

## Trofazni ispravljači

$$v_1 = V_m \sin(\omega_0 t - \theta)$$

$$v_2 = V_m \sin\left(\omega_0 t - \frac{2\pi}{3} - \theta\right)$$

$$v_3 = V_m \sin\left(\omega_0 t - \frac{4\pi}{3} - \theta\right)$$

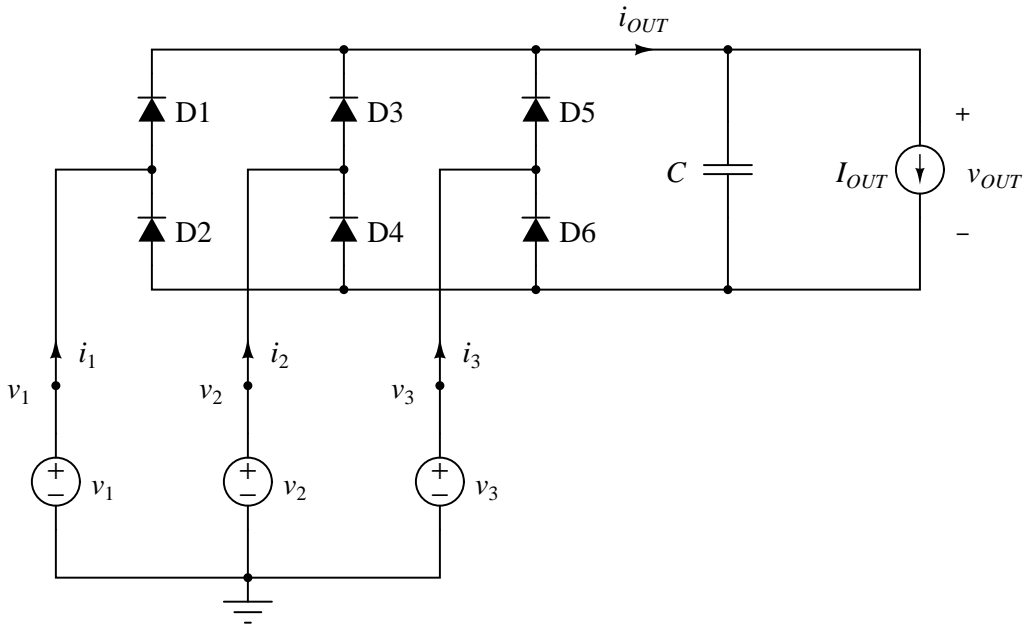
$$v_k = V_m \sin\left(\omega_0 t - (k-1)\frac{2\pi}{3} - \theta\right)$$

$$k \in \{1, 2, 3\}$$

$$v_k = V_m \sin\left(\omega_0 t - (k-1)\frac{2\pi}{3}\right)$$

$$v_k = V_m \cos\left(\omega_0 t - (k-1)\frac{2\pi}{3}\right)$$

## Trofazni diodni most sa prostim kapacitivnim filtrom



Slika 1: Trofazni diodni most sa prostim kapacitivnim filtrom.

Tabela 1: Trofazni diodni most sa prostim kapacitivnim filtrom, linijski naponi koji dostižu maksimum, provodne diode i preneti naelektrisanja.

