Revision

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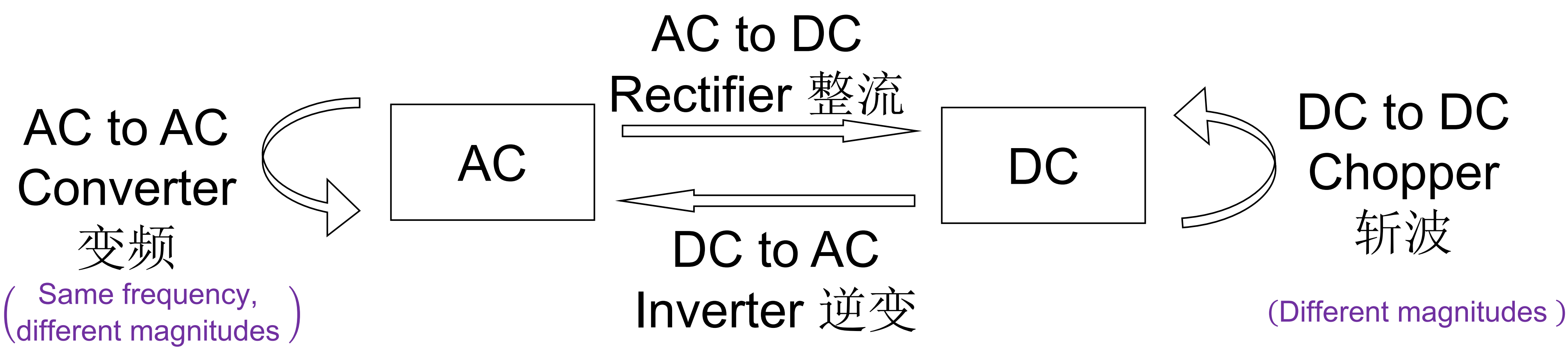
Lecture 1 Introduction

- **What is power electronics?**
  - Definition: electronics applied to convert and control of electric power
  - Conversion between AC and DC electric power

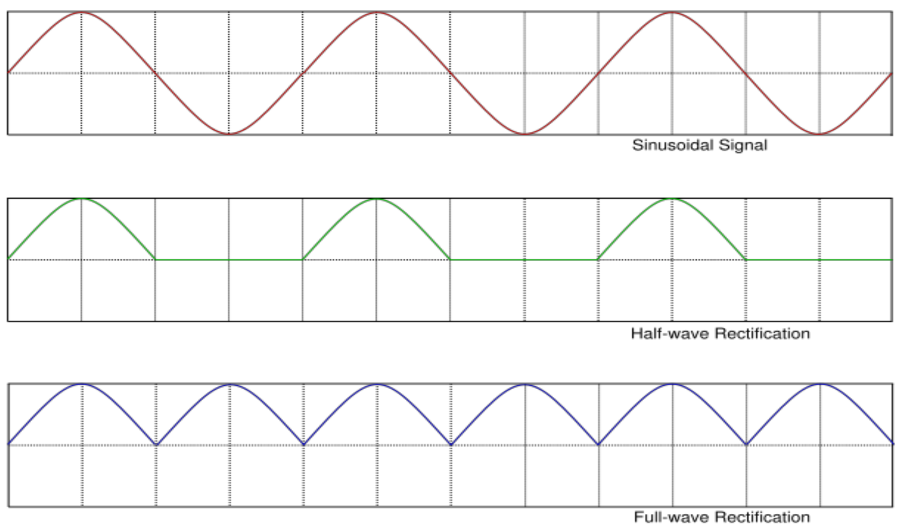


Lecture 2: Uncontrolled Rectifier (1-phase)

- Controllability
  - Uncontrolled ➡ Uncontrolled turn-ON & OFF (e.g., diode)
  - Semicontrolled ⇨ Controlled turn-ON and uncontrolled turn-OFF (e.g., SCR)
  - Controlled ⇨ Controlled turn-ON & OFF (GTO, BJT, MOSFET, IGBT)
- Input power (source)
  - Single phase
  - Three phase

Provides larger efficiency, small fluctuations, filtering of unwanted frequency is easier

- Waveform
  - Half-wave
  - Full-wave



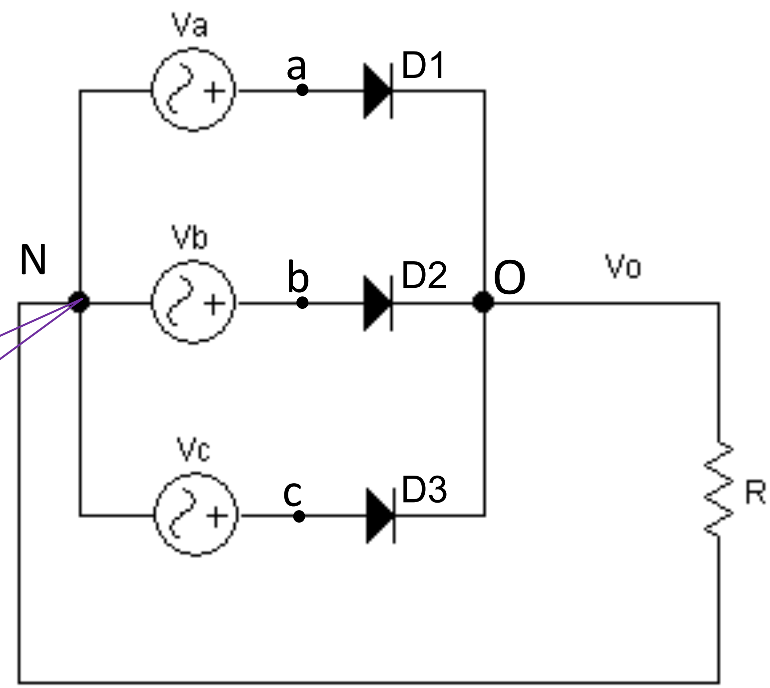
Lecture 3: Uncontrolled Rectifier (3-phase)

- Single phase rectifiers are extensively used in *low-power applications* particularly for power supplies to electronic circuits.
- Single phase rectifiers have several *disadvantages*:
  - Large output voltage and current form factor;
  - Large low frequency harmonic ripple current causing harmonic power loss and reduced efficiency;
  - Very large filter capacitor for obtaining smooth output dc voltage;
  - Low frequency harmonic current is injected in the input ac line which is difficult to filter. The situation becomes worse with capacitive loads.
- Many of these disadvantages are *mitigated/attenuated* to a large extent using *three-phase rectifiers*.

Lecture 3: Uncontrolled Rectifier (3-phase)

Source is star-connected with Va, Vb, Vc (whose magnitudes & frequencies are same with 120 degree phase difference).

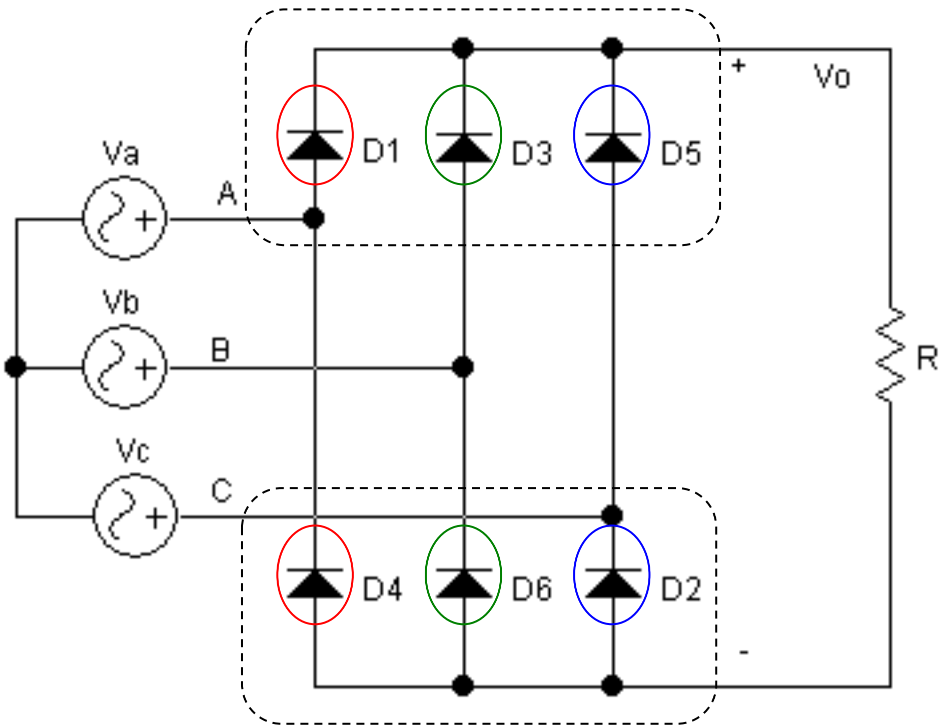
Negative ends of the sources are connected together to ground (GND)



