Module 5

Voltage-Sourced Converters

Content

- Voltage-sourced three-phase inverter
  - Output voltage waveform
  - Output current waveform with induction machine
  - Pulse-width modulation
    - Analog vs. digital modulation
    - Adding a third harmonic
    - Space-vector modulation
- Multilevel converters
- Voltage-sourced PWM rectifier
  - Active front end

Learning outcomes of the module

After the module, you will be able to:

- are having a more detailed understanding of voltage sourced converters, both dc-ac and ac-dc
- can analyze voltage and current waveforms of the voltage-sourced inverter when induction machine is a load
- understand the difference between analog and digital pulse-width modulation and how space-vectors are used in PWM
- understand the difference between two- and multilevel converters
- understand the operating principle of PWM rectifier

Three-phase voltage-source inverter

- When taking three single-phase inverters and connecting the load to star (or delta) we are achieving the shown three-phase converter
- Individual legs can be connected either to + or –
- There are two reference points
  - star point of the load N
  - minus bar of the dc-bus n

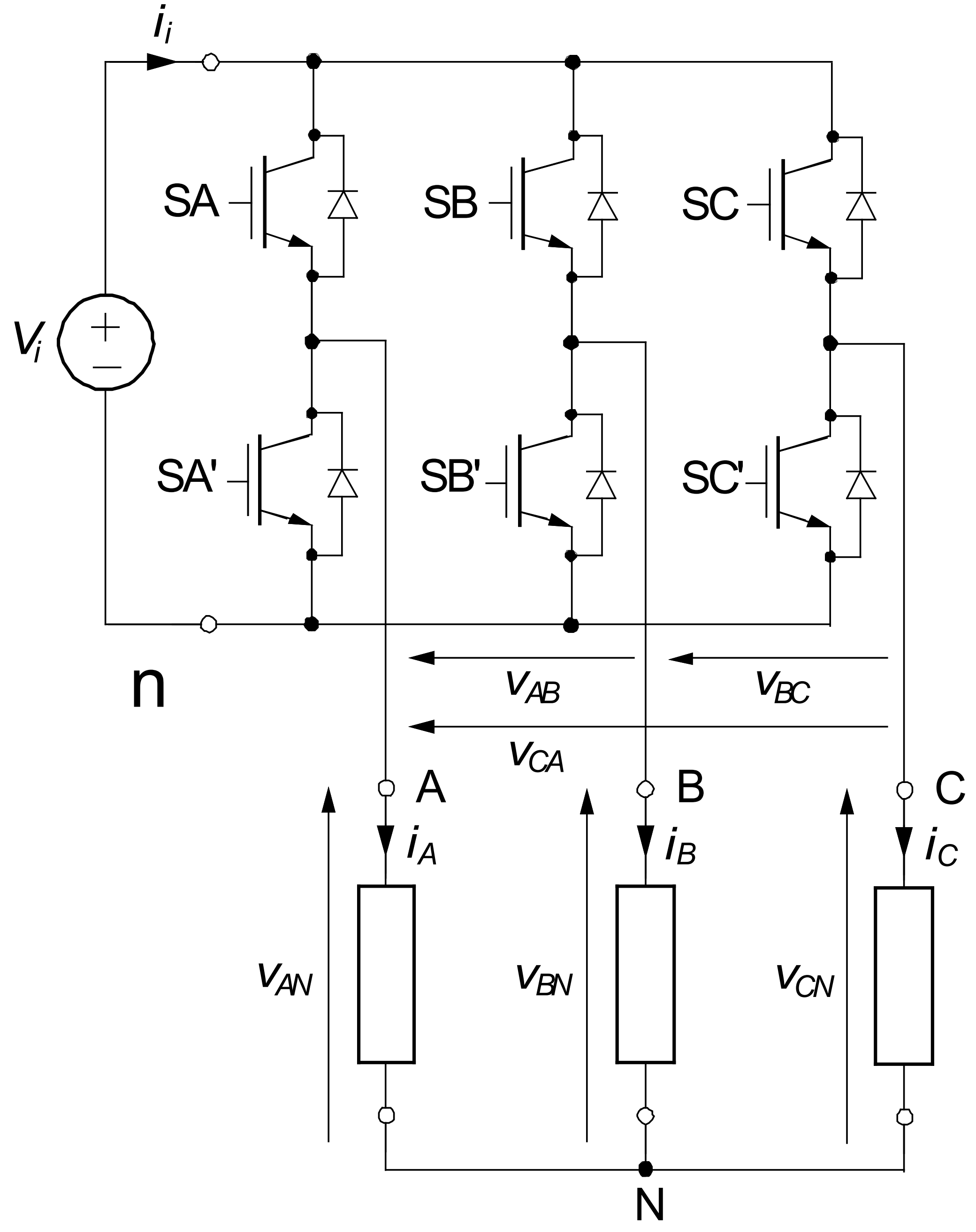


Fig. 7.14

It is easy to show that in the three-phase inverter the instantaneous line to line output voltages, v_{AB}, v_{BC}, and v_{CA}, are given by

$$\begin{bmatrix} v_{AB} \\ v_{BC} \\ v_{CA} \end{bmatrix} = V_i \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix}$$

In a balanced three-phase system, the instantaneous line-to-neutral output voltages, v_{AN}, v_{BN}, and v_{CN}, can be expressed as

$$\begin{bmatrix} v_{AN} \\ v_{BN} \\ v_{CN} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 0 & -1 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \begin{bmatrix} v_{AB} \\ v_{BC} \\ v_{CA} \end{bmatrix}$$

which yields

$$\begin{bmatrix} v_{AN} \\ v_{BN} \\ v_{CN} \end{bmatrix} = \frac{V_i}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix}.$$

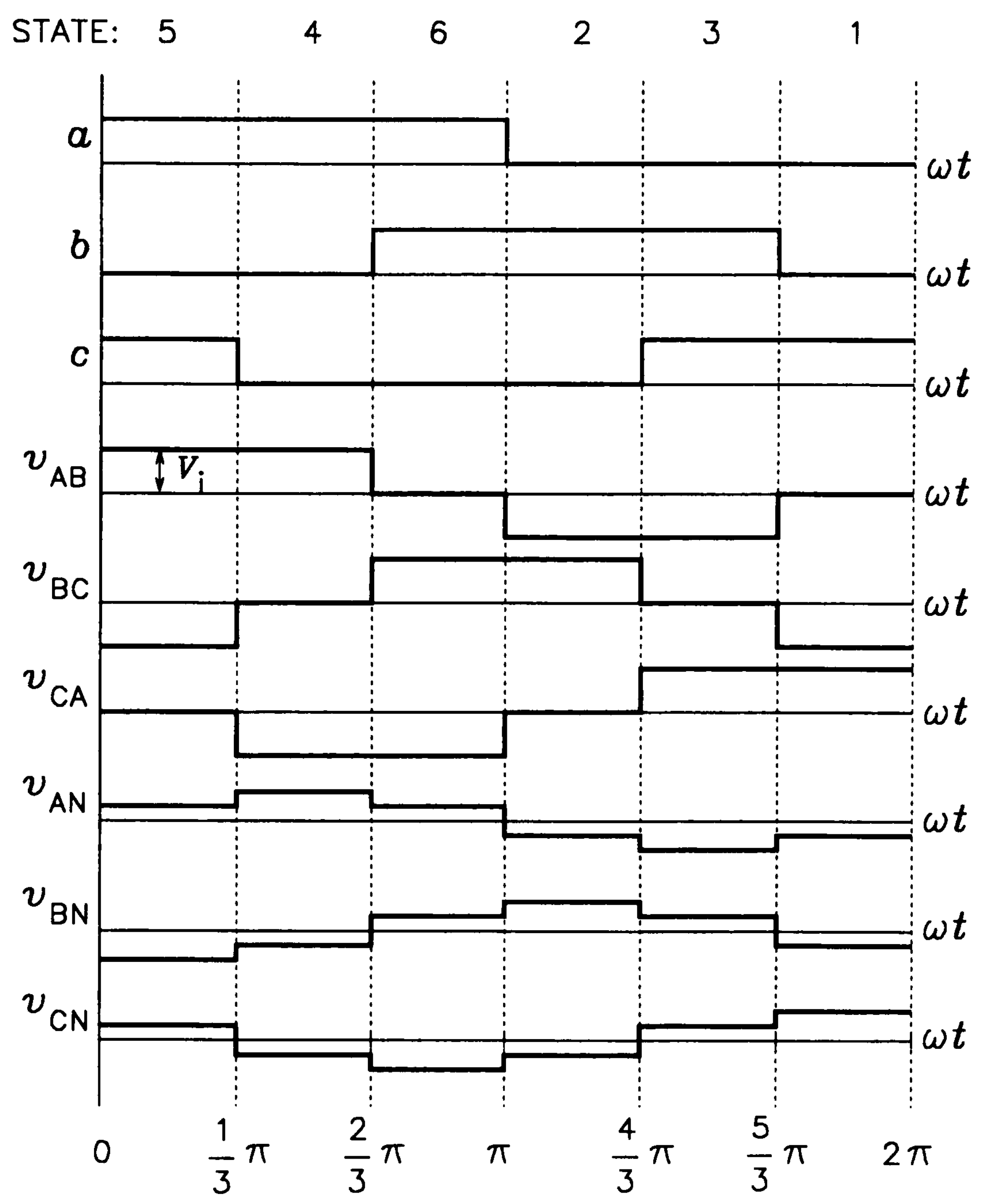
The line-to-line voltages can only assume three values, 0 and $\pm V_i$, while the line-to-neutral voltages can assume five values, 0, $\pm V_i/3$, and $\pm 2V_i/3$.

If the 5 – 4 – 6 – 2 – 3 – 1 – ... sequence of states is imposed, each state lasting one-sixth of the desired period of the output voltage, the individual line-to-line and line-to-neutral voltages acquire waveforms shown in Figure 7.15. This is the square-wave mode of operation, in which each switch of the inverter is turned on and off once within the cycle of output voltage. The peak value, $V_{LL,1,p}$, of the fundamental line-to-line output voltage equals approximately 1.1 V_i and that, $V_{LN,1,p}$, of the line-to-neutral voltage, 0.64 V_i. Both voltages have the same total harmonic distortion, *THD,* of 0.31. As in the square-wave single-phase inverter, the magnitude control of the output voltage must be realized on the dc supply side.

TABLE 7.1 States and Voltages of the Three-Phase Voltage-Source Inverter

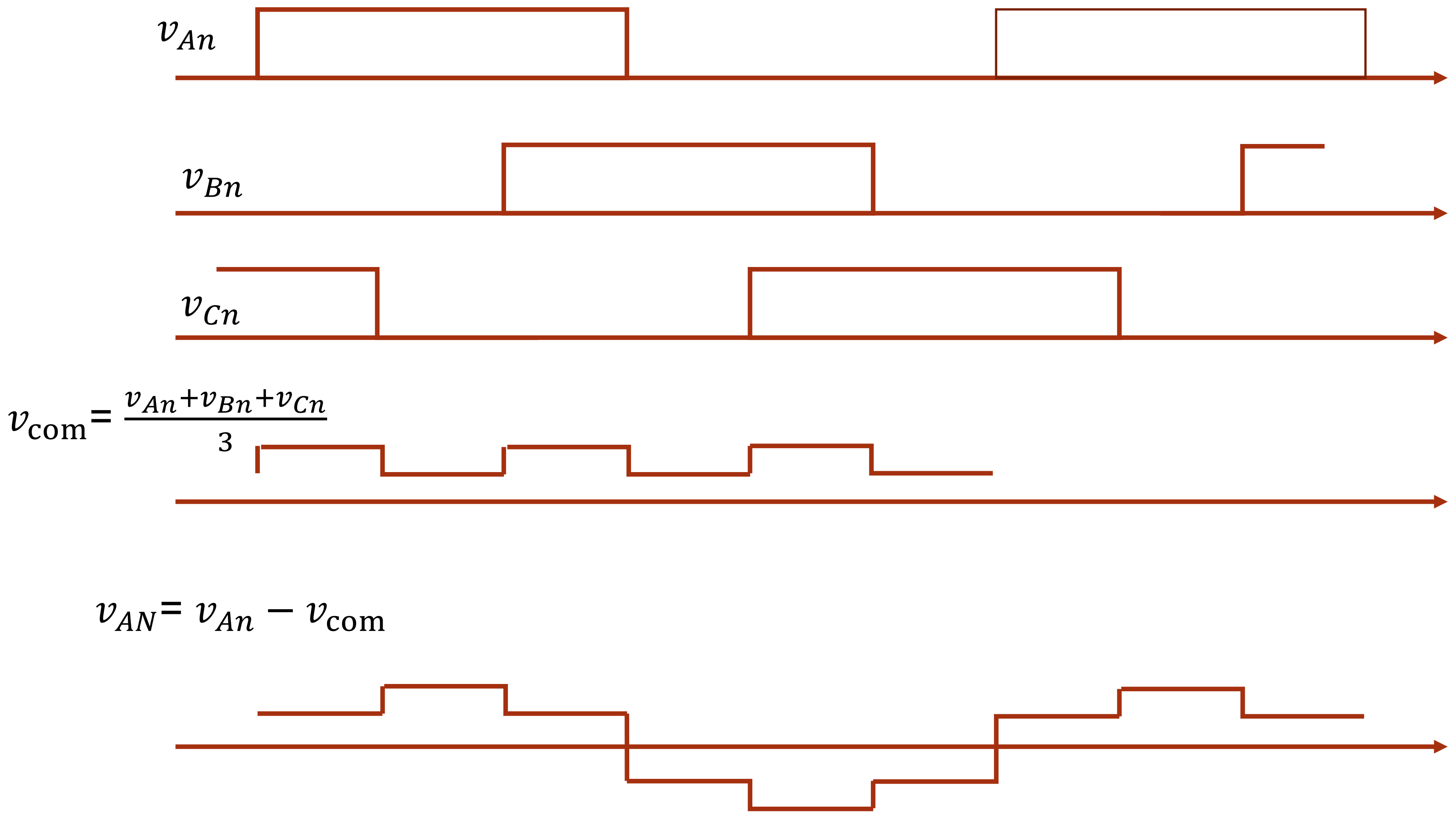
State	abc	v_{AB}/V_i	v_{BC}/V_i	v_{CA}/V_i	v_{AN}/V_i	v_{BN}/V_i	v_{CN}/V_i
0	000	0	0	0	0	0	0
1	001	0	-1	1	-1/3	-1/3	2/3
2	010	-1	1	0	-1/3	2/3	-1/3
3	011	-1	0	1	-2/3	1/3	1/3
4	100	1	0	-1	2/3	-1/3	-1/3
5	101	1	-1	0	1/3	-2/3	1/3
6	110	0	1	-1	1/3	1/3	-2/3
7	111	0	0	0	0	0	0

Switching variables and waveforms of output voltages in a three-phase VSI in the square-wave mode



Common-mode voltage

- As the output voltage has only two choices, + or – the sum of all leg voltages, Van, vBn, vCn cannot be zero
- Figure shows the same leg voltages are in the previous slide
- Common-mode voltage has values 1/3 and 2/3 of the dc
- Phase voltage can also be obtained by subtracting the common-mode voltage and result is the same as in the previous slide



Waveforms of output voltage (line-to-neutral) and current in a three-phase VSI in the square-wave mode (RL load)

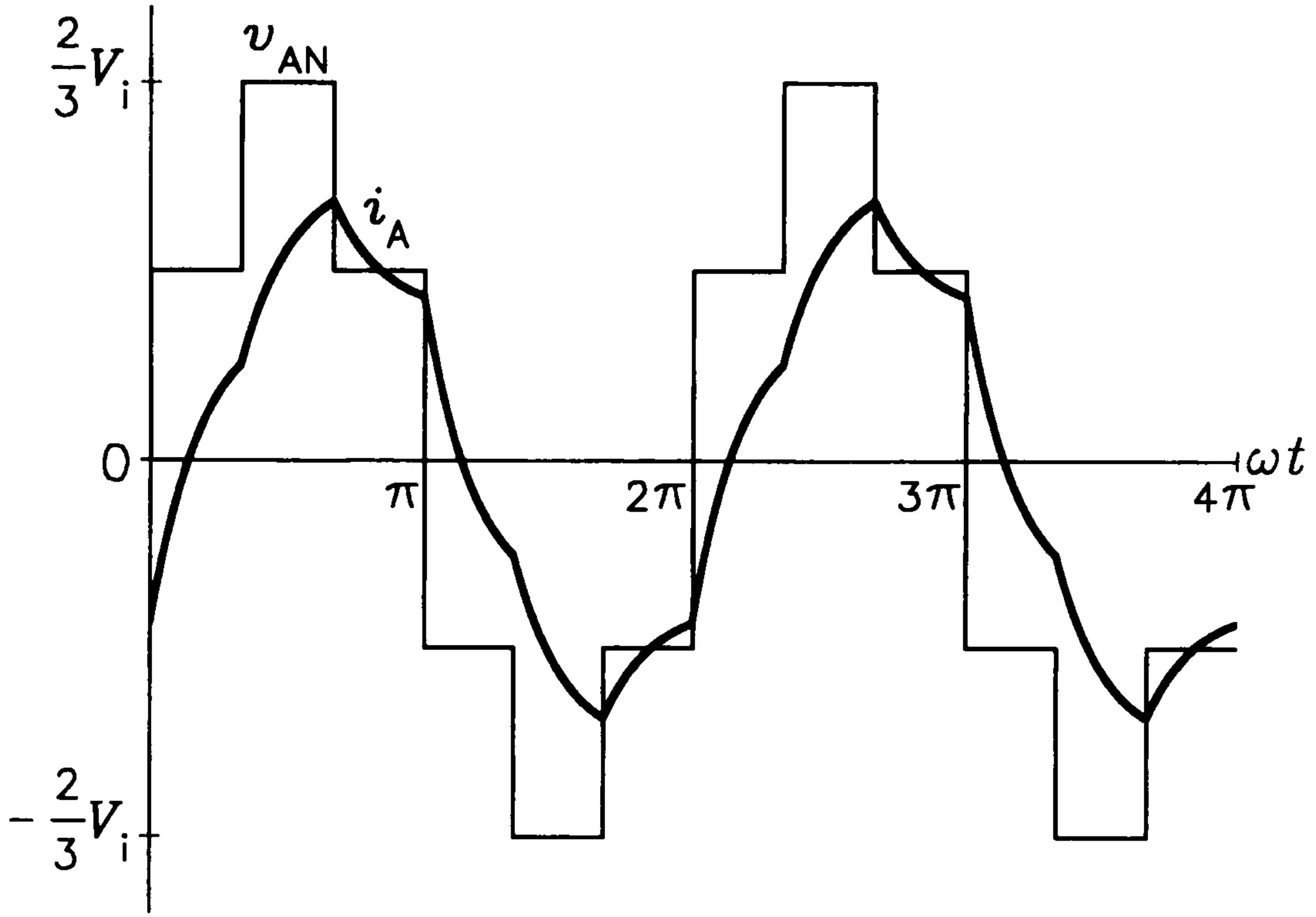


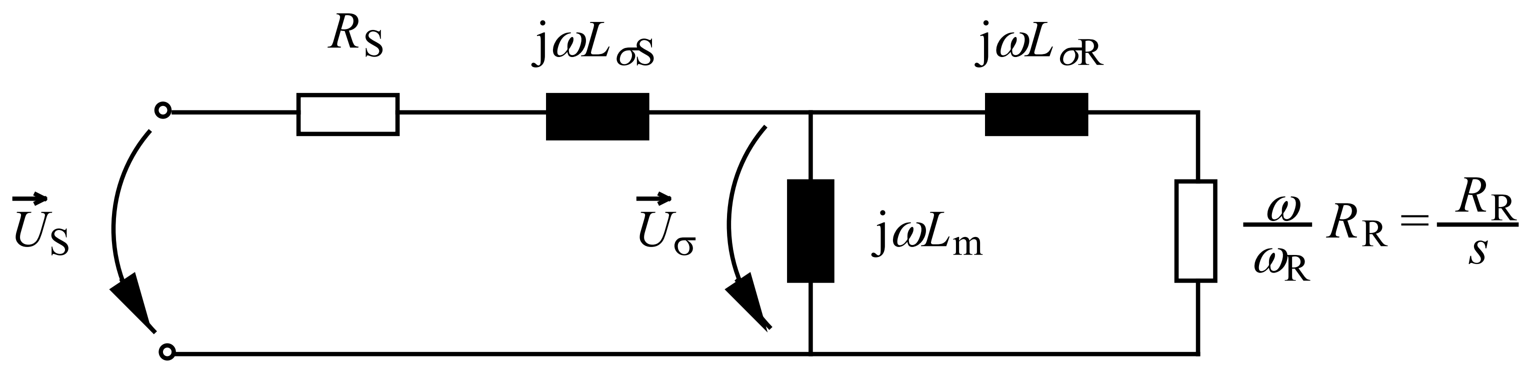
Fig. 7.16

Output current waveform

- Voltage-sourced inverter, VSI
  - Inverter is a voltage source => output voltage waveform is given by the converter
  - Output current depends on the impedance of the load
    - Fundamental component and harmonics can be analysed separately in linear circuits, so called superposition principle

Induction machine as a load

How the impedance behaves in frequency domain?



Equivalent circuit of an induction machine

High frequency impedance can be approximated with the leakage inductances of the induction machine

$$\vec{Z}_n \approx jn\omega\left(L_{\sigma S} + L_{\sigma R}\right)$$

Harmonic current

- When induction machine is at stand still connected to nominal supply U_N, starting current I_s is

$$Z_k = \frac{U_N}{I_s} \approx j\omega_N \left(L_{\sigma S} + L_{\sigma R}\right)$$

- High frequency impedance can be estimated with starting impedance

$$Z_n \approx nZ_k \frac{\omega}{\omega_N}$$

- Harmonic current

$$I_n = \frac{U_n}{Z_n} = \frac{U_n}{n}\frac{I_s}{U_N}\frac{\omega_N}{\omega} = \frac{U_n}{\frac{\omega}{\omega_N}U_N}\frac{I_s}{n}$$

  - $(\omega/\omega_N)\, U_N$ is the wanted output voltage U_1 at frequency ω

- Harmonic current when compared to the starting current

$$\frac{I_n}{I_s} = \frac{U_n}{n\,U_1}$$

- We can estimate relative harmonic current components from the voltage waveform, and we do not need to know the impedance of the load!

