Programmable calculator allowed
Answers in English or in Finnish allowed

5 questions/ á 6 p

1. Rectifier

The grid line-to-line voltage (U_{ll}), DC voltage (U_a) and DC current (I_a) are shown in Fig. 1

a) What is the used rectifier topology according to the DC voltage waveform shown in Fig. 1?
b) Draw the used rectifier topology
c) Sketch the waveform of the grid current as a function of time
d) Calculate the average output voltage value
e) What should be the maximum peak repetitive reverse voltage rating of the power semiconductor switching components used in the rectifier if 1.5 safety margin is used?
f) What is the lowest frequency of the produced grid current harmonic component?

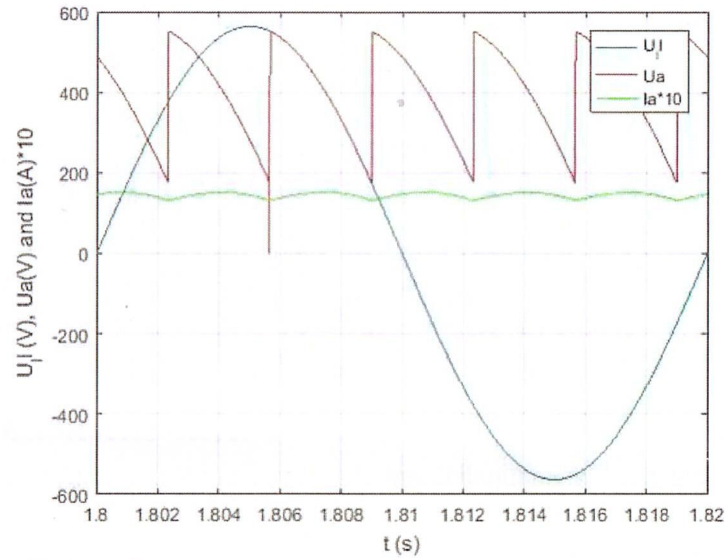


Fig. 1. Grid line-to-line voltage (U_{ll}), DC voltage (U_a) and DC current (I_a)

2. Ideal boost converter

Ideal boost converter is shown in Fig. 2a and the input current waveform is shown in Fig. 2b. Input voltage is 200V. Assume that the capacitor voltage ripple is negligible.

a) What is the average input current?
b) What is the average output voltage?
c) What is the inductance L value?
d) What is the average capacitor current?
e) What is the average diode current?
f) Sketch the diode current waveform

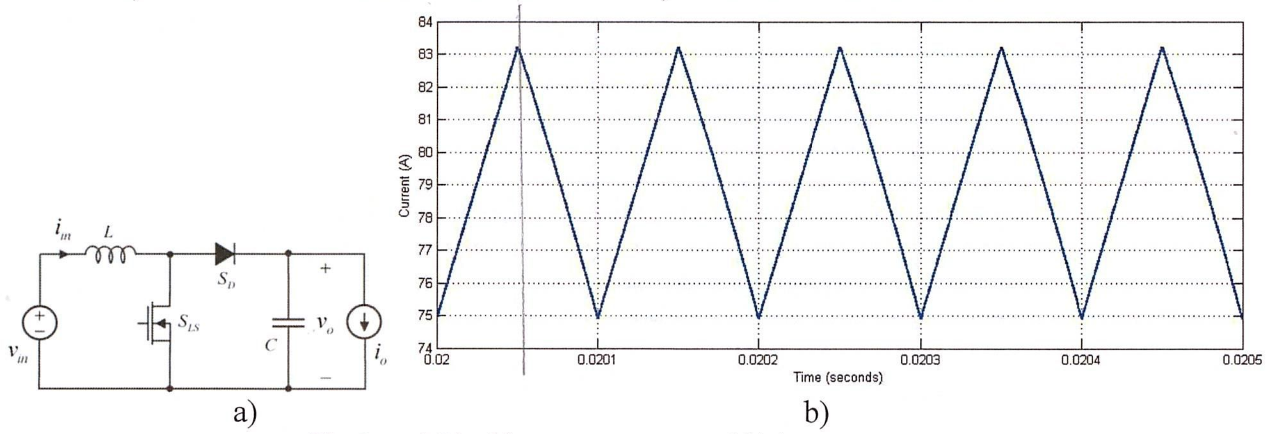


Fig 2. a) Ideal boost converter and b) input current

3. The frequency converter

The frequency converter of a three-phase synchronous motor is shown in Fig. 3.

a) What is the rms value of the maximum fundamental-frequency line voltage that can be produced to the motor terminals with conventional SPWM operating in linear range? Assume that the converter is connected to the Finnish utility grid (rms value of the line voltage is 400 V at 50 Hz), the rectifier has large output capacitor, and L = 0 H.
b) Why the resistor R_s and the switch S_s are connected to the circuit?
c) Is it possible to supply the regenerative power of the motor back to the grid by using this circuit?
d) Why the capacitor C_{dc} is connected to the circuit?
e) Why the diodes are connected antiparallel with the IGBTs?
f) Why the inductance L is connected in the grid side?

