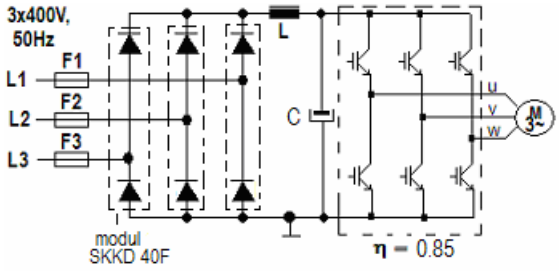
VISER- Master studije(elektrotehničko inženjerstvo) ISPIT SEPT 2019 –REŠENJA ZADATAKA

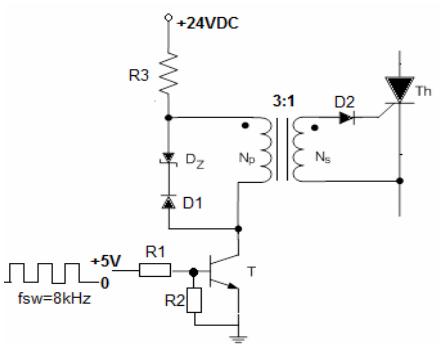
1. ZADATAK: Trofazni AC/AC pretvarač na Slici 1 se koristi za frekventnu regulaciju elektromotora čiji su podaci: 400V, 50Hz, P=22kW, η =90%, $cos\varphi$ = 0.82. Stepen iskorišćenja trofaznog tranzistorskog pretvarača je η_p =0.87. Za ulazni ispravljač su na raspolaganju tri diodna moduli SKKD 40F čiji su tehnički podaci dati u Prilogu 1.



Slika 1- Trofazni AC/AC pretvarač

(a) Projektovati LC filtar u DC međukolu ako je zahtevana talasnost DC napona ≤ 3% i talasnost DC struje ≤ 10% .
(b) Izračunati potrebnu termičku otpornost hladnjaka diodnog ispravljača za temperaturni opseg okoline -25ºC...+60ºC. Pretpostaviti da su svi diodni moduli montirani na istom hladnjaku. Za izabrani sistem hlađenja odrediti temperaturu na kućištu modula i temperaturu hladnjaka.

2. ZADATAK: Dimenzionisati pobudno kolo tiristora prikazano na Slici 2 (R1, R2, R3, Vz) , uz pretpostavku da je u kolu gejta tiristora potrebno ostvariti struju od 1.6A pri naponu gejt-katoda od 3V. Usvojiti da je pad napona na diodama 0.7V. Podaci za tranzistor: napon V_{bes}=0.75V, napon V_{ces}=0.3V, pojačanje tranzistora h_{fe}=400. Induktivnost magnećenja impulsnog transformatora je 22mH, dok je njegova rasipna induktivnost zanemarljiva.

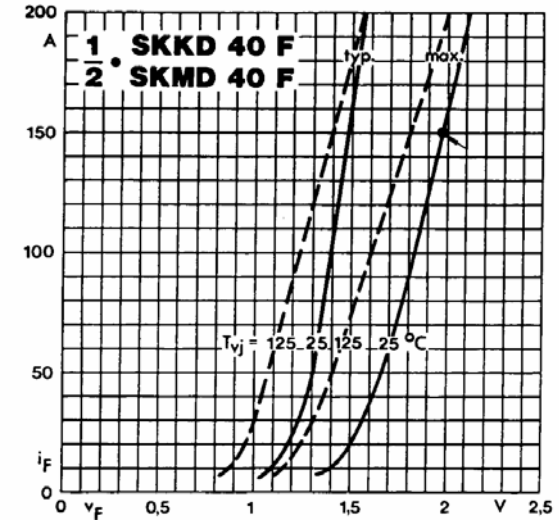


Slika 2-Pobudno kolo SCR

3. ZADATAK: Potrebno je nacrtati električnu šemu i projektovati DC/DC električni neizolovani pretvarač napona koji treba da radi u kontinualnom režimu, kao punjač baterije 12V/240Ah. Ulazni podaci za projektovanje: (1) nominalni DC ulazni napon 24V ±20%, (2) Napon baterije u ispražnjenom stanju 11.2V, (3) talasnost struje prigušnice ≤ 5%, (4) radna učestanost pretvarača je 100kHz. Zanemariti padove napona i komutacione gubitke na prekidačkim elementima, kao i unutrašnje otpornosti pasivnih elemenata.

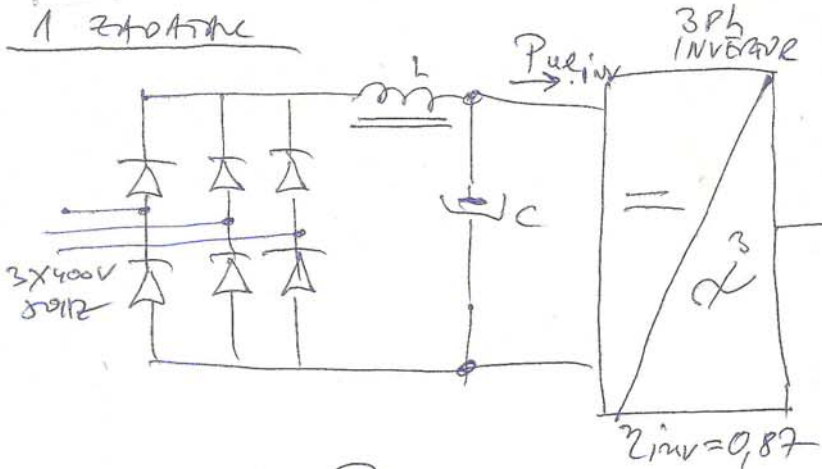
4. ZADATAK: Potrebno je projektovati DC/DC električni neizolovani pretvarač napona koji treba da radi u kontinualnom režimu, za koji su dati ulazni podaci za projektovanje: (1) nominalni DC ulazni napon 48V ±10%, (2) izlazni napon 110VDC, (3) izlazna snaga 4kW, (4) talasnost struje prigušnice ≤ 10%, (5) talasnost izlaznog napona ≤ 1%, (6) radna učestanost 100kHz. Zanemariti pad napona na prekidačkom tranzistoru i komutacione gubitke na prekidačkim elementima, kao i unutrašnje otpornosti pasivnih elemenata.

