ELG4139: Power Electronics Systems

Objective

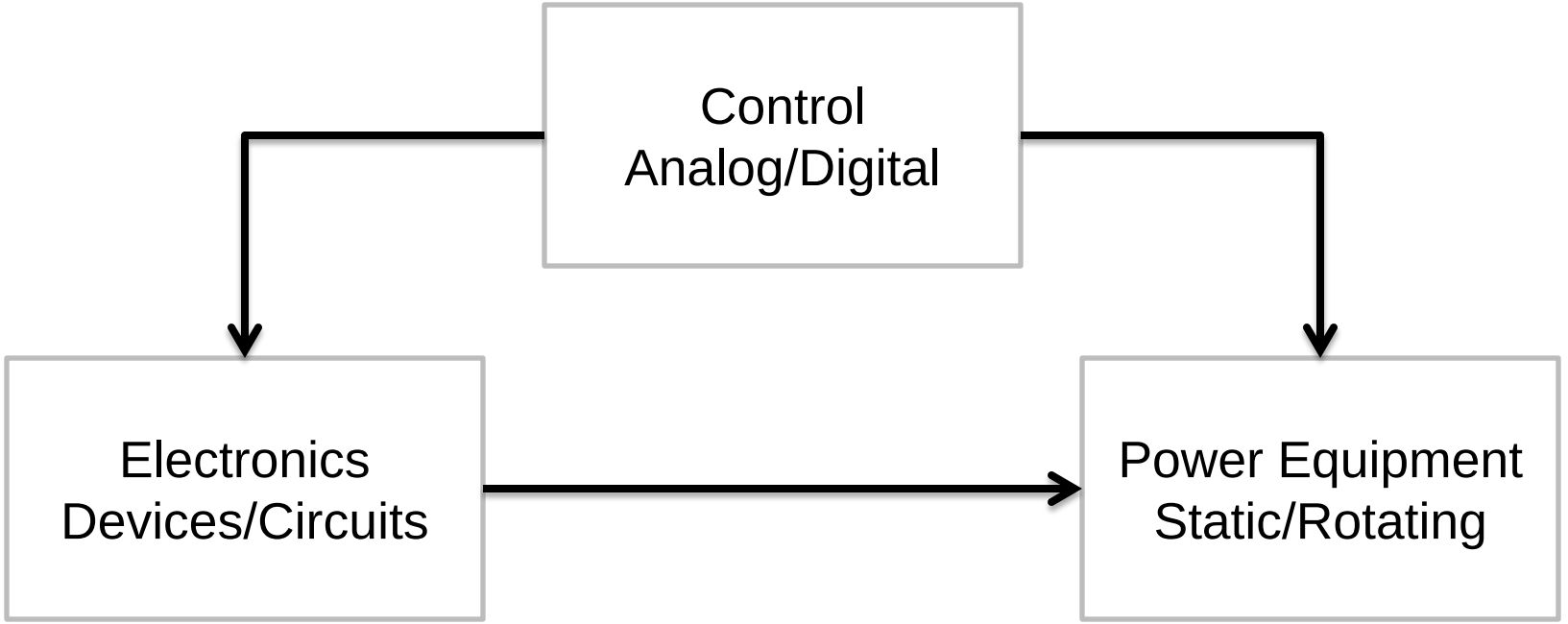
To Realize and Design Various

Power Supplies and Motor Drives!

Power electronics refers to control and conversion of electrical power by power semiconductor devices wherein these devices operate as switches. Advent of silicon-controlled rectifiers, abbreviated as SCRs, led to the development of a new field of application called the power electronics. Before SCRs, mercury-arc rectifiers were used for controlling electrical power, but such rectifier circuits were part of industrial electronics and the scope for applications of mercury-arc rectifiers was limited. The application spread to many fields such as drives, power supplies, aviation electronics, high frequency inverters and power electronics.

Why Power Electronics?