Half-bridge rectifier (Common-Cathode)

Lecture 3: Uncontrolled Rectifier (3-phase)

Top/positive group



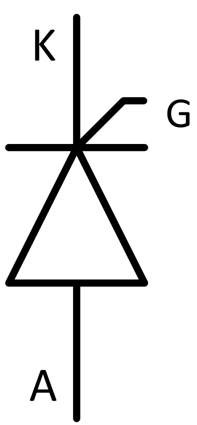
Bottom/negative group

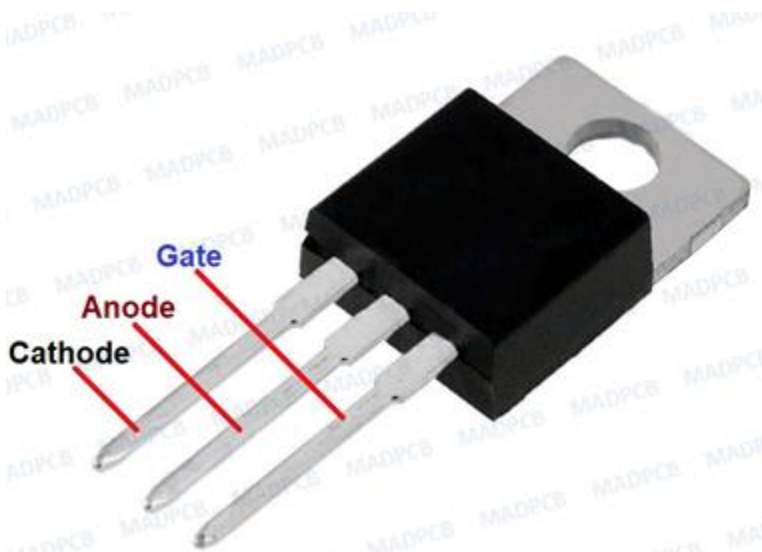
Full-bridge rectifier

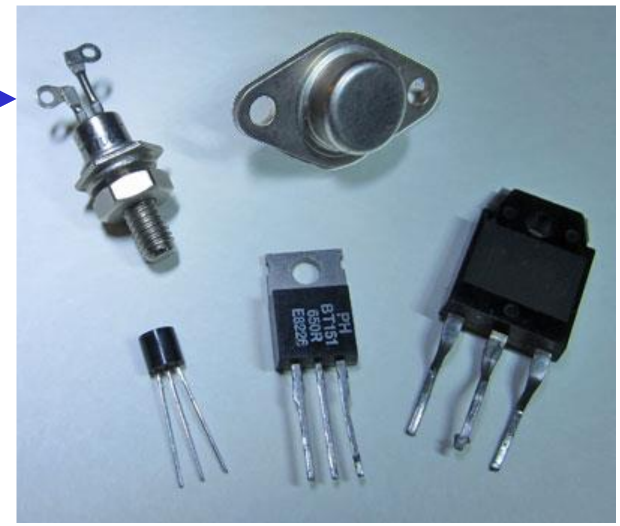
- For full-wave circuit, *6 diodes* are used and arranged in three legs – each leg has two series-connected diodes.
- Top group: Diodes D1, D3, and D4.
- Bottom group: Diodes D4, D6, and D2.
- Note that *diodes are not in the sequence*.
- To form a conduction loop, there always are two diodes conducting, *one from top group and one from bottom group*:
  - Top group: the one has the highest anode voltage will conduct;
  - Bottom group: the one has the lowest cathode voltage will conduct;

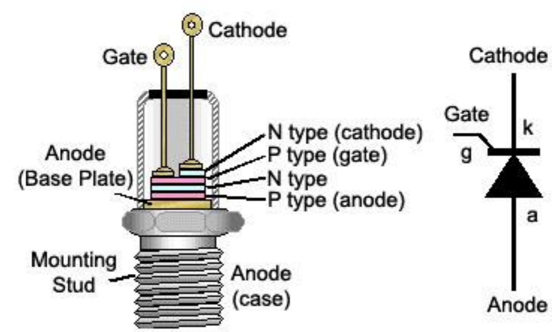
Lecture 4: Controlled Rectifier (1-phase)

- SCR acts as bi-stable switches, conducting when their gate receives a current pulse, and continue to conduct for as long as they are forward biased (that is, as long as the voltage across the device has not reversed).
  - Three-terminals: anode, cathode, gate









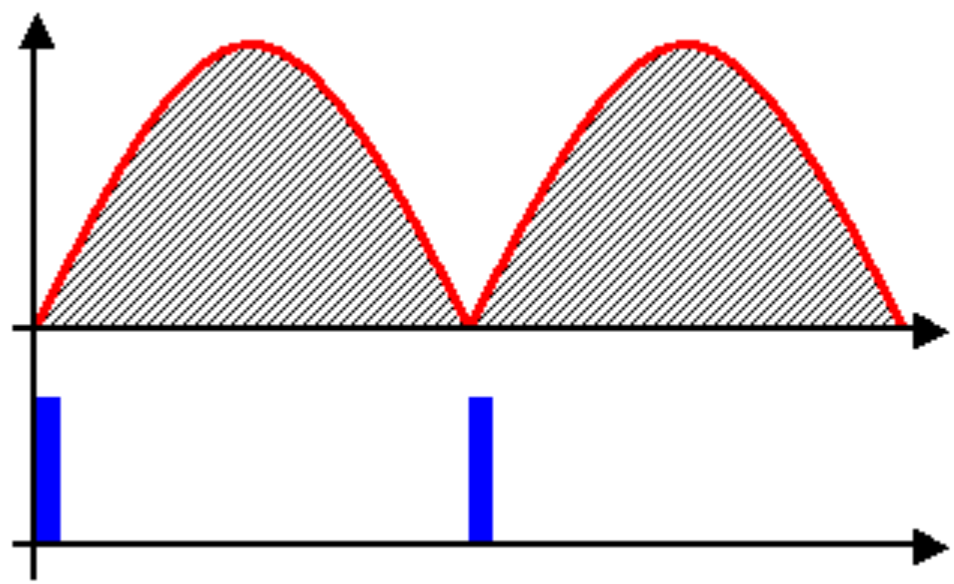
Lecture 4: Controlled Rectifier (1-phase)

- Two conditions must be met before the SCR can conduct:

1. The SCR must be forward biased ($v_{AK} > 0$).
2. A current must be applied to the gate of SCR.

- A *SCR is turned ON* by increasing the anode current. This can be accomplished in one of the following ways:

1. Forward voltage triggering
2. Gate triggering
3. The dv/dt triggering
4. Temperature triggering
5. Light triggering

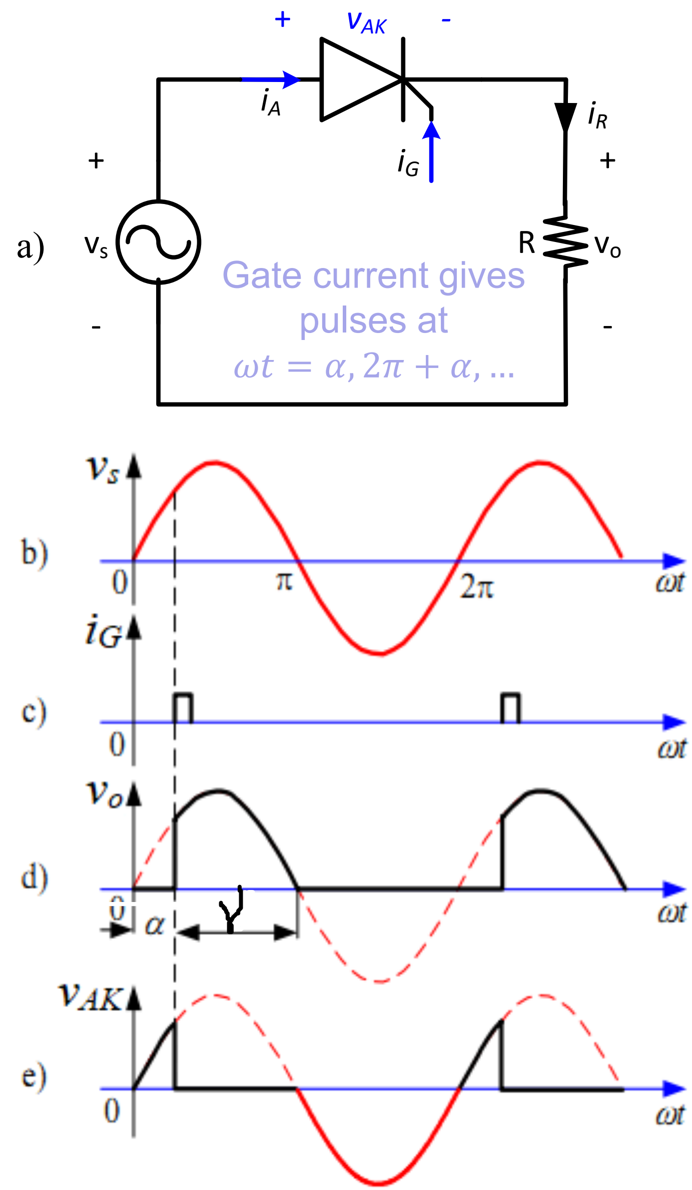


Lecture 4: Controlled Rectifier (1-phase)

