VISER-NET-SPECIJALISTIČKE STUDIJE
PREDMET: Upravljanje Elektroenergetskim Pretvaračima

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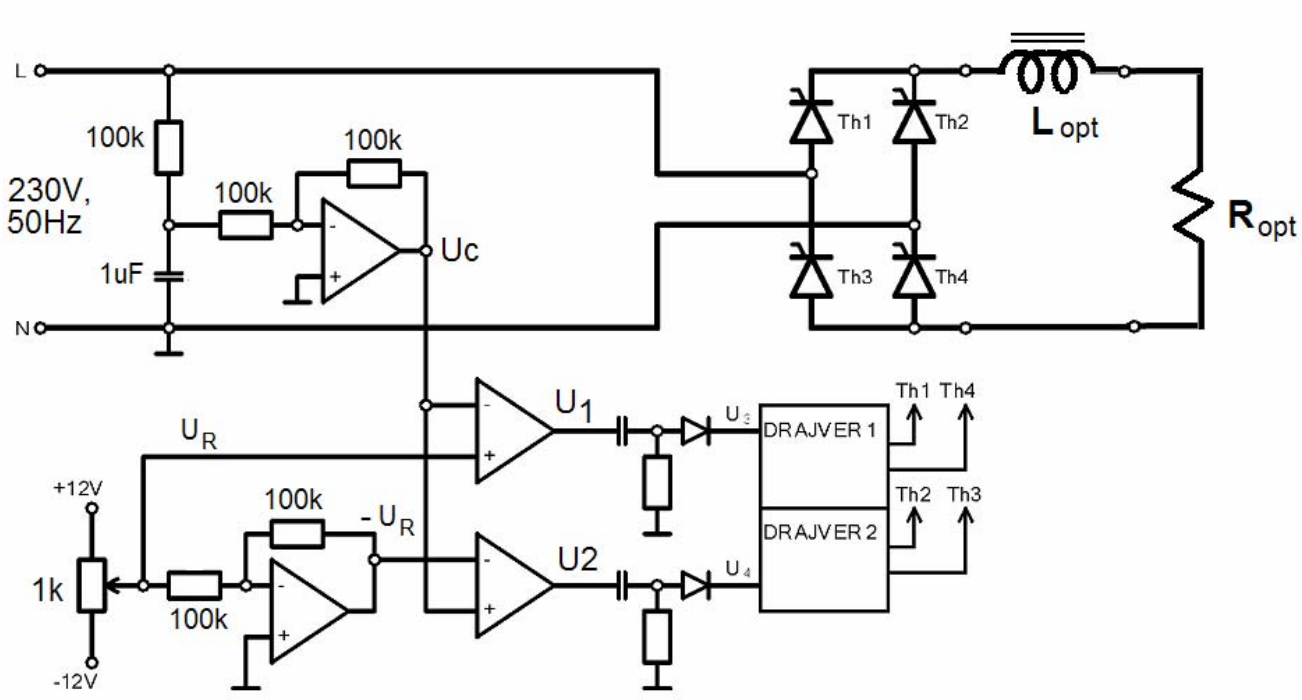
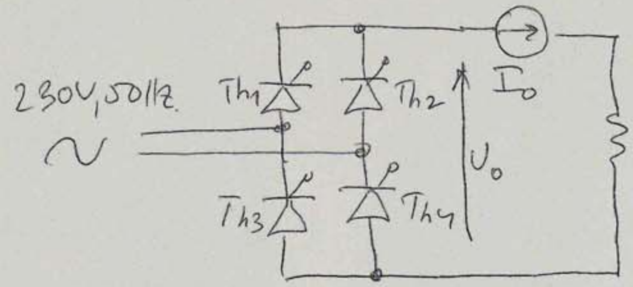
Za energetsko kolo ispravljača na slici, nacrtati za vrednosti ugla upravljanja $\alpha = 0^0, 90^0, 120^0$, karakteristične talasne oblike: napon na izlazu iz ispravljača, struje tiristora Th1-Th4 i struju koju ispravljač uzima iz mreže. Za upravljačko kolo nacrtati karakteristične talasne oblike signala U_C, U_R, U_1, U_2. Odrediti prenosnu karakteristiku U_0 / U_C (odnos izlaznog napona U_0 i upravljačkog napona U_R). Takođe odrediti prenosnu karakteristiku – zavisnost ugla upravljanja od upravljačkog napona $\alpha = F(U_R)$. Odrediti opseg promene struje opterećenja u zavisnosti od upravljačkog napona U_R, ako su dati parametri $R_{opt} = 10\Omega$ i $L_{opt} \to \infty$. Smatrati da su tiristori i diode u ispravljaču idealnih karakteristika.