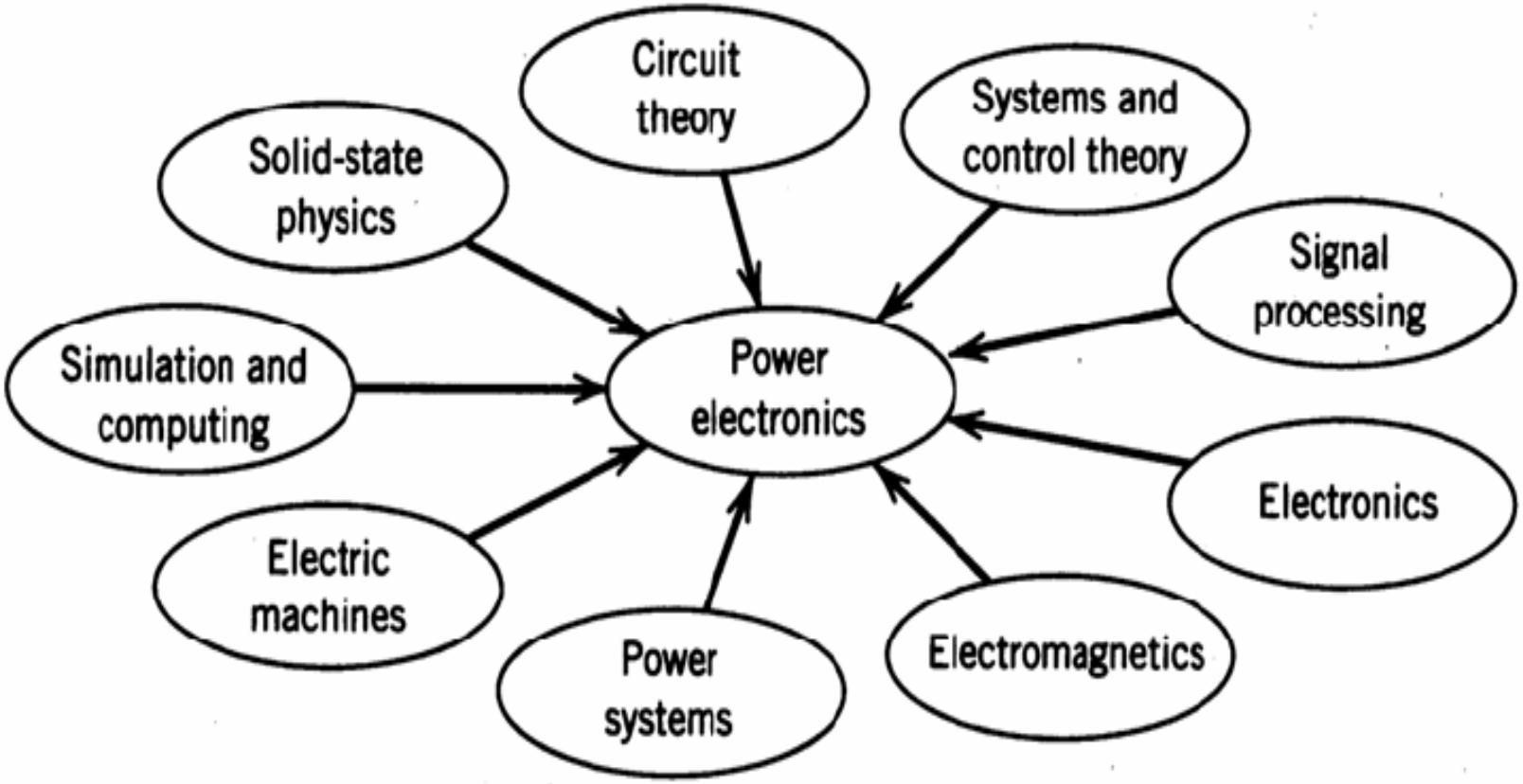
Power electronics is a growing field due to the improvement in switching technologies and the need for more and more efficient switching circuits.



Scope of Power Electronics

Power Level (Watts)	*System*
0.1-10	• Battery-operated equipment • Flashes/strobes
10-100	• Satellite power systems • Typical offline flyback supply
100 – 1kW	• Computer power supply • Blender
1 – 10 kW	• Hot tub
10 – 100 kW	• Electric car • Eddy current braking
100 kW –1 MW	• Bus • micro-SMES
1 MW – 10 MW	• SMES
10 MW – 100 MW	• Magnetic aircraft launch • Big locomotives
100 MW – 1 GW	• Power plant
> 1 GW	• Sandy Pond substation (2.2 GW)

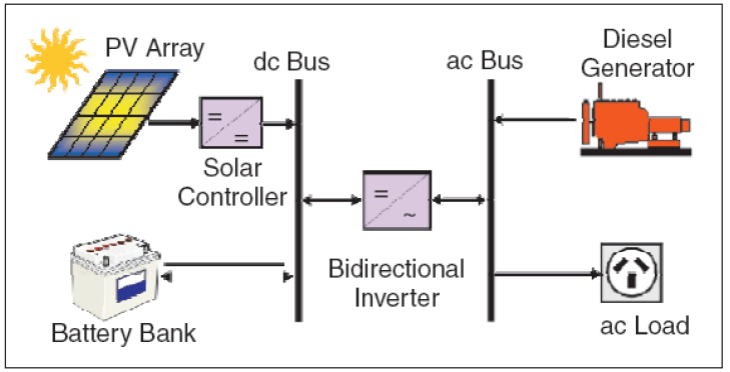
Interdisciplinary Nature of Power Electronics



Applications

- Heating and lighting control
- Induction heating
- Uninterruptible power supplies (UPS)
- Fluorescent lamp ballasts: Passive; Active
- Electric power transmission
- Automotive electronics
- Electronic ignitions
- Motor drives
- Battery chargers
- Alternators
- Energy storage
- Electric vehicles
- Alternative power sources: Solar; Wind; Fuel Cells
- And more!

Photovoltaics



Power Converters

Electronic power converter is the term that is used to refer to a power electronic circuit that converts voltage and current from one form to another.

- Rectifier converting an AC voltage to a DC voltage
- Inverter converting a DC voltage to an DC voltage
- Chopper or a switch-mode power supply that converts a dc voltage to another dc voltage
- Cycloconverter and cycloinverter converting an AC voltage to another AC voltage.

Rectifiers

Rectifiers may be classified as uncontrolled and controlled rectifiers. Controlled rectifiers can be further divided into semi-controlled and fully-controlled rectifiers. Uncontrolled rectifier circuits are built with diodes, and fully-controlled rectifier circuits are built with SCRs. Both diodes and SCRs are used in semi-controlled rectifier circuits.

- Single-phase semi-controlled bridge rectifier
- Single-phase fully-controlled bridge rectifier
- Three-phase three-pulse, star-connected rectifier
- Double three-phase, three-pulse star-connected rectifiers with inter-phase transformer (IPT)
- Three-phase semi-controlled bridge rectifier
- Three-phase fully-controlled bridge rectifier
- Double three-phase fully-controlled bridge rectifiers with IPT.

