Tampere University of Technology **DEE-33116 Power Electronics Converters** 18.12.2018
Electrical Energy Engineering
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Answers in English or in Finnish allowed

5 questions/ á 6 p, answer 4 questions out of 5. Maximum 24 p/exam.

1. Rectifier

The grid phase voltage, DC voltage and grid current are shown in Fig. 1

a) What is the used rectifier topology according to voltage and current waveforms shown in Fig. 1?
b) Draw the used rectifier topology
c) Calculate the average output voltage value
d) 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?
e) What is the lowest frequency of the produced grid current harmonic component?
f) What kind of problems the non-sinusoidal grid-current may cause for the grid?

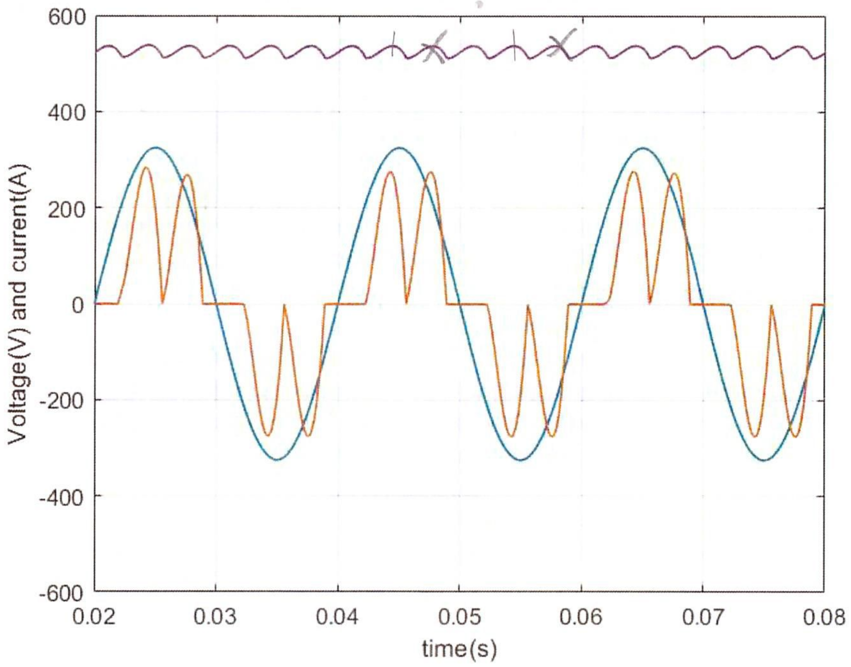

Fig. 1. Grid phase voltage and grid current

2. Power supply of LED lights

The power supply of LED lights is shown in Fig. 2.

a) What is the average output voltage of diode rectifier when LED lights are connected to Finnish utility grid?
b) Why PFC-boost converter is included in the circuit?
c) What is the duty cycle of the buck-converter is the voltage of the LED lights is 2,2V?
d) The energy efficiency of the power supply is supposed to be 97%. The power of LED lights is 8,5W/each. The power level of regulating resistor is 5W. How large is the required grid current?
e) How large inductor is required in the buck-converter if the switching frequency is 20 kHz. The allowed inductor current ripple is 30% of the average current value.
f) Why transformer-isolated DC/DC converter topologies are often used in LED light applications?

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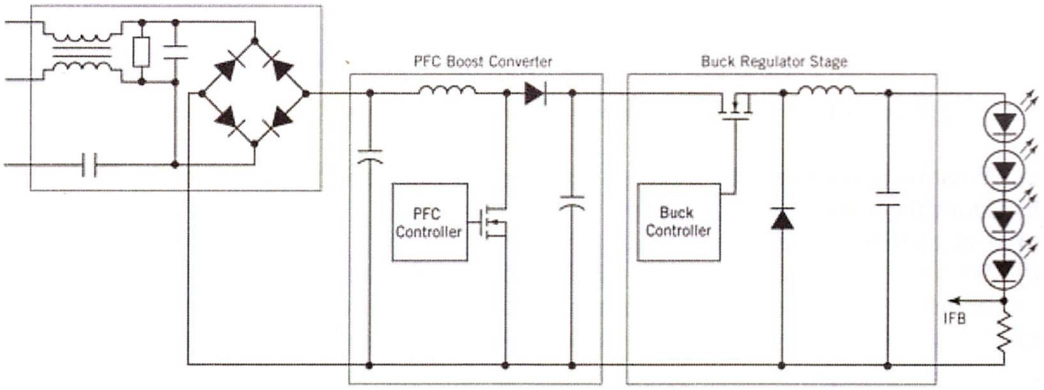
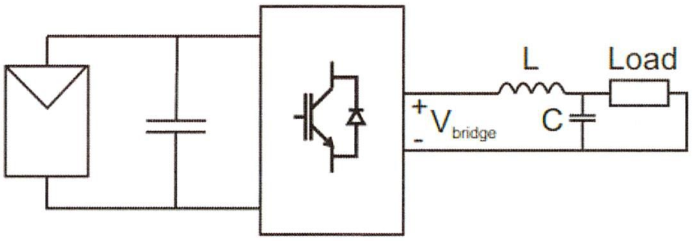