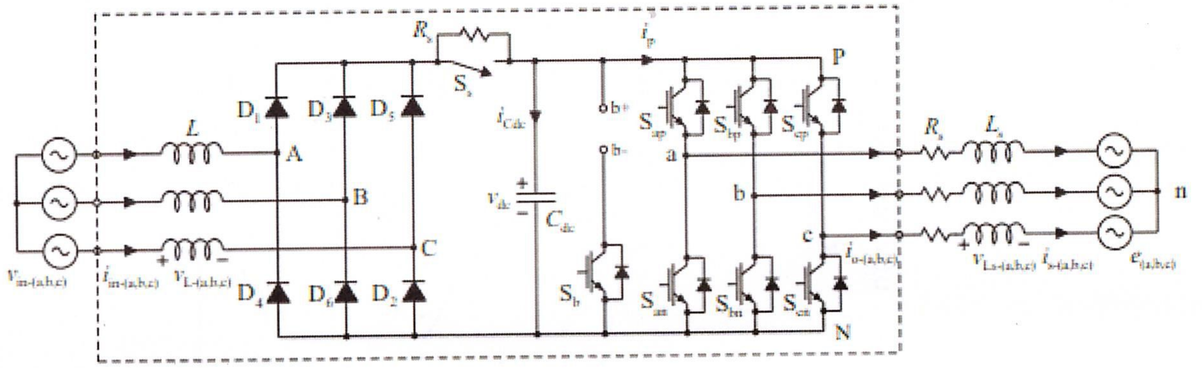
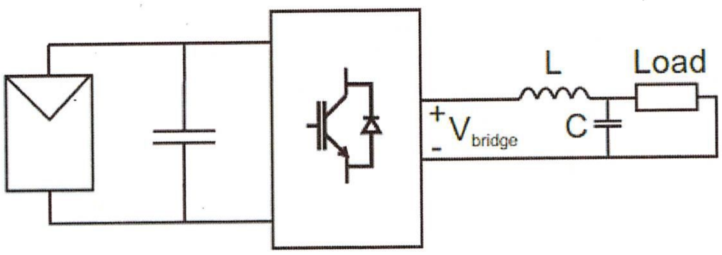


Fig 3. Schematic diagram of a conventional frequency converter

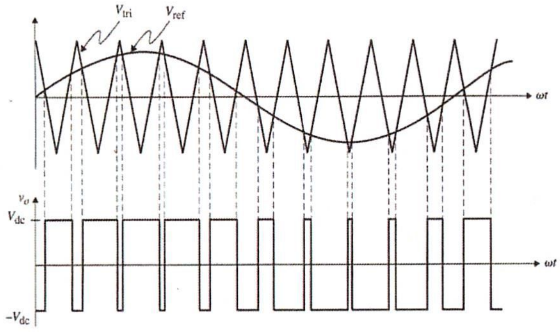
4. Single-phase inverter

The single-phase inverter is used in the solar power system shown in Fig. 4a and the output voltage waveform is shown in Fig. 4b. The peak amplitude of triangular waveform (V_{tri}) is 5V and the reference voltage is 4.5 V. The DC voltage value is 560V.

a) What is the inverter bridge topology used in the solar power system according to the output voltage waveform? Draw the inverter bridge.
b) What is the switching frequency of the transistors?
c) What is the modulation index of the inverter?
d) What is the maximum output voltage rms value in linear modulation region?
e) What should be the modulation index if the load is designed to be grid connected (230 Vrms) and the DC voltage is the same as in Fig. 4b?
f) What is the lowest frequency of the produced output current harmonic component?



a)



b)

Fig. 4. a) Solar power system and b) inverter bridge voltage v_{bridge}

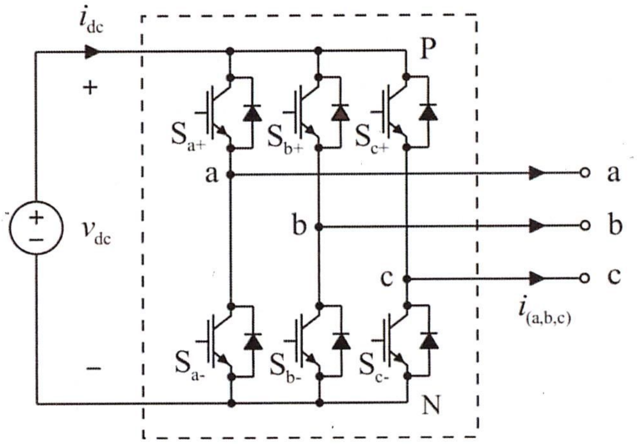
5. Space-vector modulation

Three-phase inverter is shown in Fig. 5a and the corresponding space vector sectors (i.e., hexagon) in Fig. 5b. Assume that dc-link voltage equals 560 V.

a) What is the length of the active vectors?
b) How many active switching states and zero switching states can be produced by the converter presented in Fig. 5?
c) Present the switching sequence of the inverter bridge when a conventional space-vector pulse-width modulation (SV-PWM) algorithm is used and the reference voltage equals $v^{ref} = 200\ \text{V} \cdot e^{j\frac{7\pi}{8}}$. (2 p)
d) What is the maximum output voltage with the analyzed inverter in the linear modulation region when SV-PWM modulation method is used?
e) What are the advantages of SV-PWM compared to conventional PWM method?

The complex space vector of three-phase variable is defined as

$$\underline{x} = \frac{2}{3}\left(x_a + \underline{a}x_b + \underline{a}^2 x_c\right), \qquad \text{where} \qquad \underline{a} = e^{j\frac{2\pi}{3}}. \tag{1}$$



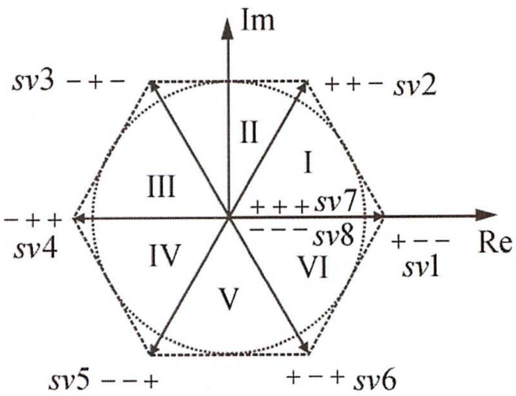


Fig. 5. a) Three-phase inverter b) vector diagram