PRILOG 1-Karakteristike dioda



Symbol	Conditions	SKKD 40 F SKMD 40 F
I_{FAV}	sin. 180; T_{case} = 85 °C	36 A
I_{FSM}	T_{vj} = 25 °C; 10 ms T_{vj} = 125 °C; 10 ms	1100 A 940 A
i^2t	T_{vj} = 25 °C; 8,3 ... 10 ms T_{vj} = 125 °C; 8,3 ... 10 ms	6000 A^2s 4400 A^2s
t_{rr}	T_{vj} = 25 °C; I_F = 1 A; – di_F/dt = 15 A/µs; V_R = 30 V	200 ns
Q_{rr} I_{RM}	T_{vj} = 125 °C; I_F = 100 A; – di_F/dt = 30 A/µs; V_R = 30 V	3 µC 10 A
I_R	T_{vj} = 25 °C; V_R = V_{RRM} T_{vj} = 125 °C; V_R = V_{RRM}	0,5 mA 50 mA
V_F	T_{vj} = 25 °C; I_F = 150 A	2,0 V
$V_{(TO)}$	T_{vj} = 125 °C	1,2 V
r_T	T_{vj} = 125 °C	4 mΩ
R_{thjc}	per diode/per module	0,7 °C/W/0,35 °C/W
R_{thch}	per diode/per module	0,2 °C/W/0,1 °C/W
T_{vj}		– 40 ... +125 °C
T_{stg}		– 40 ... +125 °C

1 ZADATAK

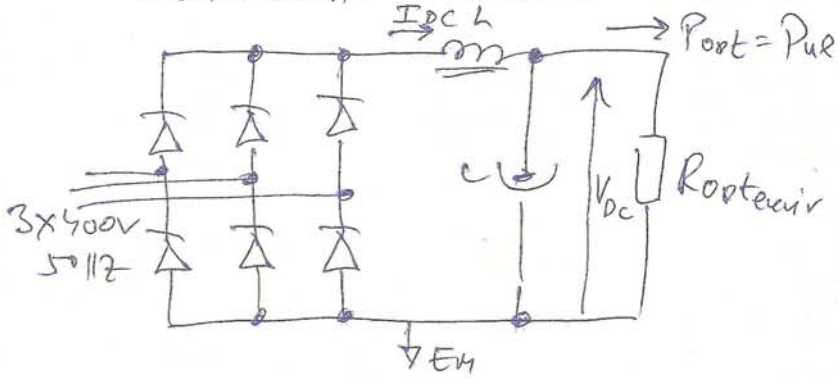


$$P_{mot} = \eta_{mot} \cdot P_{elmot}$$

$$P_{elmot} = \frac{P_{mot}}{\eta_{mot}} = \frac{22\,kW}{0,9} = 24,44\,kW$$

$$P_{ul\,inv} = \frac{P_{elmot}}{\eta_{inv}} = \frac{24,44\,kW}{0,87} = 28,092\,kW$$

Ekviv. šema trofaznog ispravljača



$P_{ost} = P_{ul\,inv} = 28,092\,kW$

$$V_{DC} = \frac{3 \cdot V_m^*}{\pi}$$

$$V_m^* = V_m - 2V_D$$

$$V_m^* = 400\sqrt{2} - 2 \cdot 1\,V$$ (1V je pad napona na jednoj diodi u mostu)

$$V_m^* = 562\,V$$

$$V_{DC} = \frac{3 \cdot V_m^*}{\pi} = \frac{3 \cdot 562}{\pi} = 536,94\,V$$

$$R_{optecni} = \frac{V_{DC}}{I_{DC}} = \frac{V_{DC}}{\frac{P_{ost}}{V_{DC}}} = \frac{V_{DC}^2}{P_{ost}} = \frac{536,94^2}{28,092 \cdot 10^3} = 10,26\,\Omega$$

$$I_{DC} = \frac{V_{DC}}{R_{optecni}} = \frac{536,94}{10,26} = 52,33\,A$$

Kondenzator u „LC" filtru (izbor):

$$C \geq \frac{1}{n \omega R_{ekv.ot}} \cdot \frac{\delta_i}{\delta_M}$$

$n = 6$ (6-pulsni ispravljač)

$\omega = 2\pi \cdot f = 2\pi \cdot 50\,Hz = 314\ rad/s$

$R_{ekv.ot} = 10{,}26\,\Omega$

$\delta_i = 10\%\ (0{,}1)$

$\delta_M = 3\%\ (0{,}03)$

$$C \geq \frac{1}{6 \cdot 314 \cdot 10{,}26 \cdot \frac{3}{10}}$$

$C \geq 172{,}44\,\mu F \xrightarrow{\text{usvajamo}}$ **$C^* = 220\,\mu F / 800\,V_{DC}$ ($1000\,V_{DC}$)**