Fig 2. Schematic diagram of a power supply of LED lights

3. Single-phase inverter

The single-phase inverter is used in the solar power system shown in Fig. 3a and the output voltage waveform is shown in Fig. 3b.

a) What is the inverter bridge topology used in the solar power system according to the output voltage waveform? Why this converter topology is often used?
b) Draw the inverter bridge.
c) What is the switching frequency of the transistors?
d) What is the modulation index of the inverter? Why this modulation method is often used?
e) What is the maximum output voltage rms value in linear modulation region?
f) 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. 3b?



a)

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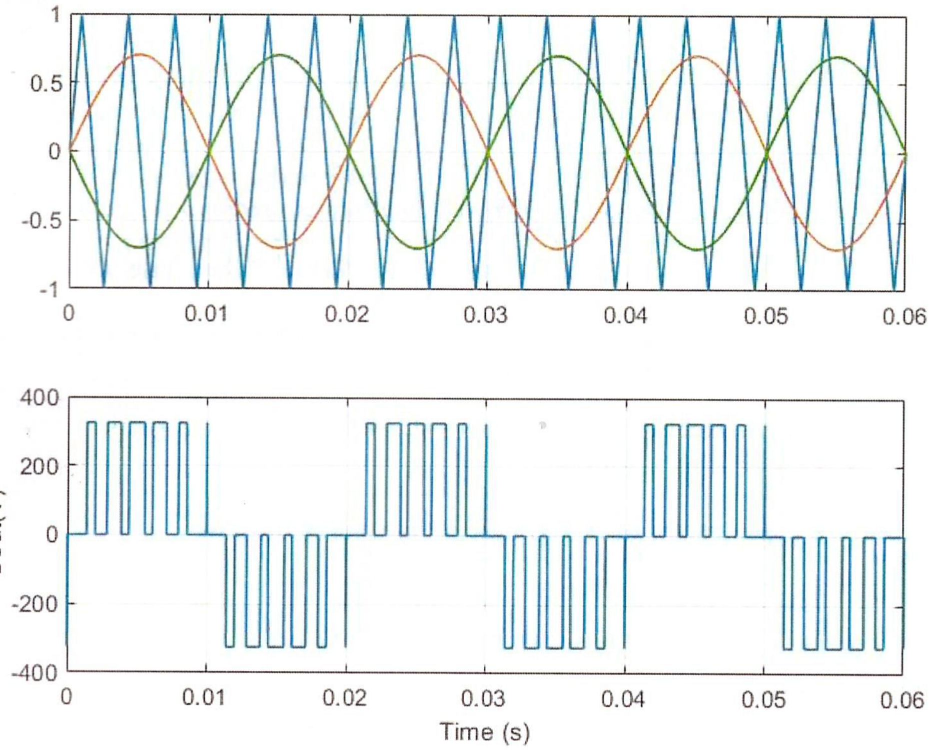

b)

Fig. 3. a) Solar power system and b) inverter bridge voltage v_{bridge}

4. Single-phase inverter

Continue to analyze the single-phase inverter in the solar power system as shown in Fig. 3a. The output voltage waveform is shown in Fig. 3b.

a) What is the lowest frequency of the produced output current harmonic component?
b) Why LC-filter is connected in the converter output? How the inductor and capacitor values are chosen?
c) Why DC/DC converter is often connected between the solar power panel and the inverter?
d) What is the maximum reverse voltage capability of the IGBTs in the inverter?
e) Why capacitor is connected between the panel and the inverter?
f) Why three-phase inverters are used in high-power solar power plants instead of single-phase inverters?