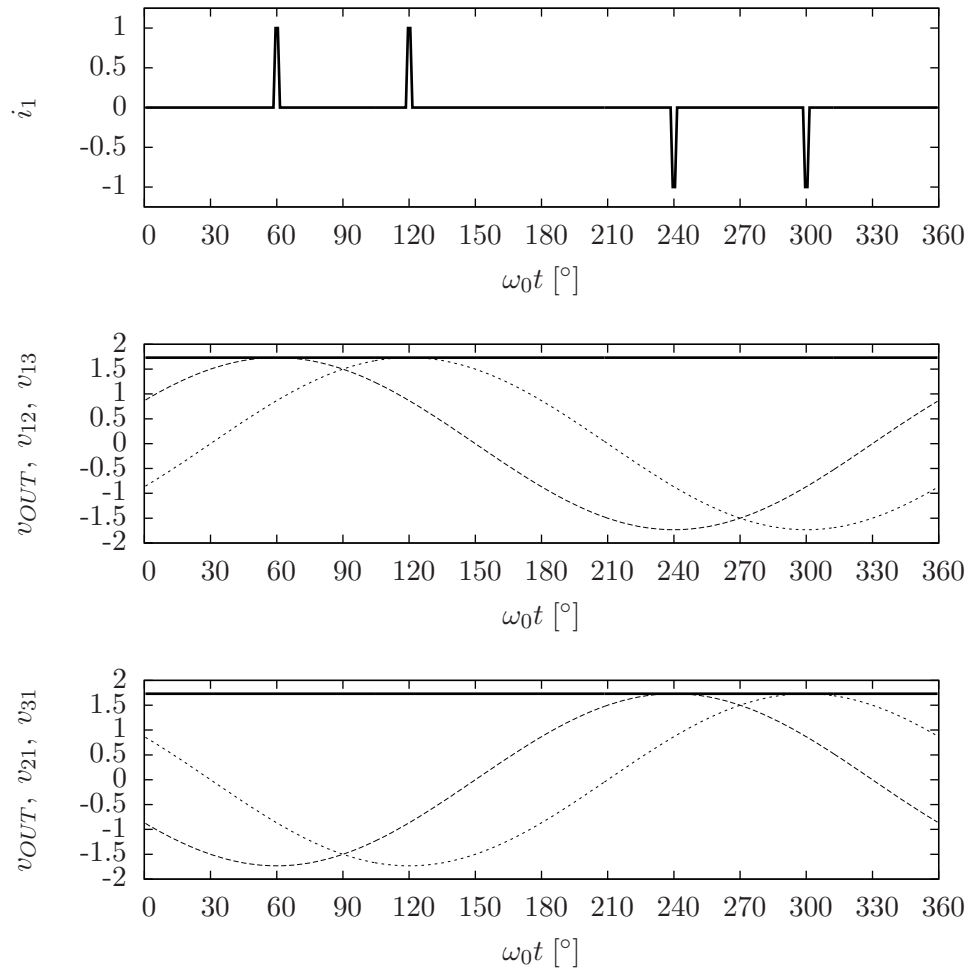
maksimum	provode	$\int_{t_a}^{t_b} i_1(t) dt$	$\int_{t_a}^{t_b} i_2(t) dt$	$\int_{t_a}^{t_b} i_3(t) dt$
$v_{12}$	D1 D4	$Q$	$-Q$	$0$
$v_{13}$	D1 D6	$Q$	$0$	$-Q$
$v_{21}$	D3 D2	$-Q$	$Q$	$0$
$v_{23}$	D3 D6	$0$	$Q$	$-Q$
$v_{31}$	D5 D2	$-Q$	$0$	$Q$
$v_{32}$	D5 D4	$0$	$-Q$	$Q$

