EEE213 Power Electronics and Electromechanism

6. AC-AC Controller

EEE213 Power Electronics and Electromechanism

Lab arrangement (Room EE411)

11th April Thursday (9:00-12:00 & 2:00 -5:00)

Deadline: May 5th, 23:55pm

TA (PhD students) :

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EEE213 Power Electronics and Electromechanism

Assignment 1

Deadline: ~~21st April,~~ 12th May2019. Time: 23.55.

Assignment 2

Deadline: 19th May 2019. Time: 23.55.

ALL Tutorial questions (week11 &12)

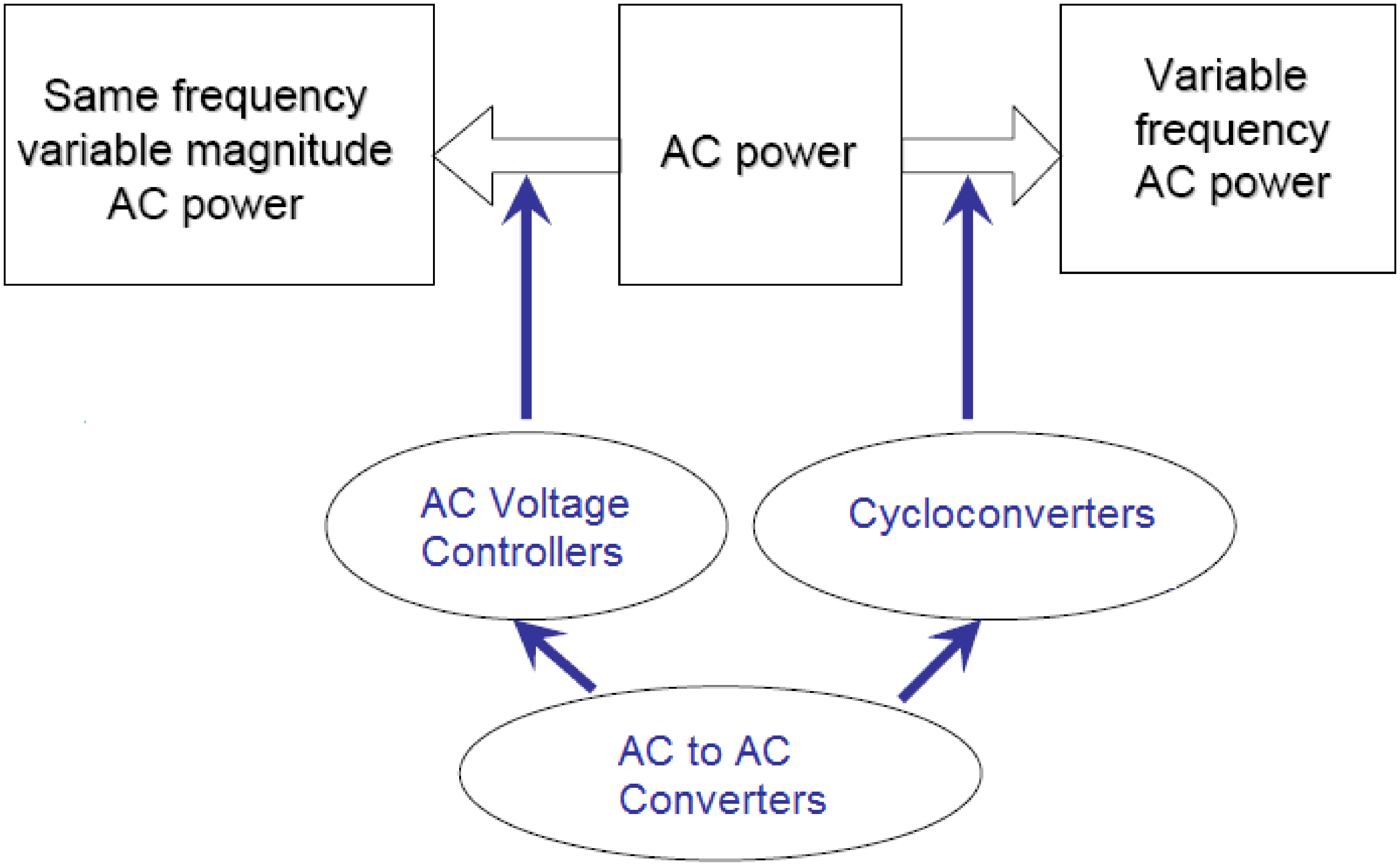
TA (PhD student) :

1. Yujie Liu: Yujie.liu@xjtlu.edu.cn

Outline

- 1. AC-AC Voltage Converters
  - 1.1 Phase control
    - Resistive load
    - Inductive load
    - Three-phase system
  - 1.2 On-off control
    - Principles
    - Static switches (AC)
    - Bus transfer
- 2. Cycloconverters
  - 2.1 Basic operation principle
  - 2.2 Single phase system
  - 2.3 Three phase system
    - Three-phase to single phase
    - Three-phase to three phase

Classification of AC to AC converters



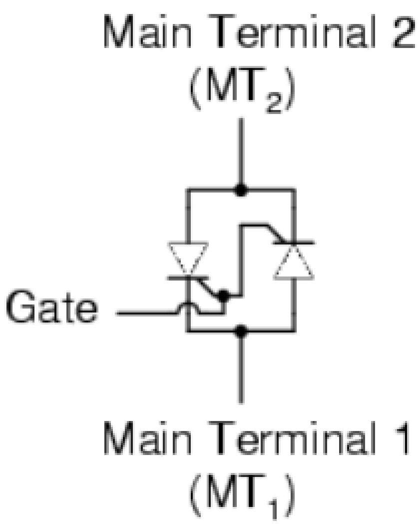
1. AC-AC voltage control

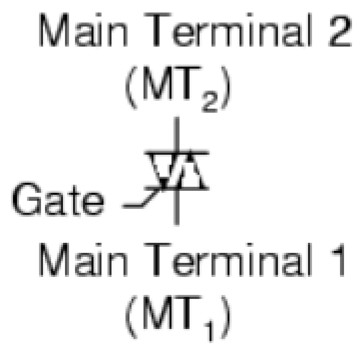
In order to get variable AC voltage from an AC source, two techniques are often used:

- Phase control
  - Similarly in AC-DC converters, the firing angle of the devices are controlled.
  - The devices conduct a portion of each cycle
- On-off 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

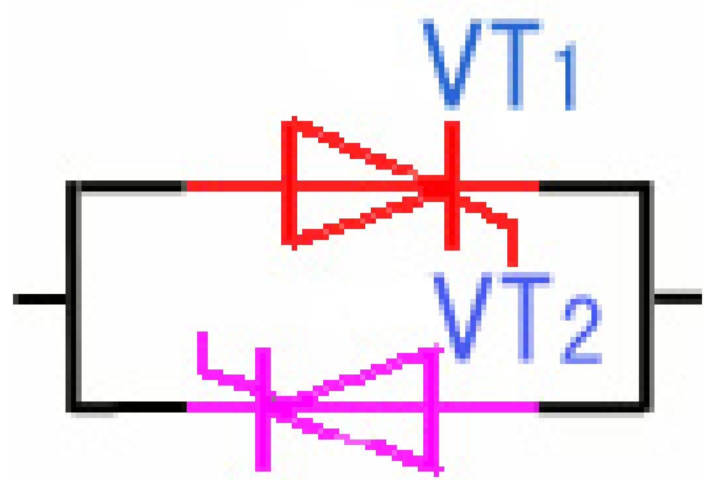
1.1 Phase control

- The strategy is to use anti-parallel connected thyristors or TRIACS (Triode AC Switch).
  - Two SCRs connected in anti-parallel with a common gate
  - Can conduct in both ways

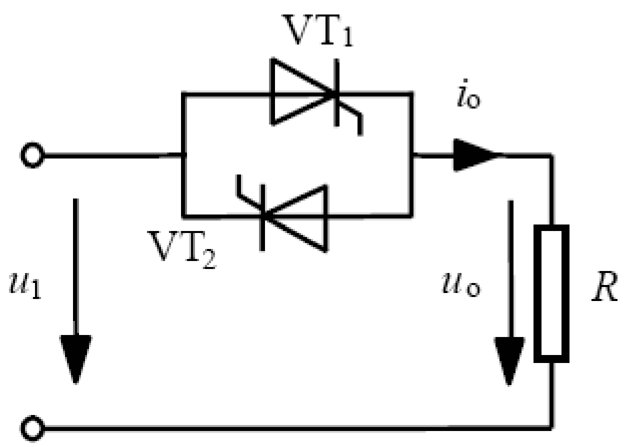


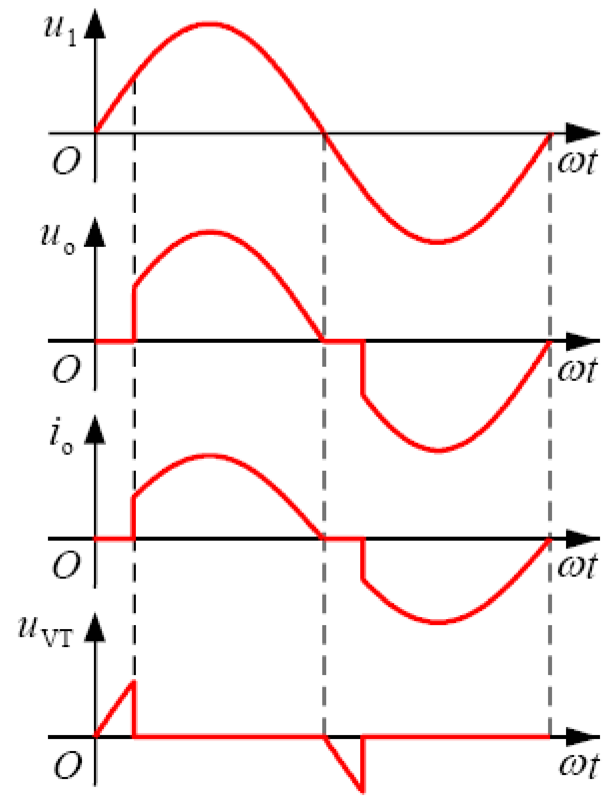


TRIAC schematic symbol



1.1.1 Single-phase, resistive load





The phase shift range (operation range of phase delay angle): $0 \leq \alpha \leq \pi$

Very similar to the case of rectifiers. Instead of having a DC output voltage, the output is alternative.

