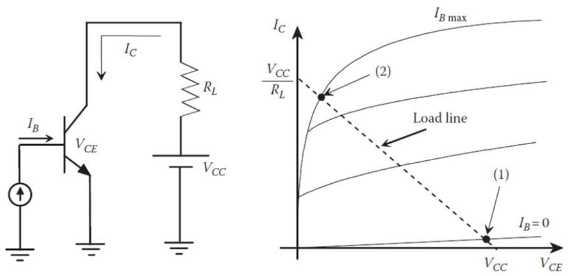
ELEC-E8422 An Introduction to Electric Energy

Exercise Session 4: Power Electronics

EX 1 Bipolar Transistor

A bipolar transistor is used in the circuit below, V_{CC} = 40 V and the load resistance R_L = 10Ω. In the saturated region, the collector-emitter voltage V_{CE} = 0,1 V and the current gain of the base β = 5. Calculate the following numerical values

a) The current and power of the load.
b) The losses in the collector circuit.
c) The losses in the base circuit, when the base-emitter junction is a diode with a voltage drop V_{BE}=0,7 V
d) The efficiency of the whole circuit.



EX 2 Bipolar Transistor

In the previous circuit the system is working in an operating point where the collector current I_c = 2 A. Calculate the power of the load resistance and the efficiency of the system.

EX 3 Diode Bridge

A single-phase diode bridge is supplied from 50 Hz ac system where the rms value of the voltage is 230 V and its peak value $\sqrt{2} * 230$ V. The load of the rectifier is a 10 Ω resistance.

a) Draw the waveforms of the dc voltage and current and calculate their average values.
b) Calculate the power delivered to the resistance.

EX 4 Diode Bridge

A single-phase diode bridge is supplied from 50 Hz ac system where the rms value of the voltage is 230 V. The load of the rectifier is a 10 Ω resistance. However, now we are assuming that the dc side has a large filtering inductance and therefore the dc side current is ideal dc. With this assumption, repeat the questions in EX 3, i.e.

a) Draw the waveforms of the dc voltage and current and calculate their average values.
b) Calculate the power delivered to the resistance.

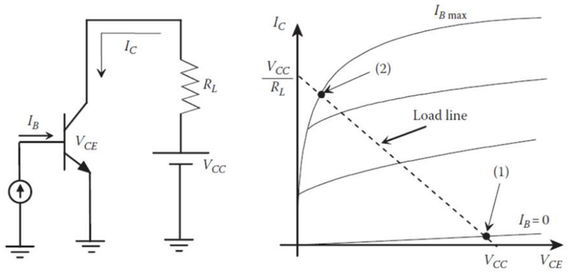
ELEC-E8422 An Introduction to Electric Energy

Exercise Session 4: Power Electronics

EX 1 Bipolar Transistor

A bipolar transistor is used in the circuit below, V_{CC} = 40 V and the load resistance R_L = 10Ω. In the saturated region, the collector-emitter voltage V_{CE} = 0,1 V and the current gain of the base β = 5. Calculate the following numerical values

a) The current and power of the load.
b) The losses in the collector circuit.
c) The losses in the base circuit, when the base-emitter junction is a diode with a voltage drop V_{BE}=0,7 V
d) The efficiency of the whole circuit.



Solution

a) The current is given by:

$$I_C = \frac{V_{CC} - V_{CE}}{R_L} = \frac{40 - 0{,}1}{10}\,\mathrm{A} \approx 3{,}99\ \mathrm{A}$$

The power delivered to the resistor is:

$$P_L = I_C^2 R_L \approx 159{,}2\ \mathrm{W}$$

b) The losses in the collector circuit are:

$$P_{CE} = I_C V_{CE} \approx 3{,}99 \cdot 0{,}1 \approx 0{,}399\ \mathrm{W}$$

c) In order to calculate the losses in the base circuit we need the value of the base current. It is obtained from the current gain of the base, thus:

$$P_{BE} = I_B V_{BE} = \frac{I_C}{\beta} V_{BE} = \frac{3{,}99}{5} 0{,}7 \approx 0{,}56\mathrm{W}$$

d) The input power is

$$P_{in} = V_{CC} I_C + P_{BE} = 40 \cdot 3{,}99\ \mathrm{W} + 0{,}56\ \mathrm{W} \approx 160{,}16\ \mathrm{W}$$

The efficiency is:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_L}{P_{in}} = \frac{159{,}2}{160{,}16} \approx 0{,}994 \mathrel{\widehat{=}} 99{,}4\ \%$$

EX 2 Bipolar Transistor

In the previous circuit the system is working in an operating point where the collector current I_C = 2 A. Calculate the power of the load resistance and the efficiency of the system.

