Module 3

AC-to-AC Converters

Direct AC-AC conversion without an intermediate DC-bus

Content

- AC Voltage Controllers
  - Phase-Controlled Single-Phase AC Voltage Controller
  - Phase-Controlled Three-Phase AC Voltage Controllers
  - PWM AC Voltage Controllers
- Cycloconverters
- Classic Matrix Converter

Learning outcomes of the module

After the module you will be able to:

- understand how ac voltage can be stepped down in choppers, no frequency control
- understand how ac-ac conversion can be done without an intermediate dc-bus
- analyze the operation of cycloconverter and see how it is very similar to a thyristor rectifier
- understand the operating principle of matrix converter

Single-phase ac voltage controller

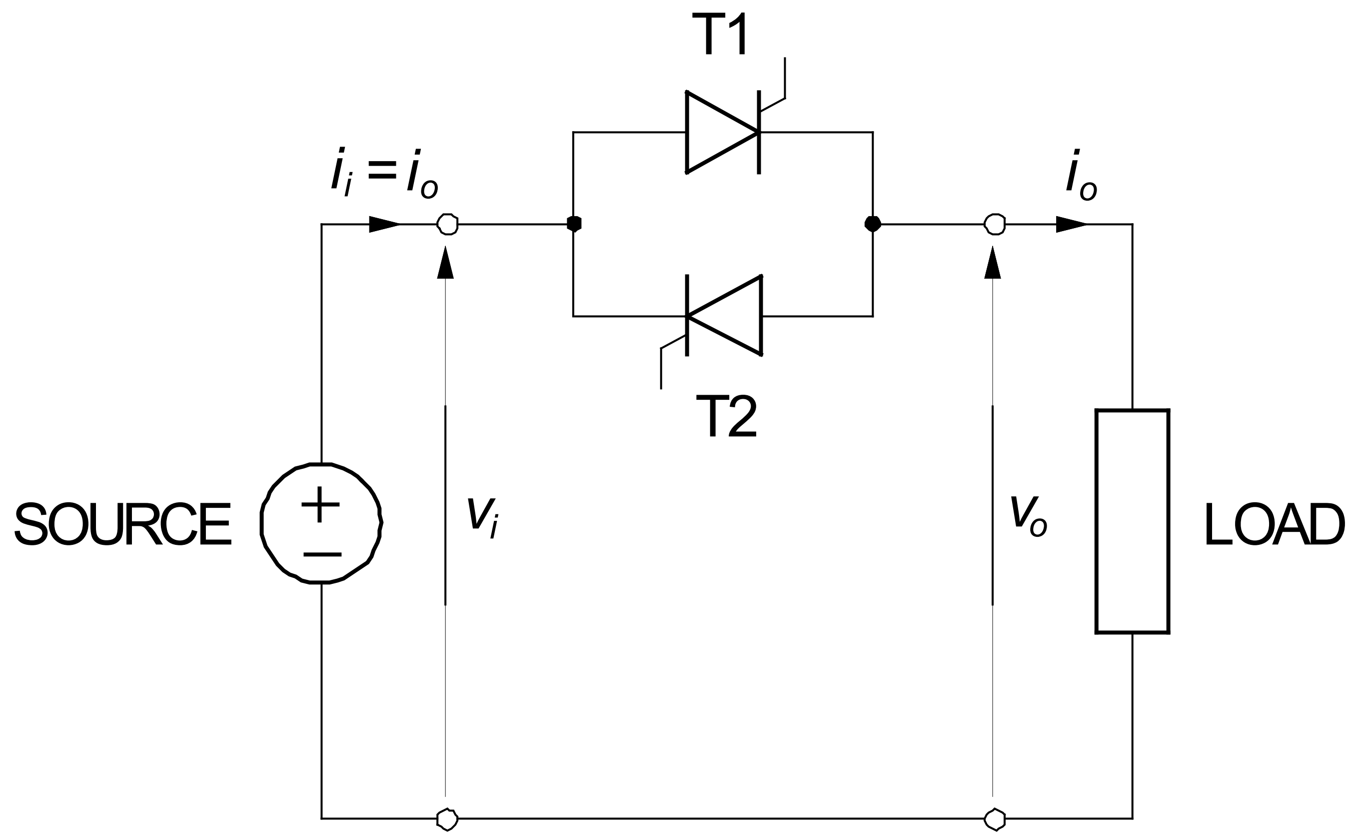


Fig. 5.1

Waveforms of output voltage and current in a single-phase ac voltage controller ($\varphi = 30^o$): (a) $\alpha_f = 45^o$, (b) $\alpha_f = 135^o$

- RMS value of the output voltage

$$V_o = \sqrt{\frac{1}{\pi}\int_0^{\pi} v_o^2(\omega t)\, d\omega t} = \sqrt{\frac{1}{\pi}\int_0^{\pi} \left[V_{i,p}\sin(\omega t)\right]^2 d\omega t}$$

Vi rms

$$= V_{i,p}\sqrt{\frac{1}{\pi}\left\{\alpha_e - \alpha_f - \frac{1}{2}[\sin(2\alpha_e) - \sin(2\alpha_f)]\right\}},$$

- Depends on firing angle α_f and extinction angle α_e
- Note: There is no close form solution for α_e

