TSTE19 Power Electronics

- Lecture 7
- Tomas Jonsson
- ISY/EKS

Outline

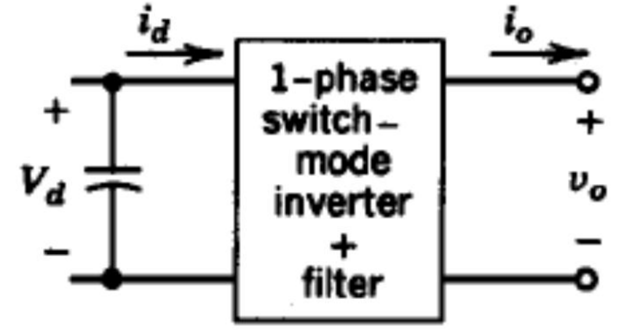
- DC-AC switching inverters
  - Switch-mode principle
  - Single-phase inverter
  - PWM switching
  - Current ripple and commutation

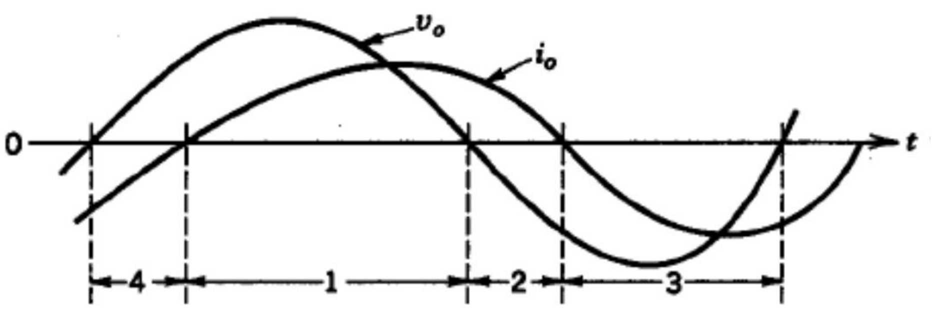
Switch-mode dc-ac inverter

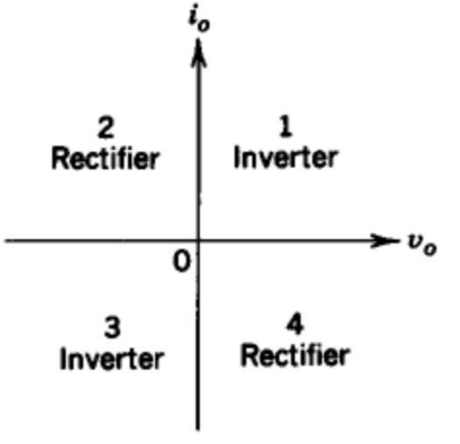
- Sinusoidal ac
- Controlled magnitude
- Controlled frequency
- Common use
  - Ac motor drive
  - Uninterruptable ac power supply
  - 12V DC -> 230V AC inverter

Switch-Mode DC-AC Inverter

- Fixed dc-voltage
- Switched output filtered to generate sinusoidal v_o
- Assume inductive load at v_o, i_o lagging
- Waveforms in all four quadrants



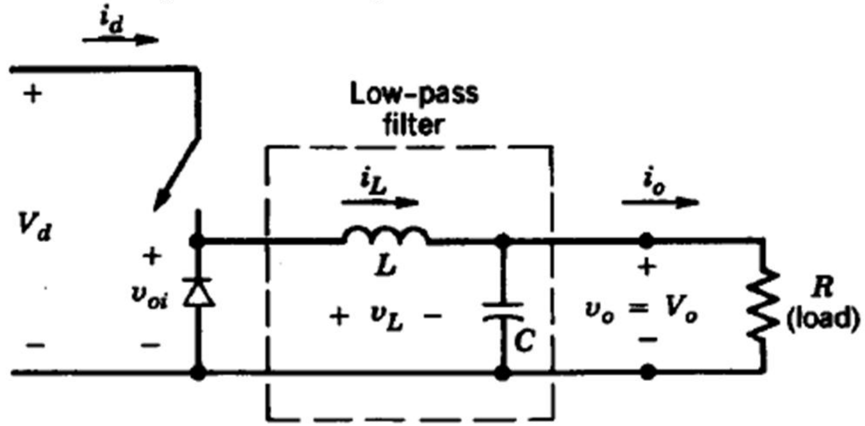




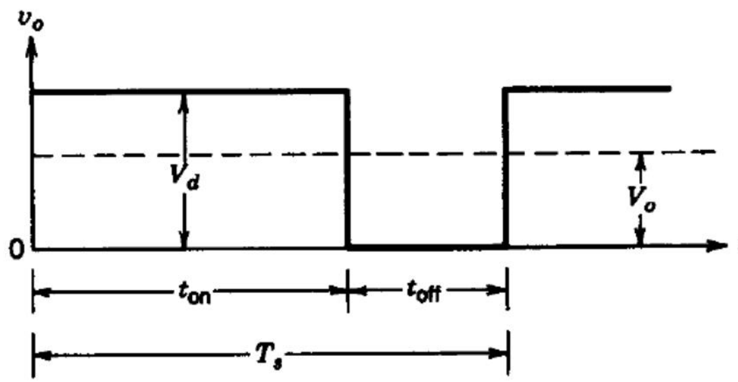
Compare: Step-down (buck) converter

- Output voltage amplitude controlled by switch duty cycle

$$\frac{V_o}{V_d} = D$$



- Uni-directional load current defined by diode, from high voltage to low voltage side