Example

- 5th voltage harmonic is 10%
  - I_5 = 0,1/5* I_s = 0,02 I_s
  - Starting current of the motor is I_s = 5…7 I_N
  - I_5 = 0,1…0,14 I_N fifth harmonic is therefore larger than the corresponding voltage harmonic
- Harmonic currents are the higher
  - the higher the starting current of the motor is
  - i.e. the smaller leakage inductances are
- Motors with high power
  - Leakage inductances are getting smaller
  - Harmonic currents are higher than in smaller machines

Current in induction machine

a) output voltage and fundamental component

b) harmonics of the voltage

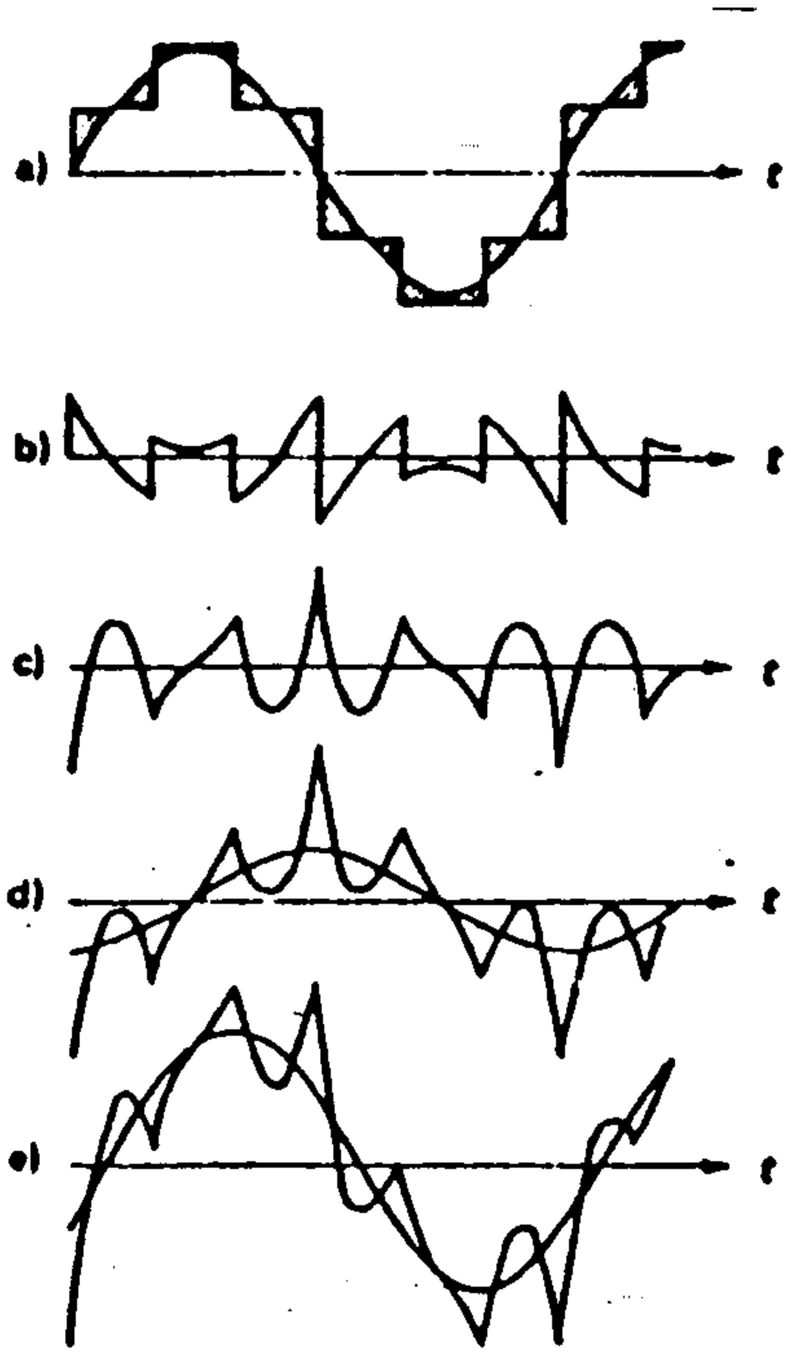
c) harmonics of the current

- integral of voltage harmonics

$$\tilde{i} = \frac{\int (u - u_1)dt}{L_{\sigma S} + L_{\sigma R}} = \frac{\int \sum_{n=2}^{\infty} u_n(t)dt}{L_{\sigma S} + L_{\sigma R}}$$

d) current at no load

e) current at load



Side effects of harmonics

- In the inverter
  - Peak values of current are higher, higher current rating for the power semiconductor devices needed
- Motor
  - RMS value of current includes harmonics
  - Fundamental current component is reduced and torque production is lower
  - More losses, magnetising and winding losses
  - Motor rating must be higher than with sinusoidal current

Torque harmonics

- Torque harmonics caused by current harmonics are often small but not in six step (square wave) operation
- Fundamental component of airgap flux and current harmonics
  - Are causing torque harmonics
  - 5th current harmonic rotates in reverse direction compared to the fundamental => speed difference six
  - 7th current harmonic rotates in same direction as the fundamental => speed difference six
  - Both are producing 6th torque harmonic
- Small inertia
  - Angular speed starts to change, oscillate
- Also mechanical resonances possible

Carrier-comparison PWM technique (N = 12, m = 0.75)

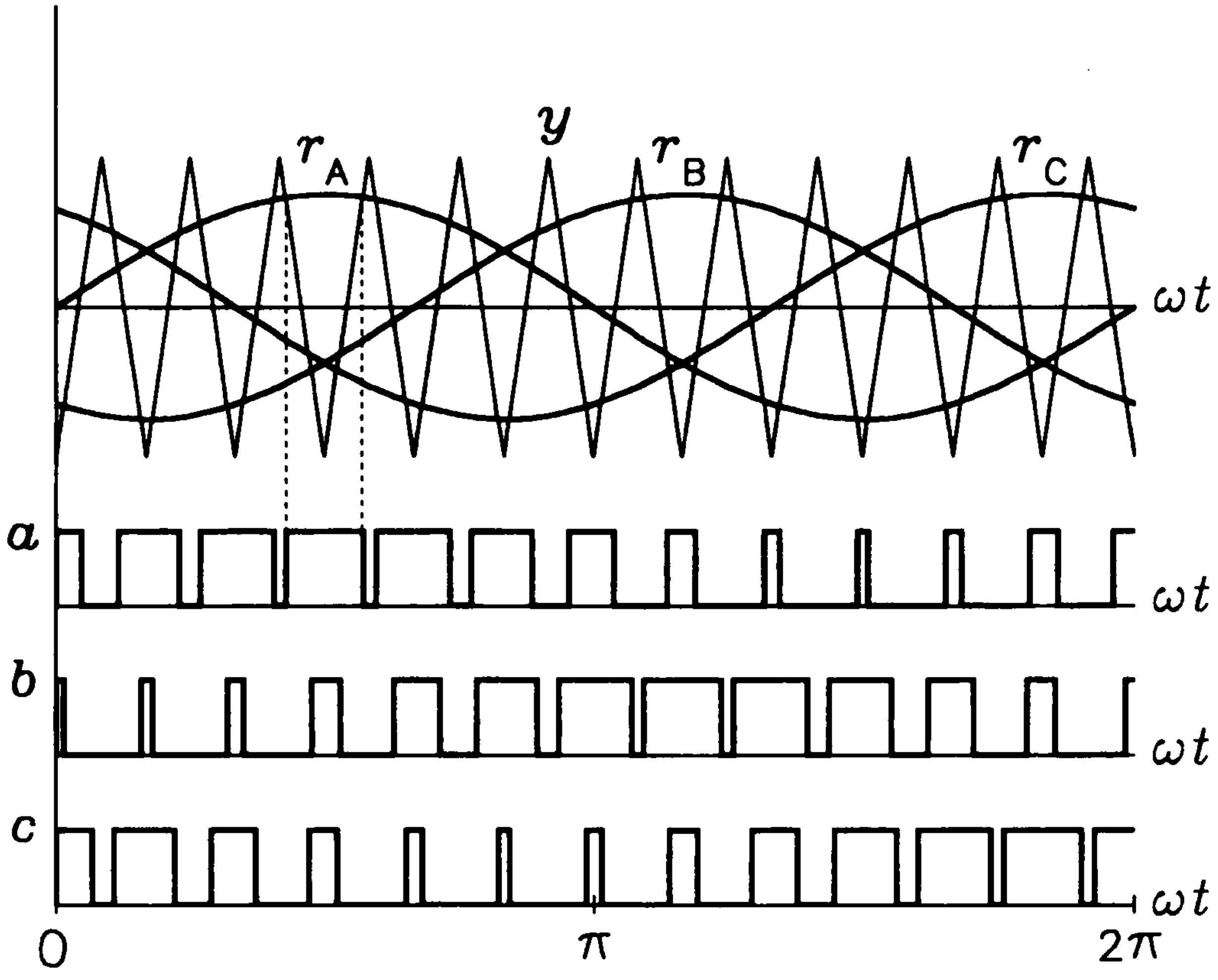


Fig. 7.21

Switching variables and waveforms of output voltages in a three-phase VSI in the PWM mode

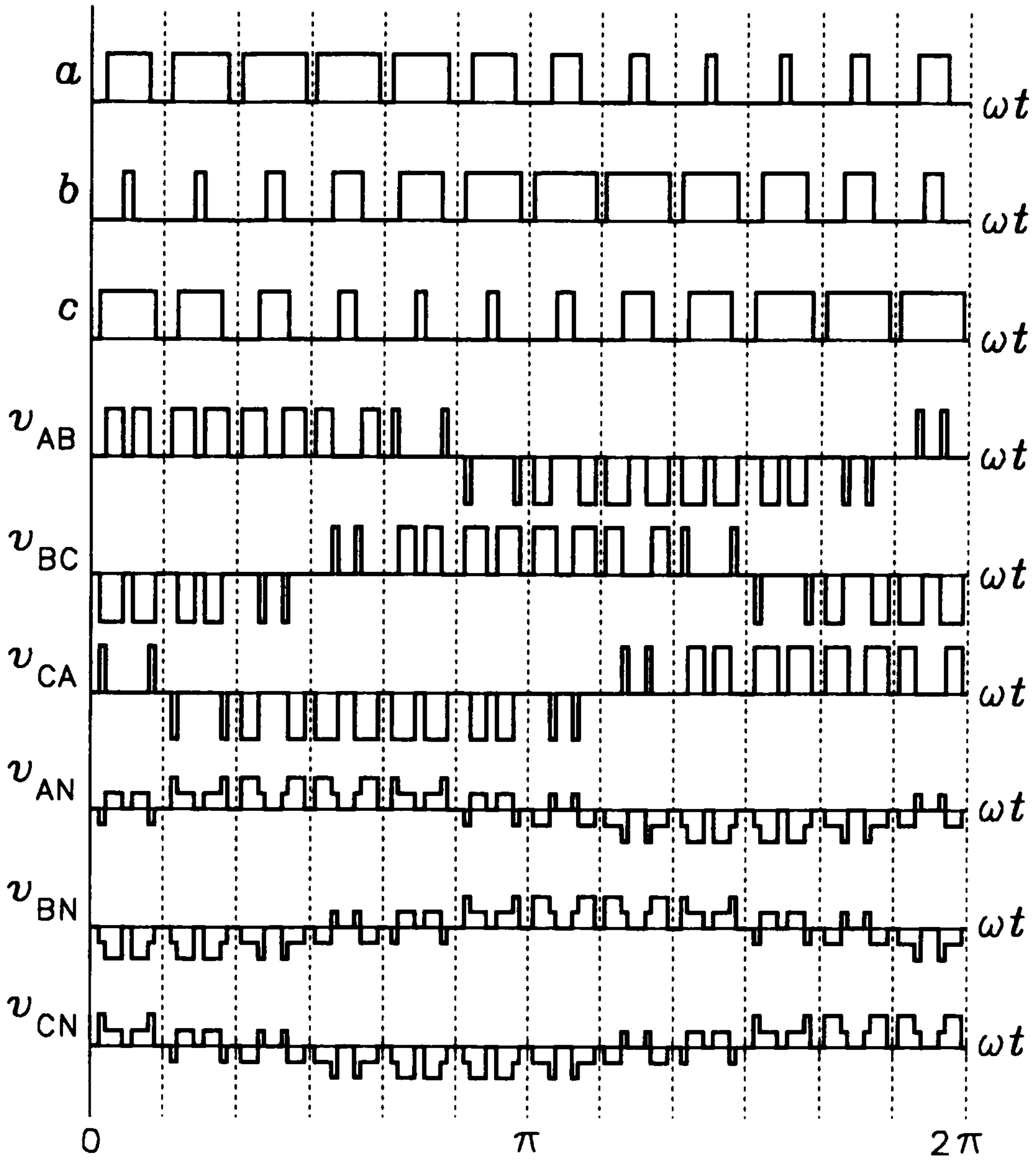


Fig. 7.18

Waveforms of output voltage and current in an RL load of a three-phase VSI in the PWM mode:
(a) load angle of 30^o, (b) load angle 60^o

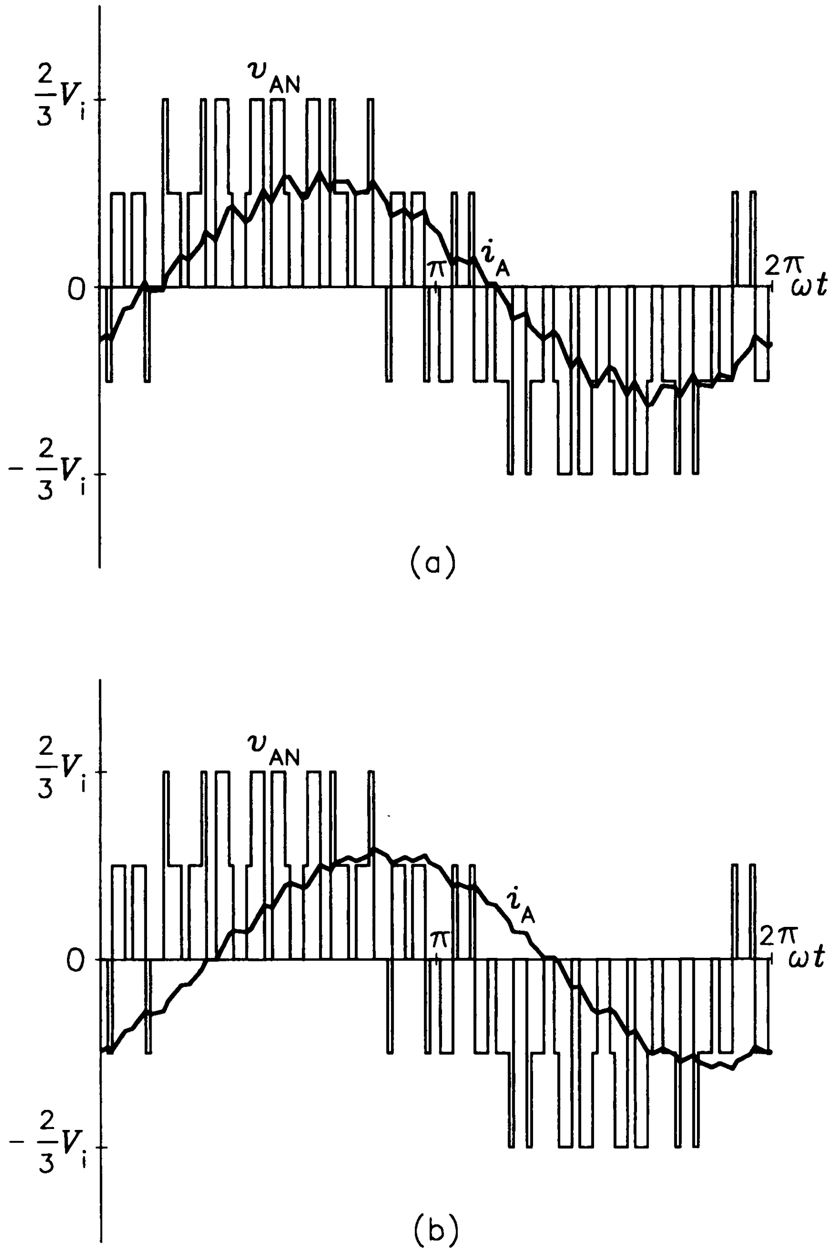


Fig. 7.19

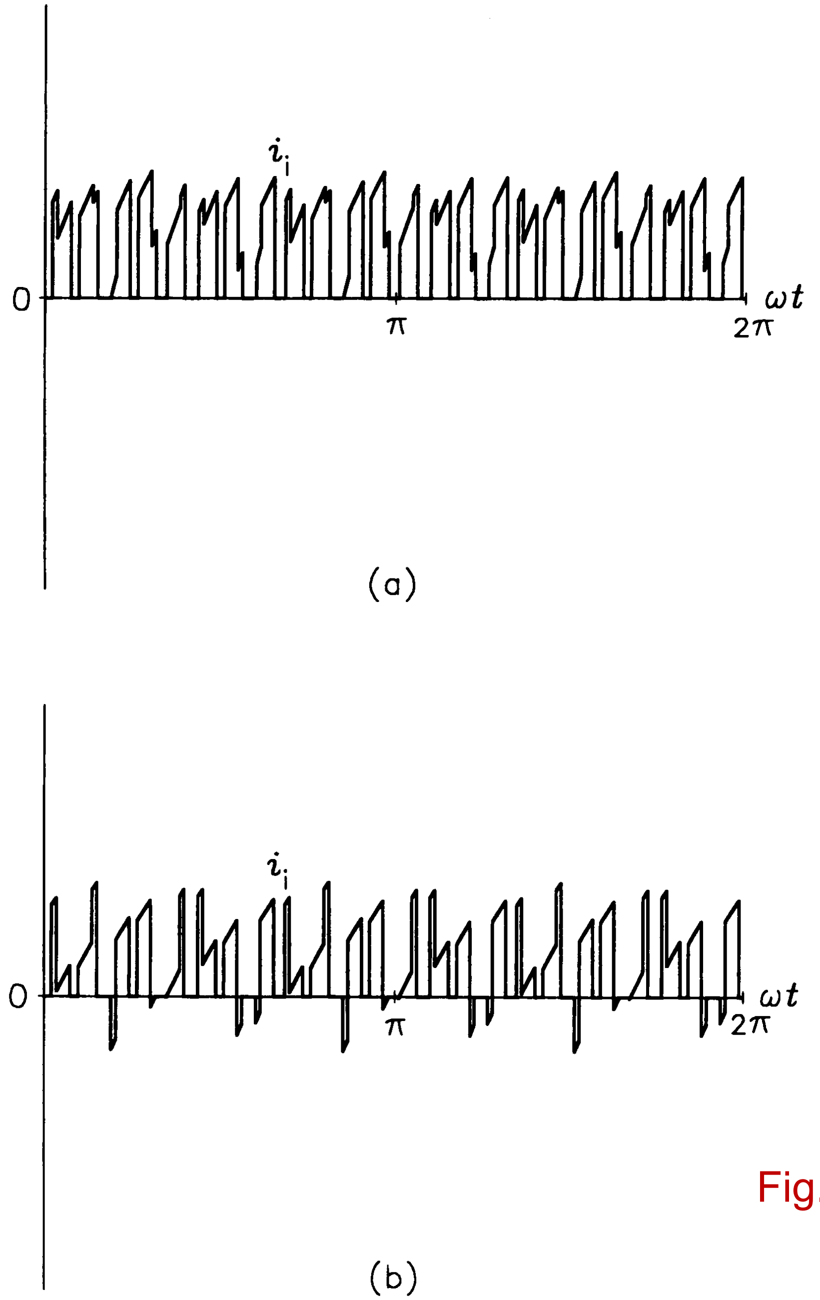


Fig. 7.20

Input current: (a) load angle of 30^o, (b) load angle 60^o

Overmodulation

- When m_a < 1, linea area
  - Harmonics around multiples of switching frequency + output frequency
  - Output voltage is not reaching its maximum
- Overmodulation, m_a > 1
  - Nonlinear
  - Also lower frequency harmonics
  - Output voltage depends also on frequency ratio of output/switching, m_f

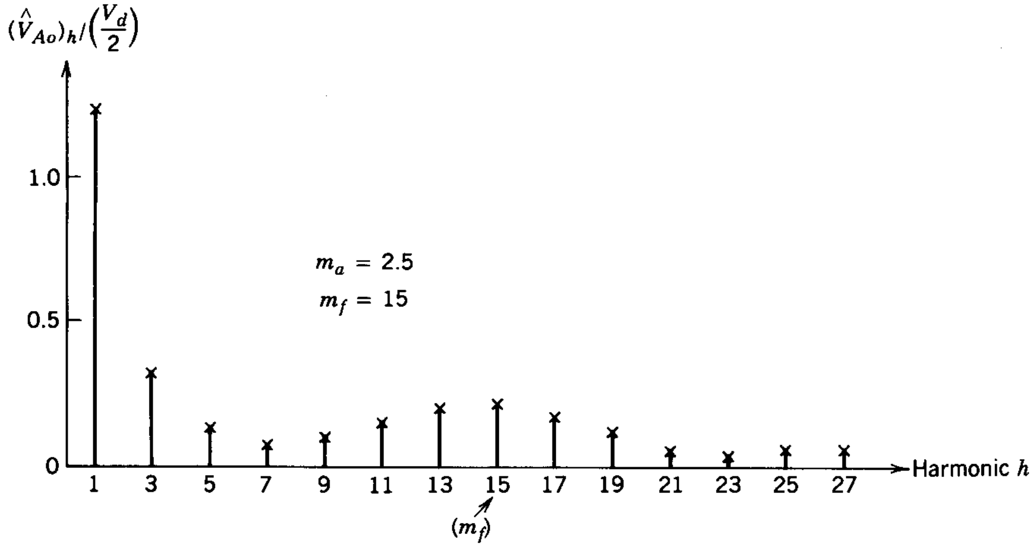


Figure 8-7 Harmonics due to overmodulation; drawn for $m_a = 2.5$ and $m_f = 15$.

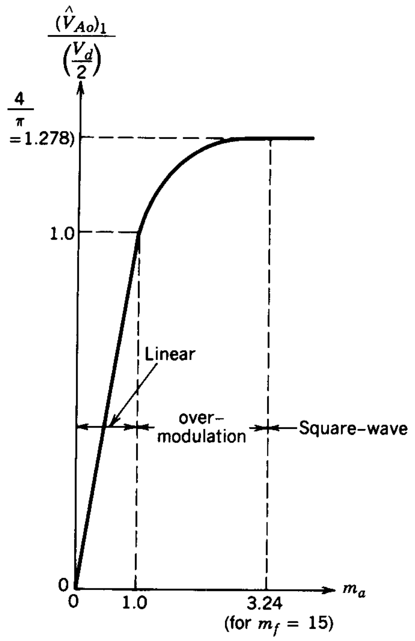
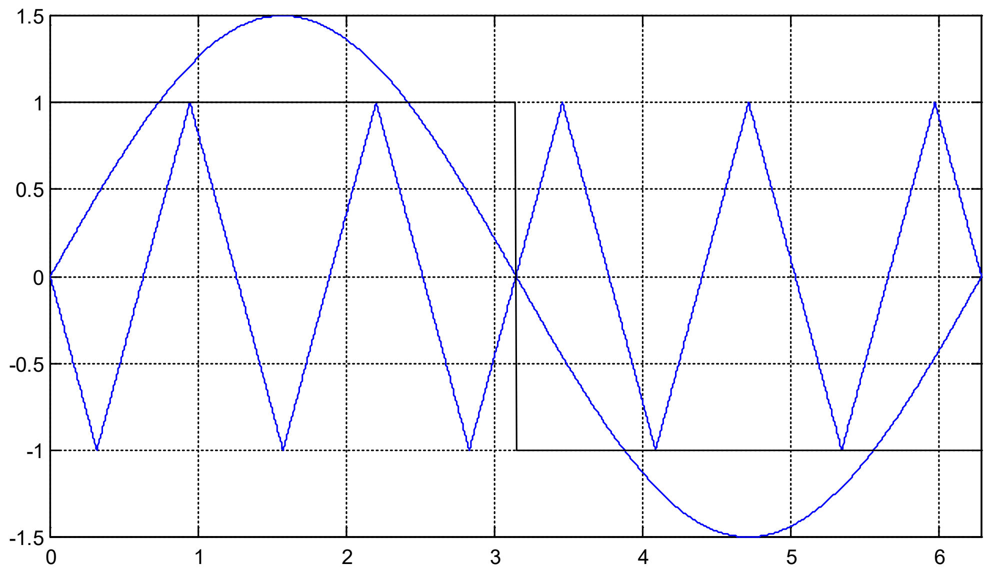


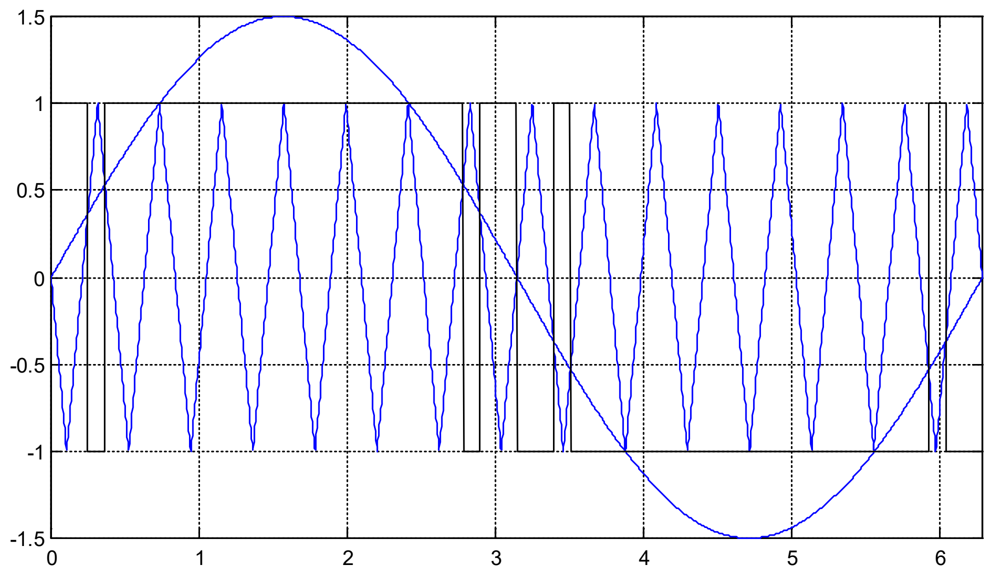
Figure 8-8 Voltage control by varying m_a.