Kritična induktivnost:

$$L_{kr} = \frac{R_{ekv.ot}}{105 \cdot \omega} = \frac{10{,}26}{105 \cdot 314} = 0{,}311\ mH$$

$L \gg L_{kr}$.

$$\frac{\Delta I_L^{(0)}}{I_{DC}} = \frac{4 R_{ekv.ot}}{35} \cdot \frac{6 \omega C^*}{(6\omega)^2 L C^* - 1} \leq 10\%\ (0{,}1)$$

$$\frac{4 R_{ekv.ot}}{35} \cdot \frac{6 \omega C^*}{(6\omega)^2 L C^* - 1} \leq 0{,}1$$

$$(6\omega)^2 L C^* - 1 \geq \frac{4 R_{ekv.ot}}{35} \cdot \frac{6 \omega C^*}{0{,}1}$$

$$(6\omega)^2 L C^* \geq \frac{4 R_{ekv.ot}}{35} \cdot \frac{6 \omega C^*}{0{,}1} + 1$$

$$L \geq \frac{1}{(6\omega)^2 C^*} \cdot \frac{4 R_{ekv.ot} \cdot 6 \omega C^*}{35 \cdot 0{,}1} + \frac{1}{(6\omega)^2 C^*}$$

$$L \geq \frac{4 R_{ontem}}{35} \cdot \frac{1}{6\omega} \cdot \frac{1}{0{,}1} + \frac{1}{(6\omega)^2 C^*}$$

$$L \geq \frac{4 \cdot 10{,}26}{35} \cdot \frac{1}{6 \cdot 314} \cdot \frac{1}{0{,}1} + \frac{1}{(6 \cdot 314)^2 \cdot 220 \cdot 10^{-6}}$$

$$L \geq 6{,}22\,\mu H + 1{,}28\,\mu H = 7{,}5\,\mu H$$

Minimalna $L^* = 7{,}5\,\mu H$

Maksimalna struja $I_{Lmax} = I_{DC} + \frac{\Delta i}{2} = 52{,}33 + \frac{0{,}1 \cdot 52{,}33}{2}$

$$I_{Lmax} = 52{,}33 + 2{,}6165 \approx 55A$$

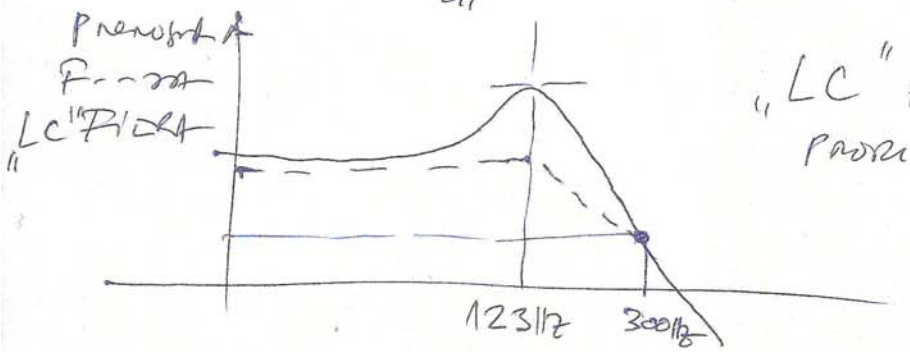
Kontrola: Maksimalno $I_{Lmax} = 60A$

$$\boxed{L^* = 7{,}5\,\mu H / 60A}$$

Rezonantna učestanost „LC" filtra

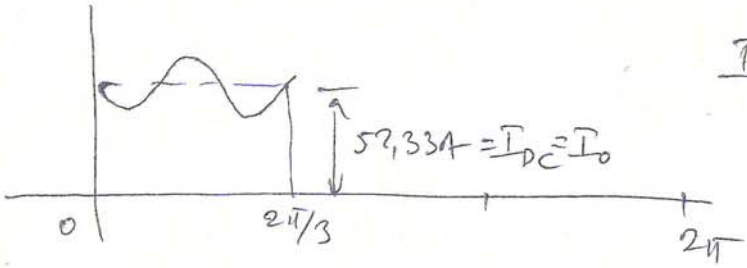
$$\omega_{rez} = \frac{1}{\sqrt{L^* \cdot C^*}} = \frac{1}{\sqrt{7{,}5\mu \cdot 220\mu}} = 778{,}5\ rad/s.$$

$$f_{rez} = \frac{\omega_{rez}}{2\pi} = 123{,}96Hz \leq 300Hz \text{ (6 puls. ispravljač)}$$



„LC" filtra se projektuje na ivici rezonanse

b) STRUJA JEDNE DIODE U TROFAZNOM MOSTU.



$$I_{DSR} = \frac{I_0}{3} = \frac{57,33}{3} = 17,45A$$

$$I_{DEff} = \frac{I_0}{\sqrt{3}} = \frac{57,33}{1,73} = 30,25A$$

SA GRAFIKA (I-V KARAKTER. DIODE) JE ODČITANA ZA KARAKTERIST. MAX I ZA MAX TEMPER. $T_j = +125°C$: $V_{T0} = 1,2V$

DINAMIČKA OTPORNOST DIODE PRI ovim USLOVIMA JE:

$$r_d = \frac{1}{\frac{200A - 0A}{2V - 1,2V}} = \frac{1}{\frac{200}{0,8}} = \frac{0,8}{200} = 4m\Omega$$