- 1. Half-wave *controlled* rectifier
  - In the positive half
    - $[0, \alpha]$: i_R is zero, v_o is zero;
    - $[\alpha, \pi]$: $v_o = v_s = V_m \sin \omega t$;

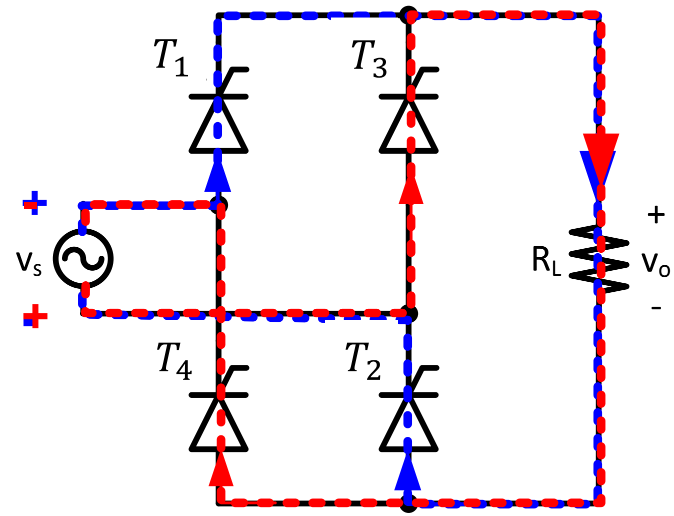
$$i_A = i_R = \frac{V_m}{R} \sin \omega t.$$

  - In the negative half
    - $[\pi, 2\pi]$: i_R drops to zero, v_o is zero.



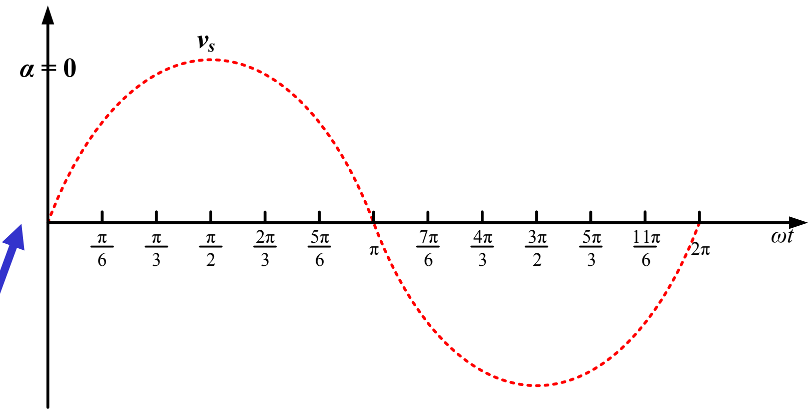
- Firing angle: α
- Conduction angle: $\gamma = \pi - \alpha$

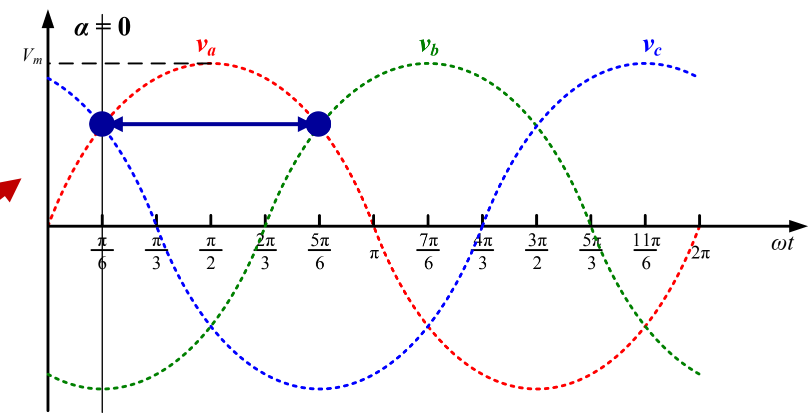
- Full-bridge rectifier (R)
  - T_1 and T_2 is a pair of bridge arm: In the positive half of v_s, they start to conduct when triggered by a pulse, and will be closed when v_s passes 0 to negative.
    - → Blue current path
  - T_3 and T_4 is another pair of bridge arm: In the negative half of v_s, they start to conduct when triggered by a pulse, and will be closed when v_s passes 0 to positive.
    - → Red current path



Lecture 5: Controlled Rectifier (3-phase)

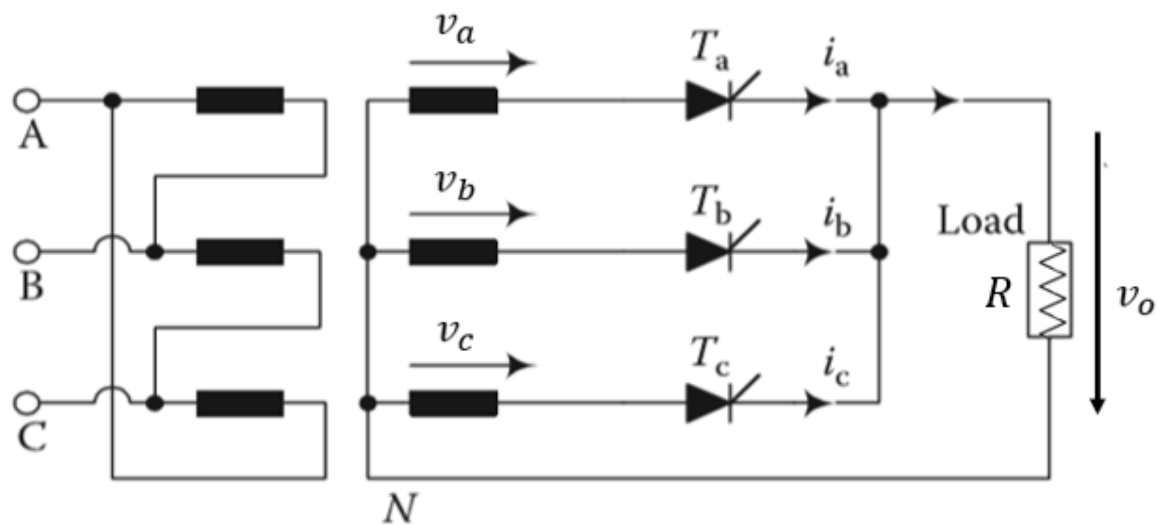
- In controlled rectifier, controllability of the circuit is realized by triggering the thyristors at different phases, which is called the ***firing/triggering angle***. It is usually represented by “$\boldsymbol{\alpha}$”;
  - This trigger signal is a current pulse at the “gate” terminal of thyristors;
  - For single phase circuit, $\alpha = 0$ means trigger signal is sent at $\omega t = 0$;
  - For three-phase circuit, $\alpha = 0$ means trigger signal is sent at $\omega t = \pi/6$, which is the first ***natural commutation (phase changing) point***.