$$V_{OUTmax} = V_L = \sqrt{3} V_m = \sqrt{6} V_{RMS}$$

$$C (2\Delta V_{OUT}) = \frac{T_0}{6} I_{OUT}$$

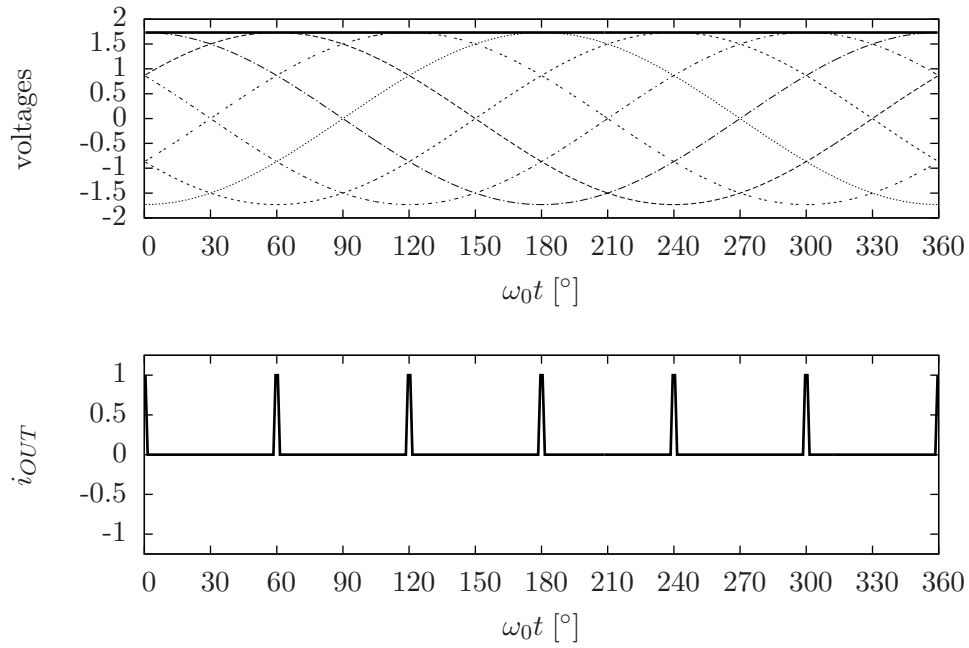
$$\Delta V_{OUT} = \frac{I_{OUT}}{12f_0C}$$

$$V_{OUT} = V_{OUTmax} - \Delta V_{OUT} = \sqrt{3} V_m - \frac{I_{OUT}}{12f_0C}$$