DISIPACIJA NA JEDNOJ DIODI JE

$$P_{D1} = V_{T0} I_{DSR} + r_d \cdot I_{DEff}^2 = 1,2 \cdot 17,45 + 4 \cdot 10^{-3} \cdot 30,25^2$$

$$P_{D1} = 20,94W + 3,66W = 24,6W \rightarrow \text{usvojeno } P_{D1} = 25W$$

UKUPNA DISIPACIJA NA SVIM JEDNOJ DIODA U ISPRAVLJAČU JE:

$$\Sigma P_D = 6 \cdot 25W = 150W$$

SVE DIODE SU MONTIRANE NA ISTU HLADNJAK (USKU U ZADNJI)

POTREBNO JE NAĆI EKVIV. TERMIČKU ŠEMU OVOG SISTEMA

$T_{j\,max} = +175°C$

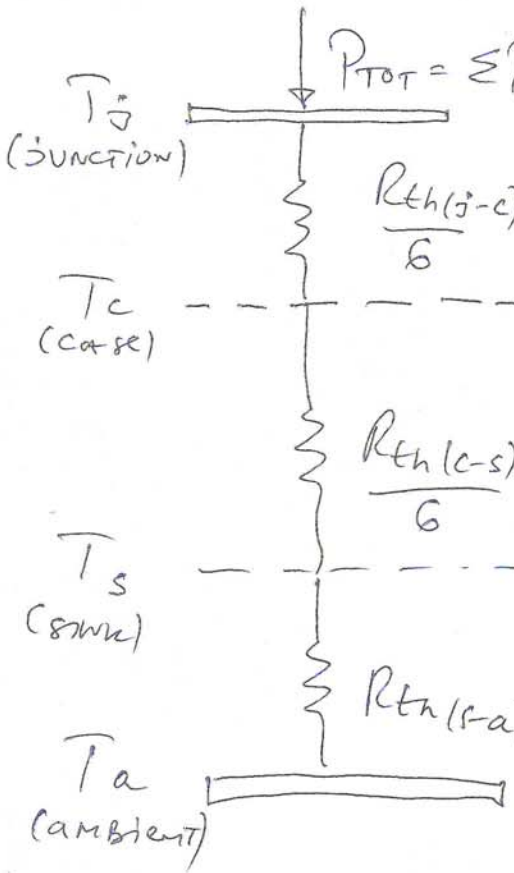
$T_{a\,max} = +60°C$ (temp. okoline)

J – JUNCTION (spoj)
C – Case (kućište)
S – SINK (HLADNJAK)

$R_{th(j-c)_1} = 0{,}7 \frac{K}{W}$ (iz serije diode – PRILOG 1) TERMIČKA OTP. J–C

$R_{th(c-s)_1} = 0{,}2 \frac{K}{W}$ (iz serije diode – PRILOG 1) TERMIČKA OTP. C–S

Ekviv. termička šema:



$T_{j\,max} = +125°C$

$T_{a\,max} = +60°C$

$\Sigma R_{th} \leq \frac{T_{j\,max} - T_{a\,max}}{P_{TOT}}$

$\Sigma R_{th} \leq \frac{125 - 60}{150}$

$\Sigma R_{th} \leq 0{,}43 \frac{K}{W}$

$R_{th(j-c)e} + R_{th(c-s)e} + R_{th(s-a)} \leq 0{,}43$

$R_{th(s-a)} \leq 0{,}43 - 0{,}1166 - 0{,}033$

$R_{th(s-a)} \leq 0{,}28 \frac{K}{W}$

Usvojićemo da je $R^*_{th(s-a)} = 0{,}25 \frac{K}{W}$

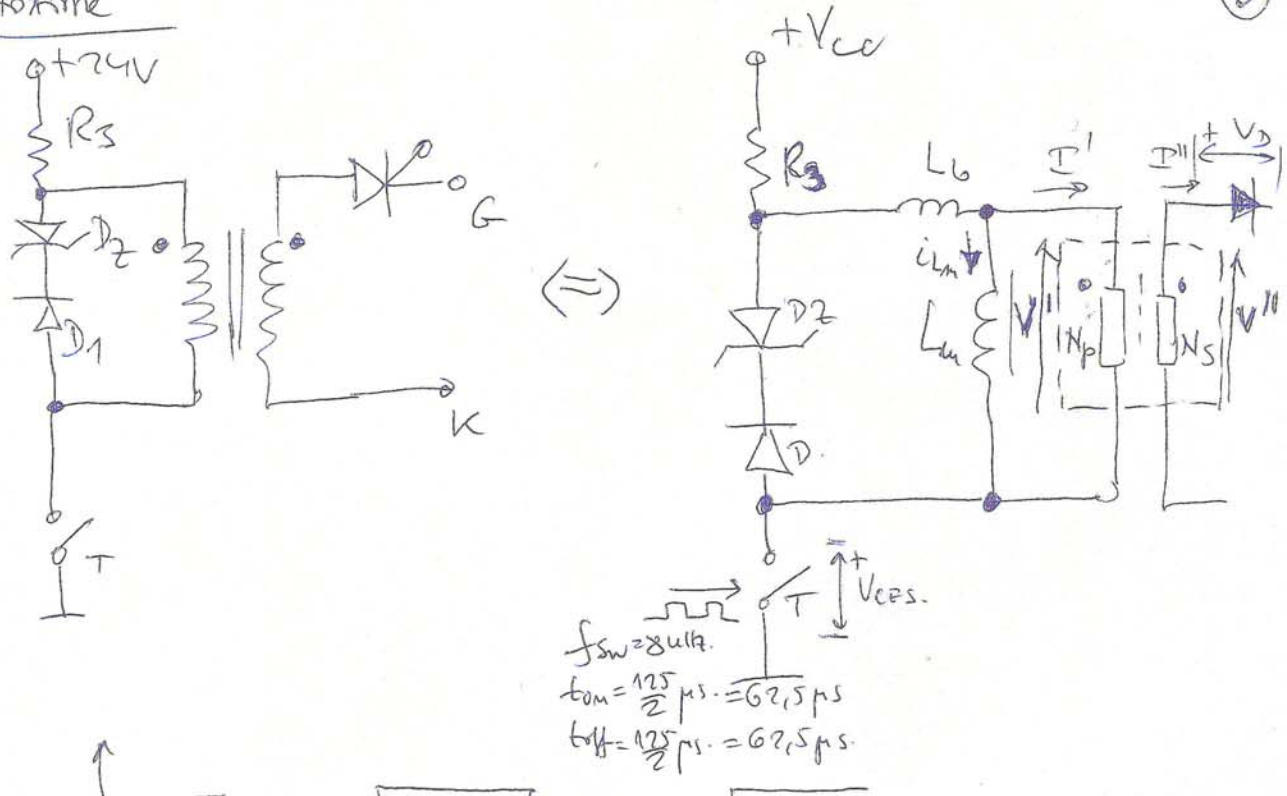
TEMPERATURA HLADNJAKA:

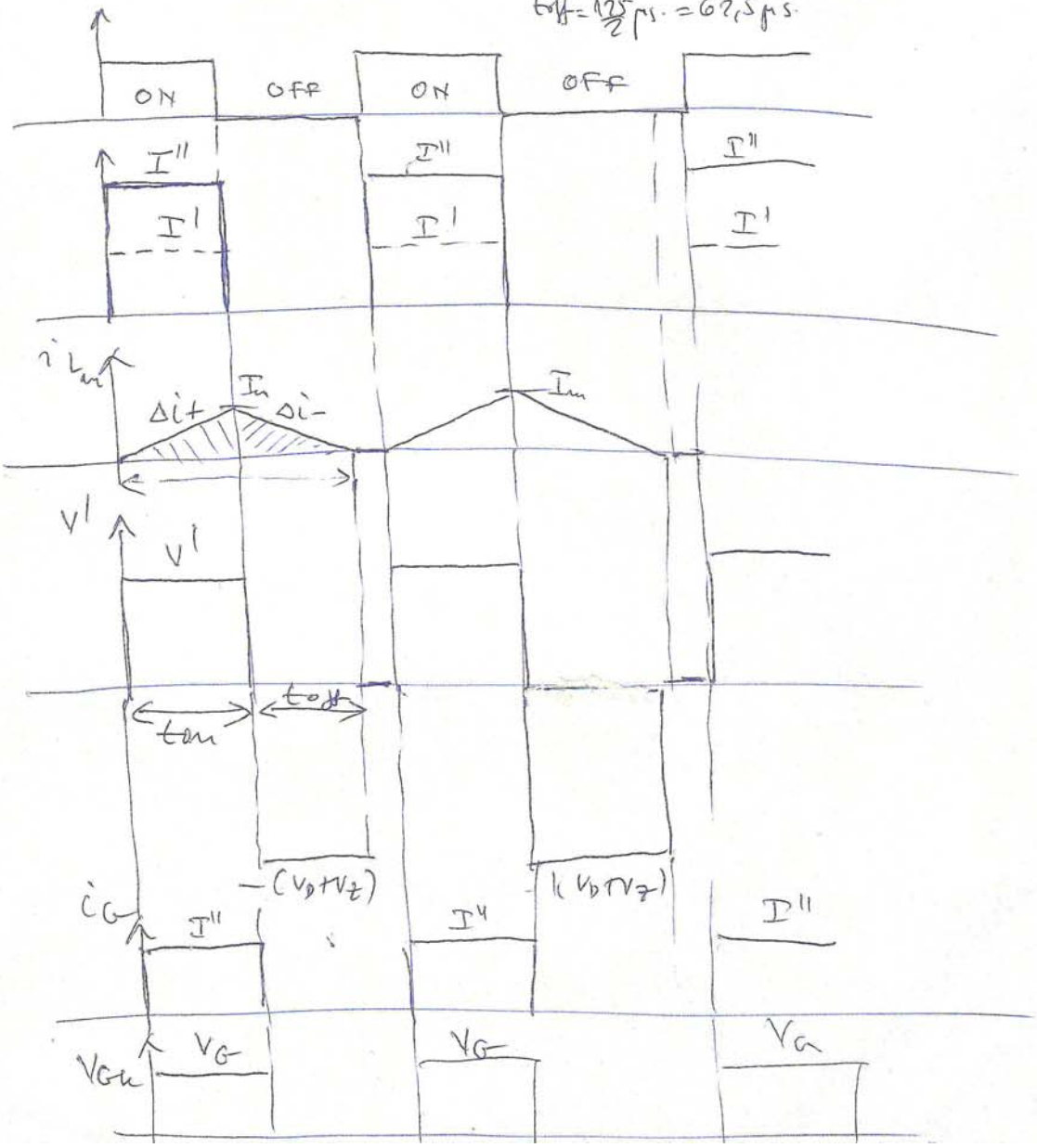
$T_s = T_{a\,max} + R_{th(s-a)} \cdot P_{TOT} = 60°C + 0{,}25 \cdot 150 = 97{,}5°C$