DC to AC Conversion

The converter that changes a DC to AC is called an inverter. Earlier inverters were built with SCRs. Since the circuitry required to turn the SCR off tends to be complex, other power semiconductor devices such as bipolar junction transistors, power MOSFETs, insulated gate bipolar transistors (IGBT) and MOS-controlled thyristors (MCTs) are used nowadays. Currently only the inverters with a high power rating, such as 500 kW or higher.

- Emergency lighting systems
- AC variable speed drives
- Uninterrupted power supplies
- Frequency converters.

DC to DC Conversion

When the SCR came into use, a dc-to-dc converter circuit was called a chopper. Nowadays, an SCR is rarely used in a dc-to-dc converter. Either a power BJT or a power MOSFET is normally used in such a converter and this converter is called a switch-mode power supply.

- Step-down switch-mode power supply
- Step-up chopper
- Fly-back converter
- Resonant converter.

AC to AC Converter

- A cycloconverter or a cycloinverter converts an ac voltage, such as the mains supply, to another ac voltage. The amplitude and the frequency of input voltage to a cycloconverter tend to be fixed values, whereas both the amplitude and the frequency of output voltage of a cycloconverter tend to be variable.
- Tthe circuit that converts an ac voltage to another ac voltage at the same frequency is known as an AC-chopper.
  A typical application of a cycloconverter is to use it for controlling the speed of an AC traction motor and most of these cycloconverters have a high power output, of the order a few megawatts and SCRs are used in these circuits. In contrast, low cost, low power cycloconverters for low power ac motors are also in use and many of these circuit tend to use TRIACS in place of SCRs.
- Unlike an SCR which conducts in only one direction, a TRIACS is capable of conducting in either direction and like an SCR, it is also a three terminal device. It may be noted that the use of a cycloconverter is not as common as that of an inverter and a cycloinverter is rarely used.

Some Applications of Power Electronics

- In a conventional car, power electronics applications are a major area of future expansion. Look inside the audio system, for example; the amplifiers in today's car stereos are usually capable of delivering 40 W or more. But a 12 V supply applied to an 8 Ohm speaker produces 18 W output at best. To solve this power supply problem, designers use a boost converter (DC to DC Converter) to provide higher voltage power to the amplifier circuit. This allows car amplifiers to generate the same audio output power as home stereos.
- Another universal power electronics application is the automobile's ignition system. Thousands of volts are required to ignite the fuel-air mixture inside a cylinder so that internal combustion can occur. Today's cars employ all-electronic ignition systems, which have replaced the traditional spark plugs with boost converters coupled to transformers.
- We are curious about new electric and hybrid cars, in which the primary electrical system is dominated by power electronics. Electric cars offer high performance, zero tailpipe emissions, and low costs, but are still limited in range by the need for batteries.

Power Electronics

Silicon

Diodes

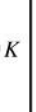
- Schottky-Diode
- Epitaxial-Diode
- Double Diffused Diode

Transistors

- Biopolar Junction Transistor
- MOSFET
- IGBT

Thyristors

- Thyristors for Phase Control
- Fast Thyristor
- GTO
- IGCT
- MCT
- MTO

Device	Device symbol
Diode	
Thyristor	
Gate turnoff thyristor (GTO)	
Triac	
npn BJT	
IGBT	
n-channel MOSFET	

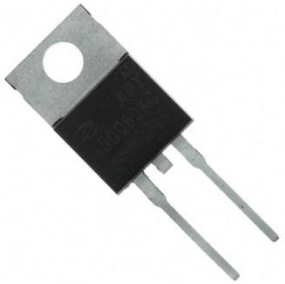
Power Electric Circuits

Circuit type	Essential features
Voltage regulators	Regulate a DC supply to a fixed voltage output
Power amplifiers	Large-signal amplification of voltages and currents
Switches	Electronic switches (e.g., transistor switches)
Diode rectifier	Converts fixed AC voltage (single- or multiphase) to fixed DC voltage
AC-DC converter (controlled rectifier)	Converts fixed AC voltage (single- or multiphase) to variable DC voltage
AC-AC converter (AC voltage controller)	Converts fixed AC voltage to variable AC voltage (single- or multiphase)
DC-DC converter (chopper)	Converts fixed DC voltage to variable DC voltage
DC-AC converter (inverter)	Converts fixed DC voltage to variable AC voltage (single- or multiphase)

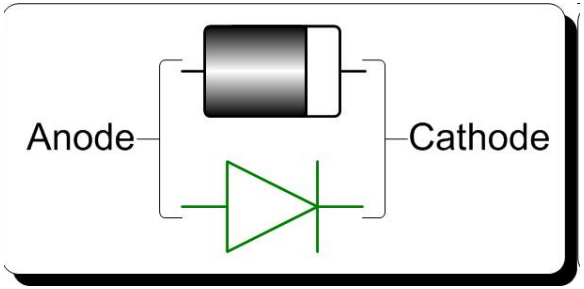
Ideal Characteristics of a Power Semiconductor

- When on: Can carry infinite current and create no resistance(i.e. no power loss)
- When off: withstand infinite reverse voltage with infinite off state resistance (i.e. no power loss)
- Instant on-of
- Almost zero power pulse to turn on and off
- Instant reaction to input
- Ideal thermal dissipation out of the device
- Can withstand infinite fault current
- Low price!