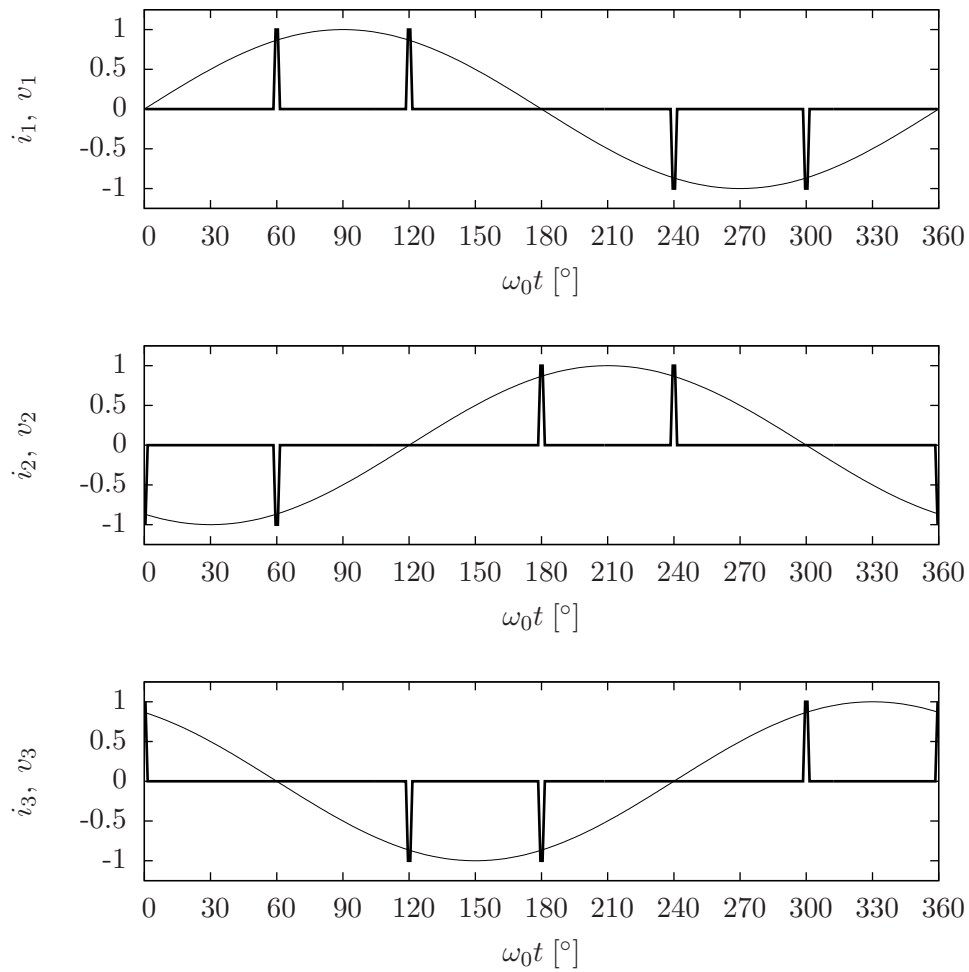


Slika 2: Trofazni diodni most sa prostim kapacitivnim filtrom, struja prve faze i linijski naponi koji uzrokuju njeno proticanje.

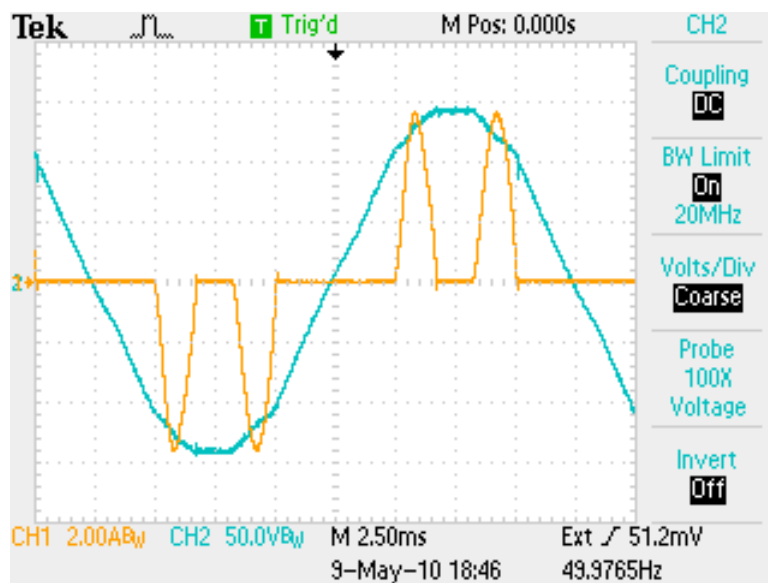
$$i_{OUT} = \frac{I_{OUT}}{6f_0} \sum_{k=-\infty}^{\infty} \delta\left(t - k \frac{T_0}{6}\right)$$



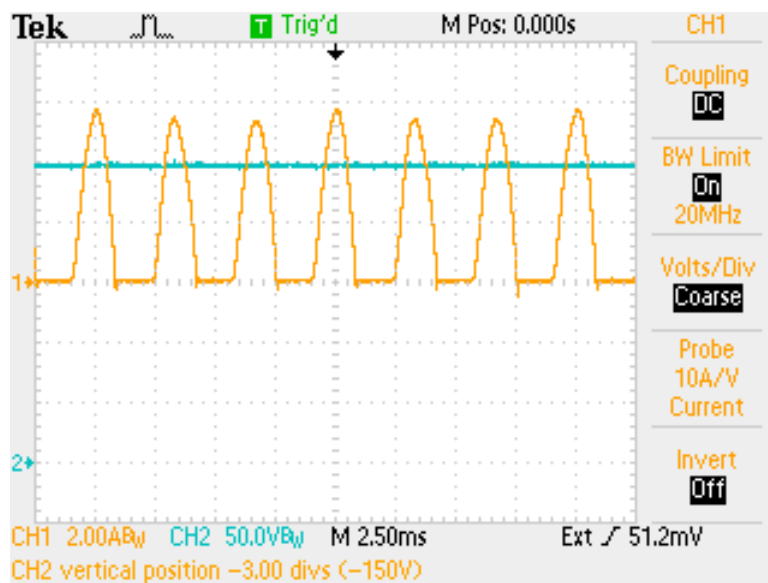
Slika 3: Trofazni diodni most sa prostim kapacitivnim filtrom, linijski naponi i izlajna struja diodnog mosta.



