for output frequency control. The development of the GTO opened the way to high-power variable-speed ac motor drives and other similar applications because a GTO, unlike a thyristor, can be turned off by injecting a large negative current to the gate. ICGT represents an integrated gate drive unit.

MOSFET

Power MOSFETs are unipolar, majority carrier, voltage-controlled devices, making them superior to bipolar devices (BJTs and IGBTs) in faster switching speeds, lower switching losses, and simpler gate drives. The gate is composed of a silicon dioxide layer, called metal oxide, that normally insulates the source from the drain. Once a forward-biased voltage is applied to the gate with respect to the source, the source becomes electrically conductive to the drain, allowing the flow of appreciable currents.

IGBT

The IGBT is one of the most popular power electronic devices at present. The IGBT combines the high-impedance, low-power gate input of a MOSFET with the power handling capacity of bipolar transistors and thyristors. The MOS gate allows a high impedance control of the current flow through the device, requiring extremely small amounts of power supplied to the control gate.

Switches Comparison

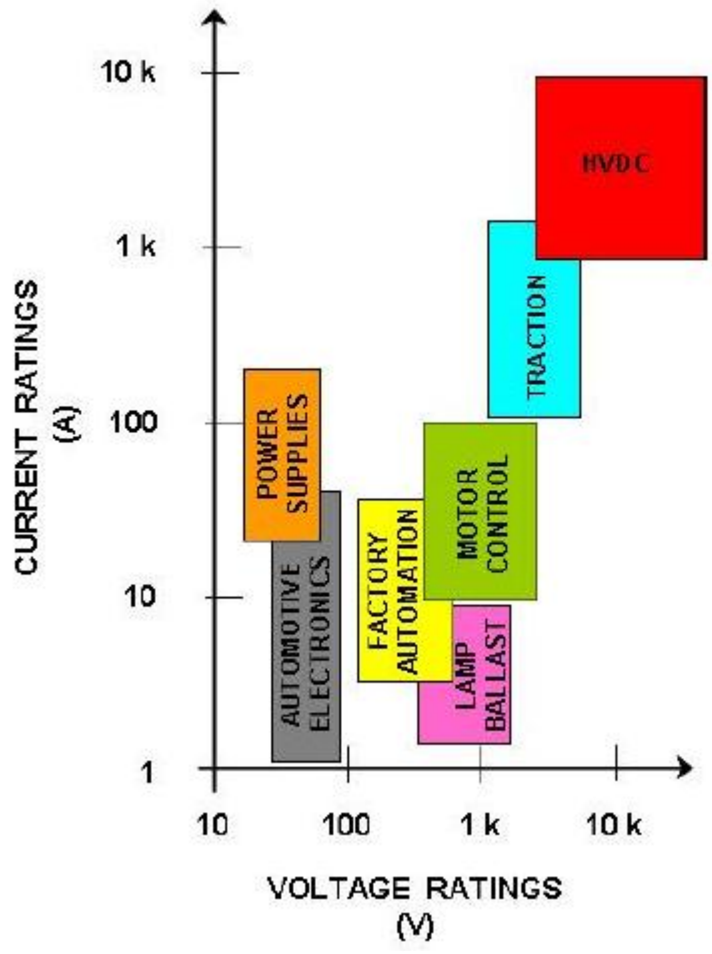
	Thy	BJT	FET	GTO	IGBT	IGCT
Avail-abilty	Early 60s	Late 70s	Early 80s	Mid 80s	Late 80s	Mid 90's
State of Tech.	Mature	Mature	Mature/ improve	Mature	Rapid improve	Rapid improvem ent
Voltage ratings	5kV	1kV	500V	5kV	3.3kV	6.5kV
Current ratings	4kA	400A	200A	5kA	1.2kA	4kA
Switch Freq.	na	5kHz	1MHz	2kHz	100kHz	1kHz
On-state Voltage	2V	1-2V	I* Rds (on)	2-3V	2-3V	3V
Drive Circuit	Simple	Difficult	Very simple	Very difficult	Very simple	Simple
Comm-ents	Cannot turn off using gate signals	Phasing out in new product	Good performan ce in high freq.	King in very high power	Best overall performanc e.	Replacing GTO