TEMPERATURA KUĆIŠTA diode:

$T_c = T_s + R_{th(c-s)e} \cdot P_{TOT} = 97{,}5°C + 0{,}033 \cdot 150 = 102{,}5°C$

2 zadatak


+24V
R_S
D_z
D_1
G
K
T
$+V_{cc}$
R_3
L_b
I'
I''
V_D
i_{Lm}
L_m
N_p
N_s
V''
D
V_{ces}
f_{sw}=8kHz.
$t_{on}=\frac{125}{2}\mu s.=62{,}5\mu s$
$t_{off}=\frac{125}{2}\mu s.=62{,}5\mu s.$


ON
OFF
ON
OFF
I''
I'
i_{Lm}
$\Delta i+$
$\Delta i-$
I_m
V'
t_{on}
t_{off}
$-(V_D+V_Z)$
i_G
V_{GM}
V_G

$V'' = V_D + V_{GK} = 0,7 + 3 = 3,7V$ $\quad V_1 = 3V''$ $\quad V' = 3 \cdot 3,7 = 11,1V$

$i_g = I'' = 1,6A \quad I' = \frac{1,6}{3} = 0,533A$

$V_{cc} = R_3 I' + V' + V_{CES} \Rightarrow R_3 = \frac{V_{cc} - V' - V_{CES}}{I'}$

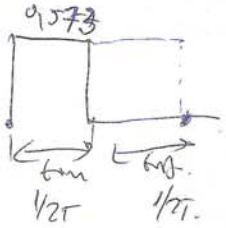
$R_3 = \frac{24 - 11,1 - 0,3}{0,533} = 23,639\Omega$

Uzimamo najmanju vrednost $R_3^* = 22\Omega$ (ili 23Ω)

$I'^* = \frac{V_{cc} - V' - V_{CES}}{R_3^*} = \frac{24 - 11,1 - 0,3}{22} = 0,573A$

$I''^* = 3 \cdot I'^* = 3 \cdot 0,573 = 1,71A > I_g$ uslov je ispunjen (OK)

$I_{R3eff} = ?$



$I_{R3eff} = \frac{0,573}{\sqrt{2}} = 0,406A.$

$P_{R3} = R_3 \cdot I_{R3eff}^2$

$P_{R3} = 22 \cdot 0,406^2 = 3,63W \rightarrow 4W.$

$R_3^* = 22\Omega / 4W$

$V' \cdot t_{on} = L_m \Delta i \Rightarrow \Delta i = \frac{V' \cdot t_{on}}{L_m} = \frac{11,1 \cdot 62,5\mu}{22m}$

$\Delta i = \frac{11,1 \cdot 62,5}{22} mA = 31,53mA.$

$L_m \Delta i = (V_Z + V_D) \cdot t_{off} \qquad t_{off} \leq 62,5\mu s$

$t_{off} = 60\mu s.$

$V_Z = \frac{L_m \cdot \Delta i}{t_{off}} - V_D = \frac{22m \cdot 31,53mA}{60\mu s} - 0,7$

$V_Z \geq 11,561 - 0,7 = 10,86V \approx 11V$ ili (12V)

$t_{off} \leq 62{,}5\,\mu s$.

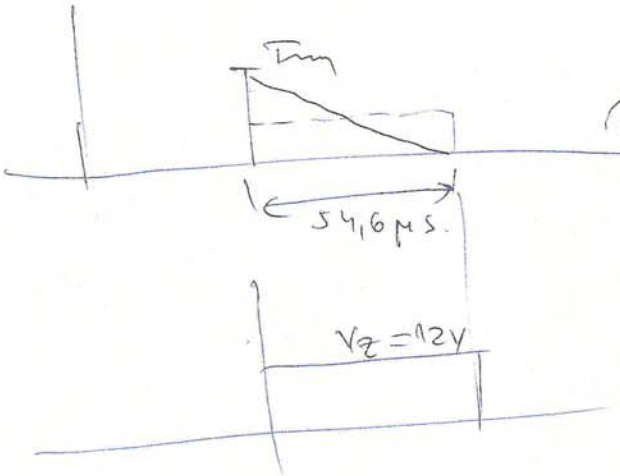
$$\frac{L_m \Delta i}{V_z + V_D} \leq 62{,}5\,\mu s.$$

$$V_z \geq \frac{L_m \Delta i}{62{,}5} - V_D$$

$$V_z \geq \frac{22\mu \cdot 31{,}53}{62{,}5\mu} - 0{,}7$$

$V_z \geq 10{,}4\,V \rightarrow V_z = 11\,V$ i.e. $\boxed{V_z = 12\,V}$

$$V_z^* = 12\,V \qquad t_{off}^* = \frac{22\mu \cdot 31{,}53\mu}{12 + 0{,}7} = \boxed{54{,}6\,\mu s}$$



$$P_{DIS}^{ZD} = \frac{12V \cdot 31{,}53}{2} \cdot \frac{54{,}6}{125} = 82{,}63\,mW$$