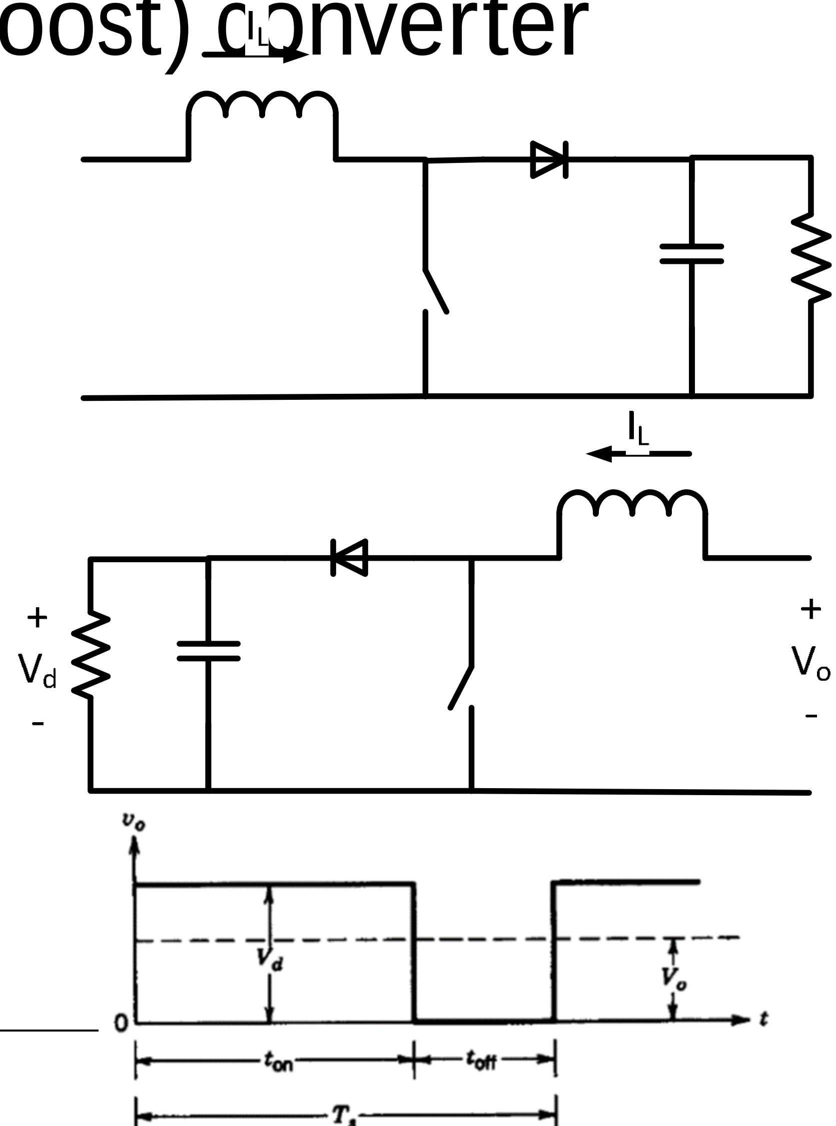


Compare: Step-up (boost) converter

- Voltage ratio defined by duty cycle

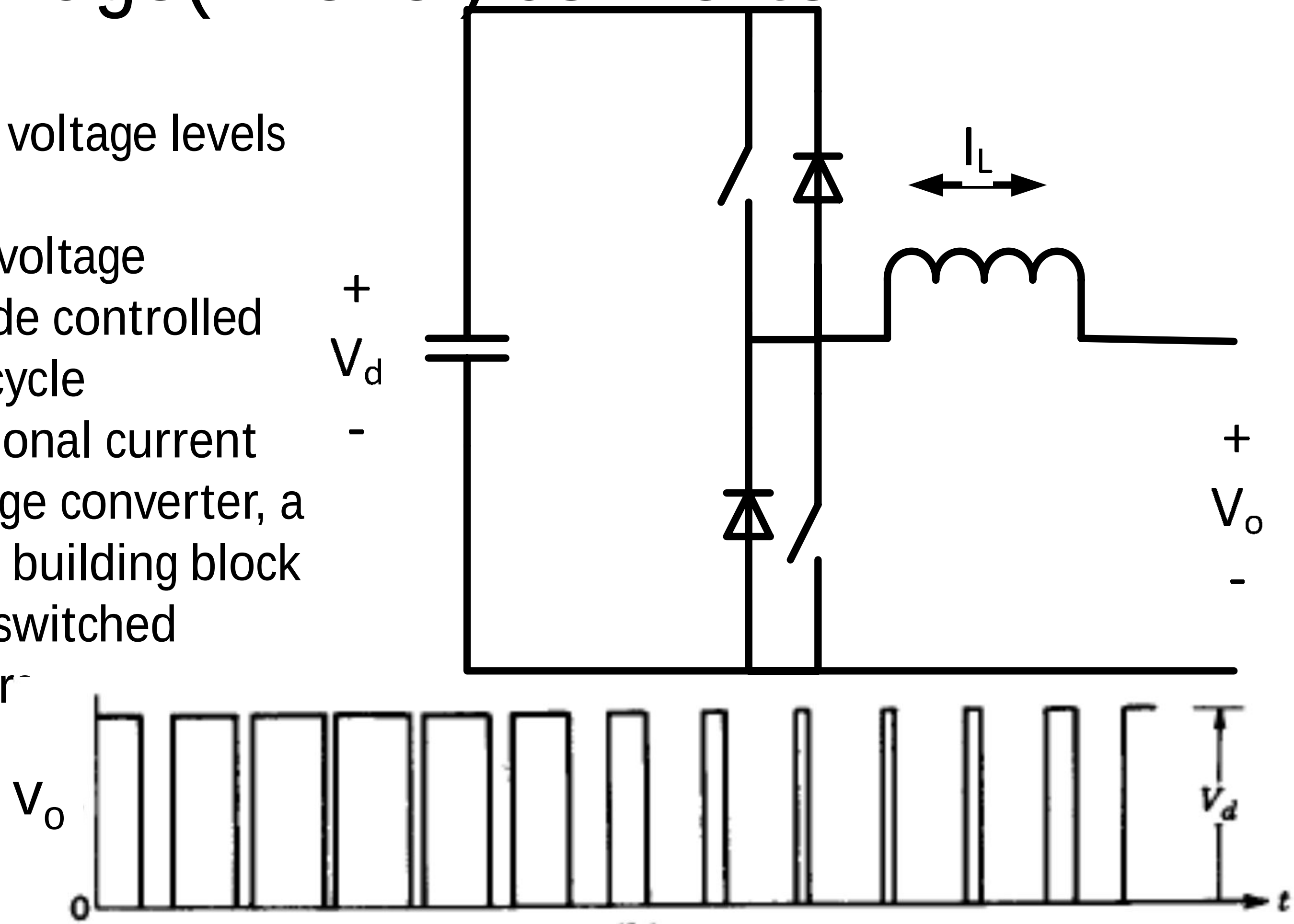
$$V_o / V_d = 1 - D$$

- Current from low voltage side to high voltage side



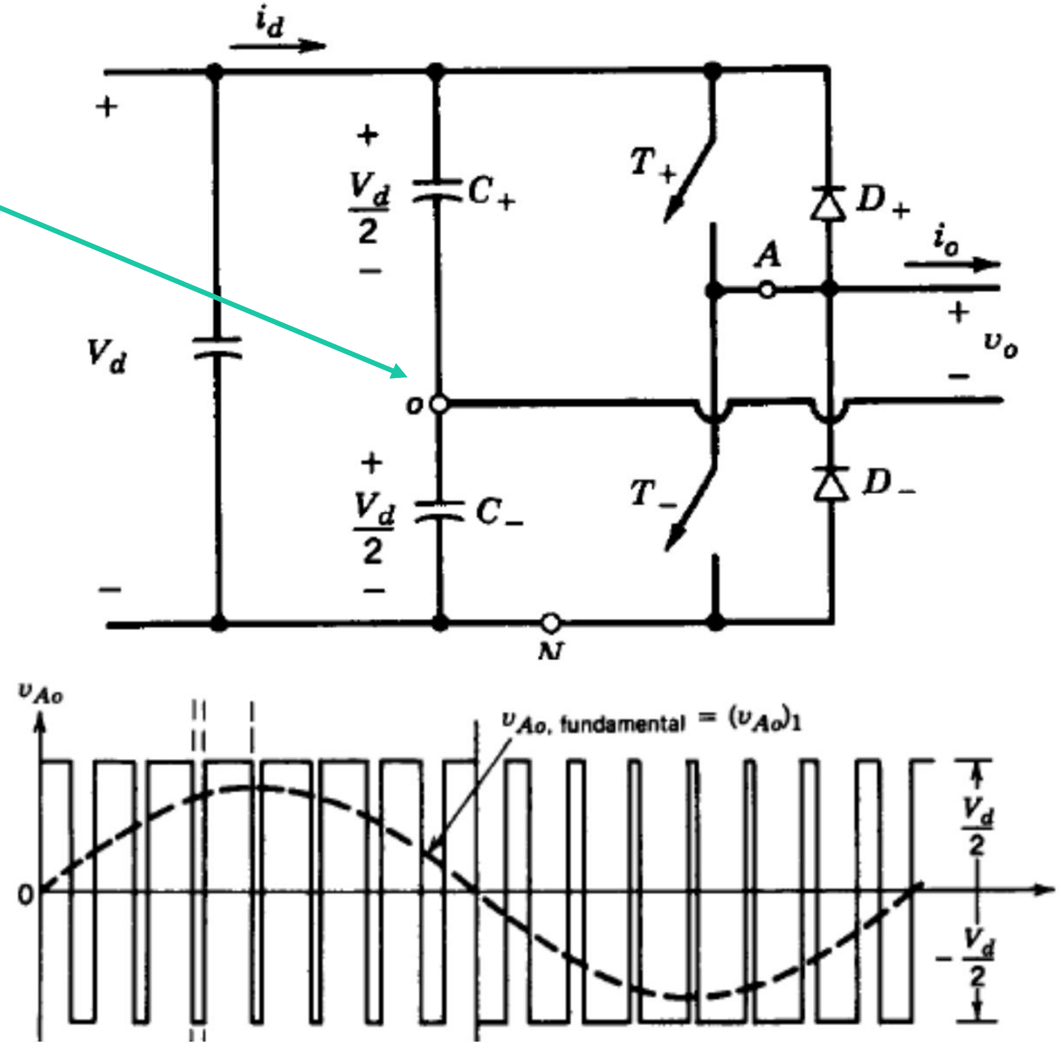
Half-bridge(2-level) converter

- 2 output voltage levels (V_d, 0)
- Average voltage magnitude controlled by duty cycle
- Bi-directional current
- Half-bridge converter, a common building block in many switched converters



Half-bridge (2-level) converter

- DC-side midpoint '0' reference point for ac-output
- Output voltage switched between $+\frac{V_d}{2}$ and $-\frac{V_d}{2}$



