VISER-MASTER studije ELIN-PE^{2}P 2019/2020
REŠENJA ZADATAKA-I kolokvijum

1.Zadatak

Inteligentni IGBT energetski modul se koristi u AC/AC frekventno regulisanom energetskom pretvaraču. Ulazni mrežni napon je 3x400V, 50Hz. Izgled i osnovne tehničke karakteristike IGBT modula su date u PRILOGU1.

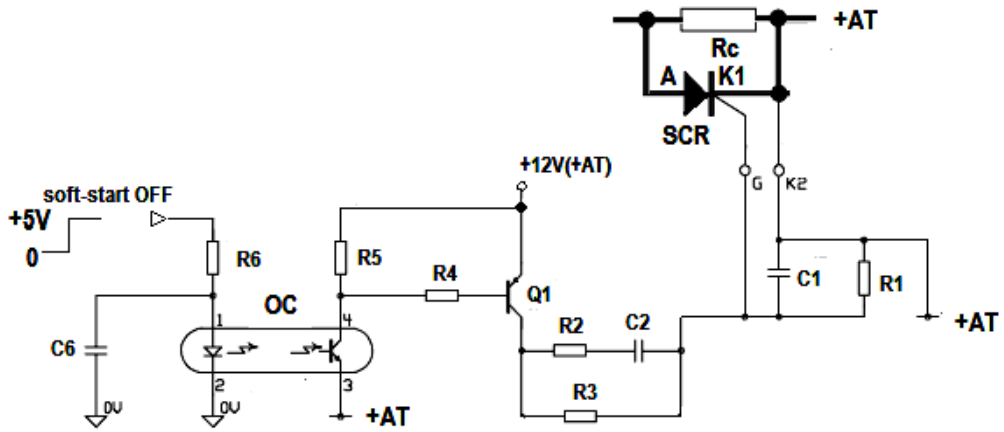
(a) Nacrtati kompletnu električnu šemu pretvarača: mrežni ulaz-ispravljač-LC filtar-kolo za početno punjenje banke elektrolita-kolo za kočenje-izlazni invertor-motor
(b) Odrediti maksimalnu snagu trofaznog asinhronog motora koji se može priključiti na izlaz modula (tačke 4-5-6)
(c) Projektovati LC filtar u jednosmernom DC međukolu, ako je talasnost DC napona <2%, a talasnost DC struje <10%
(d) Predložiti i projektovati kolo za početno punjenje banke elektrolita; usvojiti da je maksimalna struja punjenja 30A; Podaci za tiristorski modul su dati u PRILOGU2
(e) Odabrati tip i projektovati ulazne mrežne osigurače
(f) Dimenzonisati otpornik za kočenje u DC međukolu

2. Zadatak

Za uslove koji su dati u Zadatku 1 odrediti potrebnu termičku otpornost hladnjaka, na koji se montiraju sve poluprovodničke komponente u pretvaraču. Usvojiti da je za ispravljačke elemente V_{TO}=1V, r_D=5mΩ. Pretpostaviti temperaturni radni opseg -25°C...+60°C i maksimalnu temperaturu na poluprovodničkim spojevima od Tj=130°C. Nakon odabira hladnjaka izračunati temperaturu na kućištu modula temperaturu na hladnjaku.

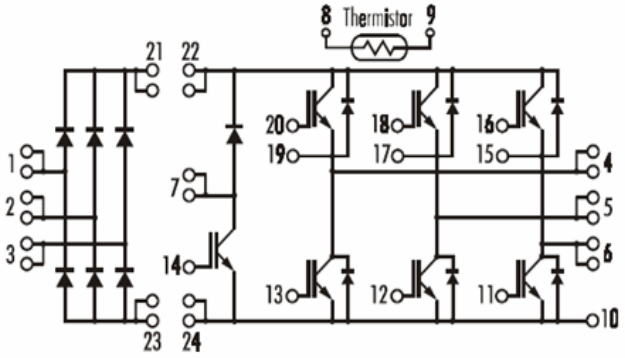
3. Zadatak

Dimenzionisati komponente impulsnog pojačavača (Slika 1) za energetski tiristor 100A/1200V- PDT 10012 koji se koristi za početno punjenje elektrolita u Zadatku 1. Pojačanje tranzistora Q1 je h_{FE}=40; V_{BES}=0.7V i V_{CES}=0.2V. Prenosni odnos optokaplera OC je I_C/I_F=10. Napon napajanja pojačavača je E=12V. Ulazni signal je pravougaoni impuls amplitude 5V. Pretpostaviti da forsirano uključenje tiristora traje 50μs.