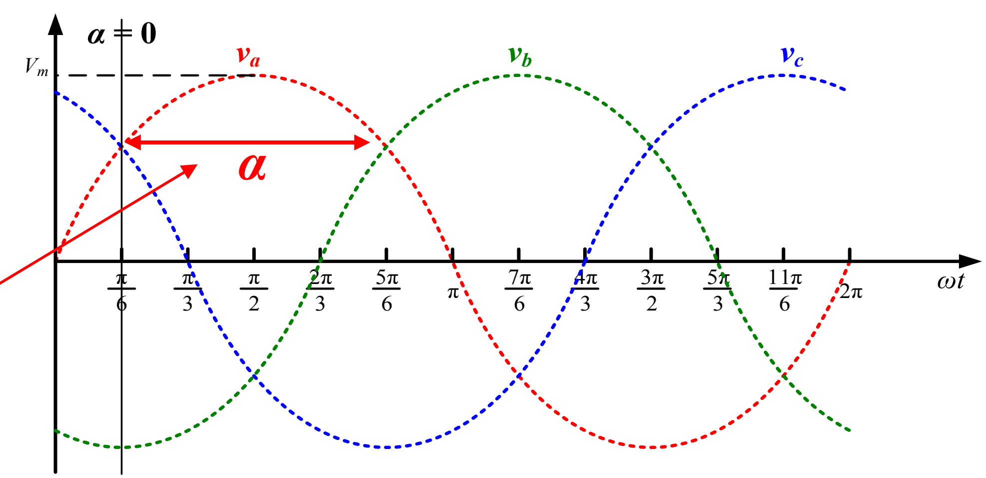


Lecture 5: Controlled Rectifier (3-phase)

- Resistive load
  - ❖ Three phase supply – primary in delta and secondary in star connection.
  - ❖ Common-cathode connection.

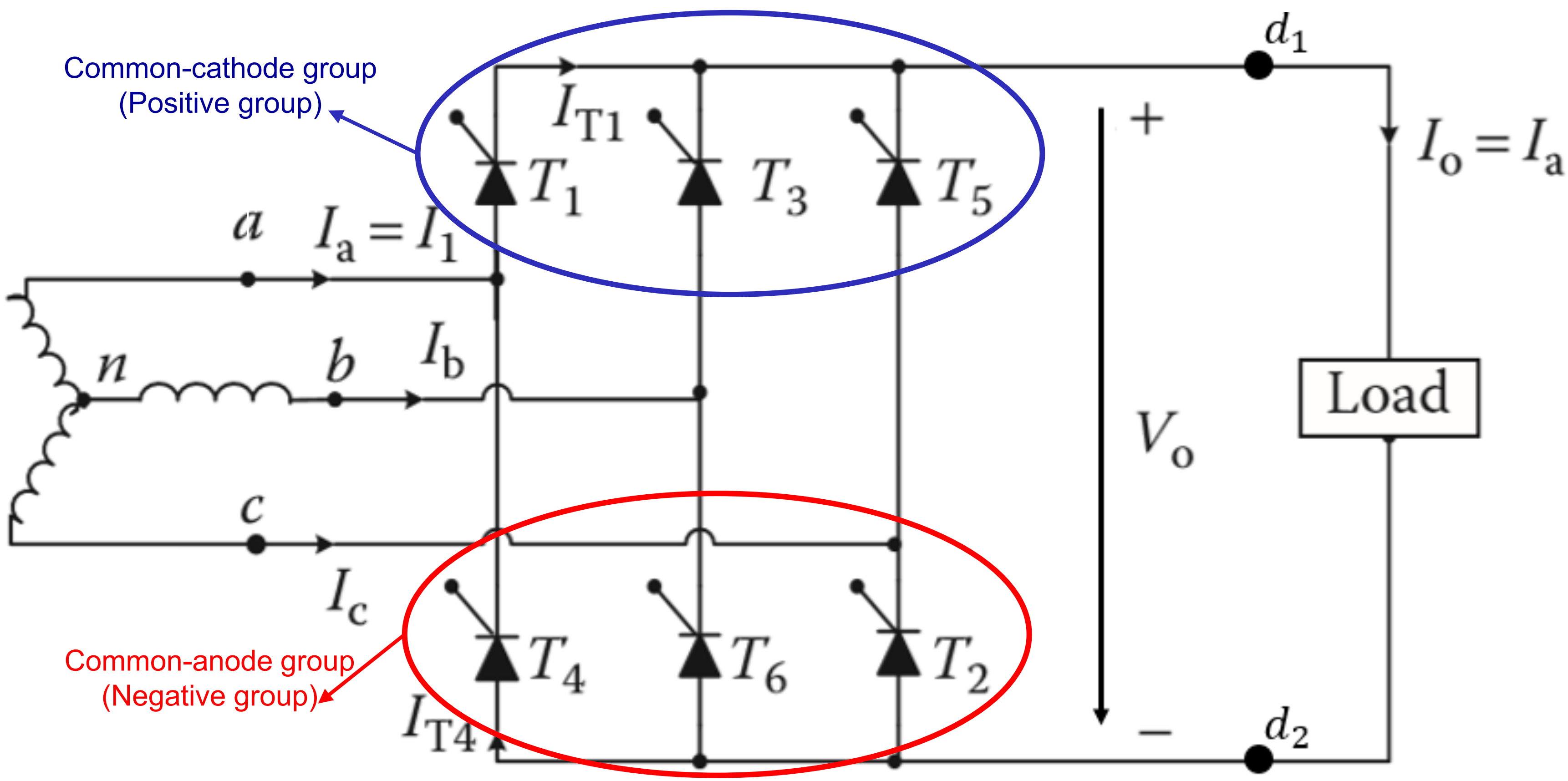


- Natural commutation (phase-changing) point
  - – It is considered as the starting point for thyristor triggering angle α, i.e. $\alpha = 0^0$.
  - – Phase-shift range: $\alpha <= 120^0$.



Three-phase, half-wave, R-load

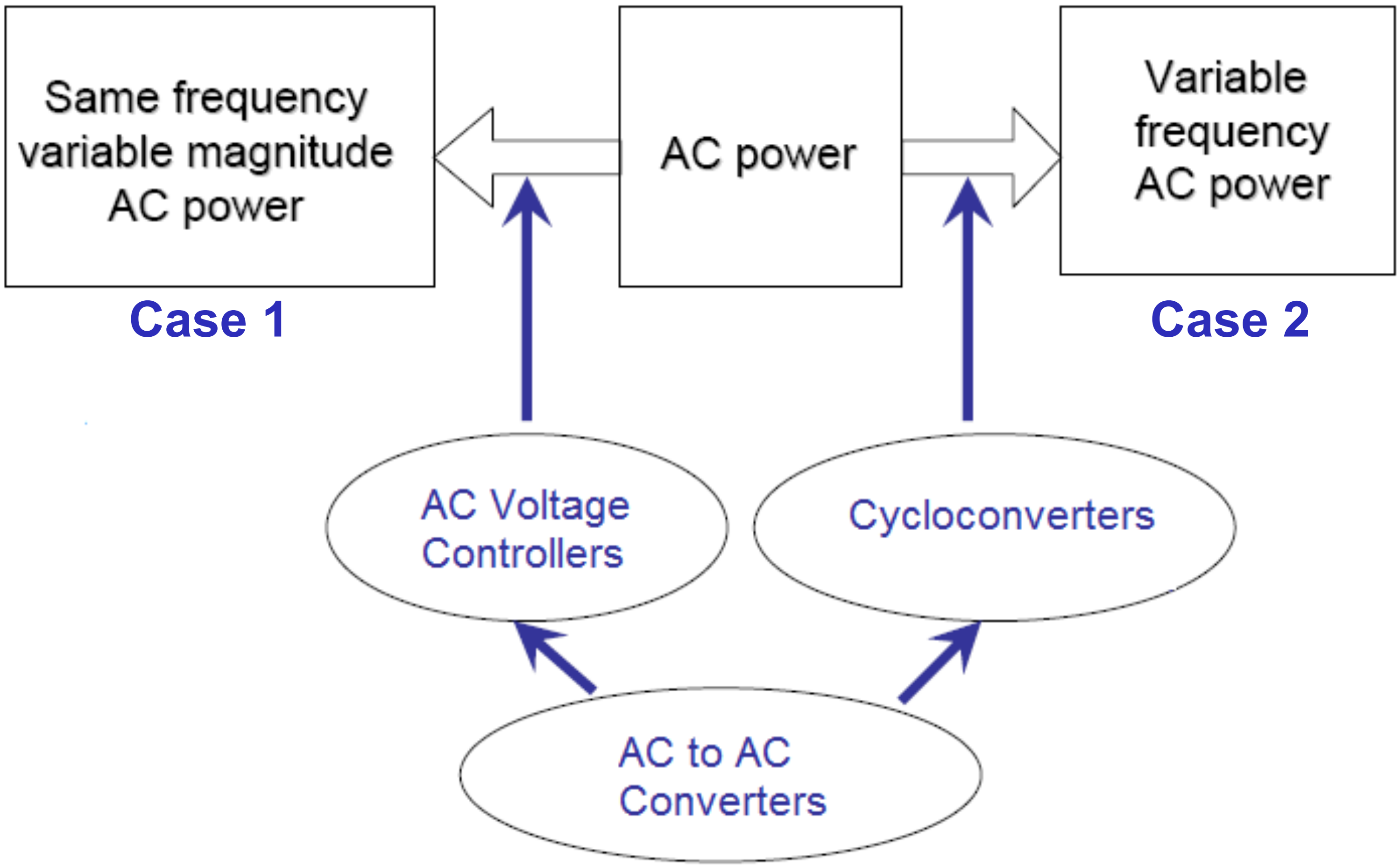
Lecture 5: Controlled Rectifier (3-phase)



- Numbering of the 6 thyristors indicates the trigger sequence:

$$T_1 \rightarrow T_2 \rightarrow T_3 \rightarrow T_4 \rightarrow T_5 \rightarrow T_6$$

Lecture 6: AC-AC Converters



✓ Used to obtain a variable ac output voltage from a fixed ac source.