Effect of switching frequency

- Same amplitude of reference but with lower fs only one pulse/half cycle
  - Fundamental of output is higher
  - Harmonics at lower frequencies and amplitudes higher



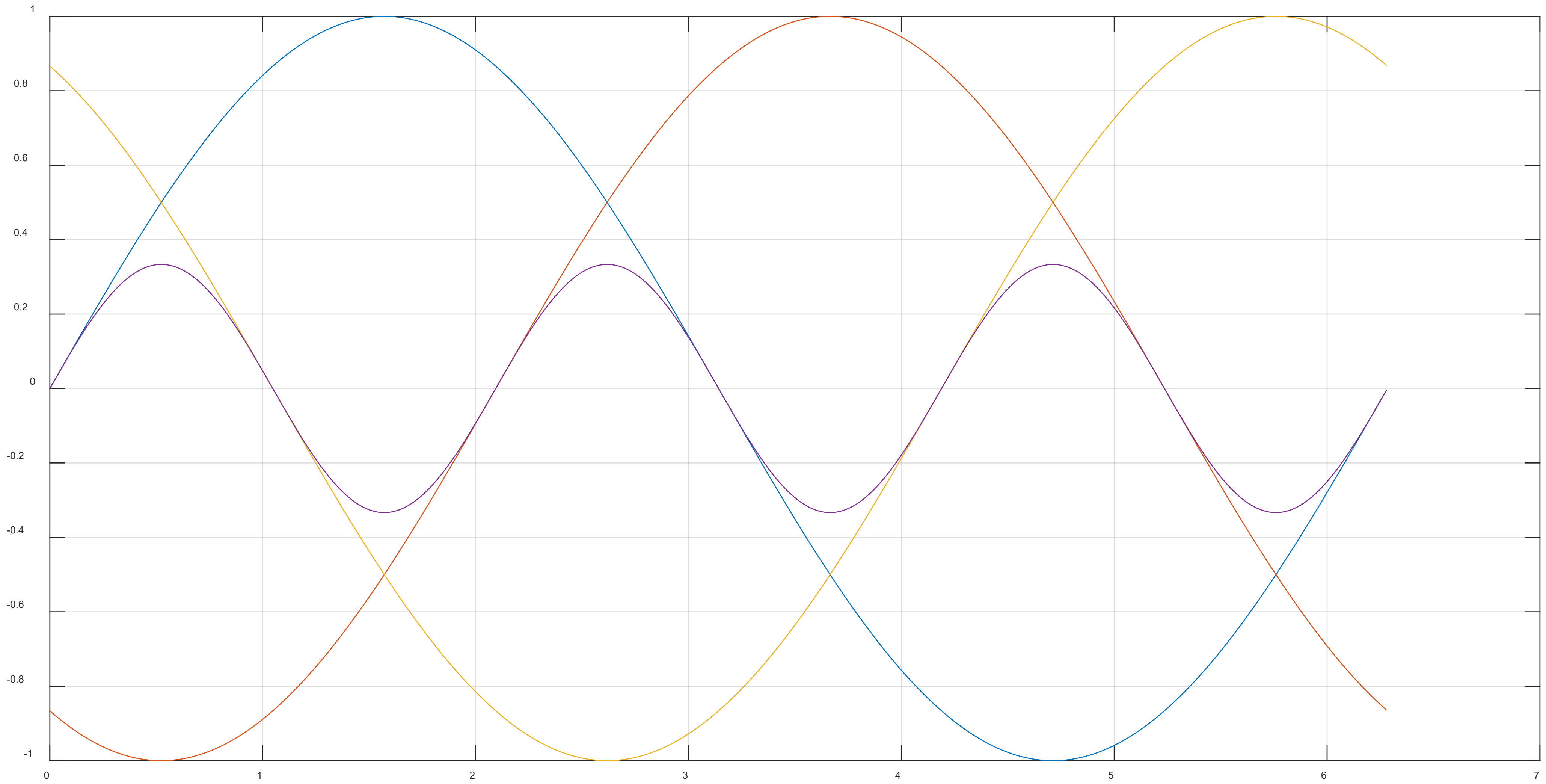
m_a = 1,5 m_f = fo/fs = 5



m_a = 1,5 m_f = 15

Third harmonic in phase quantities

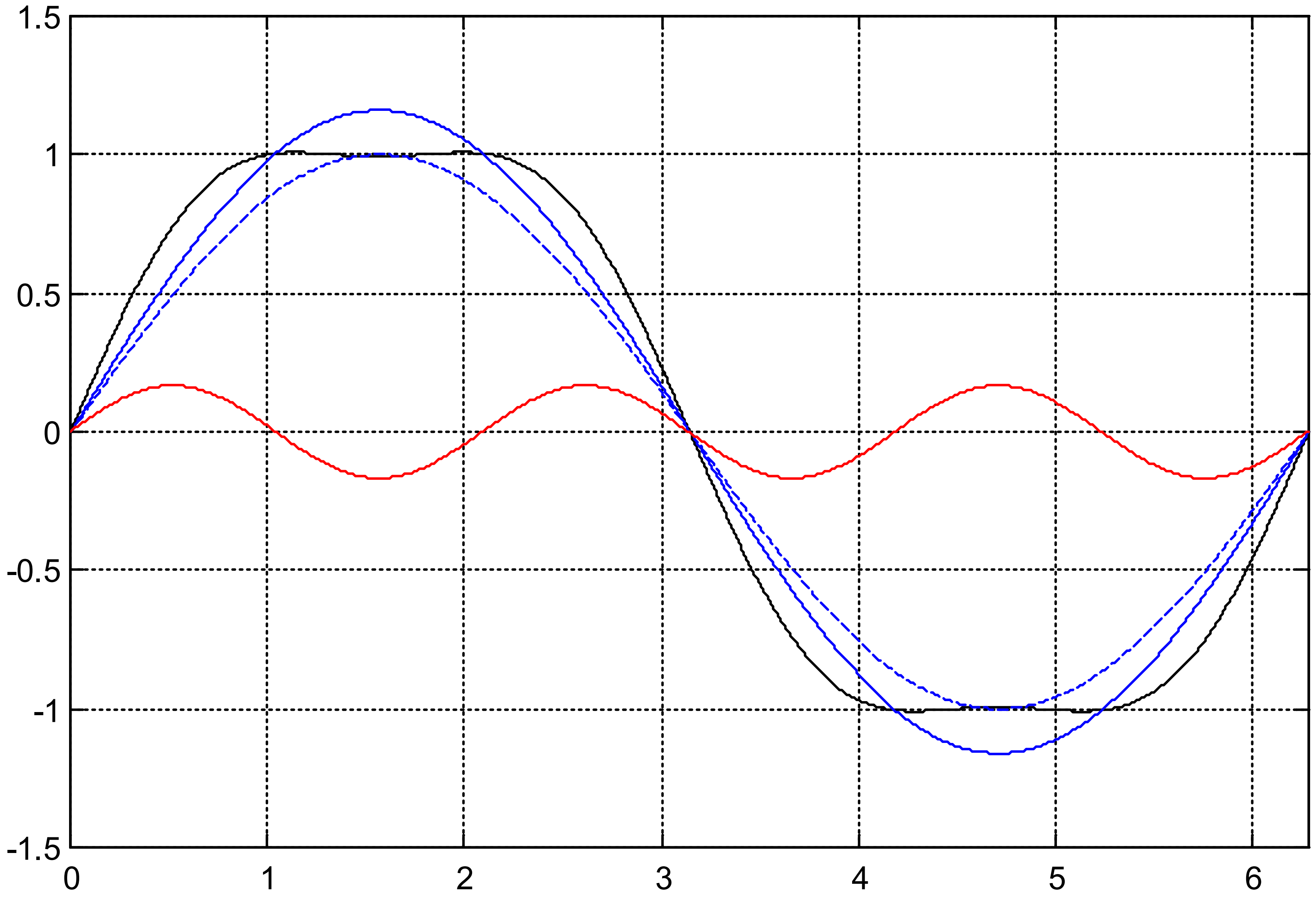
In a three-phase system eg third harmonic is the same in all three phases!



Adding third harmonic

- No effect in load
  - Eliminated in line-to-line voltages because two phase voltages a subtracted
  - In wye or delta connection loads have no path for zero-sequence current
- Amplitude of third harmonic can be 16.7 %
  - Flattens the sinusoid at its peak
  - Modulator saturation is pushed forward, wider linear area
- If added amplitude were higher than 16.7 % the result would be higher than 1 at $\pi/3$

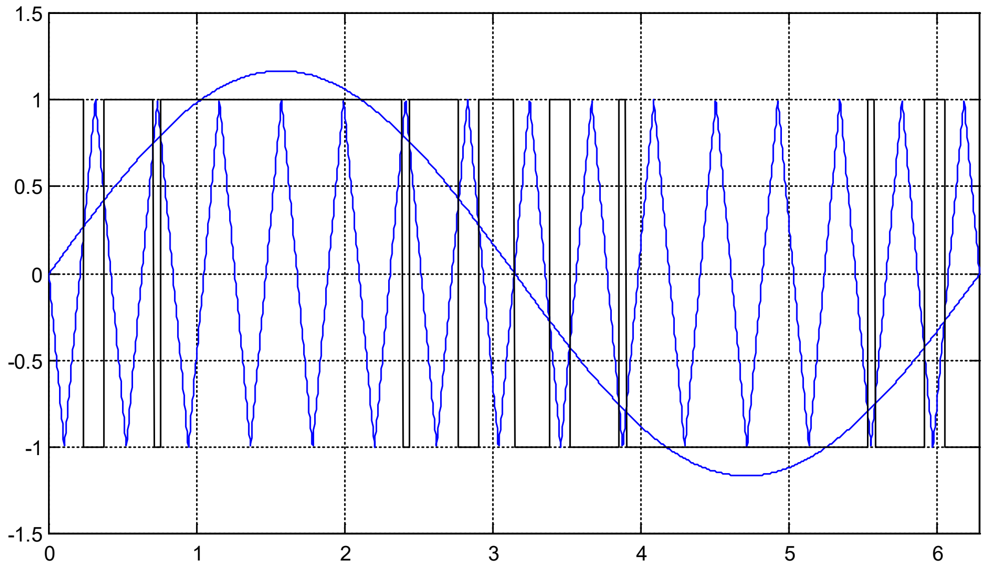
Modulating function when 16,7 % third harmonic added



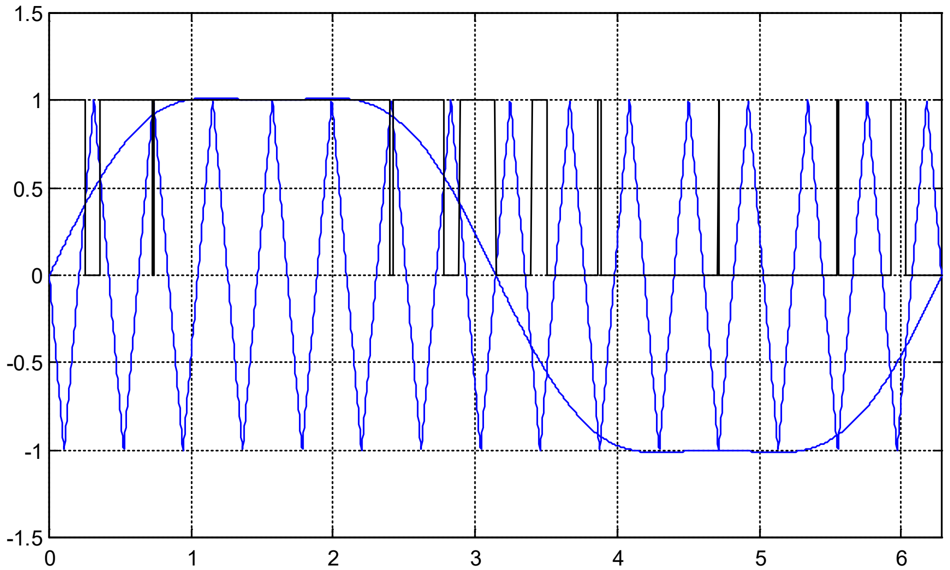
$m_a = 1,167 \qquad m_f = 15$

Adding third harmonic prevents pulses from merging together

- Modulator is linear in 0 - 1,167



No third hamonic added



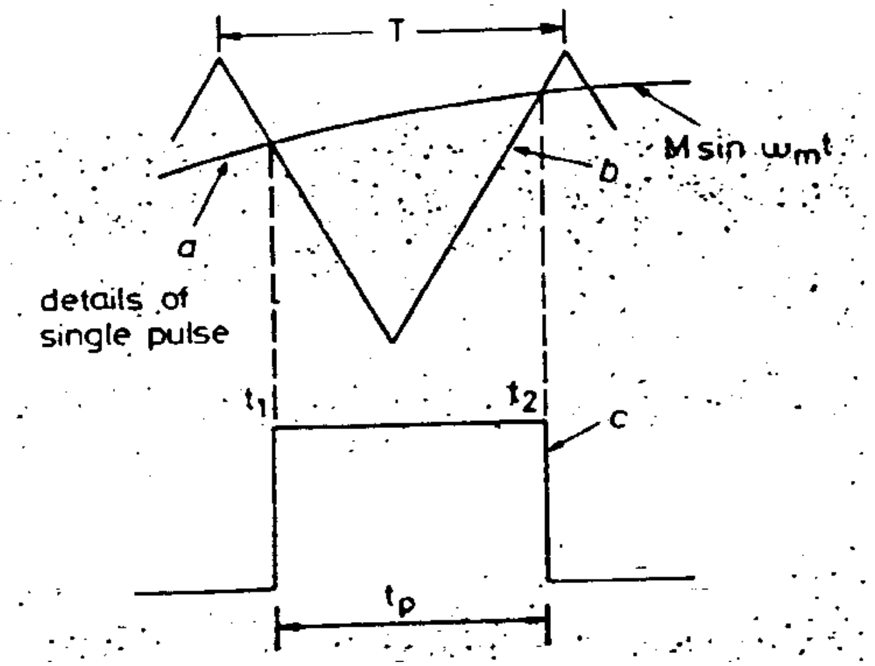
Added third harmonic is 16,7 %

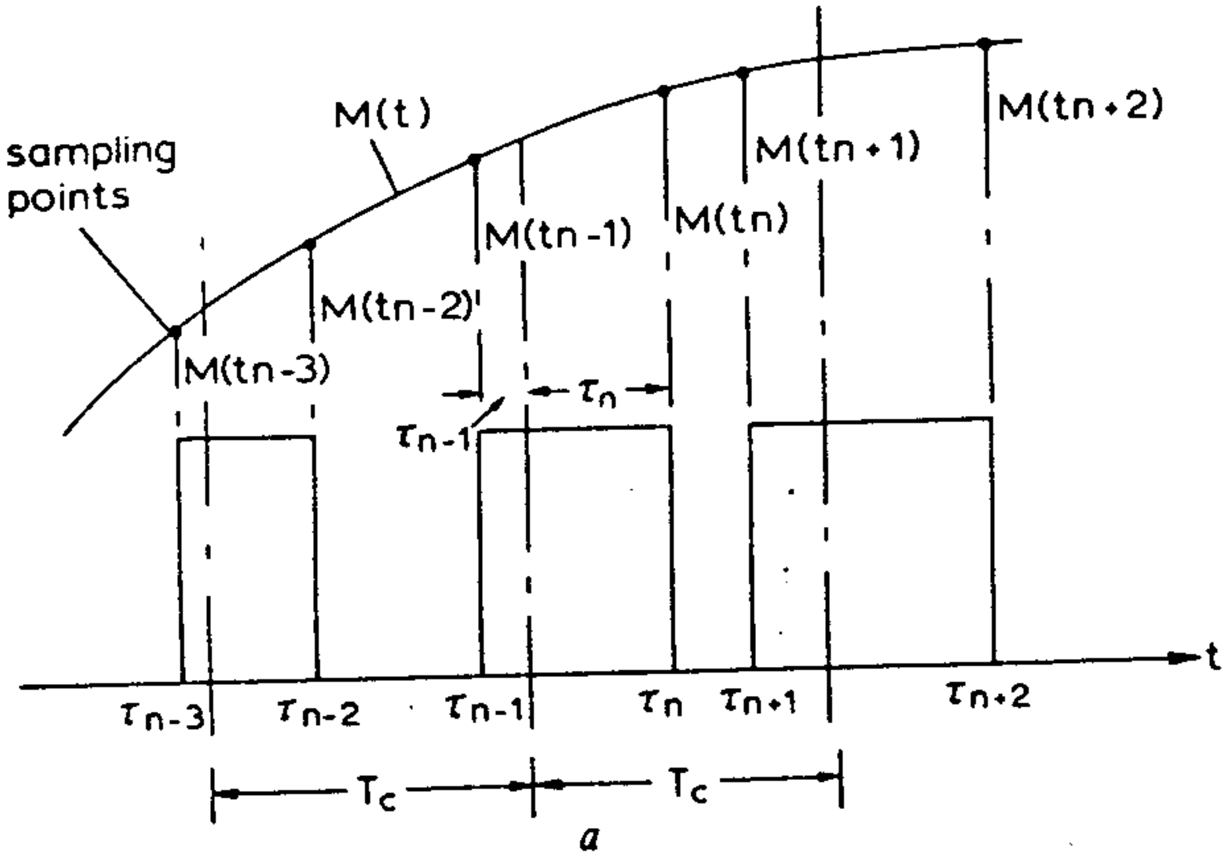
Digital modulation

- Previous methods were based on analog technologies
  - Ideal sinusoid easy to realise
  - Often called **natural sampling**
- Digital electronics
  - Everything is replaced by sampled signals
  - Symmetrical sampling (also called uniform, regular)
  - Asymmetrical sampling

Natural sampling, analog

- Comparison is done on both edges of the pulse, leading and trailing
- Result contains much information



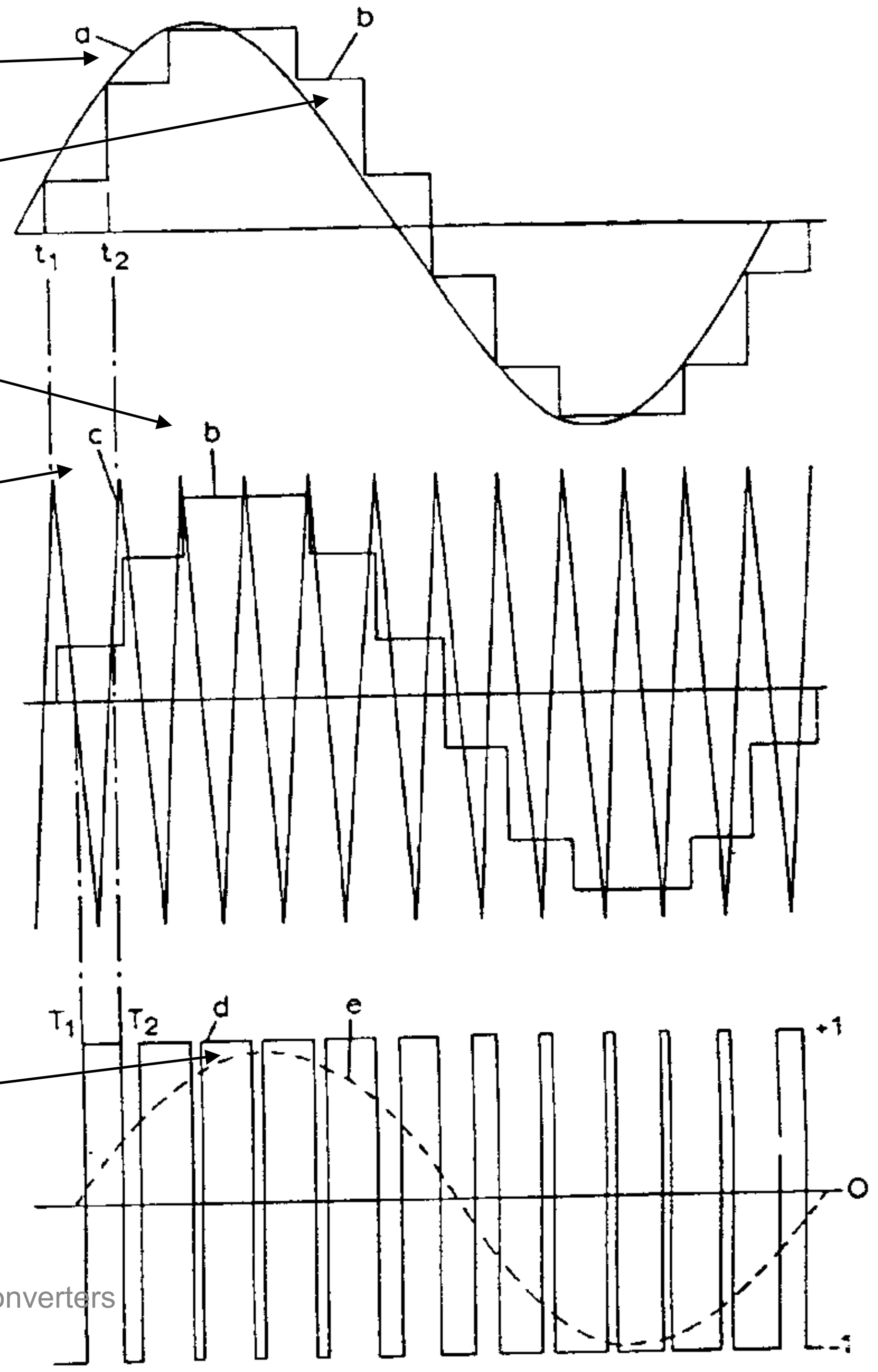


Symmetrical sampling

Modulating function is replaced by the sampled modulating function

Carrier

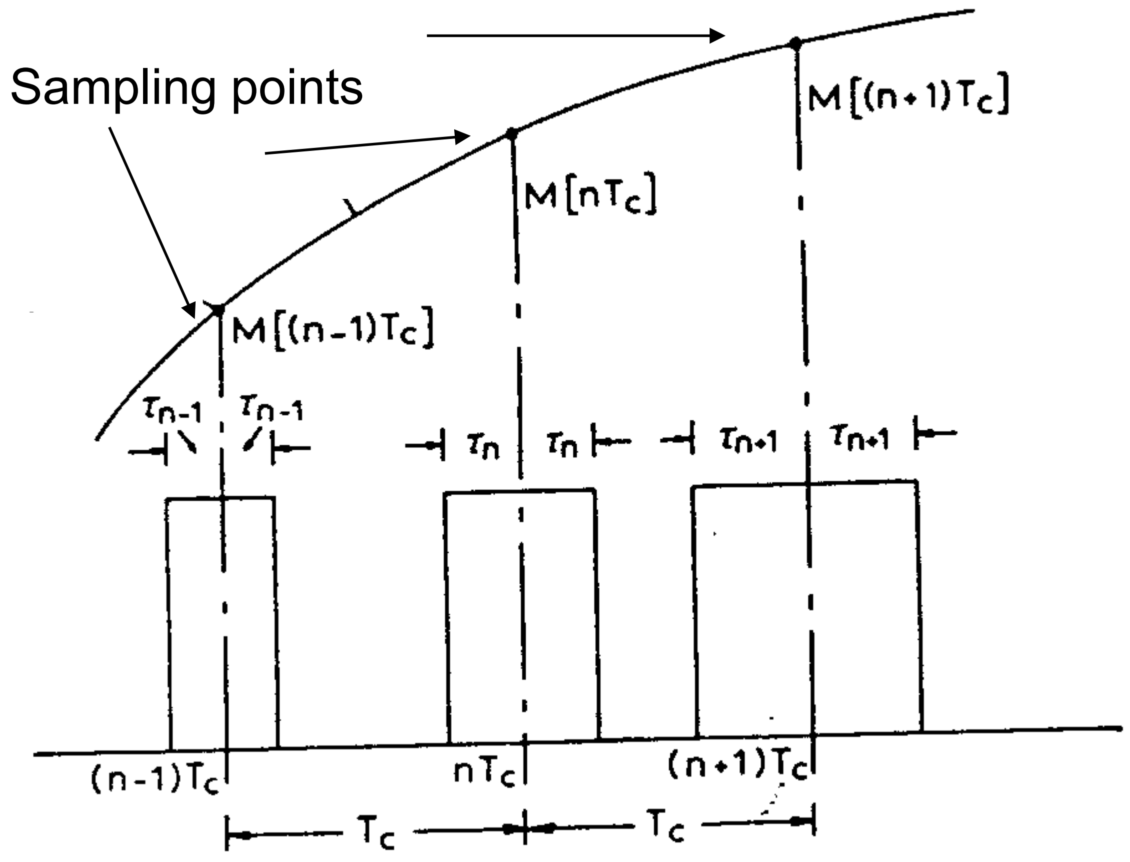
Fundamental of output



Symmetrical sampling

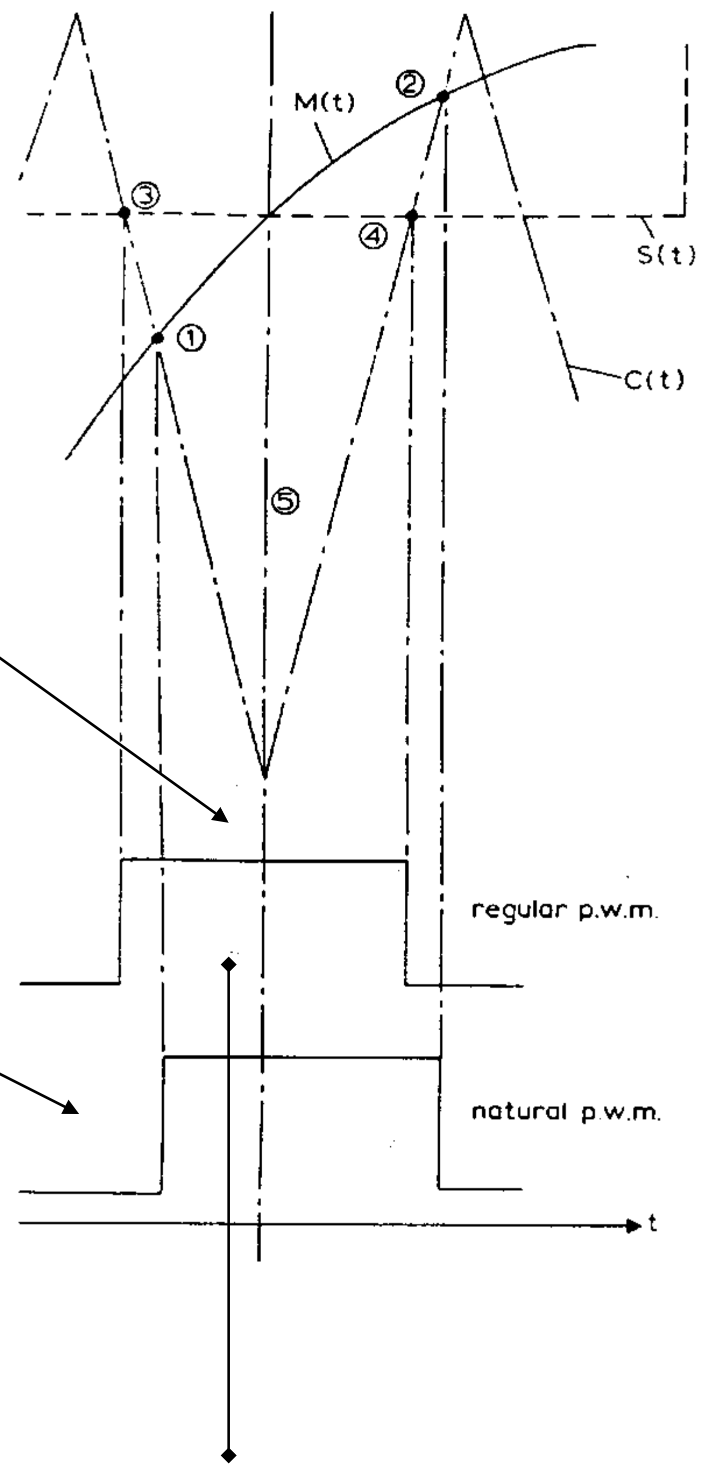
- Pulse width depends on equal distance samples
  - => symmetric
- Distance between pulse centers is constant
- Pulse width is calculated from