Slika 4: Trofazni diodni most sa prostim kapacitivnim filtrom, ulazni naponi i ulazne struje.

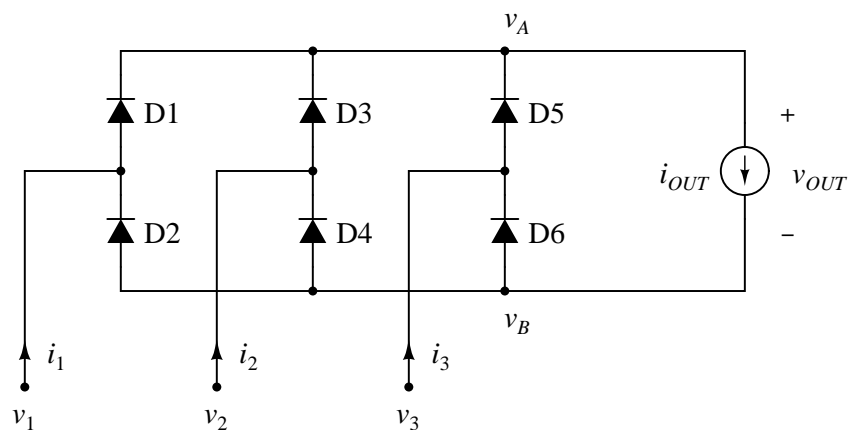


Slika 5: Trofazni diodni most sa prostim kapacitivnim filtrom, napon i struja jedne faze.

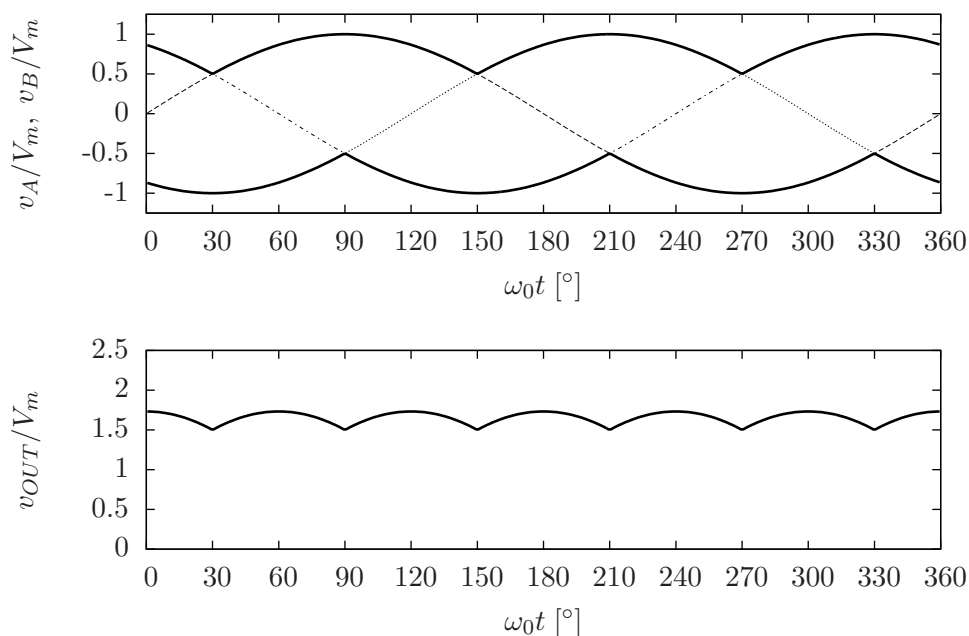


Slika 6: Trofazni diodni most sa prostim kapacitivnim filtrom, izlazni napon i izlazna struja diodnog mosta.

## Strujom opterećen trofazni diodni most



Slika 7: Strujom opterećen trofazni diodni most.



Slika 8: Strujom opterećen trofazni diodni most, potencijali izlaznih terminala diodnog mosta i izlazni napon.