REŠENJE : (1)

$L_{opt} \to \infty$ induktivnost se ponaša kao strujni ponor i može se predstaviti sa strujnim gen. $\rightarrow I_0$

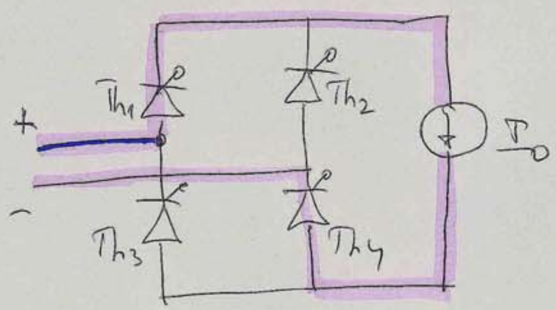


$I_0 = U_0 / R_{opt}$

$U_0 = f(\alpha)$

α = ugao upravljanja (fazni ugao)

Pozitivna poluperioda mrežnog napona (vode Th1 i Th4)

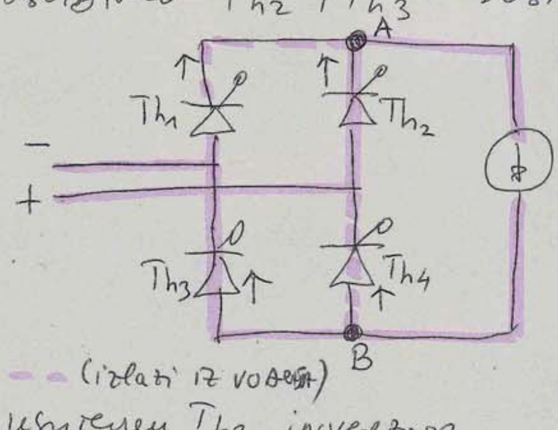


Napon na Th1, kao i napon na Th4 su jednaki ∅

$V_{Th1} = V_{Th4} \approx 0$

Th2 i Th3 su inverzno polarisani. ($V_K > V_A$)

U negativnoj poluperiodi se stiču uslovi da provedu Th2 i Th3. To je potreban ali ne i dovoljan uslov, da provedu Th2 i Th3. Dovoljan uslov je da dovedemo impulse na gejt. Dakle kada u negativ. poluperiodi pobudimo Th2 i Th3 dobija se sledeće kolo



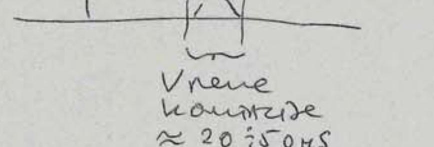
- - - - (izlazi iz vođenja)

Uključenjem Th_2 inverzno polarišemo Th_1

U tački A važi

$i_{Th1} + i_{Th2} = I_0 = const$

$i_{Th1} \searrow \quad i_{Th2} \nearrow$



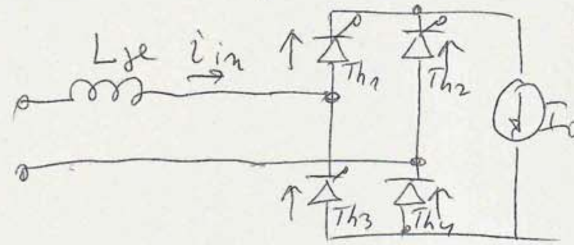
Vreme komutacije $\approx 20 \div 50 \mu s$