$$t_p = \frac{T_c}{2}\left\{1 + m_a \sin \omega_m t_1\right\}$$



Comparison

- Symmetric
  - Both pulse edges are modulated similarly and distance from pulse center the same
- Natural
  - Pulses are not symmetric around the center points



Space-vector modulation

Voltage space vector plane of a three-phase VSI: (a) in volts, (b) per unit

In module 4 space-vector was defined as $\vec{\mathcal{F}_s} = \mathcal{F}_{as} + \mathcal{F}_{bs}\mathrm{e}^{\mathrm{j}120^{\mathrm{o}}} + \mathcal{F}_{cs}\mathrm{e}^{\mathrm{j}240^{\mathrm{o}}}$

For example when switches are in position + - -

$$\vec{V}_4 = \left(1 + 0\mathrm{e}^{\mathrm{j}120^{\mathrm{o}}} + 0\mathrm{e}^{\mathrm{j}240^{\mathrm{o}}}\right)V_d = V_d$$

In position + + -

$$\vec{V}_6 = \left(1 + 1\mathrm{e}^{\mathrm{j}120^{\mathrm{o}}} + 0\mathrm{e}^{\mathrm{j}240^{\mathrm{o}}}\right)V_d = (1\text{-}\tfrac{1}{2}+\mathrm{j}\tfrac{\sqrt{3}}{2})V_d = V_d\ \mathrm{e}^{\mathrm{j}60^{\mathrm{o}}}$$

Going through all $2\cdot 2\cdot 2 = 8$ combinations we end up on six non−zero vectors shown in the Figure and two vectors where length is zero, when switches are in the same position, ie +++ or ---

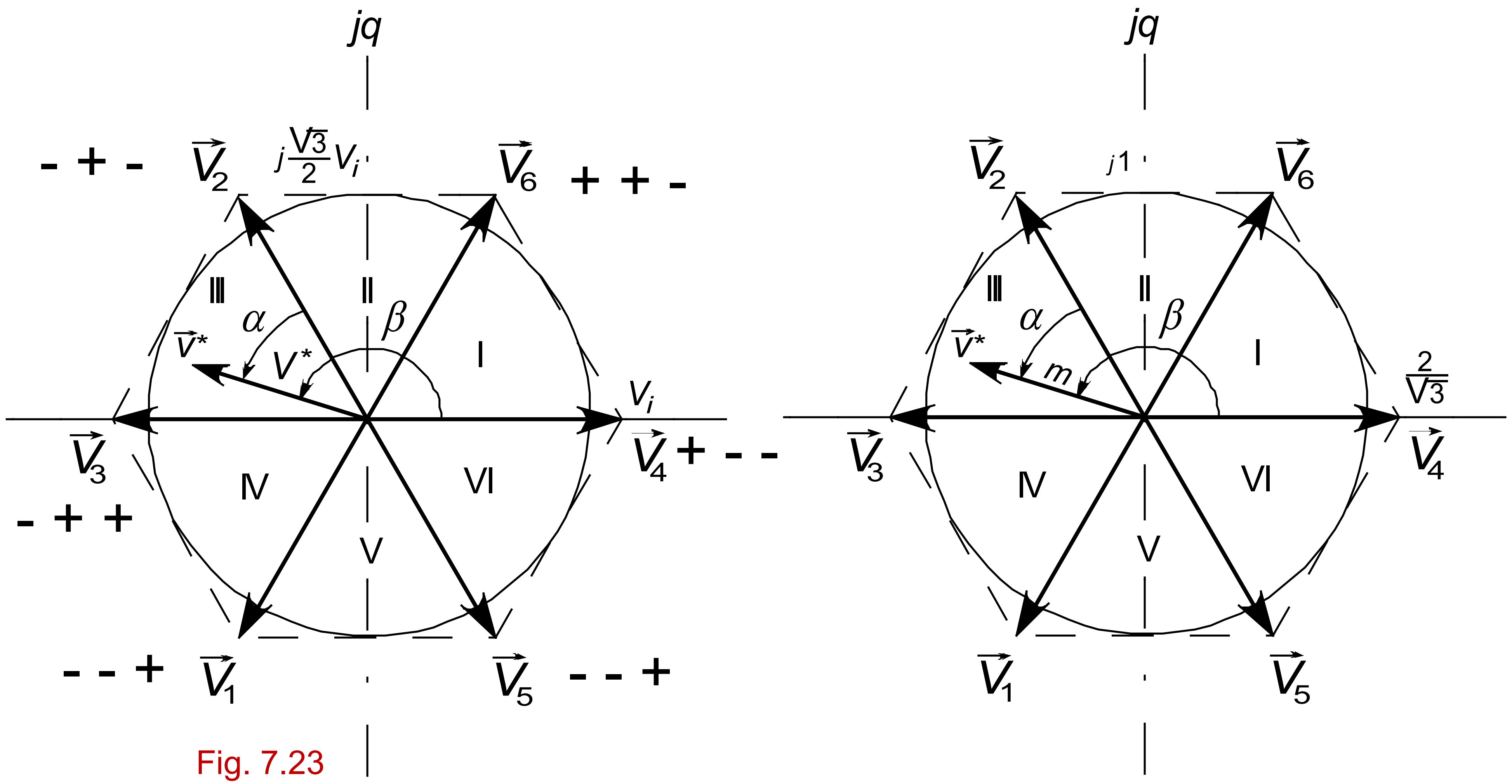


Fig. 7.23

(a) (b)

Control of the voltage

- Induction machine is a typical load for VSI
  - Inductances are smoothening current
- Voltage is caused by a changing flux

$$\underline{u}_s = d\,\underline{\psi}_s / dt$$

- Flux is an integral of voltage

$$\underline{\psi}_s = \int_0^t \underline{u}_s \,\mathrm{d}t + \underline{\psi}_{s0}$$

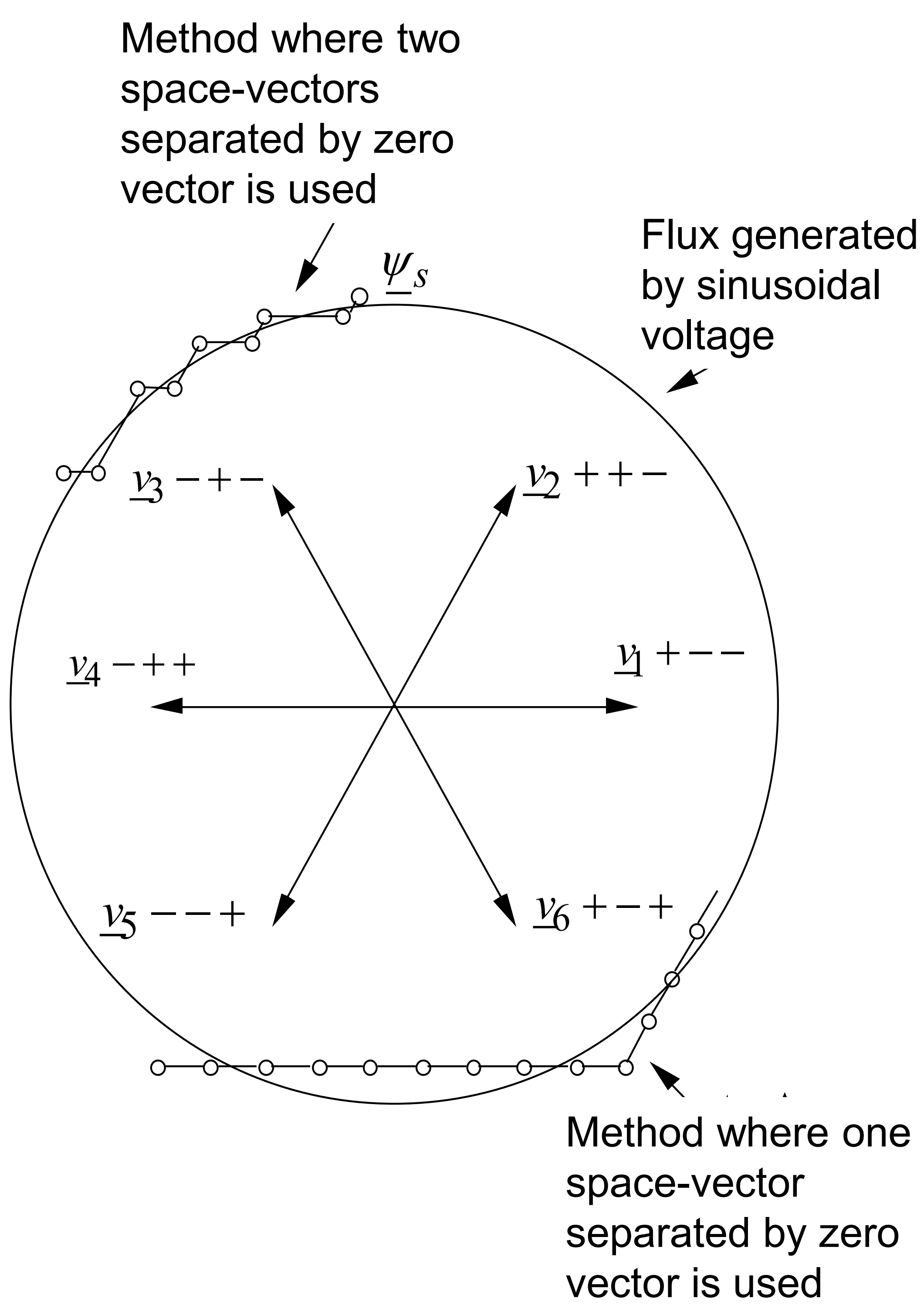
  - Resistances assumed to be small
  - Describes the air gap flux of an induction machine
  - More detailed machine models needed in accurate control

Requirements

- Ideal voltage vector causes flux $\underline{\psi}_s = \frac{\hat{u}_s}{\omega} e^{j(\omega t - \pi/2)}$
- In VSI
  - Only six non-zero voltage vectors
  - Nevertheless, output voltage integral should be similar to the ideal one
  - This is true
    - When flux has constant amplitude
    - Rotates smoothly with the wanted angular frequency

Flux vector

- Circle is created by sinusoidal voltage
- VSI
  - Integral stops when zero vector is used
  - Non-zero vectors move flux with constant speed in the direction of the voltage vector



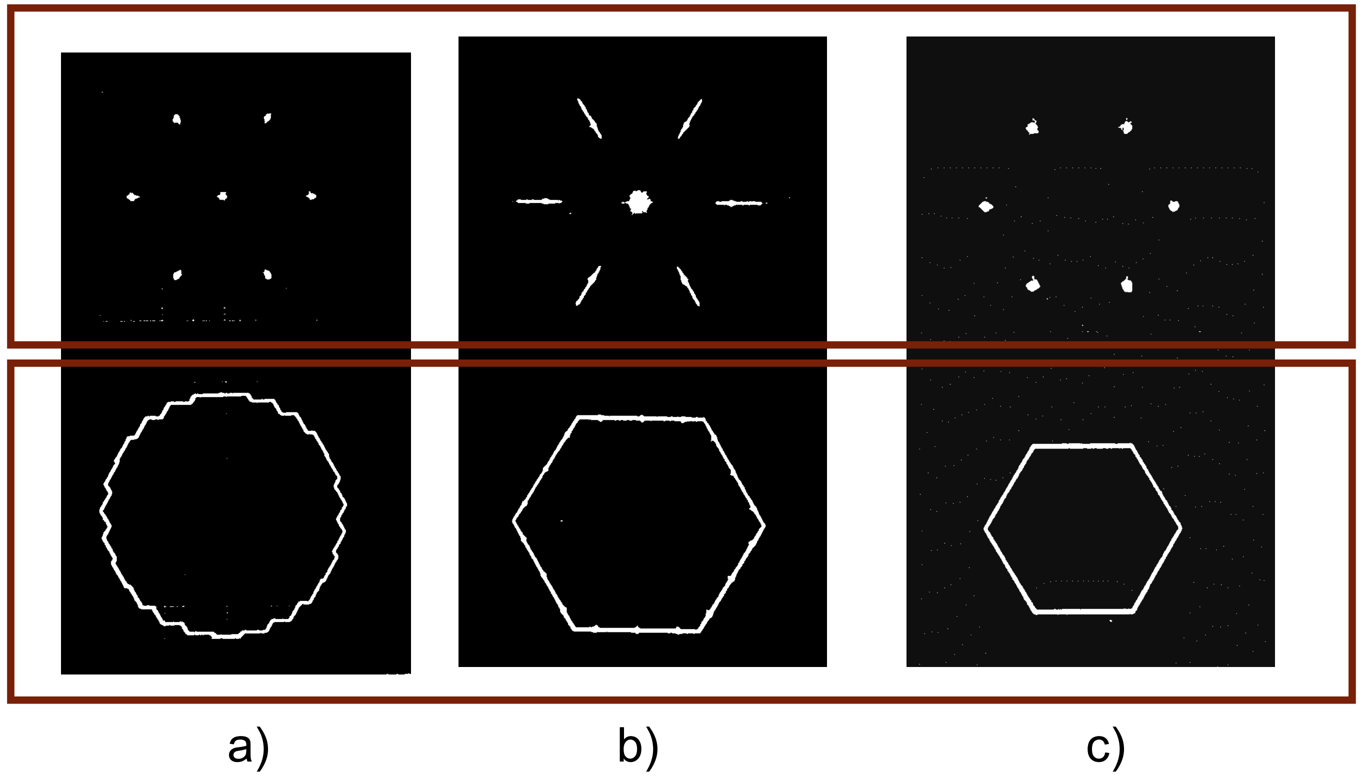
SVM, Space vector modulator

- Every 60° wide sector is divided either to
  - Constant angle slices $\Delta\alpha$
  - Or constant duration time segments ΔT
- Flux change is same with ideal voltage or with VSI

$$\Delta \underline{\psi}_s = \int_0^{\Delta T} \underline{u}_s(\alpha)\, dt = \int_0^{\Delta T} \hat{u}_s \mathrm{e}^{\mathrm{j}\omega t}\, dt$$

Examples of voltage and flux vectors

- Upper part of the figures is voltage vector
- Lower part of the figure isflux vector
- Very old frequency converters where switching frequency is low



- a) asynchronous sin-triangular wave comparison, f_1 = 40 Hz,
- b) synchronous comparison of a sine and square-wave, f_1 = 40 Hz
- c) field-weakening area, frequency higher than 50 Hz, (1 pulse / half-cycle in line-to-line voltage), f_1 = 70 Hz.

Switching patterns and voltage and current waveforms:
(1) carrier-comparison PWM with sinusoidal reference,
(2) space vector PWM with high-efficiency state sequence,
(3) programmed PWM with harmonic elimination

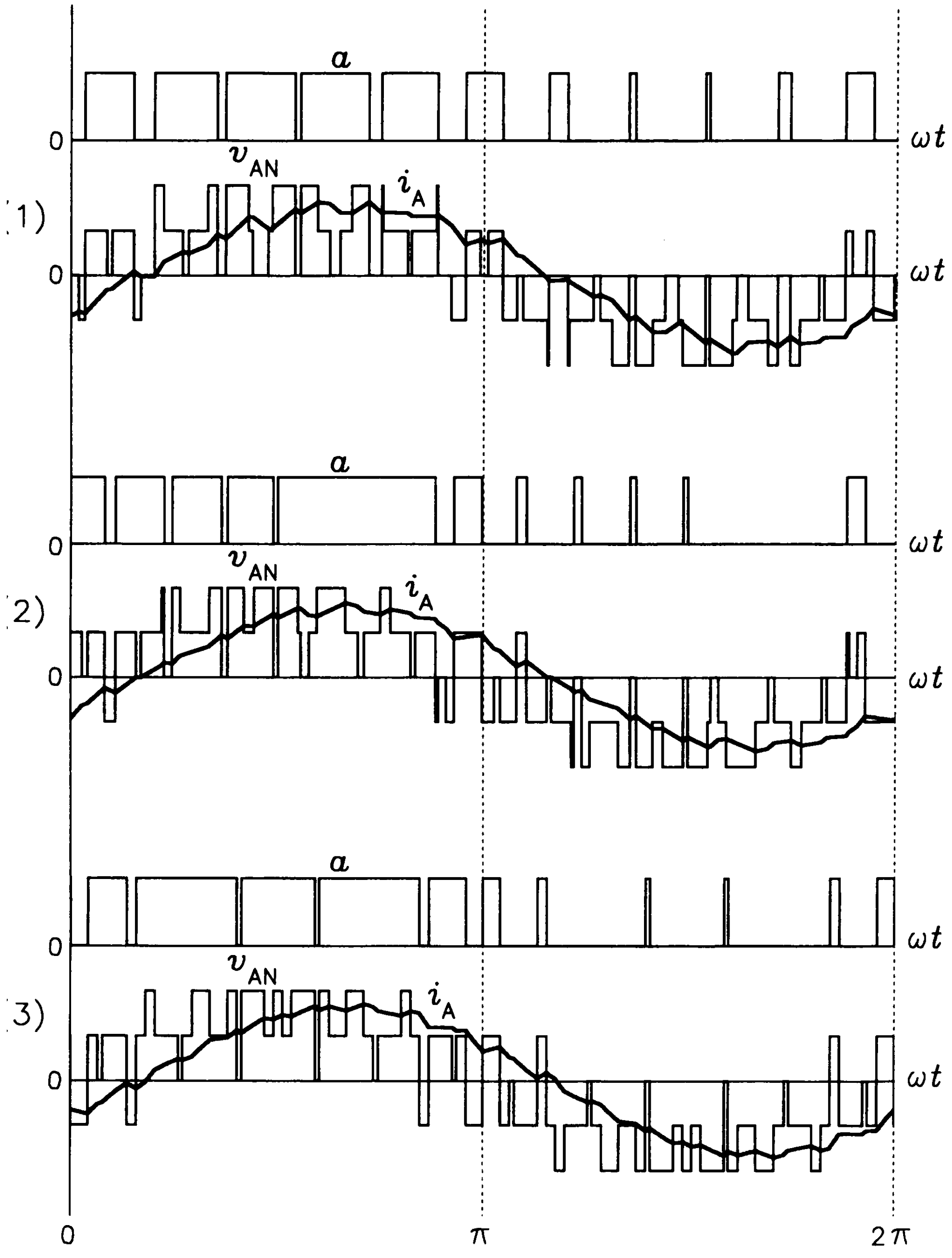


Fig. 7.29

Hysteresis current control scheme

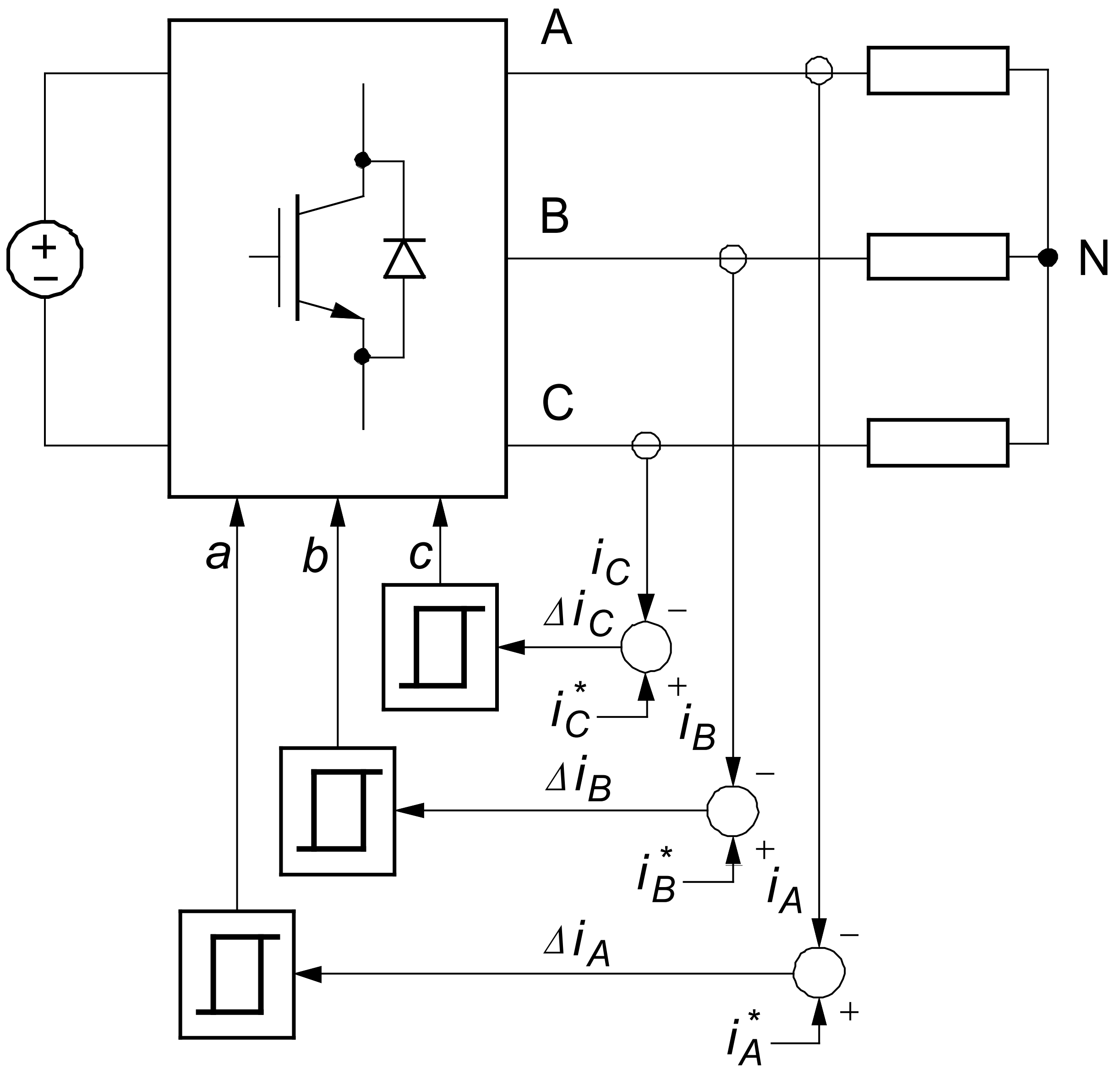


Fig. 7.33

Waveforms of output currents in a VSI with hysteresis current control:
(a) 20% tolerance, (b) 10% tolerance