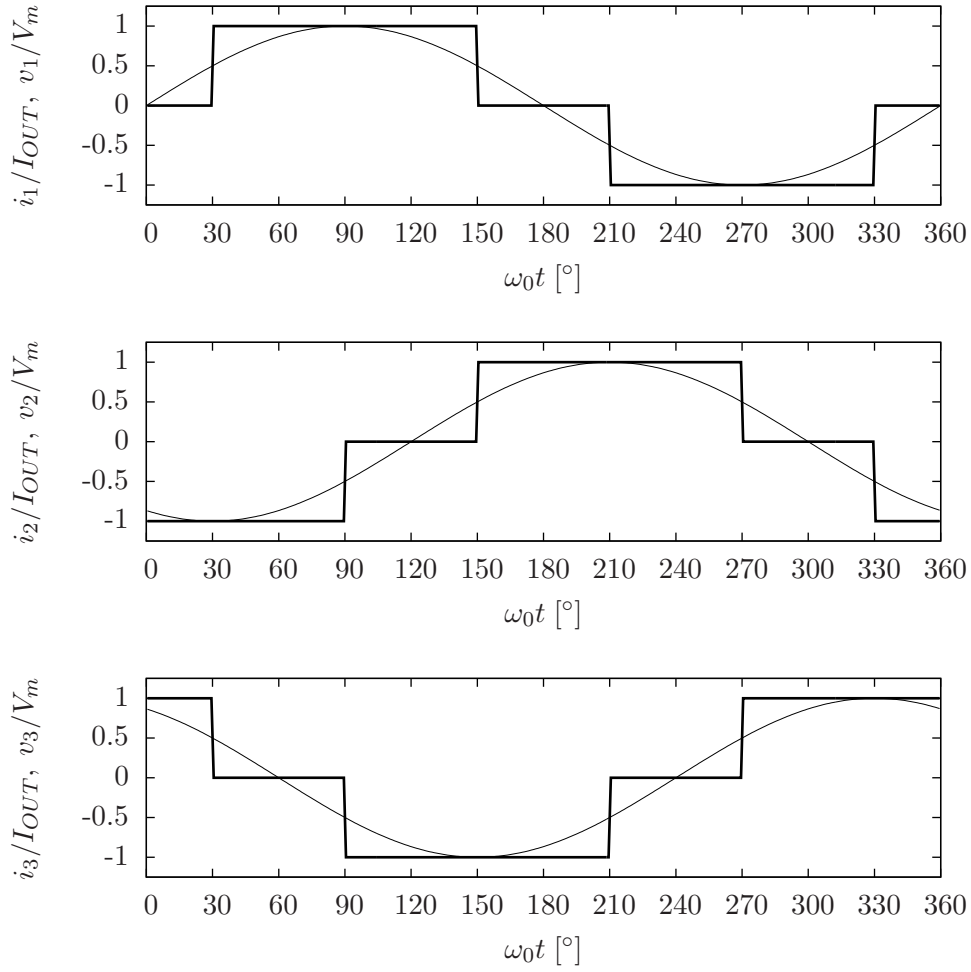
$$v_A = \max(v_1, v_2, v_3)$$

$$v_B = \min(v_1, v_2, v_3)$$

$$v_{OUT} = v_A - v_B$$

$$V_{OUT} = \overline{v_{OUT}} = \langle v_{OUT} \rangle = \frac{1}{T_0/6} \int_{t_0}^{t_0+T_0/6} v_{OUT}(t) dt$$

$$V_{OUT} = \frac{3}{\pi} V_m \int_{\pi/6}^{\pi/2} \left( \sin(\omega_0 t) - \sin\left(\omega_0 t - \frac{2\pi}{3}\right) \right) d\omega_0 t$$



Slika 9: Strujom opterećen trofazni diodni most, ulazne struje i njima odgovarajući ulazni naponi.