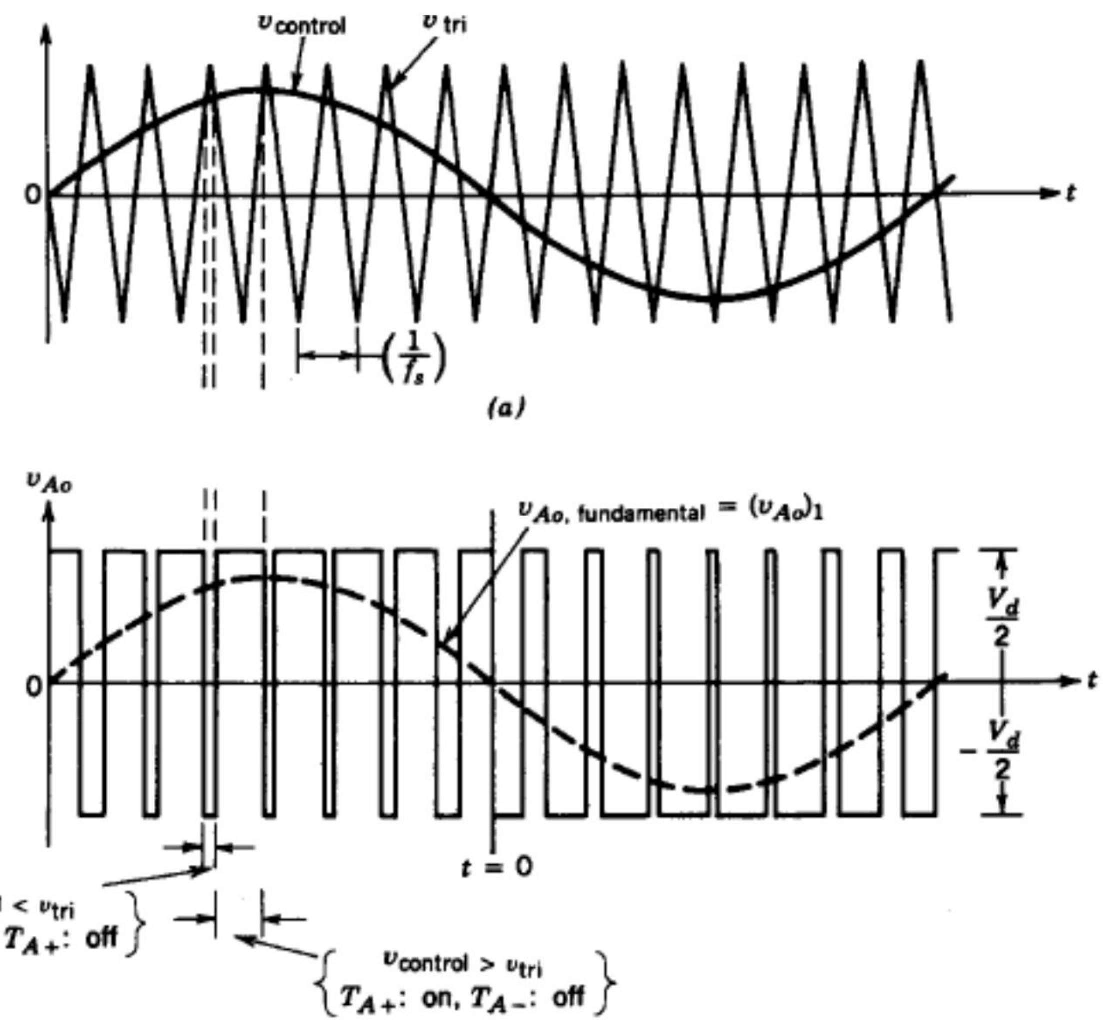
Pulse-width modulated switching scheme

- Constant f_s
- Amplitude modulation ratio

$$m_a = \frac{\hat{V}_{control}}{\hat{V}_{tri}}$$

- Frequency modulation ratio (pulse number)

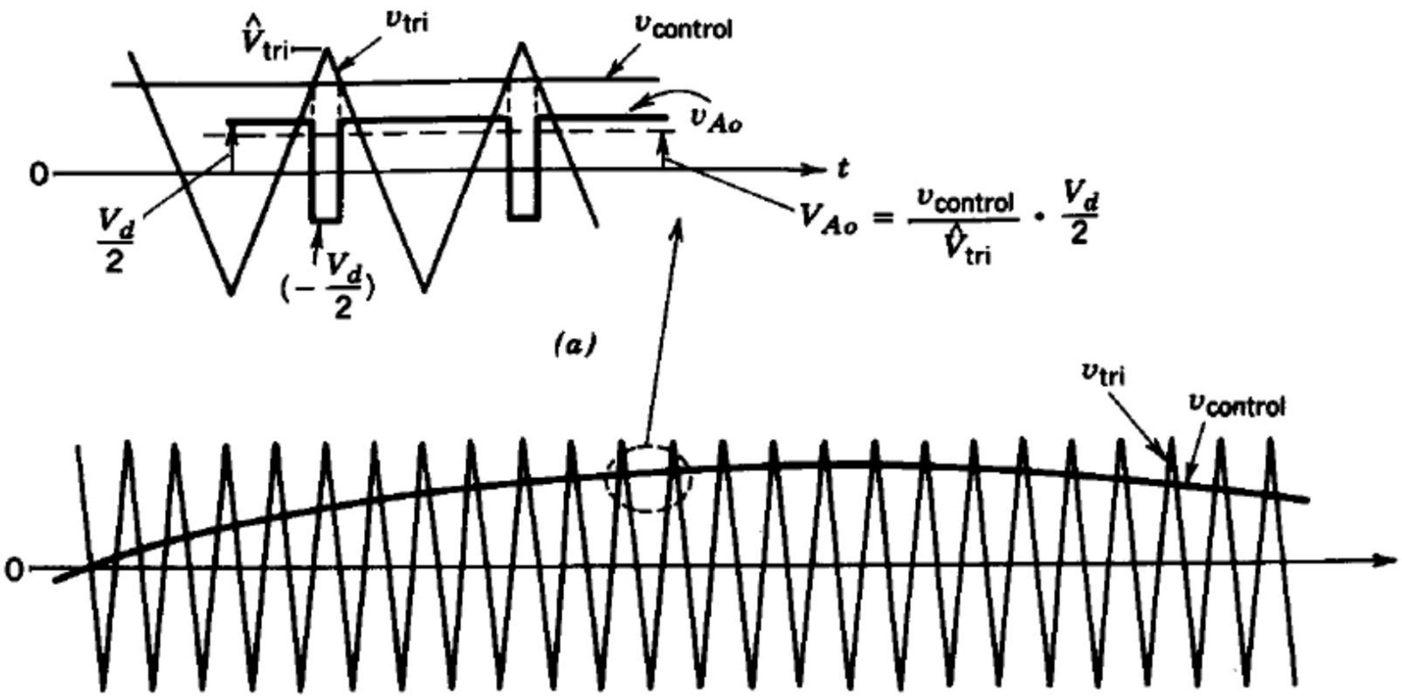
$$m_f = \frac{f_s}{f_1}$$



PWM modulation control

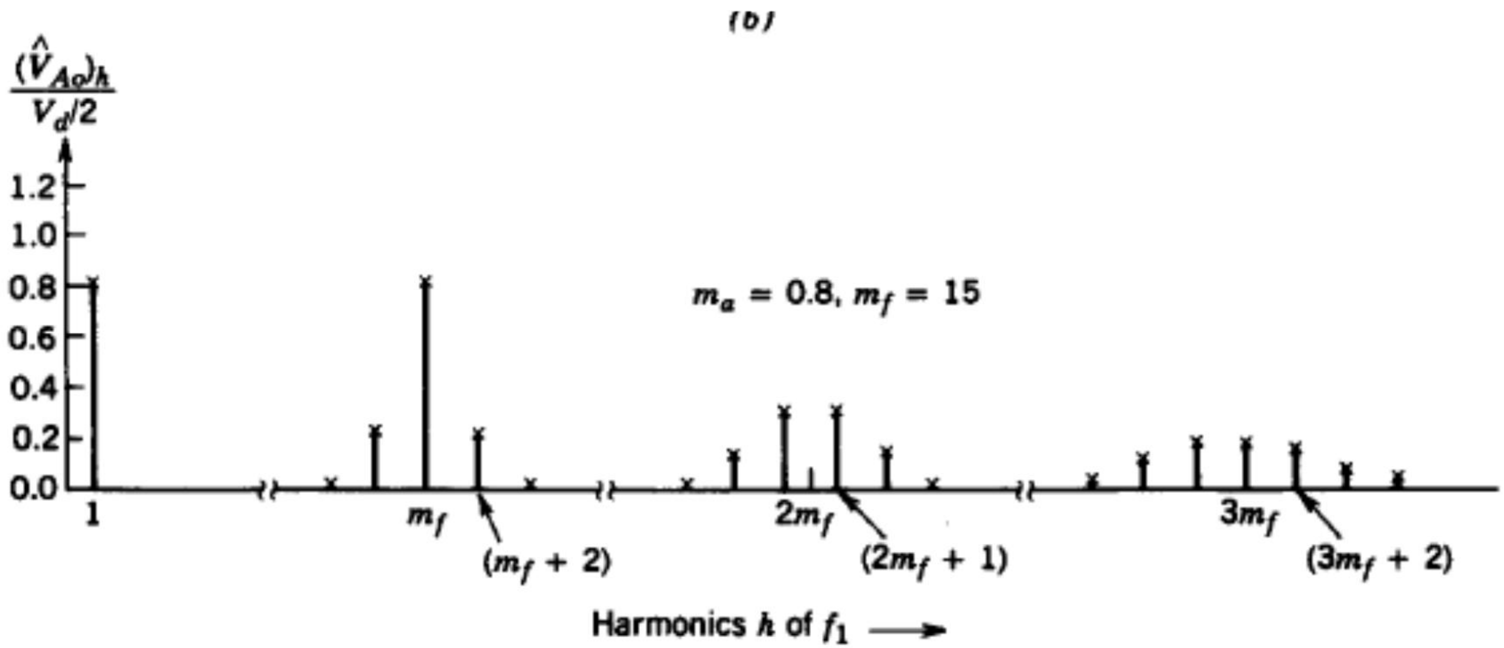
- Fundamental frequency output, $\hat{V}_{ao1} \sin \omega_1 t$
- $0 < m_a < 1$, linear range

$$\hat{V}_{ao1} = m_a \frac{V_d}{2}$$



PWM modulation harmonics

- Harmonics as sidebands around multiples of switching frequency



Harmonics due to m_a and m_f>9

- For m_f < 9 is harmonics almost independent of m_f
- Choose m_f odd integer
  - Odd symmetry
  - Half-wave symmetry
  - Only odd harmonics
  - Even harmonics = 0
  - With $v_A = \hat{V}_A \sin \omega t$ all harmonics $\sin h\omega t$