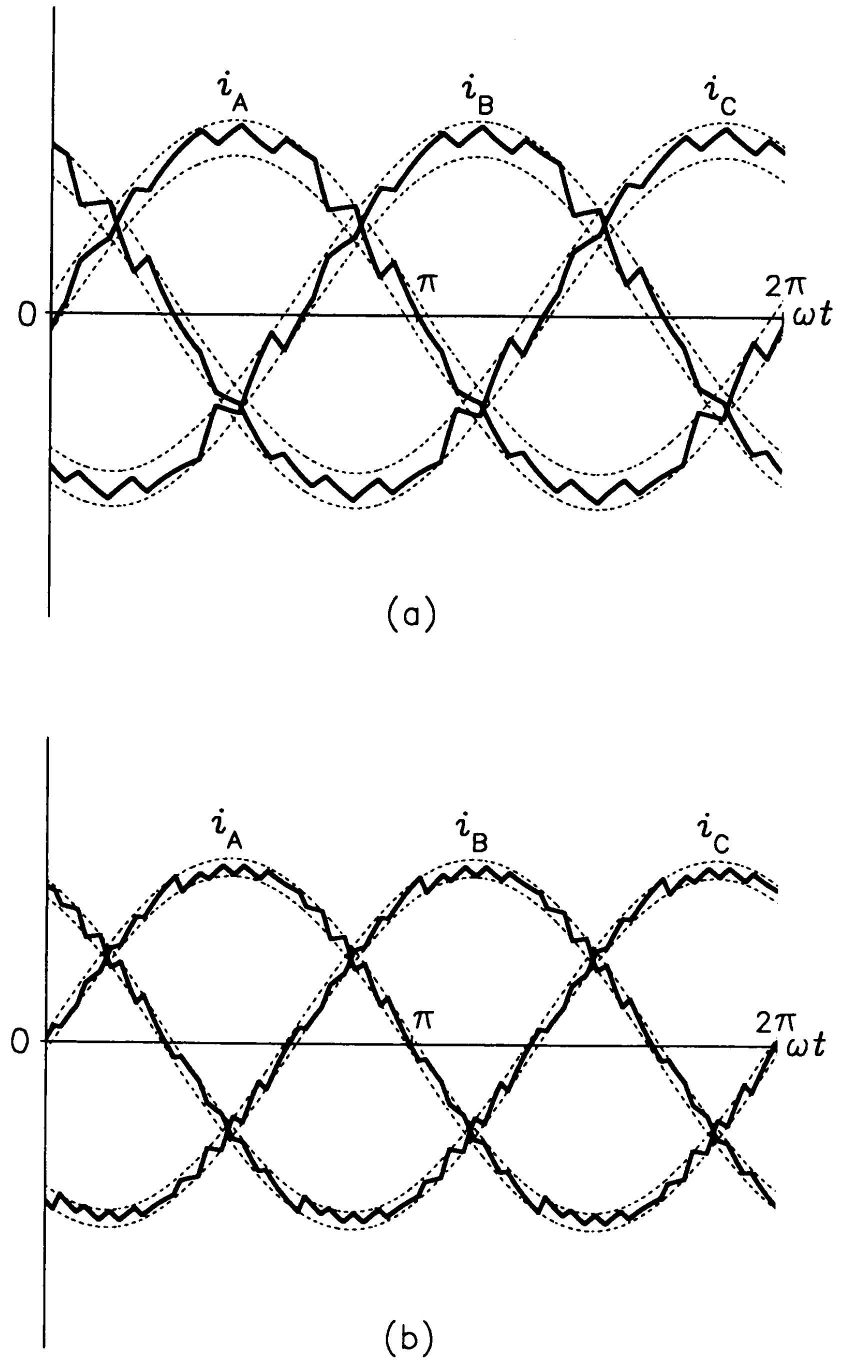


Fig. 7.35

Waveform of output currents in a VSI with hysteresis current control at a rapid change in the magnitude, frequency, and phase of the reference current

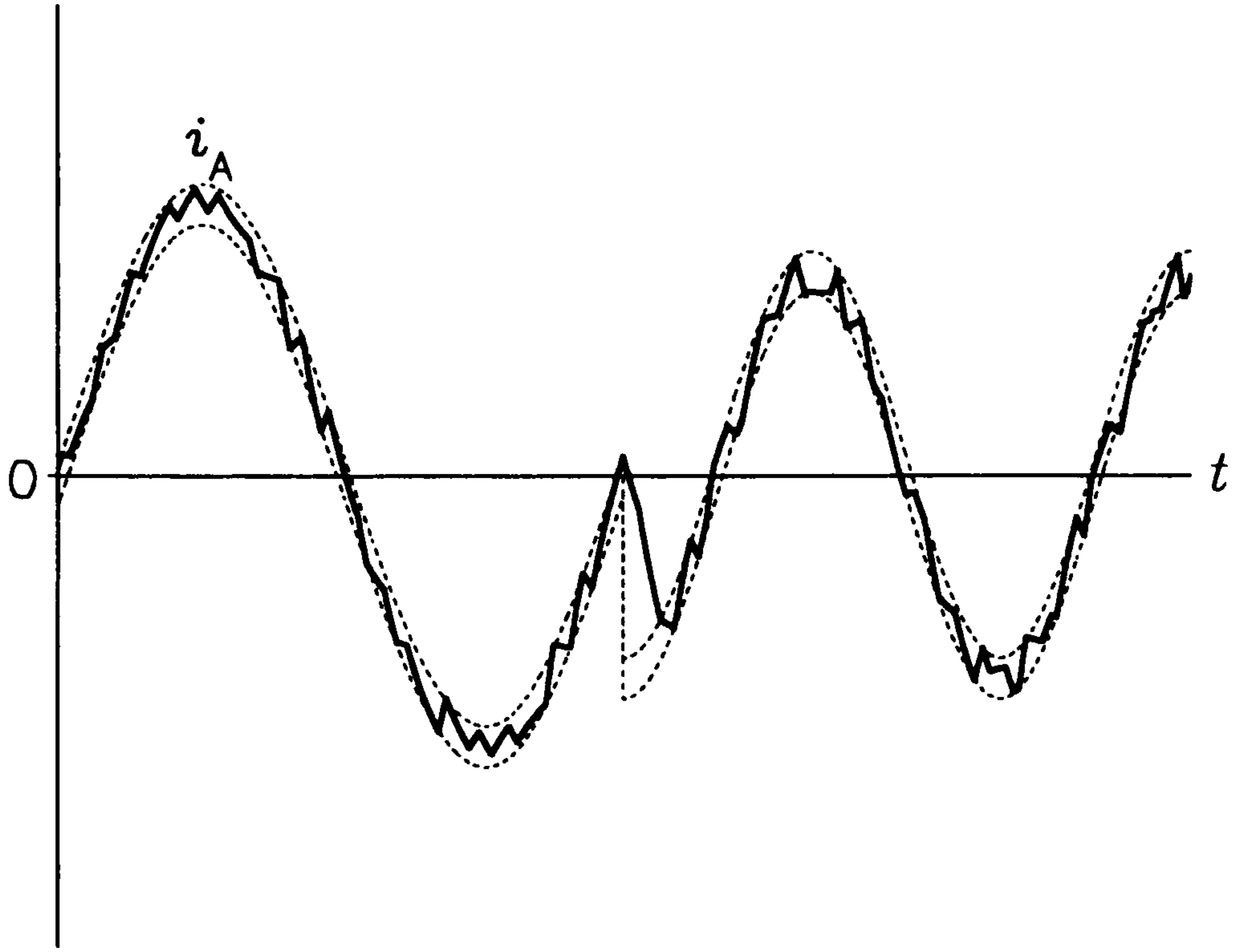
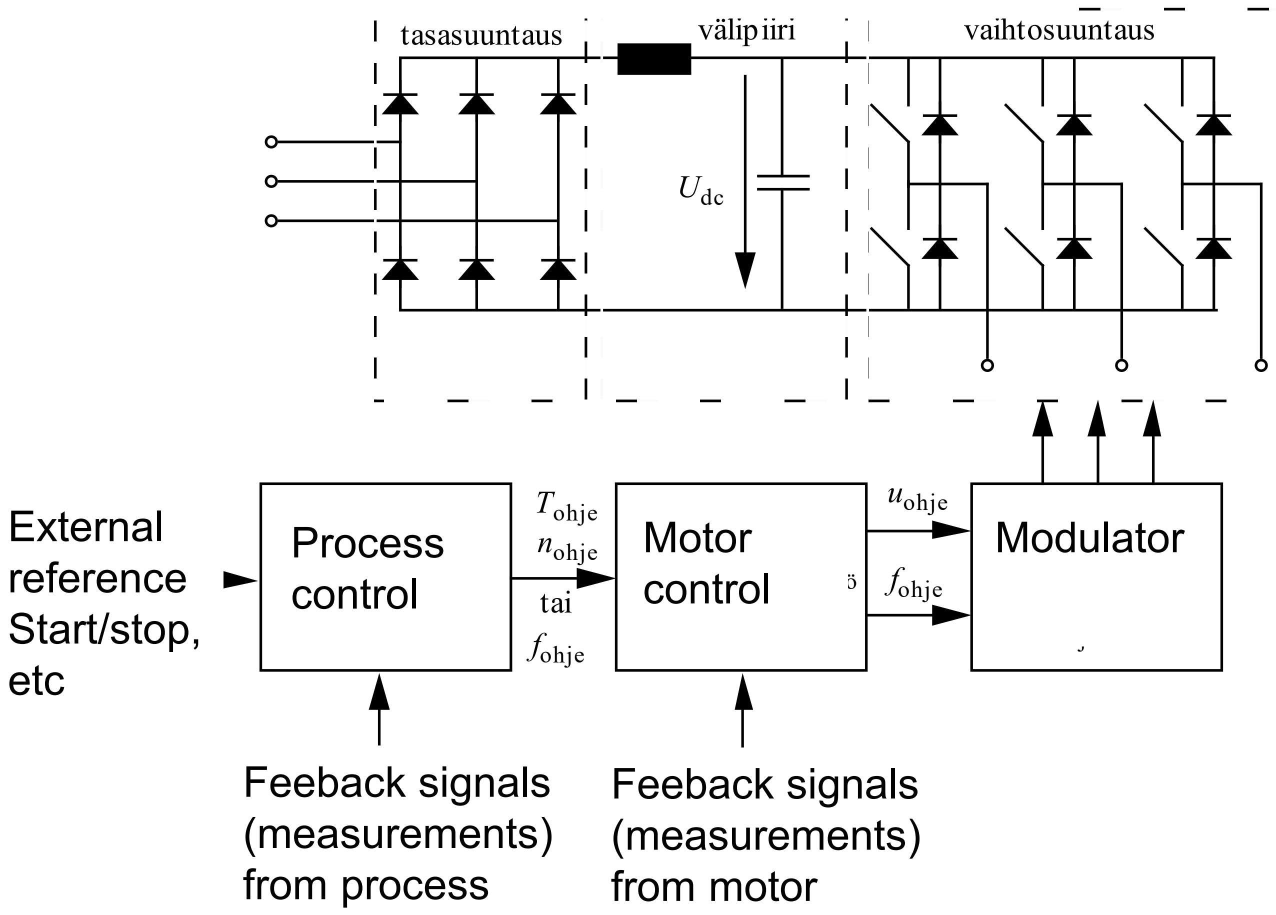


Fig. 7.36

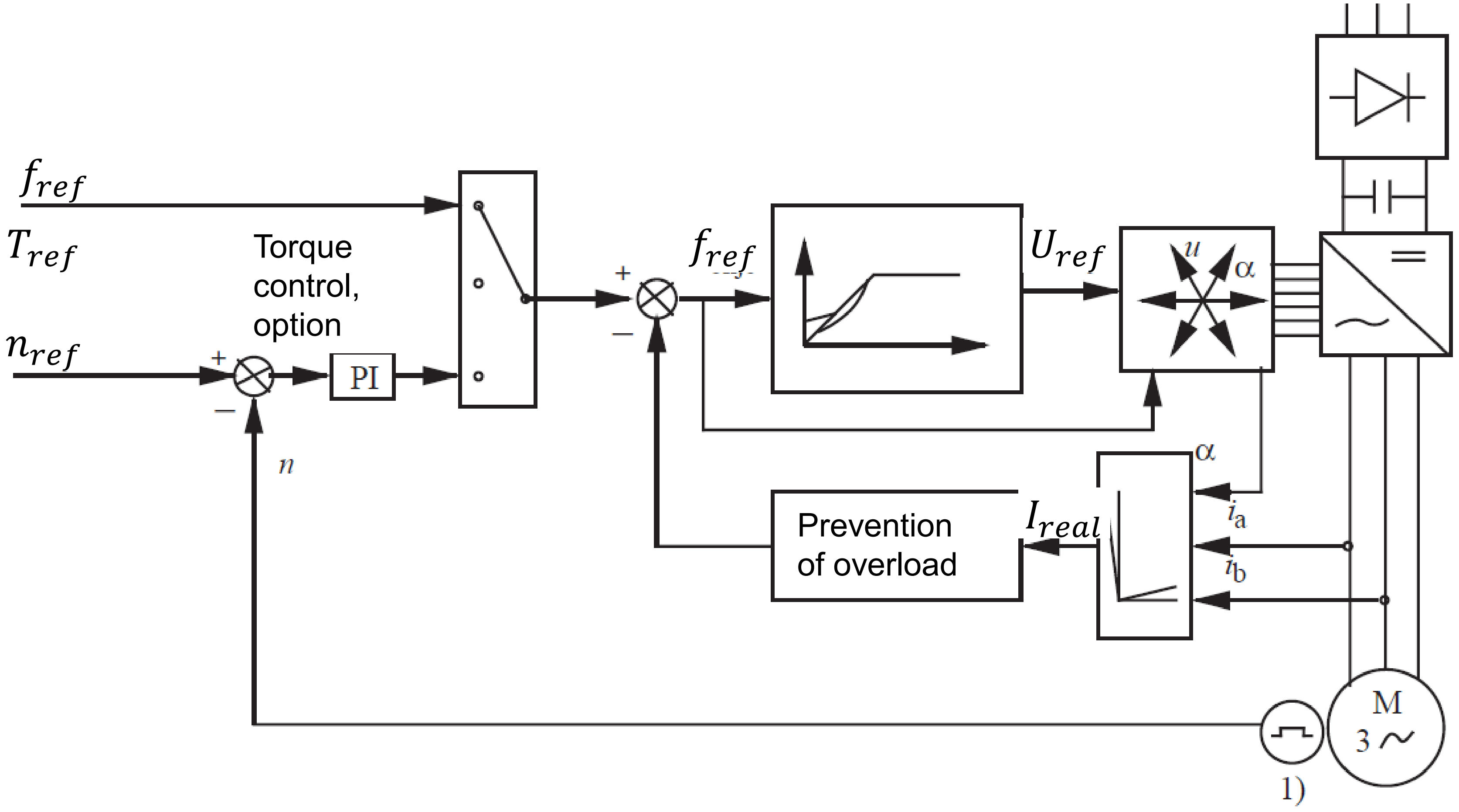
Control methods of VSI supplied induction machines

- Modulator
  - PWM based eg. on comparisons or space vectors
  - Reference comes from outer motor control
    - Scalar control
    - Vector control
- Direct Torque Control
  - Combines both motor control and modulator



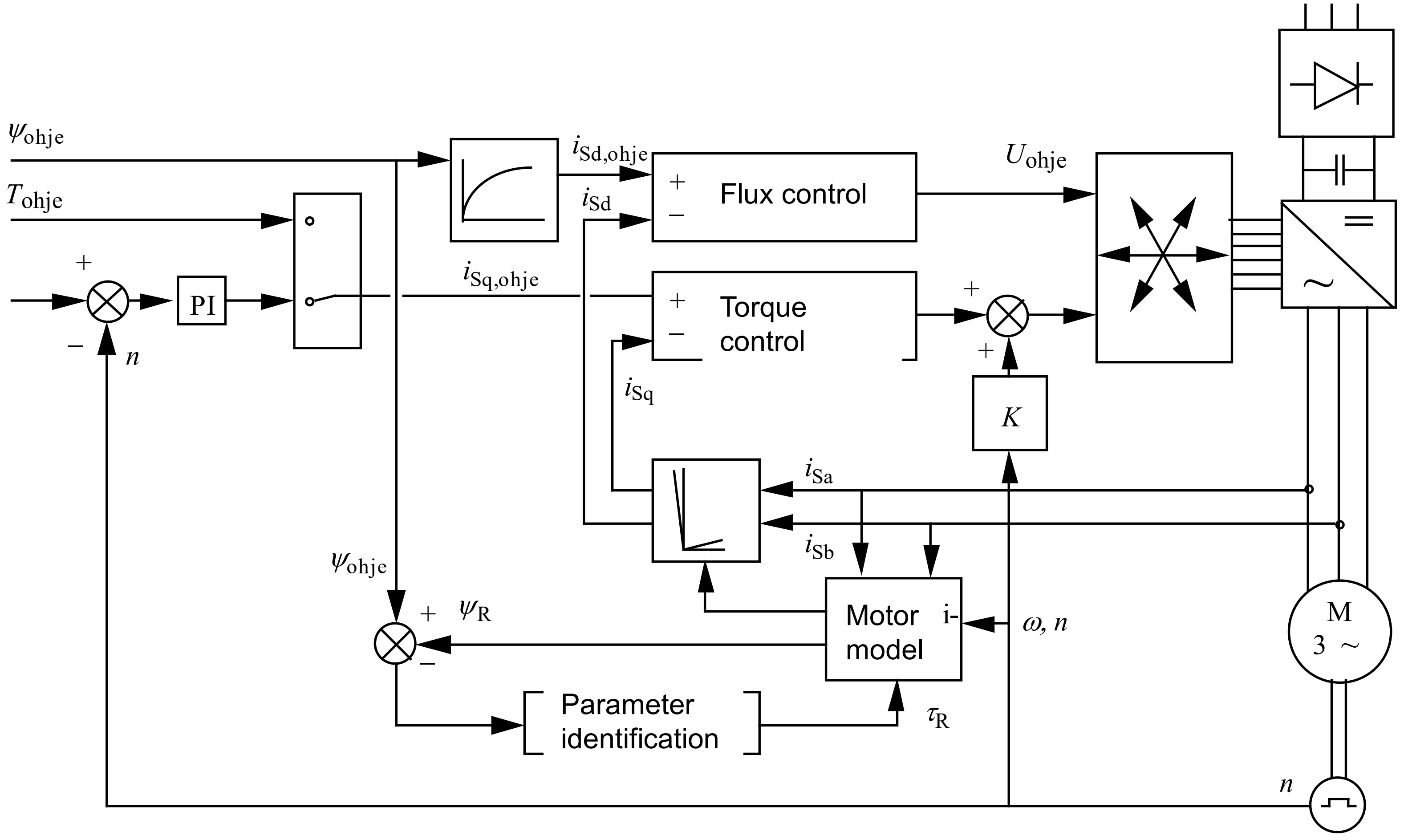
Scalar control

- Motor is controlled by changing supply frequency
- Voltage is increased simultaneus to keep flux constant
  - Modulator gets both voltage amlitude and frequency reference
- Motor current depends on the load (slip of the machine), frequency change is limited to avoid overload



Vector control

- More accurate motor model
- Controls separately flux and torque of the machine
- Modulator receives reference (ohje) to amplitude and frequency of voltage

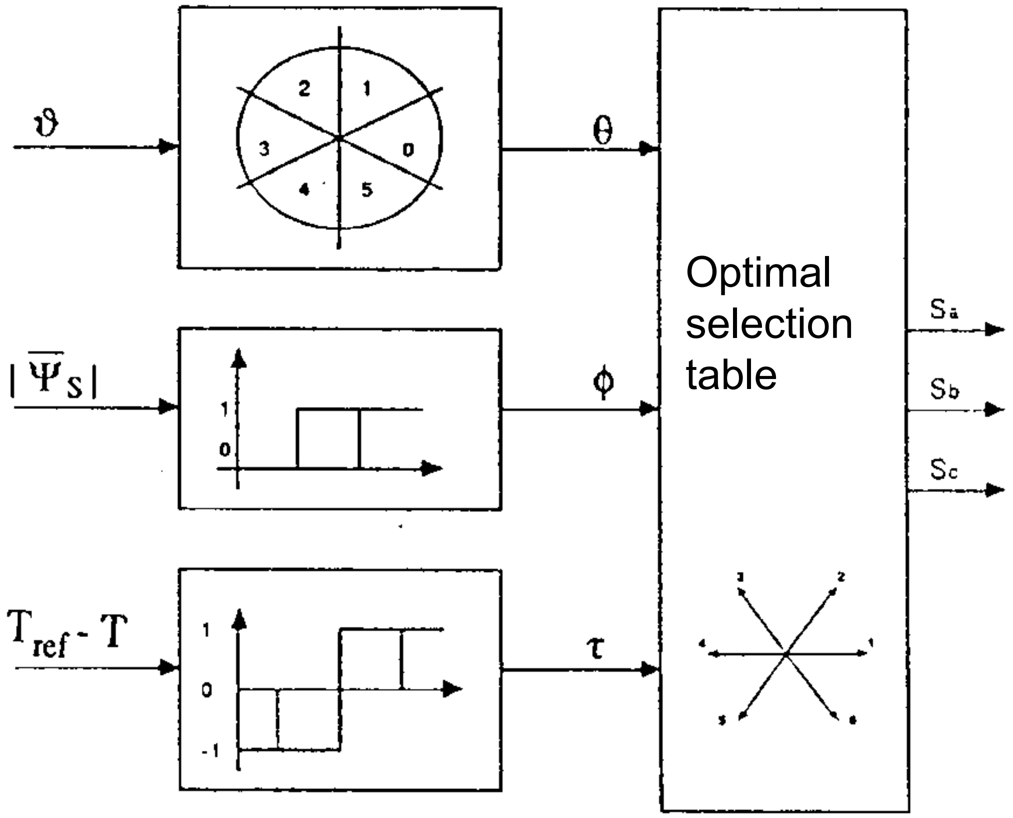


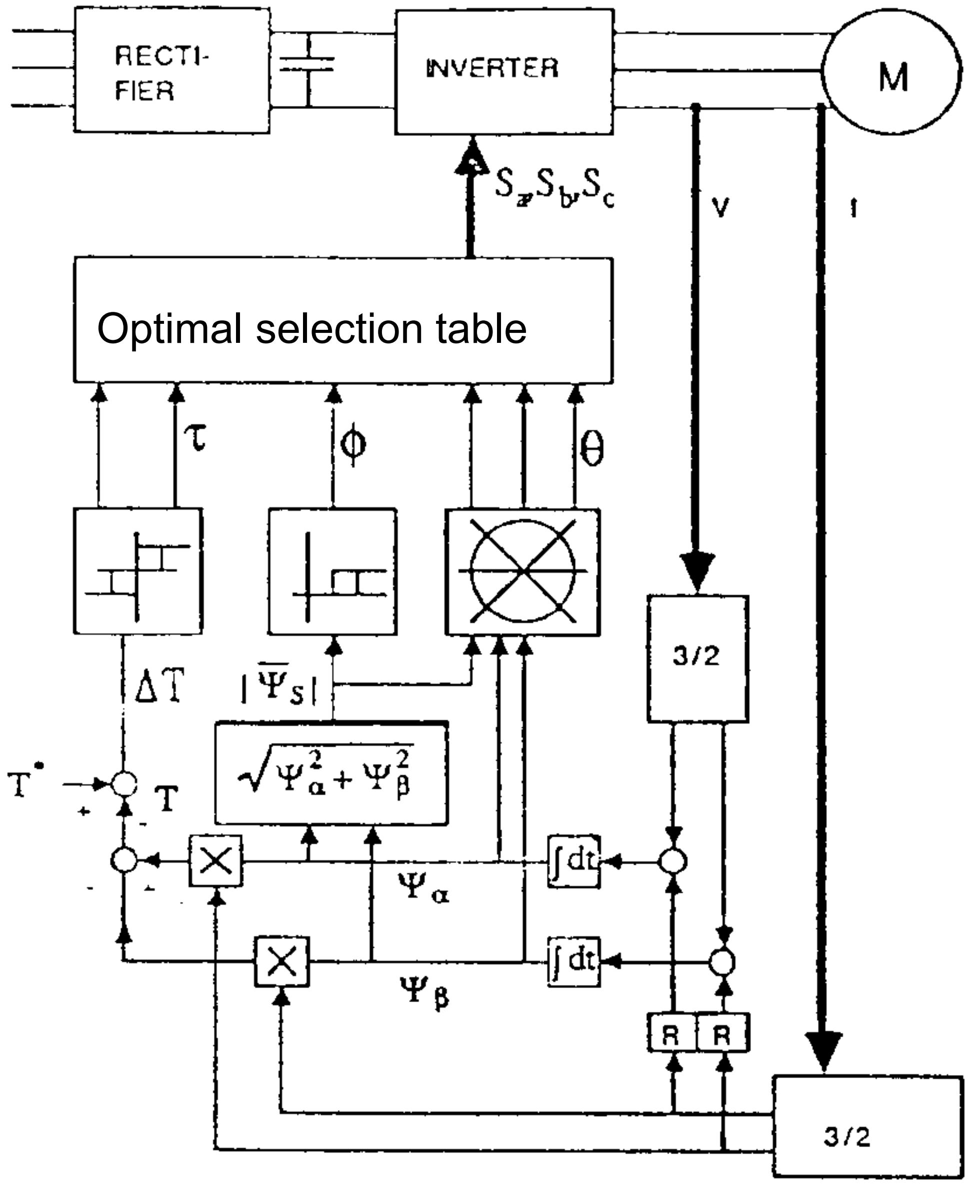
Note: Here d and q are referring to current components in the rotor coordinate system and not in stator as the textbook dose