Uključenjem Th_3 inverzno polarišemo Th_4

$i_{T3} + i_{Th4} = I_0$

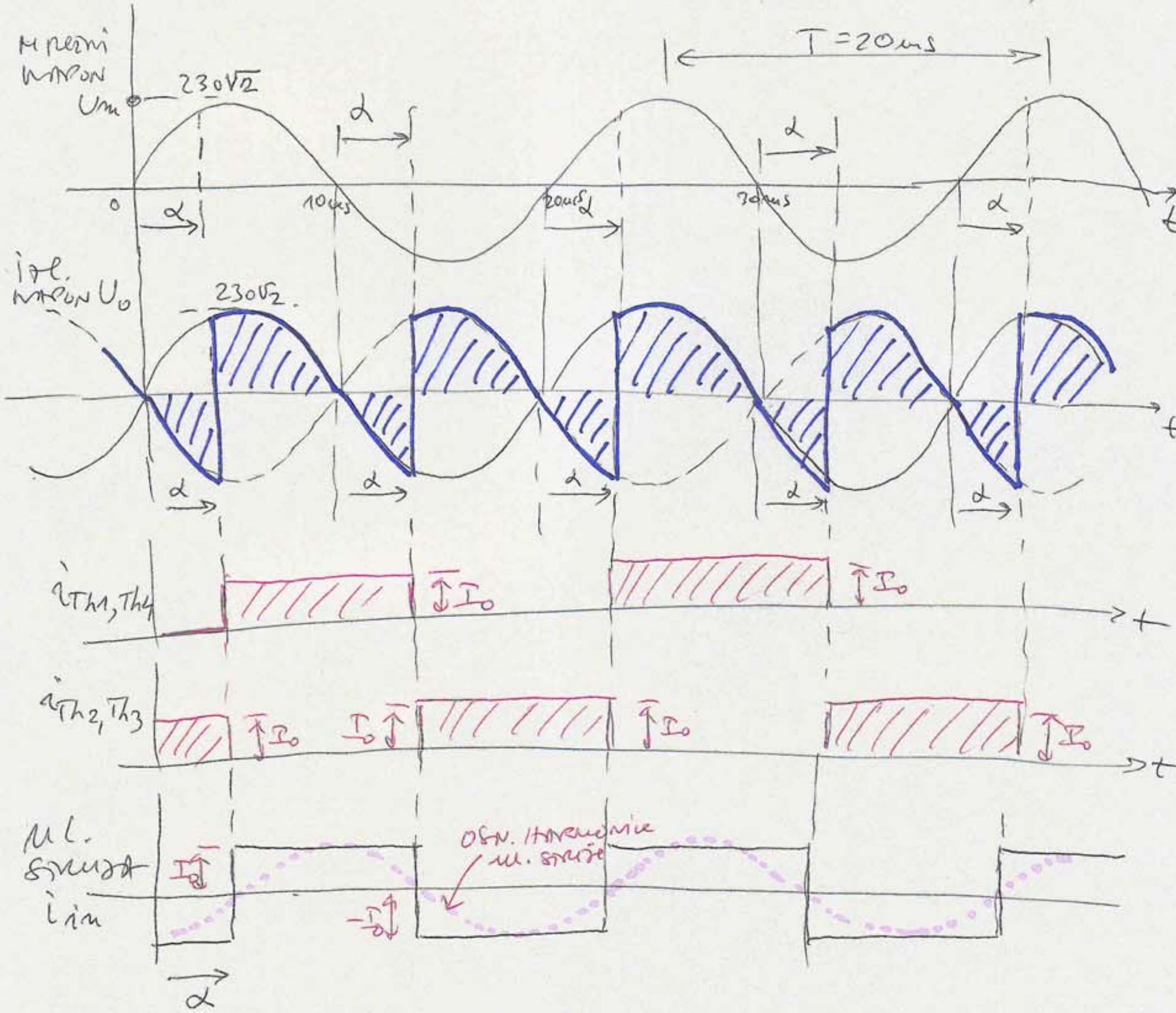
$i_{Th3} \nearrow \quad i_{Th4} \searrow$

U ovom kratkom trenutku vode sva četiri tiristora, tako da je ceo most stvara "kratki spoj" za mrežu. Da bi se ovaj efekat ublažio prema mreži se postavlja prigušnica L_{je}



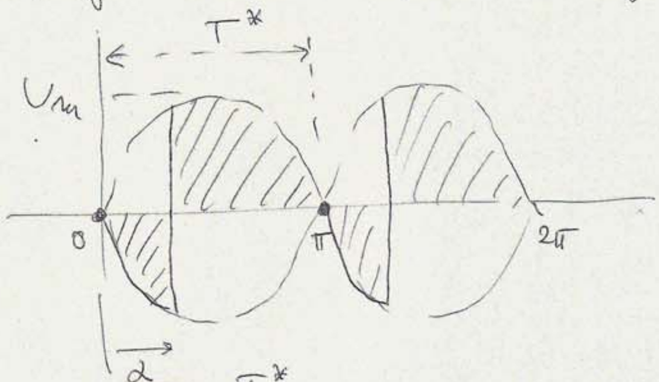
L_{je} ograničava struju kratkog spoja kada komutiju tiristori.

Talasni oblici za ugao α (proizv. vrednost)



Fazni pomeraj između prvog harmonika ul. struje i mrežn. napona je jednak α

Izračunavanje izlaznog napona (srednja vrednost)



