Energoelektronika

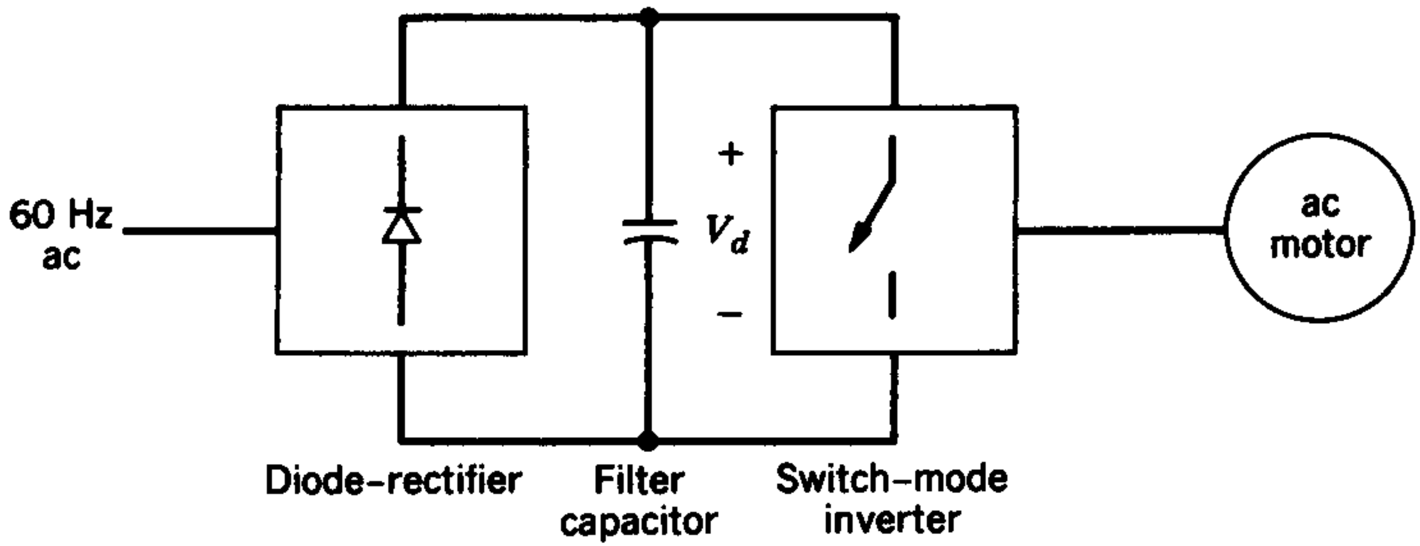
7. Switch-Mode DC- Sinusoidal AC Inverters

dr inż. Dariusz Janiszewski

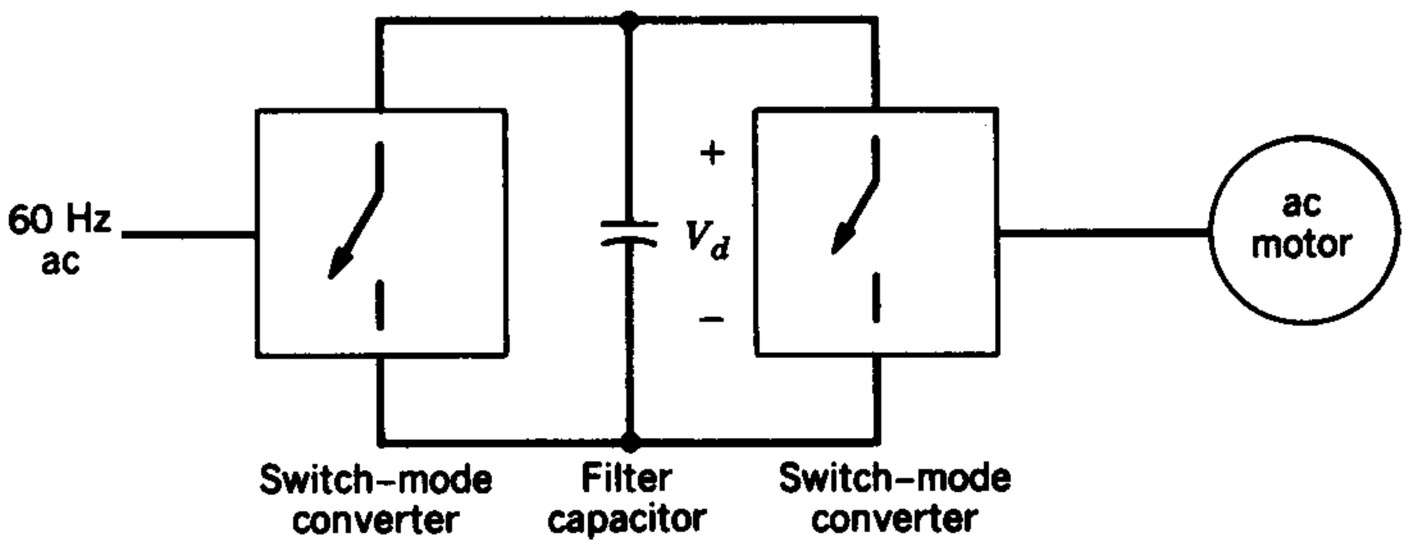
Plan

- Wprowadzenie do przetwornic DC-AC
- Koncepcja przetwornicy impulsowej – falownika
- Falownik jednofazowy
- Falownik trójfazowy
- Wpływ czasu martwego
- Inne falowniki
- Praca prostownikowa falownika

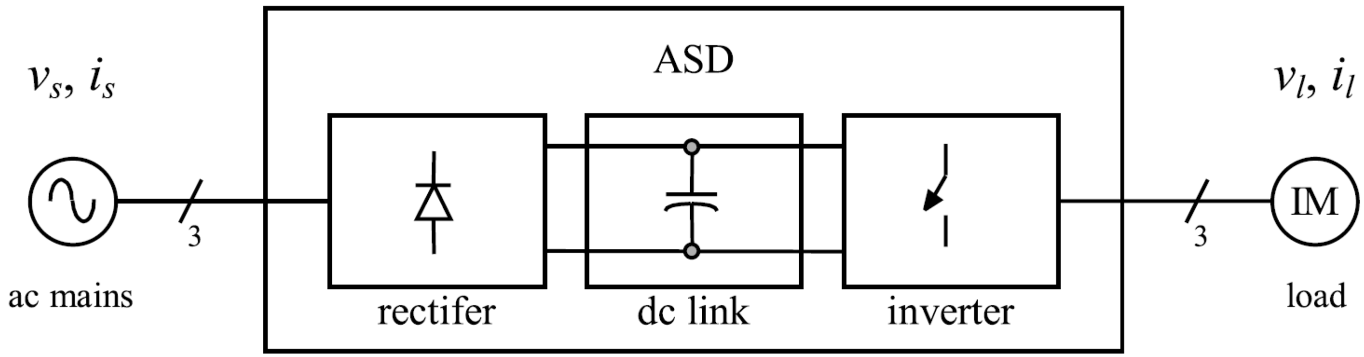
Switch-Mode DC-AC Inverter unidirectional