Source: Dr. Zainal Salam, UTM-JB

Applications

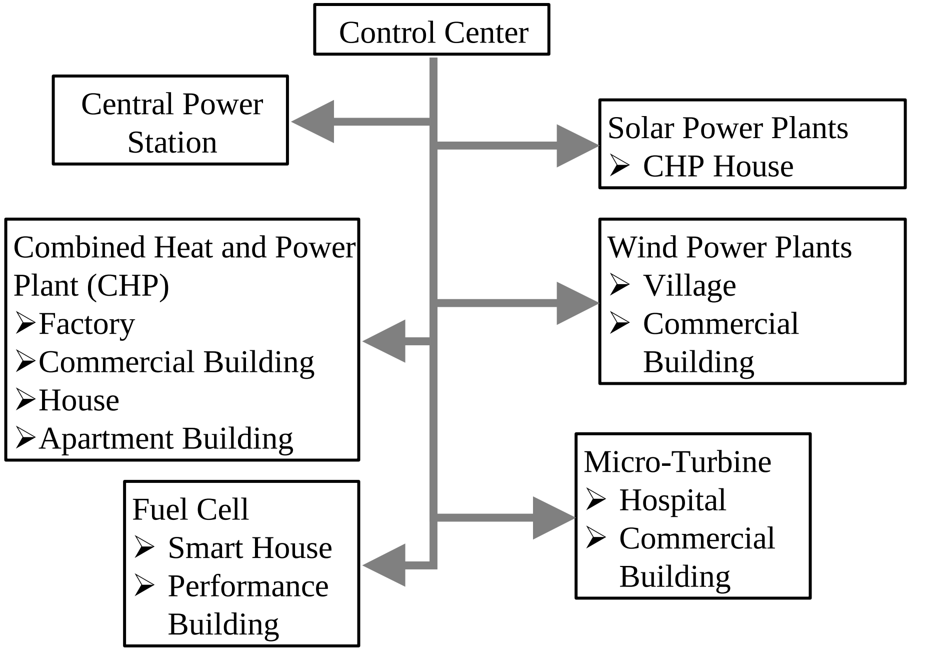
- For each of the following application, choose the best power switches and reason out why.
  - An inverter for the light-rail train (LRT) locomotive operating from a DC supply of 750 V. The locomotive is rated at 150 kW. The induction motor is to run from standstill up to 200 Hz, with power switches frequencies up to 10 kHz.
  - A switch-mode power supply (SMPS) for remote telecommunication equipment is to be developed. The input voltage is obtained from a photovoltaic array that produces a maximum output voltage of 100 V and a minimum current of 200 A. The switching frequency should be higher than 100 kHz.
  - A HVDC transmission system transmitting power of 300 MW from one AC system to another ac system both operating at 50 Hz, and the DC link voltage operating at 2.0 kV.

Voltage and Current Requirements



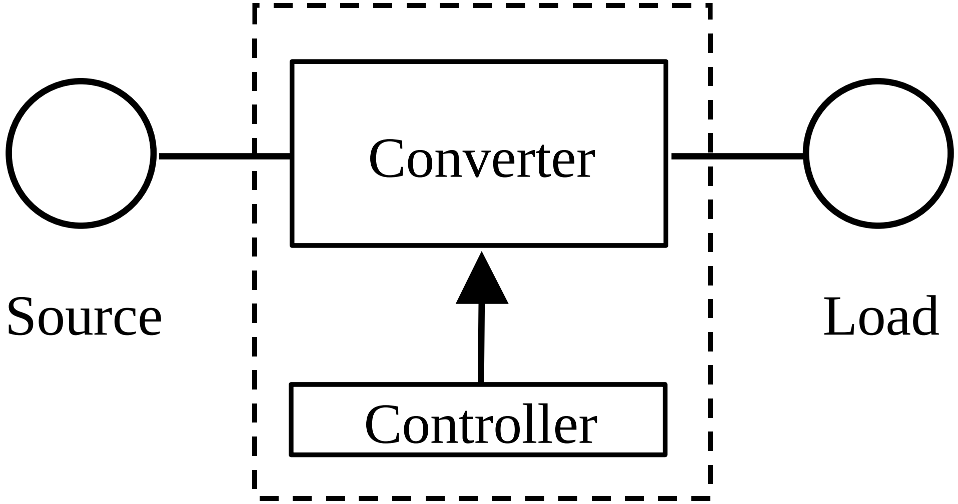
Importance

- Increasing applications of Power Electronic Equipment in Power Systems
  - Availability of high power semiconductor devices
  - Decentralized renewable energy generation sources
  - Increased power transfer with existing transmission system
  - Effective control of power flow needed in a deregulated environment
  - Norms for Power quality