Lecture 6: AC-AC Converters

In order to get variable AC voltage from an AC source, two techniques are often used:

Allows a current flow in both directions

- **Phase control**
  - The strategy is to use anti-parallel connected thyristors or TRIACS (Triode AC Switch).
  - Like AC-DC converters, the firing angle of the devices are controlled.
  - The devices conduct for a portion of each cycle.
- **On-off/integral-cycle control**
  - The devices conduct some cycles in a period of time and then disconnect some cycles.
  - The firing angle of devices is 0. But for some cycles, the firing pulses are turned off.
  - Lower switching losses.

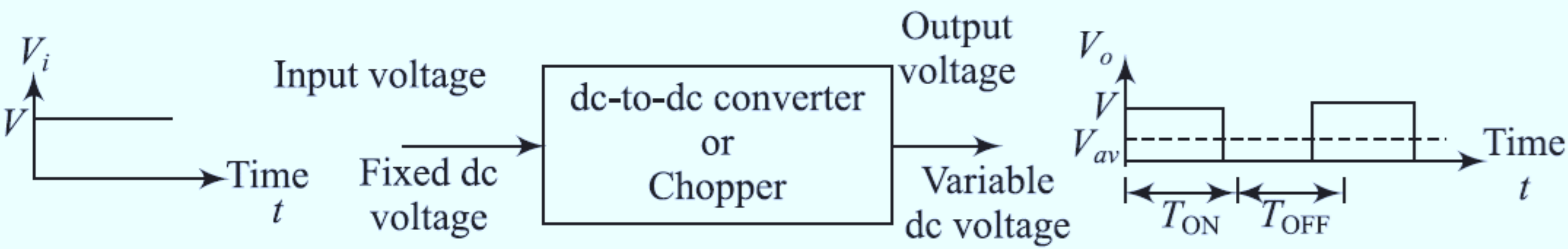
Lecture 6: AC-AC Converters

Cycloconverters

- Converts input power at one frequency to output power at a different frequency with one-stage conversion.
- It can be used to eliminate the requirement of one or more intermediate converters.
  - ✓ Another name—*direct frequency converter* (as compared to AC-DC-AC frequency converter)
    - If the output frequency is greater than input frequency → *step-up (forced)*
    - If the output frequency is less than input frequency → *step-down (natural)*
- Applications of cycloconverters are:
  - ✓ Speed control of very high power ac drives
  - ✓ Industrial heating etc.,

Lecture 7: DC to DC Converters

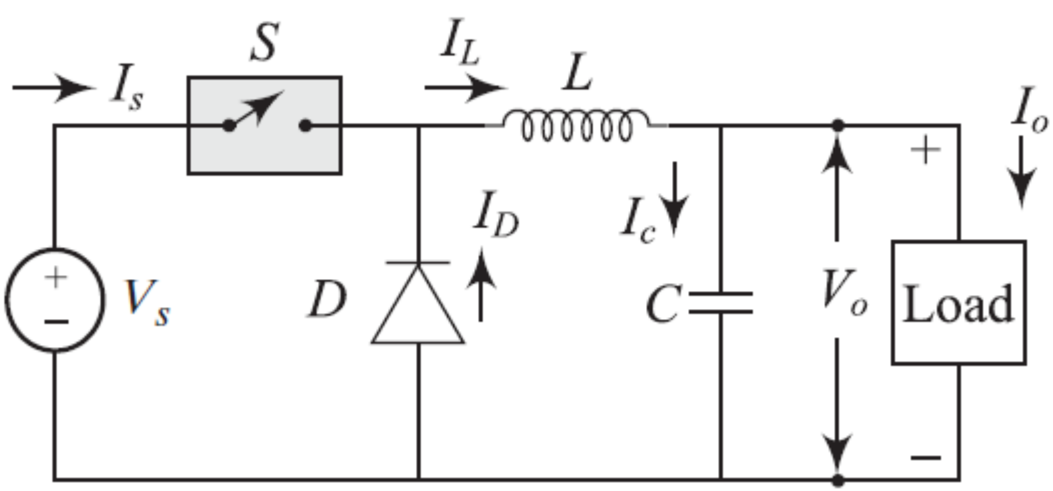
- DC-DC converters (also called *choppers*) can be used to obtain a *variable dc voltage from a fixed dc supply*.
- Step-down (*Buck converters*) – output voltage is less than input voltage.
- Step-up (*Boost converters*) – output voltage is higher than input voltage.
- Step-up/down: *Buck-boost converters*
  - the output voltage can be higher or less than the input voltage.

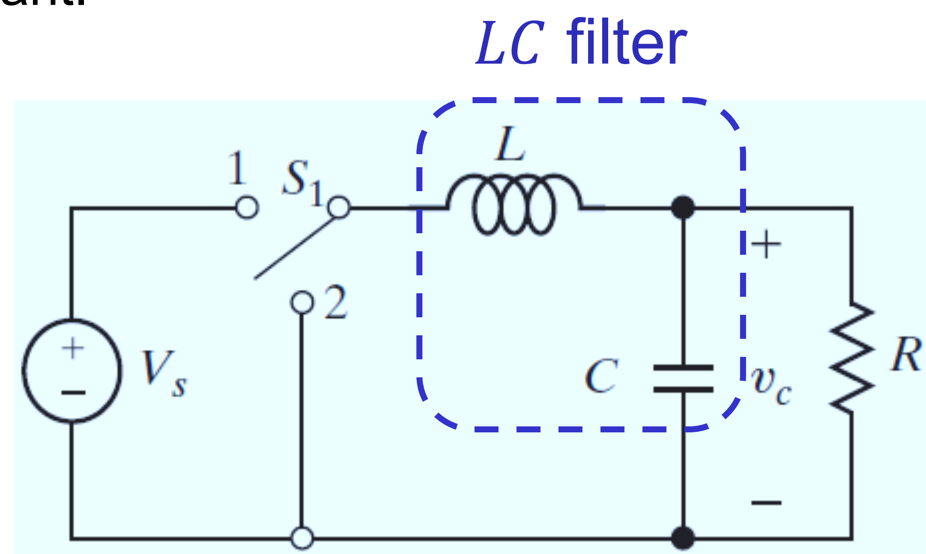


T_{ON} Is ON time of switch
T_{OFF} Is OFF time of switch

Lecture 7: DC to DC Converters (Buck)

- Average output voltage is *less than* input voltage – hence, called *buck* converter.
- One switch and one diode (to overcome the problem of stored inductive energy).
- Switch S can be a power BJT and acts as a controlled switch; diode D is uncontrolled switch – operate as *two* SPST bidirectional switches, shown below.
- LC filter to remove switching harmonics and to pass only the DC component so that the output voltage v_o is nearly a constant.