Direct Torque Control, DTC

- Flux vector and torque are controlled simultaneously with hysteresis control
- Suitable voltage vector changing flux and torque in correct way is selected => separate modulator is not needed
- Optimal selection table selects the correct voltage space-vector to control torque and motor flux, to keep them within hysteris band

Block diagram of DTC





Multilevel converters

Two-level vs. multilevel converters

- In previous dc-ac converters we had a dc-bus with + and –
- Number of dc-stages can be increased by splitting the dc-bus into smaller dc-voltages by series connection of capacitors
- Voltage stresses over components is reduced
- Quality of output voltage is increased, more steps

Three-level neutral-clamped inverter
(Note: most often used name is Neutral Point Clamped inverter, NPC

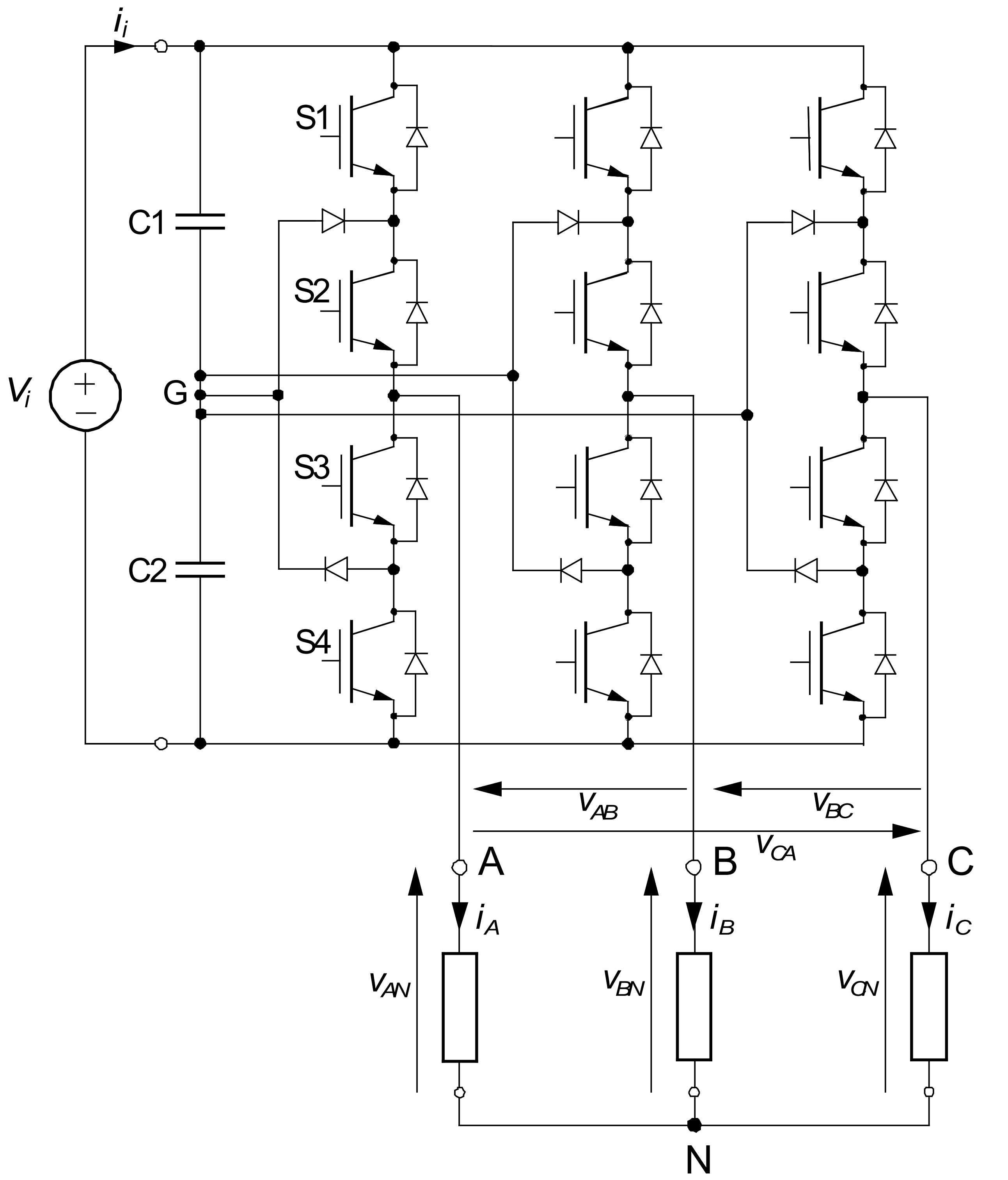


Fig. 7.54

States, switching variables, and waveforms of output voltages in a three-level neutral-clamped inverter in the square-wave mode

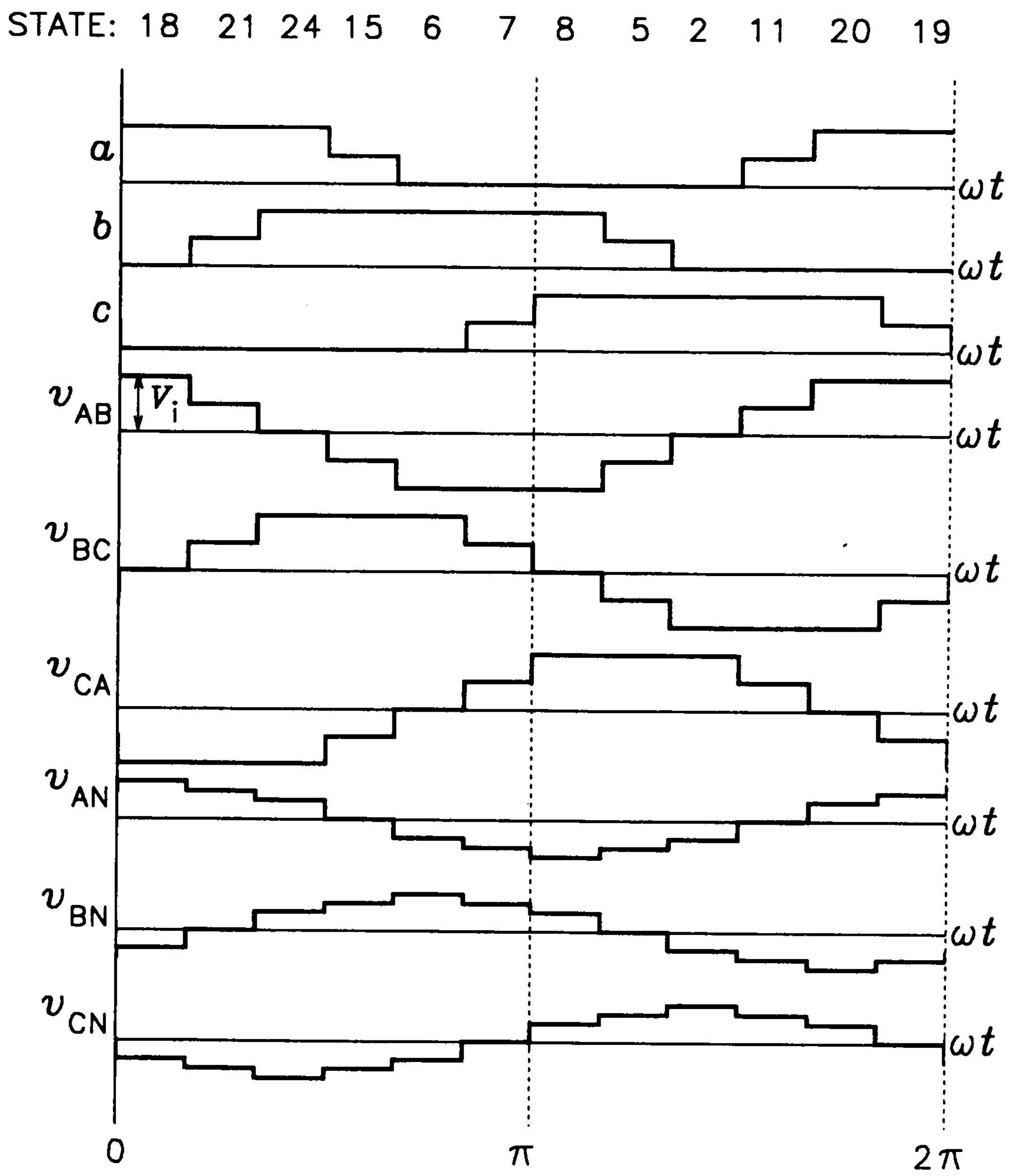


Fig. 7.56

Waveforms of output voltage and current
in a three-level neutral-clamped inverter
in the square-wave mode

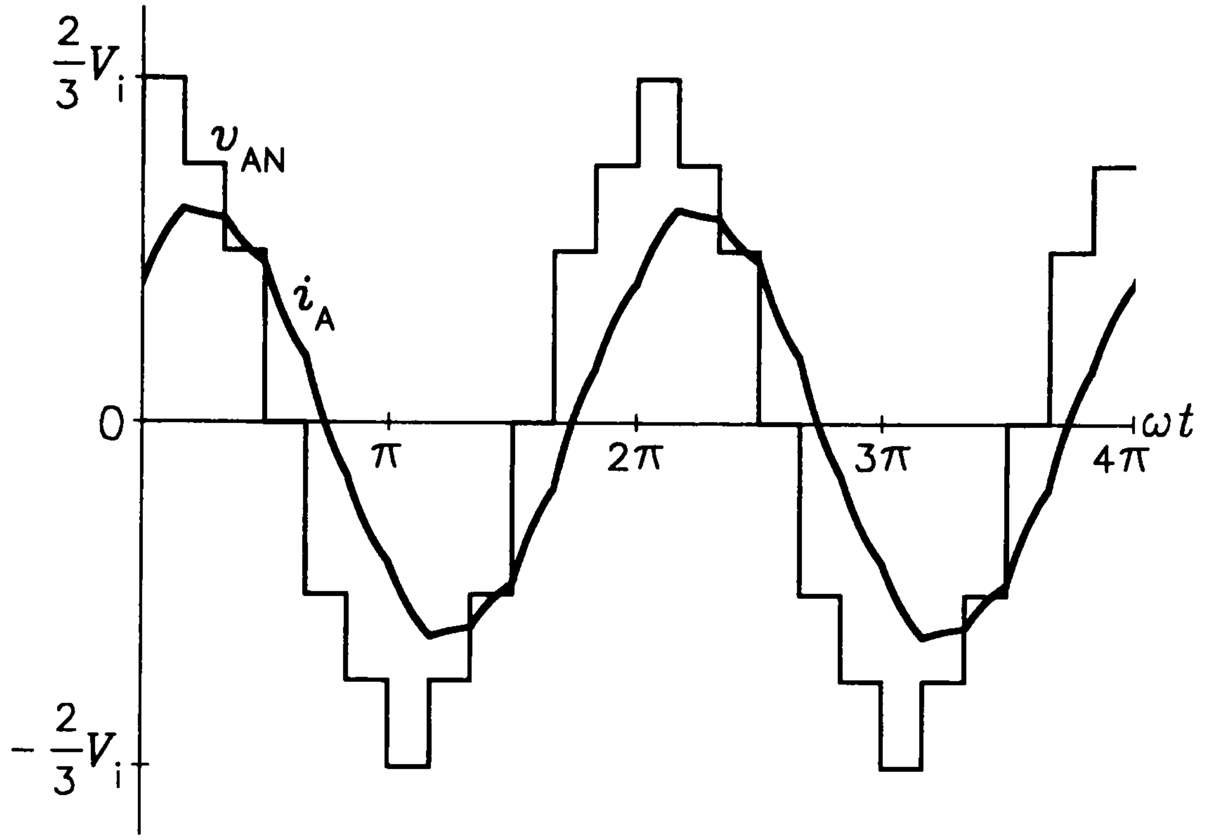
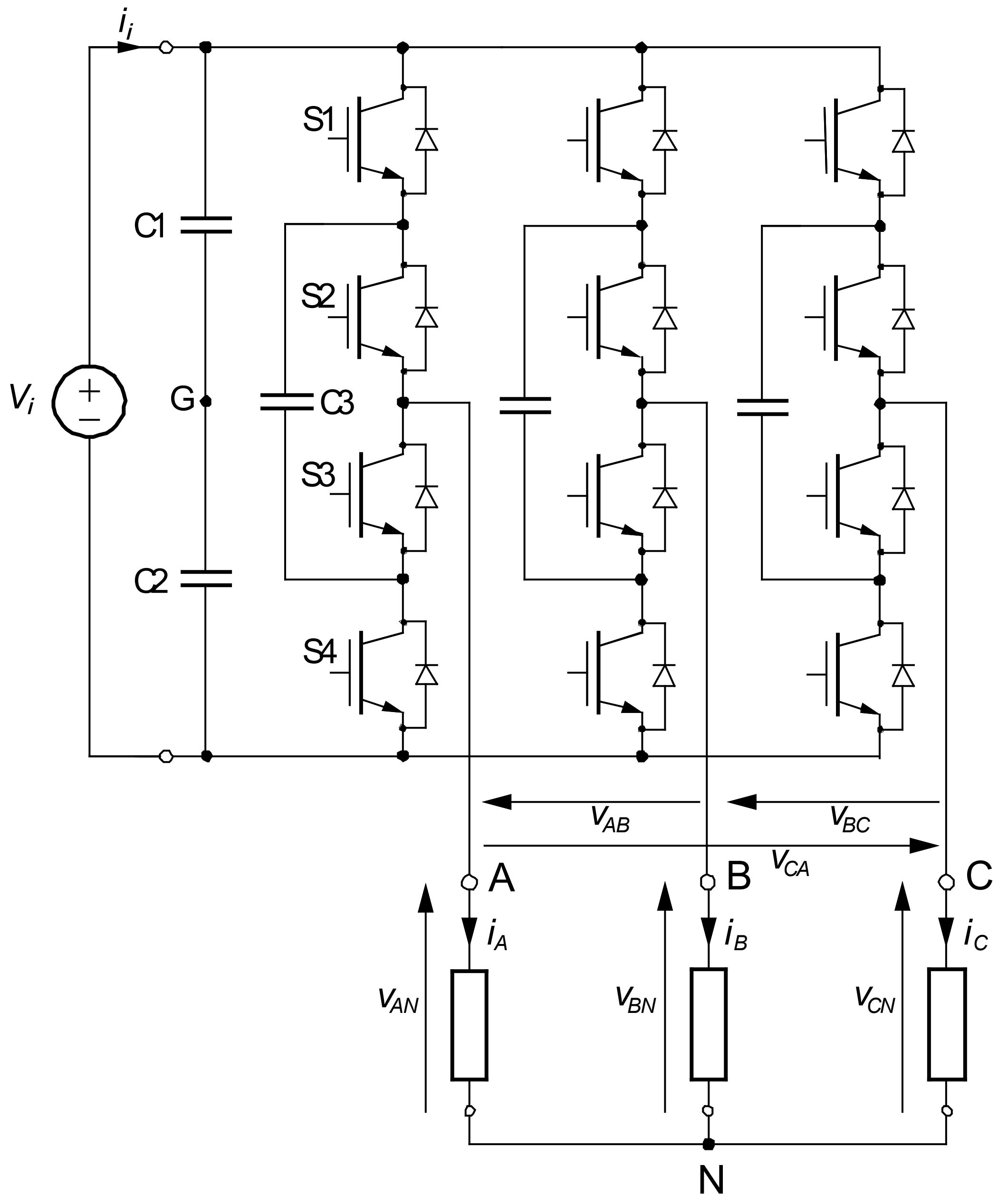


Fig. 7.57

Three-level flying-capacitor inverter



$$a = \begin{cases} 0 & if\ S3\&S4\ are\ ON \\ 1 & if\ S1\&S3\ or\ S2\&S4\ are\ ON \\ 2 & if\ S1\&S2\ are\ ON \end{cases}$$

Fig. 7.58

Cascaded H-bridge inverter:
(a) block diagram, (b) constituent bridge
(Note; often called Modular Multilevel Converter , MMC)

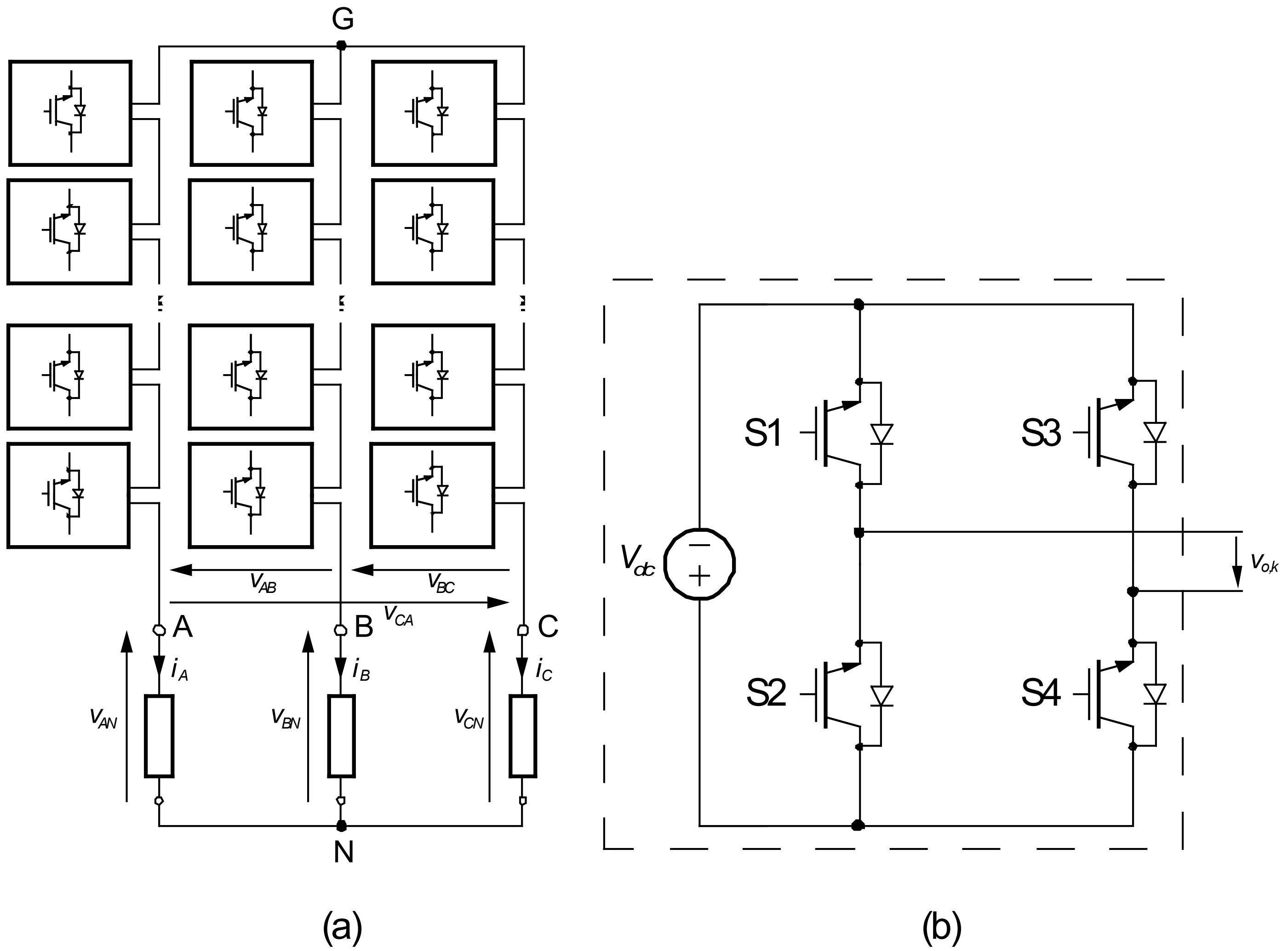


Fig. 7.59

Approximation of a sinewave by a stepped waveform in the H-bridge cascaded inverter

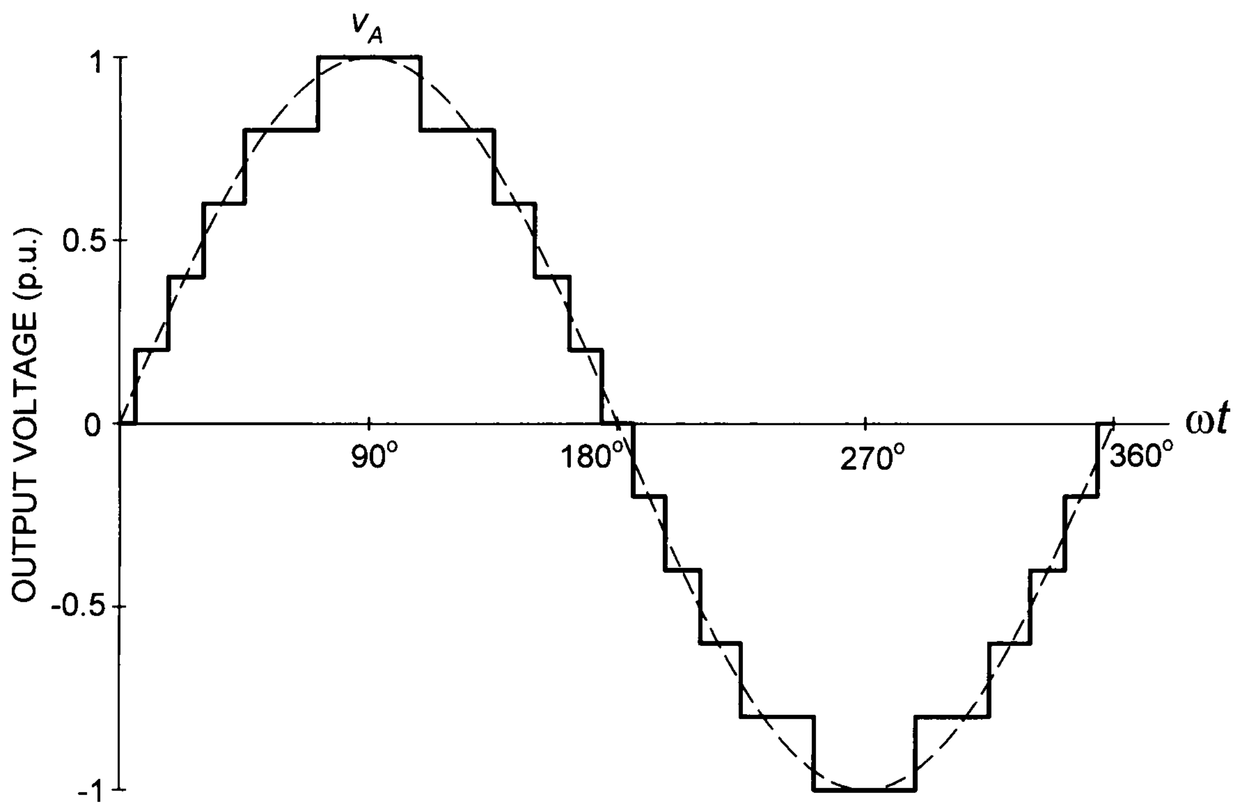


Fig. 7.60

PWM rectifier-inverter cascades for bidirectional power flow in ac motor drives:

(a) current-type rectifier, inductive dc link, and current-source inverter,
(b) voltage-type-rectifier, capacitive dc link, and voltage-source inverter

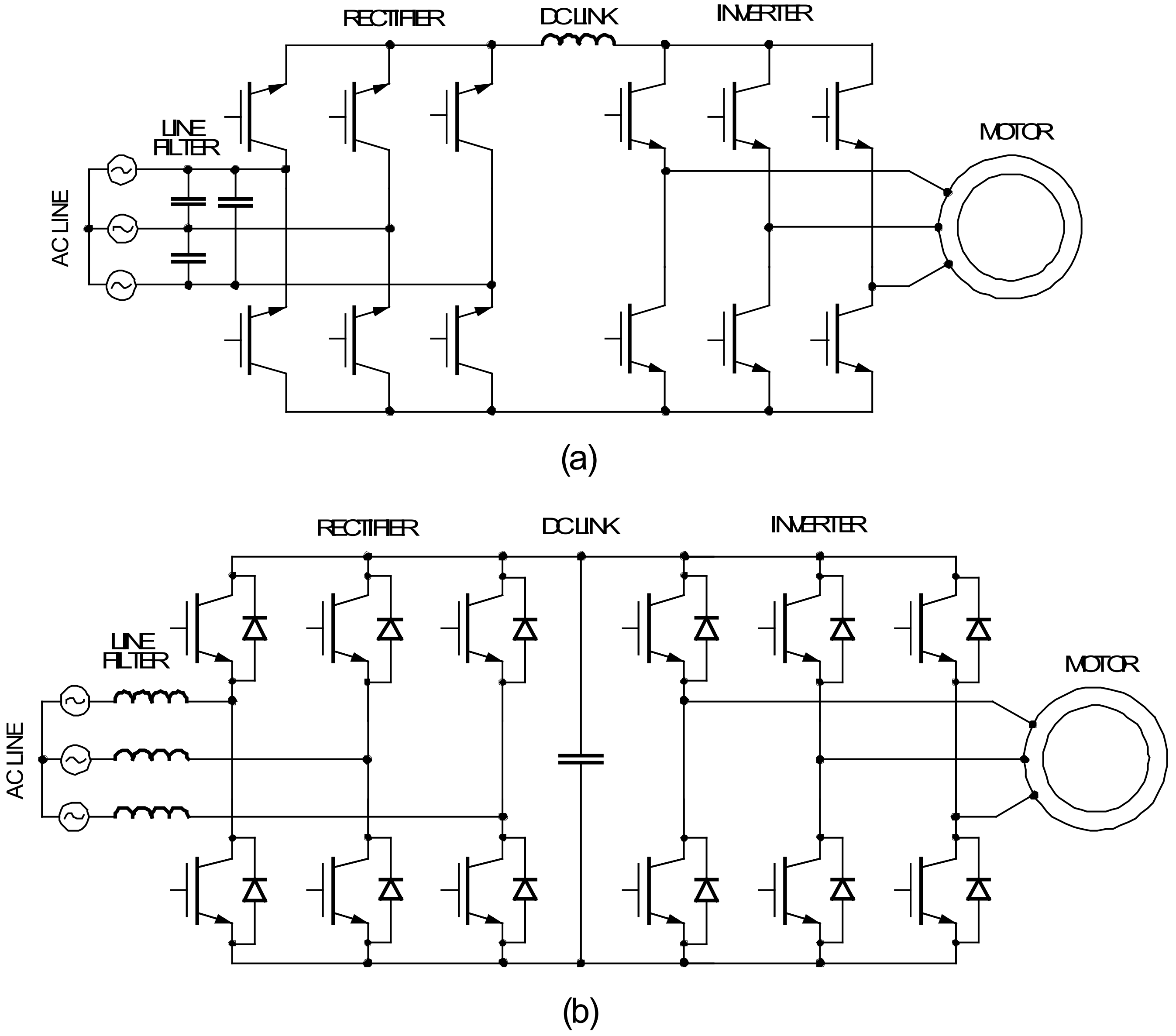


Fig. 7.76

Voltage-type PWM rectifier

- Power stage is the same as in a voltage-sourced dc-ac inverter
- Input side requires inductors and output has dc capacitor
  - Sometimes called boost PWM recitifier, operating principle is similar to a boost converter
  - Output voltage must be higher than the peak of input line-to-line voltage, otherwise diodes are conducting
- Output voltage cannot change polarity, but output current can
  - Power can flow in both directions
- Animation of a single-phase PWM rectifier

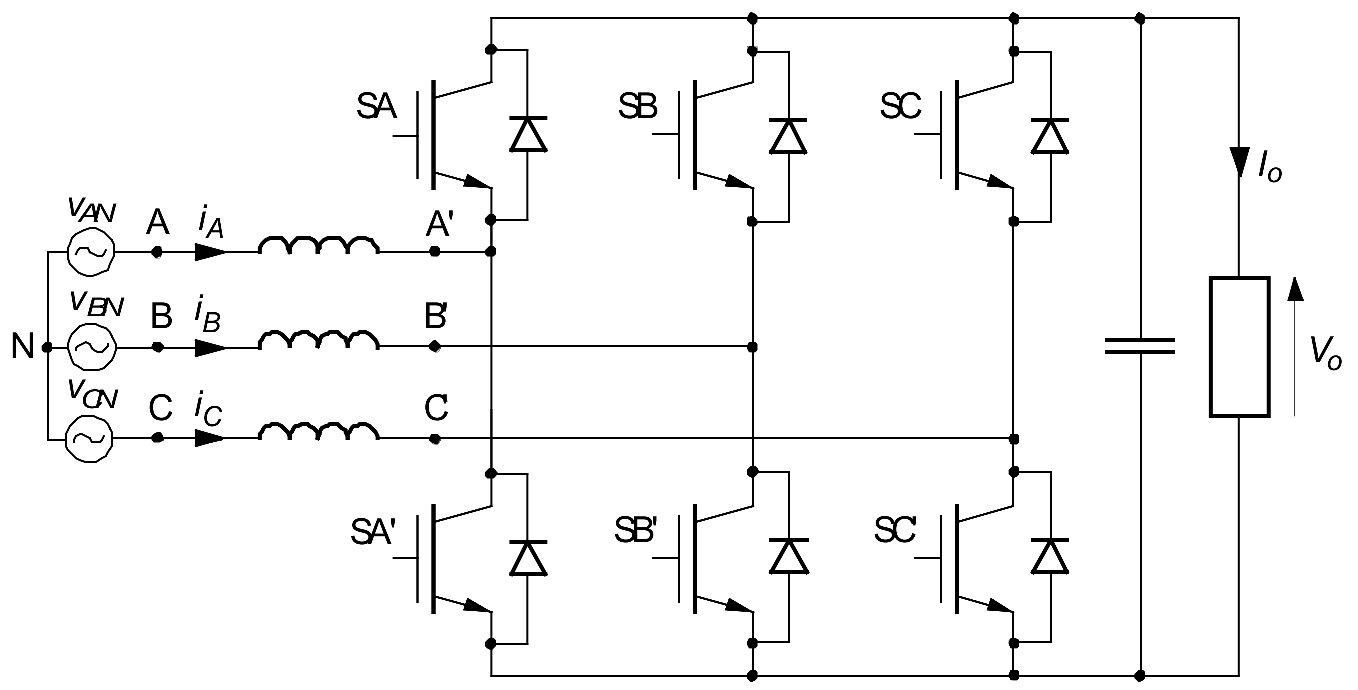


Fig. 4.53

Phase A branch of a voltage-type PWM rectifier

- One phase-leg of the converter is such that every input phase can be connected to the plus or minus of the dc-bus with both polarities of the current
- SA and SA’ must not be turned on simultaneously
  - this would short-circuit the dc-bus
- SA and SA’ can be turned off simultaneously
  - But then current polarity decides is the input phase connected to plus or minus
  - This time is also called often as dead-time and it causes nonlinearity in the modulation
  - Output voltage is not following the reference => if used it must be as short as possible or compensated

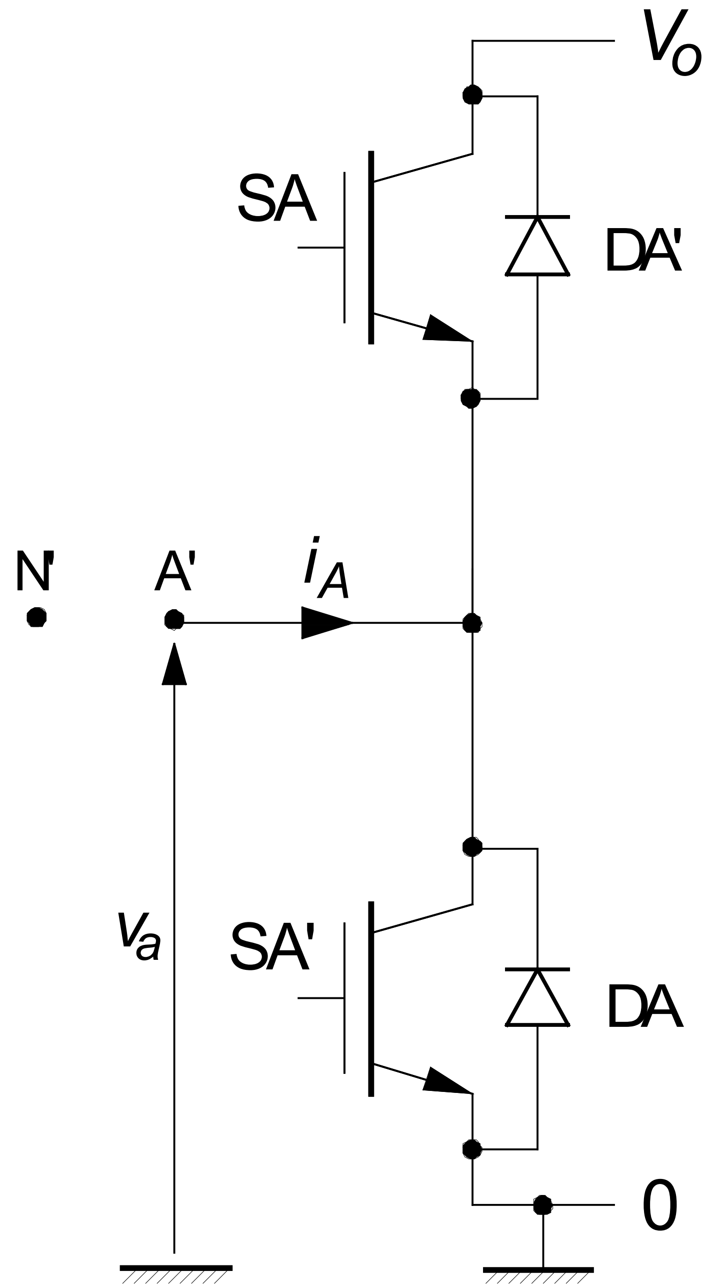


Fig. 4.54

Only two states of the rectifier branch can be allowed: SA = ON and SA' = OFF, or SA = OFF and SA' = ON. Thus, a single switching variable, *a*, defined as

$$a = \begin{cases} 0 \; if \; SA = OFF \; \& \; SA' = ON \\ 1 \; if \; SA = ON \; \& \; SA' = OFF \end{cases}$$

is sufficient to describe the state of the branch. Similarly defined switching variables *b* and *c* apply to the other two branches of the rectifier. Terminal voltages are given by

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = V_o \begin{bmatrix} a \\ b \\ c \end{bmatrix}.$$

Consequently,

$$\begin{bmatrix} v_{ab} \\ v_{bc} \\ v_{ca} \end{bmatrix} = V_o \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix}$$

and

$$\begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} = \frac{V_o}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix}.$$

Input-voltage space-vector of a voltage-type PWM rectifier

- Space-vectors of the converter are the same as in voltage-sourced inverter
- There are six non-zero vectors and two zero vectors when all switches are connected to the plus or minus simultaneously

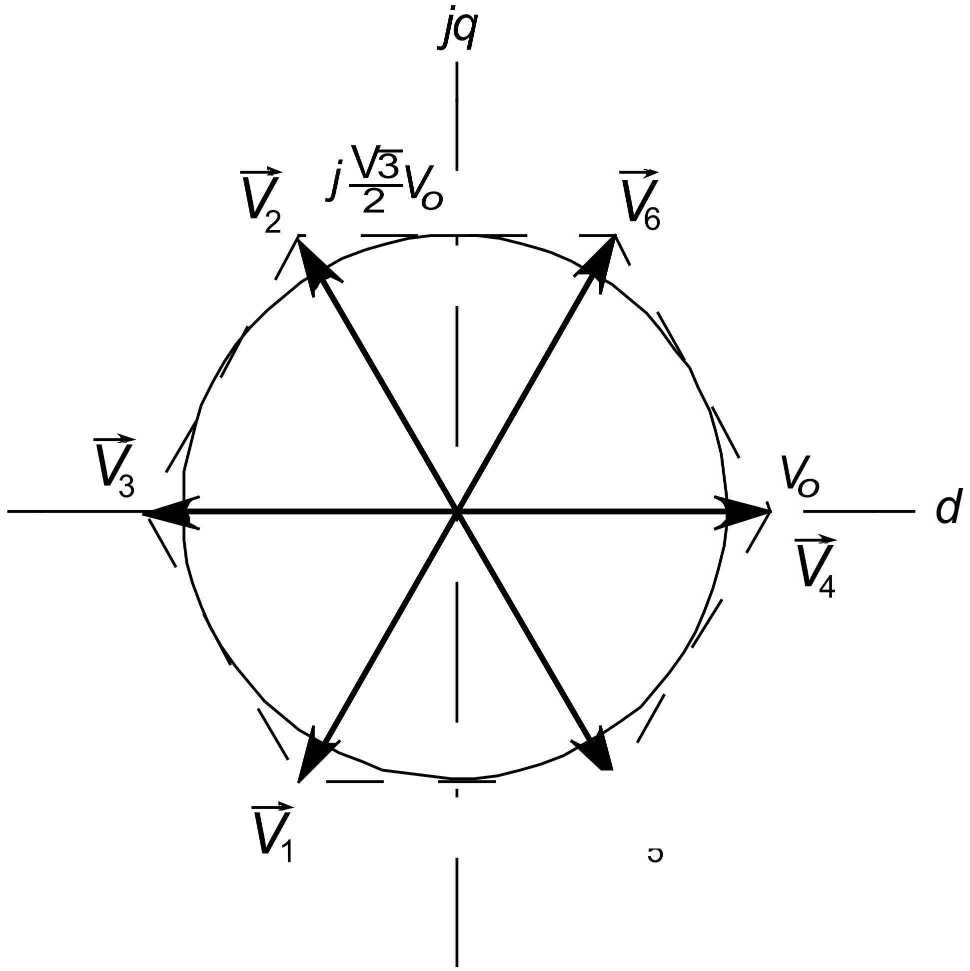


Fig. 4.55

(b)

Reference voltage vector in the vector space of line-to-neutral input voltages of a voltage-type PWM rectifier

- SVPWM, Space-vector pulse width modulation
- Durations of states X and Y, framing a sector in which the reference current vector is currently located are given by the same equations as in current-type

$$T_X = mT_{sw}\sin(60^{o} - \alpha)$$

$$T_Y = mT_{sw}\sin(\alpha)$$

- and the duration of a zero-vector state Z by

$$T_Z = T_{sw} - T_X - T_Y$$

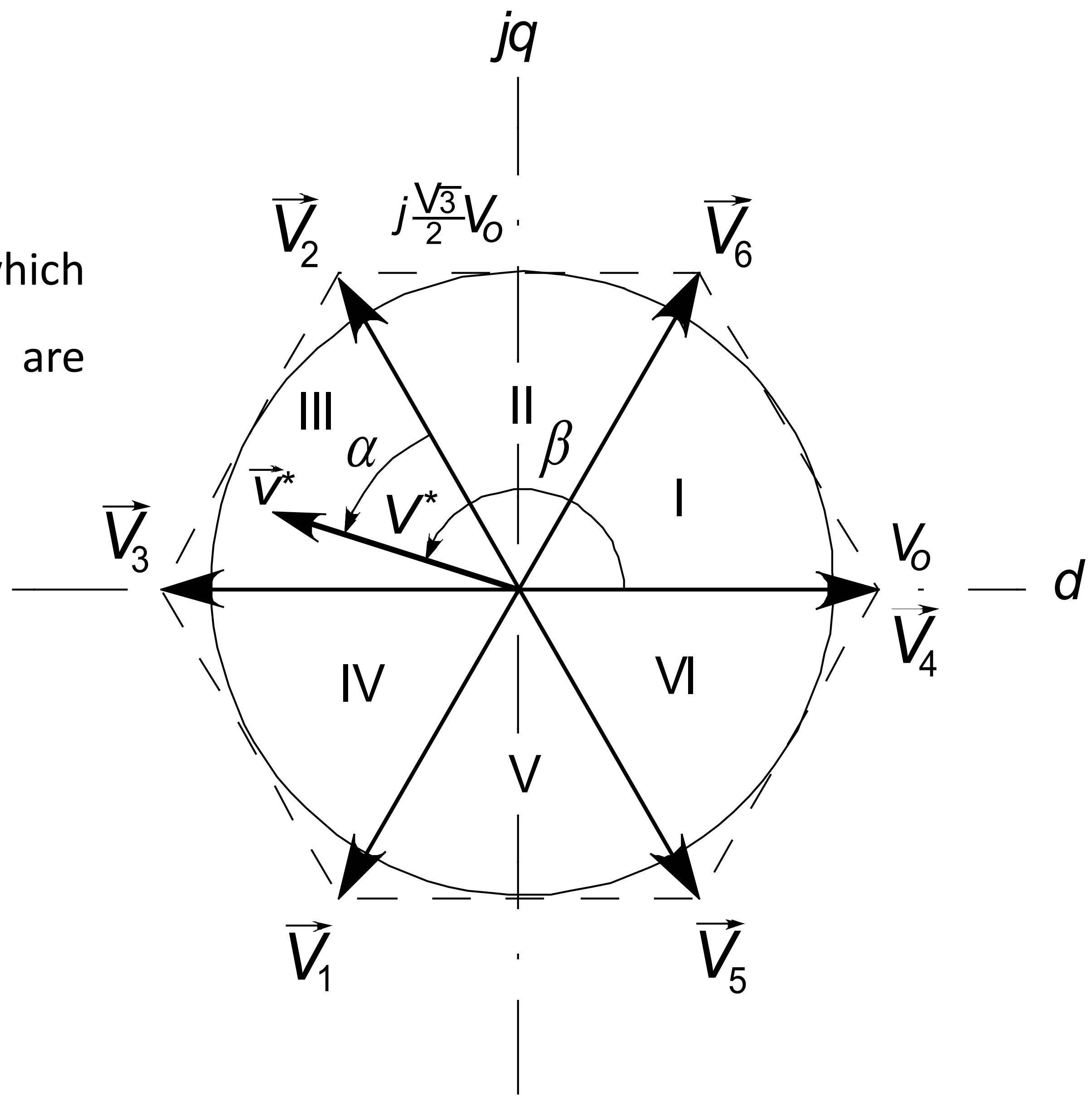
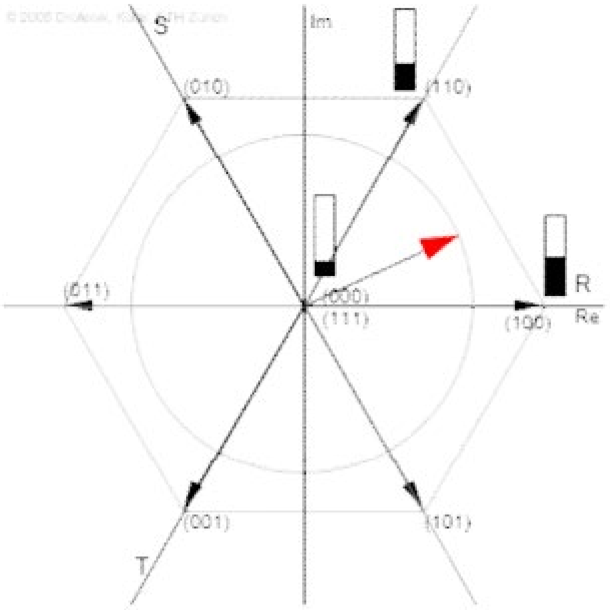


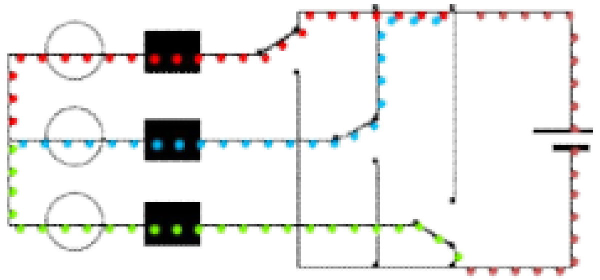
Fig. 4.56

Space vector animation

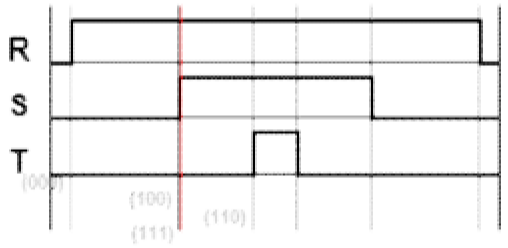
- PWM with space vectors is demonstrated with this animation
  - White/black bars in the animation are demonstrating the relative on time of different space vectors, i.e. they are based on the equations shown in the previous slide
  - When amplitude is increased, black part increases and use of zero vector is reduced
- Fig. b) shows the position of the switches
- Fig. c) shows the status of the switches in time domain within two consecutive time intervals ΔT
  - E.g in sector I, $0 < \alpha < 60$, sequence is 000, 110, 111 and then the same reversed i.e. 111, 110, 000 to reduce switching frequency
- Fig. d) shows the ideal output voltage



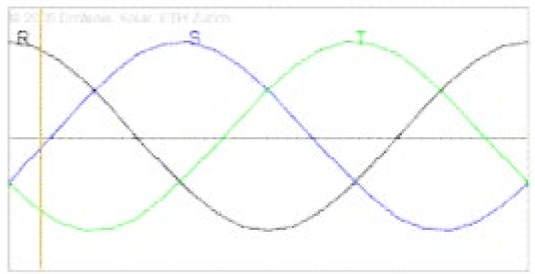
a)



b)



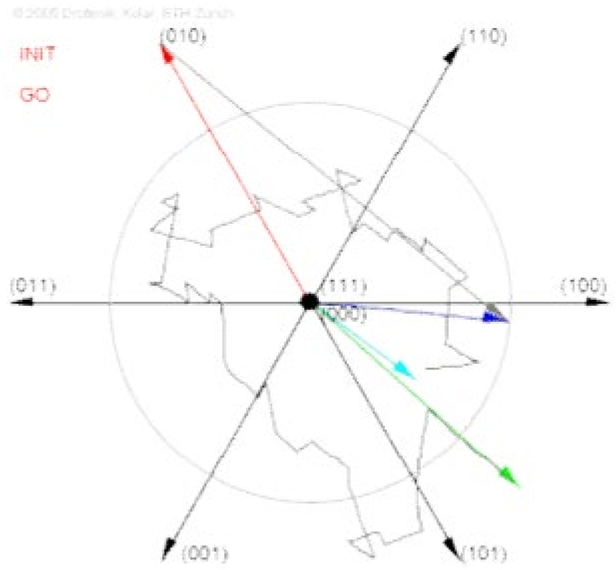
c)