Solution

The load line contains two easily calculated points. When V_{CE} is zero, we are on the y-axis and the collector current is equal to V_{CC}/R_L = 4 A. On the x-axis, the collector current is zero and V_{CE} is equal to 40 V. Therefore, when the collector current is 2 A, we are in the middle of the load line and V_{CE} is 20 V.

a) The current is given I_C=2A

b) The Losses in the collector circuit are:

$$P_{CE} = I_C V_{CE} \approx 2 \cdot 20 \approx 40 \text{ W}$$

c) In order to calculate the losses in the base circuit we need the value of the base current, which is is obtained from the current gain of the base.

$$P_{BE} = I_B V_{BE} = \frac{I_C}{\beta} V_{BE} = \frac{2}{5} 0{,}7 \text{ W} \approx 0{,}28\text{W}$$

d) The input power is:

$$P_{in} = V_{CC} I_C + P_{BE} = 40 \cdot 2 \text{ W} + 0{,}28 \text{ W} \approx 80{,}28 \text{ W}$$

The efficiency is:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_L}{P_{in}} = \frac{40}{80{,}28} \approx 0{,}498 \mathrel{\widehat{=}} 49{,}8\ \%$$

In exercise 1 the transistor is operating in the fully saturated range in a similar way as in power electronics when conducting. Then the voltage drop over the device is minimal and as we can see, efficiency is high. In exercise 2 the transistor is operating in the linear range and introducing a voltage drop over it. This is the way, so called linear electronics operates and the transistor can be interpreted as a controllable resistor. Because of this, also efficiency is much lower.

EX 3 Diode Bridge

A single-phase diode bridge is supplied from 50 Hz ac system where the rms value of the voltage is 230 V and its peak value $\sqrt{2} * 230$ V. The load of the rectifier is a 10 Ω resistance.

a) Draw the waveforms of the dc voltage and current and calculate their average values.
b) Calculate the power delivered to the resistance.

Solution

The diode bridge is shown in the next drawing with the voltages. When the ac voltage is positive, the diodes D_1 and D_2 conduct, and when the voltage is negative, the diodes D_3 and D_4 conduct. Because load is resistive, the current in the dc side has the same waveform as the voltage, but the amplitude is v_t/R.

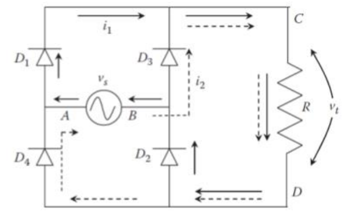


Figure 10.19 Full-wave rectifier circuit.

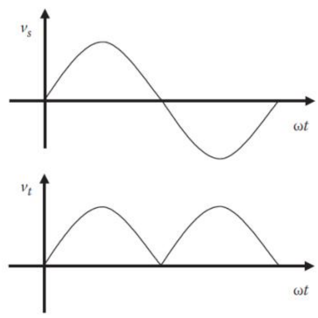


Figure 10.20 Waveforms of full-wave rectifier circuit.