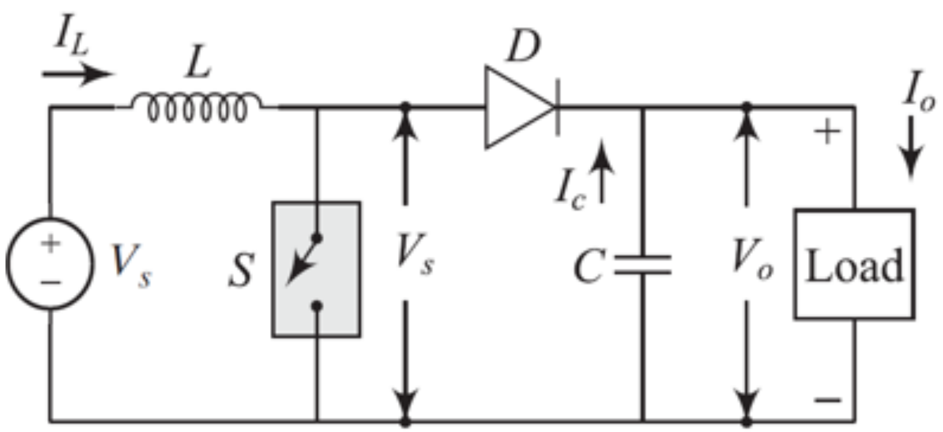


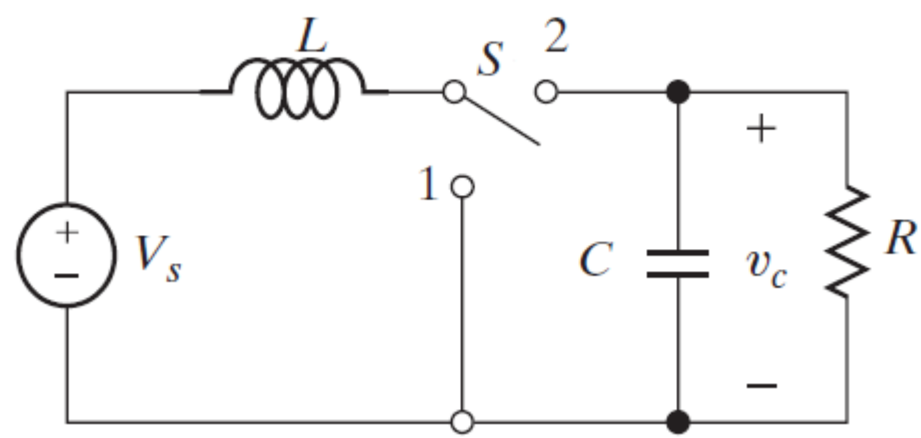


Buck converter → Two switches representation

Lecture 7: DC to DC Converters (Boost)

- Average output voltage is *greater than* input voltage – hence, called *boost* converter.
- One switch and one diode (to overcome the problem of stored inductive energy).
- Switch S can be a power MOSFET and acts as a controlled switch; diode D is uncontrolled switch – operate as *two* SPST bidirectional switches, shown below.

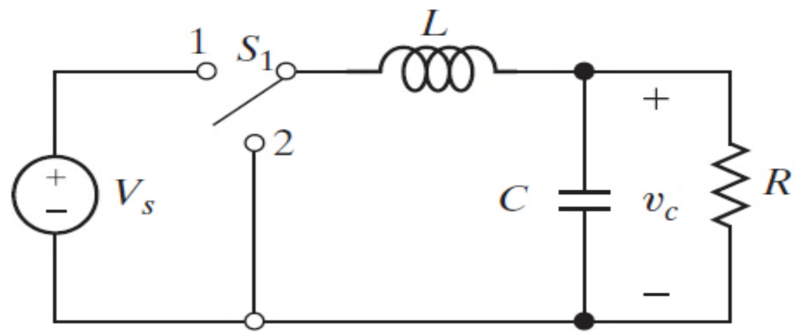


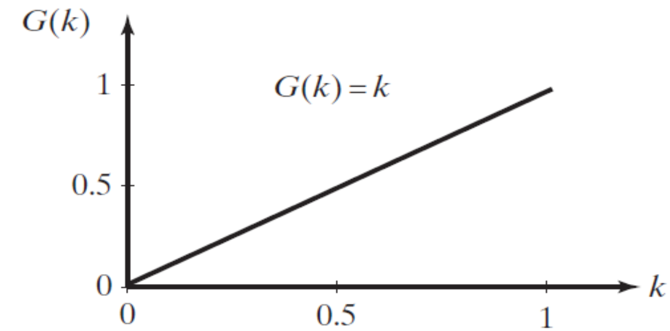


Boost converter → Two switches representation

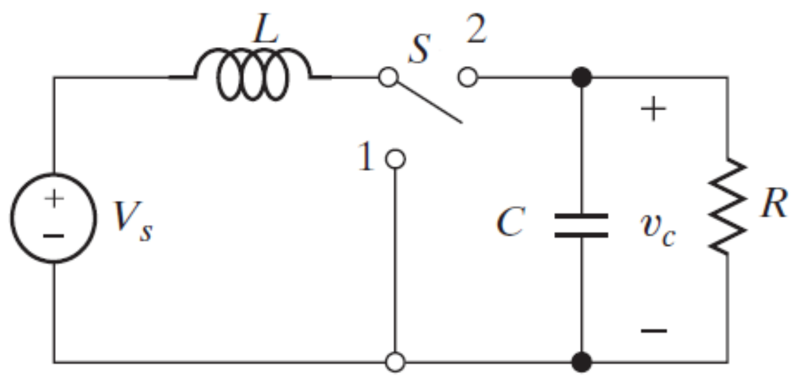
Lecture 7: DC to DC Converters (Comparison)