Future Power System

Function of Power Electronics in Utility Applications

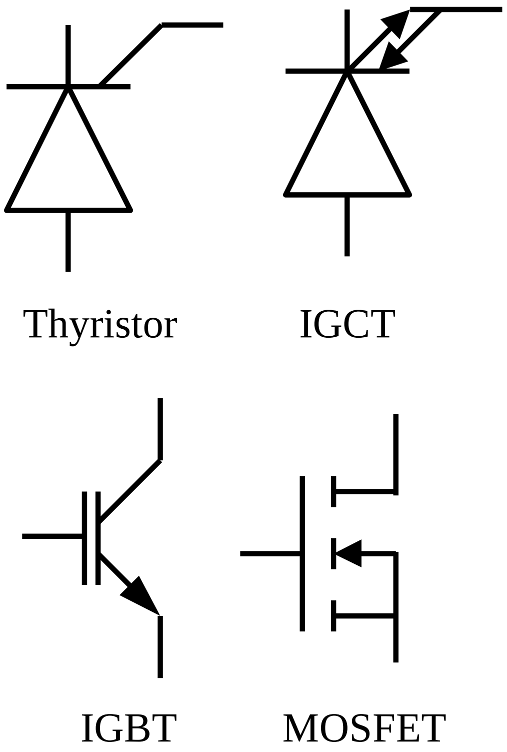


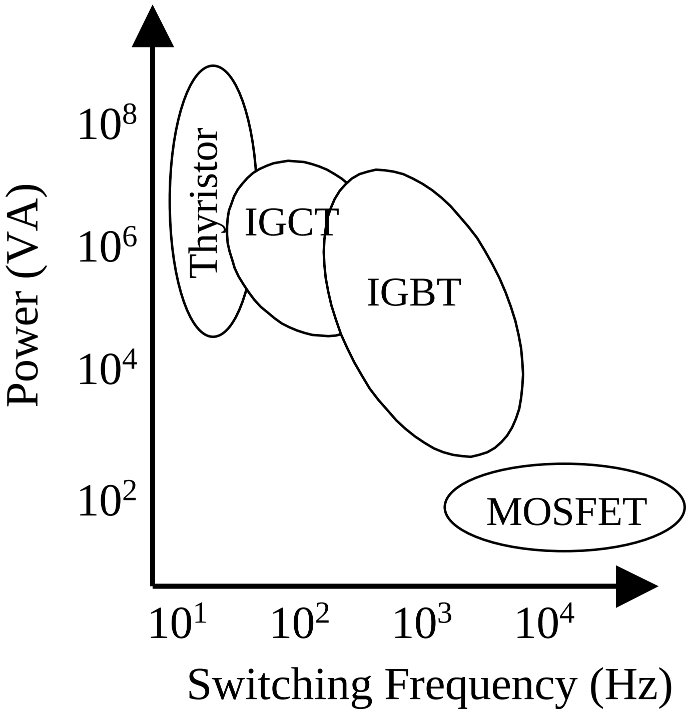
- Enabling technology providing interface between two (ac/dc) electrical systems
- E.g.
  - Interconnection of two asynchronous ac systems.
  - DC to ac conversion is required to connect fuel cells or photovoltaics to the utility grid.

Listing of Power Electronic Applications

- Distributed generation (DG)
  - Renewable resources (wind and photovoltaic)
  - Fuel cells and micro-turbines
  - Storage: batteries, super-conducting magnetic energy storage, flywheels
- Power electronics loads: Adjustable speed drives
- Power quality solutions
  - Dual feeders
  - Uninterruptible power supplies
  - Dynamic voltage restorers
- Transmission and distribution (T&D)
  - High voltage dc (HVDC) and medium voltage dc
  - Flexible AC Transmission Systems (FACTS): Shunt and Series compensation, and the unified power flow controller

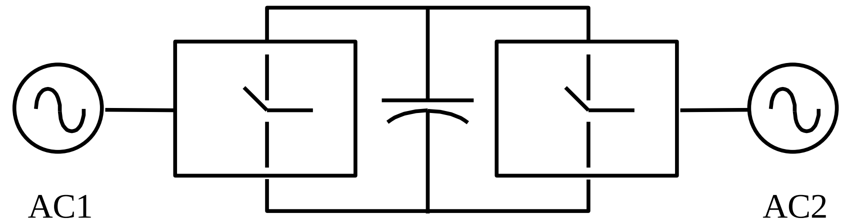
Power Device Capabilities and Resulting Power Electronic Structures



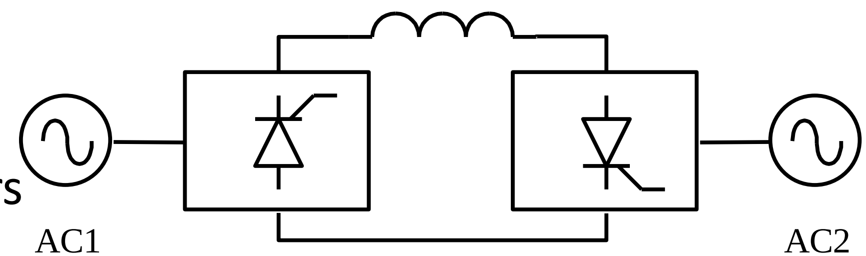


Structure of Power Electronic Systems

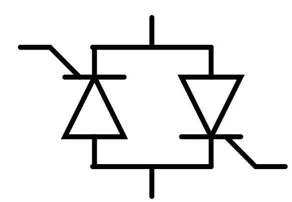
- Voltage-Link Systems
  - Transistors and diodes that can block voltage of only one polarity



- Current-Link Systems
  - higher power bipolar voltage-blocking capabilities of thyristors

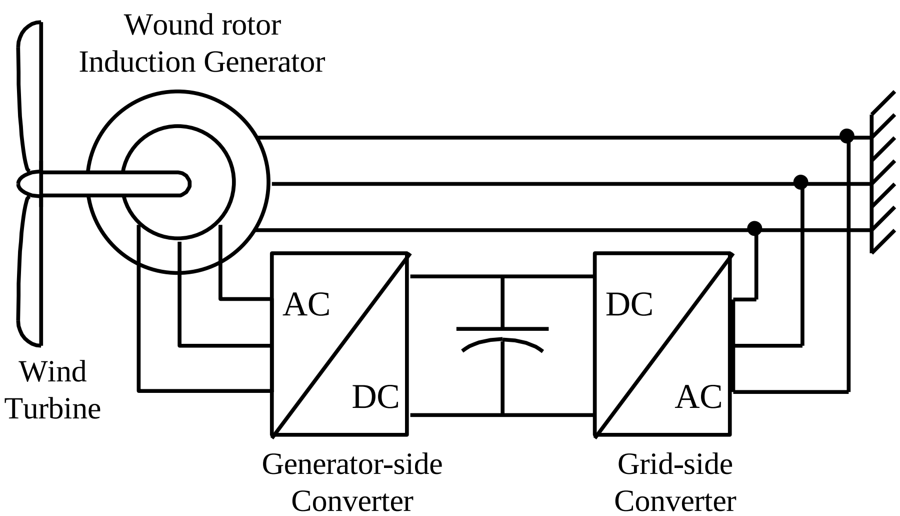


- Solid State Switches
  - bidirectional voltage blocking and current conduction



Role of Power Electronics in Utility Applications

- Distributed Generation (DG) Applications
  Power electronic interface depends on the source characteristics