Slika1- pobudno SCR kolo

PRILOG 1



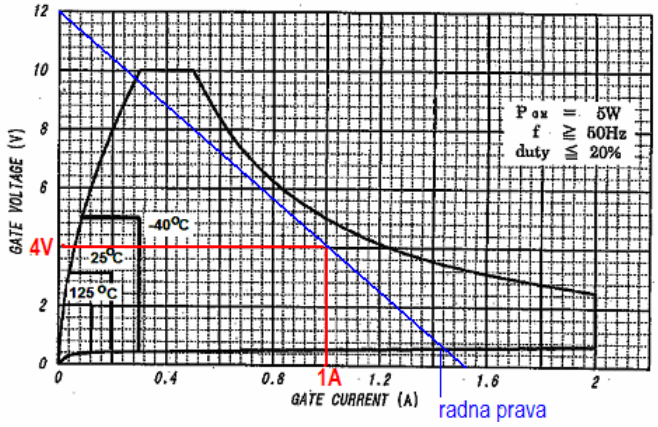
■ Absolute Maximum Ratings (T_c=25°C)

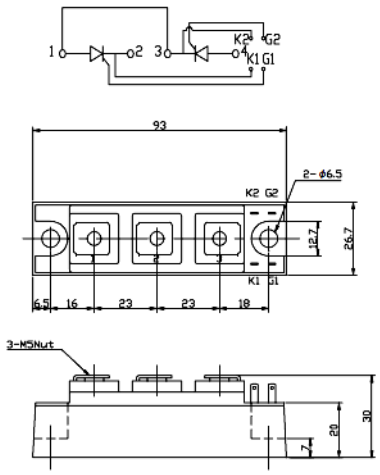
	Items	Symbols	Test Conditions		Ratings	Units
Inverter	Collector-Emitter Voltage	V_{CES}			1200	V
	Gate -Emitter Voltage	V_{GES}			± 20	
	Collector Current	I_C	Continuous	25°C / 80°C	75 / 50	A
		$I_{C\ PULSE}$	1ms	25°C / 80°C	150 / 100	
		$-I_{C\ PULSE}$			50	
	Collector Power Dissipation	P_C	1 device		360	W
Rectifier	Repetitive Peak Reverse Voltage	V_{RRM}			1600	V
	Average Output Current	I_O	50Hz/60Hz sinus wave		50	A
	Surge Current (Non Repetitive)	I_{FSM}	T_j=150°C, 10 ms, sinus wave		520	
	I^2t (Non Repetitive)				1352	A^2s
Brake Chopper	Collector-Emitter Voltage	V_{CES}			1200	V
	Gate –Emitter Voltage	V_{GES}			± 20	
	Collector Current	I_C	Continuous	25°C / 80°C	35 / 25	A
		$I_{C\ PULSE}$	1ms	25°C / 80°C	70 / 50	
	Collector Power Dissipation	P_C	1 device		180	W
	Repetitive Peak Reverse Voltage	V_{RRM}			1200	V
	Operating Junction Temperature	T_j			+150	°C
	Storage Temperature	T_{stg}			-40 ~ +125	
	Isolation Voltage	V_{ISO}	A.C. 1min.		2500	V
	Mounting Screw Torque*				3.5	Nm

■ Thermal Characteristics

Items	Symbols	Test Conditions	Min.	Typ.	Max.	Units
Thermal Resistance (1 device)	$R_{th(j-c)}$	Inverter IGBT			0.35	°C/W
		Inverter FRD			0.75	
		Brake IGBT			0.69	
		Rectifier Diode			0.50	
Contact Thermal Resistance	$R_{th(c-f)}$	With Thermal Compound		0.05		

PRILOG 2



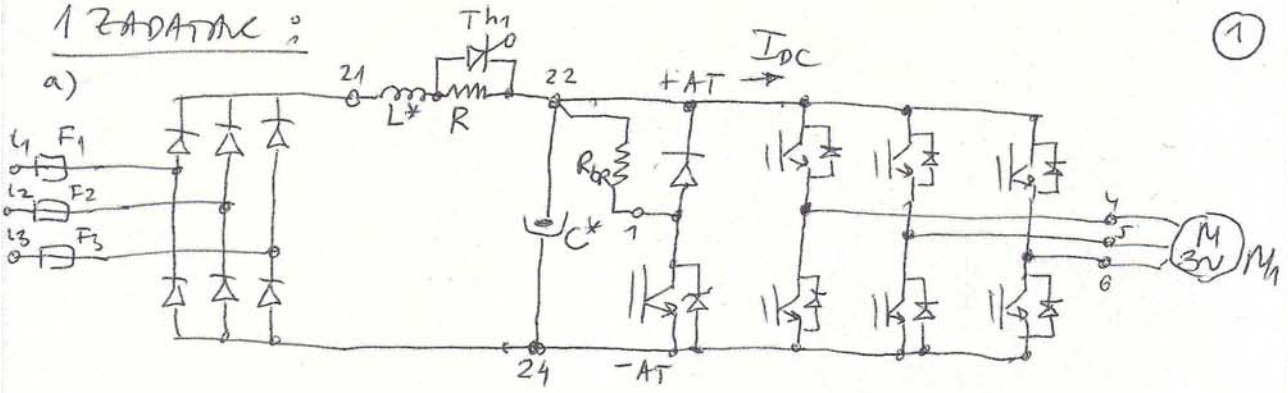


Tehnički podaci: V_{DRM}=1200V, I_{oAVG}=100A, I_{oRMS}=150A; I_{GT}=200mA, V_{GT}=4V; Rth(j-c)=0.35K/W, Rth(c-s)=0.2K/W

U Beogradu 17.12.2019. Predmetni profesor: Dr Željko Despotović, dipl.el.inž

1 ZADATAK:

a)



b) IZLAZNA SNAGA IGBT INVERTORA JE $I_c = 50A$ (KONTINUALNA STRUJA) NA 80°C

$2P_{MOT}\,[kW] \approx I_c\,[A]$, ODNOSNO $P_{MOT}^{max} \approx \frac{50}{2} = 25\,kW$