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5. Space-vector modulation

Three-phase inverter is shown in Fig. 4a and the corresponding space vector sectors (i.e., hexagon) in Fig. 4b. Assume that DC voltage equals 560 V and switching frequency is 10 kHz.

a) 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 $v^{ref} = 200\text{ V}\cdot e^{j\frac{7\pi}{8}}$ where 200V is the peak value of the phase voltage (2 p)

b) What is the maximum output voltage with the analyzed inverter in the linear modulation region when SV-PWM modulation method is used?

c) Calculate the switching times of each switching vector to realize the reference vector $v^{ref} = 200\text{ V}\cdot e^{j\frac{7\pi}{8}}$ (3p)

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

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

The reference vector is

$$\underline{v}_{ref} = \frac{t_{act1}}{T_s}\underline{v}_1 + \frac{t_{act2}}{T_s}\underline{v}_2 + \frac{t_7}{T_s}\underline{v}_7 + \frac{t_8}{T_s}\underline{v}_8$$

$$\underline{v}_{ref,\max} = v_{ref-\alpha} + jv_{ref-\beta} = \frac{t_{act1}}{T_s}\underline{v}_1 + \frac{t_{act2}}{T_s}\underline{v}_2$$

The alpha and beta components of the reference vector are

$$v_{ref-\alpha} = \sqrt{2}V\cos(\omega t)$$

$$v_{ref-\beta} = \sqrt{2}V\sin(\omega t)$$

The vectors are shown in Table I.

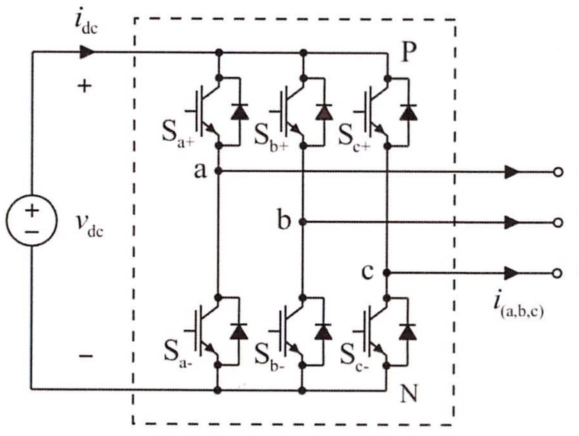
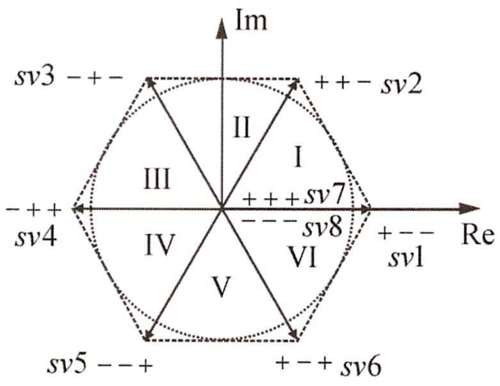


Fig. 4. a) Three-phase inverter



b) vector diagram

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Table 1. Vectors

Vector	sw	v_{aN}	v_{bN}	v_{cN}	v_α	v_β	$\underline{v}$
1	100	v_{dc}	0	0	$\frac{2}{3}v_{dc}$	0	$\frac{2}{3}v_{dc}$
2	110	v_{dc}	v_{dc}	0	$\frac{1}{3}v_{dc}$	$\frac{\sqrt{3}}{3}v_{dc}$	$\frac{2}{3}v_{dc}e^{j\frac{\pi}{3}}$
3	010	0	v_{dc}	0	$-\frac{1}{3}v_{dc}$	$\frac{\sqrt{3}}{3}v_{dc}$	$\frac{2}{3}v_{dc}e^{j\frac{2\pi}{3}}$
4	011	0	v_{dc}	v_{dc}	$-\frac{2}{3}v_{dc}$	0	$\frac{2}{3}v_{dc}e^{j\pi}=-\frac{2}{3}v_{dc}$
5	001	0	0	v_{dc}	$-\frac{1}{3}v_{dc}$	$-\frac{\sqrt{3}}{3}v_{dc}$	$\frac{2}{3}v_{dc}e^{j\frac{4\pi}{3}}$
6	101	v_{dc}	0	v_{dc}	$\frac{1}{3}v_{dc}$	$-\frac{\sqrt{3}}{3}v_{dc}$	$\frac{2}{3}v_{dc}e^{j\frac{5\pi}{3}}$
7	000	0	0	0	0	0	0
8	111	v_{dc}	v_{dc}	v_{dc}	0	0	0