$T = 20\,ms \quad f = \frac{1}{T} = 50\,Hz$

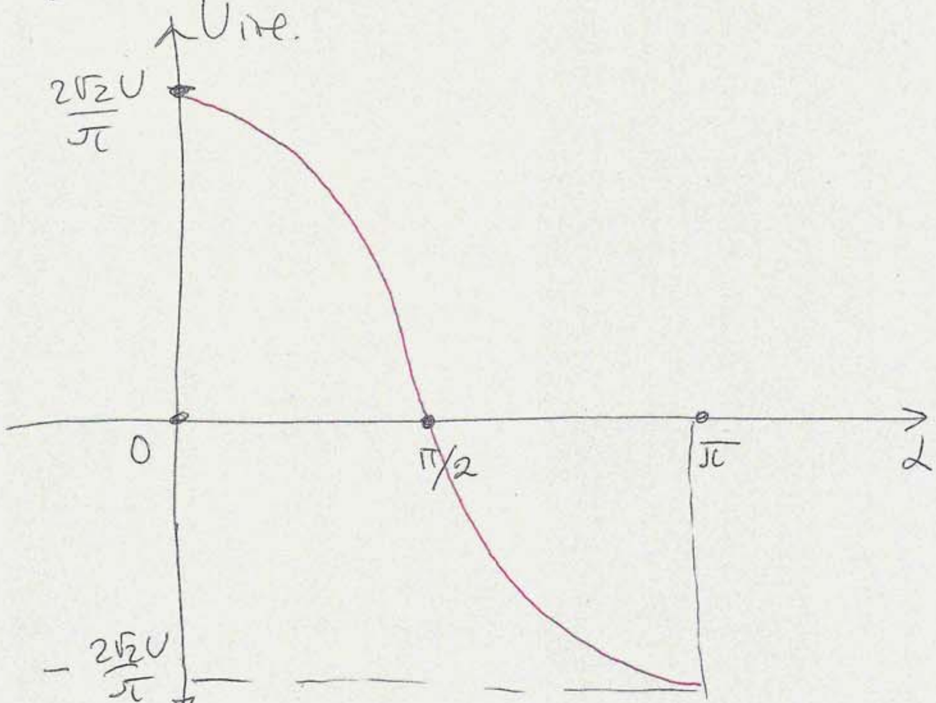
$T^* = \frac{T}{2}$

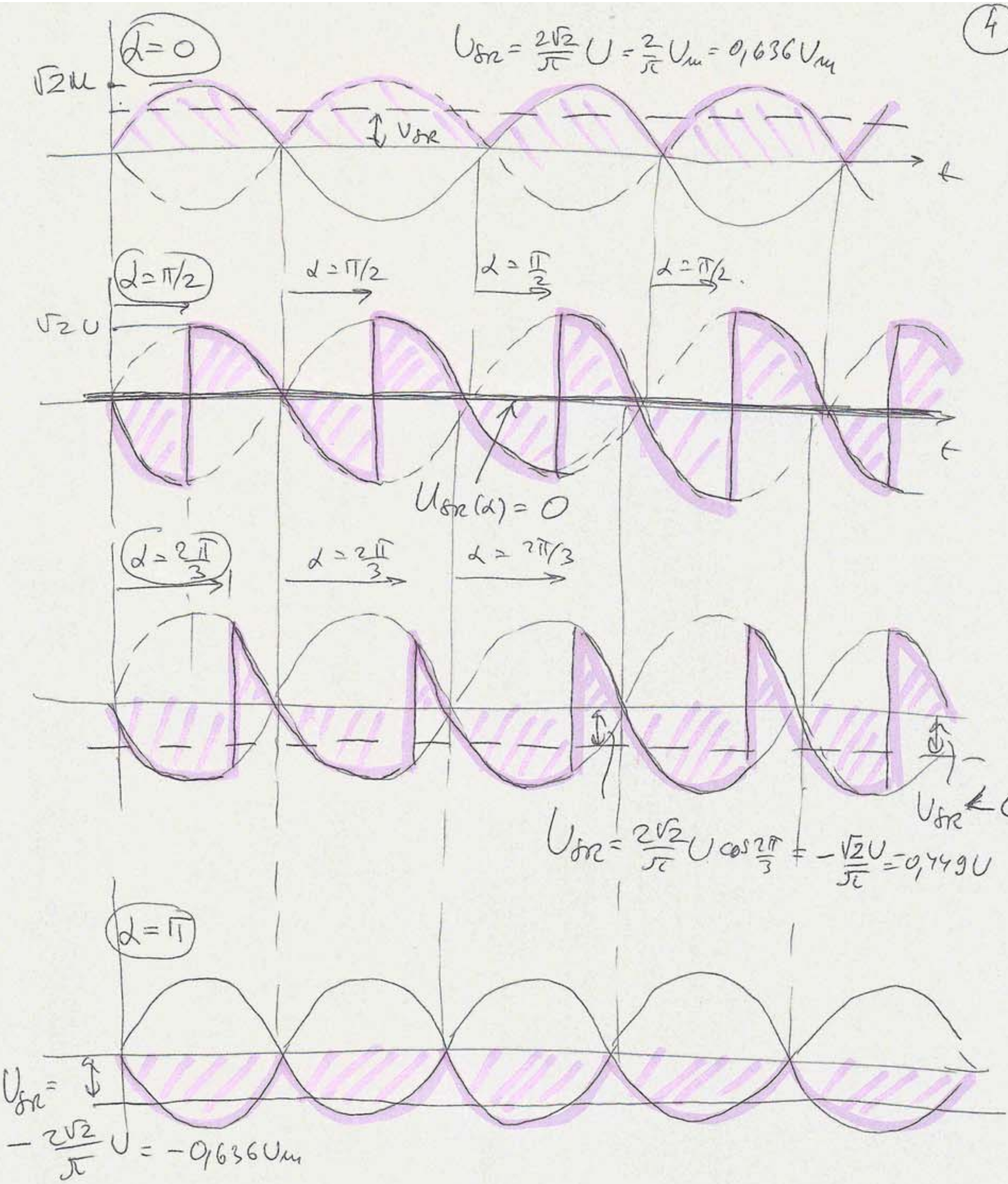
$$U_{izl\,sr} = \frac{1}{T^*}\int_0^{T^*} u_{izl}(t)\cdot dt = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} U_m \sin x\, dx$$