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

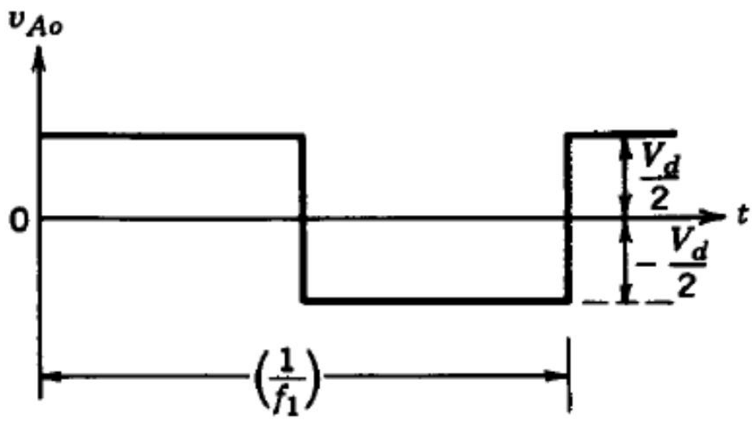
h \ m_a	0.2	0.4	0.6	0.8	1.0
1 Fundamental	0.2	0.4	0.6	0.8	1.0
m_f	1.242	1.15	1.006	0.818	0.601
$m_f \pm 2$	0.016	0.061	0.131	0.220	0.318
$m_f \pm 4$					0.018
$2m_f \pm 1$	0.190	0.326	0.370	0.314	0.181
$2m_f \pm 3$		0.024	0.071	0.139	0.212
$2m_f \pm 5$				0.013	0.033
$3m_f$	0.335	0.123	0.083	0.171	0.113
$3m_f \pm 2$	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

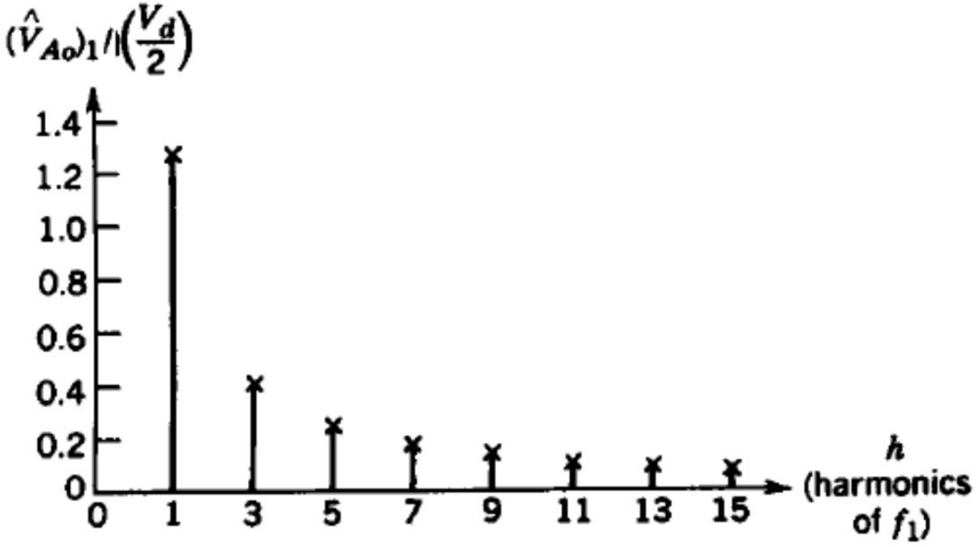
Note: $(\hat{V}_{Ao})_h/\frac{1}{2}V_d$ [$= (\hat{V}_{AN})_h/\frac{1}{2}V_d$] is tabulated as a function of m_a.

Square-wave switching

- Each switch on a half cycle of the output frequency f_1

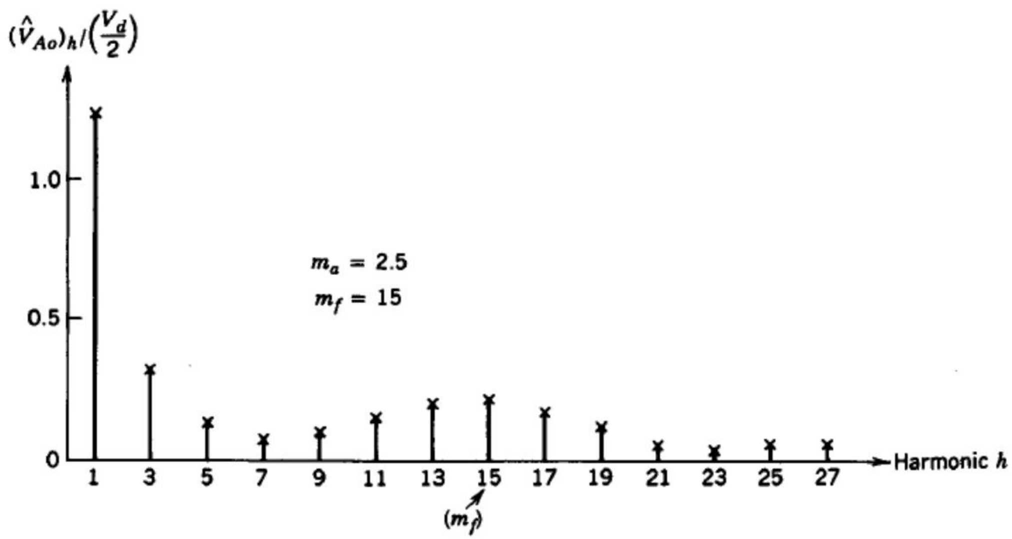
$$\left(\hat{V}_{ao}\right)_1 = \frac{4}{\pi}\frac{V_d}{2} = 1.273\,\left(\frac{V_d}{2}\right)$$