USVAJAMO DA JE NA IZLAZU INVERTORA PROJEKTOVANI STANDARDNI TROF. MOTOR M_1 22 kW; 400V, 50Hz; $\eta = 0{,}92$; $\cos\varphi = 0{,}85$

$$P_{ee}^{MOT} = \frac{P_{MOT}}{\eta} = \frac{22\,kW}{0{,}92} = 23{,}9\,kW$$

$$I_{MOT} = \frac{P_{ee}^{MOT}}{\sqrt{3}U \cdot \cos\varphi} = \frac{23{,}9\,kW}{\sqrt{3} \cdot 0{,}4\,kV \cdot 0{,}85} = 41{,}4 < 50A$$

c) NAPON DC MEĐU-KOLA

$$U_{DC} = \frac{3V_m}{\pi} \qquad V_m = 400\sqrt{2} \qquad U_{DC} = \frac{3 \cdot 400\sqrt{2}}{\pi} = 538{,}8V^*$$

* ZANEMARUJEMO PAD NAPONA NA DIODAMA U ISPR. MOSTU.

$$P_{DC} = U_{DC} I_{DC} \qquad P_{DC} \cdot \eta_{inv} = P_{ee}^{MOT} \Rightarrow P_{DC} = \frac{P_{ee}^{MOT}}{\eta_{inv}} = P_{ee}^{MOT} + P_{je*}^{inv}$$

NA OSNOVU TABELE U PRILOGU 1 ODABIRAMO INVERTOR SA $P_{je}^{inv} \approx 360\,W$, USVAJAMO $P_{je*}^{inv} = 400\,W$

$$P_{DC} = P_{ee}^{MOT} + P_{je*}^{inv} = 23{,}9\,kW + 0{,}4\,kW = 24{,}3\,kW$$

$$I_{DC} = \frac{24{,}3\,kW}{538{,}8V} = 45{,}1A$$

$\delta_{ui} \leq 2\%$ $\quad \delta_{ii} \leq 10i$

IZBOR kondenz. C

$$C \geq \frac{1}{n \cdot \omega \cdot R_{ekvi}} \cdot \frac{\delta_{ii}}{\delta_{ui}}$$

$n = 6$ (6 pulsni ispravljač)

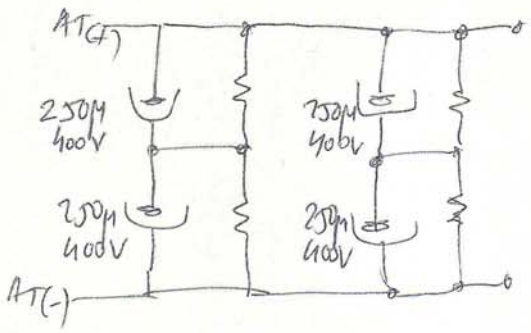
$\omega = 2\pi f = 2\pi \cdot 50Hz = 314\ rad/s$

$$R_{ekvi} = \frac{U_{DC}}{I_{DC}} = \frac{538,8}{45,1} = 11,95\Omega$$

$$C \geq \frac{1}{6 \cdot 314 \cdot 11,95} \cdot \frac{10}{2} = 222\mu F \xrightarrow{usvajamo} C^* = 250\mu F/400V$$

NAPOMENA: MOŽE SE USVOJITI i kondenzatore $C^{**} = 330\mu F/400V$

BATERIJSKA BANKA



KRITIČNA INDUKTIVNOST $L_{KR} = \frac{R_{ekvi}}{105\omega} = \frac{11,95}{105 \cdot 314} = 0,36mH$

INDUKTIVNOST L:

$$L \geq \frac{1}{(6\omega i)^2 C^*} \cdot \frac{4 R_{ekvi} \cdot 6\omega C^*}{35 \cdot \delta_i} + \frac{1}{(6\omega i)^2 \cdot C^*}$$

$$\delta_i = \frac{\delta_i\%}{100} = \frac{10}{100} = 91$$

$$L \geq \frac{4 \cdot R_{ekvi}}{35 \cdot 6\omega \cdot \delta_i} + \frac{1}{(6\omega i)^2 \cdot C^*}$$

$$L \geq \frac{4 \cdot 11,95}{35 \cdot 6 \cdot 314 \cdot 91} + \frac{1}{(6 \cdot 314)^2 \cdot 250\mu}$$

$$L \geq 7,25mH + 1,12mH = 8,377mH \xrightarrow{usvajamo} L^* = 8,5mH/50A$$

$I_{DC} = 45{,}1A \qquad \Delta I_{DC} = 0{,}1 I_{DC} = 0{,}1 \cdot 45{,}1 = 4{,}51A$

$I_{Cmax} = 45{,}1 + \frac{4{,}51}{2} = 47{,}4A \rightarrow$ usvajamo $I_{Cmax} = 50A$