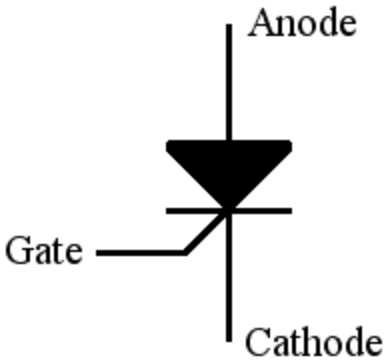
Diodes



- Characteristics:
  - Conducts one way
  - Blocks current in the opposite direction
  - Only works above an excitation voltage (ex: 3V)
- Max properties:
  - General purpose diodes: 6000V, 4500A
  - Fast recovery: 6000V, 1100A
  - Schottky(low voltage drop, fast switching, high efficiency): 100V, 300A



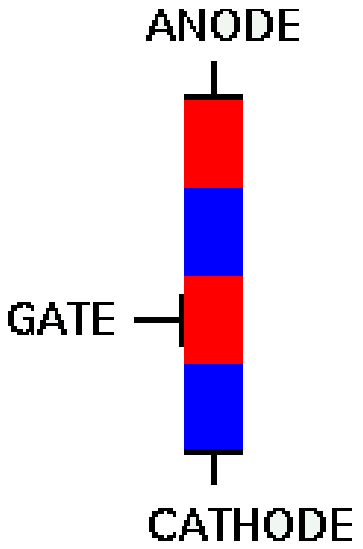
Thyristors

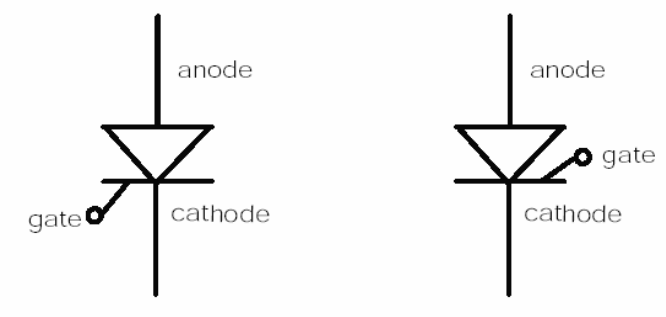


- Characteristics:
  - Only conducts when triggered by a signal at its gate
  - Some can conduct in two directions (e.g. RCTs)
- Maximum properties:
  - 6000V-4500V for line commutated thyristors
  - 10-20 nanosecond turn-off time for 3000V-3600V

Silicon Controlled Rectifiers

The basic purpose of the SCR is to function as a switch that can turn on or off small or large amounts of power. It performs this function with no moving parts that wear out and no points that require replacing. There can be a tremendous power gain in the SCR; in some units a very small triggering current is able to switch several hundred amperes without exceeding its rated abilities. The SCR can often replace much slower and larger mechanical switches.





Power Transistor

- Characteristics
  - If the base current is flowing, a voltage between the collector and emitter will cause current to flow between them. (i.e. the base turns on the transistor)
  - Commonly used as a switch
- Max properties
  - 1700V,2400A for IGBTs

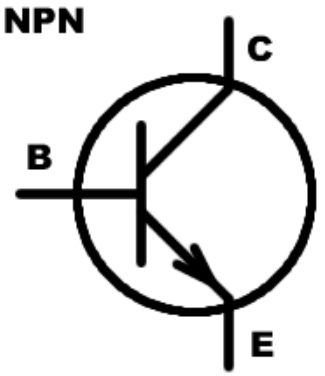
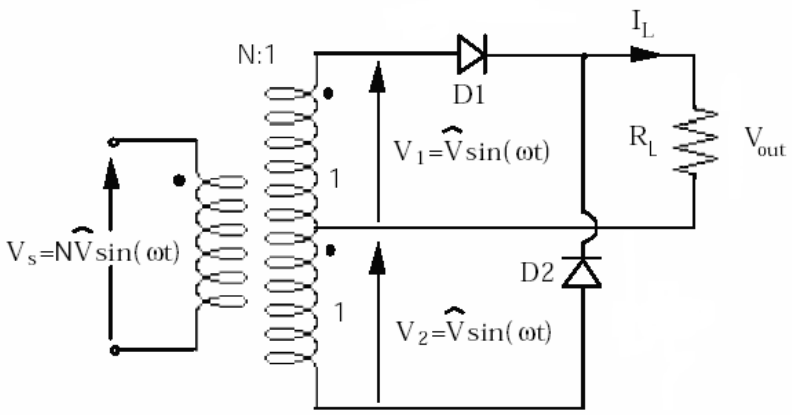


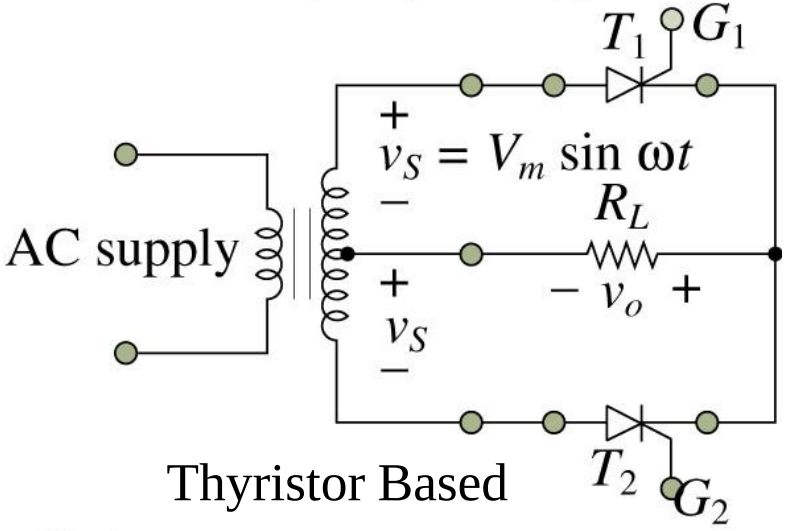
TABLE 1.4 Switching Characteristics of Power Semiconductors