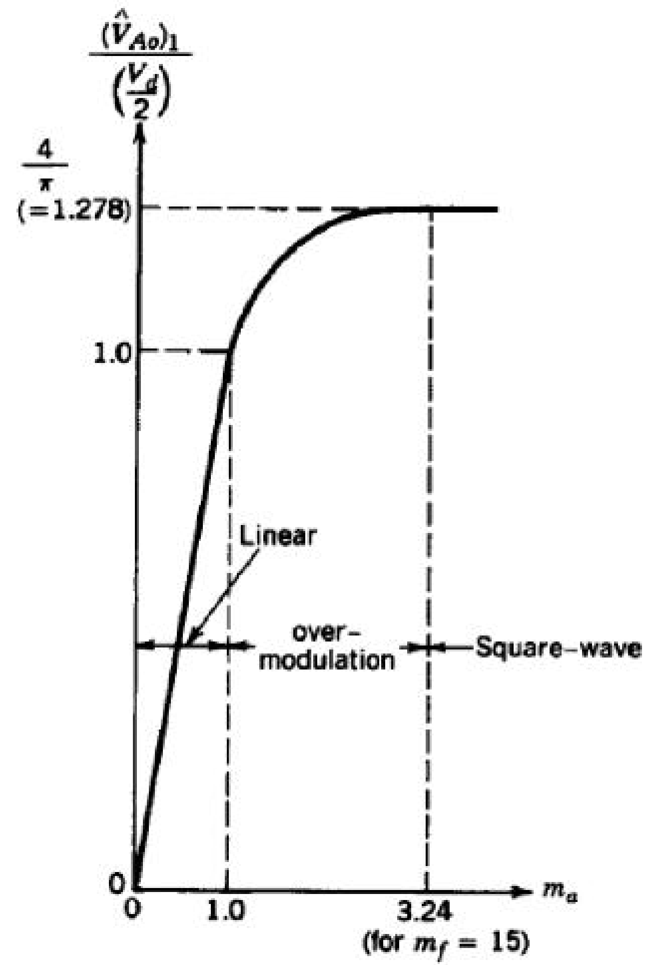




Over-modulation

- $m_a > 1$
- Increased harmonics with over-modulation



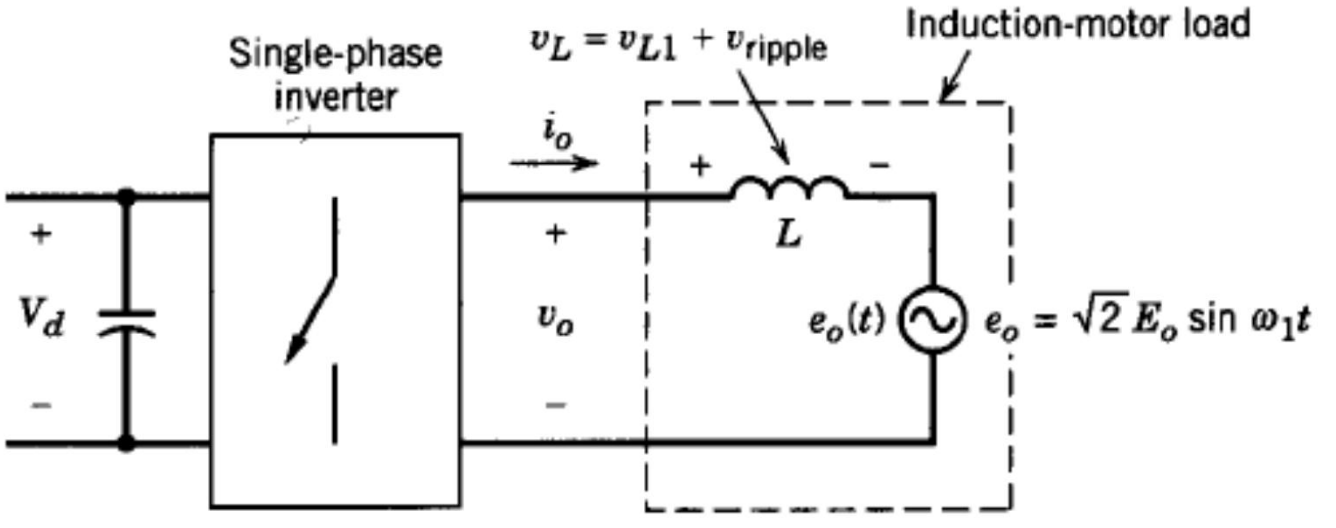


8-1

- In a single-phase full-bridge PWM inverter, the input dc voltage varies in a range of 295-325 V. Because of the low distortion required in the output v_o, $m_a < 1.0$.
  a) What is the highest V_{o1} that can be obtained and stamped on its nameplate as its voltage rating?
  b) Its nameplate volt-ampere rating is specified as 2000 VA, that is, $V_{o1,max} I_{o1,max} = 2000$ VA, where i_o is assumed to be sinusoidal. Calculate the combined switch utilization ratio when the inverter is supplying its rated volt-amperes.

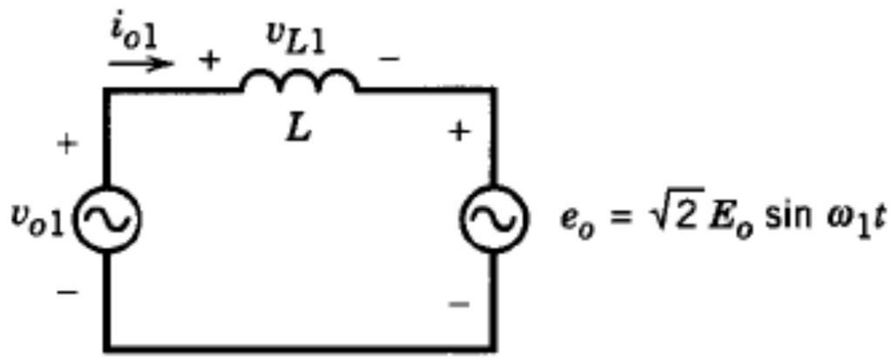
Ripple in single-phase inverter output

- Assume induction-motor load
- Counter electromotive force (emf) e_0

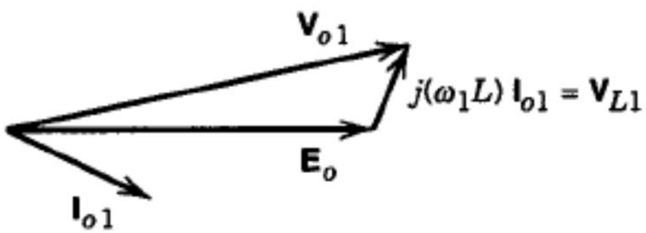


Ripple in single-phase inverter output, cont.

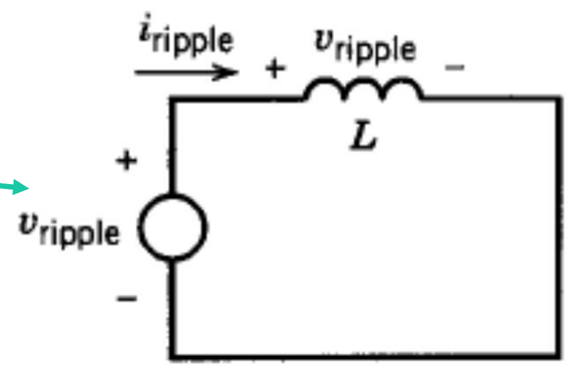
- Superposition gives two circuits



1. Fundamental frequency components

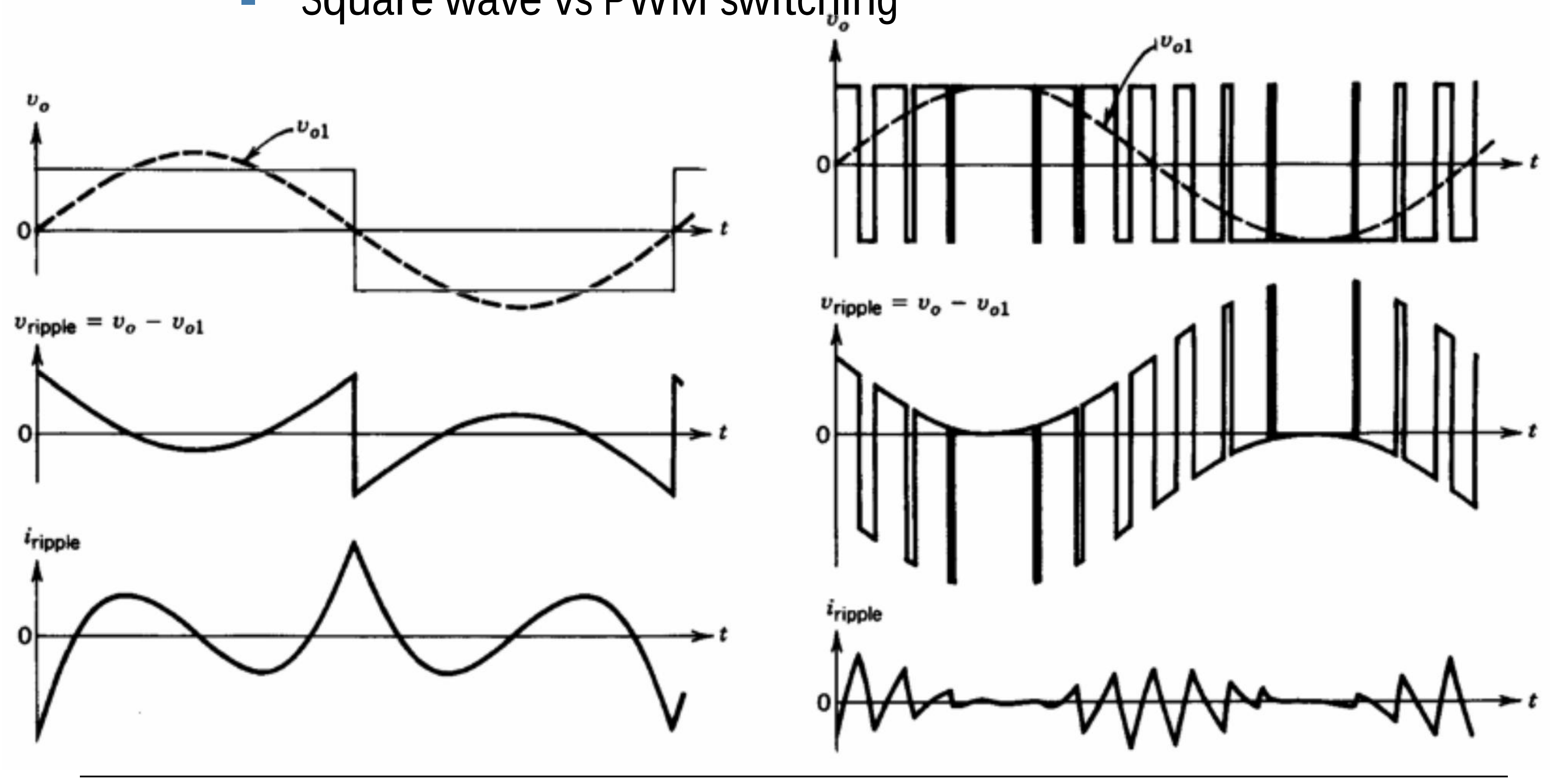


2. All voltage ripple across L



Ripple in single-phase inverter output, cont.