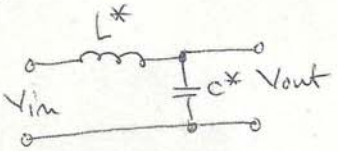
$L^* = 8{,}5mH / 50A$

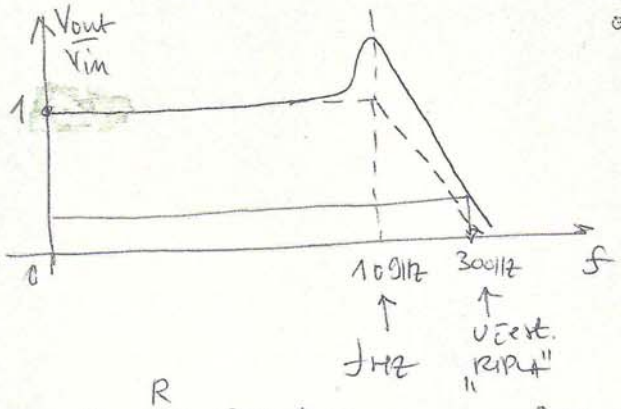
REZONANTNA UČESTANOST „LC" FILTRA

$$\omega_{REZ} = \frac{1}{\sqrt{L^* C^*}} = \frac{1}{\sqrt{8{,}5m \cdot 0{,}75m}} = 686 \text{ rad/s}$$

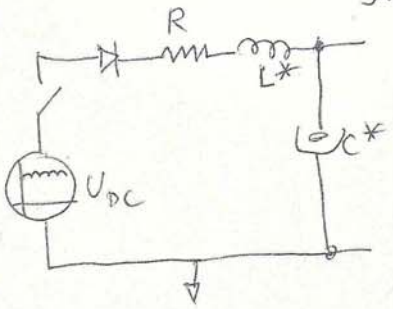
$$f_{REZ} = \frac{\omega_{REZ}}{2\pi} = \frac{686}{6{,}28} = 109{,}2Hz.$$

PRENOSNA F-NA „LC" FILTRA





d)



BEZ OTPORNIKA R MAX STRUJA PUNJENJA KONDENZATORA C JE:

$$I_{Cmax} = \frac{U_{DC}}{Z_C} = \frac{U_{DC}}{\sqrt{\frac{L^*}{C^*}}} = \frac{538{,}8}{\sqrt{\frac{8{,}5m}{0{,}75m}}}$$

$$I_{Cmax} = \frac{538{,}8}{5{,}83} \approx 92{,}4A \approx 93A$$

OTPORNIK R SE BIRA TAKO DA ZADOVOLJI KRITIČNI ODNOS $R_{KR} = 2\sqrt{\frac{L^*}{C^*}}$

$R_{KR} = 11{,}66\Omega$ USVAJAMO $R = 12\Omega$

STRUJA SE MAKS. STRUJA PUNJENJA $I'_{Cmax} = \frac{1{,}1 U_{DC}}{R + Z_C} = \frac{1{,}1 \cdot 538{,}8}{12 + 5{,}83}$

$$I'_{Cmax} = \frac{593}{17{,}83} = 33{,}26A$$

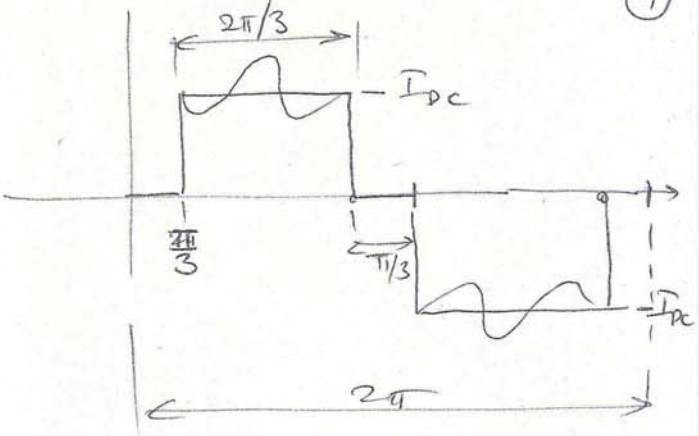
ZA OGRANIČENJE STRUJE PUNJENJA OD 30A, MEĐU PLOČAMA

$I''_{Cmax} = 30A \quad \frac{1{,}1 U_{DC}}{R + Z_C} = 30 \quad R + Z_C = \frac{1{,}1 U_{DC}}{30} \Rightarrow R = \frac{1{,}1 U_{DC}}{30} - Z_C = 14\Omega$

USVAJAMO $R = 14\Omega / 100W$

e) $I_{DC} = 45{,}1\,A$

EFEKTIVNA VREDNOST UKUPNE STRUJE



$$I_{Leff} = \sqrt{\frac{2 I_{DC}^2 \cdot \frac{2\pi}{3}}{2\pi}}$$

$$I_{Leff} = \sqrt{\frac{2}{3}}\, I_{DC}$$

$$I_{Lef} = \sqrt{\frac{2}{3}} \cdot 45{,}1 = 36{,}8\,A$$

- MSRMA DE OSIGURAČ ZA 40A, NAPONA 650V~
- OSIGURAČ MORA BITI ULTRA-BRZI (UBO)

$$I^2t\,(\text{diode}) \geq I^2t\,(UBO)$$
$$\text{ispr.}$$

PRAKTIČNO $I^2t\,(\text{diode}) \approx 2\,I^2t\,(UBO)$

$$\Rightarrow I^2t\,(UBO) = \frac{1}{2} I^2t\,(\text{diode}) = \frac{1}{2} \cdot 1352\,A^2s$$

$$I^2t\,(UBO) \approx 670\,A^2s$$

UBO:

40A / 650V~ ; $670\,A^2s$

f) $P_{BR} \approx \frac{1{,}2\,U_{DC}^2}{R_{BR}}$ $\quad P_{BR} \approx P_{MOT}^{el} = 23{,}9\,kW$

$$R_{BR} = \frac{1{,}2\,U_{DC}^2}{P_{BR}} = \frac{1{,}2 \cdot 538{,}8^2}{23{,}9\,kW} = 14{,}57\,\Omega \rightarrow 15\,\Omega$$

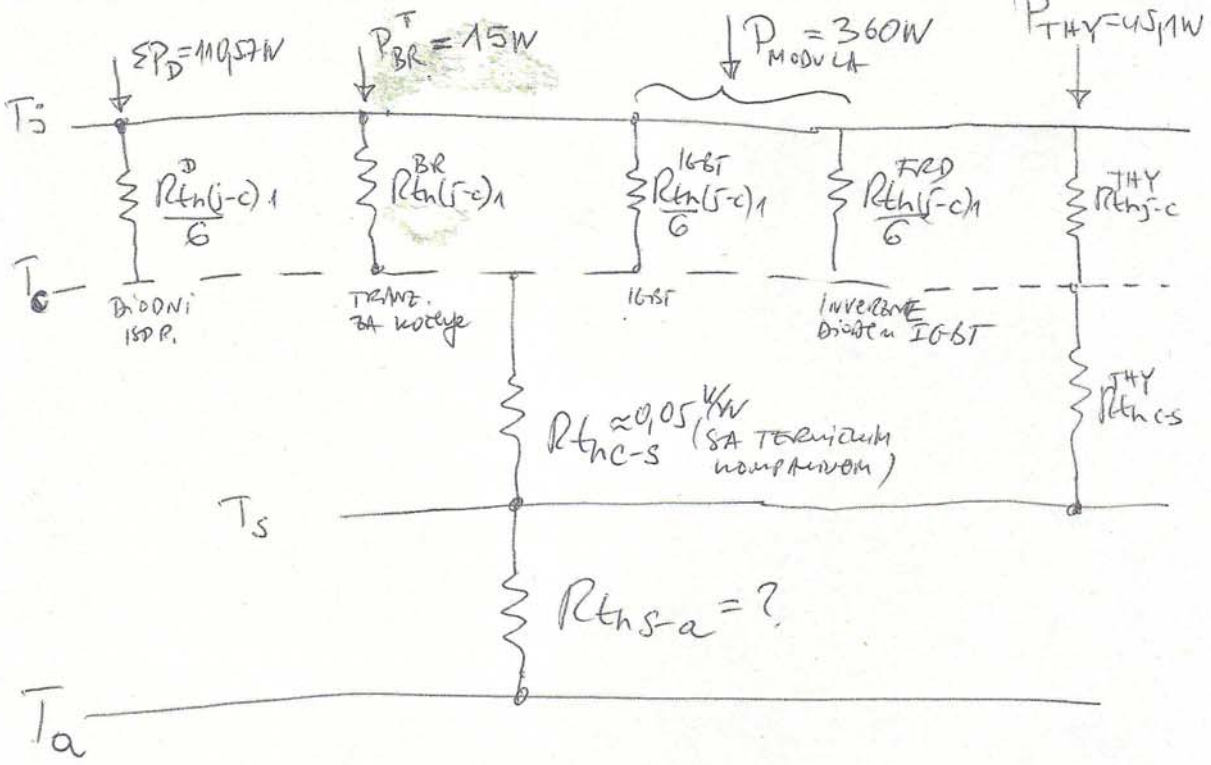
$R_{BR} = 15\,\Omega / 1\,kW_{cont.}$ $\quad t_u \approx 1s$ $\quad E = \frac{1{,}2 \cdot 538{,}8^2}{15\,\Omega} \cdot 1s = 6{,}45\,kWh$

2 ZADATAK

$V_{TO} = 1V$ $r_d = ?$

$-25°C \ldots +60°C$ $T_{j\,max} = 130°C$

Ekvivalentna termička šema:



* $\Sigma P_D = 6 \cdot P_{D1}$ – disipacija na diodnim ispravljačima

$P_{D1} = V_{TO} I_{DSR} + r_D \cdot I_{Deff}^2$ $\quad I_{DSR} = \frac{I_{DC}}{3} = \frac{45,1}{3} = 15,03A$

$P_{D1} = 1 \cdot 15,03 + 5 \cdot 10^{-3} \cdot 26,07^2$ $\quad I_{Deff} = \frac{I_{DC}}{\sqrt{3}} = \frac{45,1}{\sqrt{3}} = 26,07A$

$P_{D1} = 18,42W$

$P_D = 6 P_{D1} = 110,57W$

* $P_{BR}^T \approx 60W \left(\frac{1}{6} \cdot 360W\right)$ → obzirom da se kočioni otpornik ne mjenja često moramo uzeti

$P_{BR}^T \approx 10 \div 20W$ (maksimum 15W)