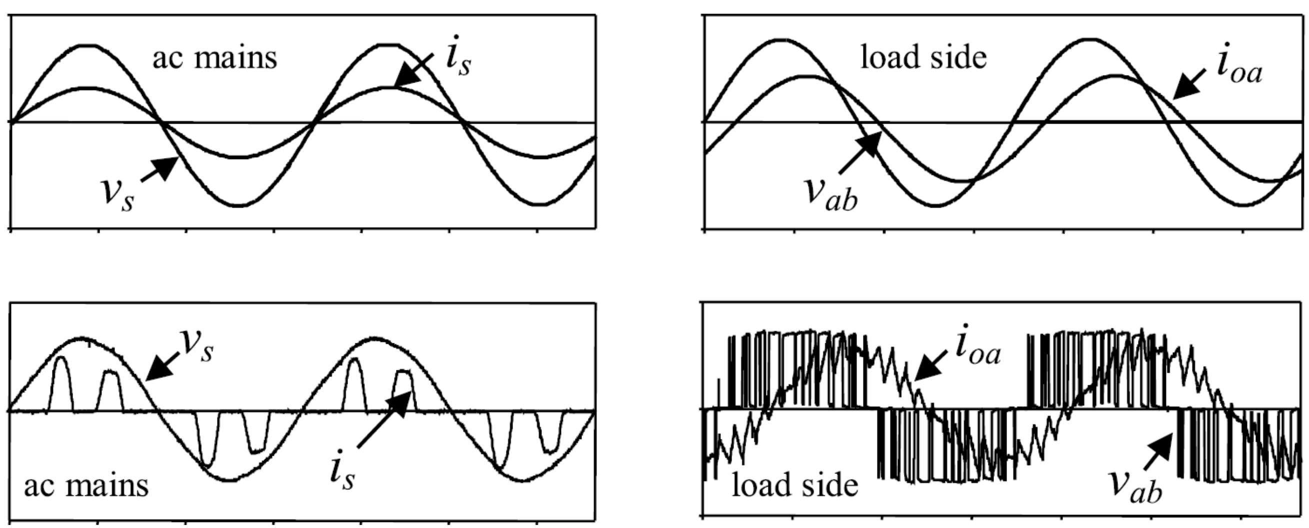


Switch-Mode DC-AC Inverter bidirectional



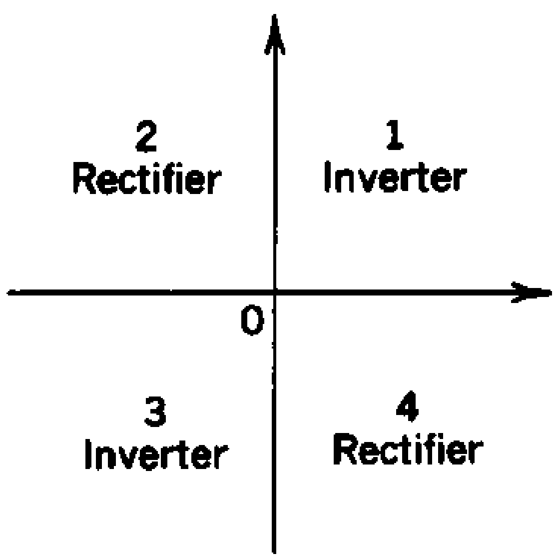
Standard adjustable speed drive scheme

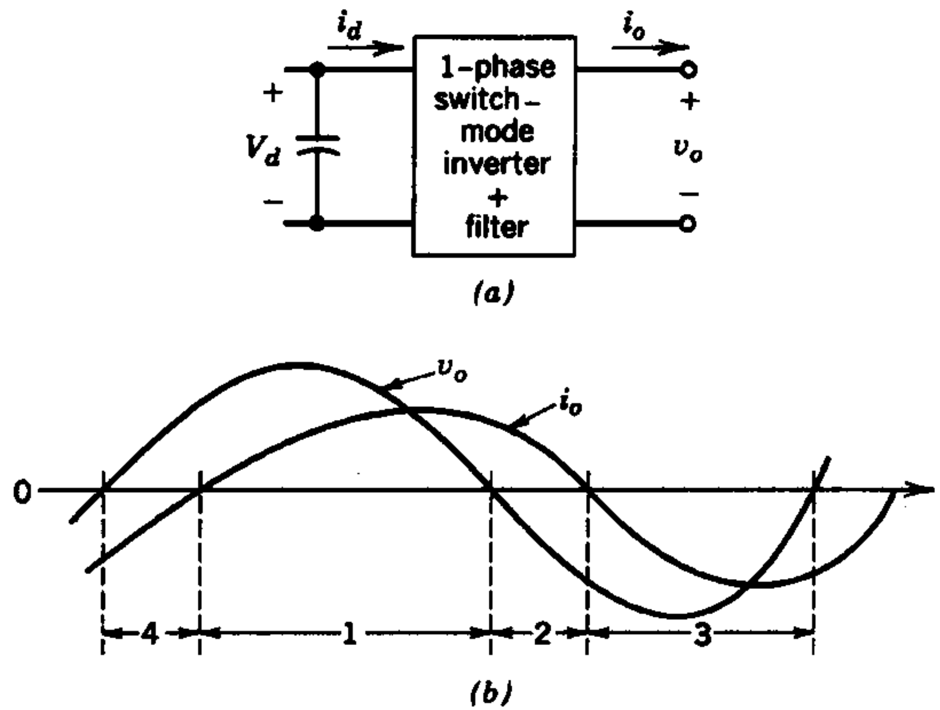




Switch-Mode DC-AC Inverter

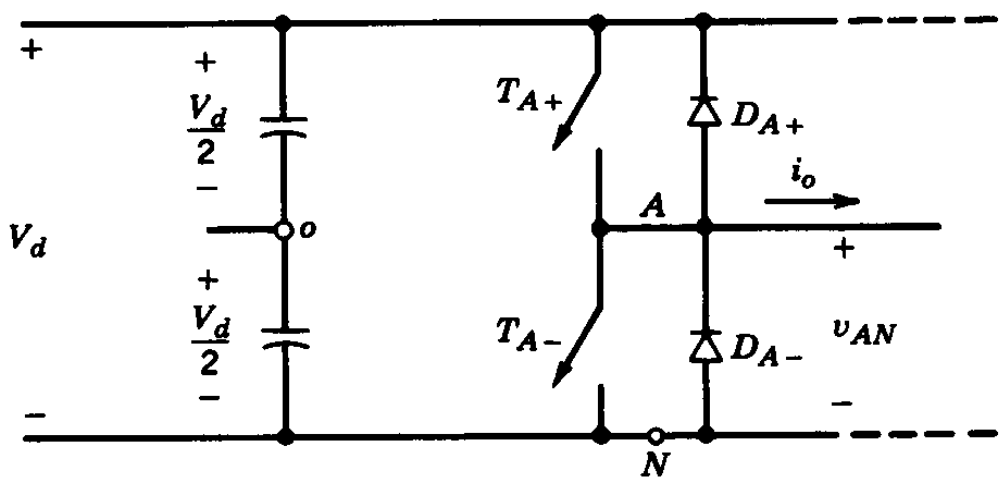
- Four quadrants of operation



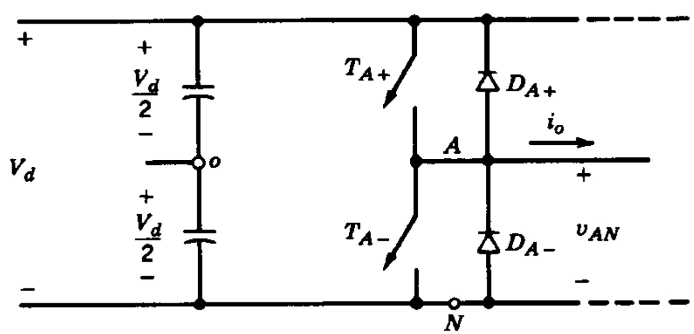


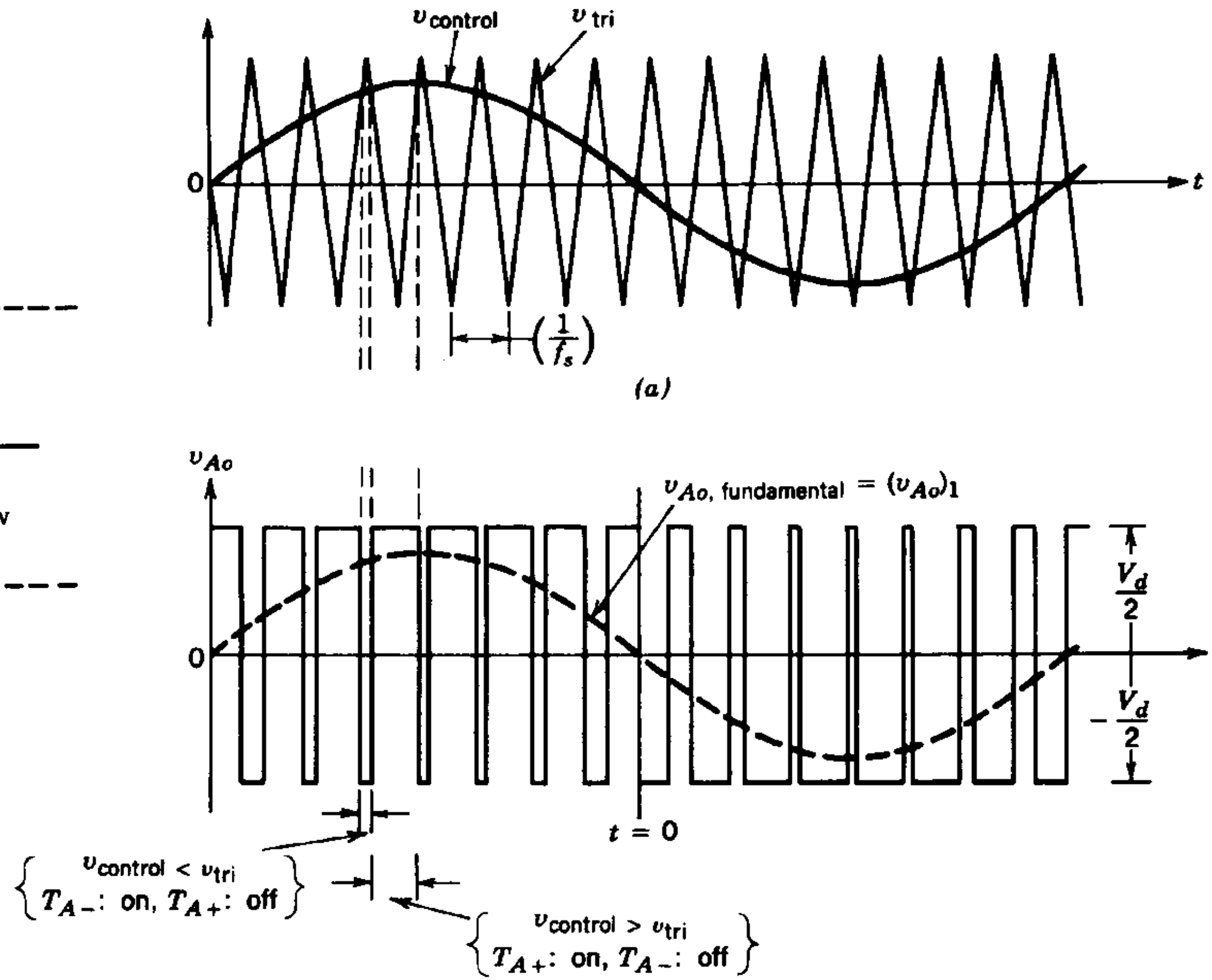
One Leg of a Switch-Mode DC-AC Inverter

- The mid-point shown is fictitious



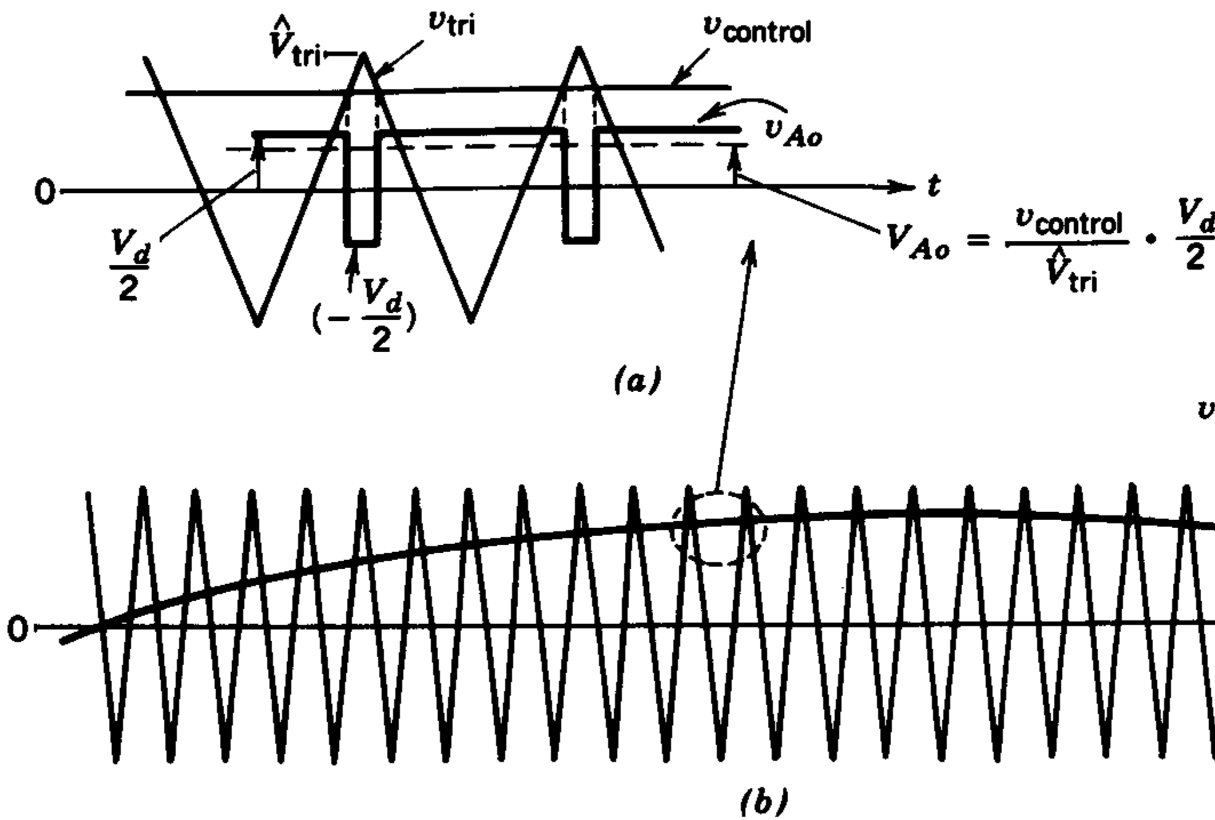
Synthesis of a Sinusoidal Output by PWM





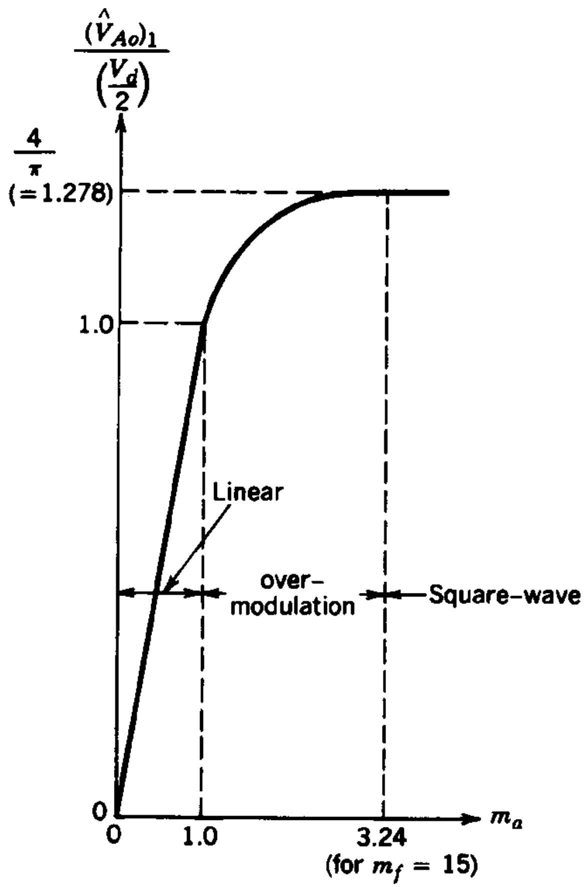
Details of a Switching Time Period

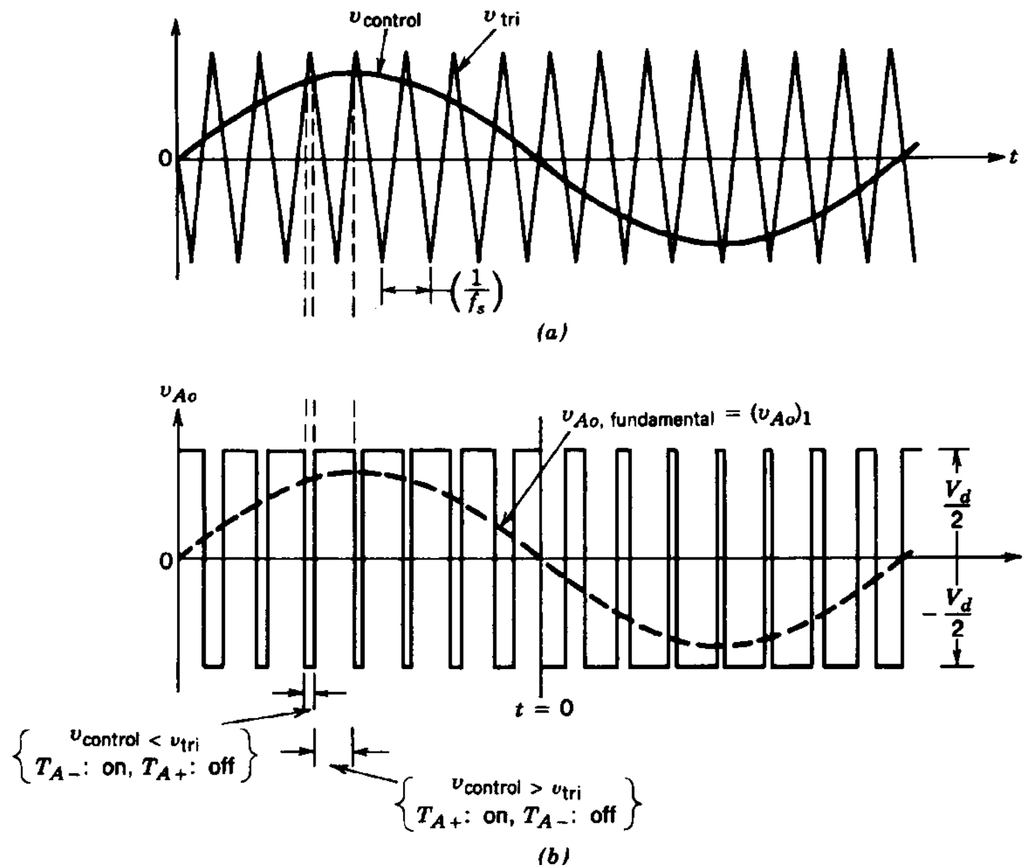
- Control voltage can be assumed constant during a switching time-period



Output voltage Fundamental as a Function of the Modulation Index

- Shows the linear and the over-modulation regions; square-wave operation in the limit





Harmonics in the DC-AC Inverter Output Voltage

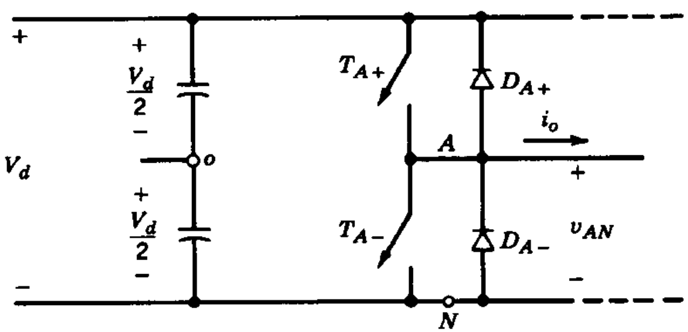
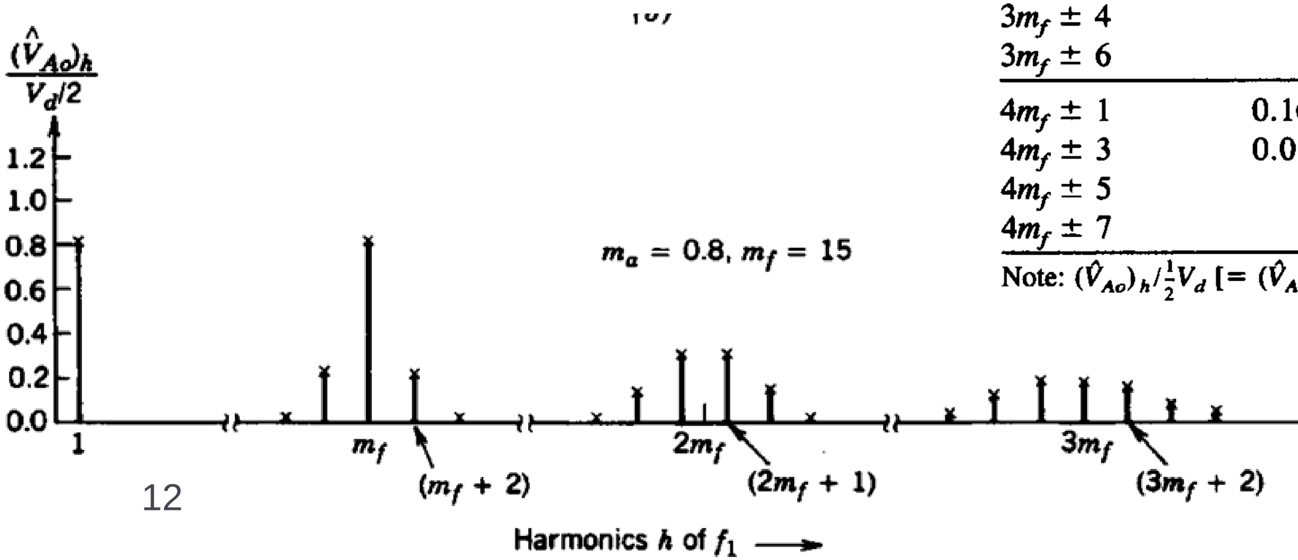


Table 8-1 Generalized Harmonics of v_{Ao} for a Large m_f.

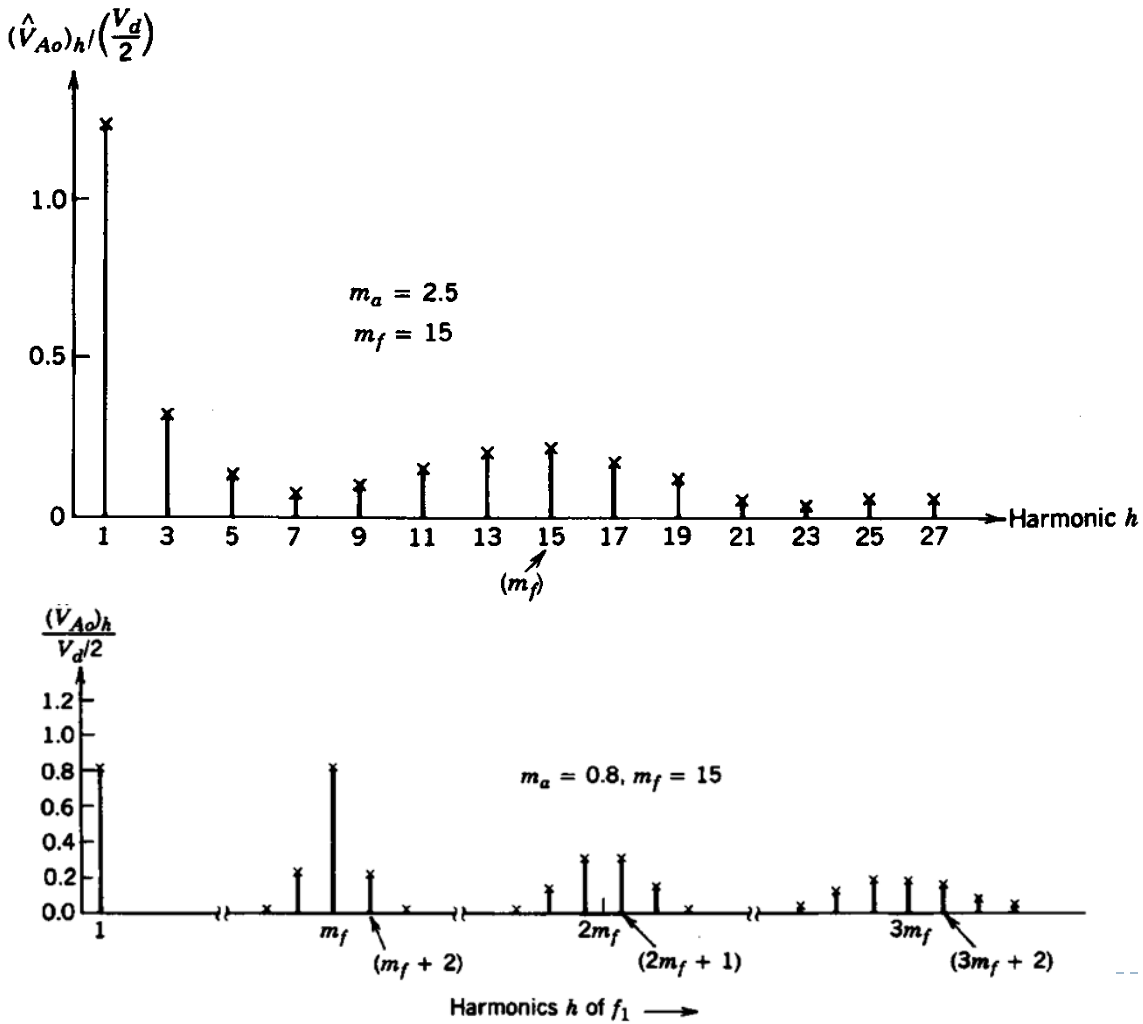
h \ m_a	0.2	0.4	0.6	0.8	1.0
1 Fundamental	0.2	0.4	0.6	0.8	1.0
m_f	1.242	1.15	1.006	0.818	0.601
$m_f \pm 2$	0.016	0.061	0.131	0.220	0.318
$m_f \pm 4$					0.018
$2m_f \pm 1$	0.190	0.326	0.370	0.314	0.181
$2m_f \pm 3$		0.024	0.071	0.139	0.212
$2m_f \pm 5$				0.013	0.033
$3m_f$	0.335	0.123	0.083	0.171	0.113
$3m_f \pm 2$	0.044	0.139	0.203	0.176	0.062
$3m_f \pm 4$		0.012	0.047	0.104	0.157
$3m_f \pm 6$				0.016	0.044
$4m_f \pm 1$	0.163	0.157	0.008	0.105	0.068
$4m_f \pm 3$	0.012	0.070	0.132	0.115	0.009
$4m_f \pm 5$			0.034	0.084	0.119
$4m_f \pm 7$				0.017	0.050

Note: $(\hat{V}_{Ao})_h / \frac{1}{2}V_d$ [$= (\hat{V}_{AN})_h / \frac{1}{2}V_d$] is tabulated as a function of m_a.



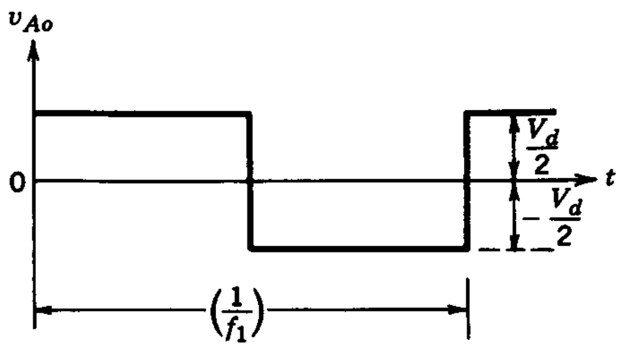
Harmonics due to Over-modulation

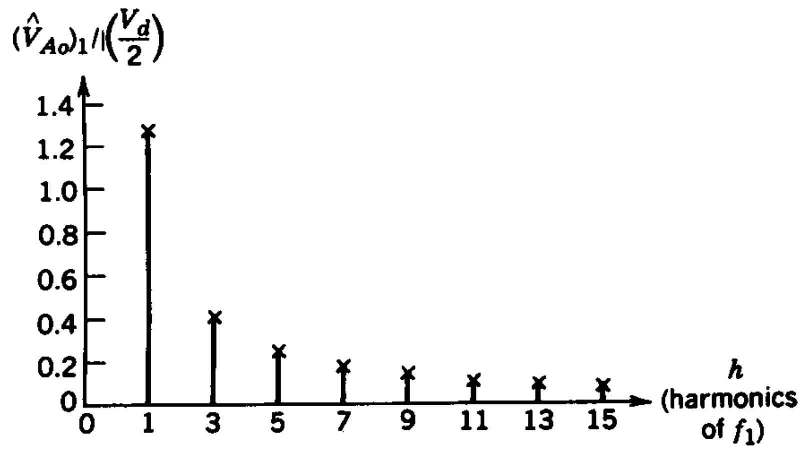
- These are harmonics of the fundamental frequency



Square-Wave Mode of Operation

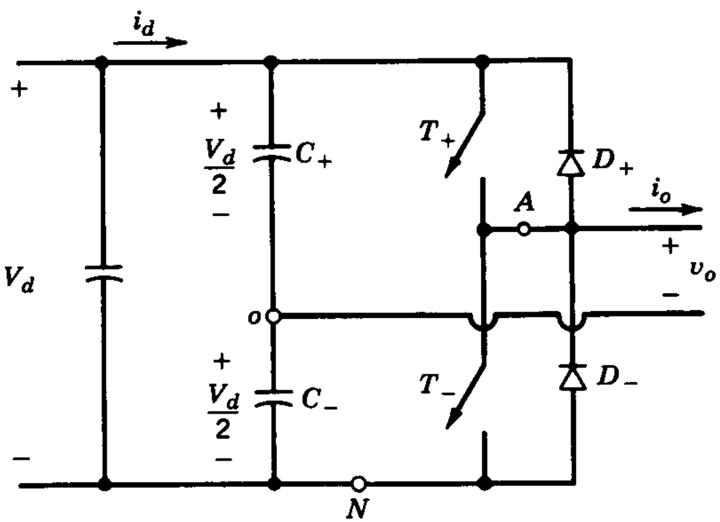
- Harmonics are of the fundamental frequency