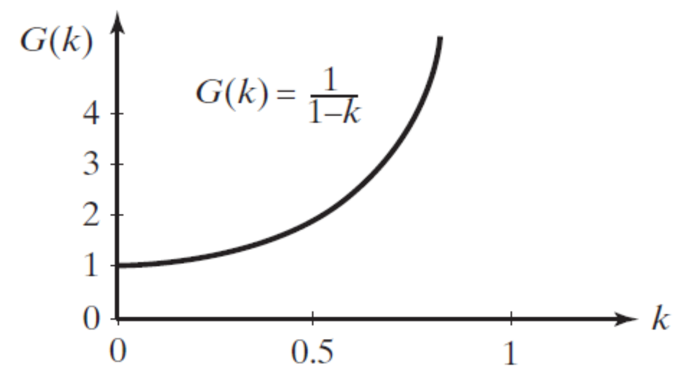
Buck



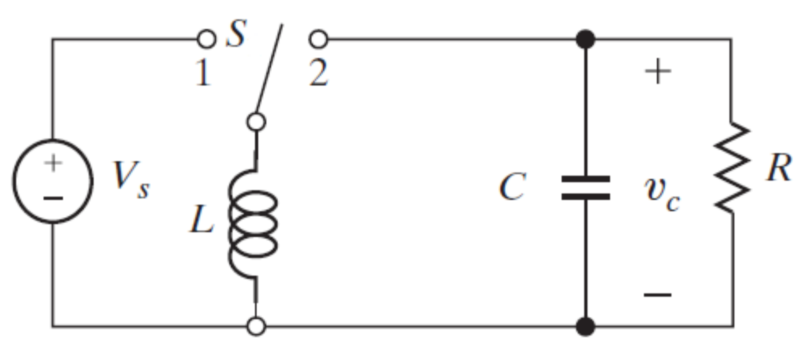


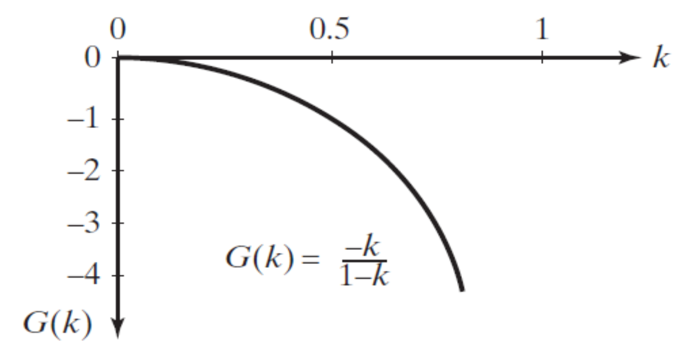
Boost





Busk-Boost





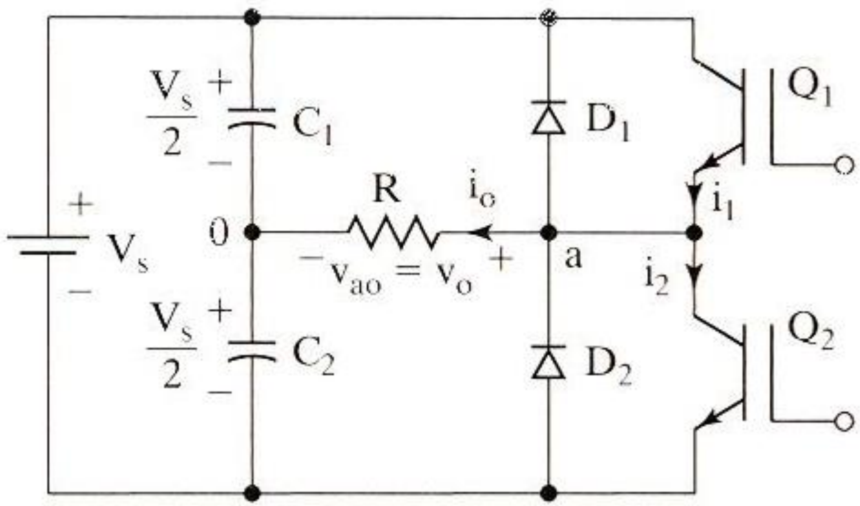
Switch representation

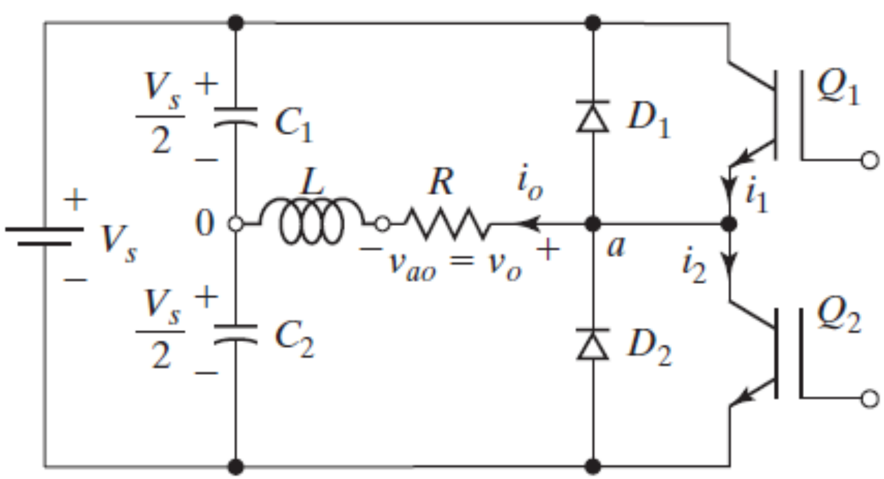
Comparison of voltage gains

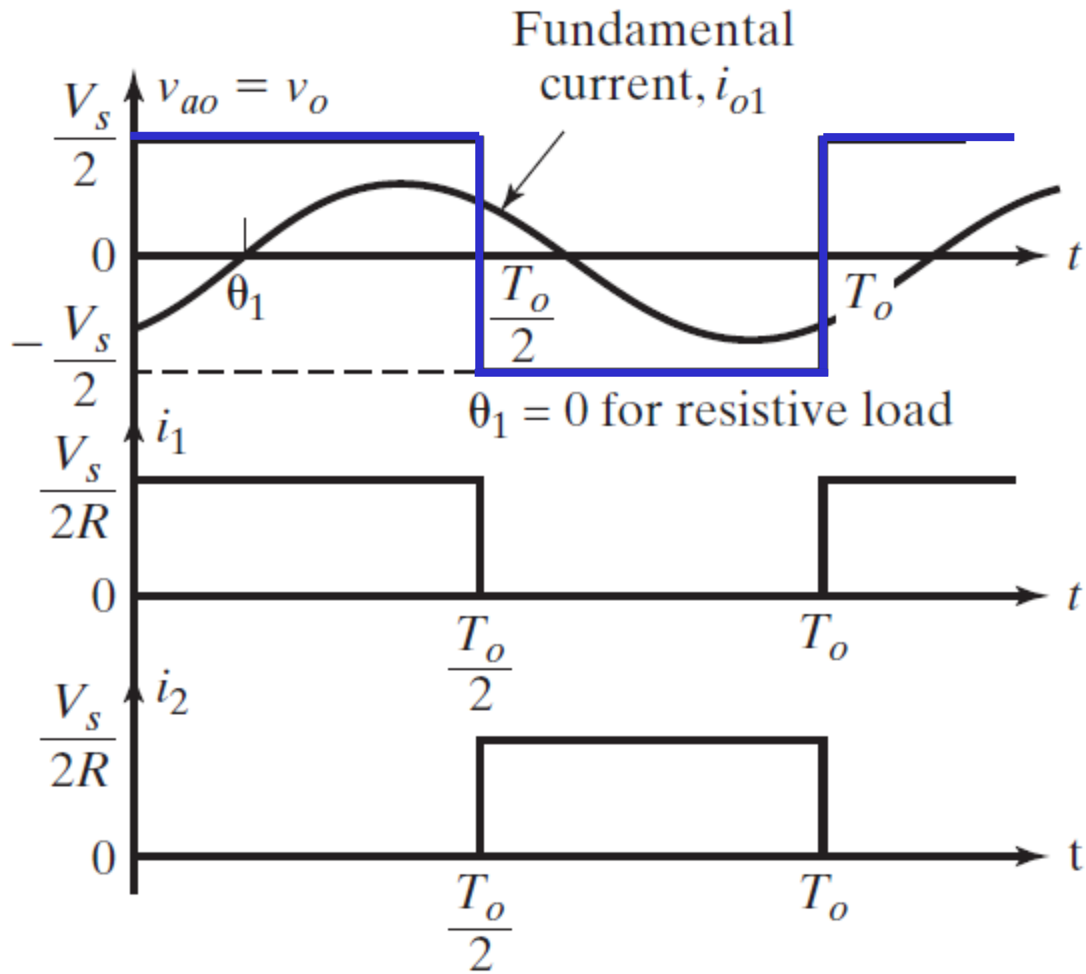
Lecture 8: DC to AC Inverters

- Changes DC input voltage to a symmetric AC output voltage of desired magnitude and frequency – *Inverter*
- Variable output voltage can be obtained by *varying the input dc voltage* and maintaining the gain of the inverter constant
- If the *DC input voltage is fixed*, the output voltage can be controlled using – *pulse-width-modulation (PWM)*
- The output voltage should be sinusoidal, *however*, practical inverters are non-sinusoidal and contain *certain harmonics*
- Inverters are widely used in industrial applications – inputs may be battery, fuel cell, solar cell, or other dc source
- The inverters use *fully controlled devices* – BJTs, MOSFETs

Lecture 8: Single-phase half-bridge VSI

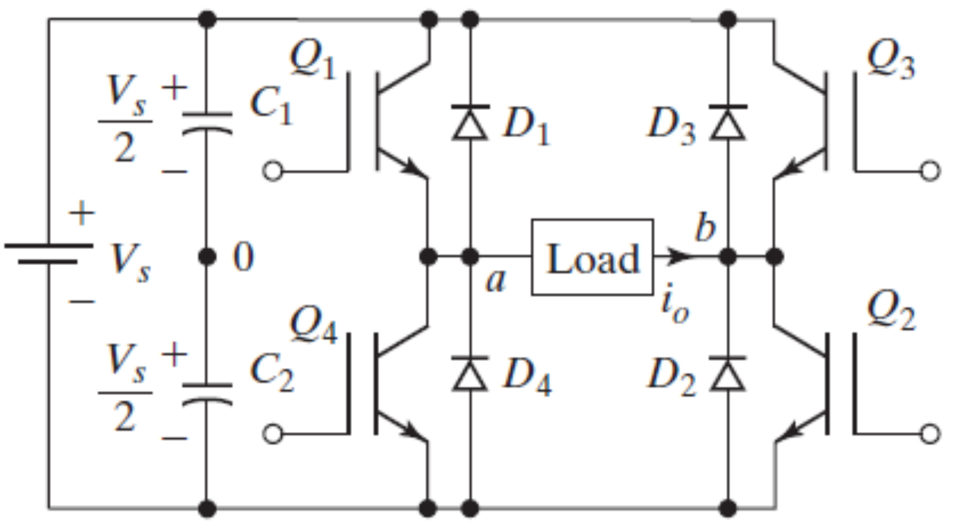


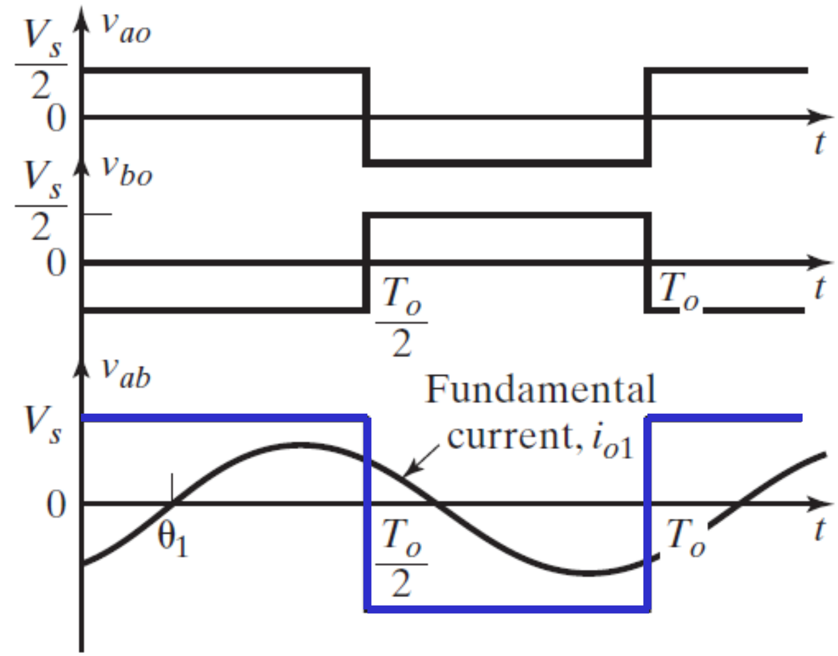




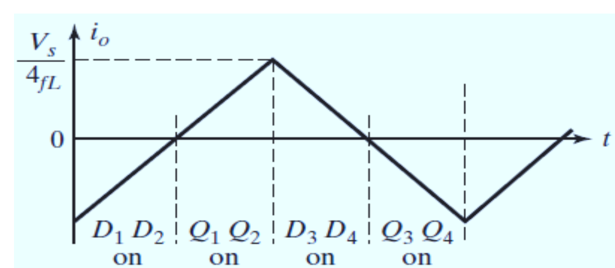
Waveforms of output voltage & transistor currents with resistive load