Device Type	Device	Continuous Gate	Pulse Gate	Controlled Turn-On	Controlled Turn-Off	Unipolar Voltage	Bipolar Voltage	Unidirectional Current	Bidirectional Current
Diodes	Power diode					x		x	
Transistors	BJT	x		x	x	x		x	
	MOSFET	x		x	x	x			x
	COOLMOS	x		x	x	x			x
	IGBT	x		x	x	x		x	
	SIT	x		x	x	x		x	
Thyristors	SCR		x	x			x	x	
	RCT		x	x			x		x
	TRIAC		x	x			x		x
	GTO		x	x	x		x	x	
	MTO		x	x	x		x	x	
	ETO		x	x	x		x	x	
	IGCT		x	x	x		x	x	
	SITH		x	x	x		x	x	
	MCT	x		x	x		x	x	

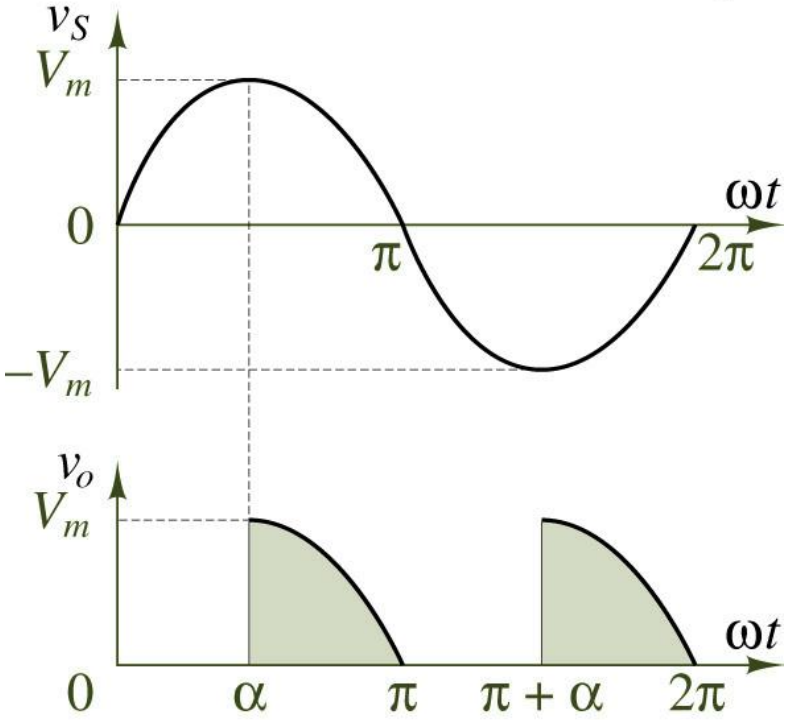
AC-DC Converter Circuit and Waveform



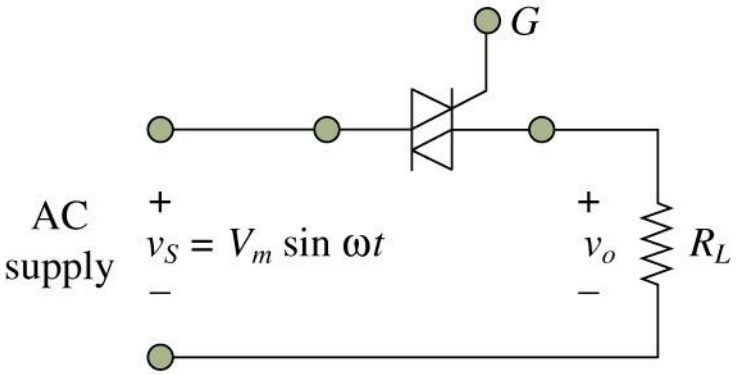
Common Diode Based