1.1.1 Single-phase, resistive load

- The rms value of the output voltage is

$$V_{RMS} = \sqrt{\frac{2}{2\pi}\int_{\alpha}^{\pi}\left(\sqrt{2}V_s \sin \omega t\right)^2 d(\omega t)}$$

$$= \sqrt{\frac{4V_s^{\,2}}{4\pi}\int_{\alpha}^{\pi}\left(1 - \cos 2\omega t\right) d(\omega t)}$$

$$= V_s \sqrt{\frac{\pi - \alpha}{\pi} + \frac{\sin 2\alpha}{2\pi}}$$

- By varying α from 0 to π , V_{RMS} can be varied from 0 to V_s.

1.1.1 Single-phase, resistive load

- The rms value of the output current is

$$I_{RMS} = \frac{V_{RMS}}{R}$$

- The rms value of thyristor current

$$I_{VT} = \sqrt{\frac{1}{2\pi}\int_{\alpha}^{\pi}\left(\frac{\sqrt{2}V_s \sin\omega t}{R}\right)^2 d(\omega t)} = \frac{I_{RMS}}{\sqrt{2}}$$

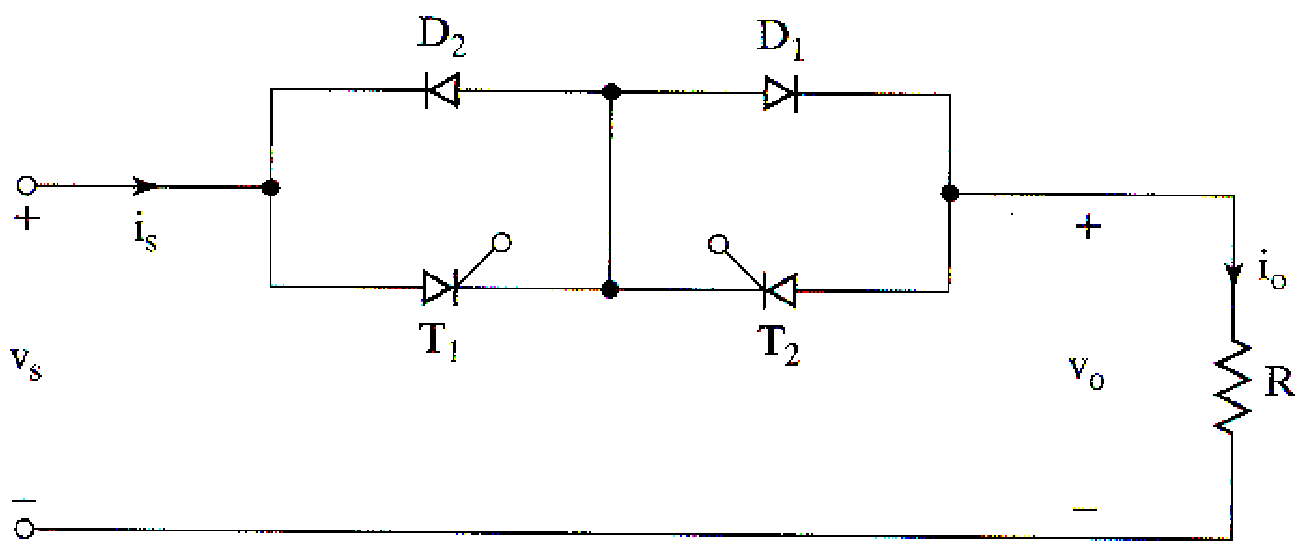
- Power factor of the circuit

$$f_P = \frac{P_{RMS}}{P_s} = \frac{V_{RMS}I_{RMS}}{V_s I_s} = \frac{V_{RMS}I_{RMS}}{V_s I_{RMS}}$$

$$= \sqrt{\frac{\pi-\alpha}{\pi} + \frac{\sin 2\alpha}{2\pi}}$$

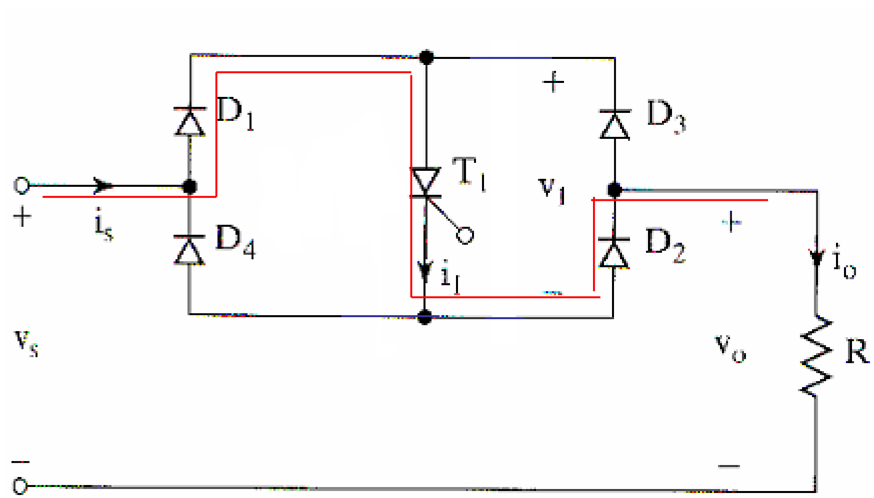
With common cathode

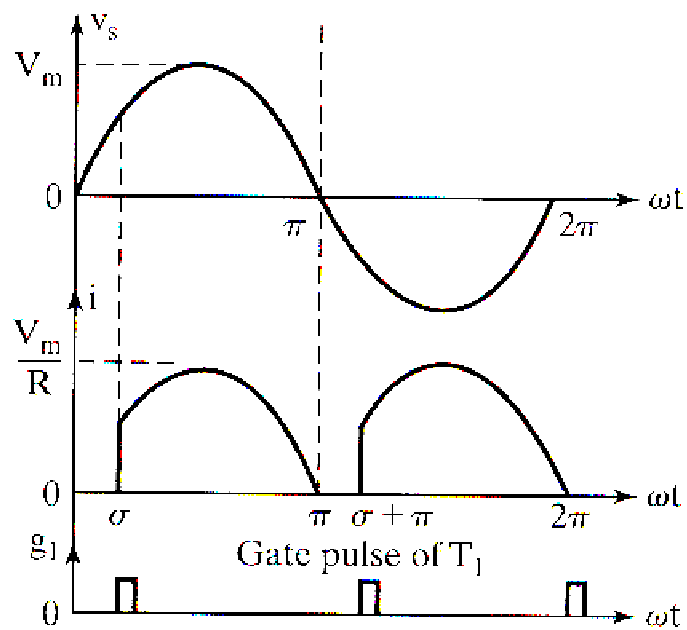
- One isolated gating circuit is needed, at the cost of two extra diodes
- Conduction losses will increase and efficiency will drop, due to two devices conduct at the same time.



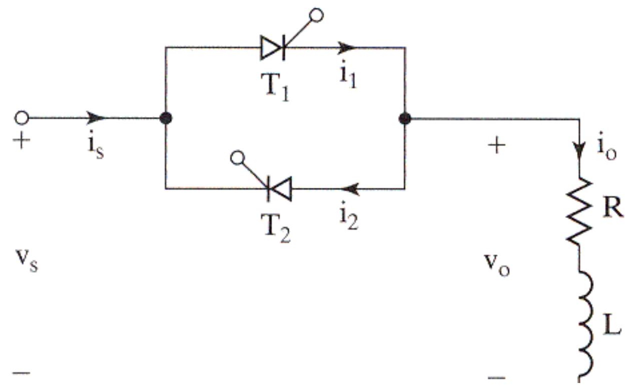
With one switch

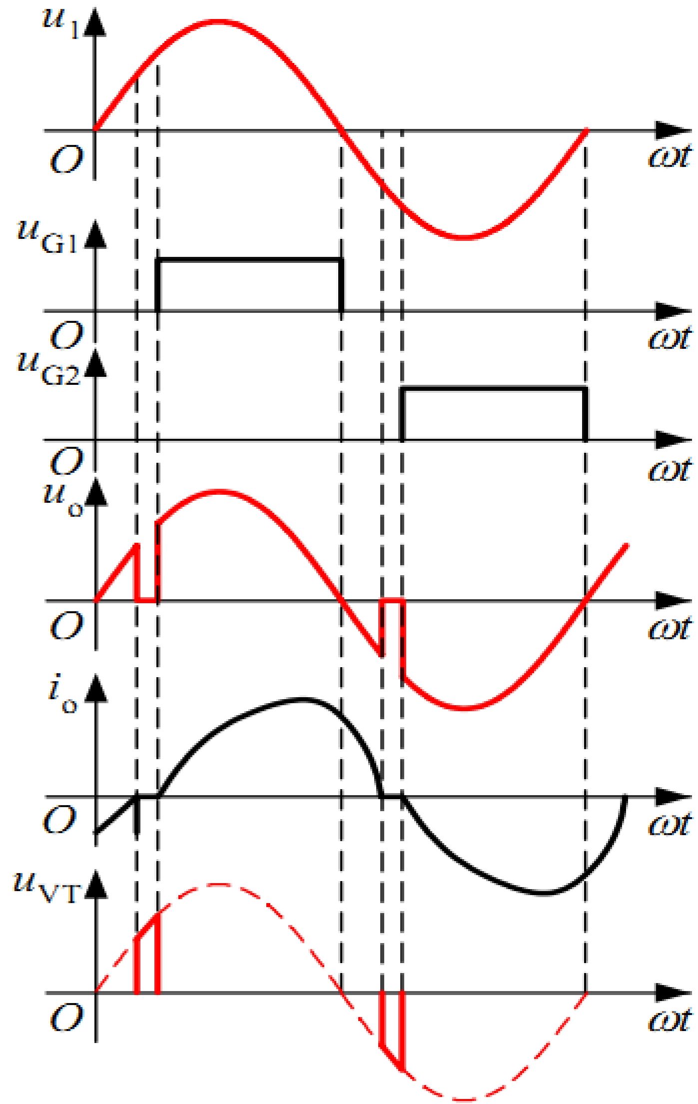
- Only works well for a resistive load.
  - With large inductance in the circuit, thyristor may not be turned off in every half-cycle, and this may result in a loss of control.
- Conduction loss is high, due to the fact that three devices conduct at the same time.