- Note: output frequency cannot be adjusted

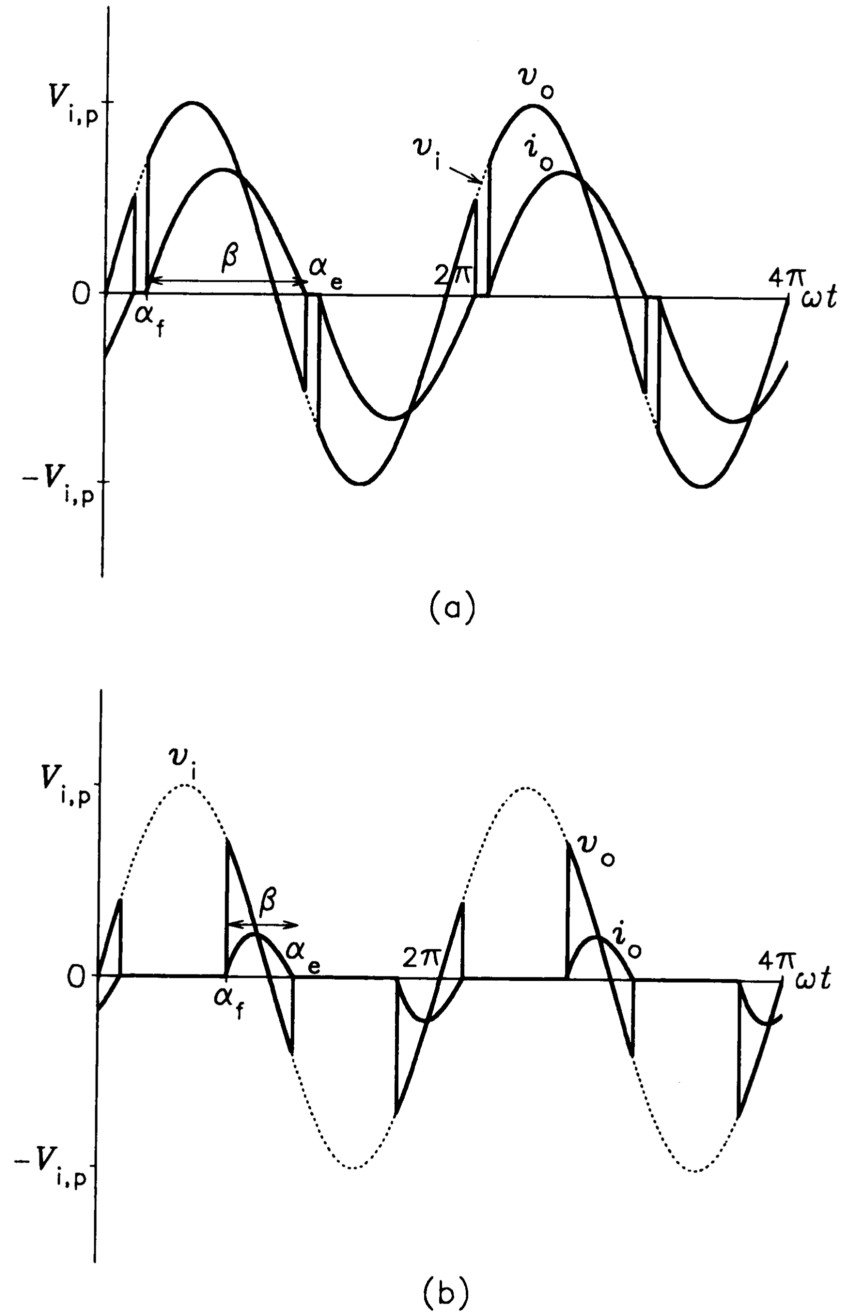


Fig. 5.2

Fully controlled three-phase ac voltage controller

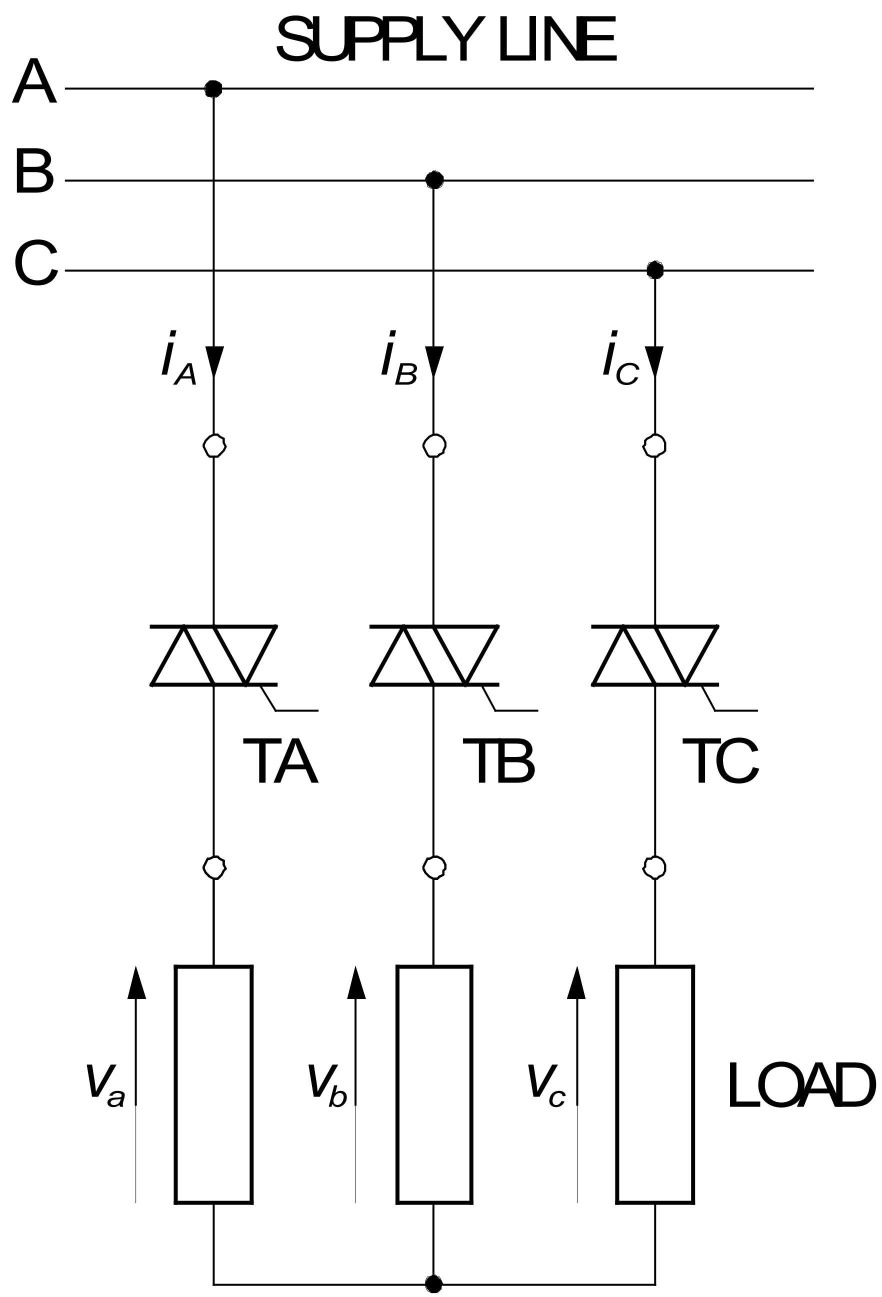


Fig. 5.7

Single-phase ac chopper with input filter

- Input filter is required to attenuate high-frequency current harmonics
- Inductance of ac system is often enough
- Ac choppers have been developed to improve input power factor, control characteristics and quality of output current