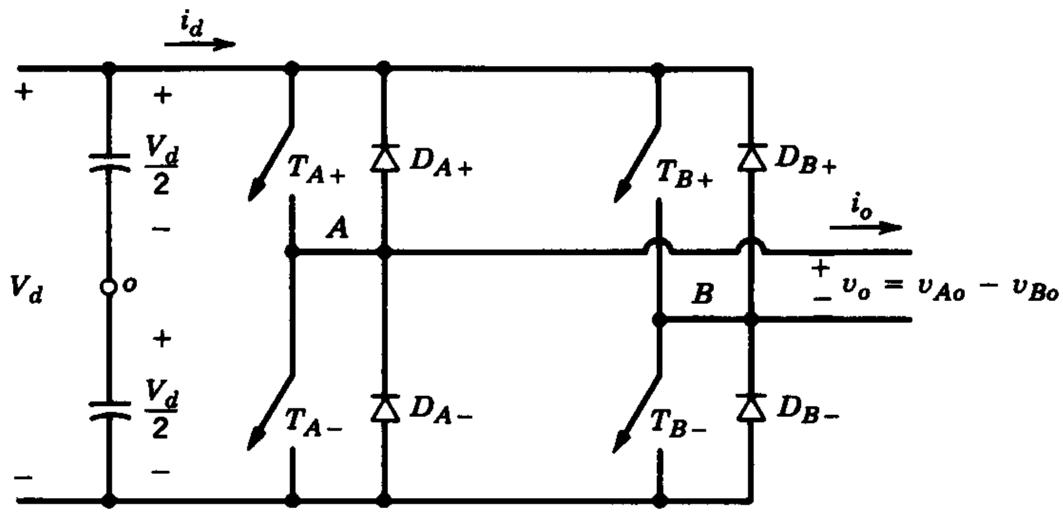


Half-Bridge / Full-Bridge Inverter

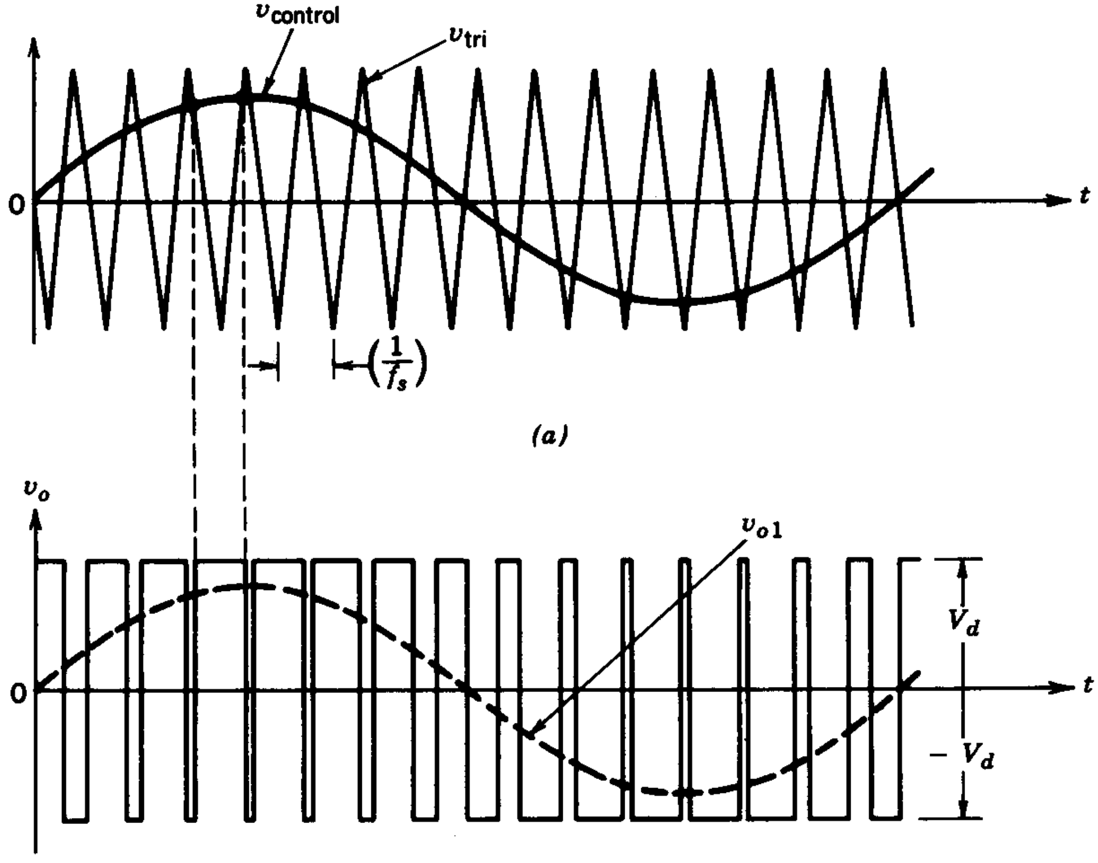
- Capacitors provide the mid-point



- Consists of two inverter legs



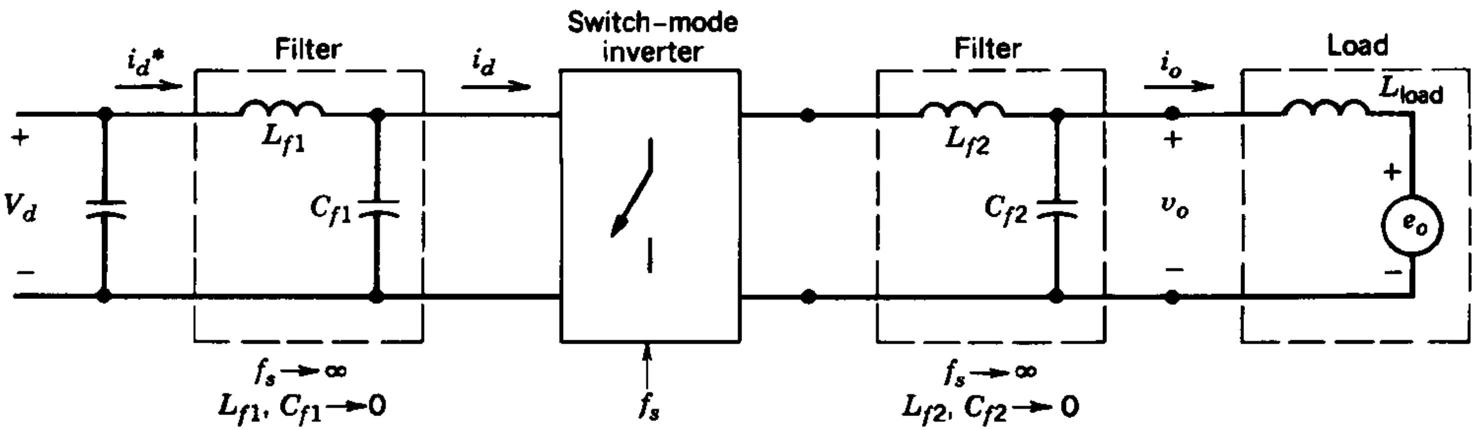
PWM to Synthesize Sinusoidal Output



- The dotted curve is the desired output; also the fundamental frequency
- Bipolar voltage switching

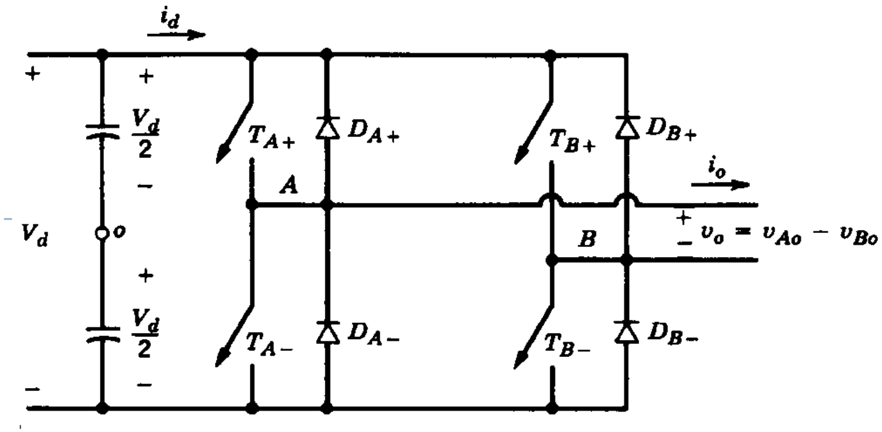
Analysis assuming Fictitious Filters

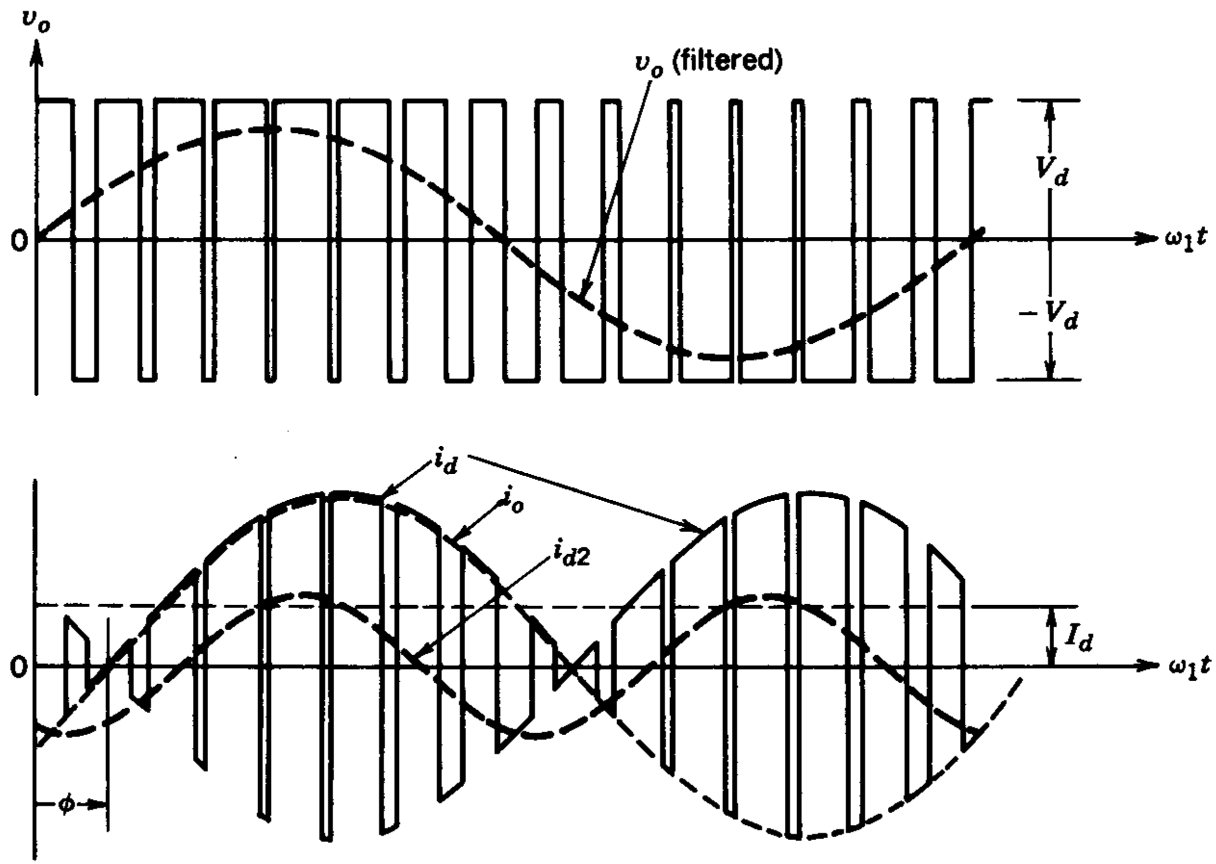
- Small fictitious filters eliminate the switching-frequency related ripple



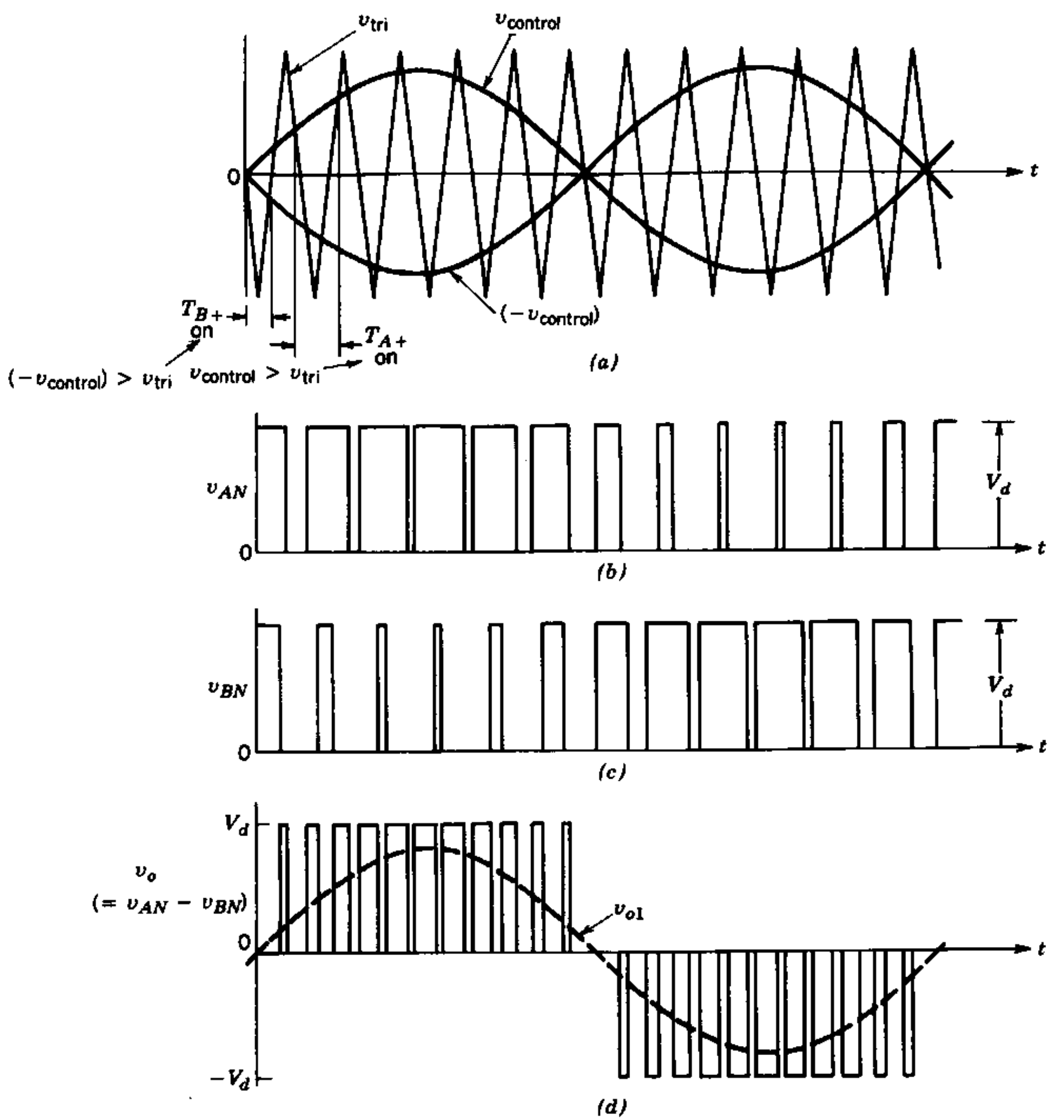
DC-Side Current

- Bi-Polar Voltage switching



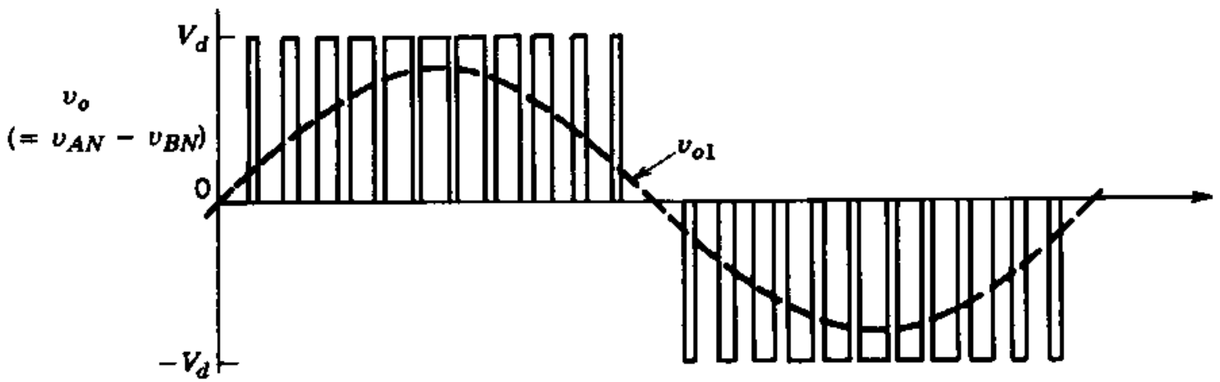


Output Waveforms: Uni-polar Voltage Switching

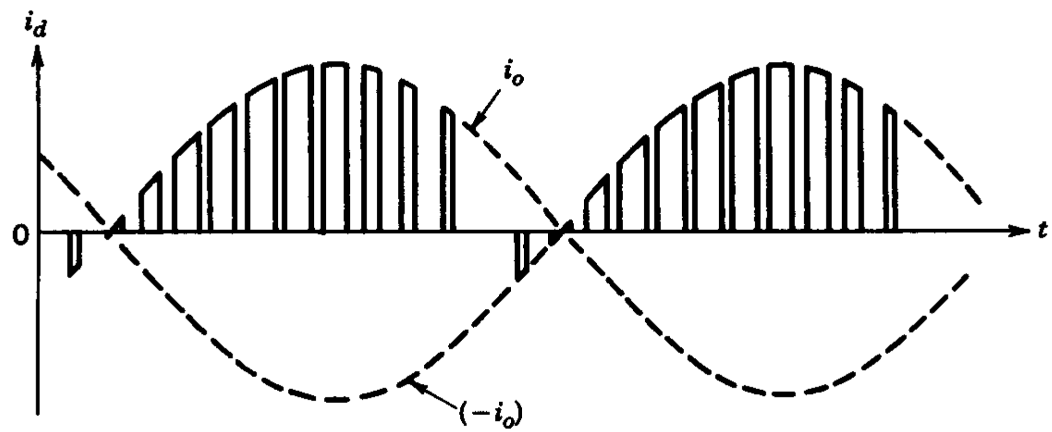


DC-Side Current in a Single-Phase Inverter

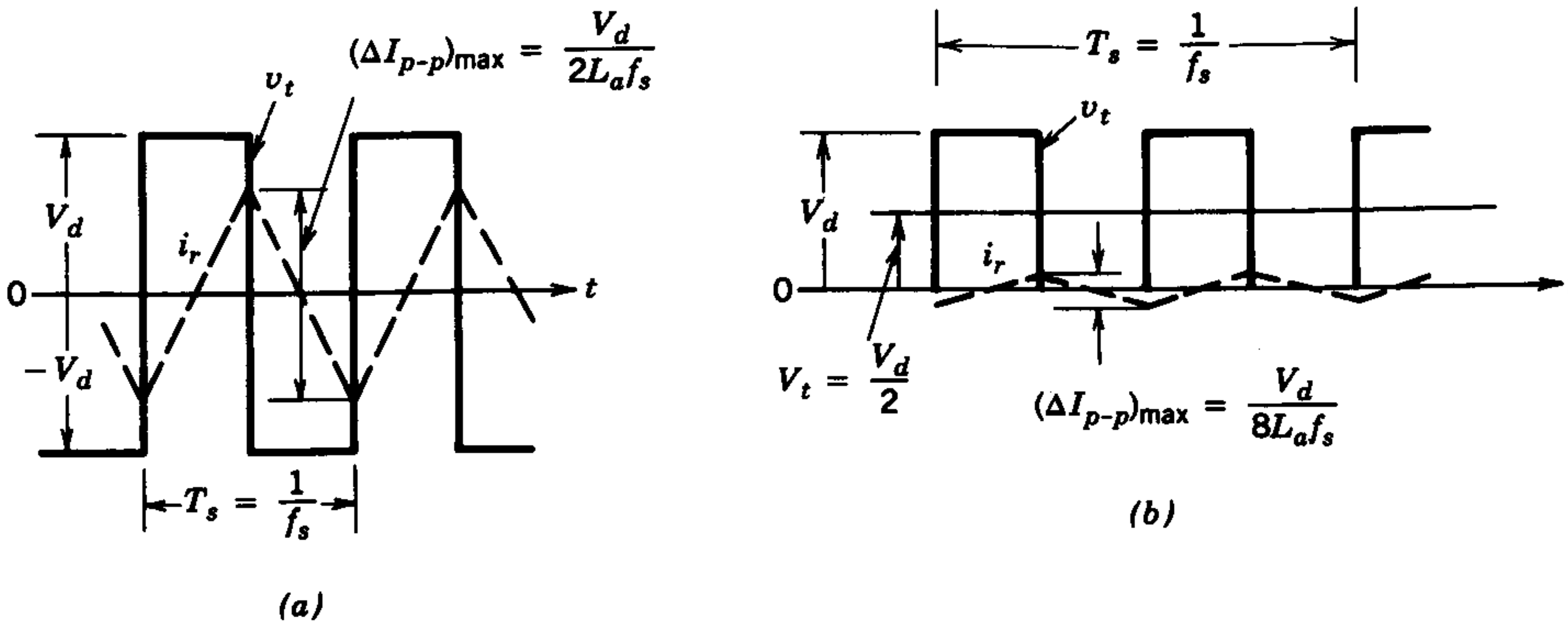
- Uni-polar voltage switching



(d)