1.1.2 Single-phase, inductive load





- The device does not turn off at $\omega t = \pi$, but continues conducting till the current falls to 0.
- Phase shift range: $\theta \leq \alpha \leq \pi$

Quantitative analysis

- Solving the differential equation

$$L\frac{di_0}{dt}+Ri_0=\sqrt{2}U_2\sin\omega t$$

$$i_0\big|_{\omega t=\alpha}=0$$

$$\Rightarrow i_0=\frac{\sqrt{2}U_2}{Z}\left[\sin(\omega t-\theta)-\sin(\alpha-\theta)e^{\frac{\alpha-\omega t}{\tan\theta}}\right]$$

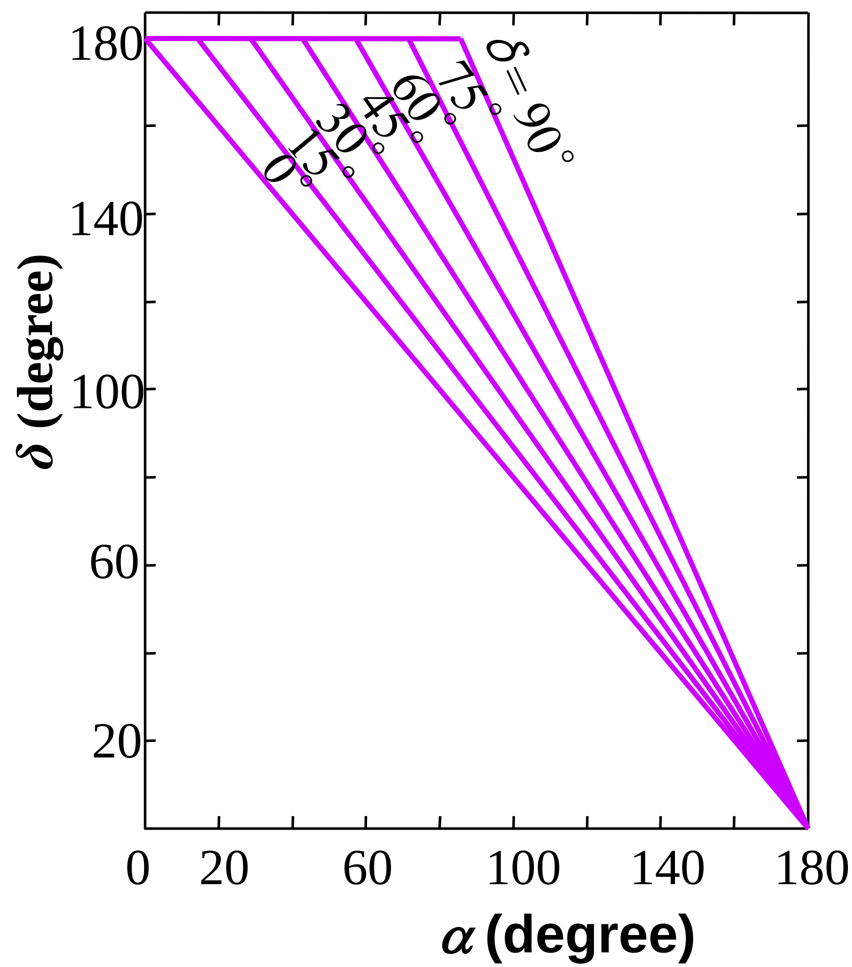
- Considering $i_o=0$ when $\omega t=\beta$

$$\Rightarrow \sin(\beta-\theta)=\sin(\alpha-\theta)e^{\frac{\alpha-\beta}{\tan\theta}}$$

  - So we can get extinction angle β
  - and conduction angle $\delta=\beta-\alpha$

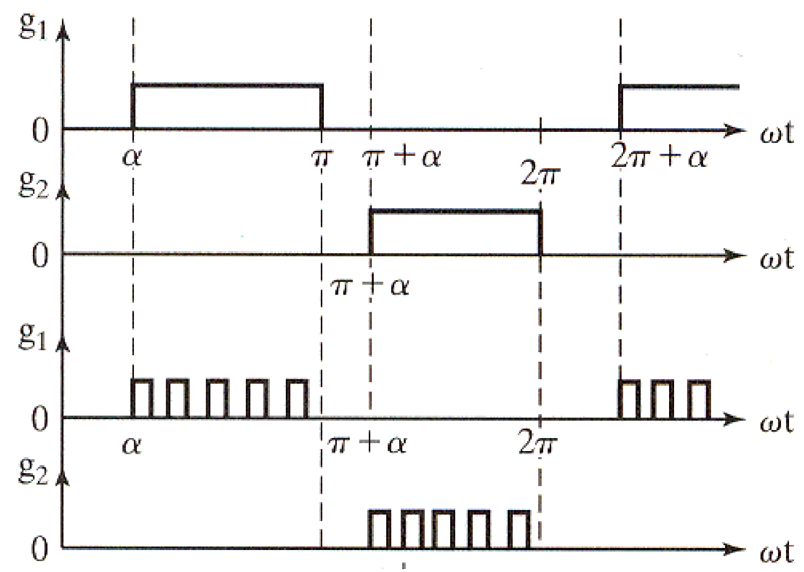
- Phase shift range

$$\theta=\arctan\frac{\omega L}{R}\le\alpha\le\pi$$



Quantitative analysis

- The larger the inductance, the longer the switch conducts. If the firing pulse for the other switch arrives earlier than this switch turns off, then it may not be fired.
  - Continuous pulse firing: increased conduction losses and a larger isolating transformer
  - A train of pulses with short duration

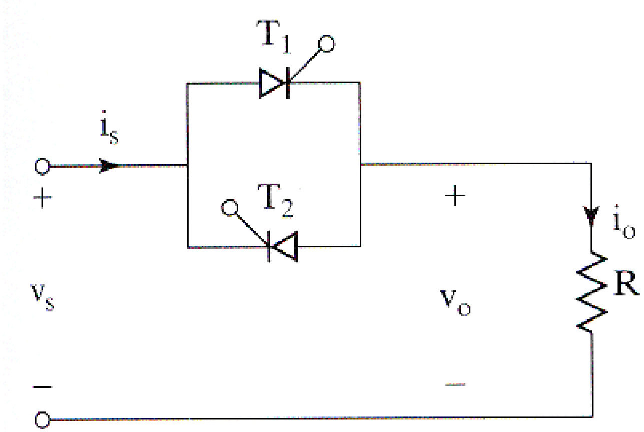


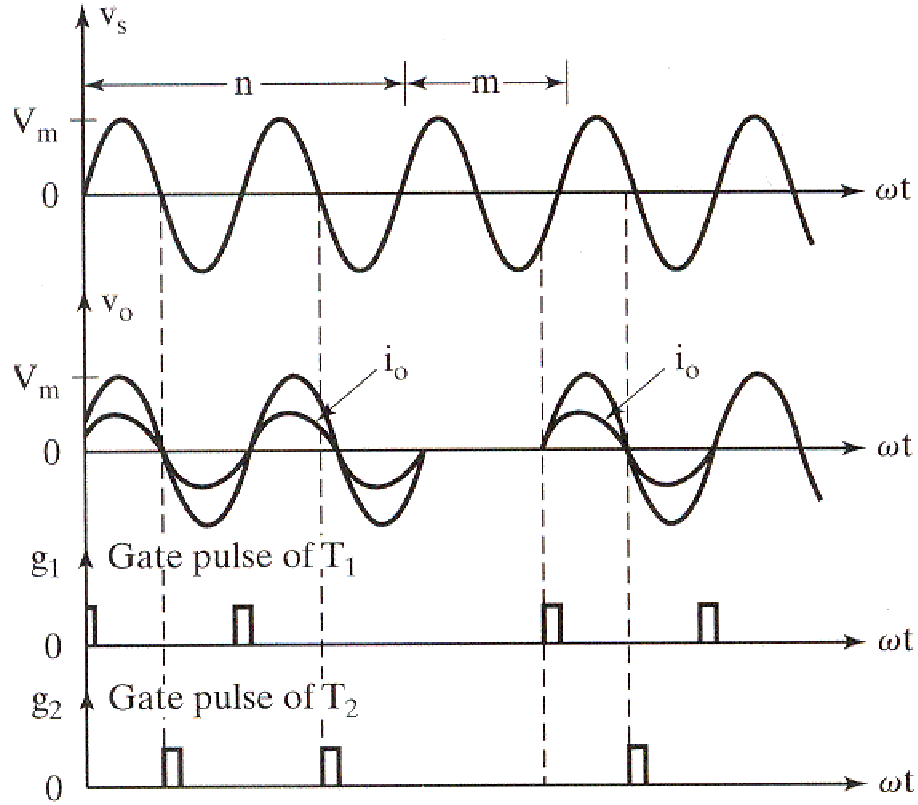
1.2. On-off control

The main problem of phase control is the high THD

- On-off control
  - The switch conducts for some cycles and then turn off for some cycles: duty cycle
  - Zero-voltage/zero-current crossing to reduce the THD
  - Very good for applications having high mechanical inertia or high thermal time constant