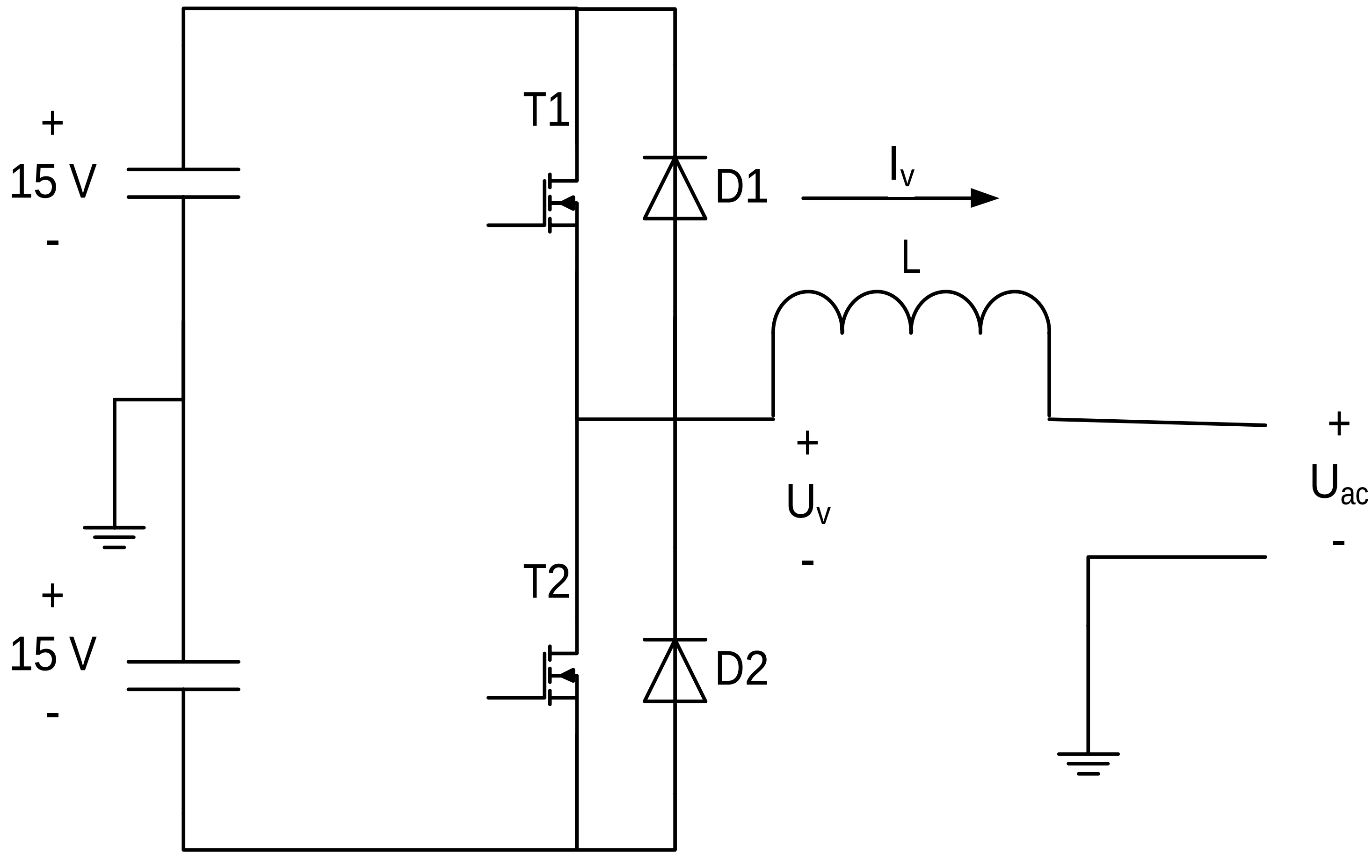
- Square wave vs PWM switching



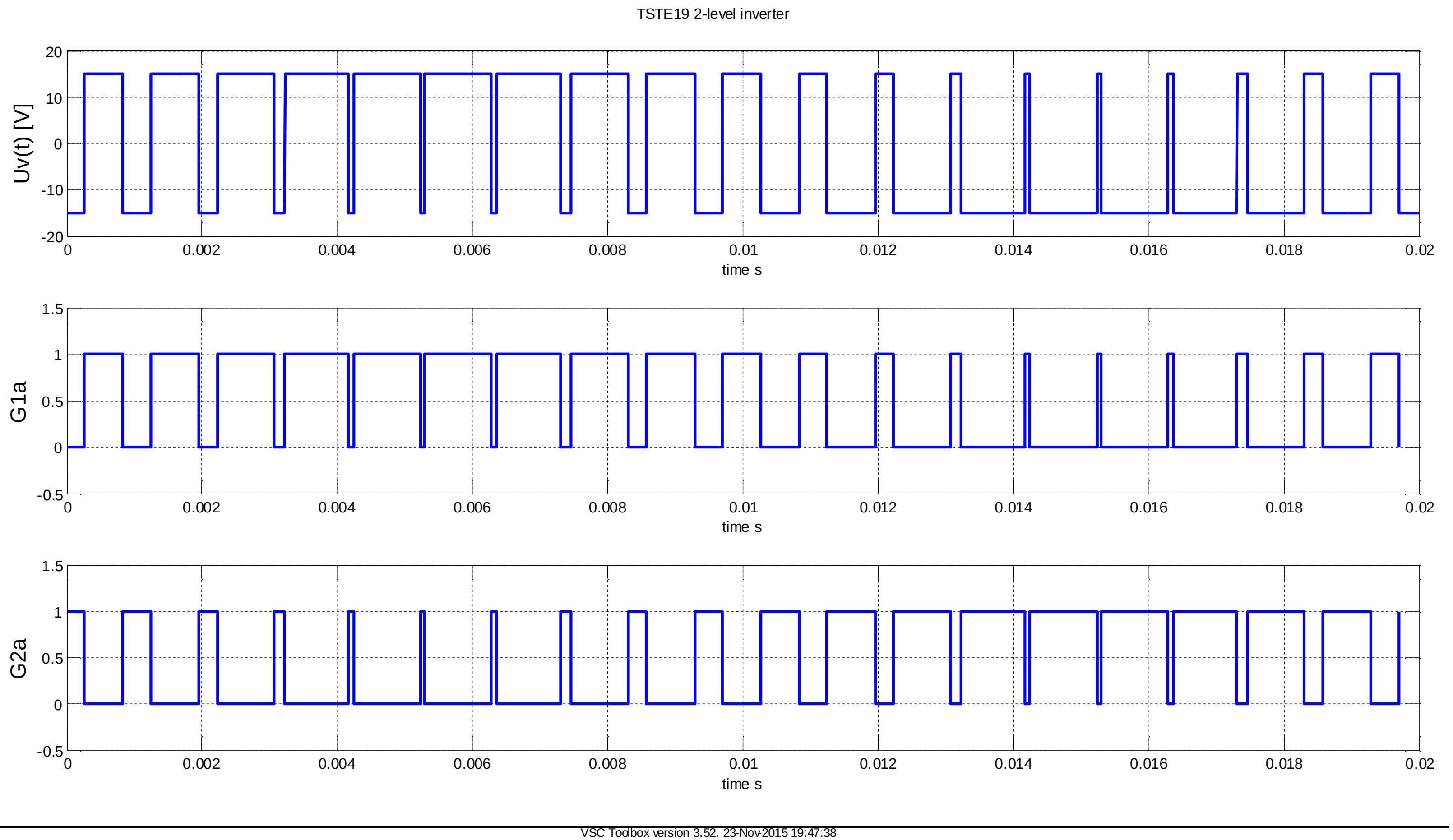
Switch utilization ratio

- The ratio between converter power rating and the combined rating of the switches
- $\frac{V_{o1,max} I_{01,max}}{q V_T I_T}$
- $V_{o1,max}$ max fundamental output rms voltage
- $I_{01,max}$ max fundamental output rms current
- q: number of switches
- V_T: Peak voltage rating a switching device
- I_T: Peak current rating of a switching device

