ELEC-E8421 - Components of Power Electronics

Exercise 1

1. Energy loss

As motor phase current is assumed to be constant during transient state, the energy in the 9uH inductance is the same at the start and end of transient.

It is enough to consider the capacitor and its series resistance.

Book mentions that **energy loss** in RC system is:

$$E = \frac{1}{2} C \Delta U^2,$$

for voltage differential of ΔU.

In this example the $\Delta U = 540\ V$, two times in one period (rising edge + falling edge)

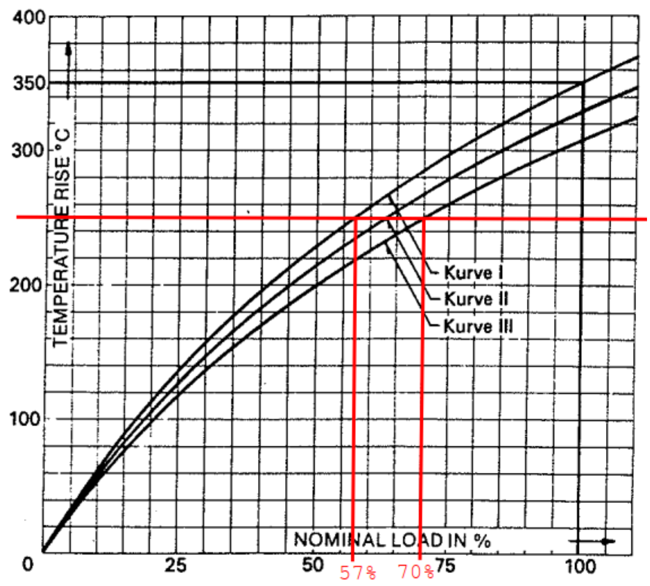
=> Loss power is

$$P = 2 \times \frac{1}{2} C \Delta U^2 \cdot \frac{1}{T_s} = 0.39\ uF \times (540\ V)^2 \times 2\ kHz = 230\ W$$

2. Rated power

Ambient is 50 °C

=> Maximum surface temperature of 300 °C, equals to 250 °C of thermal rise.



Curve I: 30, 50, 80, 200 W
Curve II: 22, 25, 35, 40, 55, 60, 100 W
Curve III: 15 W

The curves are equally applicable to Types GRV. and GRF

ELEC-E8421 - Components of Power Electronics

Datasheet figure shows (page 3) shows that $250\ °\mathrm{C}$ thermal rise means that nominal load should be de-rated to around $57 \ldots 70\ \%$ of nominal power, depending on the type of resistor

=> Therefore, the **rated power** should be

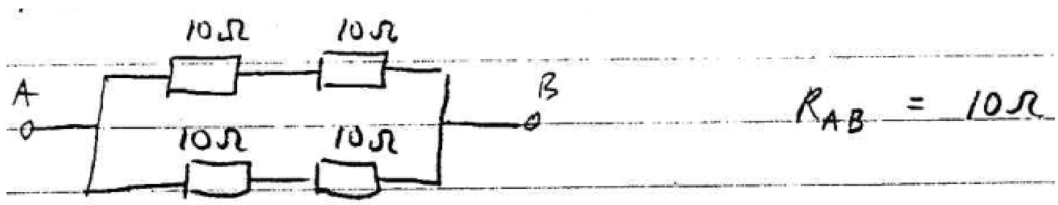
$$\frac{230\ W}{0.7} = 329W, \qquad \text{to} \qquad \frac{230\ W}{0.57} = 404W.$$

For example, 4 pcs of 100 W resistors or 2 pcs of 200 W resistor could do.

Figure (page 3) shows that since 200 W resistors are subject to ***curve I*** and the highest derating, they might still be dimensioned to be too small ($2 \times 200 = 400 < 404W$).

=> Select 4 pcs of 100 W resistors.

As required resistance is 10 Ohms, we shall use the connections shown below



GRF 20/140, 100 W and 10 Ohm resistors are selected.

Resistor could be GRF-type (not GRI), since 9 uH inductor means that the resistors own inductance is not an important factor.

ELEC-E8421 - Components of Power Electronics

Exercise 2

1. Necessary calculation equations

1.1 Calculation of the Fourier Series:

Aling the pulse series to be symmetrical, so that cos-series can be used

$$a_n = \frac{2}{\pi}\int_0^{\frac{\lambda}{2}} \hat{\imath} \cdot \cos(nx)\, dx = \frac{2}{\pi}\frac{\hat{\imath}}{n}\sin\frac{n\lambda}{2}$$

Therefore, n:th harmonic is

$$I_n = \frac{a_n}{\sqrt{2}} = \frac{\sqrt{2}}{\pi n}\,\hat{\imath}\sin\frac{n\lambda}{2}$$

1.2 Calculation of the RMS value:

Remember how to calculate the root mean square value of the current:

$$I_{RMS} = \sqrt{\frac{1}{T_s}\int_0^{T_s}[i(t)]^2 dt}$$

And how the RMS value and harmonic components are related:

$$I_{RMS} = \sqrt{\sum_{n=0}^{\infty} I_n^2}$$

2. Capacitor will sustain operation if the RMS-current squared weighted by datasheet table 4 coefficients are under maximum allowed.