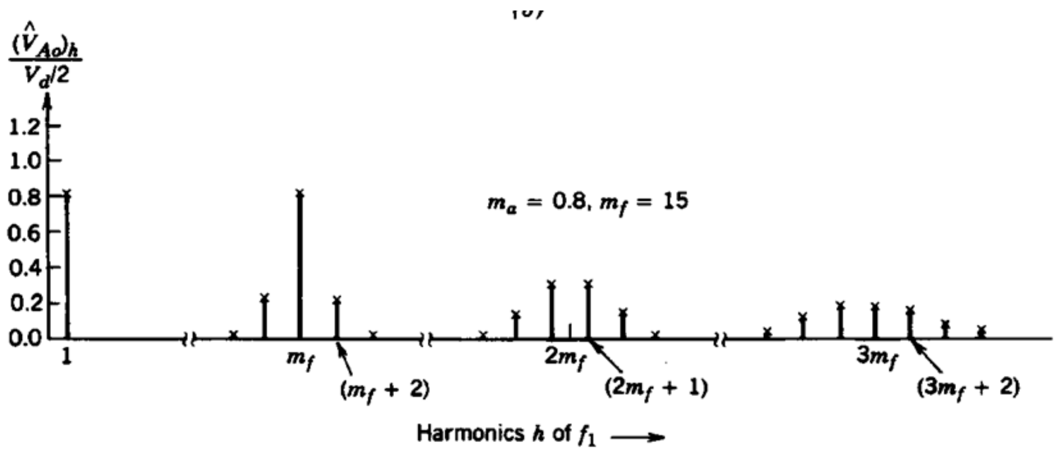


Bipolar and Unipolar Current Ripple

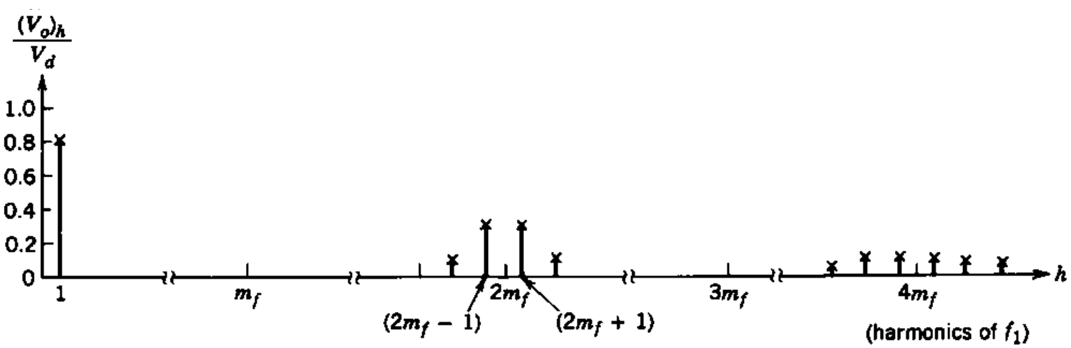


Harmonic Components during Bi-polar / Uni-polar Voltage Switching

- Bi-Polar



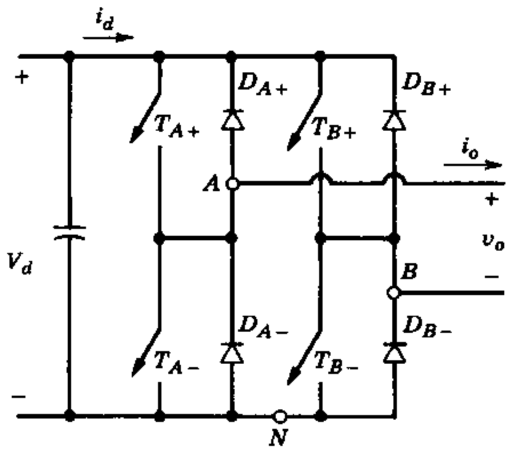
- Uni-Polar



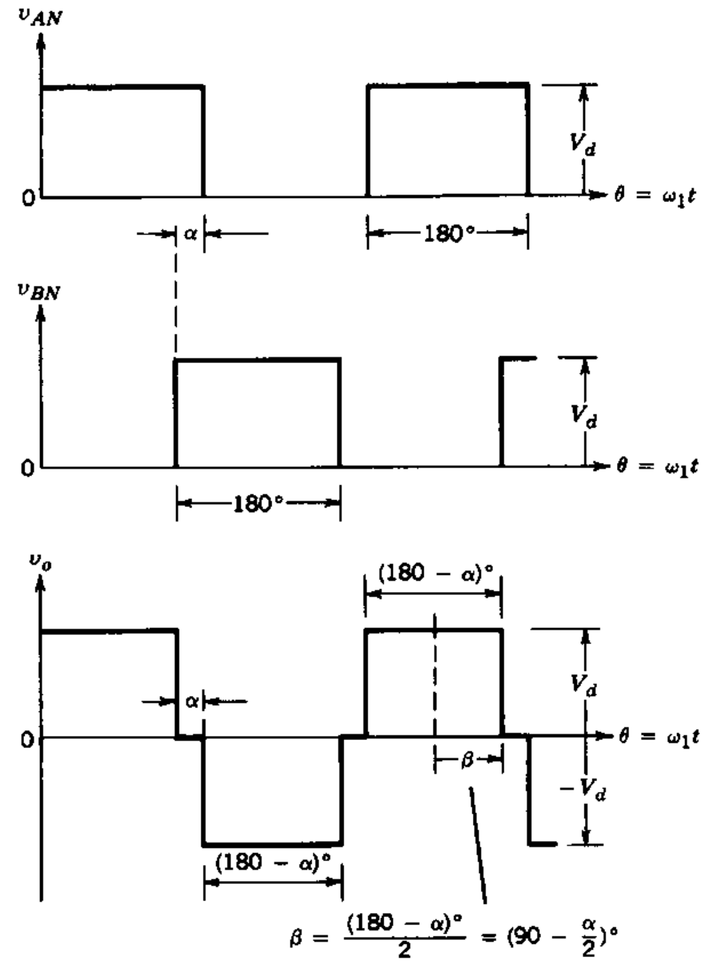
- Harmonic components around the switching frequency are absent in UP!

Sinusoidal Synthesis by Voltage Shift

- Phase shift allows voltage cancellation to synthesize a <u>1-Phase</u> sinusoidal output



(a)



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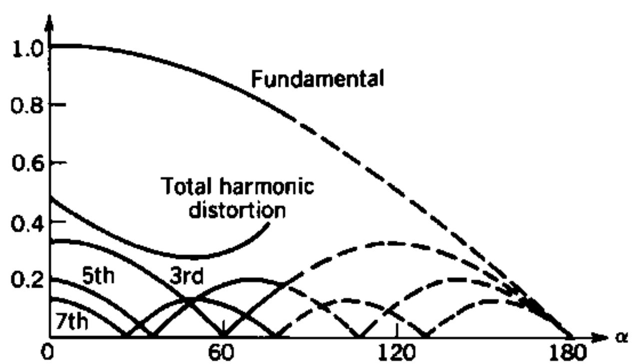
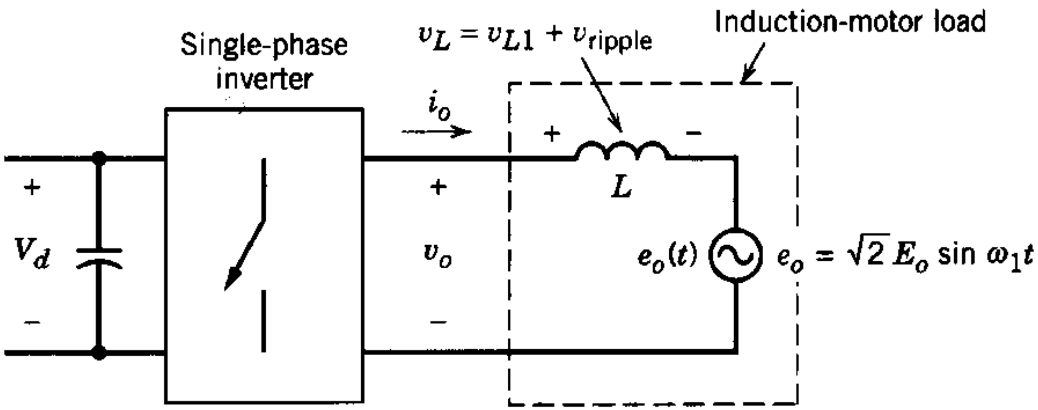


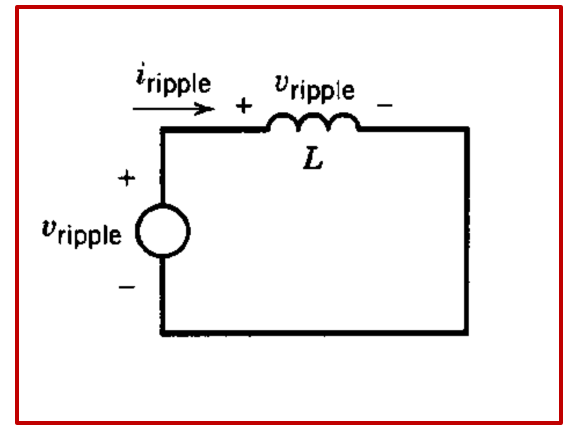
(c)

Voltage Ripple
Single-Phase Inverter

- Analysis at the fundamental frequency



(a)



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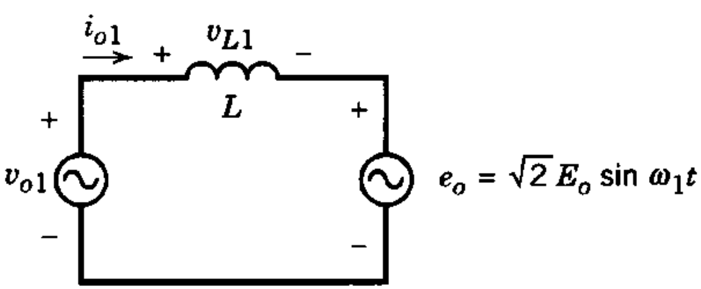
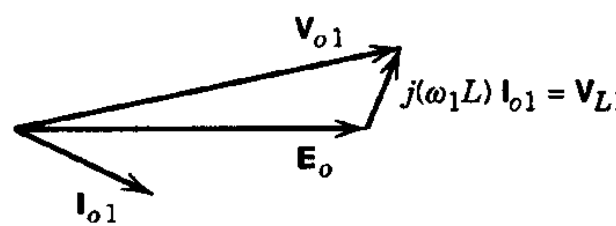
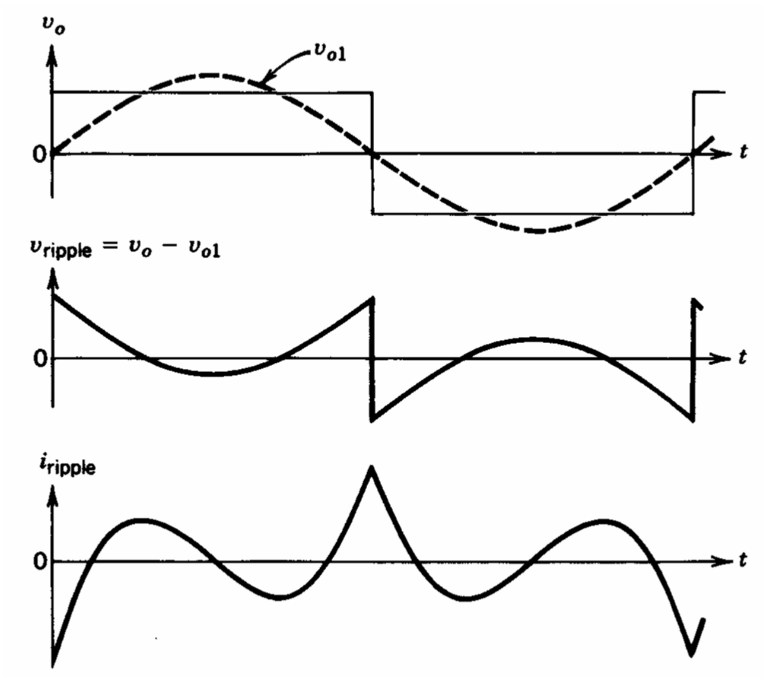
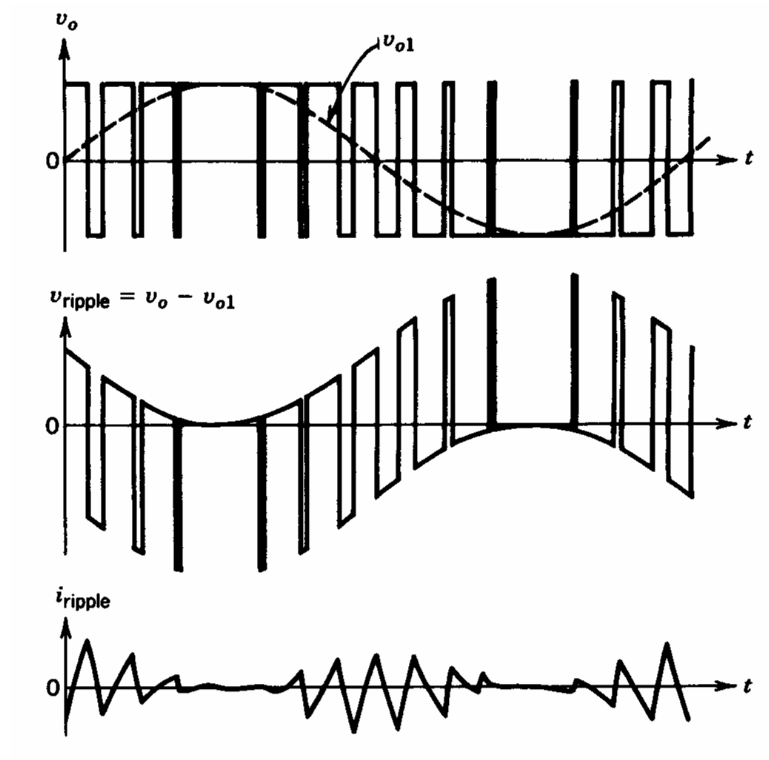




Voltage/Current Ripple
Square-Wave and PWM Operation

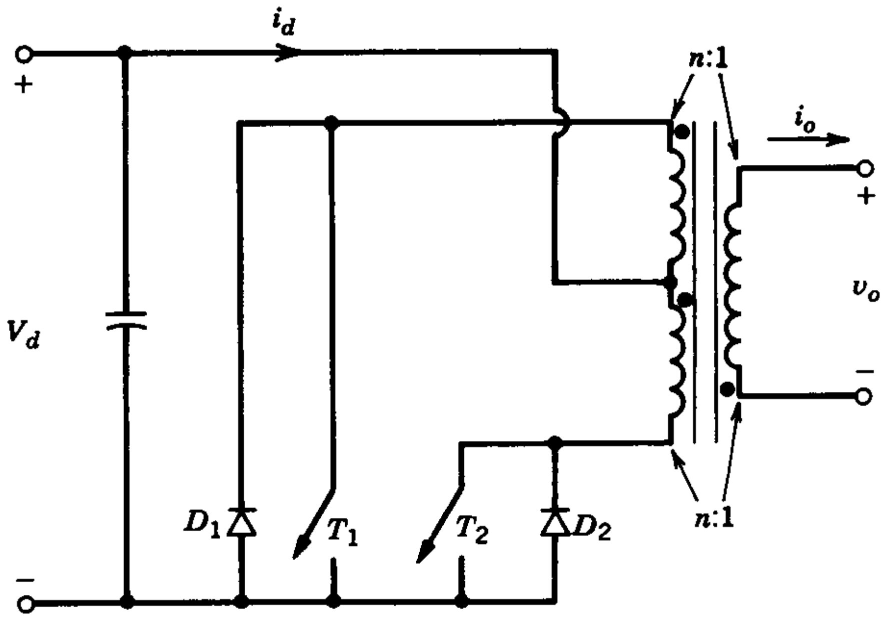
- PWM results in much smaller ripple current