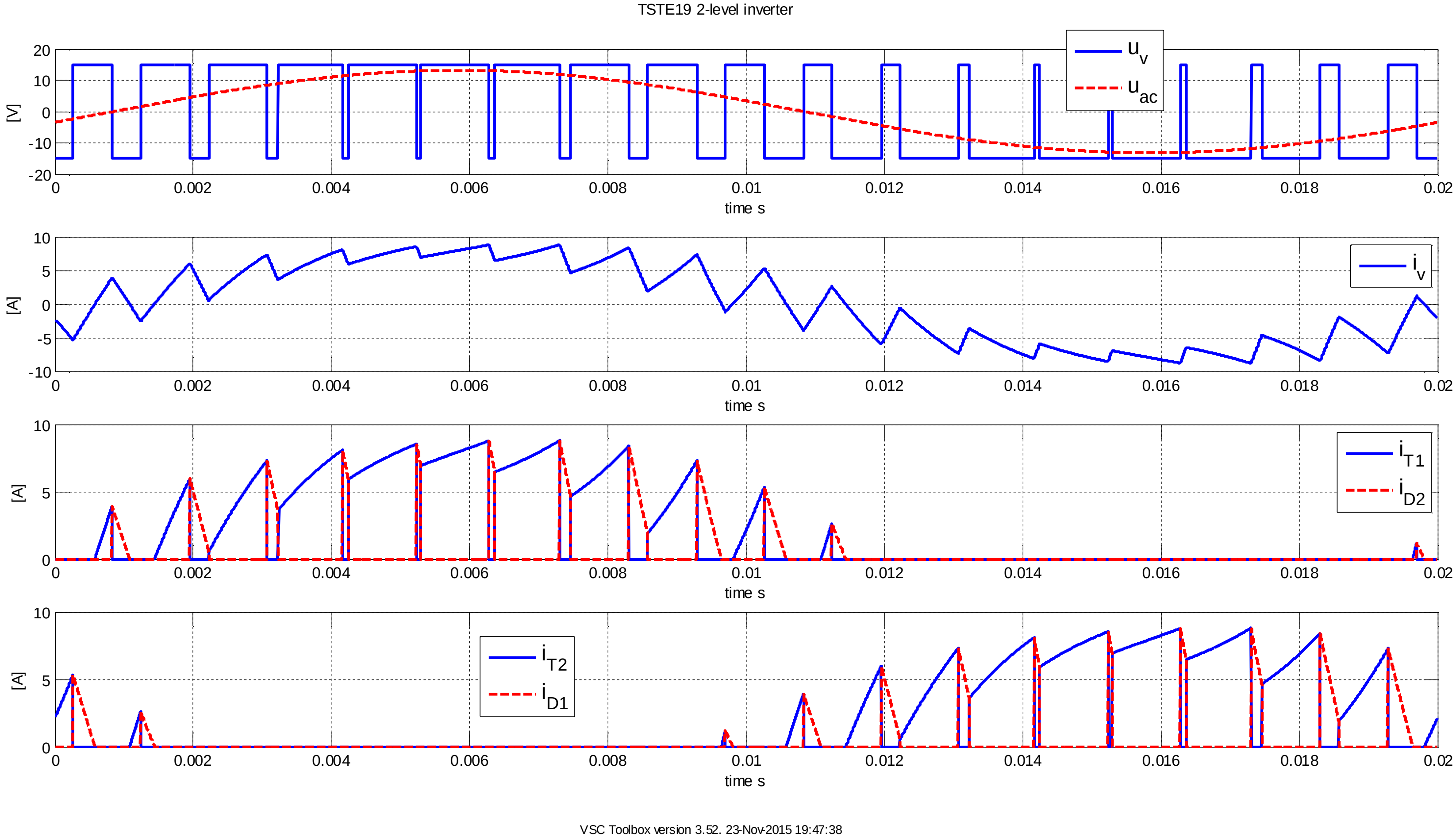
Half-bridge converter example



Output voltage & gate signals

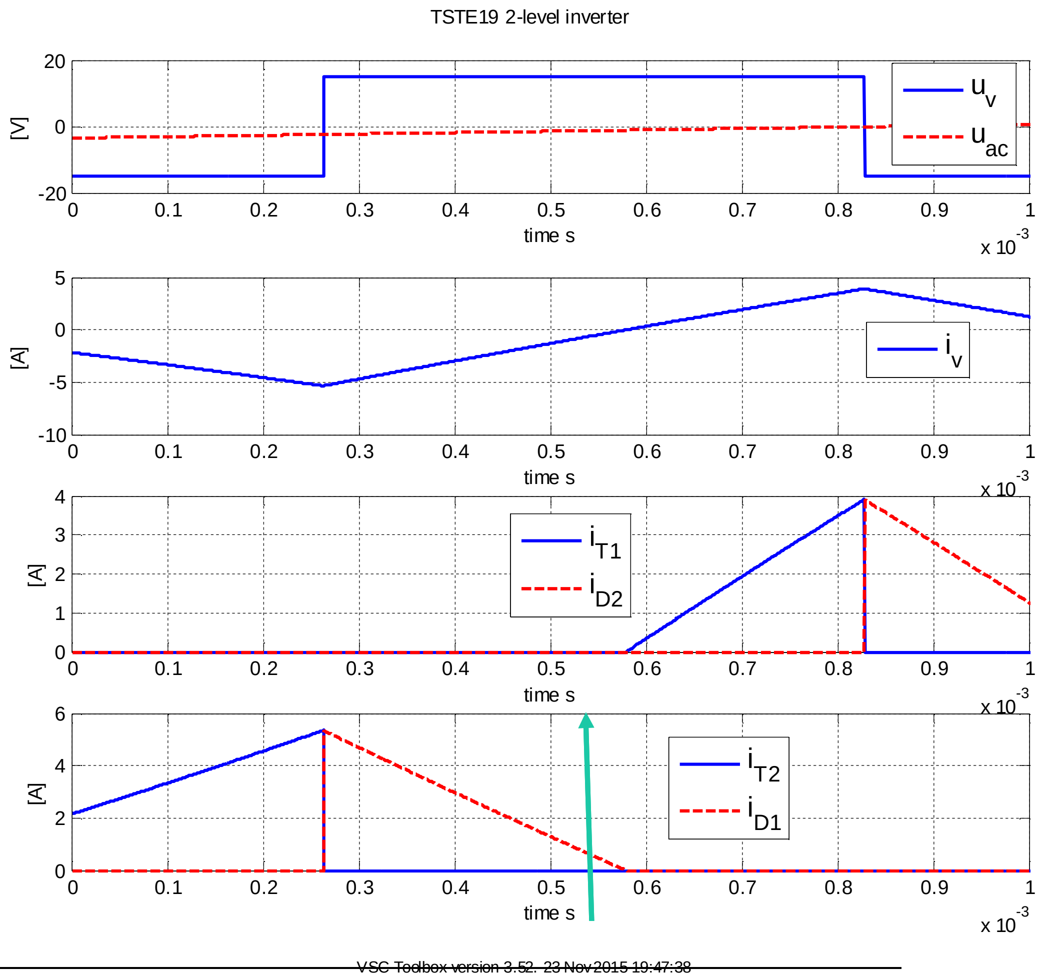


Voltage & current waveforms



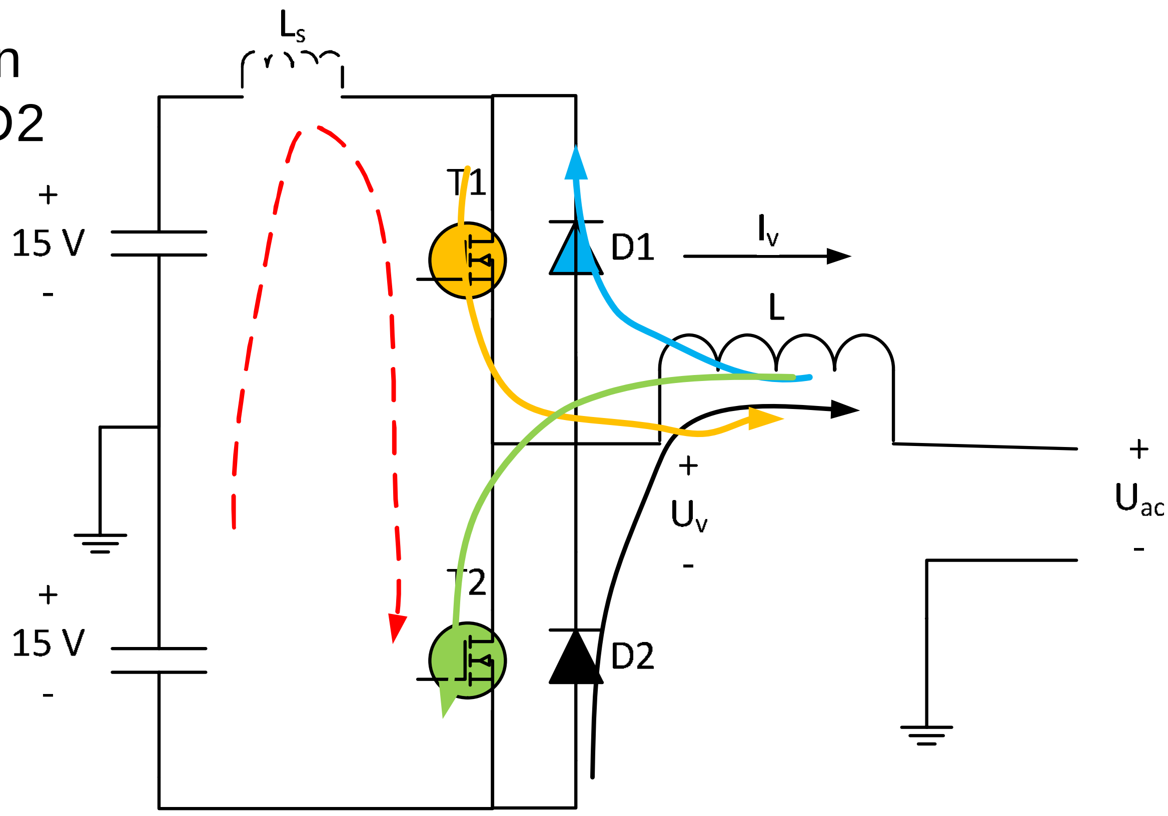
Zoom in of 1st ms

- t<0.27 ms,
  - T2 on
  - i_v <0
- t=0.27 ms,
  - G2 off, G1 on
  - i_v <0
    T2 to D1 commutation
- t=0.57 ms
  - i_v >0
    D1 to T1 conducting
- t=0.83 ms
  - G1 off, G2 on
  - T1 to D2 commutation