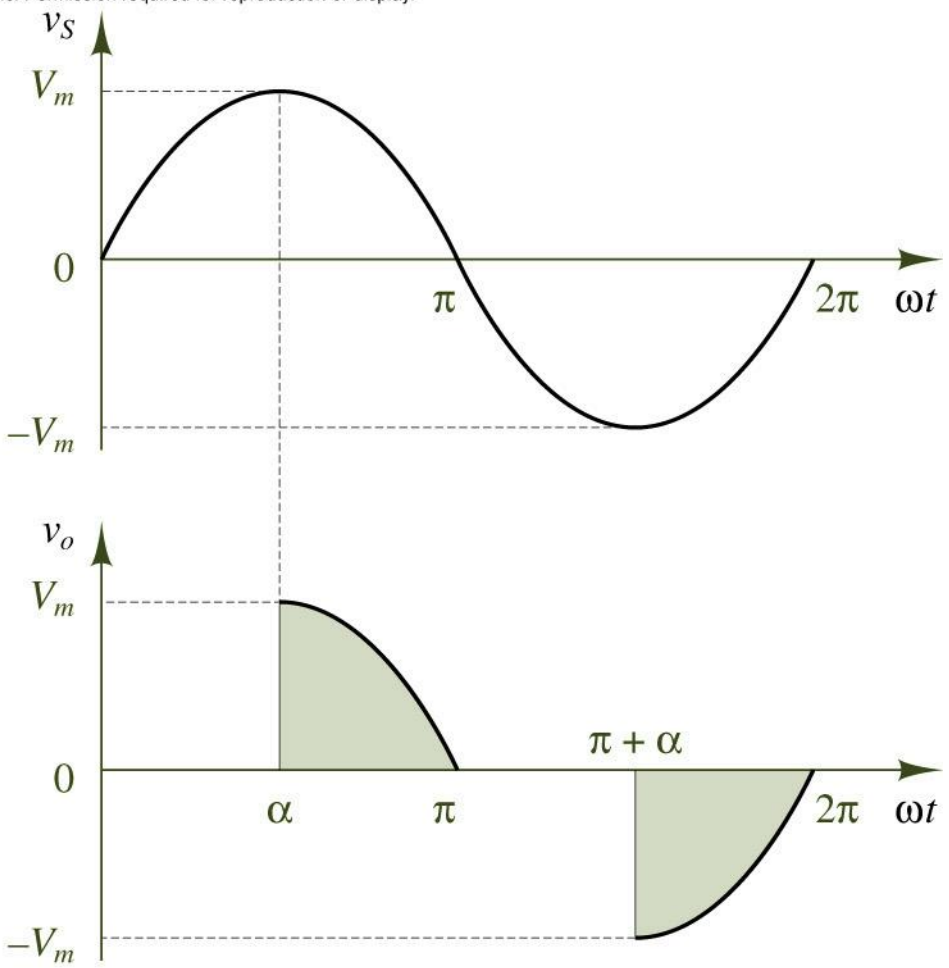


Thyristor Based

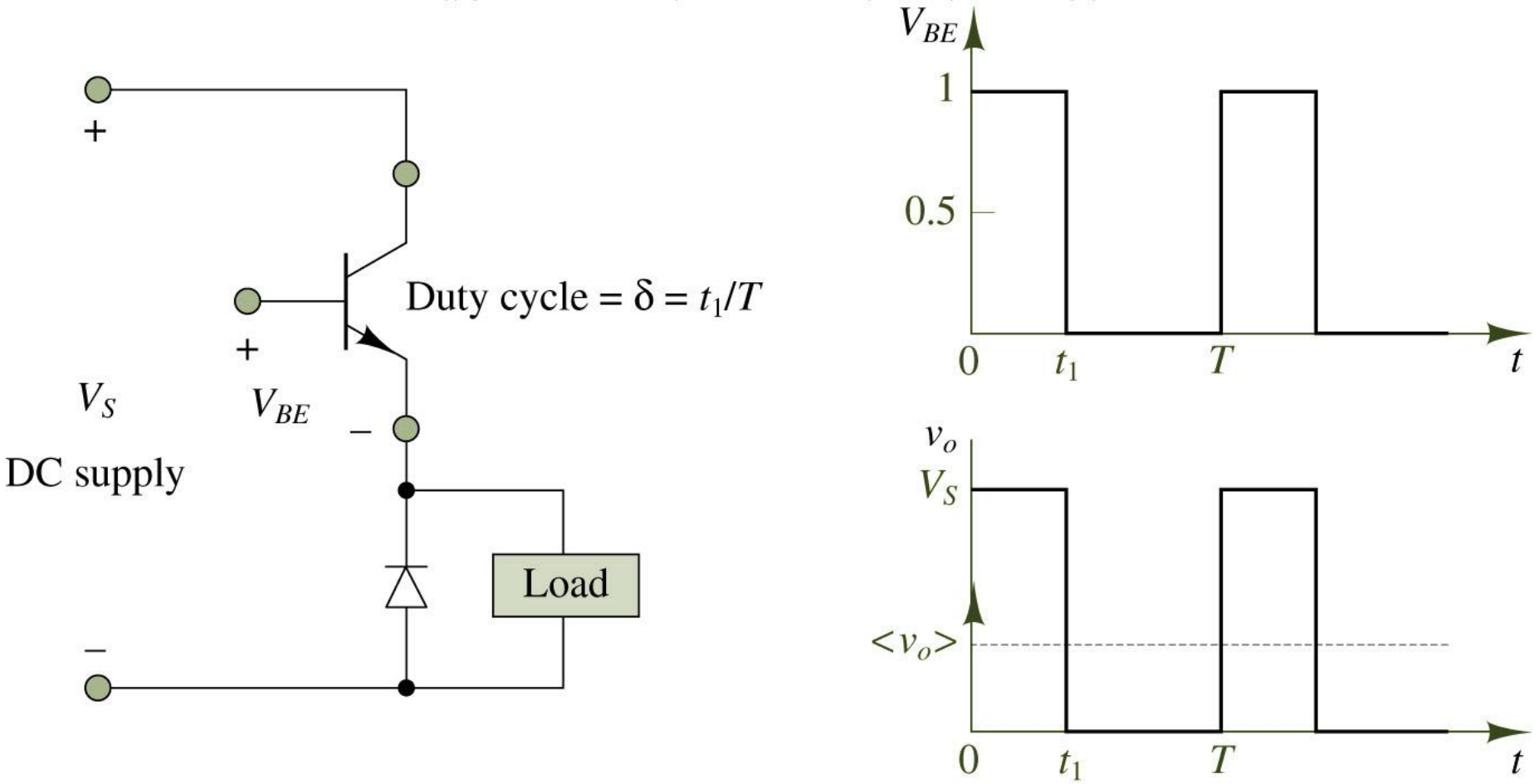


AC-AC Converter Circuit and Waveform

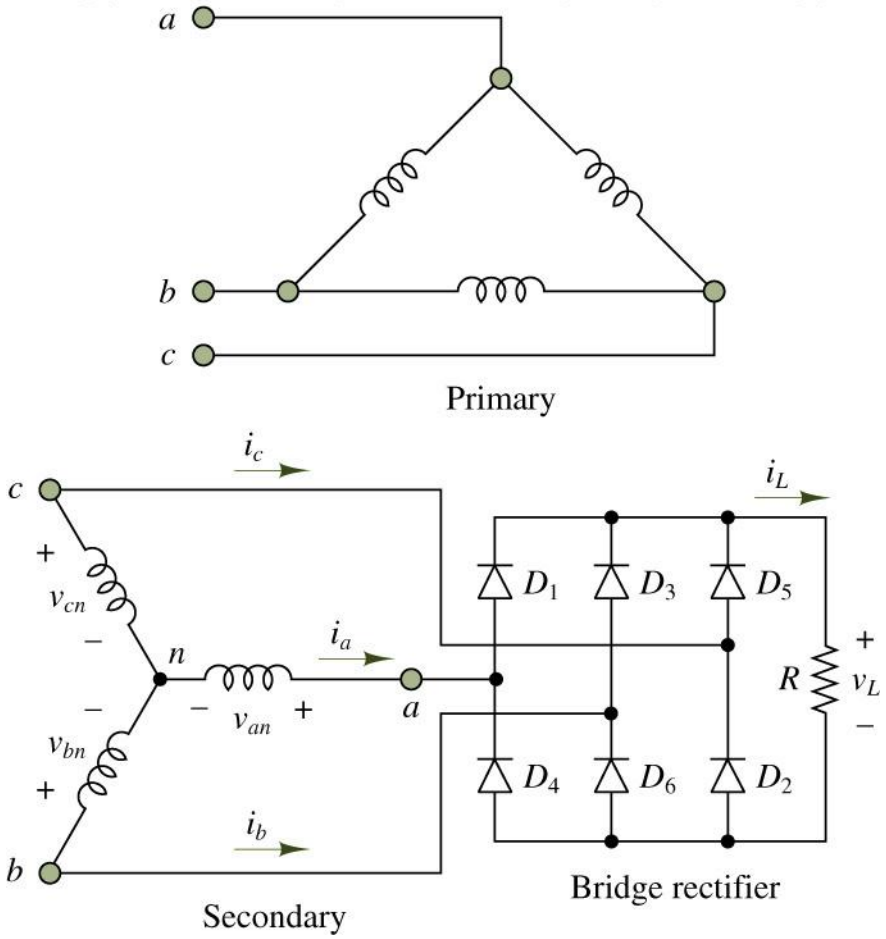




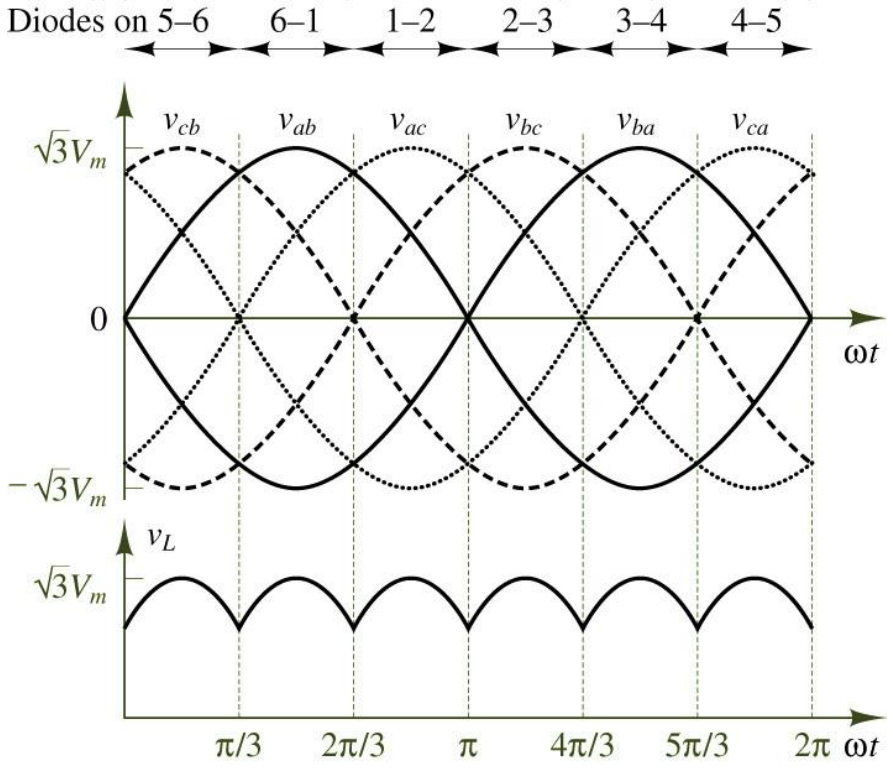
DC-DC Converter Circuit and Waveform



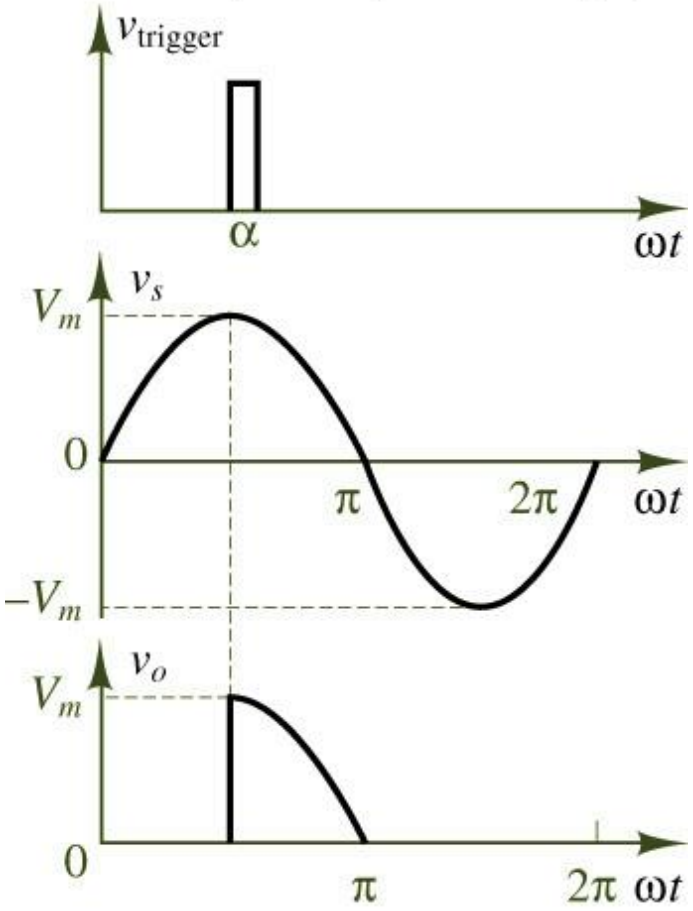
Three-Phase Diode Bridge Rectifier