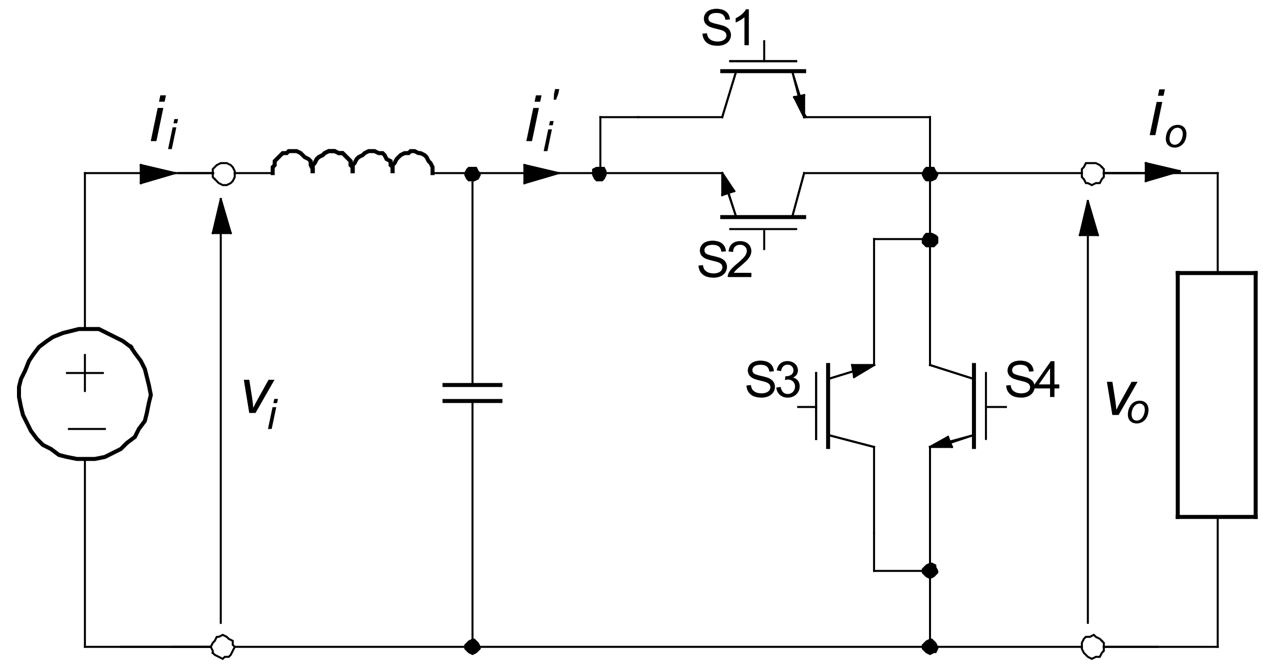
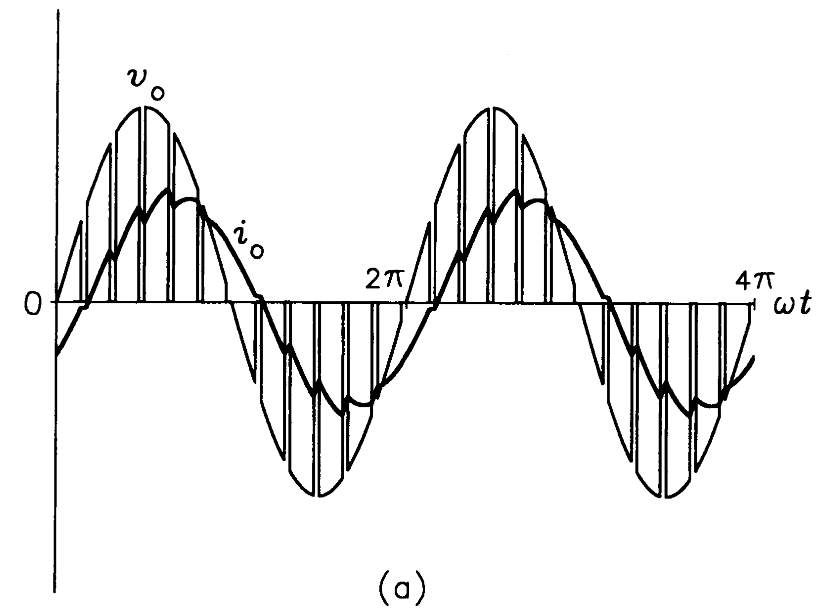


Fig. 5.16

Waveforms of voltages and currents in a single-phase ac chopper: (a) output voltage and current, (b) input voltage and current after the input filter, and the fundamental output current



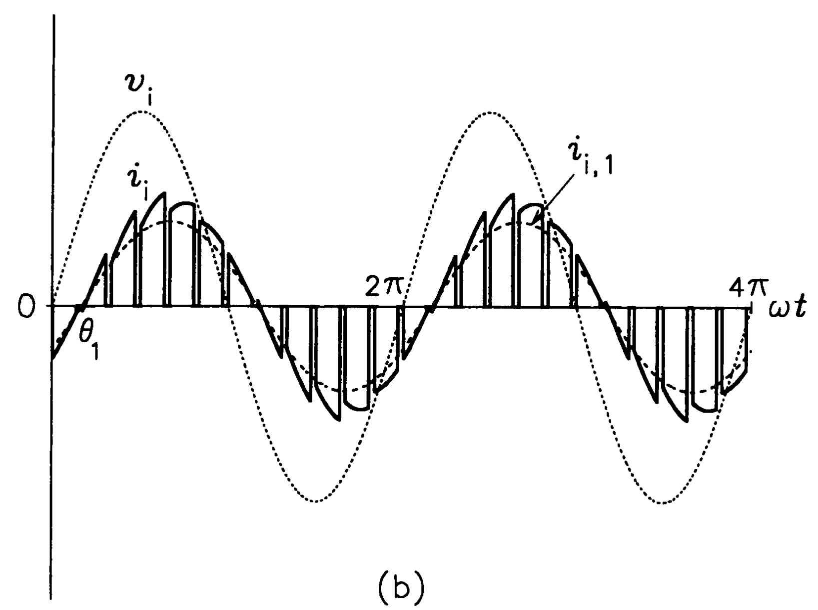
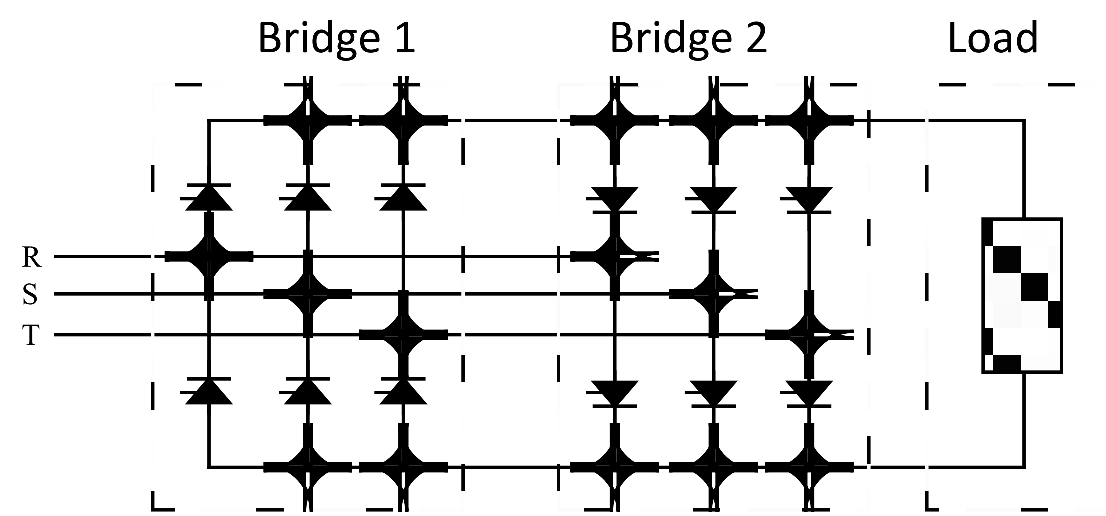