Wind Power Generation with Doubly Fed Induction Motors

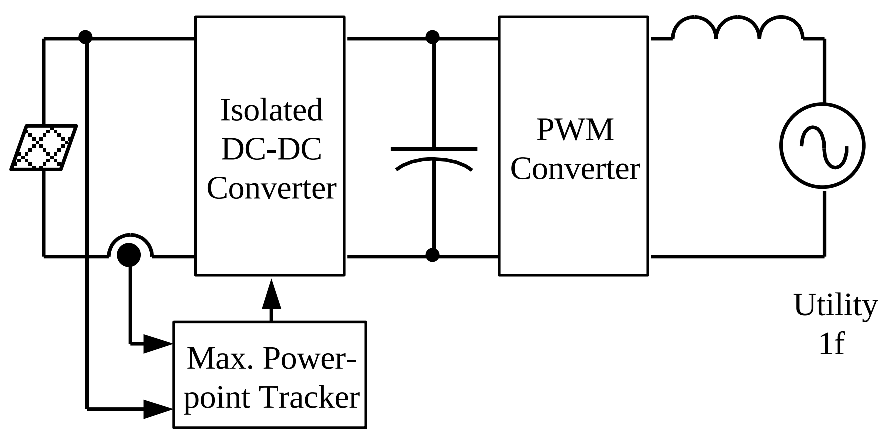
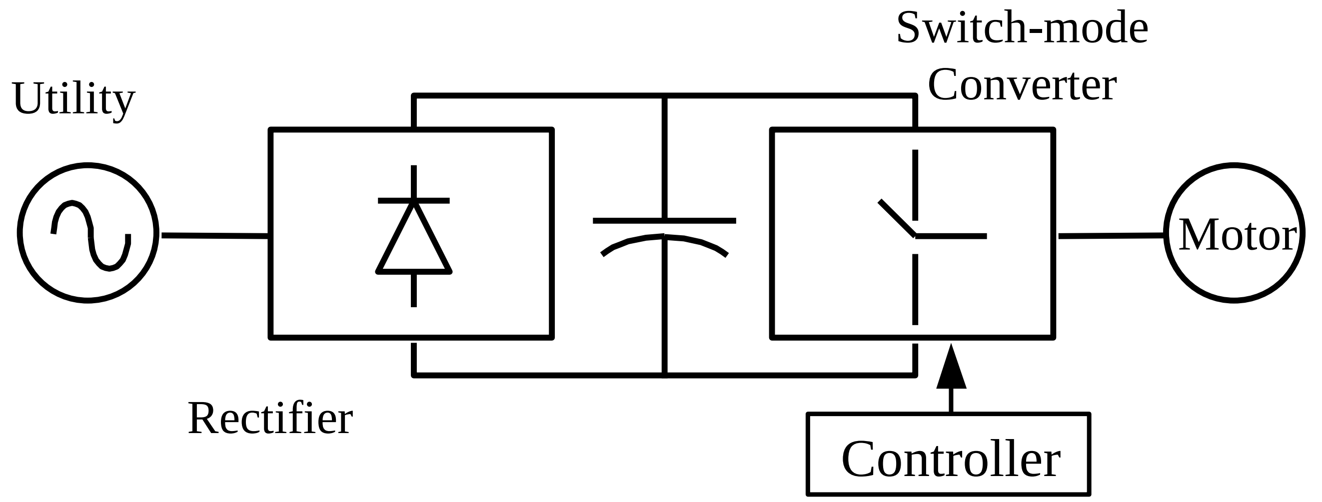


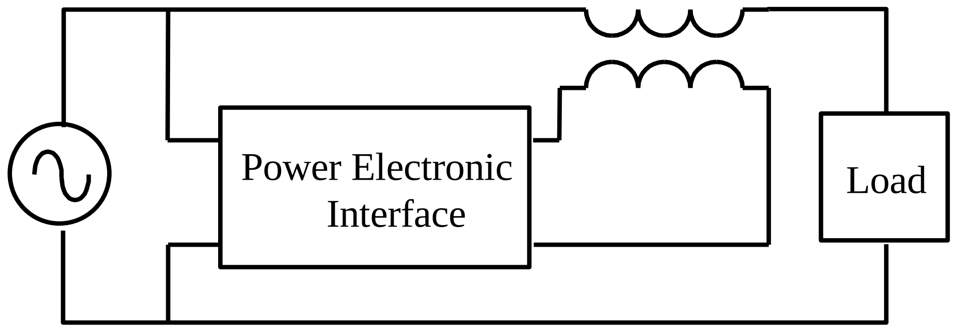
Photo-voltaics Interface

Role of Power Electronics in Utility Applications

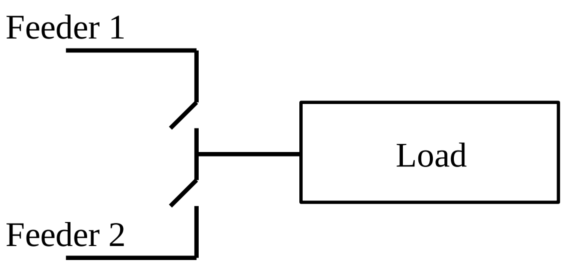
Power Electronic Loads: Adjustable Speed Drives



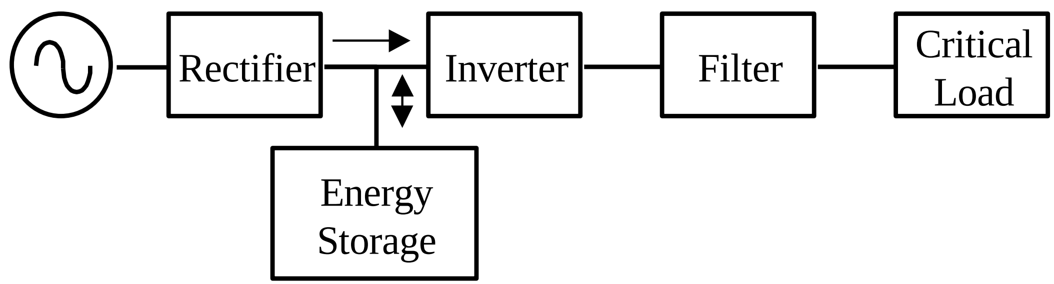
Role of Power Electronics in Utility Applications