Datasheet shows that $330\,\mu F$ / $385\,V$ capacitors can withstand $1.7\,A$ at 85 °C environment when frequency is $100\,Hz$ (Table 2). Two caps can withstand $3.4\,A$, if current is evenly distributed. Since capacitors have large tolerances this is rarely the case. Anyhow lets assume ideal 50% split between capacitors for the calculations.

From Table 3 we can find the overload factor for max RMS ripple current at 60 °C is 1.87.

Therefore, the max RMS ripple current in the exercise for EACH capacitor would be

$$I_{r\,max}(60) = k \cdot I_{r\,max}(85) = 1.7 \times 1.87 = 3.18\,A.$$

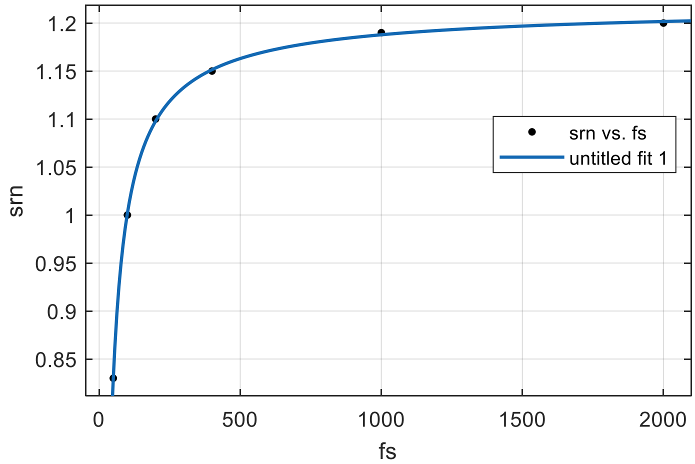
Next, according to the formula given in Page 231 (below table 4), we need to calculate the weighted RMS-current squared value.

ELEC-E8421 - Components of Power Electronics

2.1 Rectifier ripple: fundamental frequency $f_1 = \frac{1}{10}\,ms = 100\ Hz,\ \hat{\imath} = 10\ A.$

Table 4 coefficients are constant at frequencies > 2 kHz. => only 19 first harmonics are to be calculated accurately.

To fit all of these coefficients we should interpolate the weights for each frequency based on table 4, note that table 4 used coefficient $\sqrt{r_n}$ is to be used with squared current harmonics:



In a table format

n	I_n (A)	$\sqrt{r_n}$	n	I_n (A)	$\sqrt{r_n}$	n	I_n (A)	$\sqrt{r_n}$
0	2.5	---	7	0.45	1.18	14	0.32	1.19
1	3.18	1	8	0	1.18	15	0.21	1.19
2	2.25	1.11	9	0.35	1.19	16	0	1.2
3	1.06	1.13	10	0.45	1.19	17	0.19	1.2
4	0	1.15	11	0.29	1.19	18	0.25	1.2
5	0.64	1.16	12	0	1.19	19	0.17	1.2
6	0.75	1.17	13	0.24	1.19	$\geq$ **20**	0.71	1.2

where:

DC component is $I_0 = 10A \times \frac{2.5ms}{10ms} = 2.5A.$

Rectifier rms current is easy to calculate $I_{RMS} = \sqrt{\frac{1}{10ms} \times (10\ A)^2 \times 2.5\ ms} = 5\ A.$

The sum of squared current for components >20:

$$I_{>20} = \sqrt{I_{RMS}^2 - \left(\sum_{n=1}^{19} I_n^2\right) - I_0^2} = \sqrt{5^2 - 4.27^2 - 2.5^2} = 0.71\ A$$

So the sum of Table4-weighted RMS current is calculated as:

$$\sum_{n=1}^{\infty} \frac{I_n^2}{r_n} = \sum_{n=1}^{19} \frac{I_n^2}{r_n} + \frac{I_{>20}^2}{r_{20}} = 4.11^2\ A^2$$

ELEC-E8421 - Components of Power Electronics

2.2 in SMPS all the harmonics are above 2 kHz (fundamental frequency is 25 kHz, i.e., 1/40 us).

DC component is $I_0 = -5A \times \frac{20\ \mu s}{40\ \mu s} = -2.5A.$

(Naturally the DC current from rectifier and SMPS cancel each other out as the capacitor could not withstand DC current through it.)

RMS current is $I_{RMS} = \sqrt{\frac{1}{40\ \mu s} \times (5\ A)^2 \times 20\ \mu s} = 3.54\ A.$

The sum of squared current for harmonic components:

$$I_{harmn} = \sqrt{I_{RMS}^2 - I_0^2} = \sqrt{3.54^2 - 2.5^2} = 2.5\ A$$

So the sum of Table4-weighted RMS current is calculated as:

$$\sum_{n=1}^{\infty} \frac{I_n^2}{r_n} = \frac{I_{harmn}^2}{r_{20}} = 2.08^2\ A^2$$

2.3 Total capacitor current squared is

$$\sum_{n=1}^{\infty} \frac{I_n^2}{r_n} = 4.11^2 + 2.08^2 = 21.2\ A^2$$

Comparing the sum value to the given maximum RMS current rating for EACH capacitor:

$$\sum_{n=1}^{\infty} \frac{I_n^2}{r_n} = \frac{\sqrt{21.2}}{2} = 2.304\ A < I_{r\,max}(60) = 3.18\ A$$

=> Capacitors may very well be properly dimensioned.

However, it should be noted that the above comparison is done when considering an evenly distributed current in two capacitor branches. In practical, the capacitor capacitance tolerance will cause uneven current distribution.