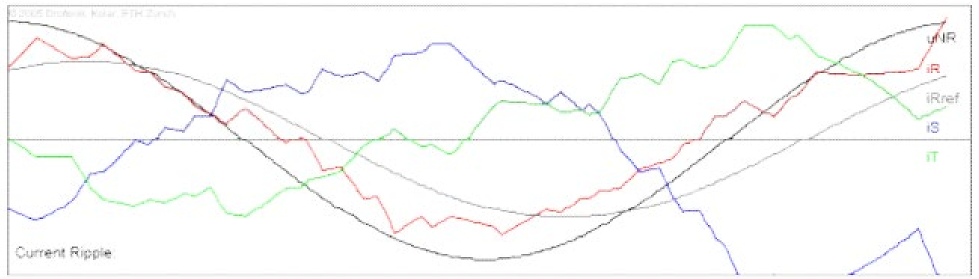


d)

Current based modulation

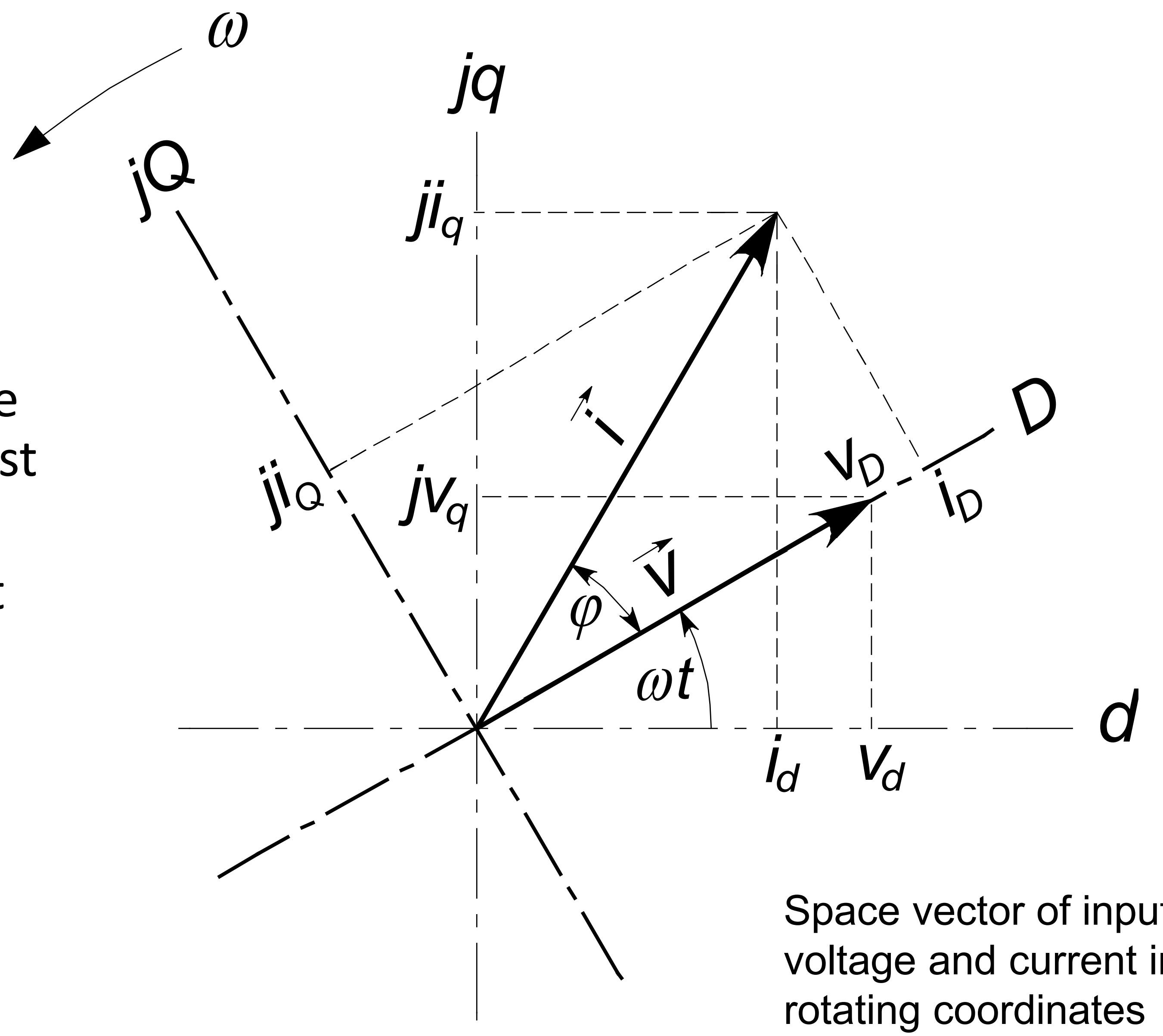
- You can try to use this current vector-based modulation animation
- Here PWM is not based on equations as before, the target is to select the correct voltage vector so that real current moves into the direction of the reference
  - Bang-bang or hysteresis type control where switching frequency is not constant
  - It will take a moment before you realize how to do this (not so successful in the attached figure ☺)
- Note that the ac system is creating
  - An ideal voltage vector
  - By selecting a proper vector of the converter, you are imposing a voltage difference (also space vector) over the line inductance
  - It is this voltage difference that drives the change in the current





Principle of voltage-oriented control of a voltage-type PWM rectifier

- For unity power factor voltage and current space-vectors must be aligned
- Because of this Q-component of current must be forced to zero



Space vector of input voltage and current in rotating coordinates

Fig. 4.57

Voltage-oriented control system of the voltage-type PWM rectifier

Reference for Q-component of current is zero

- reactive power is zero

Outter control loop is for the dc-voltage

- target is to keep it in the reference value

Decreasing dc-voltage means

- there is not enough power taken from the ac-supply
- => i_D increase

Increasing dc-voltage

- reduces i_D
- i_D even negative if needed => power flow is to the ac system

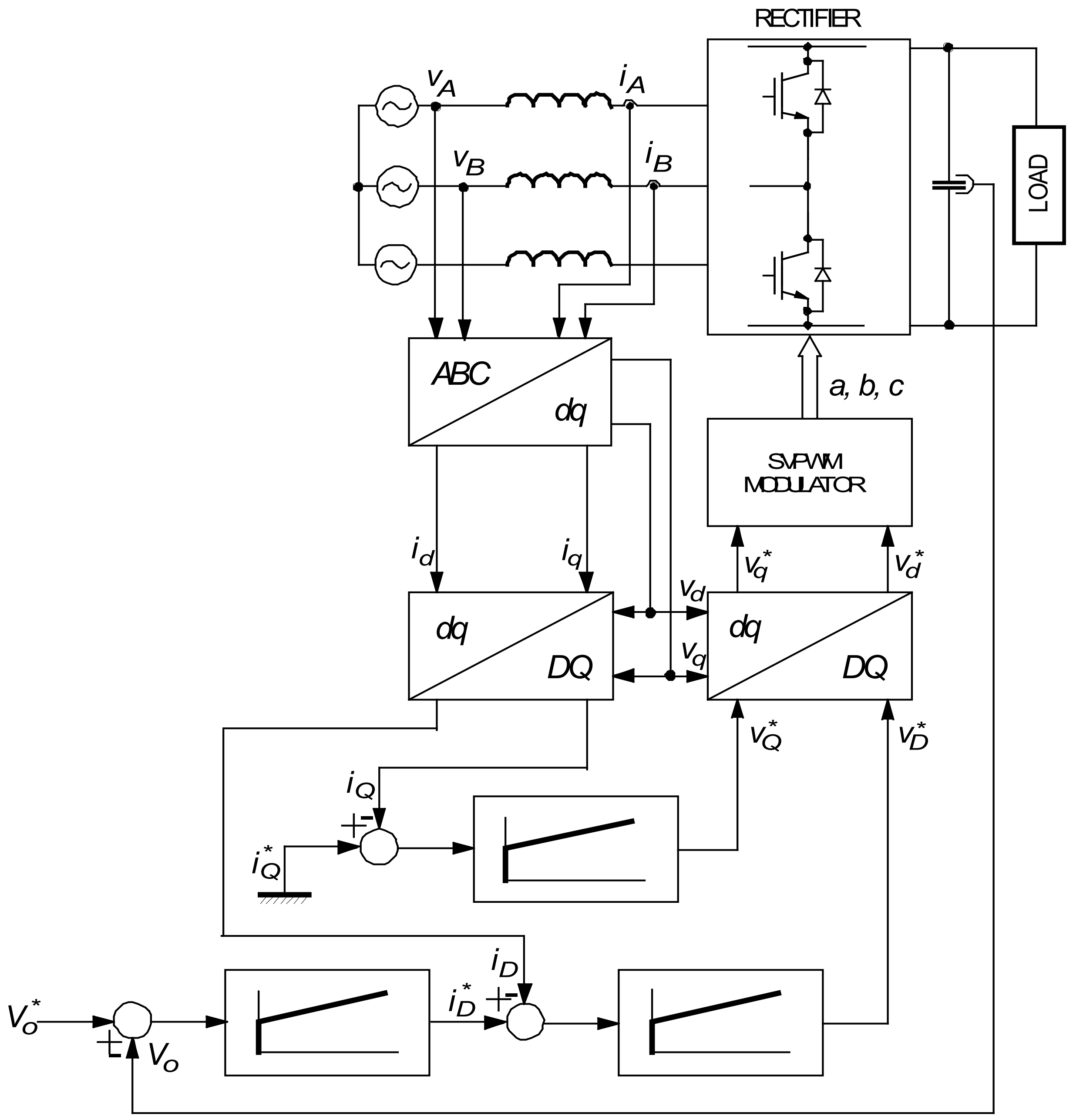


Fig. 4.58

Waveforms of input voltage and current in a voltage-type PWM rectifier at unity power factor

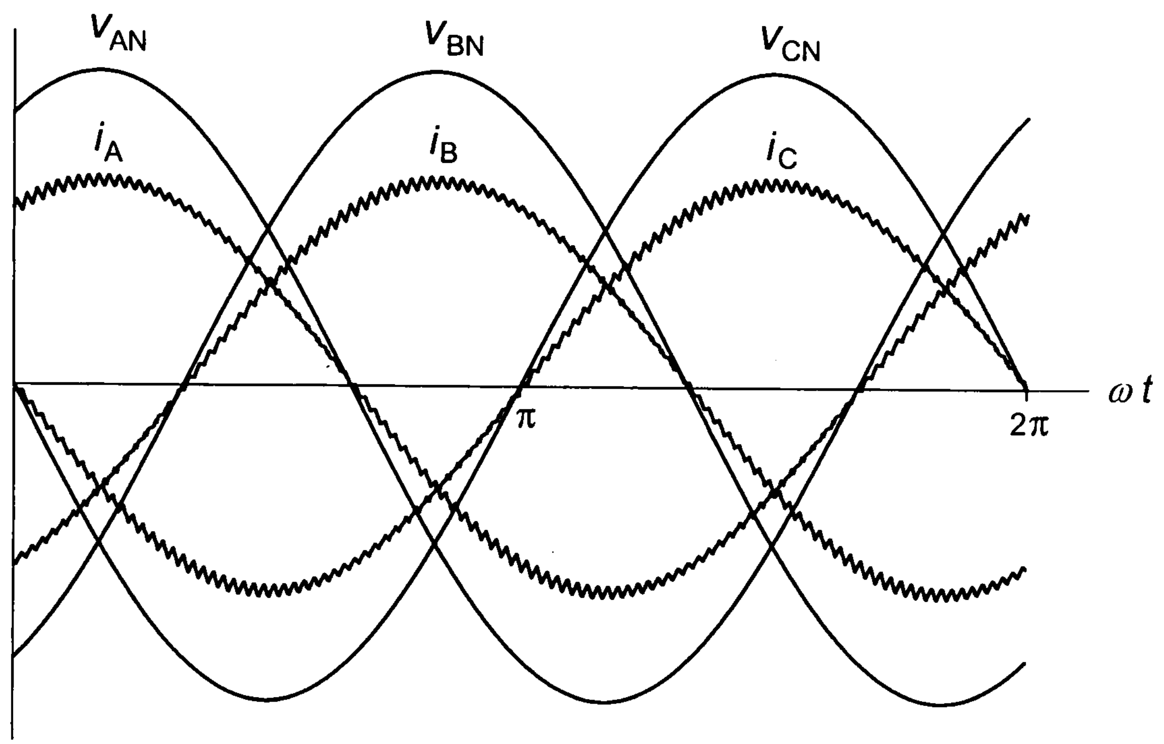


Fig. 4.60

Waveforms of output voltage and current in a voltage-type PWM rectifier

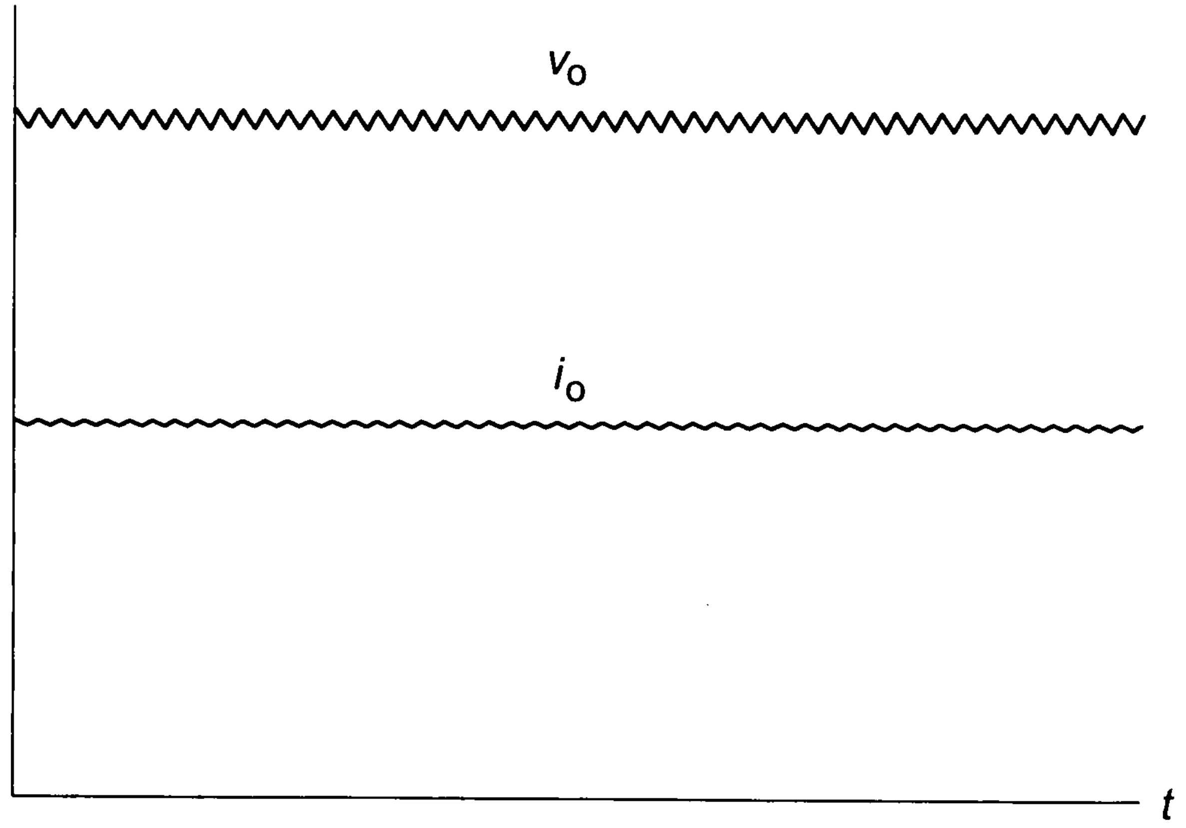


Fig. 4.61

Vienna Rectifier I

- Three-level converter
  - Power is only from ac to dc
  - Eeach phase can be connected to +, midpoint and –
- Advantages
  - Quality of output voltage can be increased
  - Voltage stresses of power semiconductor devices is only half of dc
- Originally proposed by Johann Kolar when he was working in Vienna, Austria (nowadays at ETH Zurich)

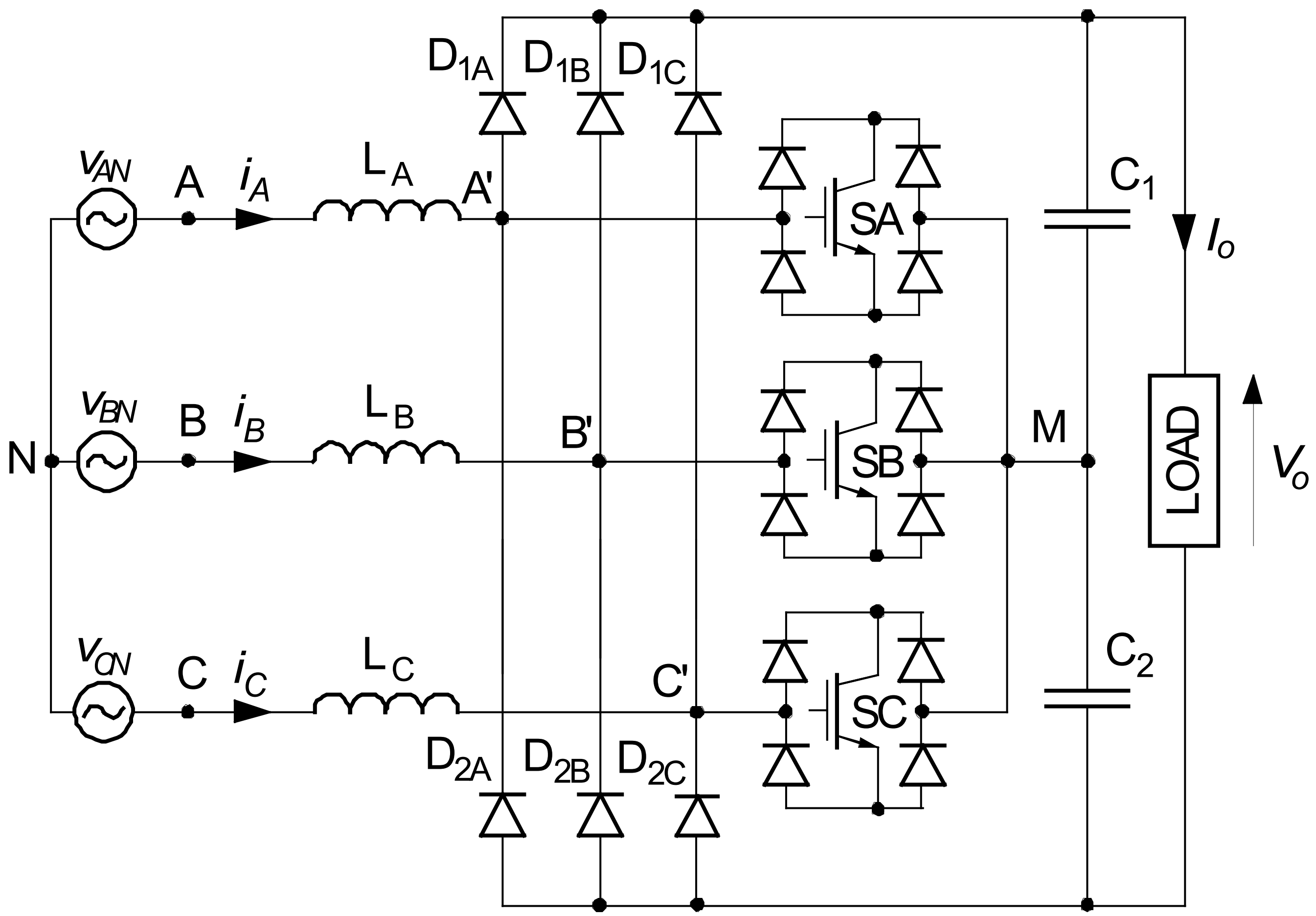


Fig. 4.62

Vienna Rectifier II

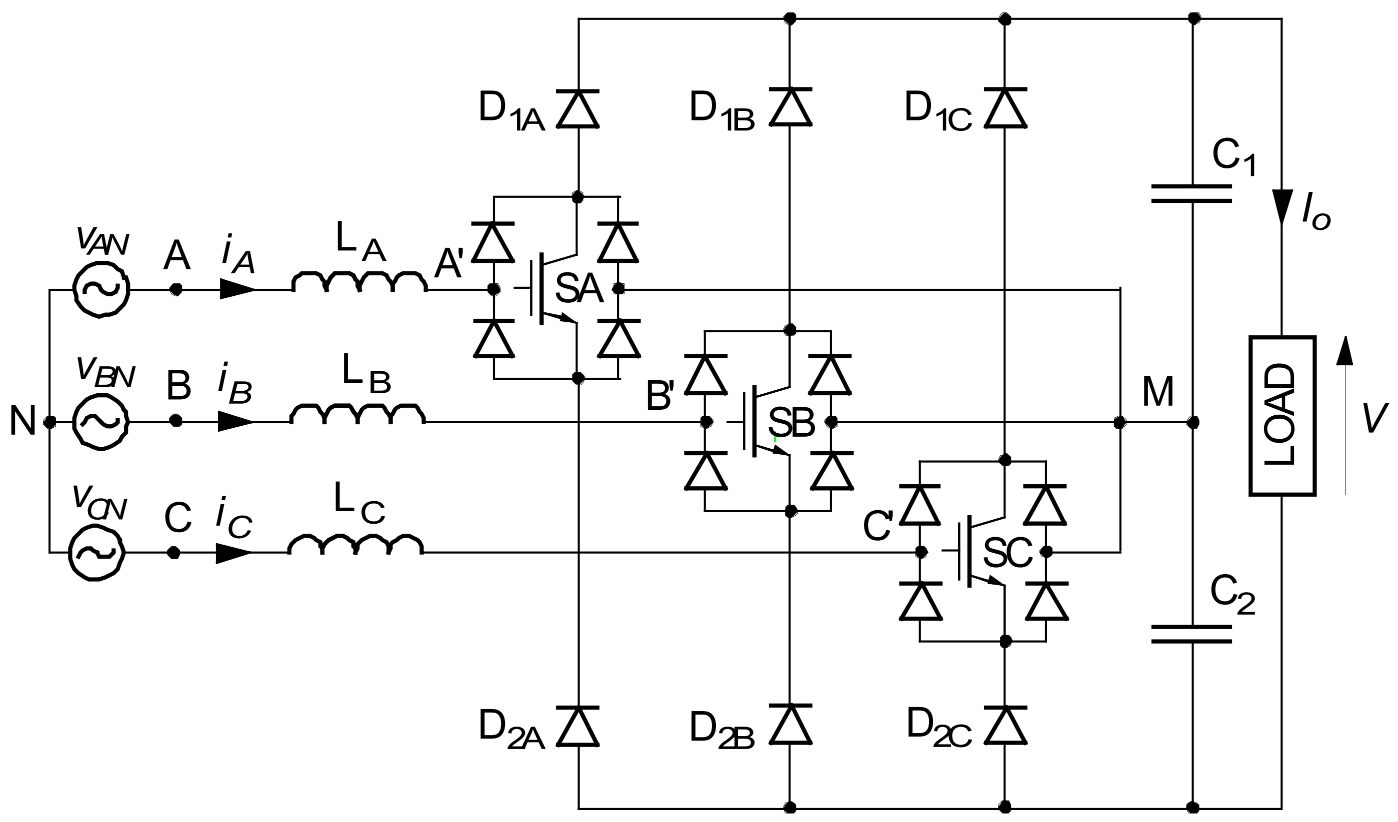


Fig. 4.65

Summary of the module

- As the name implies, Voltage Sourced Inverter, VSI, creates output voltage and it together with the impedance of the load gives the output current
- In three-phase systems, when we are adding voltages together the result is always zero. In VSI the situation is a bit different as output phases can be connected only to + or – of the dc-bus. As we are having three output phases it is impossible that the sum of these voltages is zero, thus there is so called common mode voltage.
- With Pulse Width Modulation we can simultaneously adjust the amplitude and frequency of the output voltage
    - At the same time harmonics of the voltage are reduced and quality of motor current is improved, which improves torque quality.
    - PWM can be done with phase quantities separately for each three-phases with 120 degrees phase-shift or PWM can be done with Space Vectors, and the status of all phase is achieved simultaneously
- In two-level converters we have + and – in the dc-bus. In multilevel converters the dc-bus is split, and we can achieve better output voltage quality and reduced voltage stresses for the components.