Fig. 5.17

Cycloconverters

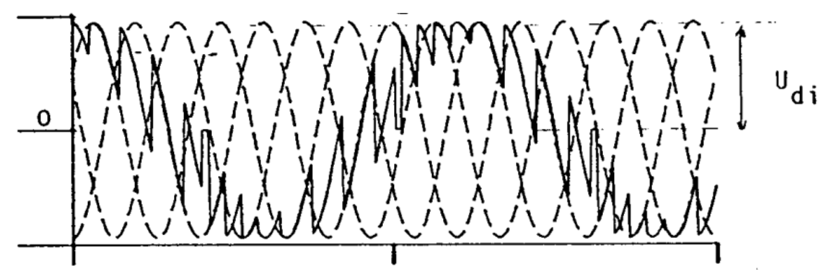
- Direct ac-ac converters without intermeadiate dc bus
- Operation is based on line-commutation, i.e. thyristors
  - Control angle of the thyristor bridge is controlled continuously
  - => variable dc-voltage, which is actually ac
- Can be built for high powers (thyristors)
- Output frequency must be much lower than input frequency,
  - nominal frequency typically one fith of line-frequency (< 10 Hz)
  - maximum around 20 Hz in 50 Hz systems



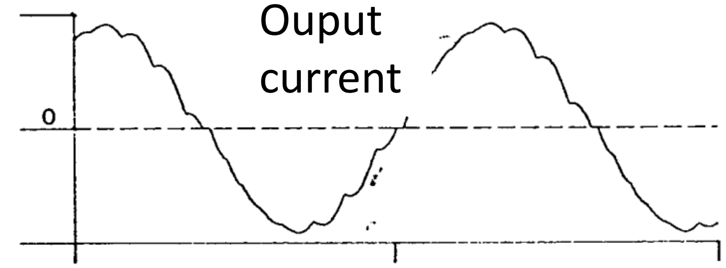
Single-phase cycloconverter

- Resistive + inductive load
  - Average of “dc” is controlled sinusoidally
  - f_1 = 50, f_2 =16,5 Hz in attached figures, output voltage is maximum in sinusoidal modulation
- Phase-shift in load can be plus (inductive), minus (capacitive) or zero
- Power flow can be in both directions
- Thyristor converter needs reactive power from the ac system when control angle is not 0 or 180
  - In cycloconverter, control angle is adjusted all the time
  - Reactive power needed even if load is not consuming reactive power

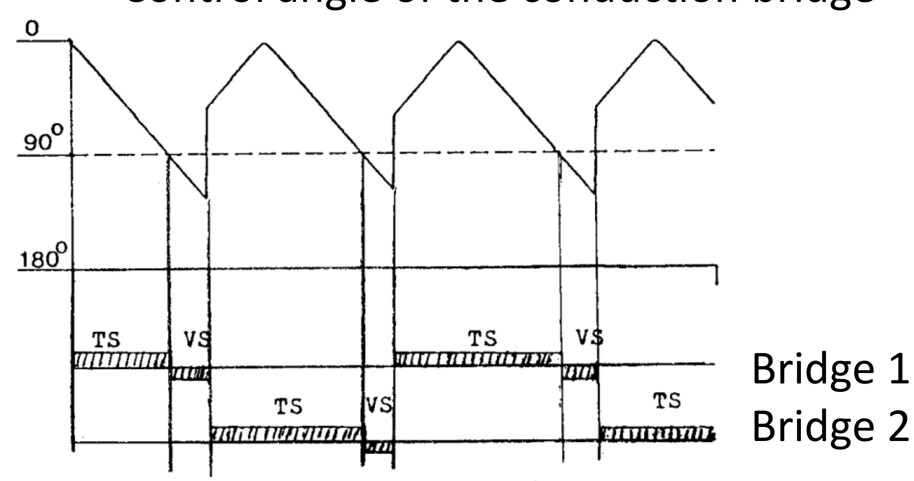
Ouput voltage



Ouput current



Control angle of the conduction bridge



TS= rectifier mode, VS=inverter mode

Waveforms of the firing angle in a cycloconverter

- Output voltage of thyristor converter depends on the control angle

$$V_{o,dc} = V_{o,dc(max)} \cos(\alpha_f)$$

- On the other hand, output needs to change sinusoidally

$$V_{o,dc}(t) = V_{o,1,p} \sin(\omega_o t),$$

- Therefore, the output angle dependent change of the control angle is

$$\alpha_f(\omega_o t) = cos^{-1}[M\, sin(\omega_o t)]$$

- Output frequency is adjusted by the slope of the change and amplitude by the modulation index *M*

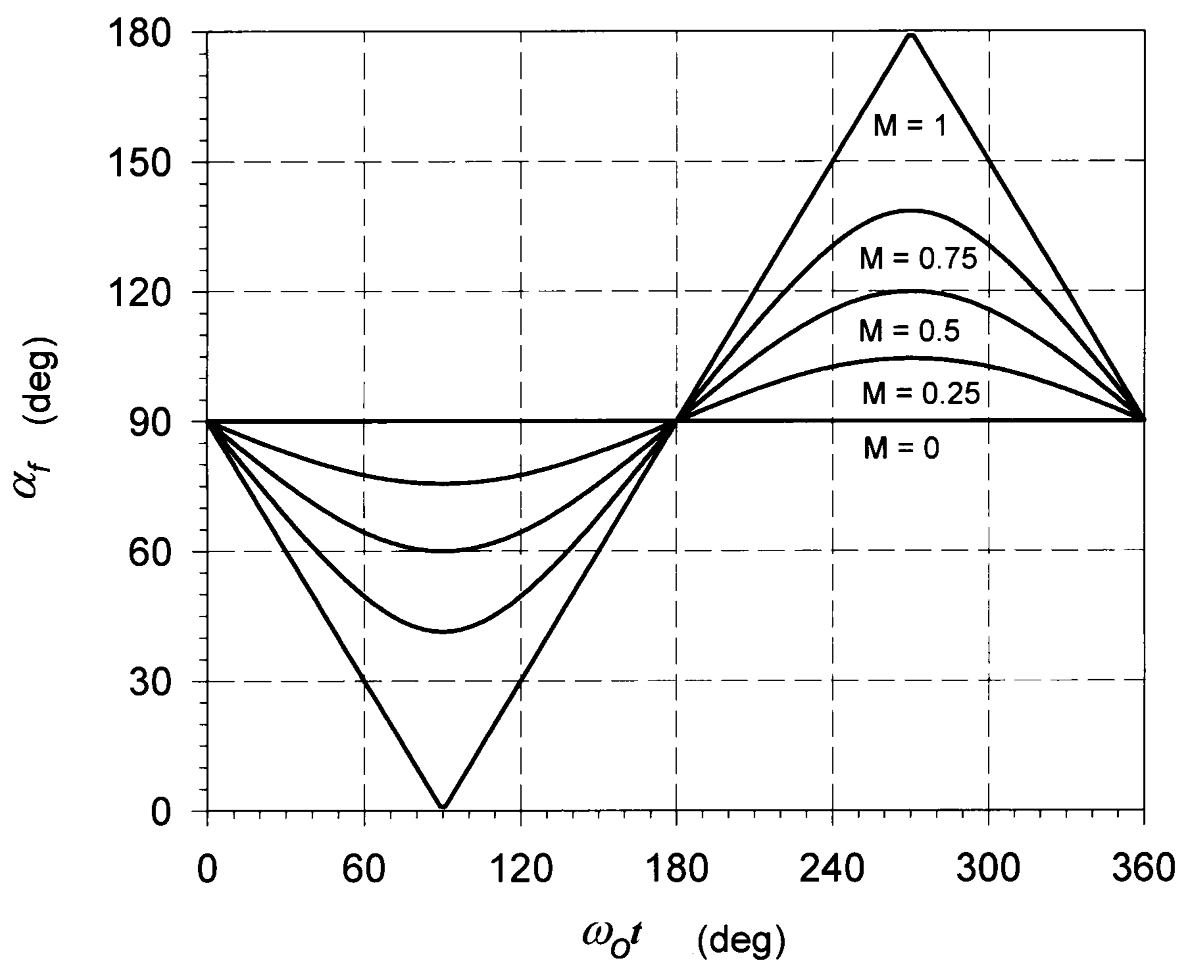


Fig. 5.24

Output voltage waveforms in a six-pulse cycloconverter ($\omega_o/\omega = 0.2$): (a) *M* = 1, (b) *M* = 0.5