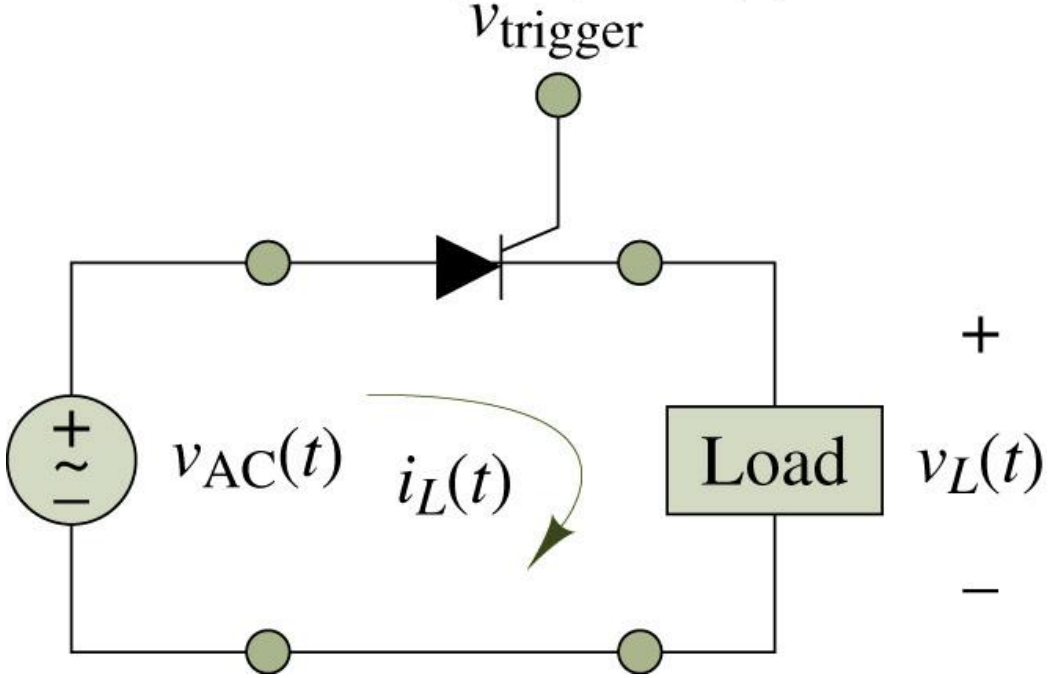
Waveforms and Conduction Times of Three-Phase Bridge Rectifier



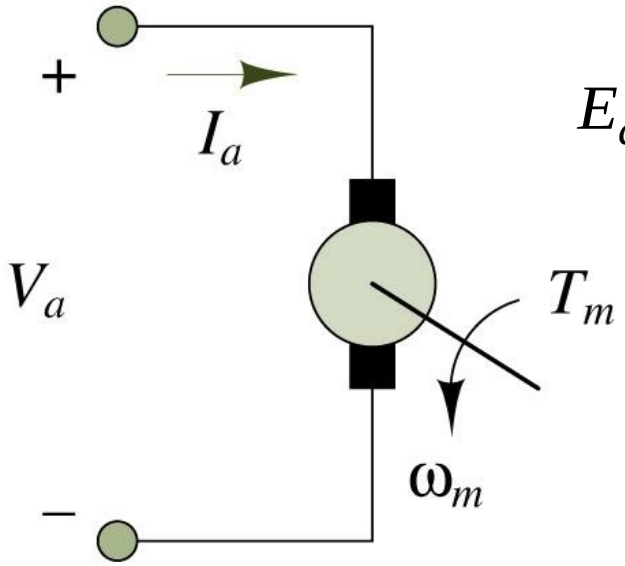
Half-Wave Controlled Rectifier Waveforms



Controlled Rectifier Circuit



DC Motor



$$E_a \times I_a = T_m \times w_m$$

Step-Down Chopper (Buck Converter)