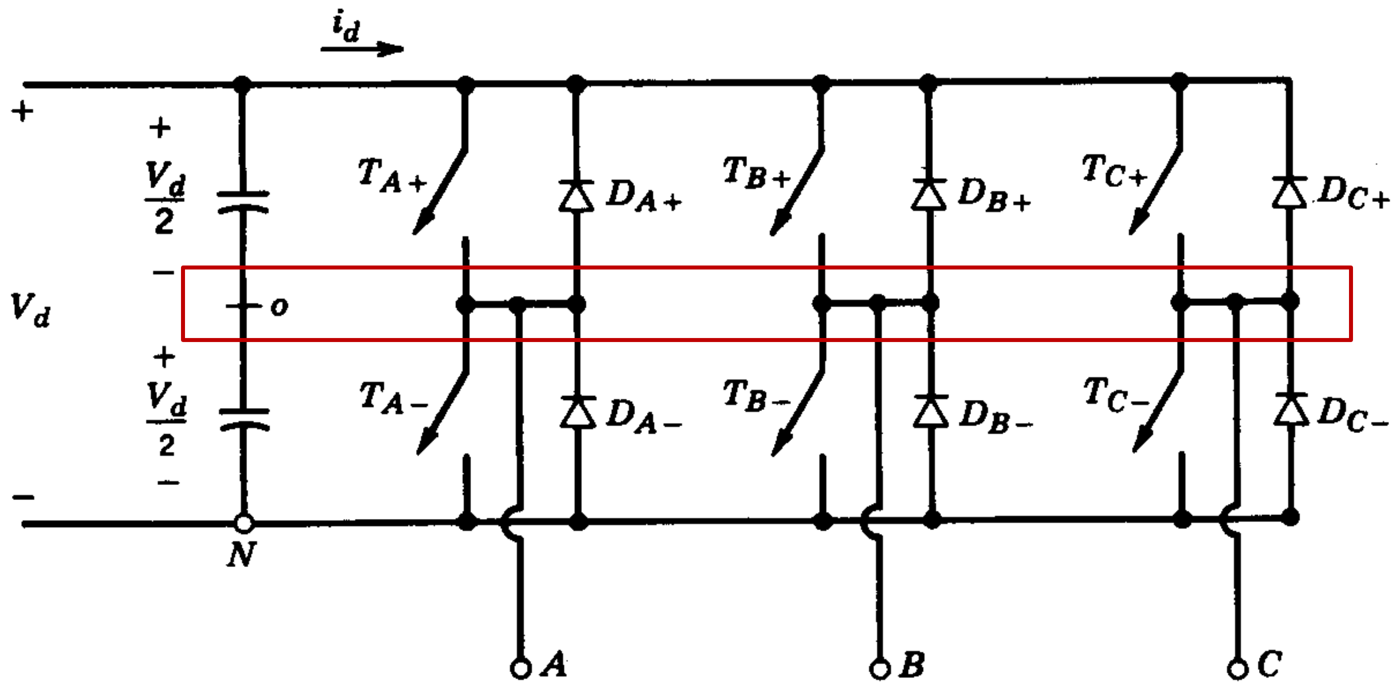
Push-Pull Inverter

- Low Voltage to higher output using square-wave operation

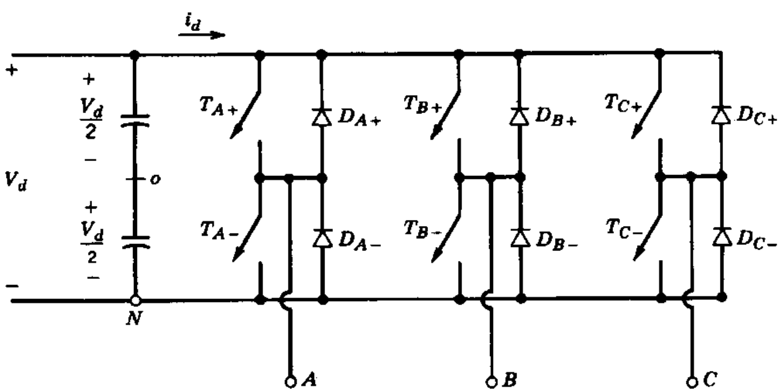


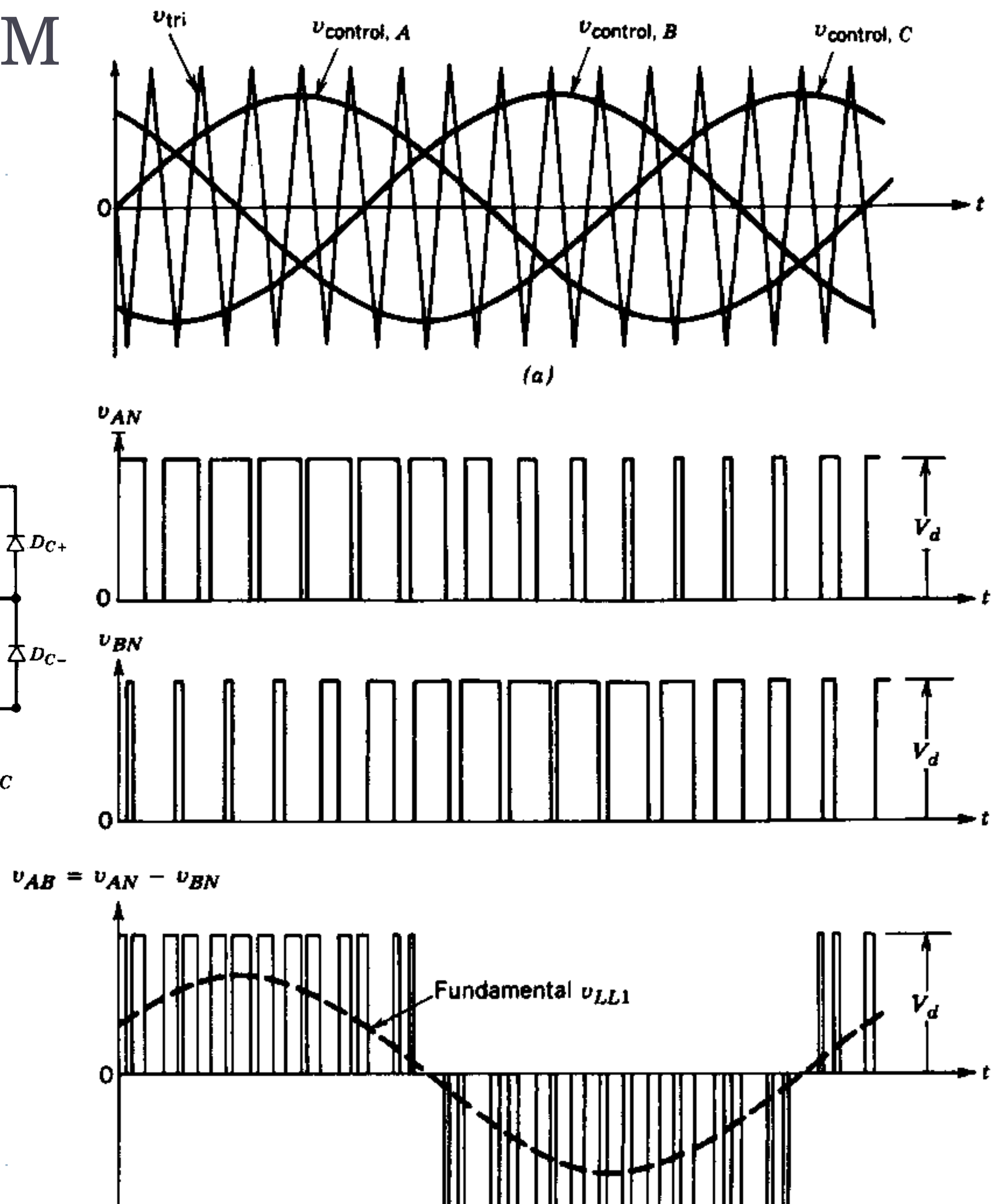
Three-Phase Inverter

- Three inverter legs; capacitor mid-point is fictitious

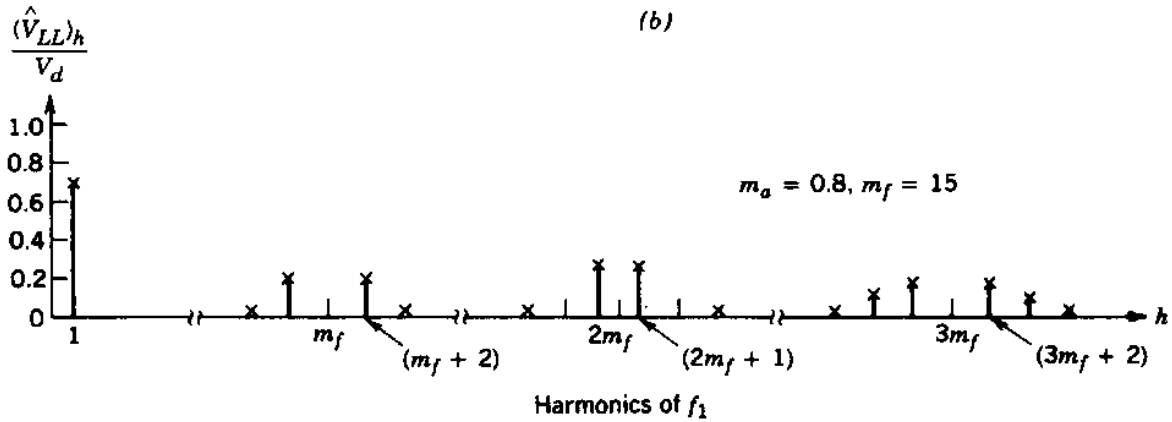


Three-Phase PWM Waveforms





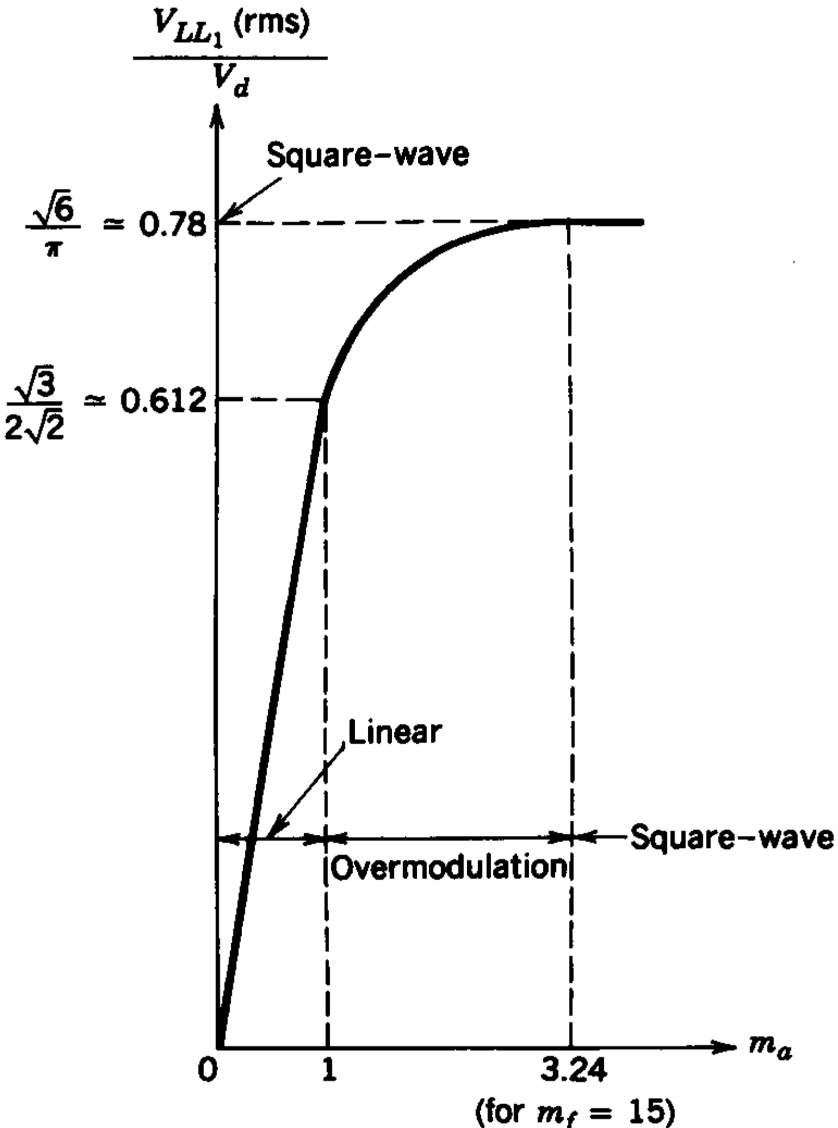
Three-Phase Inverter Harmonics



h \ m_a	0.2	0.4	0.6	0.8	1.0
1	0.122	0.245	0.367	0.490	0.612
$m_f \pm 2$	0.010	0.037	0.080	0.135	0.195
$m_f \pm 4$				0.005	0.011
$2m_f \pm 1$	0.116	0.200	0.227	0.192	0.111
$2m_f \pm 5$				0.008	0.020
$3m_f \pm 2$	0.027	0.085	0.124	0.108	0.038
$3m_f \pm 4$		0.007	0.029	0.064	0.096
$4m_f \pm 1$	0.100	0.096	0.005	0.064	0.042
$4m_f \pm 5$			0.021	0.051	0.073
$4m_f \pm 7$				0.010	0.030

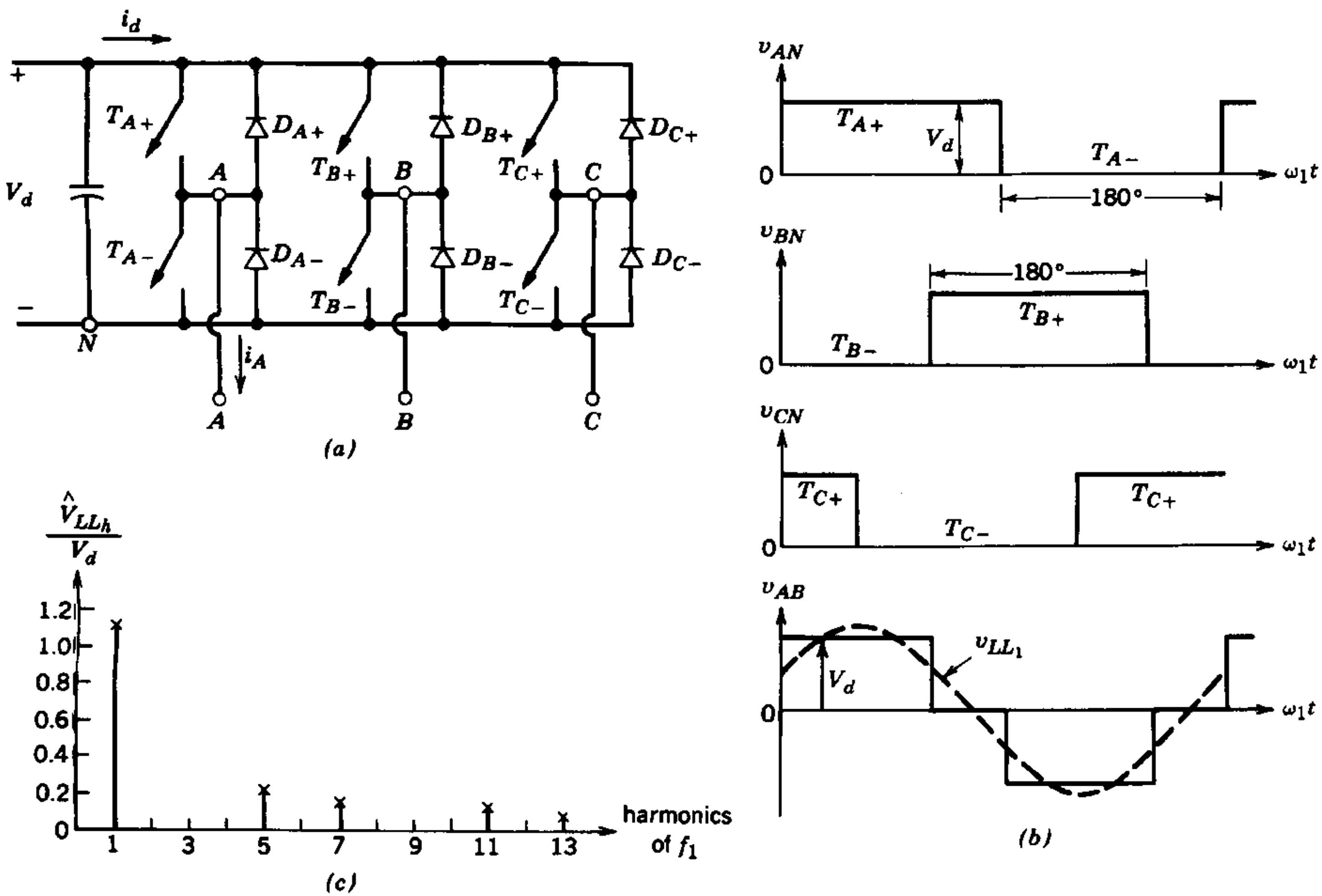
Note: $(V_{LL})_h/V_d$ are tabulated as a function of m_a where $(V_{LL})_h$ are the rms values of the harmonic voltages.

Three-Phase Inverter Output



- Linear
- over-modulation ranges

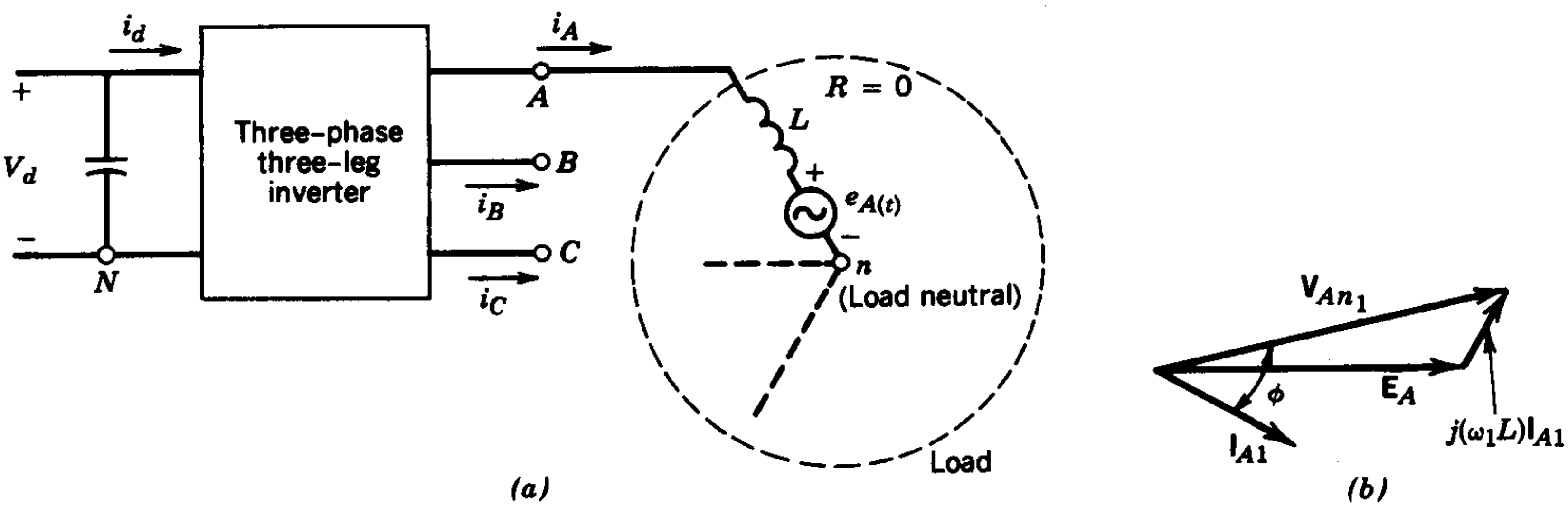
Three-Phase Inverter: Square-Wave Mode



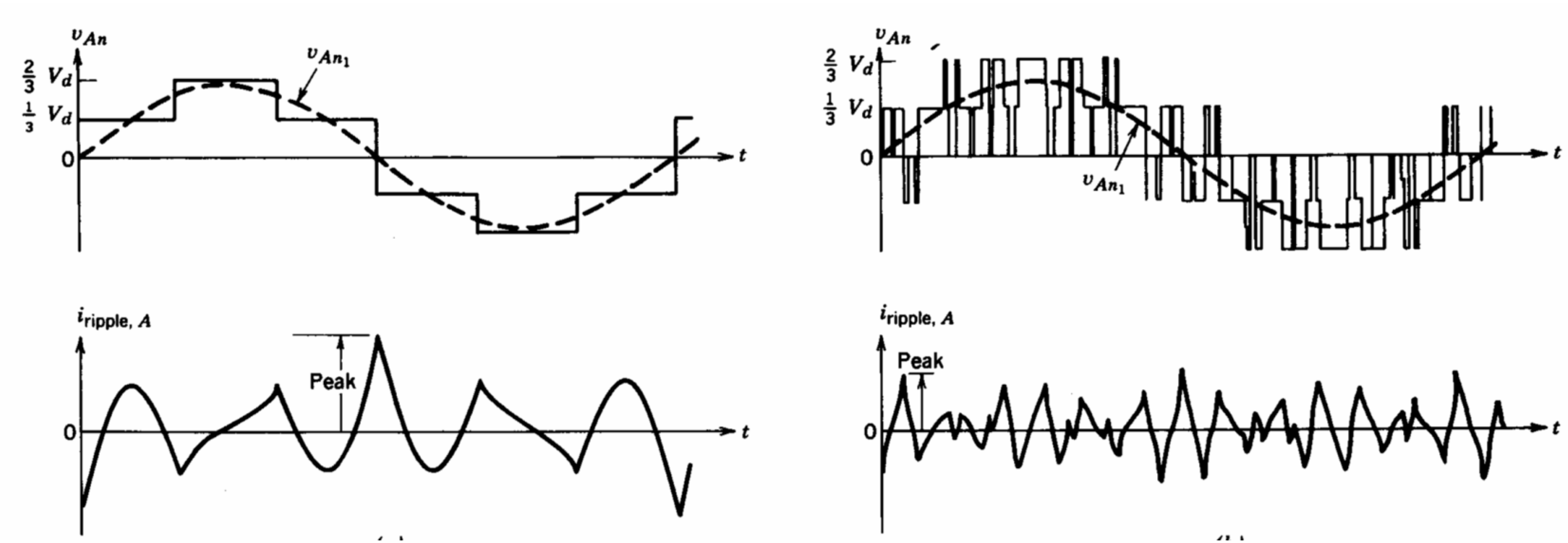
- Harmonics are of the fundamental frequency

Three-Phase Inverter: Fundamental Frequency

- Analysis at the fundamental frequency can be done using phasors

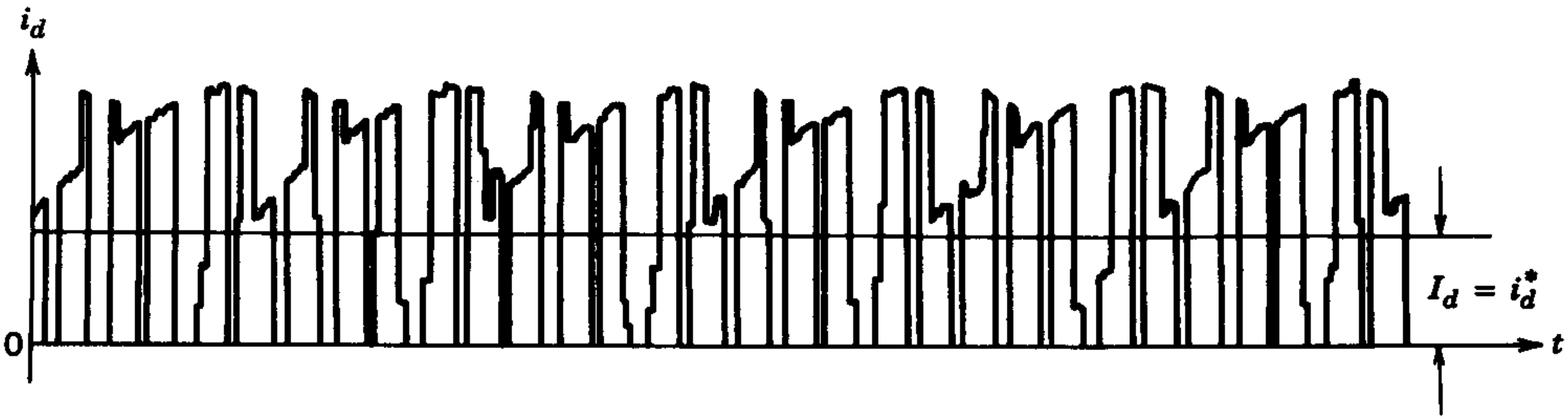


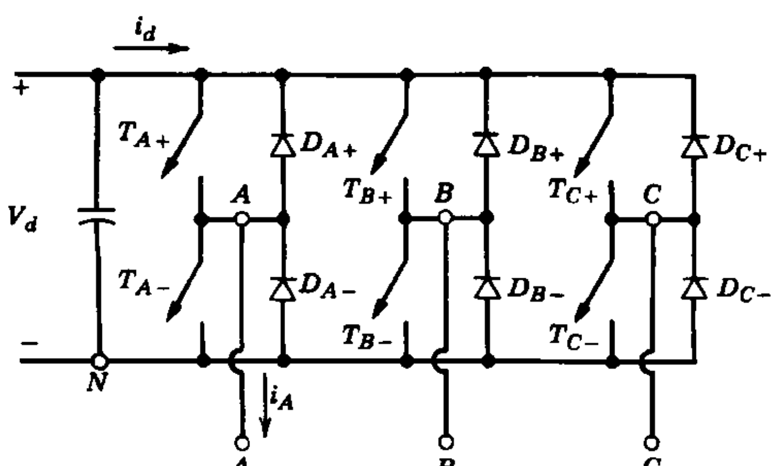
Voltage and Current Ripple Square-Wave and PWM Operation



- PWM results in much smaller ripple current

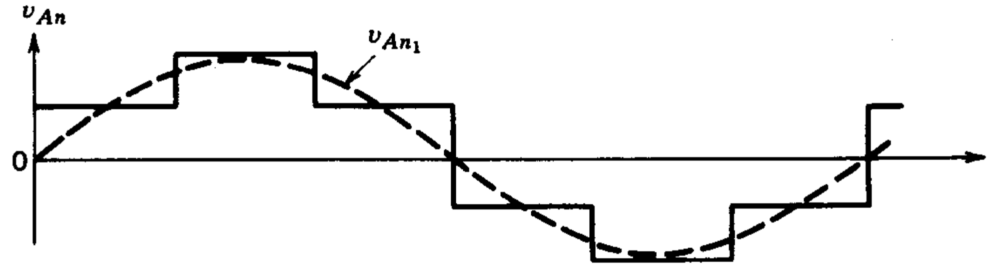
DC-Side Current in a Three-Phase Inverter





- The current consists of a dc component and the switching-frequency related harmonics