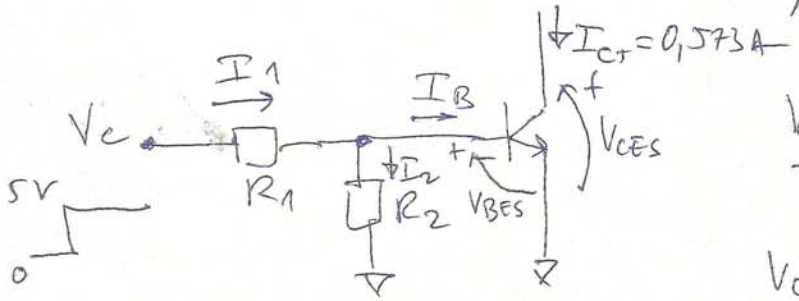
Zener DIODA

12 V / 100 mW

Dimenzionisanje R_1 i R_2:

$I_{CT} = I' = 0{,}573$ (struja kolektora tranzistora)

Struja baze tranzistora T: $I_B \geq \frac{I_{CT}}{h_{fe}} = \frac{0{,}573}{400} = 1{,}43\,mA$



$$\frac{V_C - V_{BES}}{R_1} = I_z + I_B$$

$$\frac{V_C - V_{BES}}{R_1} = \frac{V_{BES}}{R_2} + I_B$$

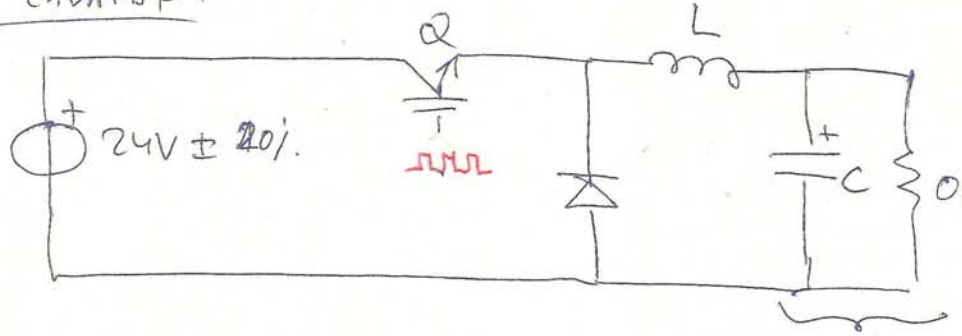
$$\frac{V_C - V_{BES}}{R_1} - \frac{V_{BES}}{R_2} \geq 1{,}43\,mA$$

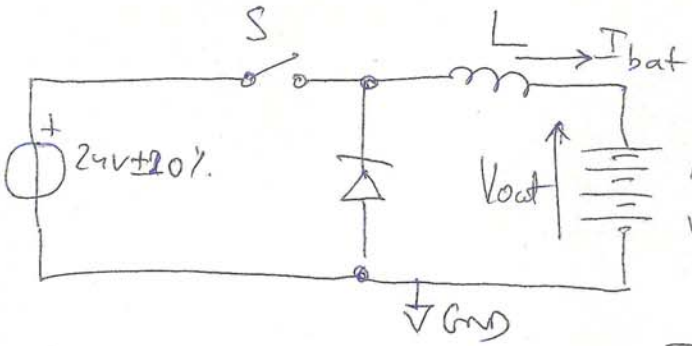
usvajamo: $\boxed{R_2 \approx 1k/0{,}25W}$

$$\frac{V_C - V_{BES}}{R_1} \geq 1{,}43\,mA + 0{,}75\,mA = 2{,}18\,mA \Rightarrow R_1 \leq \frac{5 - 0{,}75}{2{,}18\,mA} \approx 1{,}95\,k\Omega$$

$\boxed{R_1 = 1{,}6k\Omega / 0{,}25W}$

3 zadatak:





Struja punjenja baterije $I_{bat} = 0,1 \cdot C_{BAT} = 0,1 \cdot 120$

$I_{bat} = 12A$

$I_L = I_{bat} = 12A$

$V_{inmin} = 24V - 4,8V = 19,2V$

$V_{inmax} = 24V + 4,8 = 28,8V$

$19,2V \leq V_{in} \leq 28,8V$

$\Delta i_L \leq 5\% \cdot 12$

$\Delta i_L \leq \frac{5}{100} \cdot 12$

$\Delta i_L \leq 0,6A$

$$\delta = \frac{V_{out}}{V_{in}} \qquad \delta_{max} = \frac{V_{out}}{V_{inmin}} = \frac{11,2}{19,2} = 0,583$$

$$\delta_{min} = \frac{V_{out}}{V_{inmax}} = \frac{11,2}{28,8} = 0,388$$

Dimenzionisanje L: Kriticni slucaj za t_{onmin} i V_{inmax}

$$L \geq \frac{t_{onmin}(V_{inmax} - V_{out})}{\Delta i} \qquad \frac{t_{on}}{T} = \delta \qquad T = \frac{1}{f_{sw}}$$

$$L \geq \frac{\delta_{min} \cdot T (V_{inmax} - V_{out})}{\Delta i} = \frac{\delta_{min}}{f_{sw}} \cdot \frac{V_{inmax} - V_{out}}{\Delta i}$$

$$L \geq \frac{0,388}{100k} \cdot \frac{28,8 - 11,2}{0,6} = 113,81\mu H \xrightarrow{\text{standardse}} L^* = 120\mu H$$

MAX STRUJA PRIGUŠNICE L:

$$I_{Lmax} = I_L + \frac{\Delta i_L}{2} = 12A + \frac{0,6}{2} = 12,3A$$

$$\boxed{L^* = 120\mu H / 15A}$$

ZA MSTOSENO $L^* = 120\mu A$ TRANSFORM STRUJE PRI MINIM. ML. NAPON JE:

$$\Delta i = \frac{\delta_{max} \cdot T (V_{inmin} - V_{out})}{L^*} = \frac{\delta_{max}}{f_{sw} \cdot L^*} (V_{inmin} - V_{out})$$

$$\Delta i = \frac{0,583}{100k \cdot 120\mu} (19,2 - 11,2) = 0,388A < 0,6A \quad \text{OK}$$