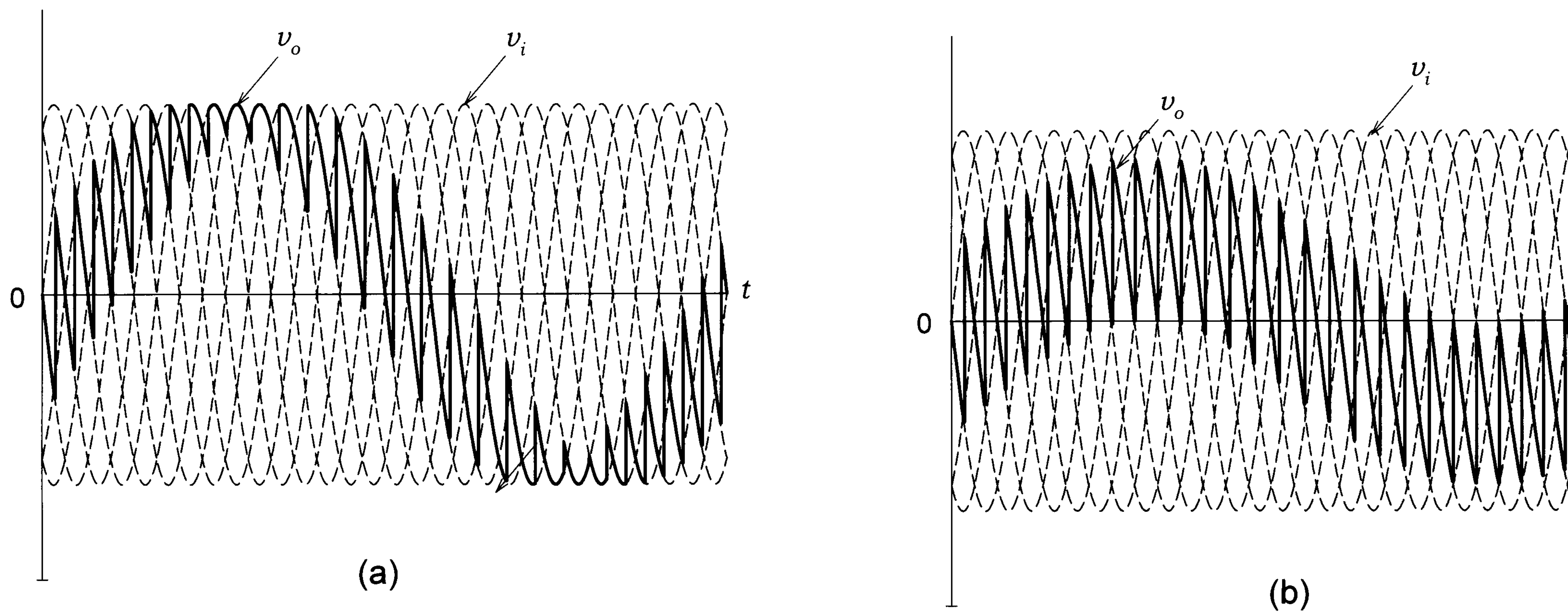
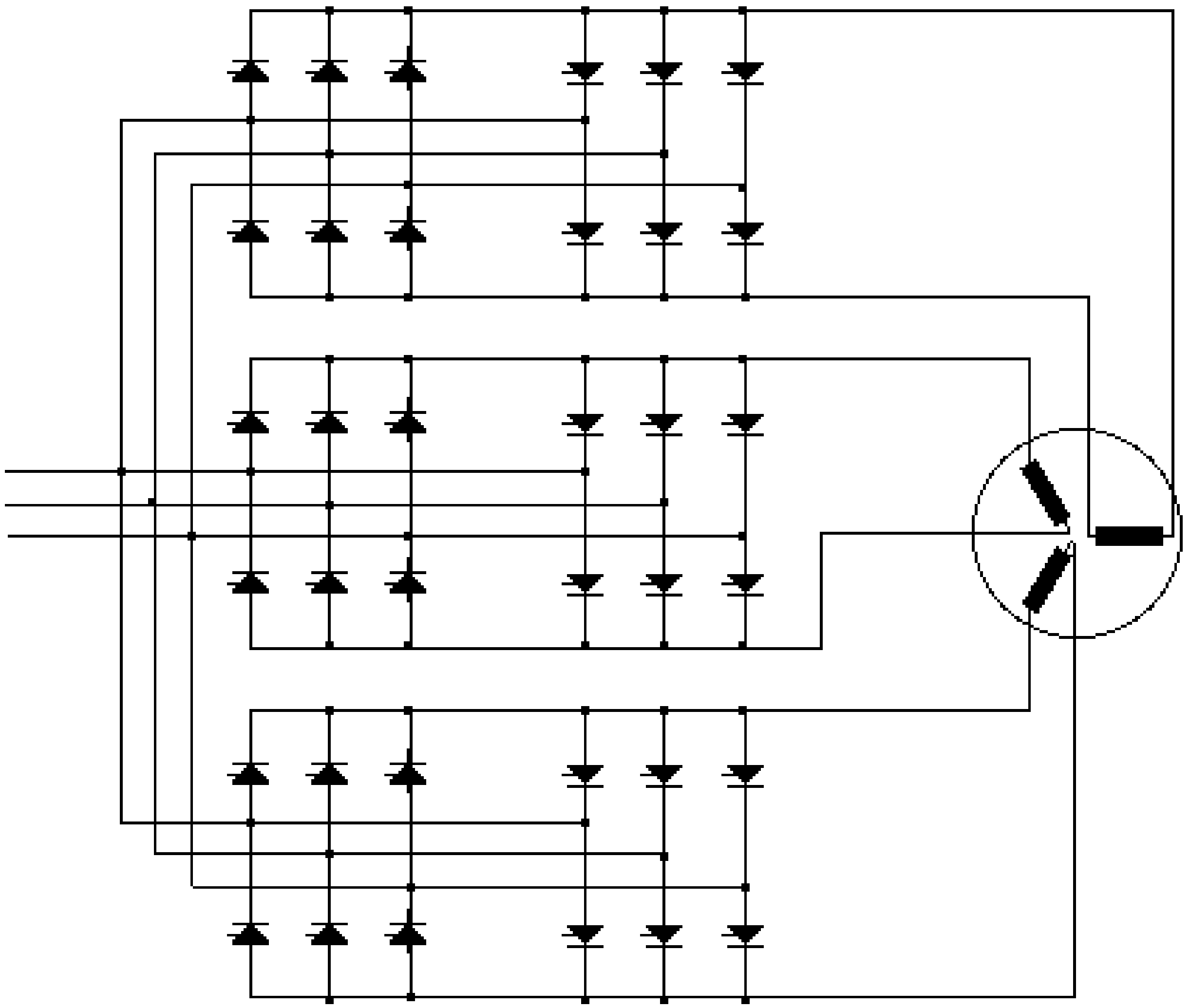