Dynamic Voltage Restorers (DVR)



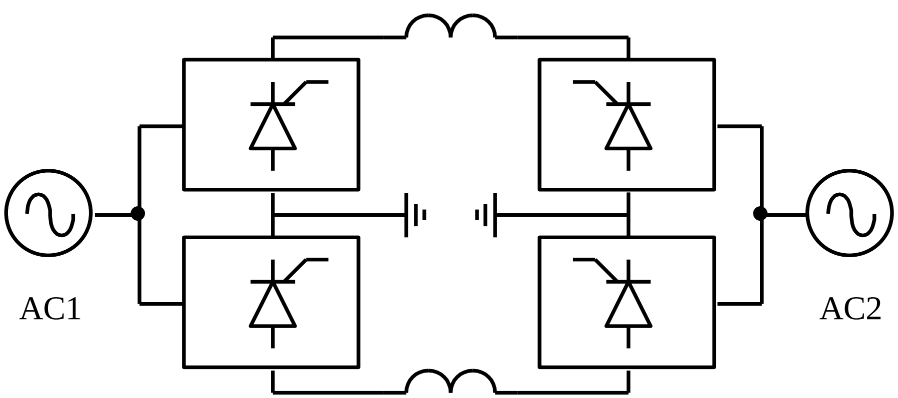
Dual Feeders



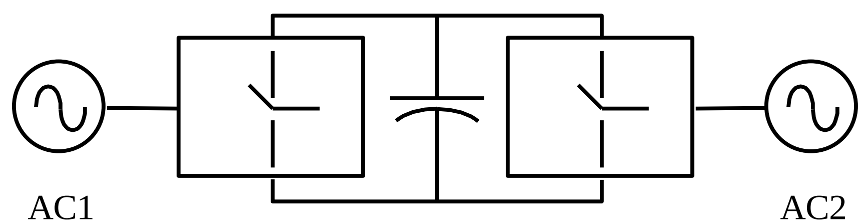
Uninterruptible Power Supplies

Role of Power Electronics in Utility Applications

- Transmission and Distribution: DC Transmission
  - most flexible solution for connection of two ac systems



HVDC

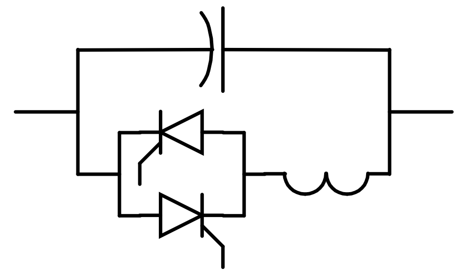


MVDC

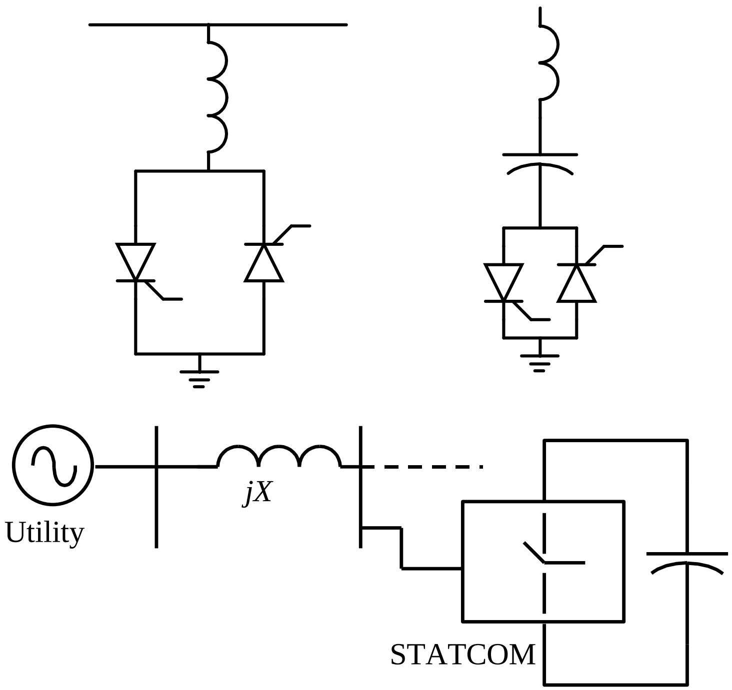
Role of Power Electronics in Utility Applications

- Transmission and Distribution: Flexible AC Transmission Systems (FACTS)