$$U_{izl\,sr} = \frac{U_m}{\pi}\int_{\alpha}^{\pi+\alpha} \sin x\, dx = \frac{U_m}{\pi}\left(-\cos x\Big|_{\alpha}^{\pi+\alpha}\right)$$

$$U_{izl\,sr} = \frac{U_m}{\pi}\left(\cos\alpha - \cos(\pi+\alpha)\right) = \frac{2U_m}{\pi}\cdot\cos\alpha$$

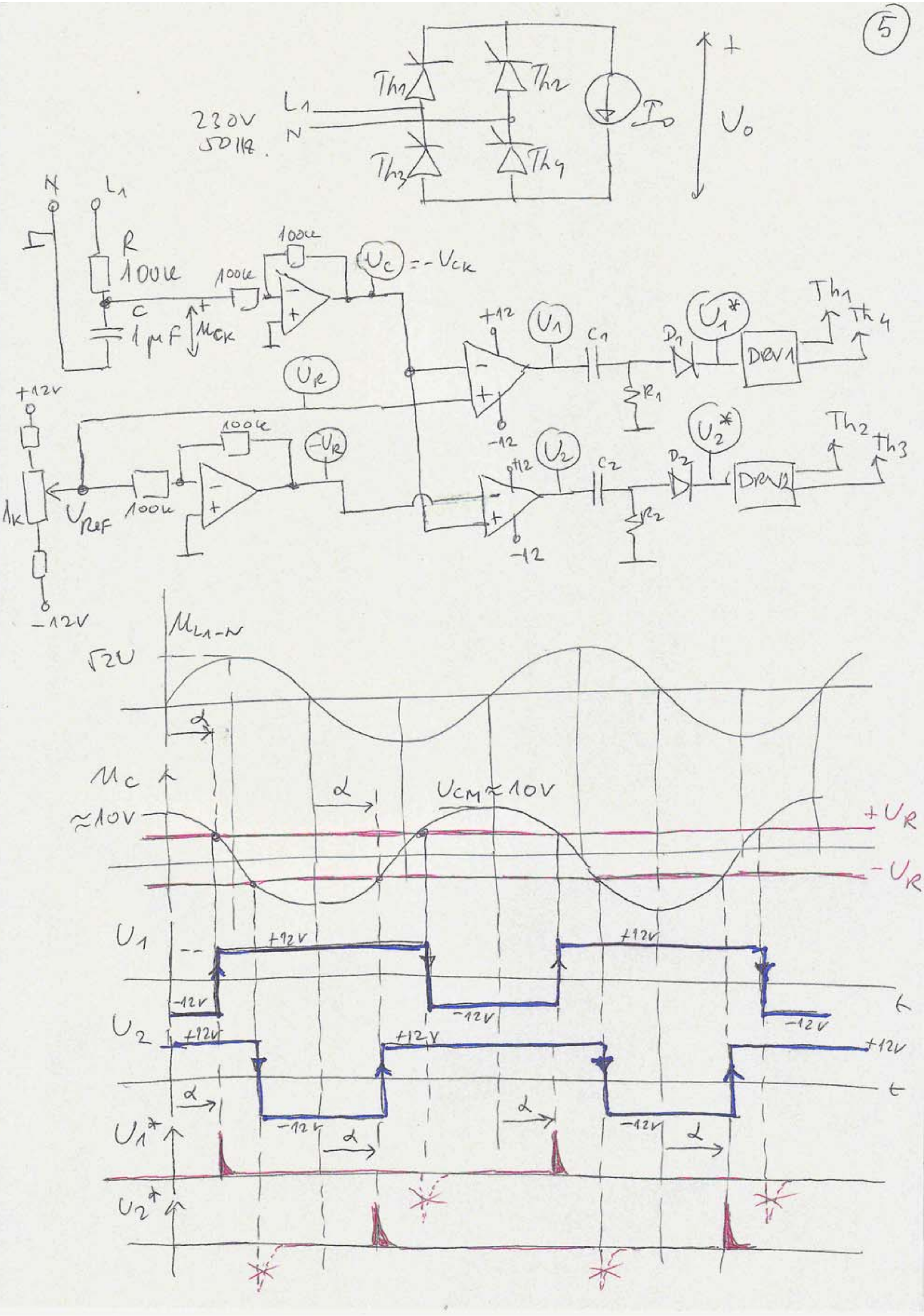
$$\boxed{U_{izl_{sr}} = \frac{2\sqrt{2}\,U}{\pi}\cdot\cos\alpha} \qquad U_{izl} = f(\alpha)$$