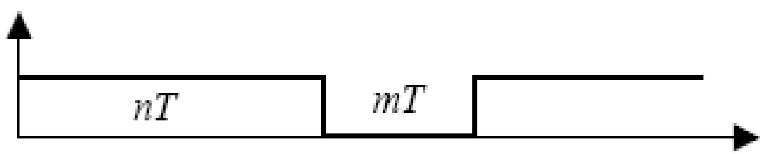
1.2.1 Basic On-off control





Duty cycle

$$k = \frac{nT}{(n+m)T} = \frac{n}{n+m}$$



T – Line period

(n+m)T – Control period

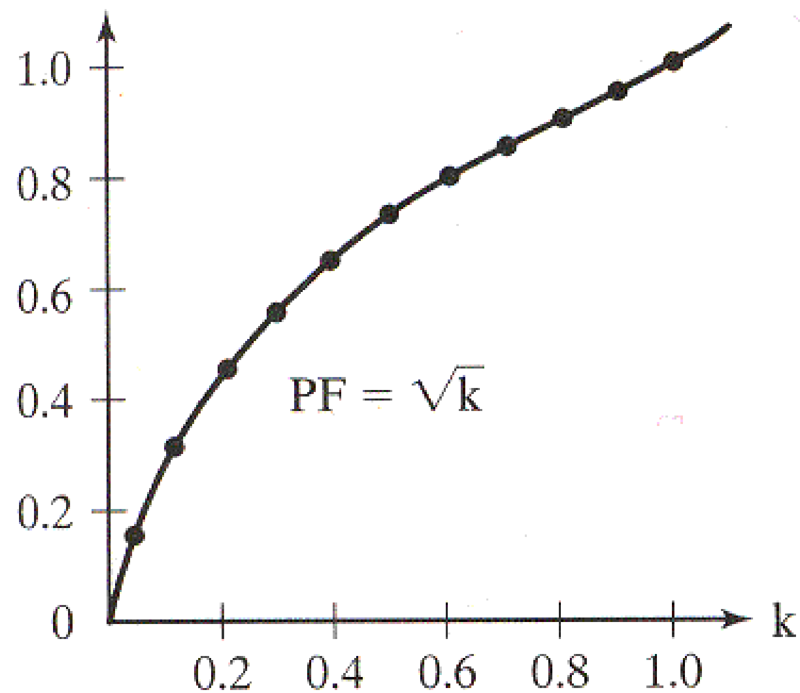
1.2.1 Basic On-off control

- The rms output voltage is

$$V_{RMS} = \sqrt{\frac{1}{2\pi}\frac{n}{n+m}\int_0^{2\pi} 2V_s^2 \sin^2 \omega t d(\omega t)} = V_s\sqrt{\frac{n}{n+m}} = V_s\sqrt{k}$$

- The input power factor is

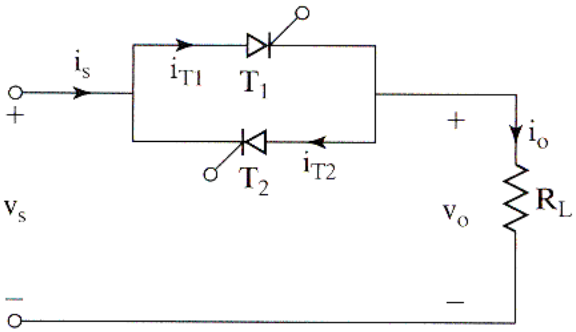
$$f_P = \frac{V_{RMS} I_{RMS}}{V_s I_s} = \frac{V_{RMS}}{V_s} = \sqrt{k}$$



1.2.2 Static switches

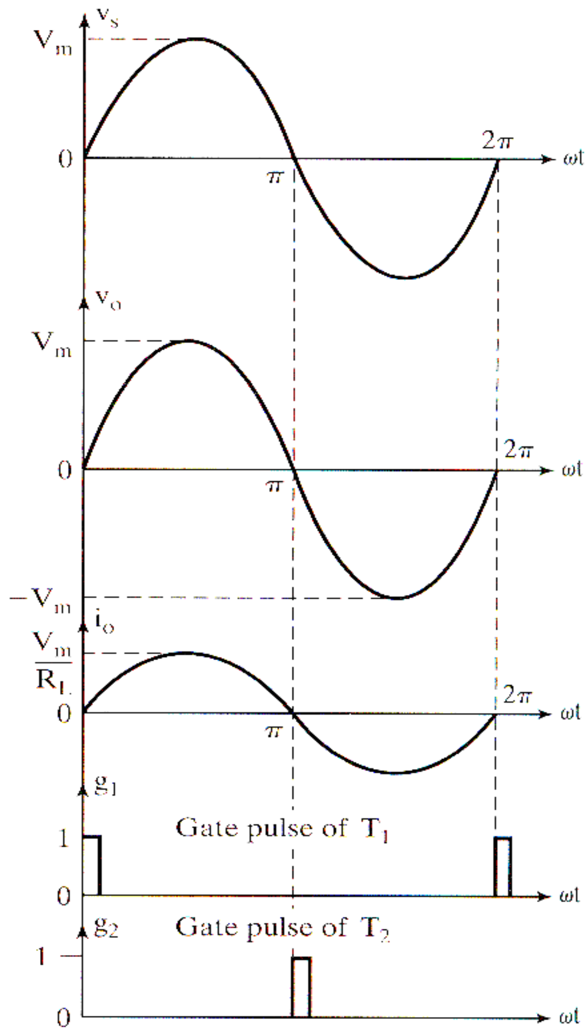
- The on-off control strategy can be easily extended to build static switches, which
  - Have very high switching speeds
  - Have no moving parts
  - Have no contacting bounce on closing

1.2.2 Single phase



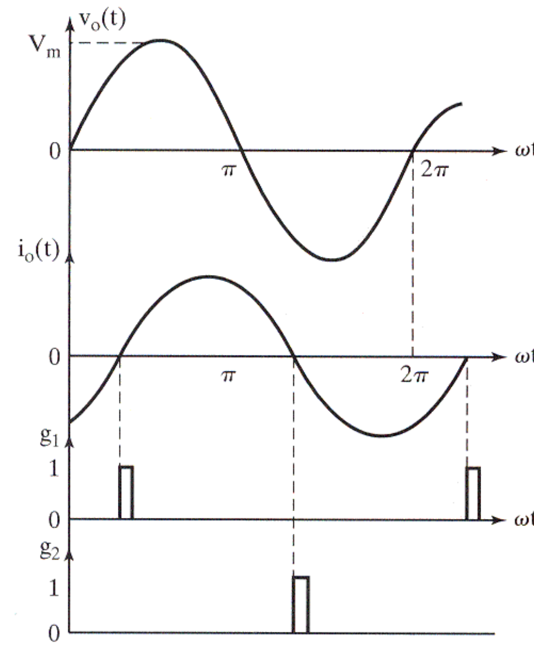
Resistive load:

zero-voltage/current crossing



Inductive load:

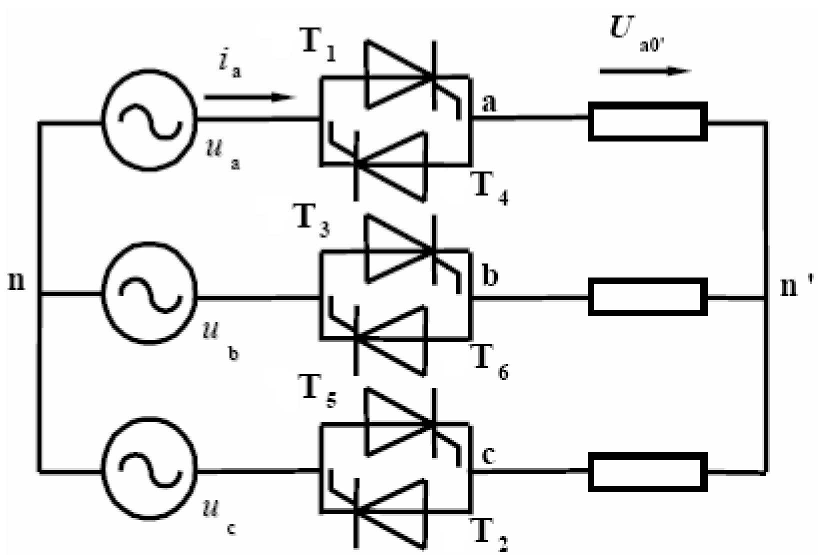
zero-current crossing

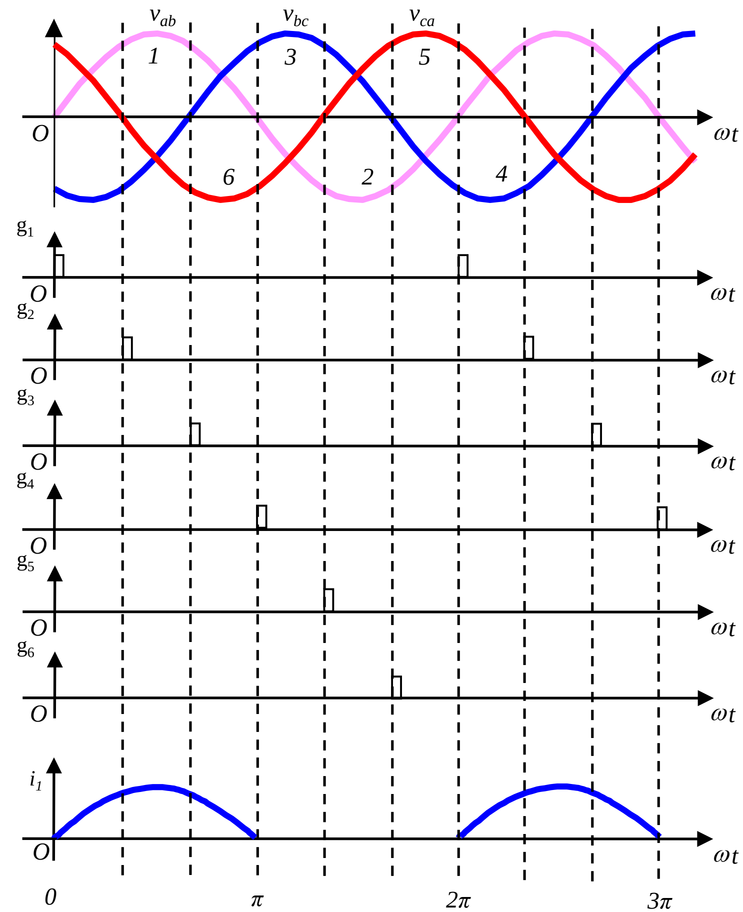


The switch reaction time: it can stop the current flow in every half-cycle (10ms for 50Hz supply).