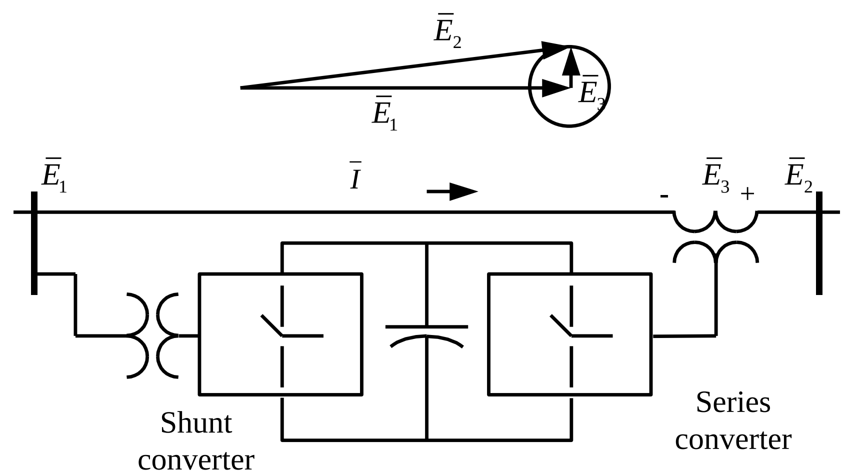
$$P = \frac{E_1 E_2}{X} \sin \delta$$



Series Compensation



Shunt Compensation



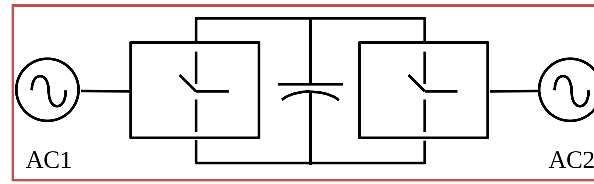
Shunt and Series Compensation

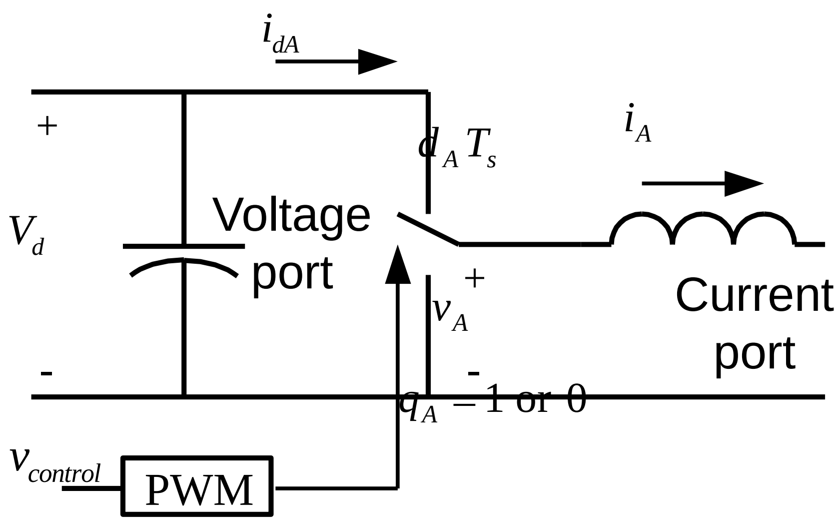
Discussion of Power Electronics Interface

- Fundamental concepts for understanding the operation of the power electronic structures
  - voltage-link systems
  - current link systems
  - solid state switches

Voltage-Link Systems

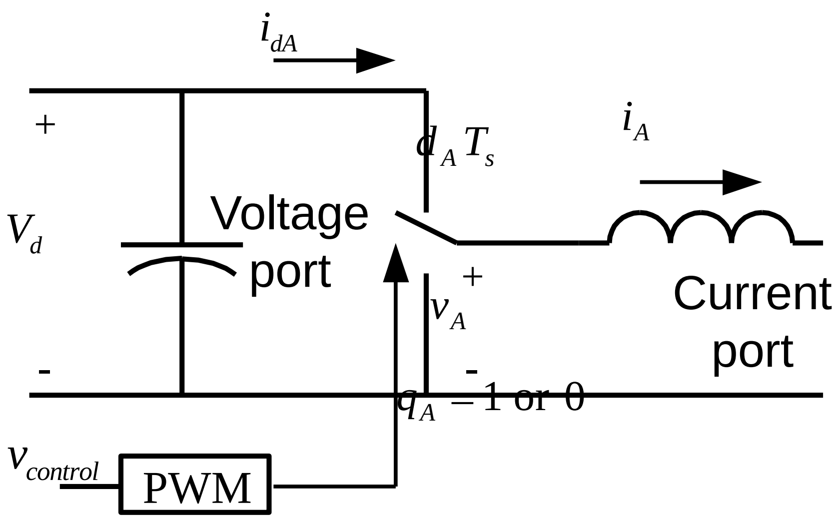
- Unifying approach: Power-Pole Building Block
  - building block of all voltage-link systems

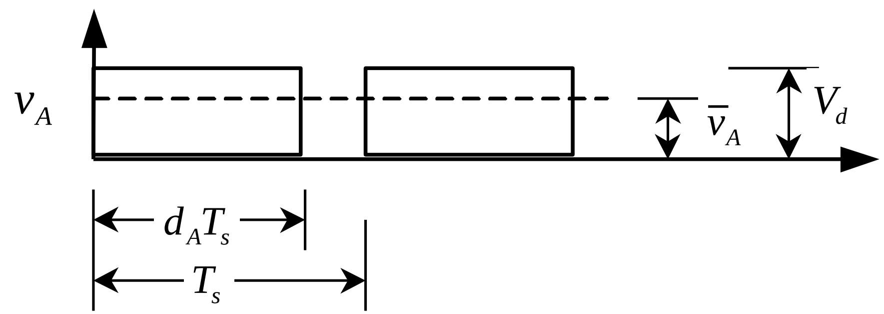




Voltage-Link Systems

- Power conversion using Pulse Width Modulation (PWM)
  - Power reversal with reversal of current direction
  - Averaged conversion