Lecture 8: Single-phase full(H)-bridge VSI





- Consists of 4 choppers – 1) When Q_1 & Q_2 are turned ON simultaneously, V_s appears across the load, 2) If Q_3 & Q_4 are turned ON simultaneously, $-V_s$ appears across the load.
- When the load is highly inductive, the current waveform is triangular.
- The RMS output voltage is,



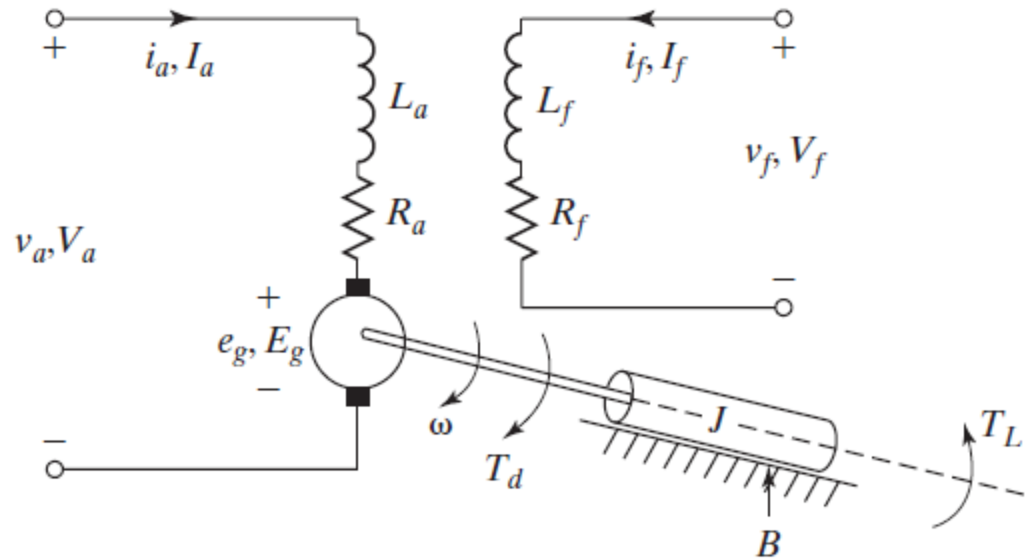
$$V_o = \left(\frac{2}{T_0}\int_0^{T_0/2} V_s{}^2 dt\right)^{1/2} = V_s$$

Lecture 8: Types of DC Motors

- Two types depending on type of field winding connections:
  - **Shunt:** field excitation is independent of armature circuit
    - controlled independently (*separately excited motor*)
    - armature and field currents are different
  - **Series:** the field excitation is in series with the armature
    - armature and field currents are same

Lecture 8: Separately Excited DC Motor

- When *excited* by a field current (i_f) and an armature current of i_a flows in the circuit, the *motor develops* a back *EMF* & a *torque* to balance the load torque at particular speed of motor.



Equivalent circuit

- The i_f is *independent* of i_a and any change in one of them would not affect other current. Normally, $i_f \ll i_a$.

- Instantaneous field current i_f is described as

$$v_f = R_f i_f + L_f \frac{di_f}{dt}$$

- Instantaneous armature current can be found from, $v_a = R_a i_a + L_a \frac{di_a}{dt} + e_g$

- The motor back emf (or *speed voltage*) is, $e_g = K_v \omega i_f$

Lecture 8: Series Excited DC Motor

- The field circuit is designed to carry the armature current. The steady-state quantities:
- The motor back emf is, $E_g = K_v \omega I_a$
- Instantaneous armature current can be found:

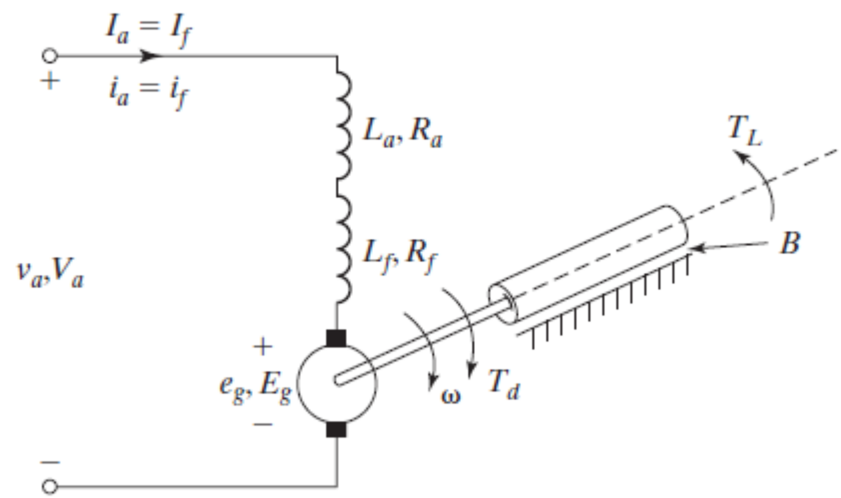
$$V_a = (R_a + R_f)I_a + E_g = (R_a + R_f)I_a + K_v \omega I_f$$

- The torque developed by the motor,

$$T_d = K_t I_f I_a = B\omega + T_L$$

- The speed of a series motor can be found as

$$\omega = \frac{V_a - (R_a + R_f)I_a}{K_v I_f}$$



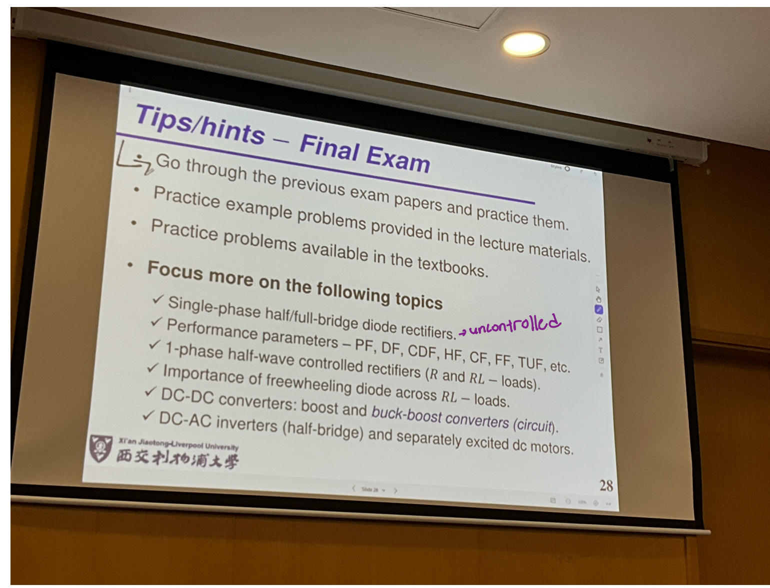
Equivalent circuit

- The speed can be varied by controlling the 1) armature voltage; or 2) armature current, which is a measure of the torque demand.
- Series motor can provide a high torque, especially at starting – commonly used in traction applications.

Units for torque constant, $K_t \rightarrow N - m/A^2$

Guidelines – Final Exam

- *Exam date:* **27th May 2025 (Tuesday) @10:00 AM**
- *Exam duration:* **2 hrs**
- *Exam venue:* **ESG09**
- *Format:* **Onsite**



You may need to write about the buck-boost circuit or output expression. There won't be any exercise problems on buck-boost converter tested in the exam

See you in the final exam

- **Hope you got *some knowledge* from this module.**
- **All the best for final exam.**
- **NO formulae sheet is provided in the final exam.**

The End