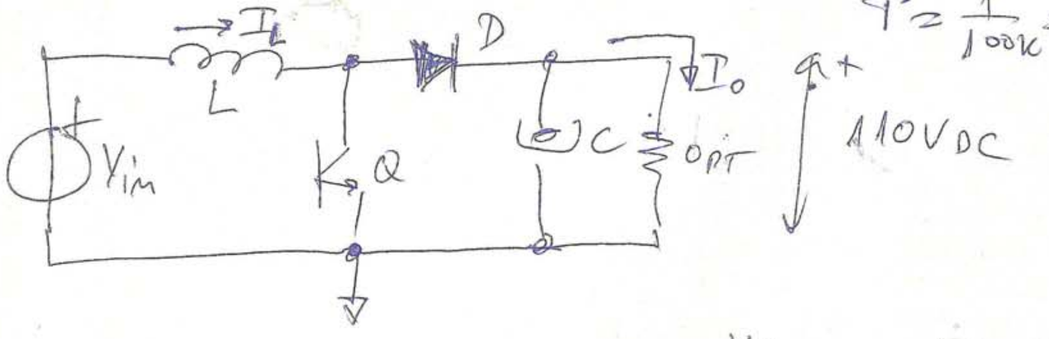
4 ZADATAK :

$V_{in} = 48V \pm 10\%$ $43{,}2V \leq V_{in} \leq 52{,}8V$ $\Delta i_{L\%} \leq 10\%$

$V_{inmax} = 1{,}1 \cdot 48 = 52{,}8V$ $V_{out} = 110V\ DC$ $\Delta V_{C\%} \leq 1\%$

$V_{inmin} = 0{,}9 \cdot 48 = 43{,}2V$ $P_{out} = 4kW$ $f_{sw} = 100kHz$

$T = \frac{1}{100k} = 10\mu s$



$$V_{out} = \frac{V_{in}}{1-\delta} \Rightarrow 1-\delta = \frac{V_{in}}{V_{out}} \Rightarrow \delta = 1 - \frac{V_{in}}{V_{out}}$$

$$\delta_{max} = 1 - \frac{V_{inmin}}{V_{out}} \qquad \delta_{min} = 1 - \frac{V_{inmax}}{V_{out}}$$

$$\delta_{max} = 1 - \frac{43{,}2}{110} = 0{,}607 \qquad \delta_{min} = 1 - \frac{52{,}8}{110} = 0{,}52$$

$$I_{inmax} = \frac{P_{out}}{V_{inmin}} = \frac{4000}{43{,}2} = 92{,}59A$$

$$I_{inmin} = \frac{P_{out}}{V_{inmax}} = \frac{4000}{52{,}8} = 75{,}75A$$

$$\boxed{L \geq \frac{V_{in} \cdot t_{on}}{\Delta i}}$$

osnovna relacija

$$L \geq \frac{V_{inmax} \cdot t_{onmin}}{\Delta i_{min}} = \frac{V_{inmax}}{\Delta i_{min}} \frac{\delta_{min}}{f_{sw}} = \frac{52{,}8}{7{,}575} \cdot \frac{0{,}52}{100k}$$

$$\Delta i_{min} = 0{,}1 \cdot I_{min} = 7{,}575A$$

$L \geq 36{,}24\mu H \rightarrow$ usvajamo $L^* = 50\mu H$

ZA $L^* = 50\mu H$ i pri min. ul. naponu, talasnost struje

$$\Delta i = \frac{V_{inmin} \cdot \delta_{max}}{L^* \cdot f_{sw}} = \frac{43{,}2 \cdot 0{,}6}{50\mu \cdot 100k} = 5{,}184A < 0{,}1 \cdot 92{,}59A < 9{,}259A$$

$L^* = 50\mu H / 100A$

$\Delta V_c = \frac{I_o}{C} \cdot t_{on}$ (u intervalu t_{on}, kad se mijenja preklopka Q, a prije toga kondenzator C)

I_o - srednja opt.

$$I_o = \frac{P}{V_{out}} = \frac{4000W}{110V} = 36{,}36A$$

$$\frac{\Delta V_c}{V_c} = \frac{I_o}{C V_c} \cdot t_{on} \qquad V_c = V_{out}$$

$$\frac{\Delta V_c}{V_{out}} = \frac{I_o}{C \cdot V_{out}} \cdot t_{on} \qquad C \geq \frac{I_o}{V_{out}} \cdot t_{on} \cdot \frac{1}{\frac{\Delta V_c}{V_{out}}}$$

$t_{on} \longrightarrow t_{on\,max} = \delta_{max} \cdot T = 0{,}607 \cdot 10\mu s = 6{,}07\mu s$

$$C \geq \frac{36{,}36A}{110V} \cdot 6{,}07\mu s \cdot \frac{1}{0{,}01} \qquad \frac{\Delta V_c}{V_{out}} \leq 1\,\% = 0{,}01$$

$C \geq 200{,}64\mu F$

$C^* = 220\mu F / 150V$

$L^* = 50\mu H / 100A$

MAX. NAPON preklopke Q
$110V \xrightarrow{\text{mrežno}}$ preklopka
$\geq 400V_{DC}$

MAX. NAPON diode
$400V_{DC}$