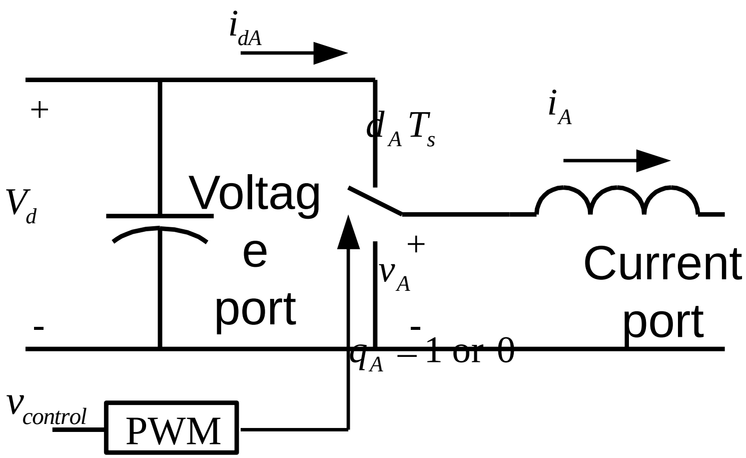


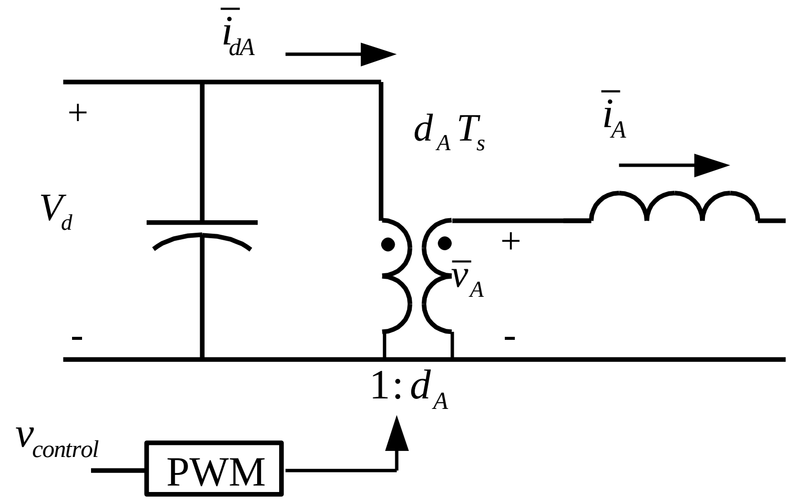


$$\bar{v}_A = \frac{T_{on}}{T_s} V_d = d_A V_d$$

Voltage-Link Systems

- Averaged Representation of Power Pole
  - Average quantities are of main interest





$$\bar{v}_A(t) = d_A(t) \cdot V_d$$

$$\bar{i}_{dA}(t) = d_A(t) \cdot \bar{i}_A(t)$$

Voltage-Link Systems

- Synthesis of AC voltages: voltage to be synthesized; duty ratio needed; dc side current

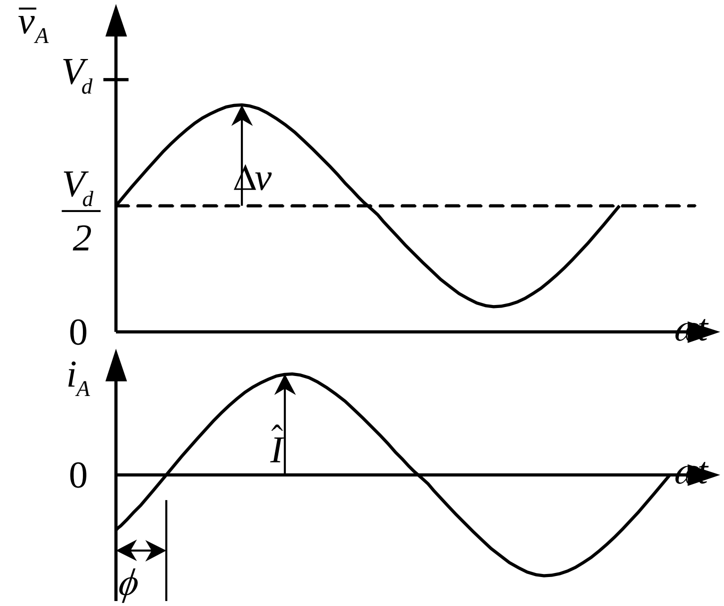
$$\bar{v}_{AN}(t) = \frac{V_d}{2} + \Delta V \sin \omega t$$

$$d_A = \frac{1}{2} + \Delta d \sin \omega t$$

$$\bar{i}_{dA}(t) = \left(\frac{1}{2} + \Delta d \sin \omega t \right) \cdot i_a(t)$$