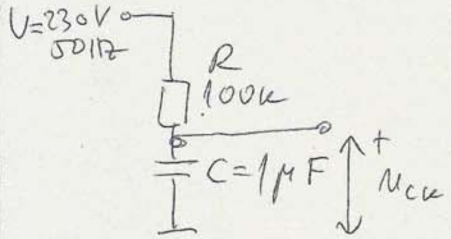


Таласни облици излазног напона за разне вредности угла управљања α.

$\alpha = 0,\ \pi/2,\ \frac{2\pi}{3},\ \pi$



Th1
Th2
Th3
Th4
230V
50Hz
L1
N
Io
Uo
R
100k
C
1μF
u_{CK}
100k
U_C = $-U_{CK}$
U_R
$-U_R$
U_{REF}
1k
+12V
-12V
U_1
U_2
U_1^*
U_2^*
C1
C2
D1
D2
R1
R2
DRV1
DRV2
u_{L1-N}
√2U
α
u_C
≈10V
U_{CM} ≈ 10V
+UR
-UR
+12V
-12V
t



$$\underline{U}_{Ck} = \frac{\underline{U}}{R + \frac{1}{j\omega C}} \cdot \frac{1}{j\omega C}$$

$\underline{Z}_1 = R$

$\underline{Z}_2 = \frac{1}{j\omega C}$

$$\underline{U}_{Ck} = \frac{\underline{U}_{LO}}{\underline{Z}_1 + \underline{Z}_2} \cdot \underline{Z}_2 \longrightarrow \underline{U} = \frac{U}{j\omega C R + 1}$$

$$U_{Ck} = \frac{U}{\sqrt{1 + (\omega C R)^2}}$$

$\omega = 2\pi \cdot f = 2\pi \cdot 50 = 314 \text{ rad/s}$

$C = 1 \cdot 10^{-6} F$

$R = 100 \cdot 10^3$

$\omega C R = 314 \cdot 10^{-6} \cdot 100 \cdot 10^3 = 31{,}4$

$(\omega C R)^2 \gg 1$

$$U_{Ck} \approx \frac{U}{\omega C R} = \frac{230}{31{,}4}$$

$U_{Ck} = 7{,}32 V$

U_{CM} = (MAX. vrednost napona U_C)

$U_{CM} = \sqrt{2} \cdot U_{Ck} = 10{,}3 V \approx 10 V$

$$U_{CM} = \frac{U\sqrt{2}}{\sqrt{1 + (\omega C R)^2}} \approx \frac{U\sqrt{2}}{\omega C R}$$

Pa odatle je $U_{REF} = U_R = U_{CM} \cos\alpha \Rightarrow \cos\alpha = \frac{U_R}{U_{CM}}$

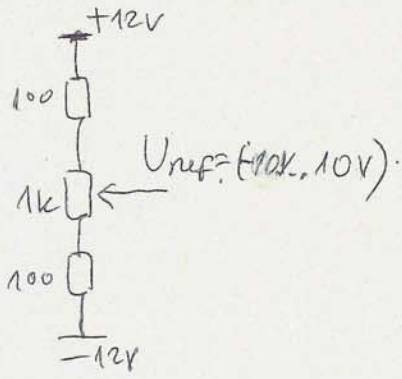
$-U_{REF} = -U_R = U_{CM} \cos\alpha.$

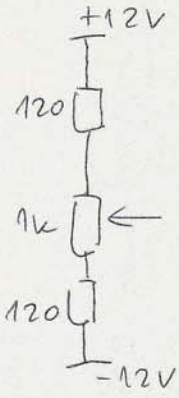
$$U_{srize} = \frac{2\sqrt{2}U}{\pi} \cos\alpha = \frac{2\sqrt{2}U}{\pi} \cdot \frac{U_R}{U_{CM}}$$

$$U_{srize} = \frac{2\sqrt{2}U}{\pi} \cdot \frac{U_R}{U_{CM}} = \frac{2\sqrt{2}}{\pi} \cdot \frac{U}{U_{CM}} \cdot U_R = k \cdot U_R$$

$$k = \frac{2\sqrt{2}}{\pi} \cdot \frac{U}{U_{CM}} = \frac{2\sqrt{2}}{\pi} \cdot \frac{230}{10} = 20{,}65$$