Device Conducting Square-Wave Operation



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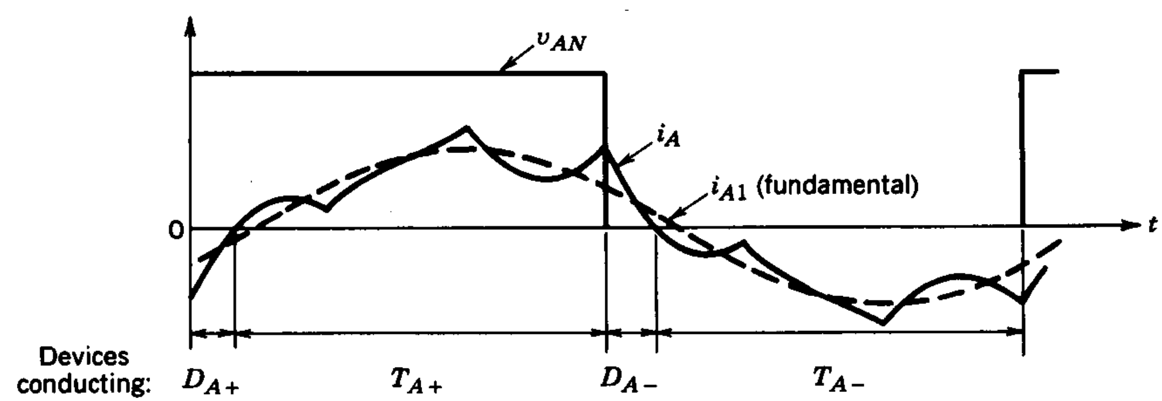
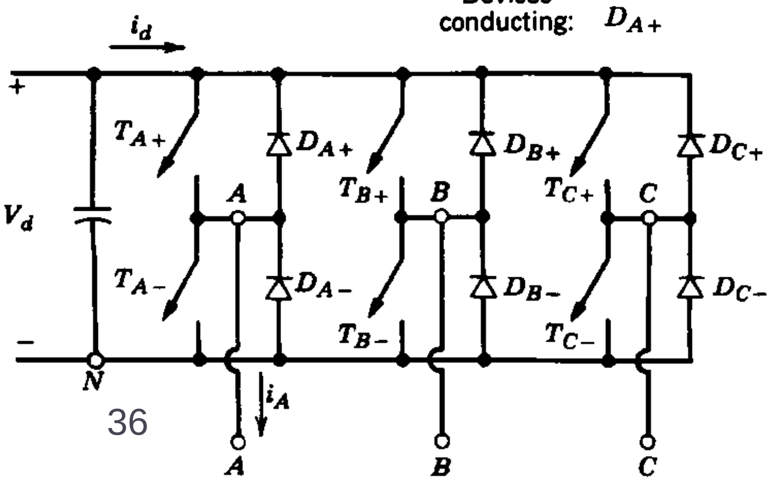
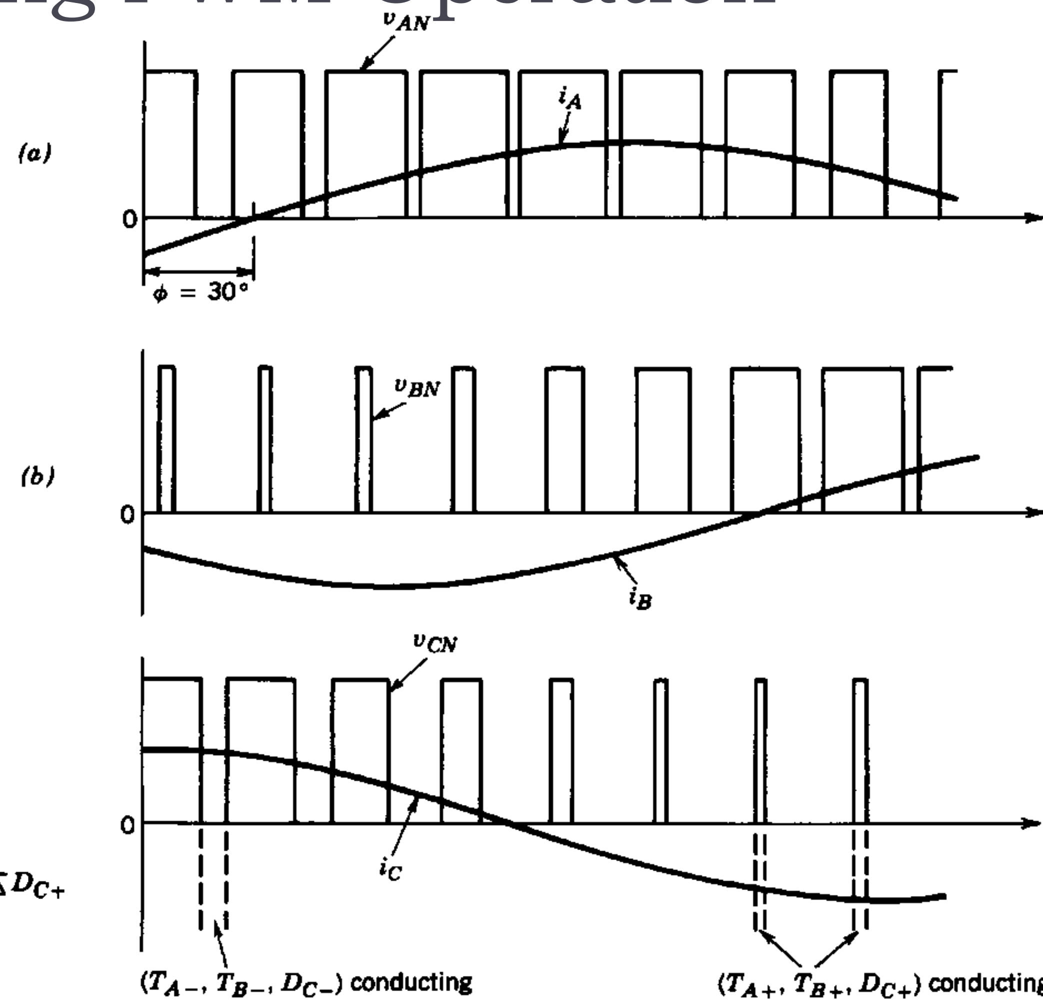
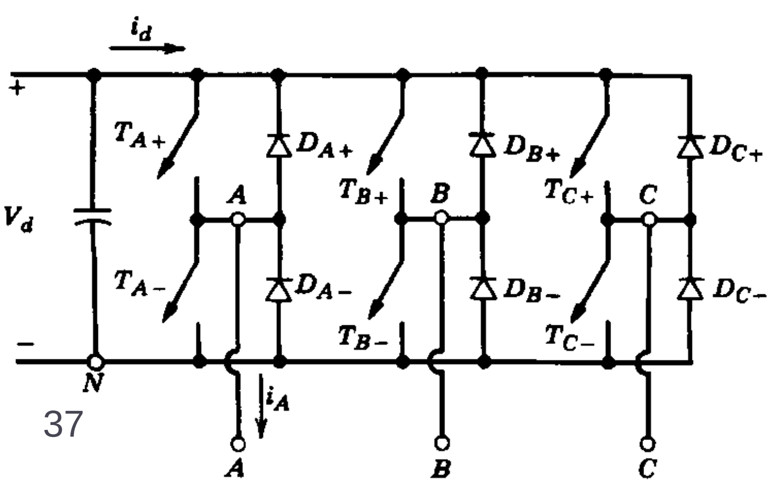


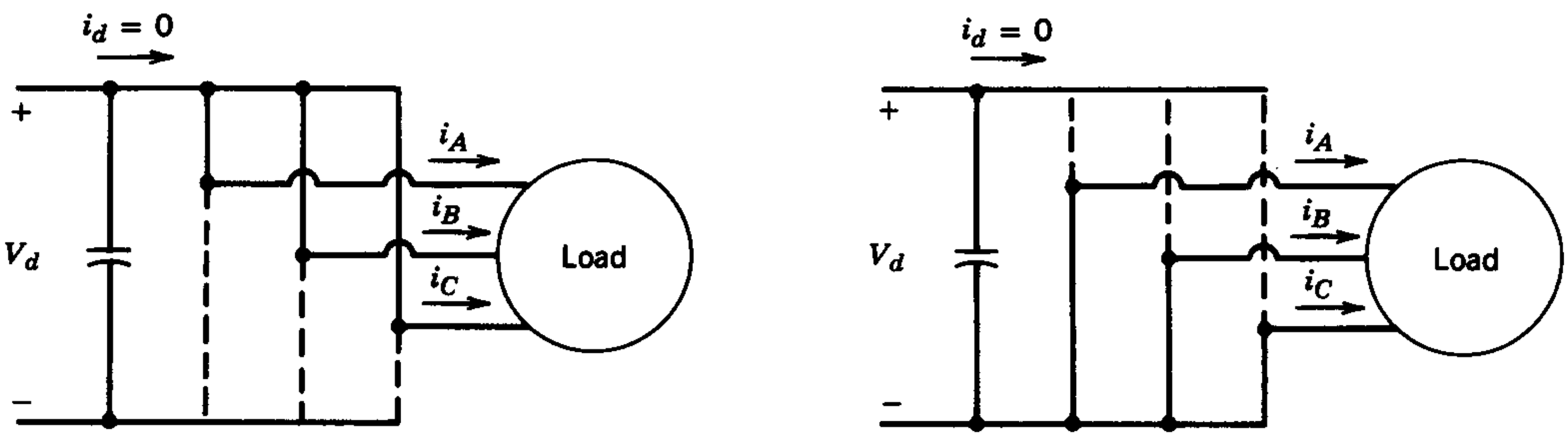


Device Conducting PWM Operation



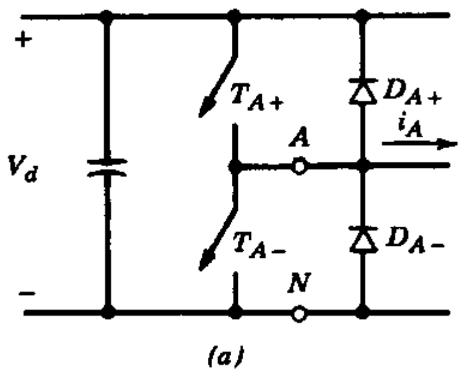


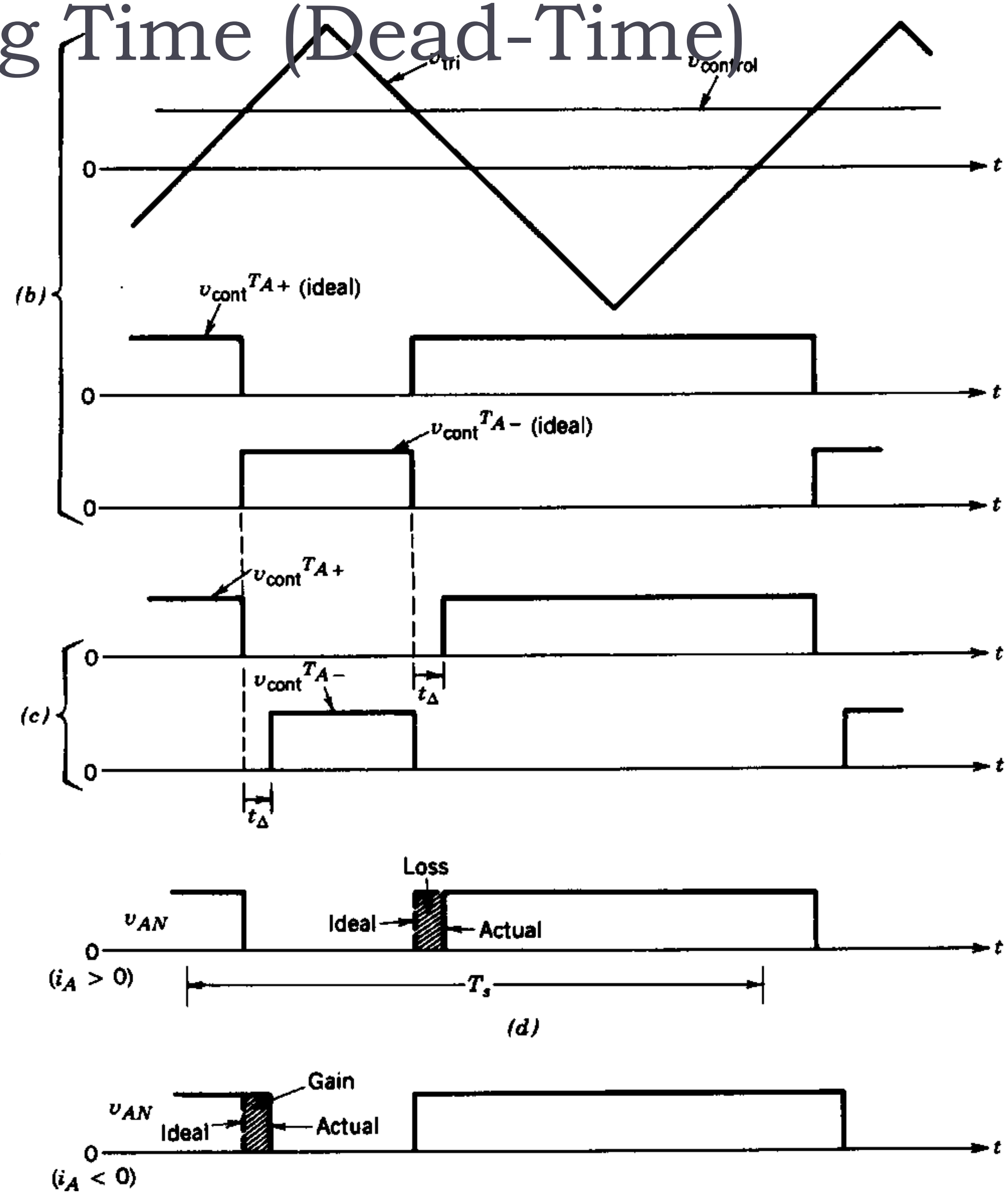
Short-Circuit States in PWM Operation



- top group or the bottom group results in short circuiting three terminals

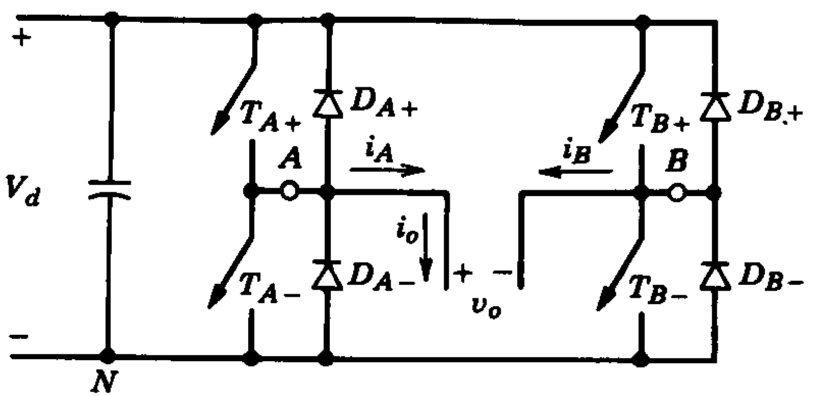
Effect of Blanking Time (Dead-Time)



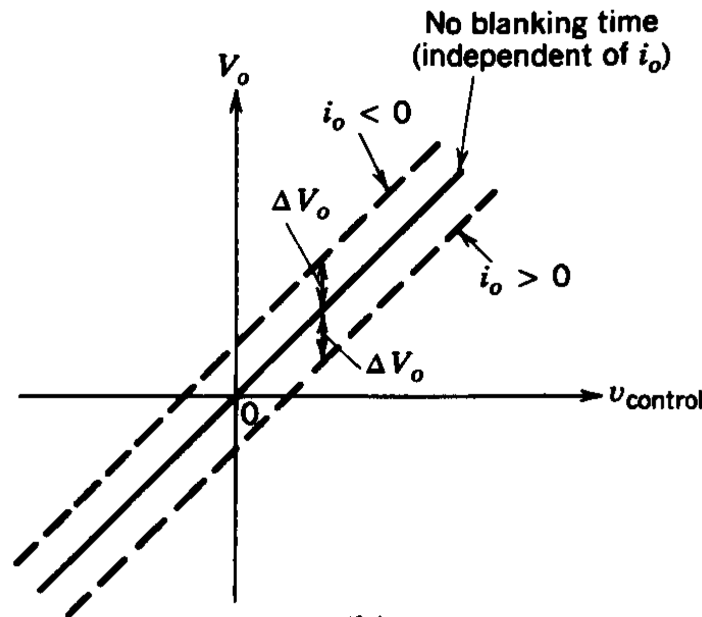


- Results in nonlinearity

Effect of Blanking Time (Dead-Time)



(a)

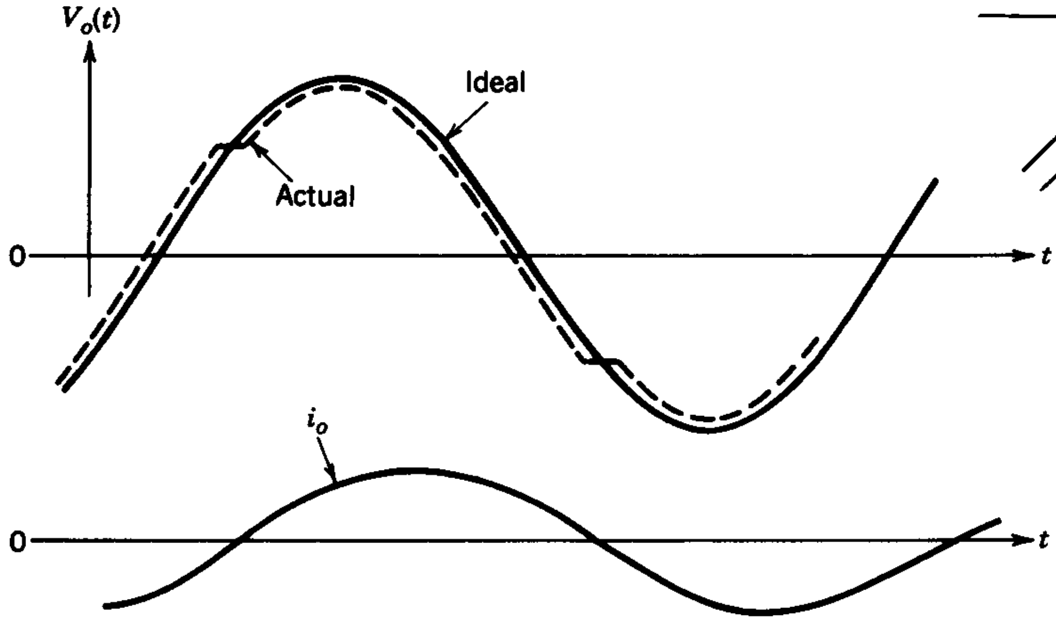


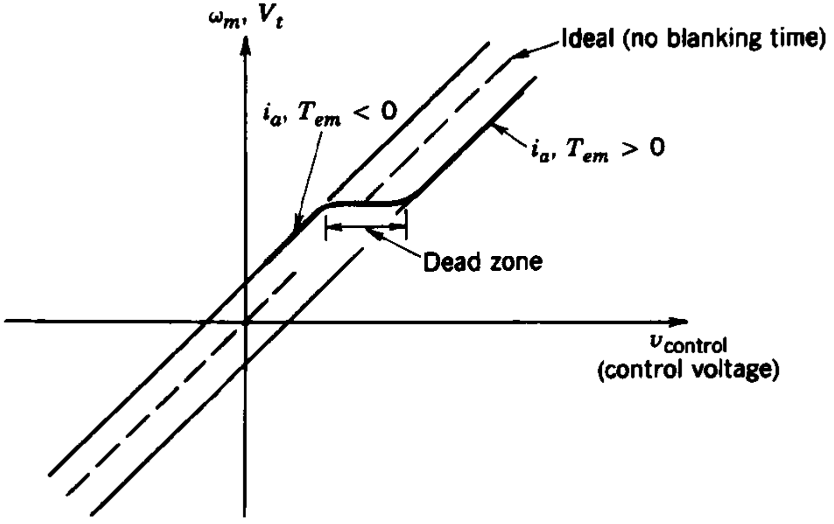
(b)