1.2.2 Three-phase switches

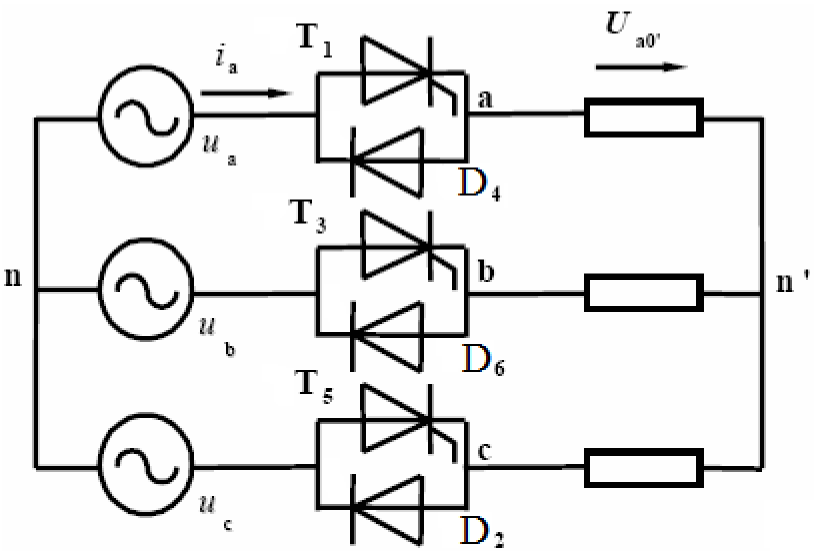
- The gating signals for thyristors are still at the current zero-crossing of each phase.
  - The switch speed: it can stop the current flow in every half-cycle (10ms for 50Hz supply).

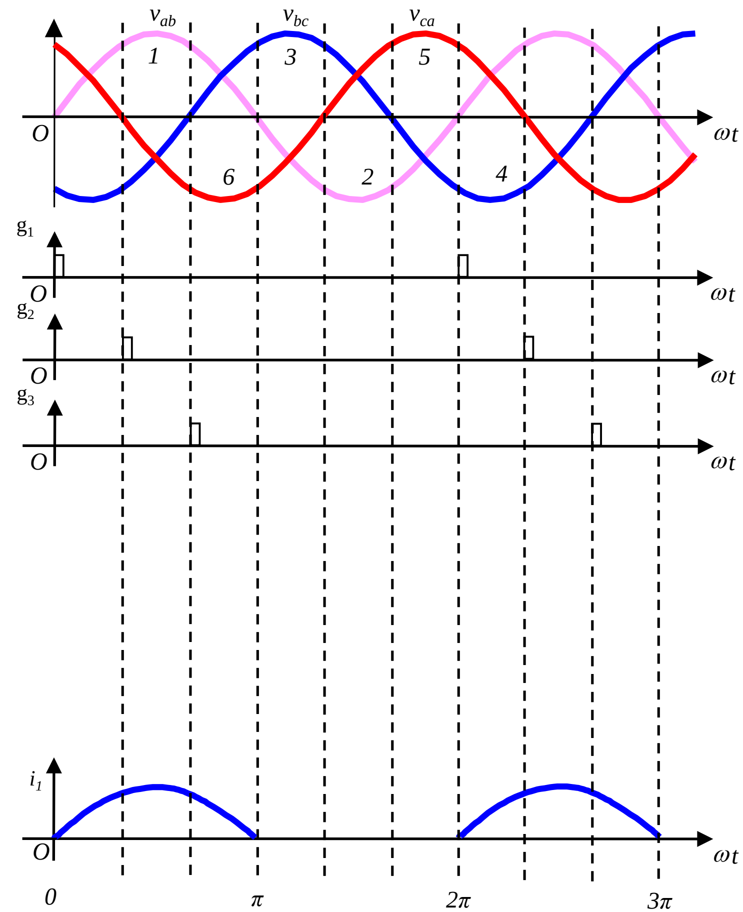




1.2.2 Three-phase switches

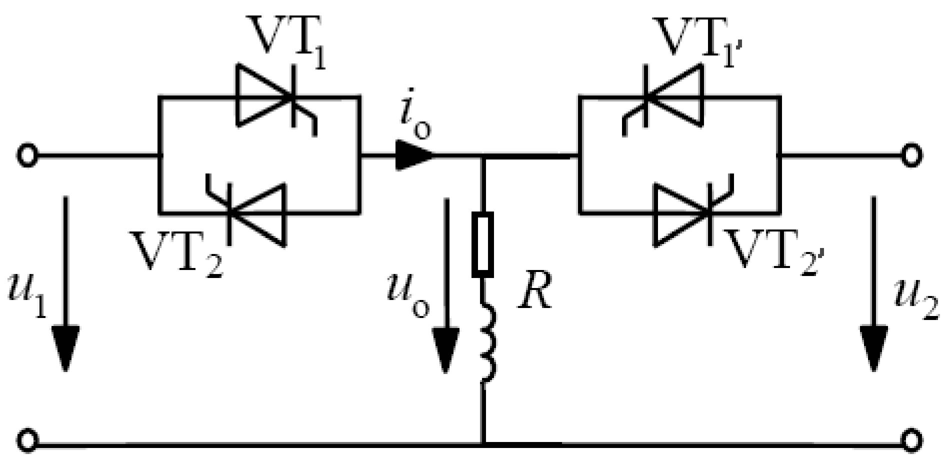
- A diode and a thyristor can also be used to form a three-phase switch.
  - The current flow can only be stopped in every whole cycle of input voltage, and the reaction time becomes slow (20ms for 50Hz supply.)





1.2.3 Bus Transfer

- The static switches can be used for bus transfer from one source to another.

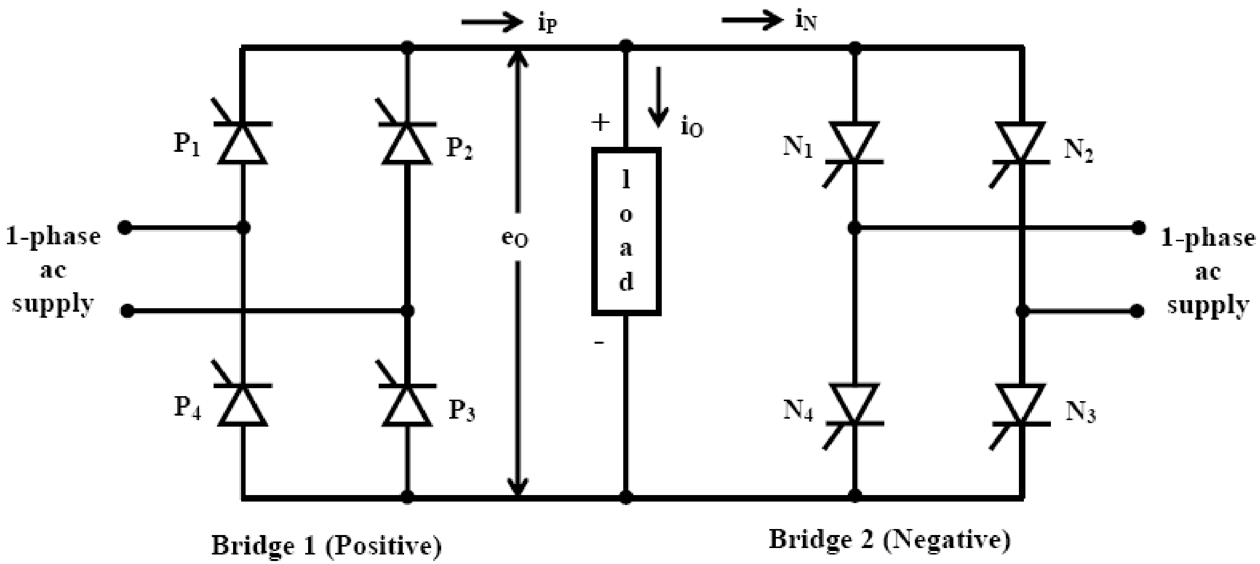


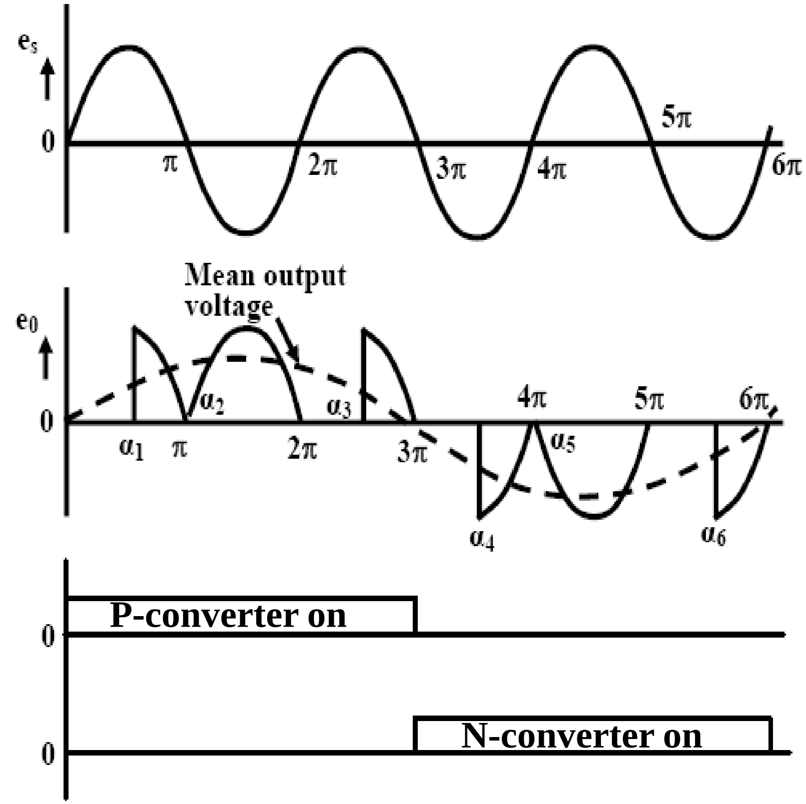
Cycloconverters (private learning activity)

- Thyristor AC to AC frequency converter
  - Another name—direct frequency converter (as compared to AC-DC-AC frequency converter)
    - Directly converting the input high frequency AC power to AC power with lower frequency
  - Can be classified into single-phase and three-phase according to the number of phases at output