$$\boxed{U_{srize} = 20{,}65 \cdot U_{REF}}$$





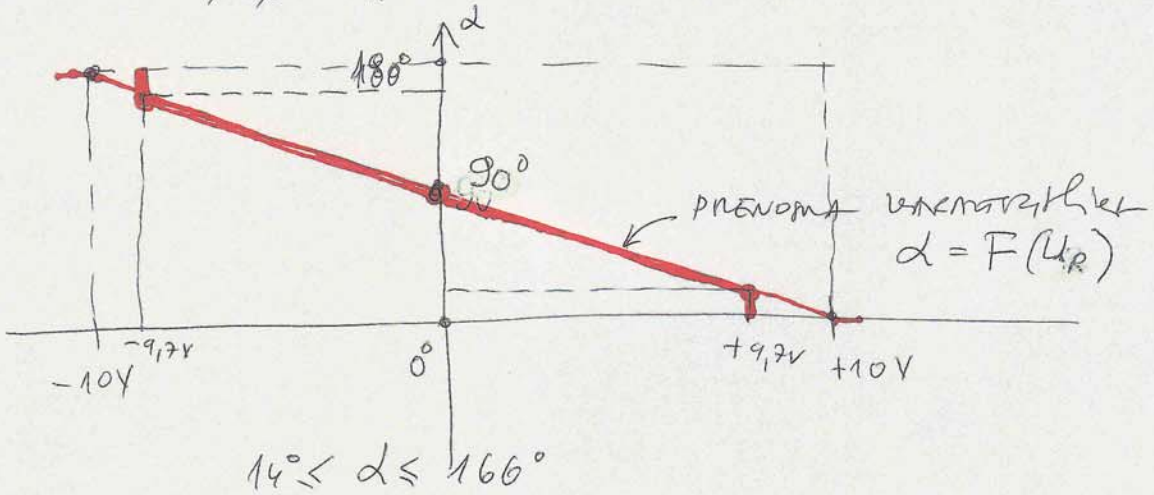
$U_{REF} = (-9{,}7 \ldots +9{,}7V)$

1) ZA $U_{REF_{MAX}} = 9{,}7V \rightarrow \cos\alpha = \frac{U_{RMAX}}{U_{CM}} = \frac{9{,}7}{10} = 0{,}97$

odnosno $\alpha_{min} = 14° \ (0{,}24 \text{ rad})$

2) ZA $U_{REF} = 0 \Rightarrow \alpha = \frac{\pi}{2}$

3) ZA $U_{REF_{MAX}} = -9{,}7V$ $\alpha_{max} = 180° - 14° = 166° \ (2{,}89 \text{ rad})$



$14° \leq \alpha \leq 166°$

$U_{SR(14°)}^{max} = \frac{2\sqrt{2}U}{\pi}\cos 14° = 200{,}4V \Rightarrow I_0 = \frac{200{,}4V}{10\Omega} = 20A$

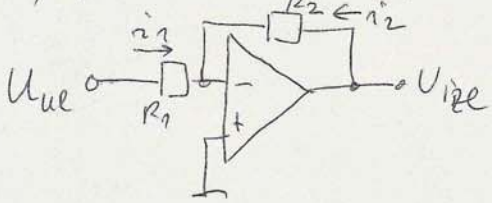
$U_{SR}^{min}(166°) = \frac{2\sqrt{2}}{\pi}\cos 166° = -200{,}4V \Rightarrow I_0 = \frac{-200{,}4}{10} = -20A$

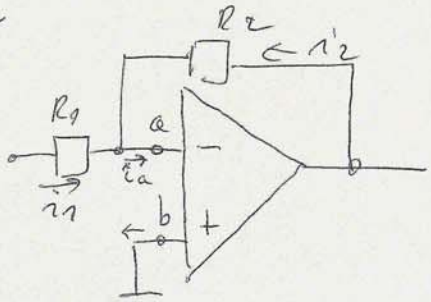
OPSEG promene struje opterećenja

$-20A \leq I_0 \leq 20A$

NAPOMENE:

1) INVERZIRAJUĆI POJAČAVAČ





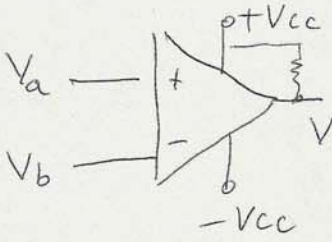
za idealni operac. pojačavač $U_{ab} = 0$ i struja $i_a = i_b = 0$

$$\frac{U_{ul}}{R_1} + \frac{U_{izl}}{R_2} = i_a \approx 0$$

$$U_{izl} = -\frac{R_2}{R_1} U_{ul}, \text{ ako je } R_2 = R_1 \quad U_{izl} = -U_{ul}$$