Half-bridge commutation

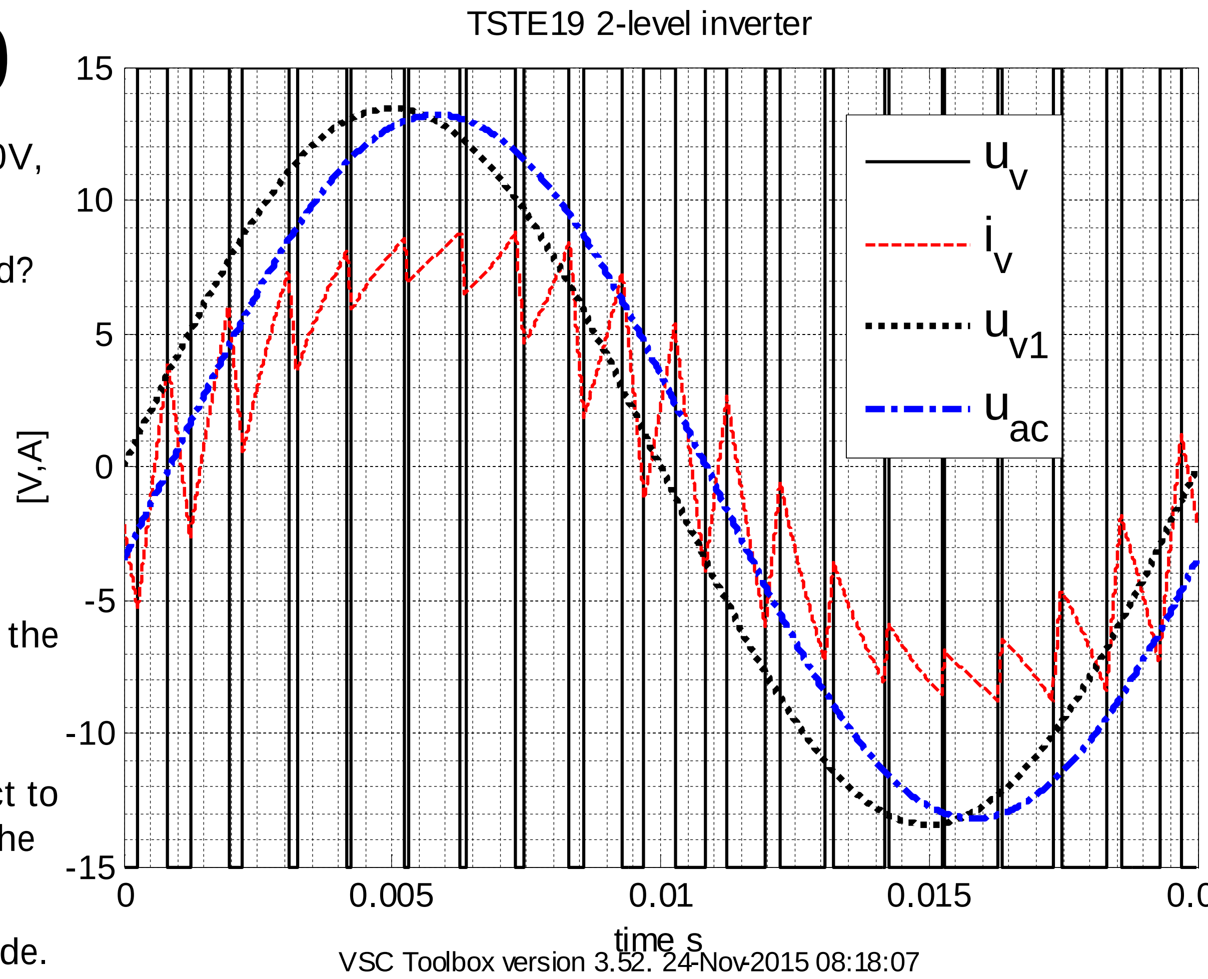
- Commutation between D1 and T2 or T1 and D2
- Commutation loop through dc-capacitor



Exercise 7-100

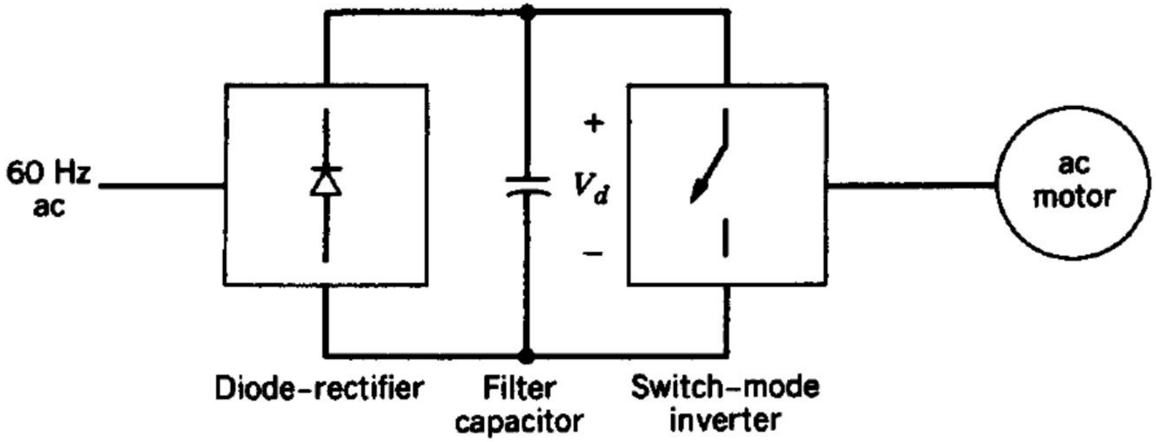
In the half-bridge example with U_d=30V, answer the following:

1. What switching frequency is used?
2. Estimate the inductance value?
3. Estimate the peak fundamental current.
4. Modulation index m_a
5. Estimate the active and reactive power on the grid side. Consider the current i_v to be in phase with u_{ac}.
6. Estiamate the phase angle of fundamental current with respect to the fundamental component of the switched valve side voltage, u_{v1}.
7. Calculate P and Q on the valve side.
8. Calculate the switch utlization ratio



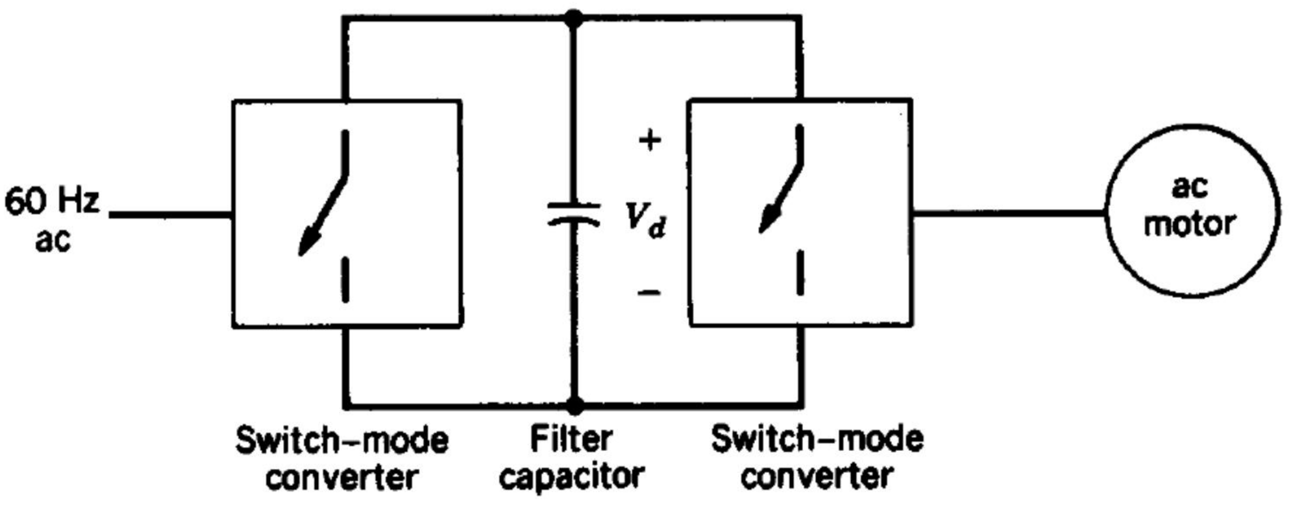
Unidirectional AC-AC converter

- Switch-mode inverter allow power reversal back to DC
- Motor sometimes behaving as a generator
- Use large capacitor to temporary store energy from ac motor
- May sometimes add resistor on DC to dissipate energy from motor braking



Bidirectional AC-AC converter

- When DC node can not accept all power from ac-motor
- E.g. train breaking, HVDC



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