2.1 Single-phase to single-phase converter

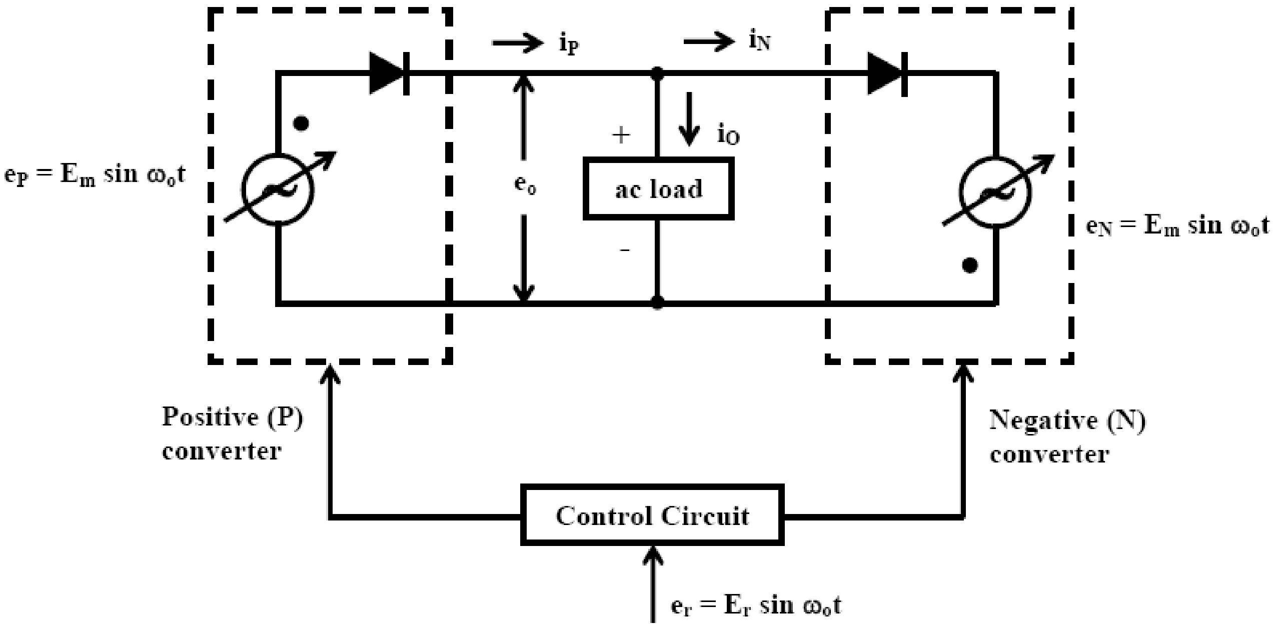
- Circuit configuration and operation principle
- Resistive load





2.1 Single-phase to single-phase converter

- Equivalent circuit and triggering principle



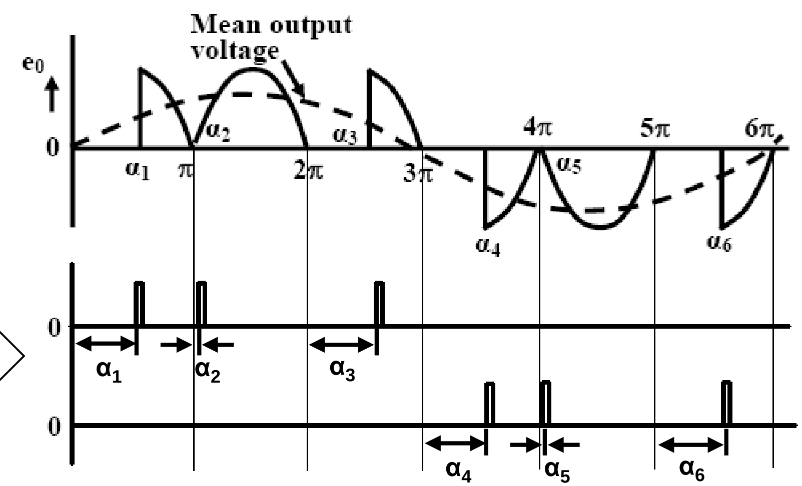
f_S = 60Hz

$f_O = f_S/3$ = 20Hz

Ripple frequency:

$f_R=2f_S$=120Hz

To make the output voltage close to sin wave, we trigger the delay angle according to sinusoidal pattern



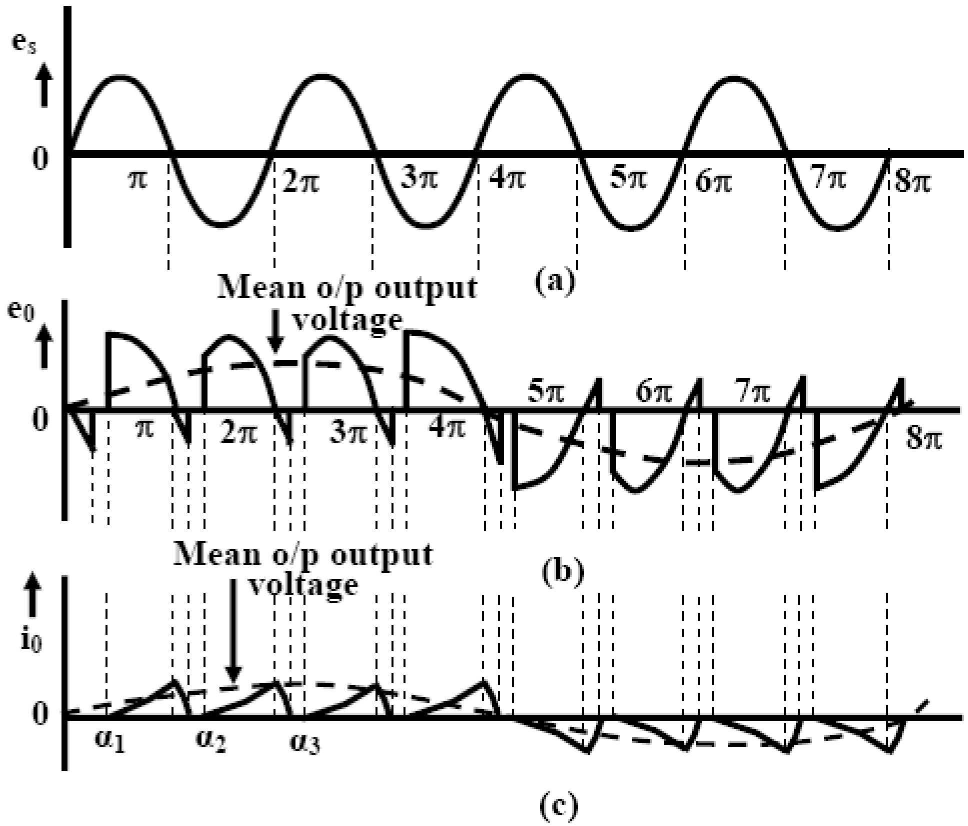
$f_s = 60Hz$

$f_o = f_s/4 = 15Hz$

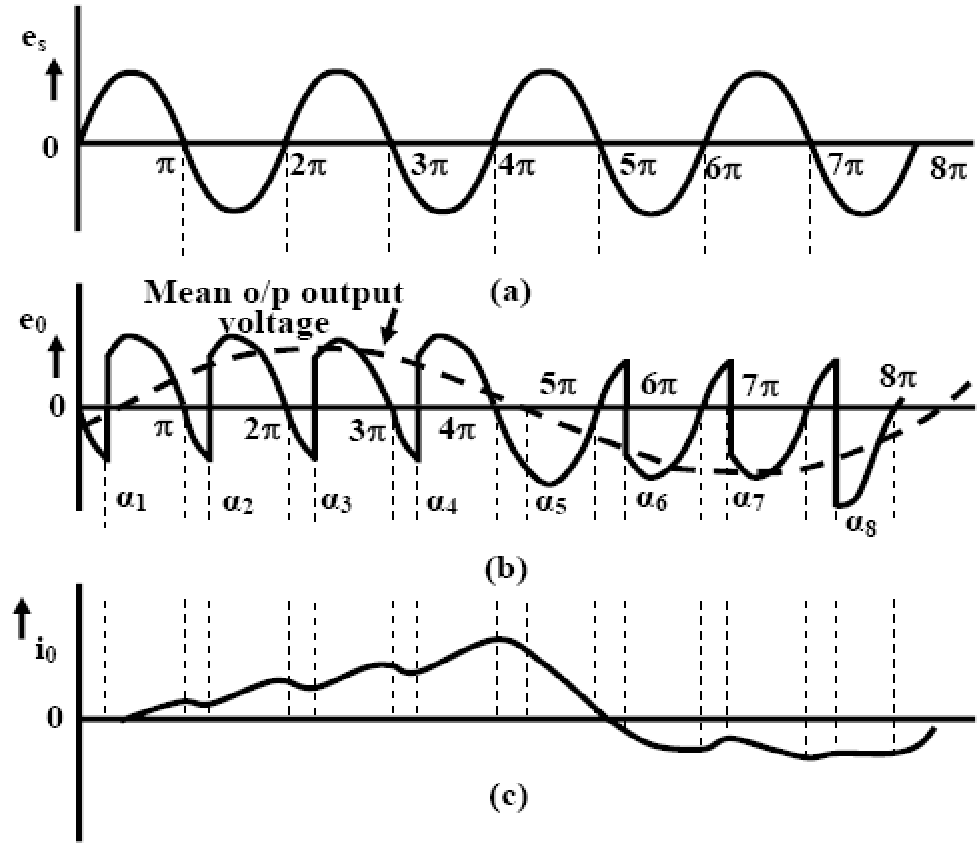
Ripple frequency:

$f_R=2f_s=120Hz$

- Inductive loading



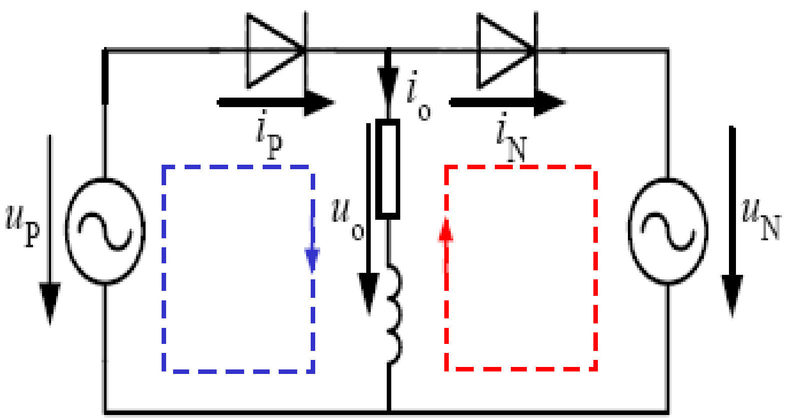
Small L



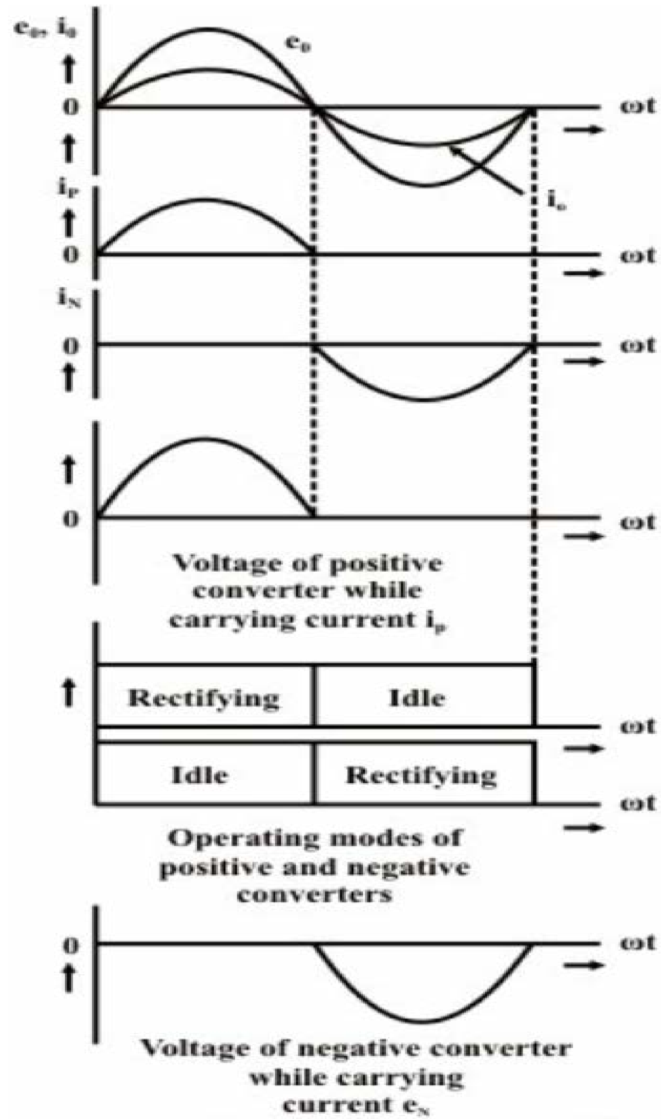
Large L

2.1 Single-phase to single-phase converter

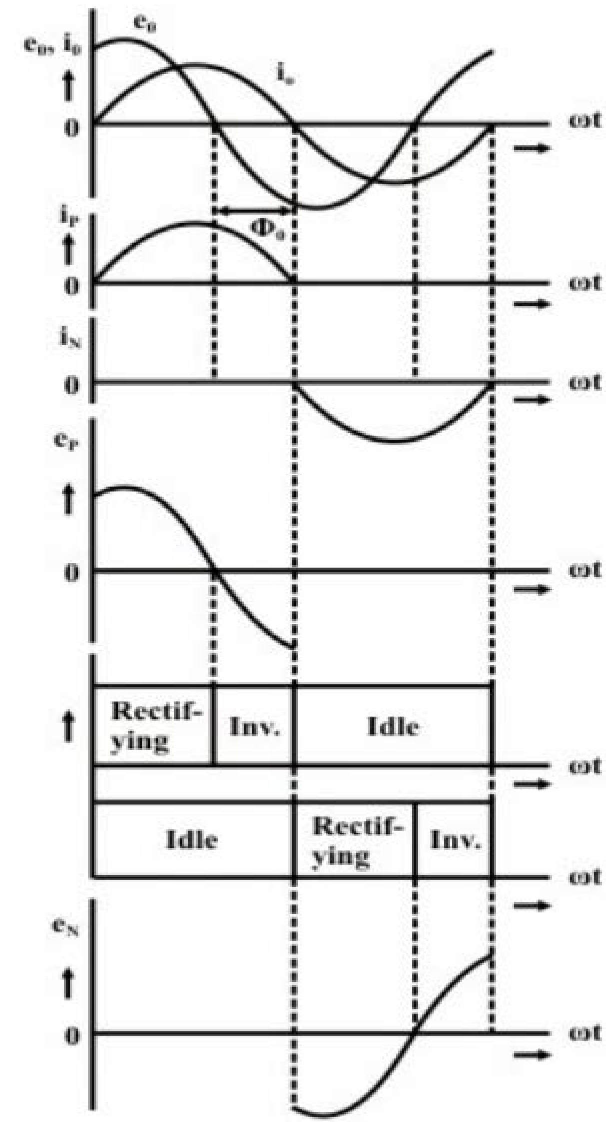
- Operating modes
  - Rectification
  - Inversion
  - Blocking (Idle)



R-load

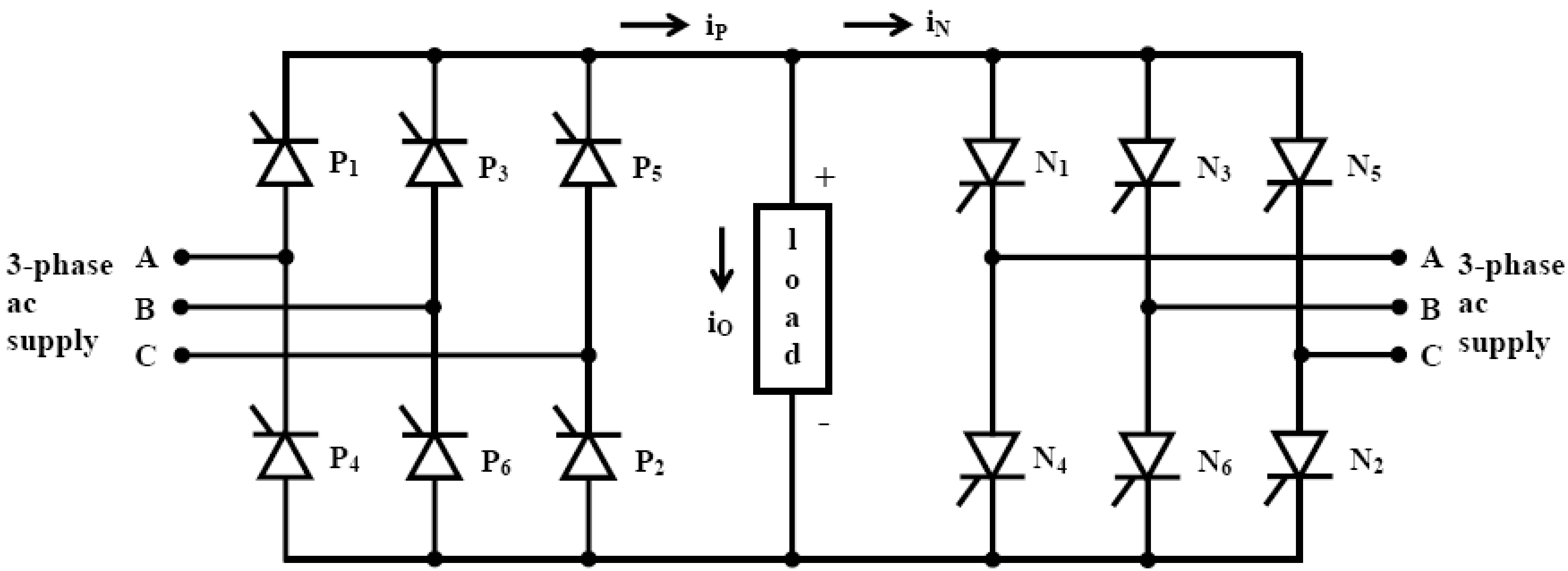


RL-load



2.2 Three-phase to single-phase converter

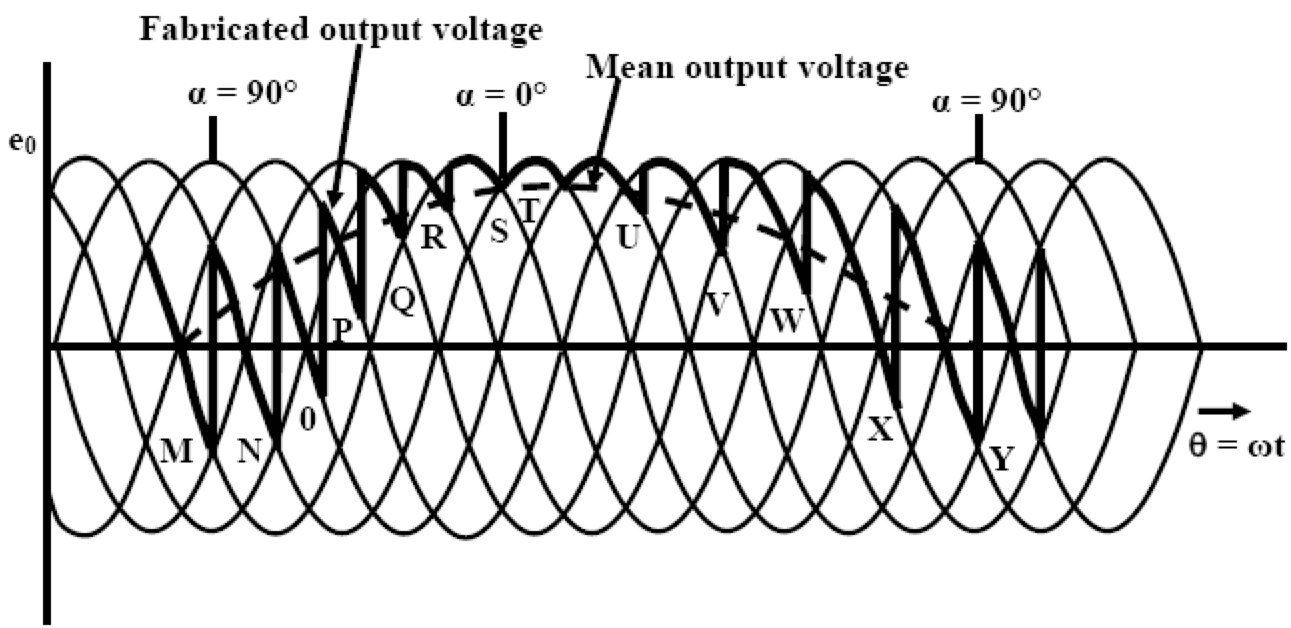
- Circuit configuration and operation principle
  - Inductive load