* $P_{modula} = 360W$

* $P^{THY} = V_{TO} \cdot I_{DC} = 1 \cdot 45,1 \approx 45,1 W$

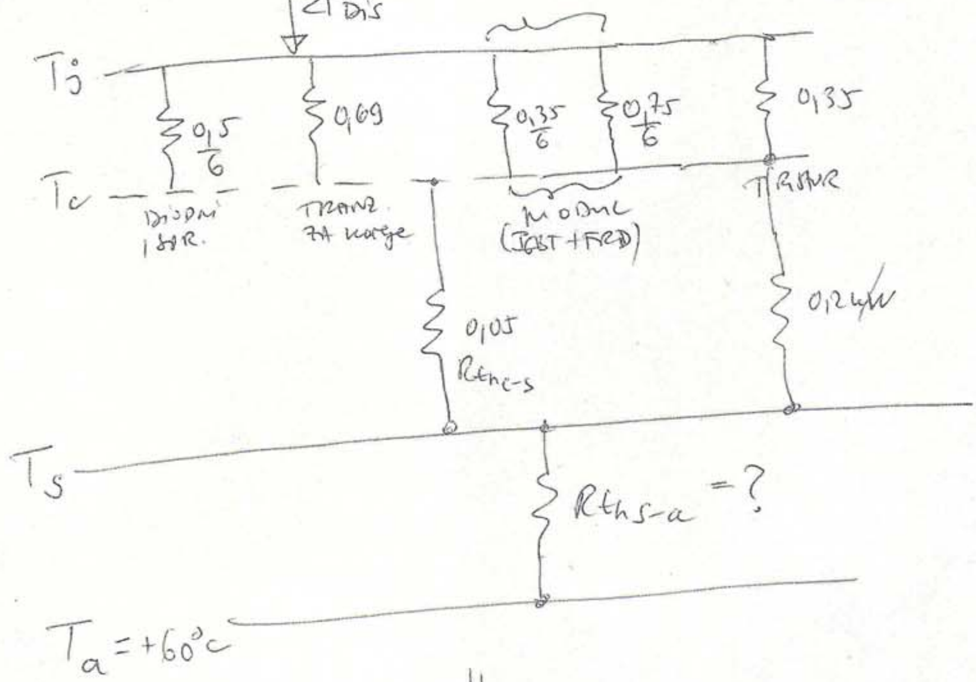
UKUPNA SNAGA DISIPACIJE SVIH ELEMENATA NA HLADNJAKU JE

$$\sum P_{DIS} = \sum P_D + P_{BR}^T + P_{modula} + P_{THY}$$
$$= 110,57 W + 15 W + 360 W + 45,1 W = 530,67 W$$

USVOJIĆEMO DA JE ZBOG DODATNIH GUBITAKA U SABIRNICAMA

$$\sum P_{DIS}^* = 550 W.$$

Ekviv. termička šema je:



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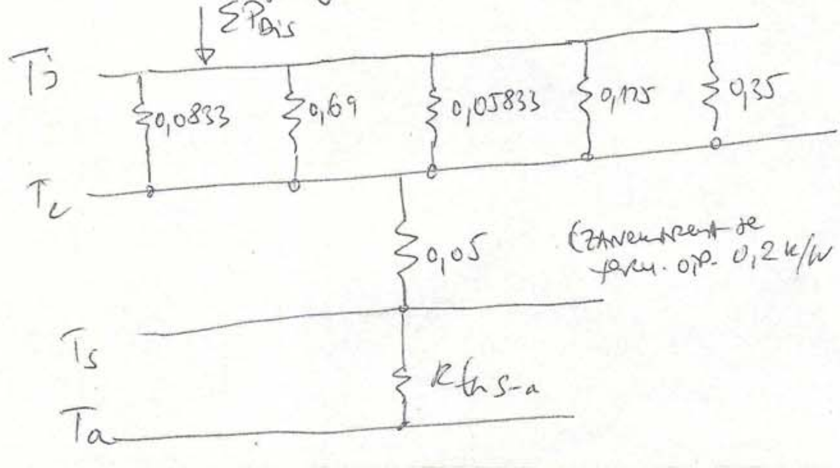
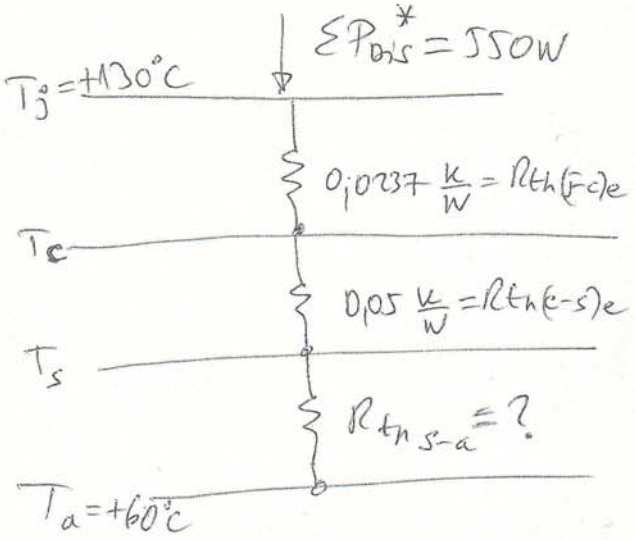




$$R_{th(S-a)} + R_{th(J-C)e} + R_{th(C-S)e} \leq R_{th}^{*}$$

$$R_{th}^{*} = \frac{T_{j\,max} - T_{a\,max}}{\mathcal{E}P_{DIS}^{*}}$$

$$R_{th(S-a)} + R_{th(J-C)e} + R_{th(C-S)e} \leq \frac{T_{j\,max} - T_{a\,max}}{\mathcal{E}P_{DIS}^{*}}$$

$$R_{th(S-a)} + 0,0237 + 0,05 \leq \frac{130° - 60°}{550W}$$

$$R_{th(S-a)} \leq \frac{130-60}{550} - 0,0237 - 0,05$$

$$R_{th(S-a)} \leq 0,127 - 0,0237 - 0,05 = 0,0535 \frac{K}{W} \left(\frac{°C}{W}\right)$$