- Voltage jump when the current reverses direction

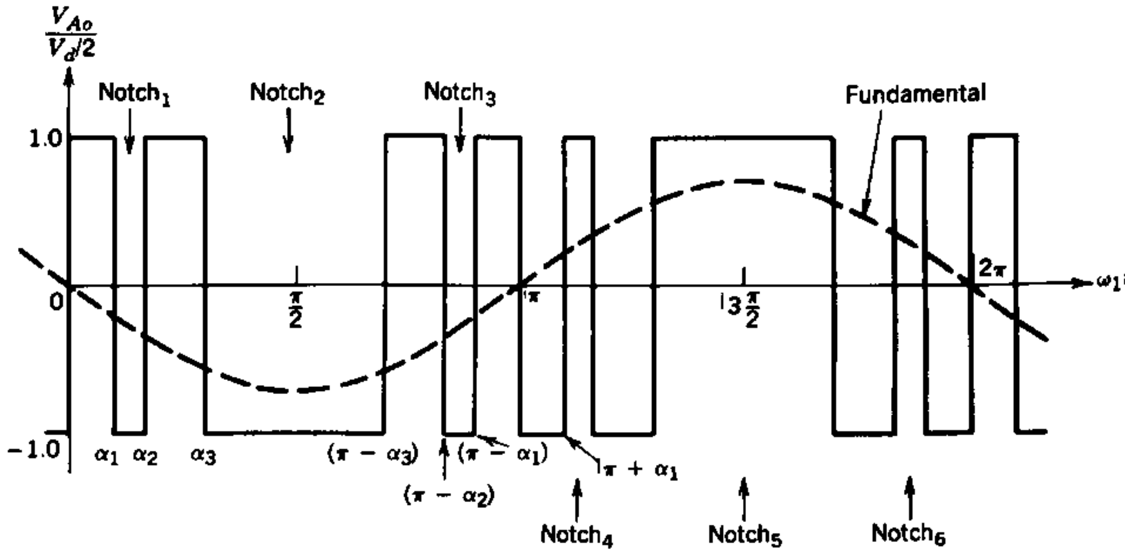
Effect of Blanking Time (Dead-Time)

- Effect on the output voltage

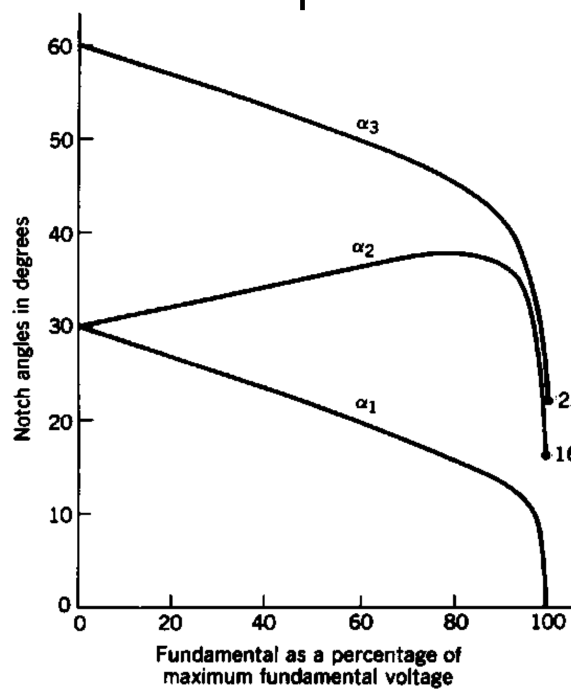




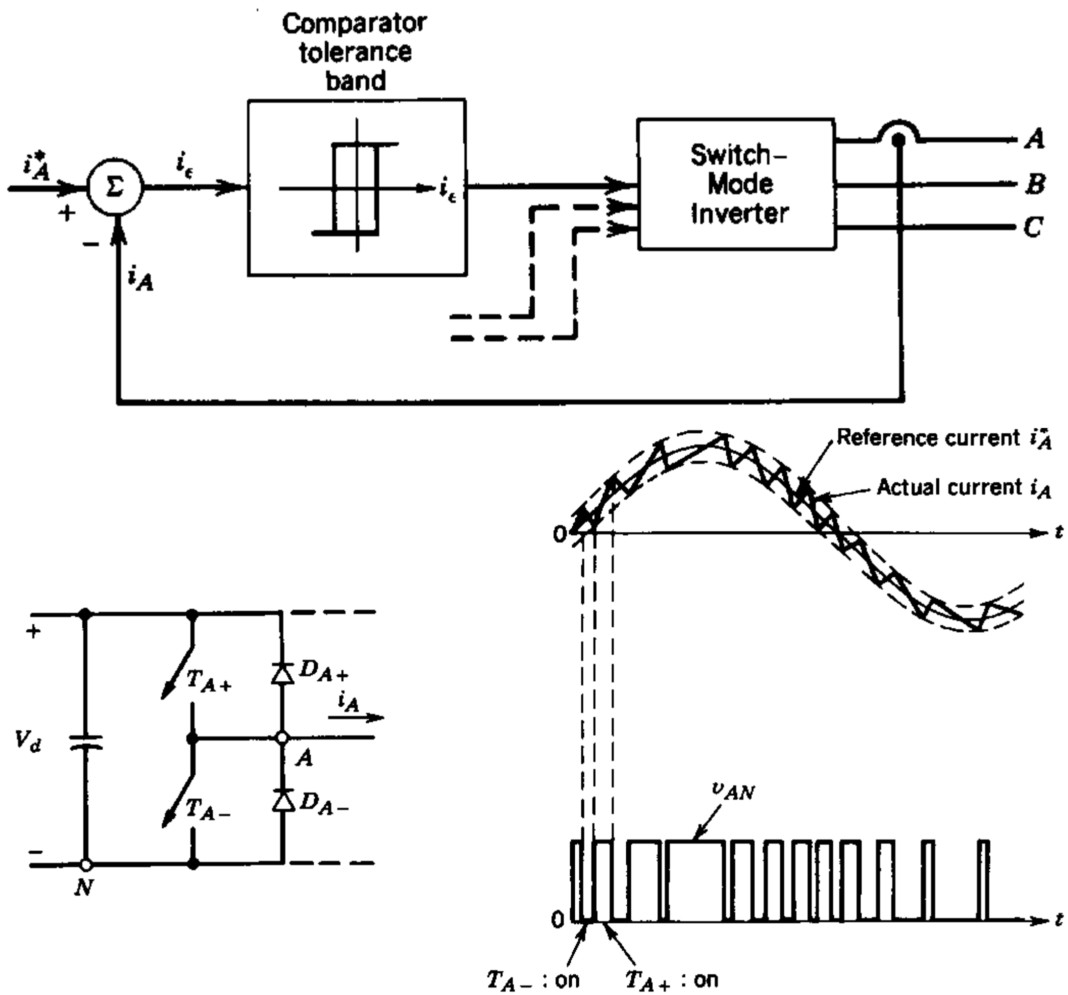
Programmed Harmonic Elimination



- Angles based on the desired output

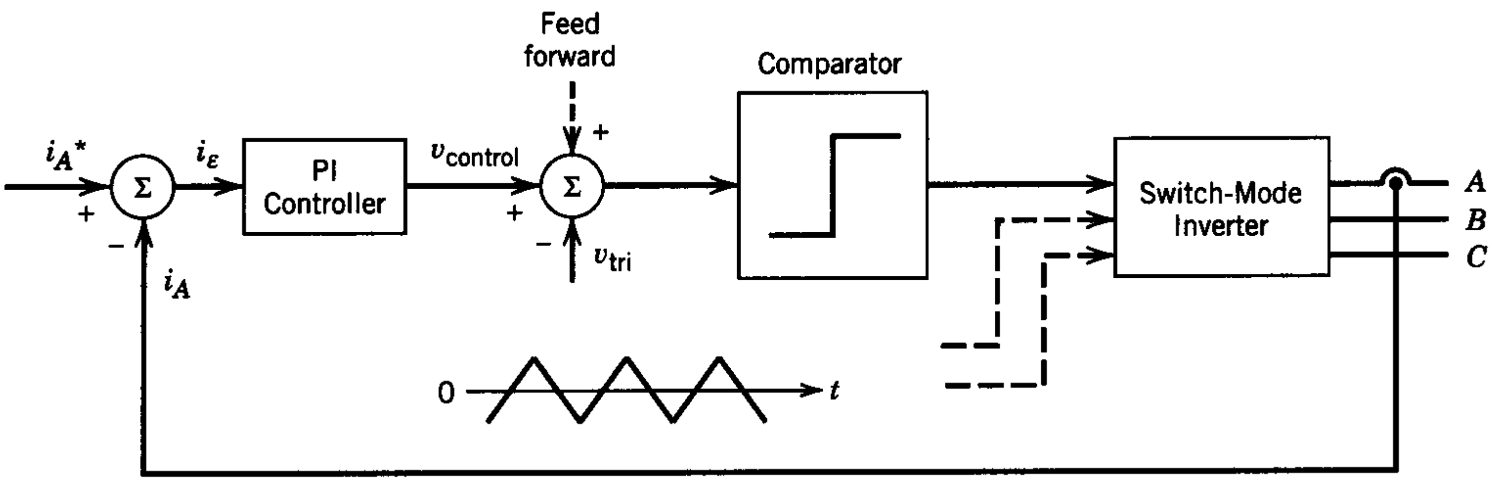


Tolerance-Band Current Control



- Results in a variable frequency operation

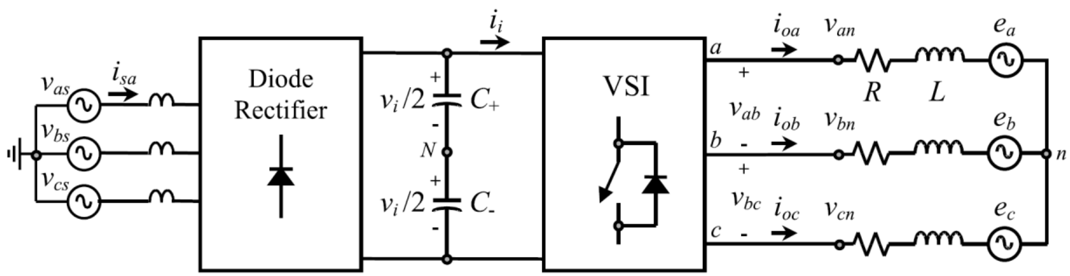
Fixed-Frequency Operation

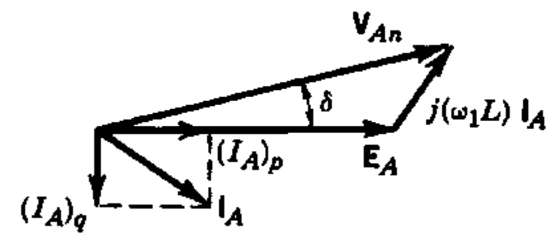


- Better control is possible using *dq* analysis!!!

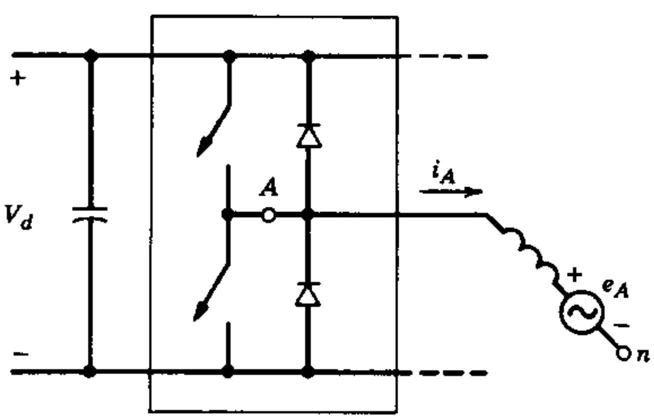
Transition from Inverter to Rectifier Mode

- Can analyze based on the fundamental-frequency

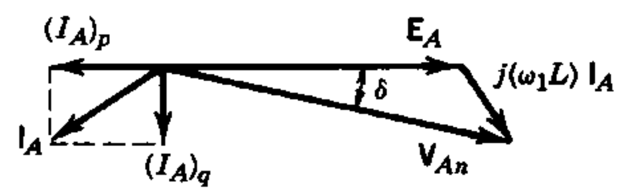




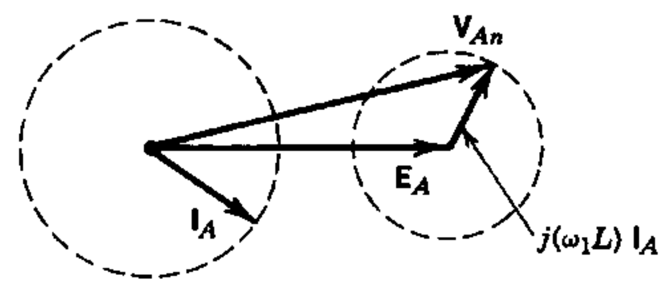
(b)



(a)

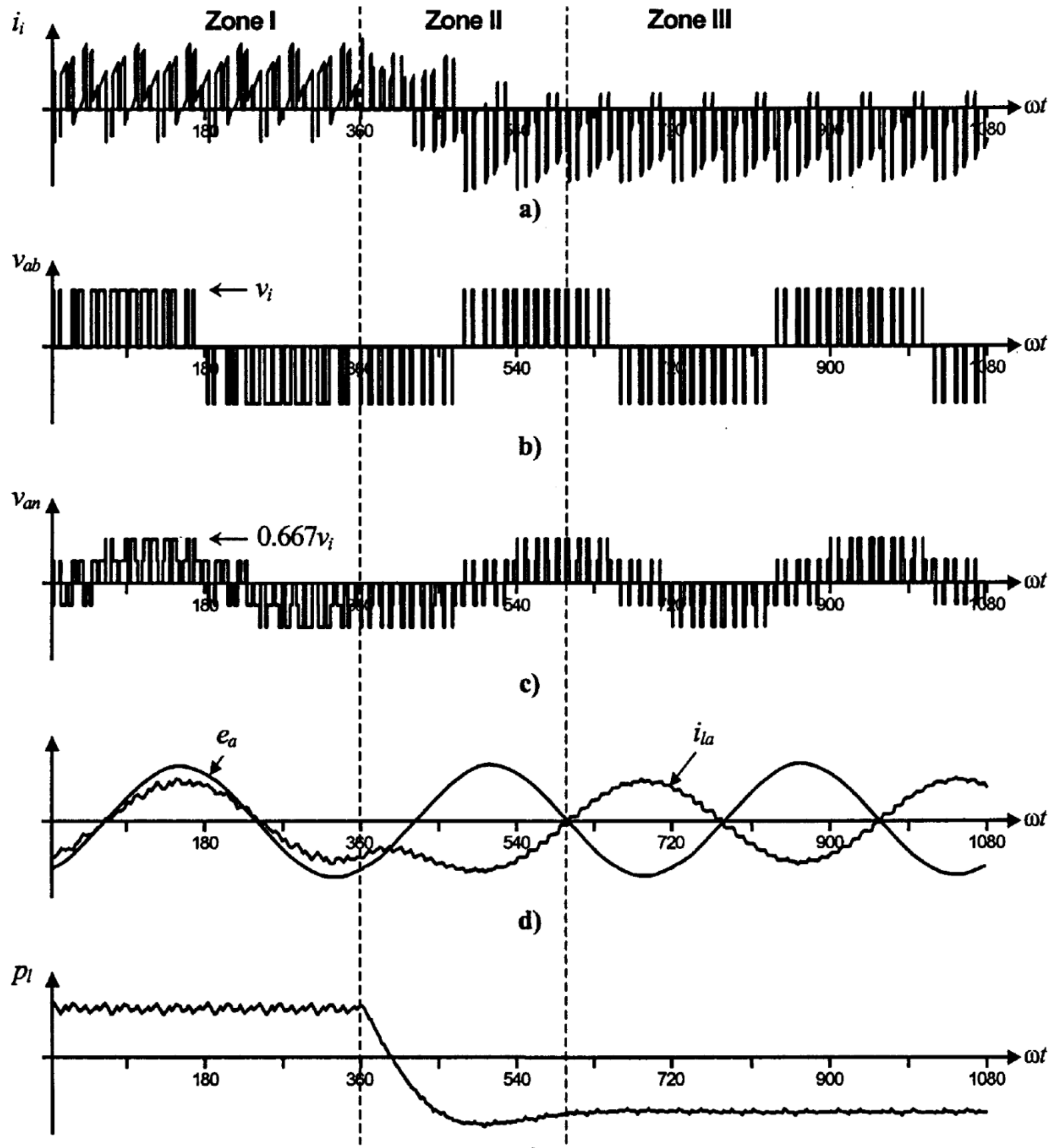


(c)

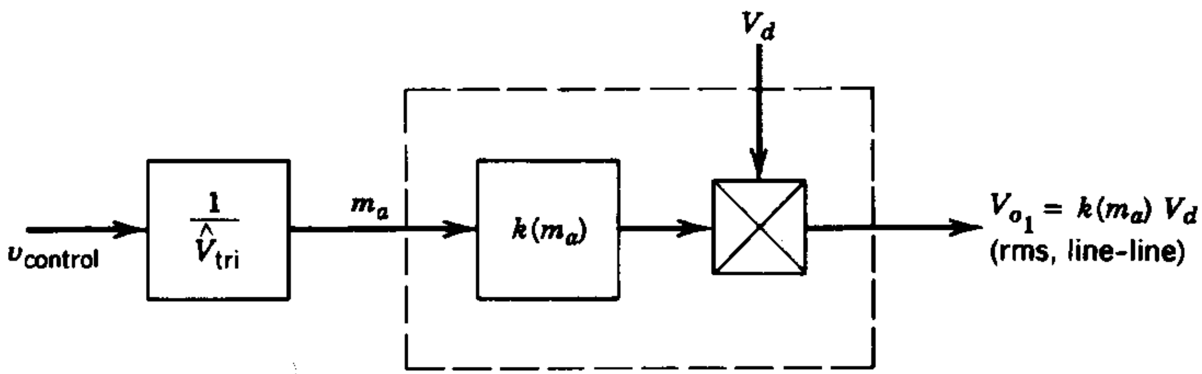


(d)

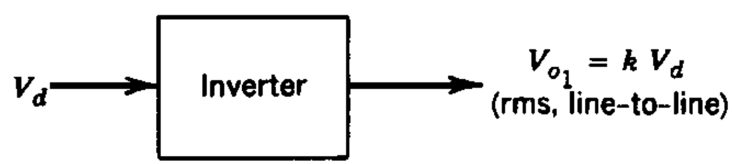
Transition from Inverter to Rectifier Mode