Fig. 5.25

Three-phase cycloconverter

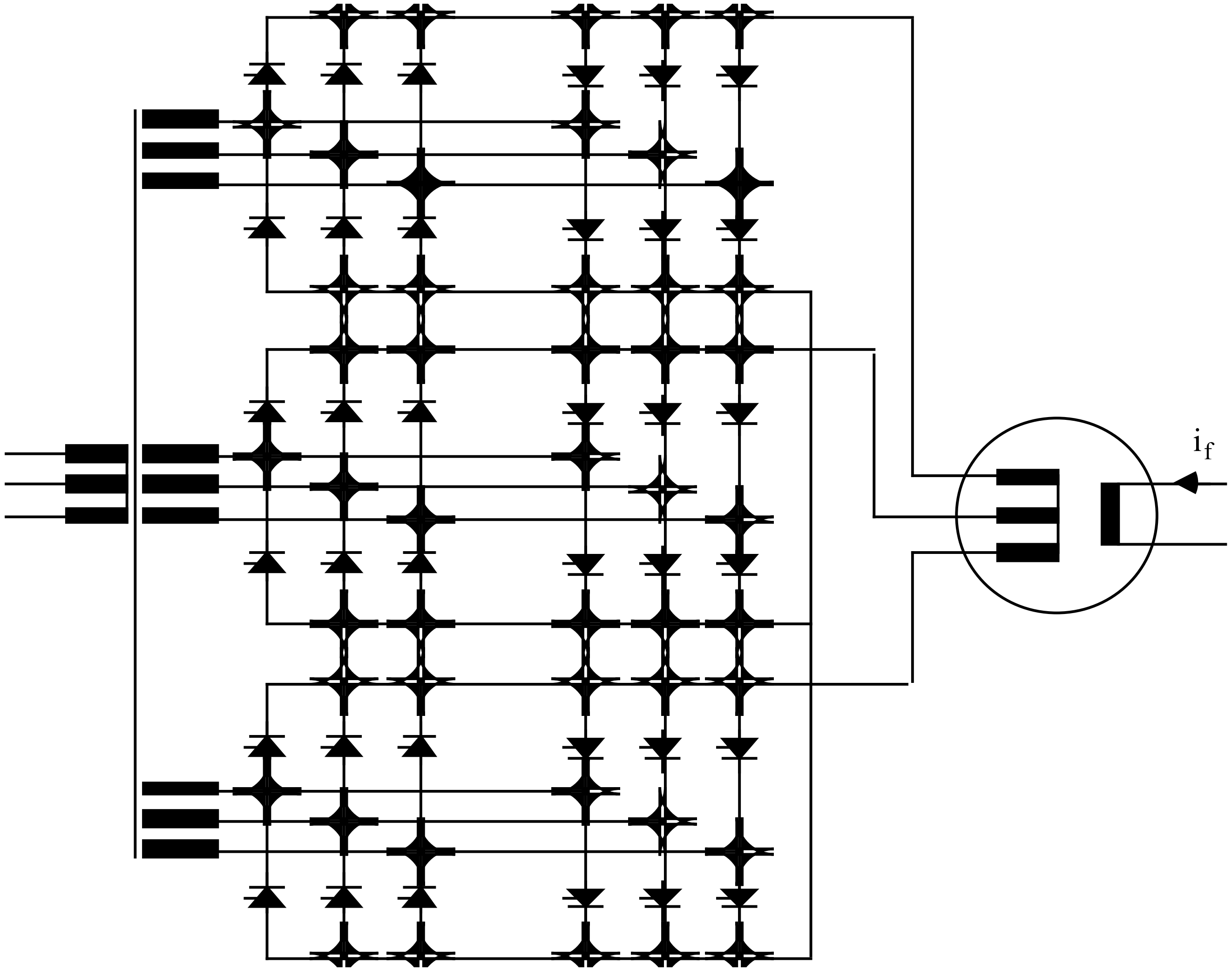
- Three separate converters
- All phases are independent, i.e. no star or delta connection used
  - Does’t quarantee the cancellation of zero sequence components as in normal three-phase connection
  - Output voltage needs to be sinusoidal, i.e no trapezoidal control to increase output voltage can be used
- No transformer in the input needed, i.e. cheaper, voltage levels of input and the load need to be similar



Three-phase cycloconverter

- Load is connected either in star or delta
- Transformer is needed in the input side!

  Why?



Matrix converter

- Direct converter between three-phase input and three-phase output
  - Phase numbers can be also other than three
- Needs power semiconductor devices that can be turned on and of any time (doesn't work with thyristors)
- Output frequency is not limited as in cycloconverters
  - If input is 50 Hz output frequency can be much higher
  - Output voltage value is limited and is lower than the input voltage
- Practical realization of the converter is very challenging