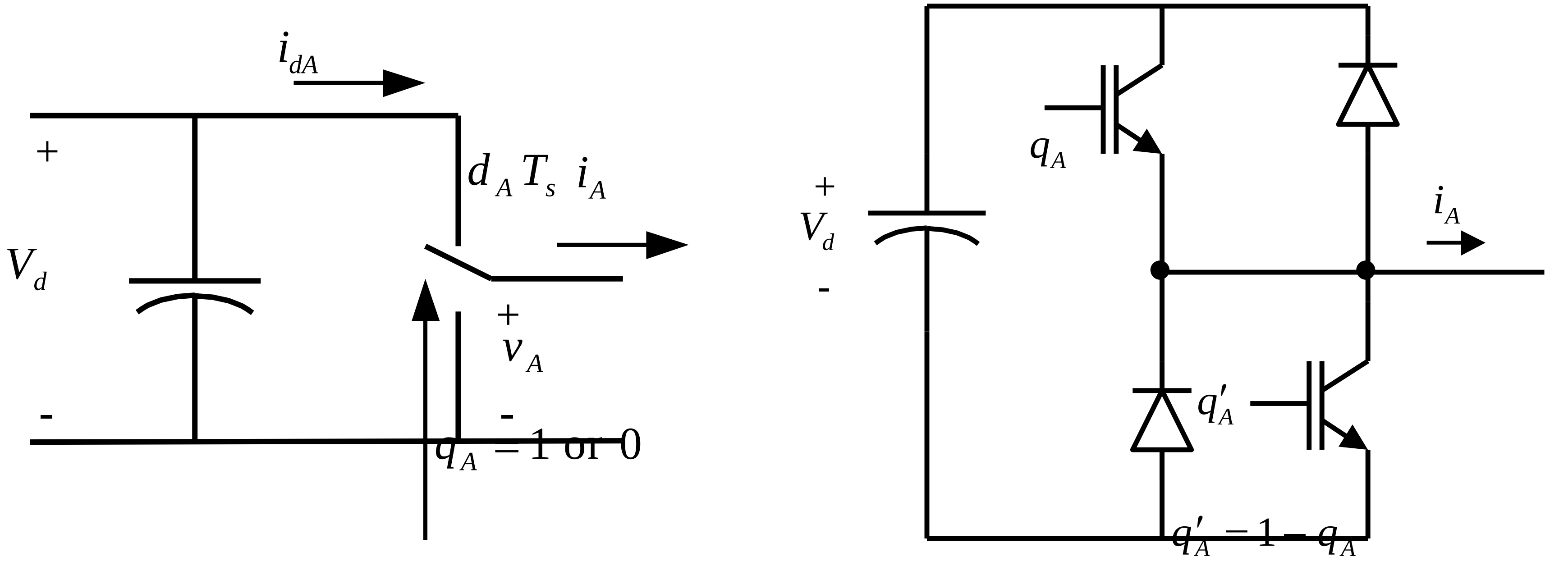
$$= \left(\frac{1}{2} + \Delta d \sin \omega t \right) \cdot \hat{I} \sin(\omega t - \phi)$$

$$= \frac{1}{2} \hat{I} \left\{ \Delta d \cos \phi + \sin(\omega t - \phi) - \Delta d \cos(2\omega t - \phi) \right\}$$



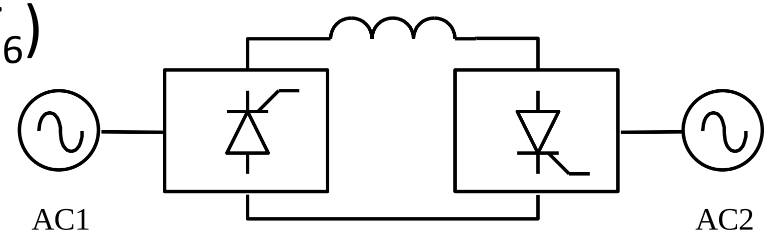
Voltage-Link Systems

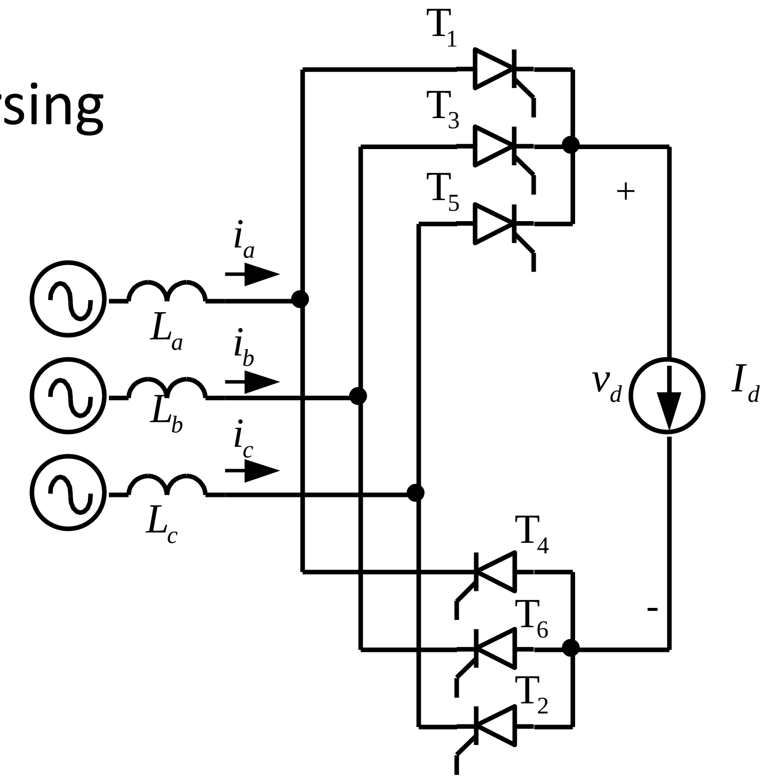
- Implementation of bi-positional switch



Current-Link Systems

- Exclusively thyristor based
  - One of (T_1, T_2, T_3) and (T_2, T_4, T_6) conduct at a time
  - Average dc voltage controlled by ‘firing angle’
  - Power flow reversed by reversing voltage polarity





$$V_d = \frac{3\sqrt{2}}{\pi} V_{LL} \cos\alpha - \frac{3}{\pi}\omega L_c I_d$$