Functional representation in a block-diagram form of DC-AC Inverters

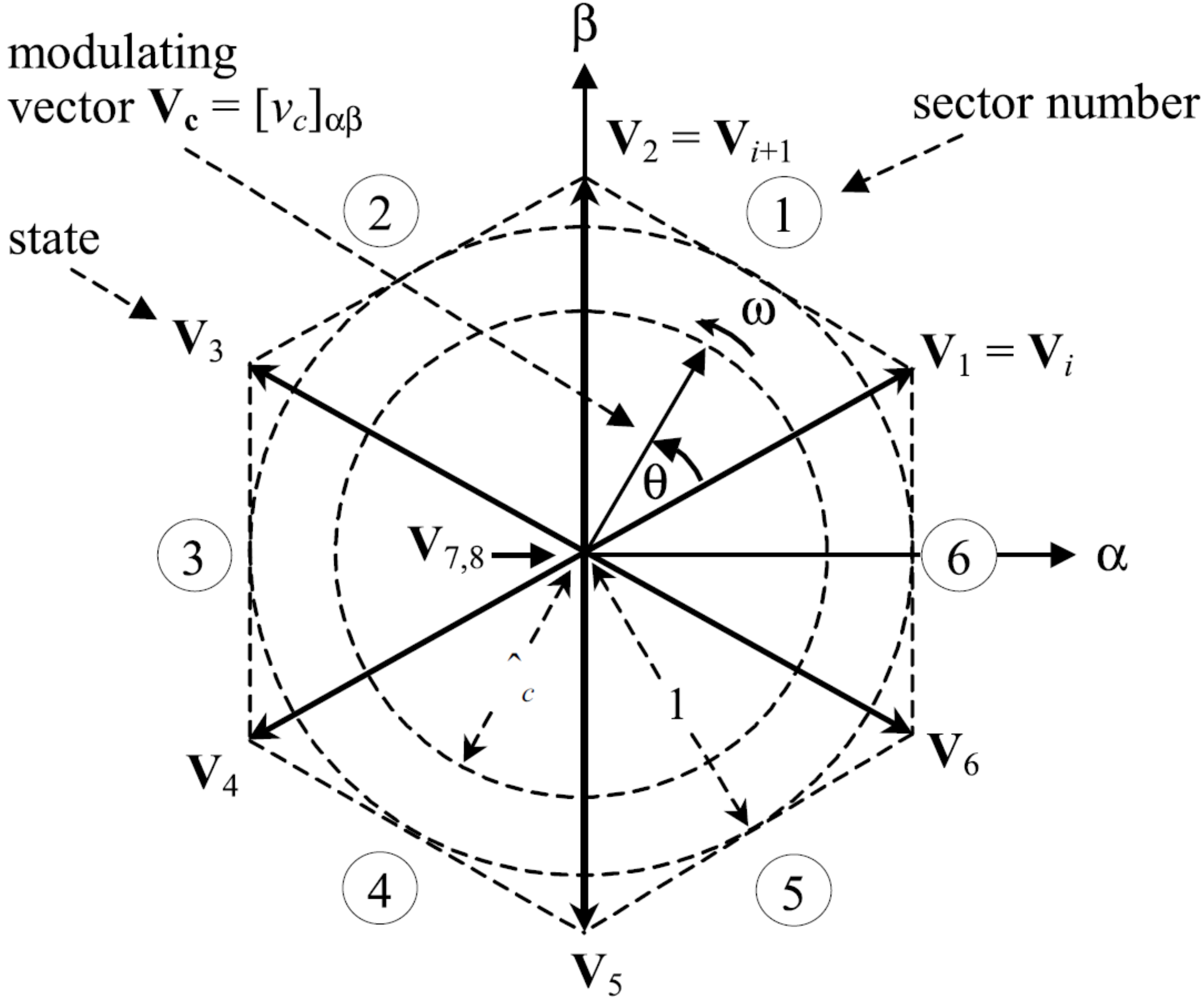


for $m_a \leq 1.0$ $\quad k(m_a) = 0.707\,m_a$ 1-phase
$= 0.612\,m_a$ 3-phase



$k = 0.9$ 1-phase
$= 0.78$ 3-phase

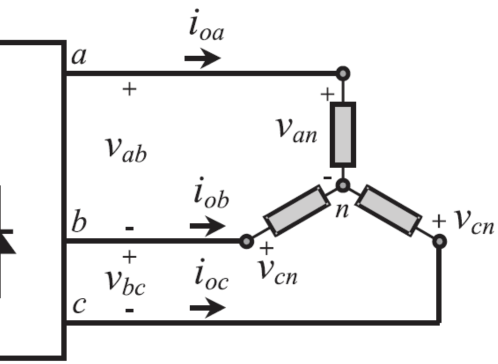
Space-Vector Transformation

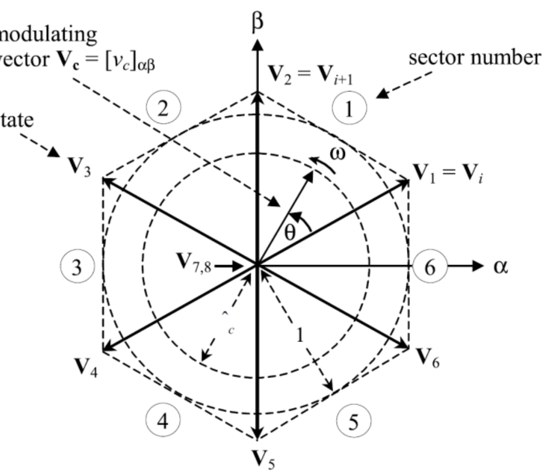


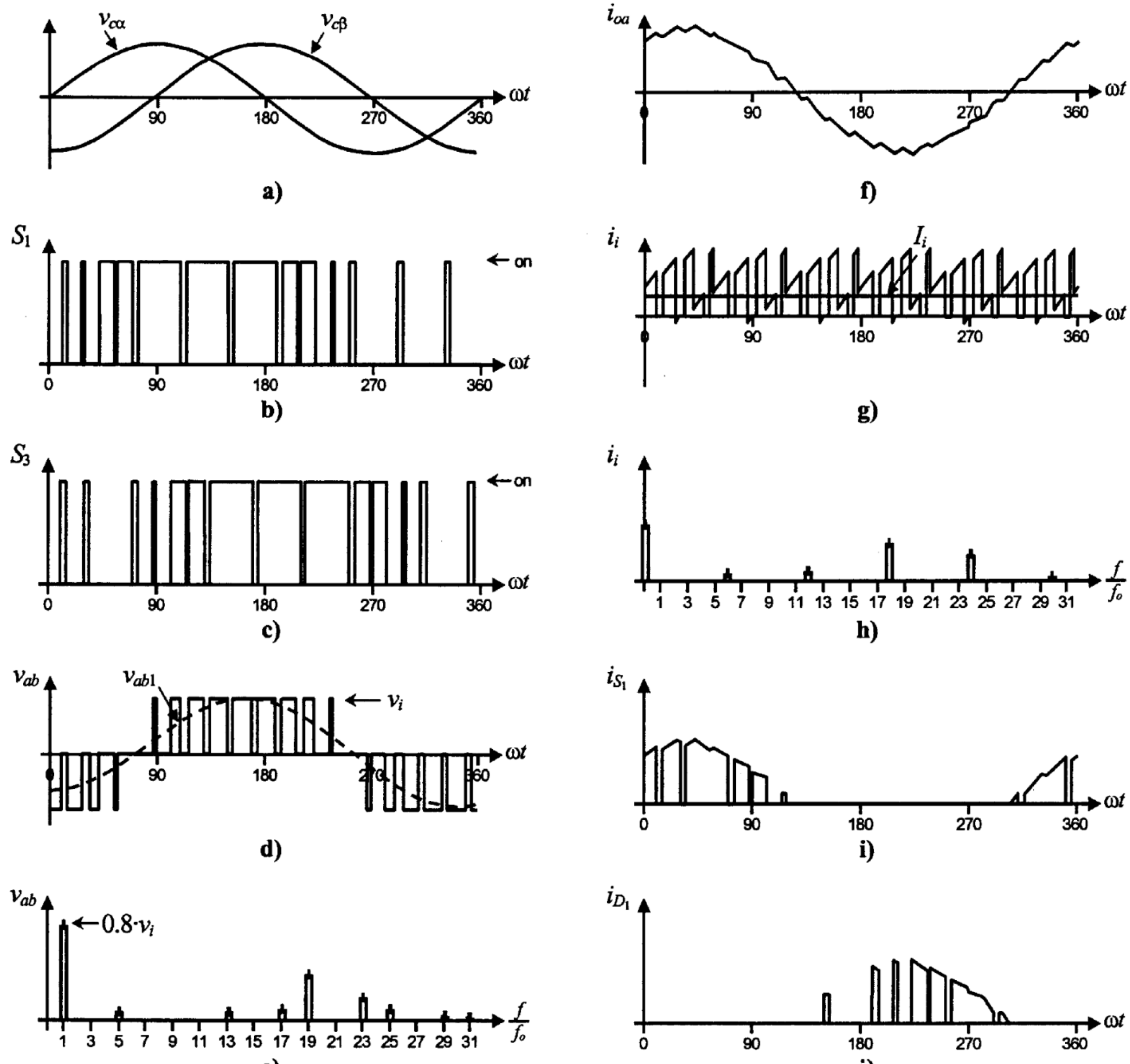
$$v_{abc} = [v_a \quad v_b \quad v_c]$$

$$v_{\alpha\beta 0} = [v_\alpha \quad v_\beta \quad v_0]$$

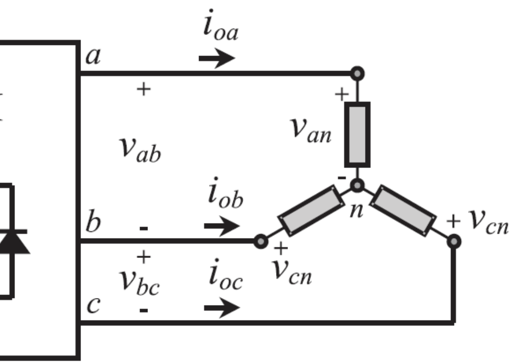
Space-Vector Modulation

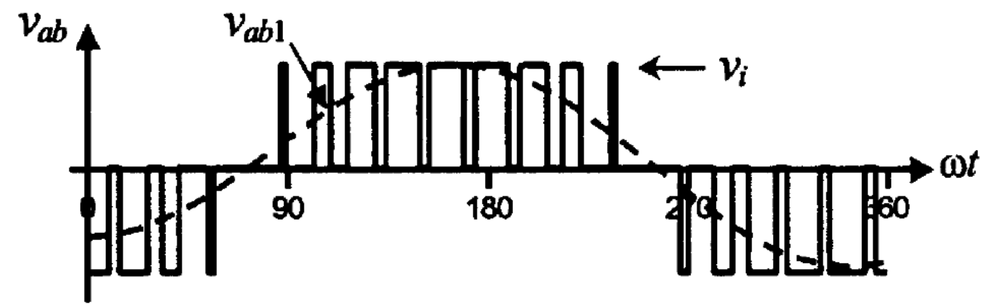




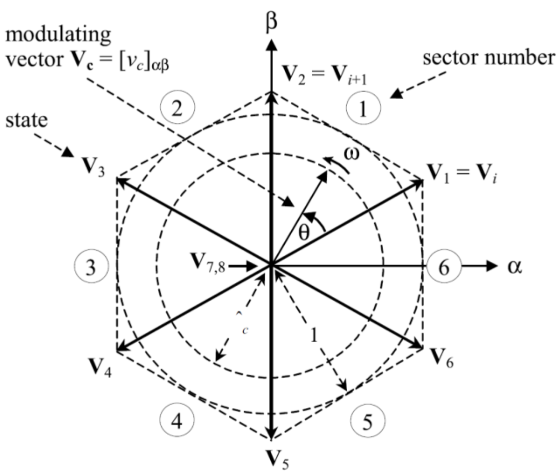


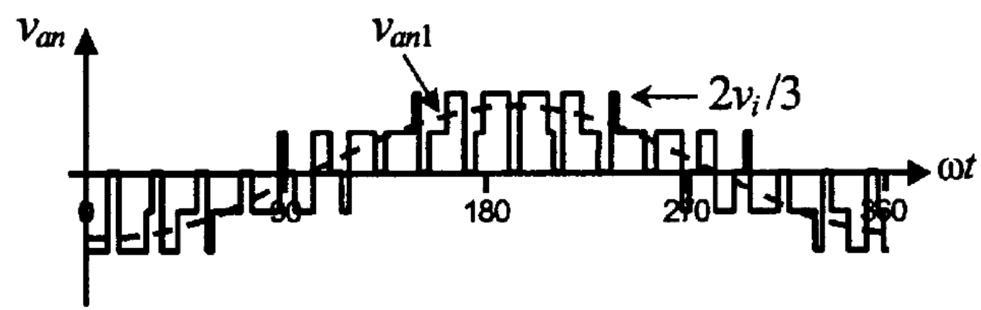
Space-Vector Modulation
Phase Voltage





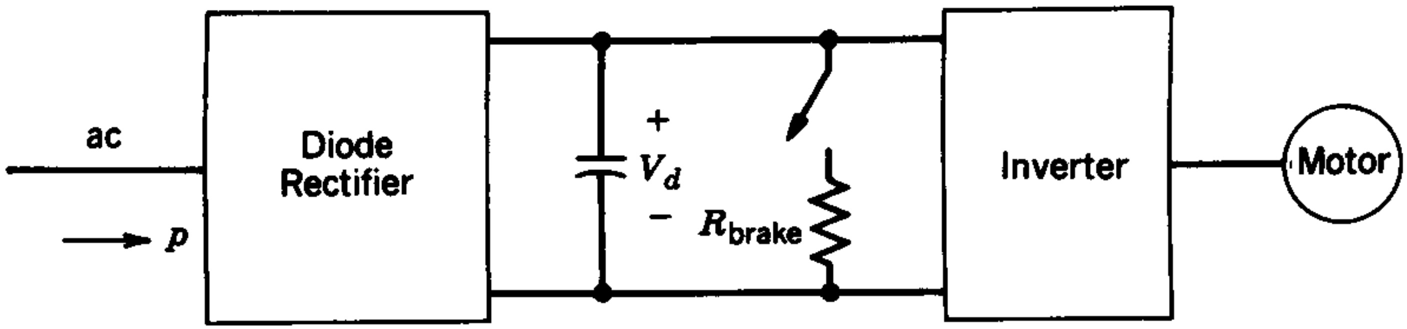
a)



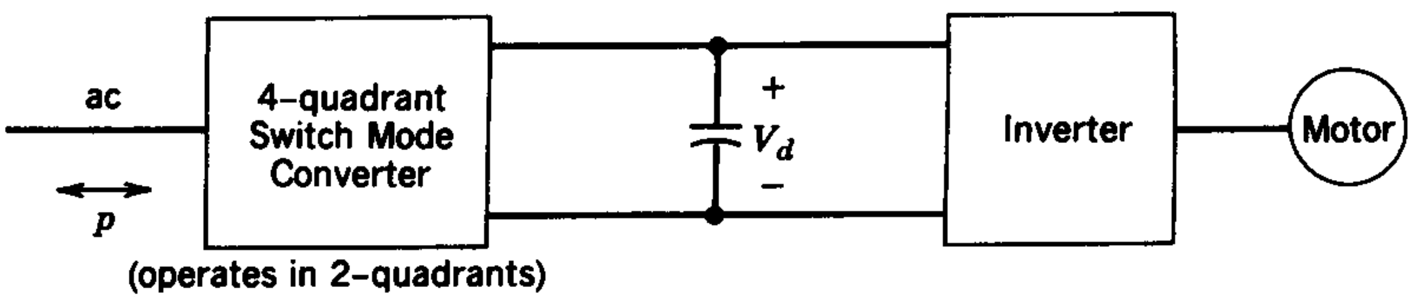


b)

Recovered/Regenarive breaking

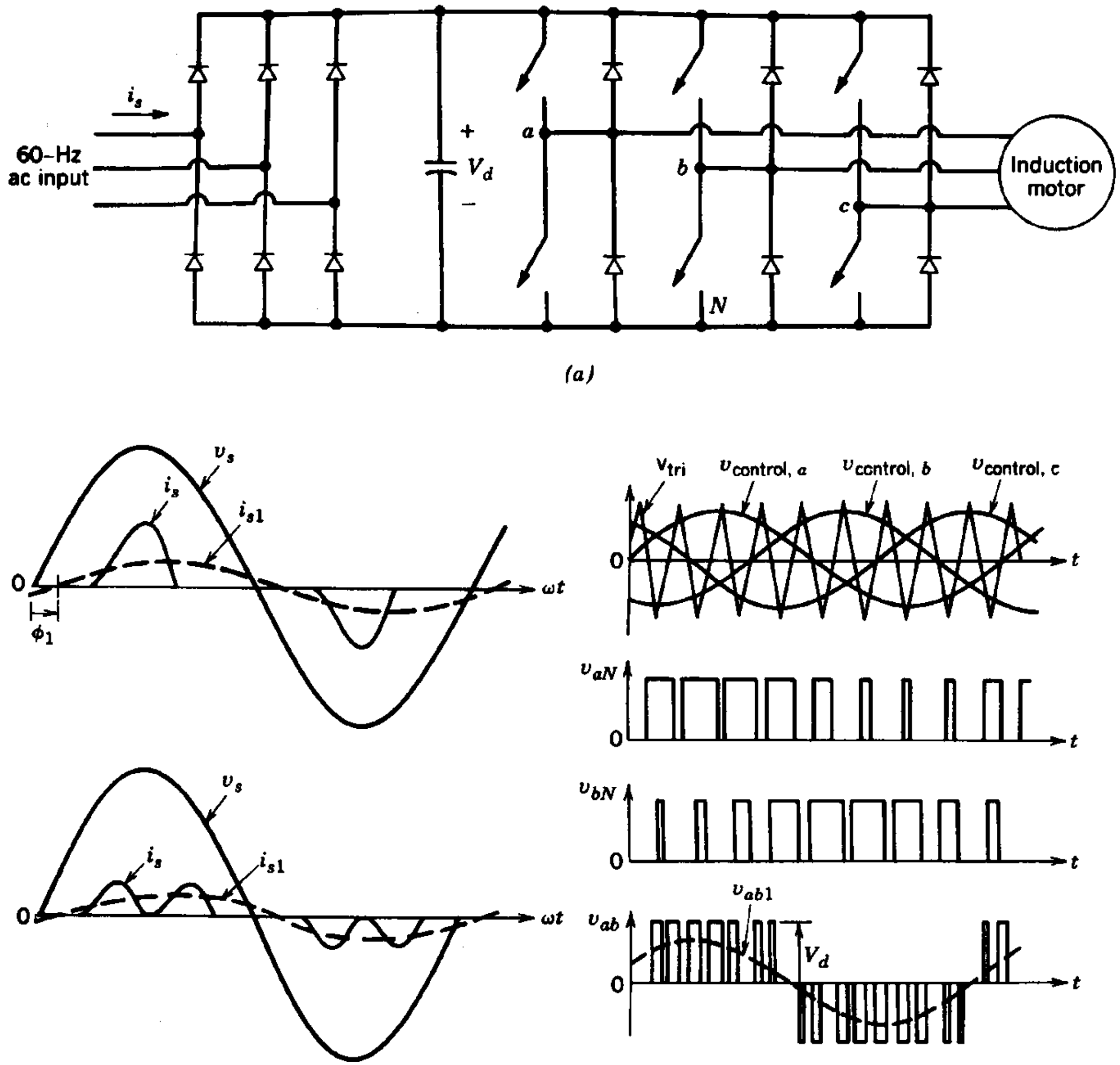


(a)

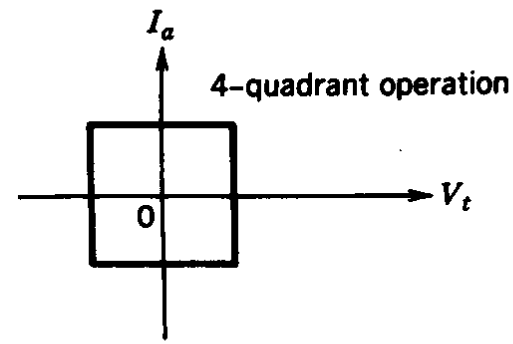


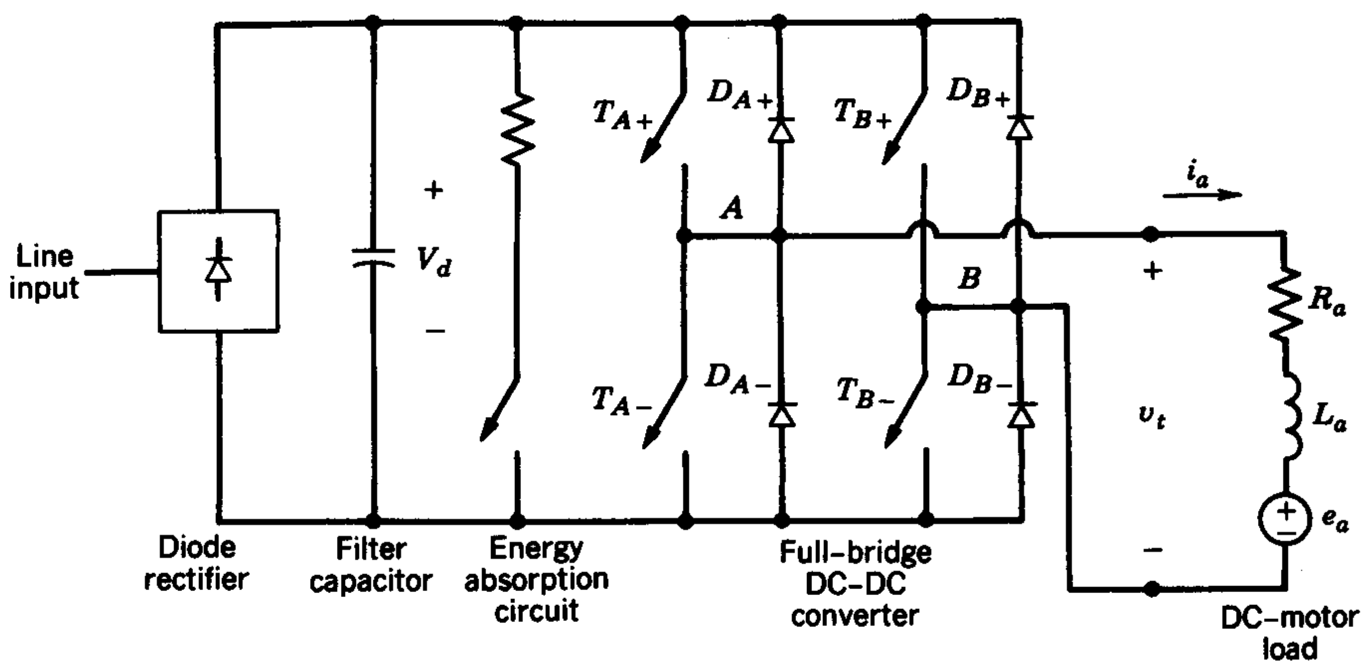
(b)

Induction Motor Power Converter



DC motor drive





Homework