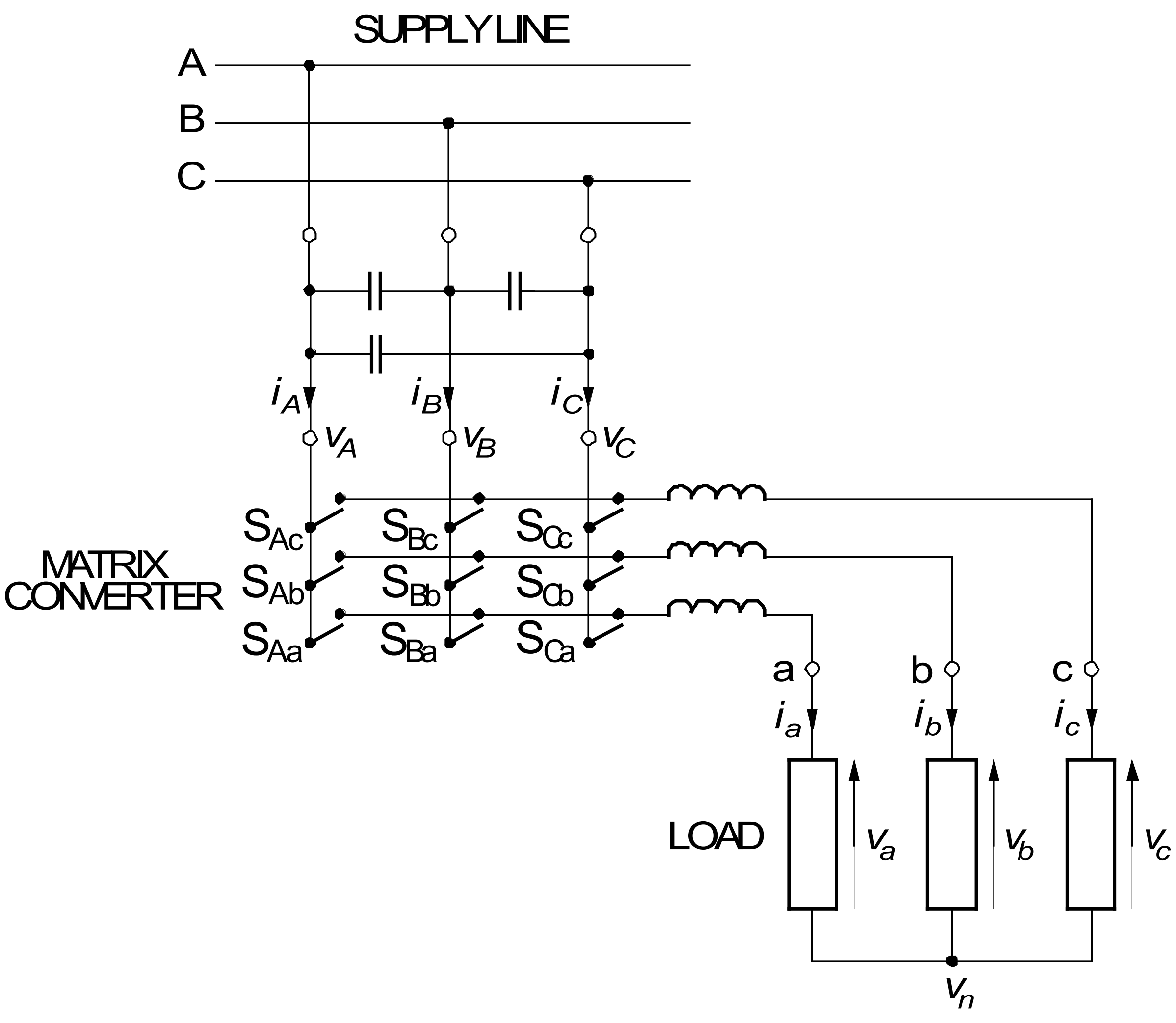


Fig. 5.26

Converter is analyzed often with matrixes => name

The voltages v_a, v_b, and v_c, at the output terminals are given by

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} x_{Aa} & x_{Ba} & x_{Ca} \\ x_{Ab} & x_{Bb} & x_{Cb} \\ x_{Ac} & x_{Bc} & x_{Cc} \end{bmatrix} \begin{bmatrix} v_A \\ v_B \\ v_C \end{bmatrix}$$

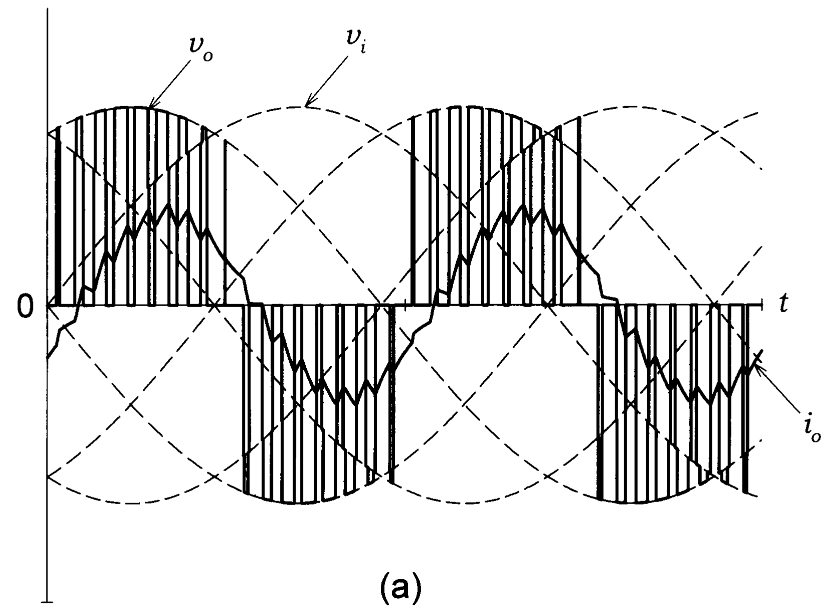
As $$v_n = \frac{1}{3}(v_a + v_b + v_c)$$

then $$\begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

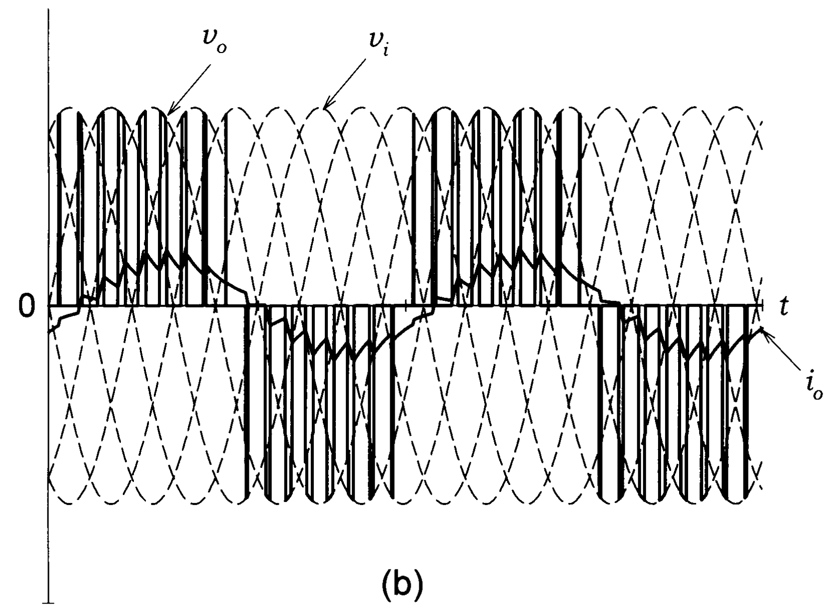
The input currents, i_A, i_B, and i_C, are related to the output currents, i_a, i_b, and i_c, as

$$\begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} = \begin{bmatrix} x_{Aa} & x_{Ab} & x_{Ac} \\ x_{Ba} & x_{Bb} & x_{Bc} \\ x_{Ca} & x_{Cb} & x_{Cc} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

Output voltage and current waveforms in a 3Φ-3Φ matrix converter: (a) m = 0.75, $\omega_o/\omega = 2.8$, (b) m = 0.35, $\omega_o/\omega = 0.7$



(a)



(b)

Fig. 5.31

Bidirectional semiconductor power switches:
(a) two IGBTs and two diodes, (b) one IGBT and four diodes