Usvojićemo da $R_{th(S-a)}^{*} = 0,05 \frac{K}{W}$

– TEMPERATURA NA HLADNJAKU ZA OVU USVOJENU VREDNOST JE:

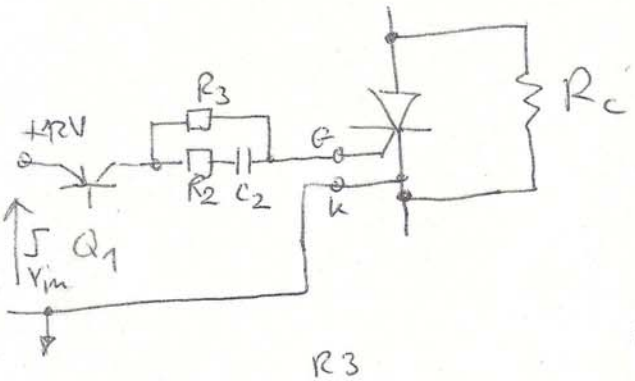
$$T_S = T_a + R_{th(S-a)} \cdot \mathcal{E}P_{DIS}^{*} = 60°C + 0,05 \cdot 550 = 87,5°C$$

– TEMPERATURA NA KUĆIŠTU MODULA

$$T_C = T_S + R_{th(C-S)e} \cdot \mathcal{E}P_{DIS}^{*} = 87,5°C + 0,05 \cdot 550$$

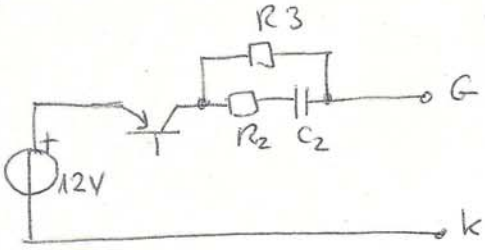
$$T_C = 115°C$$

3 ZADATAK



$V_{BES} = 0,7V$
$V_{CES} = 0,2V$
$h_{FE} = 40$
$I_d/I_F = 60$

NA OSNOVU DIJAGRAMA IZ PRILOGA 2 UKOLIKO DA je FORSIRANA STRUJA GATA $I_G^* = 1A$ A NAPON $V_{GK} = 4V$



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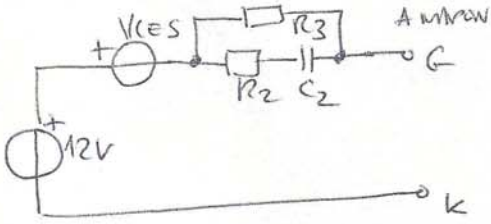
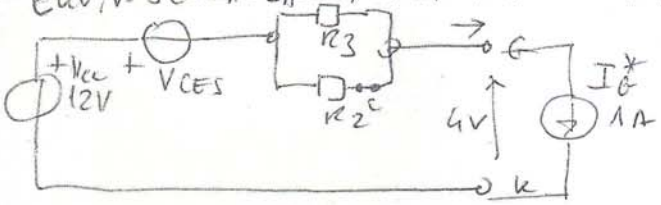


4) EKVIV. ŠEMA ZA FORSIRANI REŽIM (NA STRANI IVICU KOND. je „KS")



$$V_{CC} = V_{CES} + (R_3 \| R_2) I_G^* + V_{GK}$$

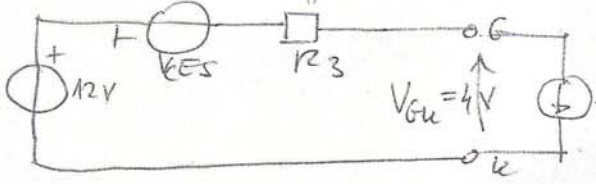
$$I_G^* = \frac{V_{CC} - V_{CES} - V_{GK}}{R_2 \| R_3}$$

$$I_G^* = \frac{V_{CC} - V_{CES} - V_{GK}}{\frac{R_2 R_3}{R_2 + R_3}}$$

$$\frac{R_2 R_3}{R_2 + R_3} = \frac{V_{CC} - V_{CES} - V_{GK}}{I_G^*} = \frac{12V - 0,2V - 4V}{1A} = 7,8\Omega$$

$$\boxed{\frac{R_2 R_3}{R_2 + R_3} = 7,8\Omega}$$

B) EKVIV. ŠEMA ZA „USTRUJENI REŽIM"