The average of the dc voltage, when the control angle α is zero, is:

$$V_{ave} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_{\max}\sin(x)dx = \frac{2}{\pi}V_{\max}\cos(\alpha) = \frac{2}{\pi}V_{\max} = \frac{2\sqrt{2}}{\pi}230 \approx 207{,}07\ \text{V}$$

The average of the current is:

$$I_d = \frac{V_{ave}}{R} = 20{,}71\ \text{A}$$

The Power of the resistance cannot be calculated by multiplying the previous dc-values. The power of the resistance is an integral of the instantaneous power over one cycle

$$P = \frac{1}{2\pi}\int_0^{2\pi} p dx = \frac{1}{2\pi}\int_0^{2\pi} vi dx = \frac{1}{2\pi}\int_0^{2\pi} Ri^2 dx = RI_{rms}^2$$

Where I_{rms} is calculated as:

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i^2 dx}$$

In this case, the current waveform repeats after a half-cycle so it is enough to integrate over one half-cycle. Therefore, the rms value of current is

$$I_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} i^2 dx} = \sqrt{\frac{1}{\pi}\int_0^{\pi} I_{max}^2 \sin^2 x\, dx} = I_{max}\sqrt{\frac{1}{\pi}\int_0^{\pi}\frac{1}{2}(1-\cos 2x)dx}$$

$$= I_{max}\sqrt{\frac{1}{2\pi}(\pi - \sin 2\pi - 0 - \sin 0)} = \frac{I_{max}}{\sqrt{2}}$$

The rms value is the maximum value divided by the square root of two. The result is the same as if the current would be sinusoidal.

The power is:

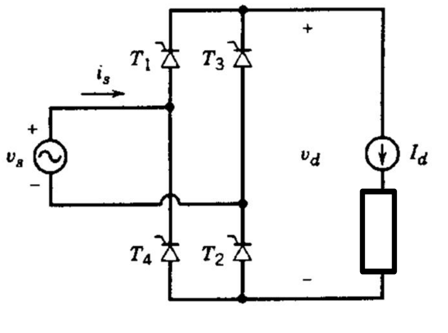
$$P = RI_{rms}^2 = \frac{V_{rms}^2}{R} = \frac{230^2}{10}\text{W} = 5290\ \text{W}$$

EX 4 Diode Bridge

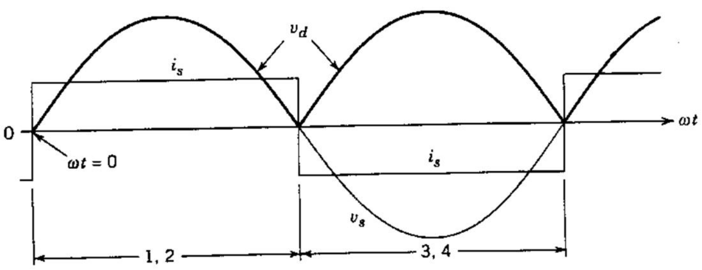
A single-phase diode bridge is supplied from 50 Hz ac system where the rms value of the voltage is 230 V. The load of the rectifier is a 10 Ω resistance. However, now we are assuming that the dc side has a large filtering inductance and therefore the dc side current is ideal dc. With this assumption, repeat the questions in EX 3, i.e. draw the waveforms of dc voltage and current and calculate their average values. Calculate the power delivered to the resistance.

Solution

Compared to exercise 3, the case is nearly the same but with some remarkable differences too. The dc voltage waveform is similar, but on the dc side we only have constant dc current due to strong filtering. Because of this, the line current of the ac system is as shown in the next drawing.



(a)



(a) $\alpha = 0$

The average value of the dc-voltage is not changing from EX 3 and it is

$$V_{ave} = \frac{2}{\pi} V_{\max} = \frac{2\sqrt{2}}{\pi} 230 \approx 207{,}07 \text{ V}$$

Also the dc current is the same

$$I_d = \frac{V_{ave}}{R} = 20{,}71 \text{ V}$$

However, the power delivered to the resistance is changing. In this case, the dc side current is a perfect dc and therefore, the power of the resistance is

$$P = RI_d^2 \approx 4288 \text{ W}$$

Note that it is smaller than in EX 3.

If the 10 Ω resistance would be connected directly to a single phase ac system without the diode rectifier, the power of the resistance is:

$$P_{ac} = RI_{rms}^2 = \frac{V_{rms}^2}{R} = \frac{230^2}{10} = 5290 \text{ W}$$

This is the same result as in EX 3. There is no reasons to supply a purely resistive load with a diode bridge because from the resistance point of view, only the current and voltage waveforms change, but the power does not change.