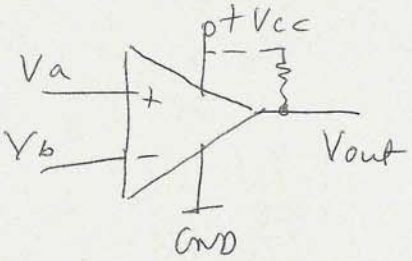
(invertirajući pojačavač sa pojačanjem $k_p = -1$)

2) KOMPARATOR



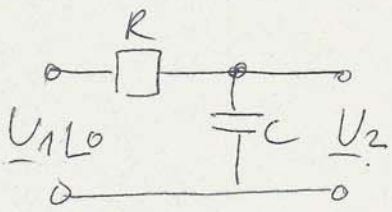
$V_a > V_b \quad V_{out} = +V_{cc}$

$V_a < V_b \quad V_{out} = -V_{cc}$



$V_a > V_b \quad V_{out} = +V_{cc}$

$V_a < V_b \quad V_{out} \approx 0$



RC INTEGRATOR

$$\underline{U}_2 = \frac{1}{j\omega RC + 1}\underline{U}_1$$

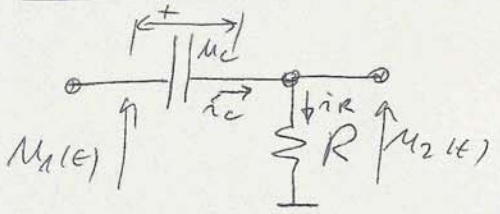
$\omega RC \gg 1$ (na nižjih frekvencah)

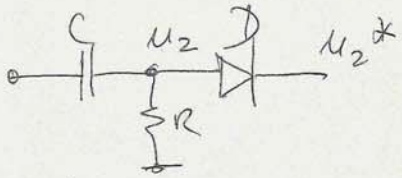
$$\underline{U}_2 \approx \frac{1}{j\omega RC}\underline{U}_{1L^0} = \frac{1}{j\omega RC}U_1 = \frac{U_1}{\omega RC}\cdot e^{-j\pi/2}$$

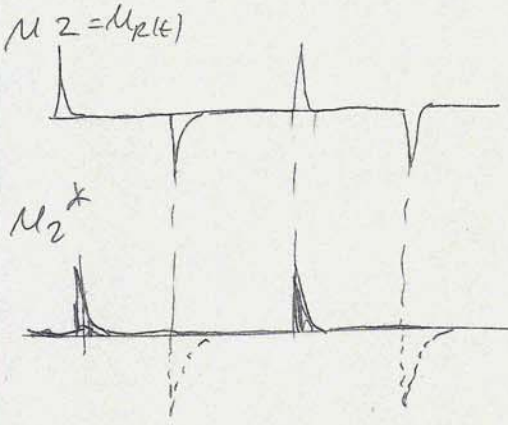
$$\underline{U}_2 = -\frac{U_1}{\omega RC}e^{j\frac{\pi}{2}} \quad \text{(obrne fazo za } -\tfrac{\pi}{2}\text{)}$$

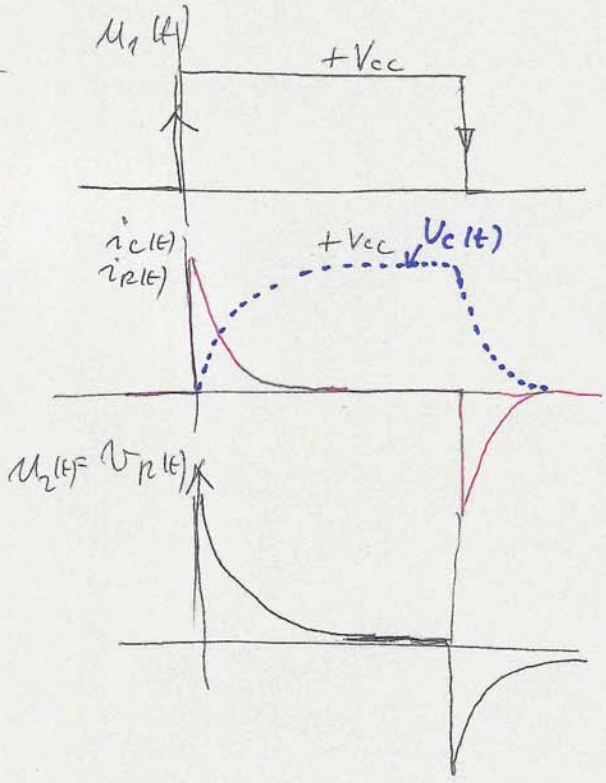
Ker je $u_1 = U_m \sin\omega t \Rightarrow u_2 = -\frac{U_m}{\omega RC}\cos\omega t$

RC DIFERENCIATOR









DIODA PROPUSTA SAMO POZITIVNE IMPULSE