$$R_3 = \frac{V_{CC} - V_{CES} - V_{GK}}{I_{GT}}$$

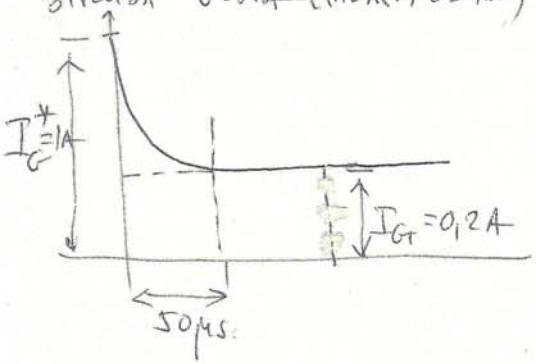
$$R_3 = \frac{12 - 0,2 - 4}{0,2}$$

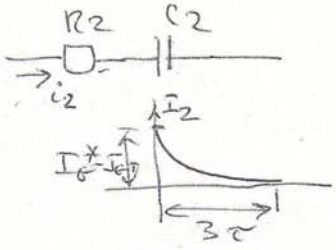
$$R_3 = 39\Omega$$

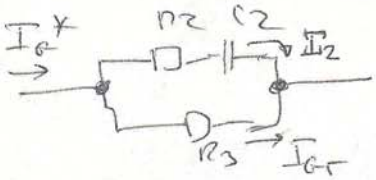
$$\frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{7,8} \Rightarrow \frac{1}{R_2} = \frac{1}{7,8} - \frac{1}{39} = 0,128 - 0,0256 = 0,1023$$

$$R_2 = 9,76 \rightarrow R_2 = 10\Omega$$

Structura circuit (parțial)

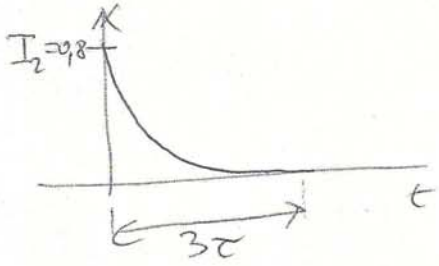






$I_2 = 1A - 0,2 = 0,8A$

$I_2 + I_{GT} = I_G^*$



$i_2 = I_2 e^{-\frac{t}{\tau}}$

$3\tau = 50\mu s$

$3 \cdot R_2 C_2 = 50\mu s \quad R_2 C_2 = \frac{50}{3}\mu s$

$C_2 = \frac{50}{3}\mu s \cdot \frac{1}{R_2} = \frac{50}{3} \cdot \frac{1}{10}\mu F = 1,66\mu F$

se alege $\boxed{C_2^* = 2,2\mu F}$

Disipația pe R_2:

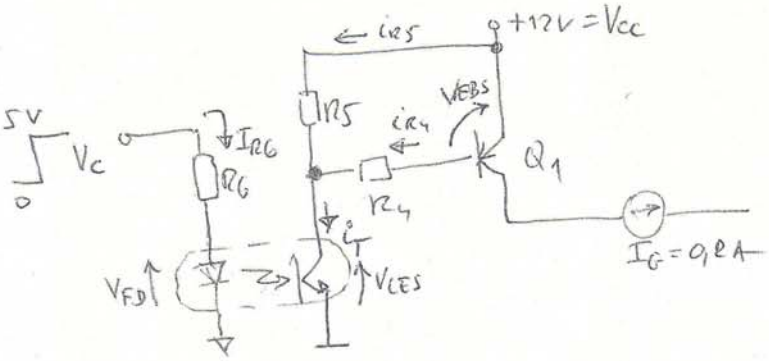
$P_{R_2} = R_2 I_{R_2}^2 = 10 \cdot I_2^2 = 10 \cdot 0,8^2$

$P_{R_2} = 6,4W$ (în tranzitoriu ~ 50μs)

Disipația pe R_3:

$P_{R_3} = R_3 I_{R_3}^2 = 30 \cdot 0,2^2 = 1,56W$

* PRORAČUN OTPORNIKA R_4, R_5, R_6



$V_c = R_6 I_{R6} + V_{FD}$

V_{FD} - NAPON NA (FD) DIODI OPTOKAPLERA

$V_{FD} = 1,2V$

$V_c = 5V \quad V_{FD} = 1,2V$

$I_{R6} = 2mA$ (usvojeno)

$$R_6 = \frac{V_c - V_{FD}}{I_{R6}} = \frac{5 - 1,2}{2m} = 1,9K.$$

$\boxed{R_6^* = 2K/0,25W}$

ODNOS OC

$$I_T = \left(\frac{I_C}{I_F}\right) \cdot I_{R6}$$

$I_T = 10 \cdot 2mA = 20mA.$

$$i_{R4} = \frac{I_C}{h_{FE}} = \frac{I_G}{h_{FE}} = \frac{0,2}{40} = 5mA$$

$V_{CC} = V_{EBS} + R_4 i_{R4} + V_{CES}$

$V_{CC} = \underbrace{V_{EBS}}_{0,7V} + R_4 i_{R4} + 0,2V$

$$\frac{12 - 0,7 - 0,2}{i_{R4}} = R_4$$

$$\frac{11,1}{i_{R4}} = R_4 \Rightarrow \frac{11,1}{5m} = 2k2$$

$R_4 = 2k2 \qquad P_{R4} = 2k2 \cdot (5m)^2 = 0,055W$

$\boxed{R_4^* = 2k2/0,25W}$

$i_{R5} + i_{R4} = i_T$

$i_{R5} = i_T - i_{R4} = 20mA - 5mA$

$i_{R5} = 15mA.$

$V_{CC} = R_5 i_{R5} + V_{CES}$

$$\frac{V_{CC} - V_{CES}}{i_{R5}} = R_5$$

$$R_5 = \frac{12 - 0,2}{15m} = 786,7\Omega$$

usvojeno $\boxed{R_5^* = 1K/0,25W}$