2.2 Three-phase to single-phase converter

- Left-bridge: positive half
- Right-bridge: negative half

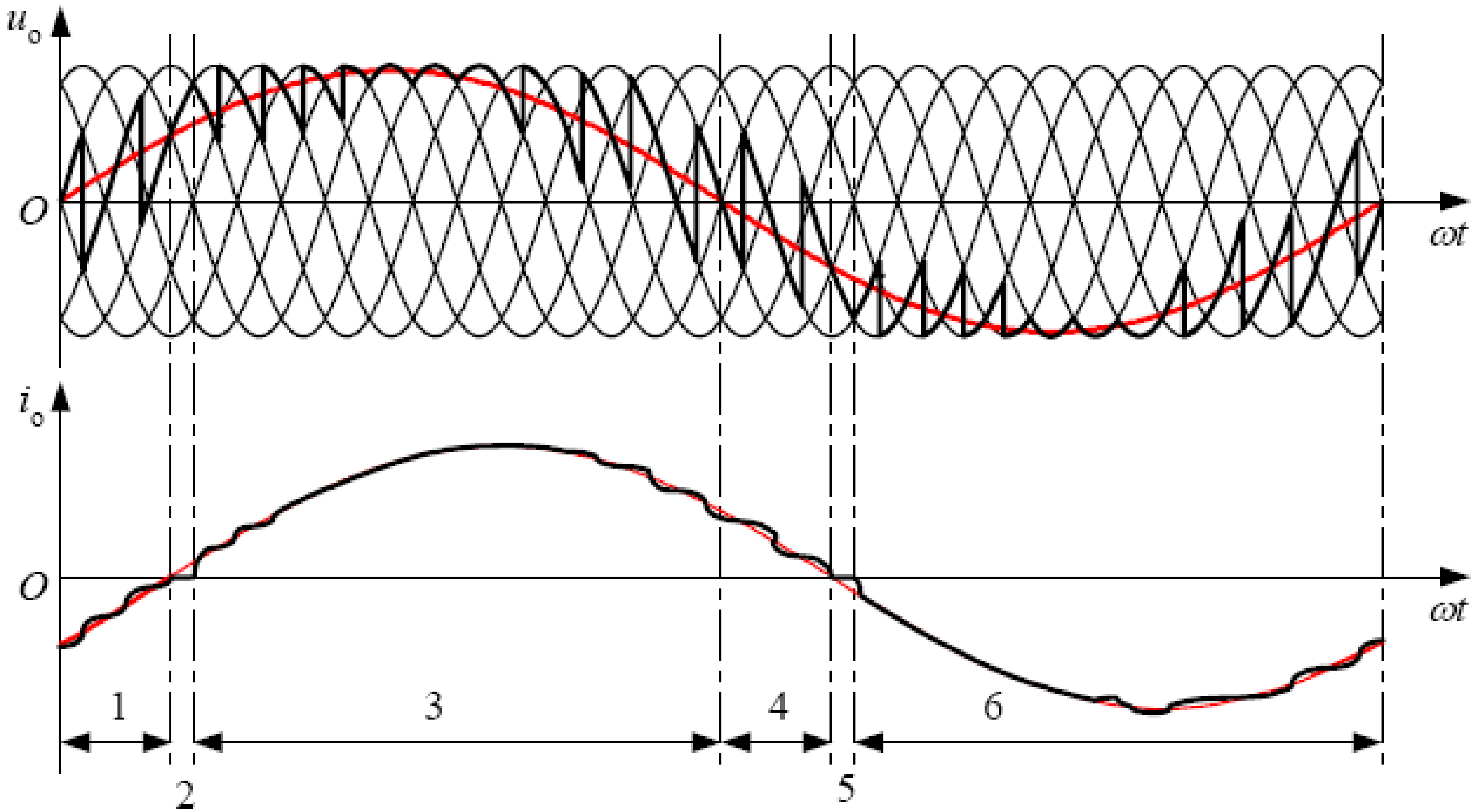
f_s = 60Hz
$f_o = f_s/4$ = 15Hz
Ripple frequency:
$f_R=6f_s$=360Hz



- More segments used => lower output frequency
- More segments used => closer to sinusoidal wave

f_s = 60Hz
$f_o = f_s/5$ = 12Hz
Ripple frequency:
$f_R=6f_s$=360Hz

- Typical waveforms of output voltage and current



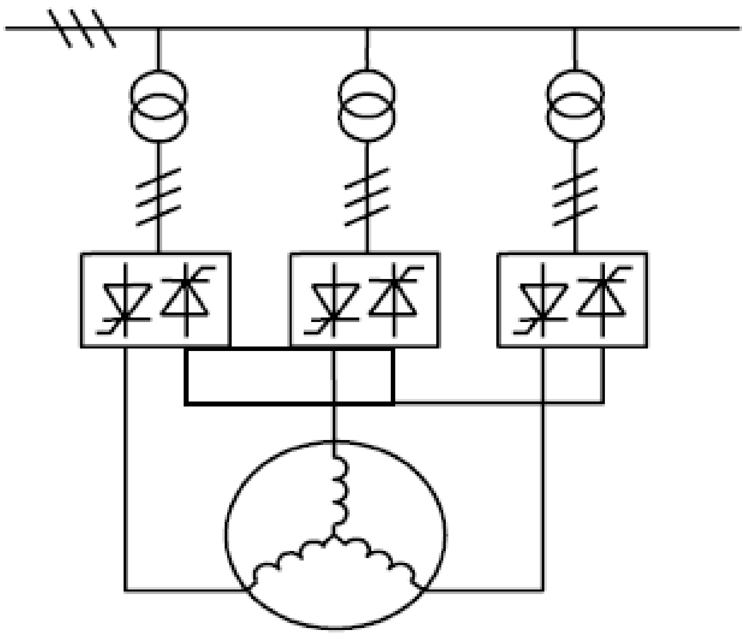
- The maximum output frequency is limited to a value that is only a fraction of the source frequency.

- As a result the major applications of cycloconverters are low-speed, ac motor drives ranging up to 15,000 kW with frequencies from 0 to 20Hz.

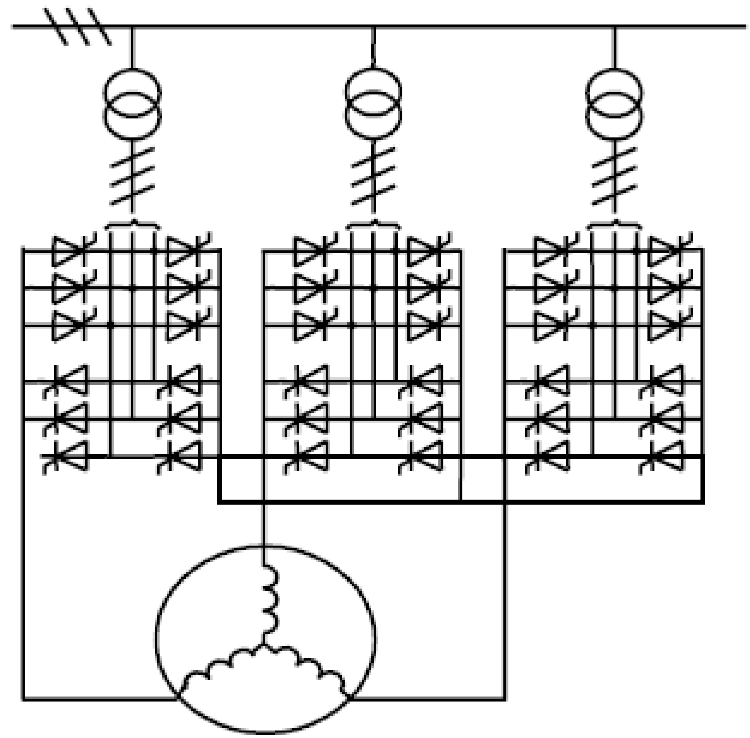
- Cycloconverter can deliver a high quality sinusoidal waveform at low output frequencies, since it is fabricated from a large number of segments of the supply waveform. This is often preferable for very low speed applications.

2.3 Three-phase to three-phase converter

- The configuration with star-connected output



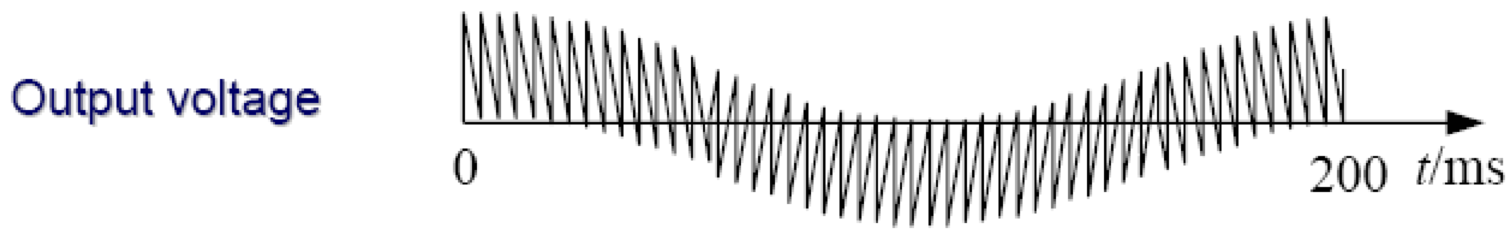
(a) simplified



(b) detailed

2.3 Three-phase to three-phase converter

- Typical waveforms of output voltage and current



  - The maximum output frequency and the harmonics in the output voltage are the same as in single phase circuit.
  - Input power factor is a little higher than single phase circuit.
  - Harmonics in the input current is a little lower than the single-phase circuit due to the cancellation of some harmonics among the 3 phases.