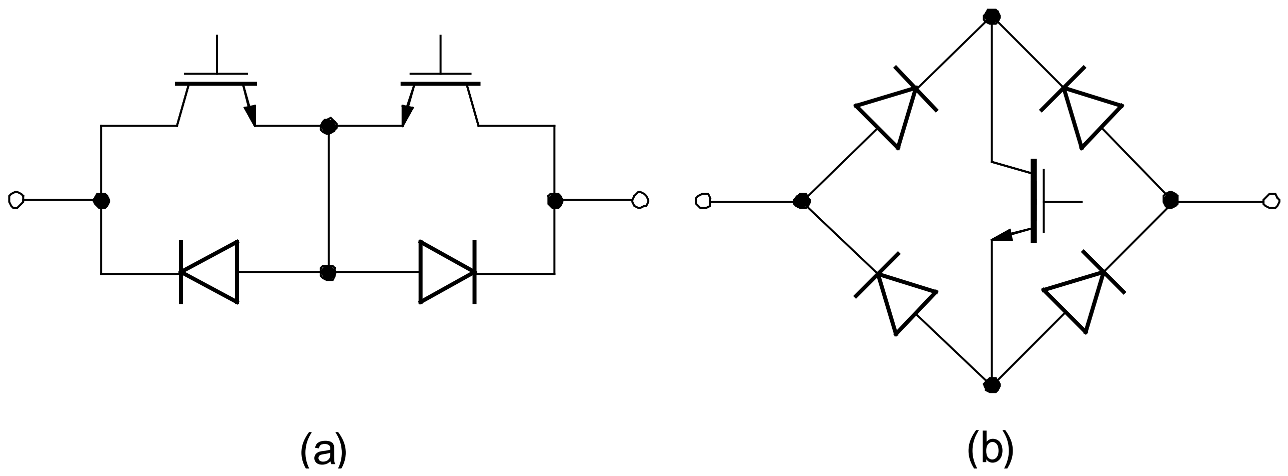


Fig. 5.32

Circuit diagram of the classic 3Φ-3Φ matrix converter

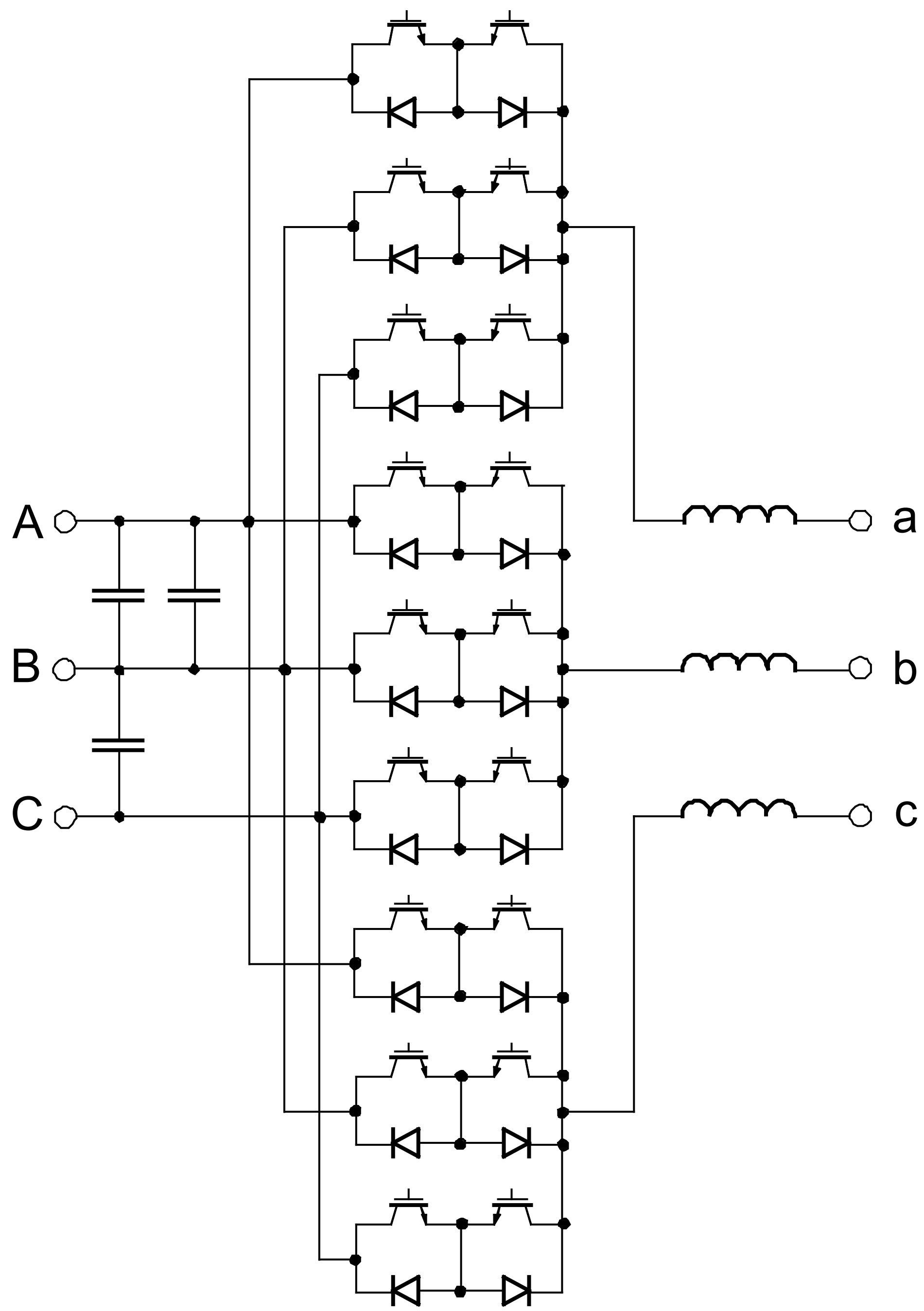


Fig. 5.33

Summary of the module

- Amplitude of ac voltage can be reduced with ac-choppers a bit in a similar way as dc-voltage in dc-dc converters. However, this is not adjusting the frequency of the output voltage. AC choppers can be used e.g. when heating power of resistors is reduced or in so-called soft-starters to reduce the start-up current of induction machines.
- Cycloconverter is a direct ac-ac converter, which converter an existing ac voltage to another one without having an intermediate dc-bus. We don't need the large dc-bus capacitors, which is an advantage.
- Cycloconverter can be thought as a four-quadrant thyristor rectifier, where we are adjusting the control angle continuously. Thus, the result is varying dc-voltage, which can be considered as ac voltage.
    - Because of the operating principle, output frequency can in maximum be half of the grid frequency.
    - As control angle is adjusted continuously, cycloconverter consumes reactive power even if load is a pure resistor.
- Matrix converter does the same as cycloconverter but uses turn-on-off devices. It needs a switch with current carrying in both directions and voltage blocking in both directions.
- Matrix converter is self-commutated whereas cycloconverter is line-commutated using thyristors. Thus, pulse-width modulation can be used in matrix converter and output frequency is not limited. Output voltage value in matrix converter cannot be so high as in cycloconverter because of different operating principle.
- The main challenging in matrix converter is the commutation, i.e. how to guarantee that input voltages are not short-circuited when switches are turned on and off, also so that inductive current paths remain. Because of these challenges, matrix converter has not been in wide use so far.