$$V_{OUT} = \frac{3\sqrt{3}}{\pi} V_m \approx 1.65 V_m \approx 2.34 V_{RMS}$$

$$V_{OUT} = \frac{3}{\pi} V_m \int_{-\pi/6}^{\pi/6} \cos(\omega_0 t) d\omega_0 t = \frac{3\sqrt{3}}{\pi} V_m$$

$$P_{OUT} = V_{OUT} I_{OUT} = \frac{3\sqrt{3}}{\pi} V_m I_{OUT}$$

$$I_{RMS} = \sqrt{\frac{2}{3}} I_{OUT}$$

$$S = 3 V_{RMS} I_{RMS} = \sqrt{3} V_m I_{OUT}$$

$$P = P_{IN} = P_{OUT}$$

$$PF = \frac{P}{S} = \frac{3}{\pi} \approx 0.955$$

$$P_{IN} = \frac{3}{2} V_m I_{1m} \cos \varphi_1$$

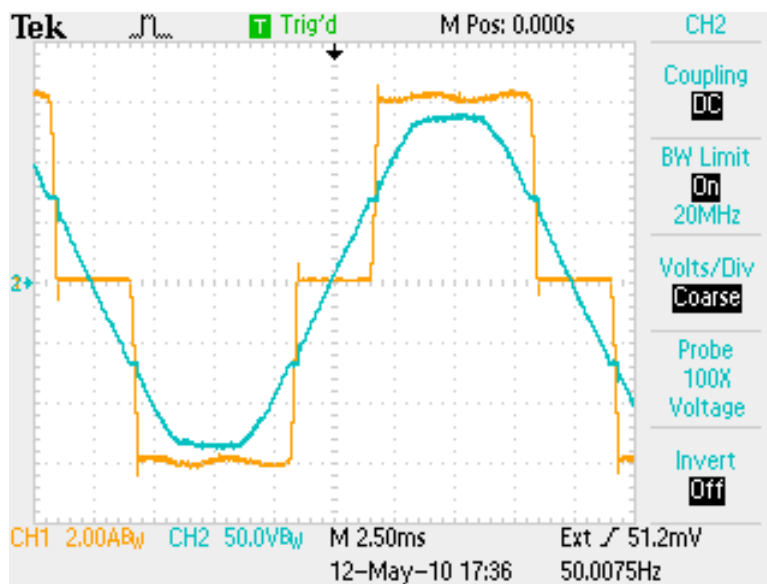
$$I_{1m} = \frac{2\sqrt{3}}{\pi} I_{OUT}$$

$$\varphi_1 = 0$$

$$I_{1RMS} = \frac{\sqrt{6}}{\pi} I_{OUT}$$

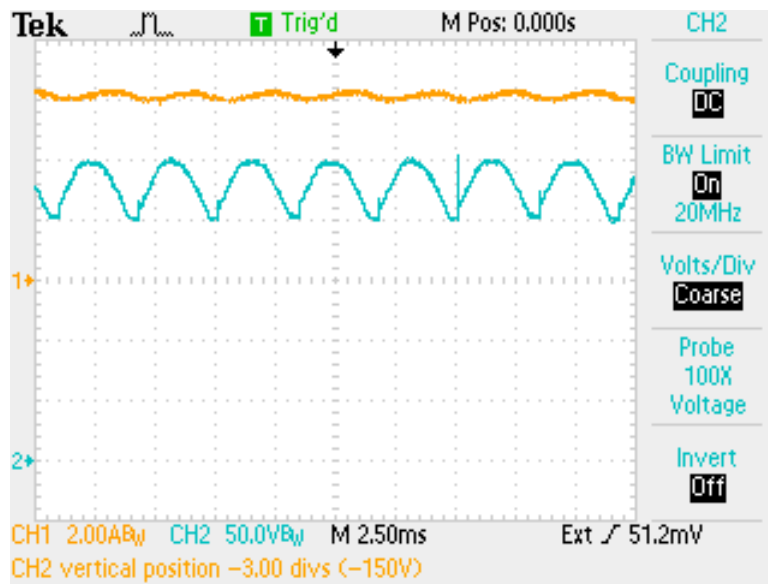
$$THD = \sqrt{\frac{I_{RMS}^2}{I_{1RMS}^2} - 1}$$

$$THD = \sqrt{\frac{\pi^2}{9} - 1} \approx 31.08\%$$



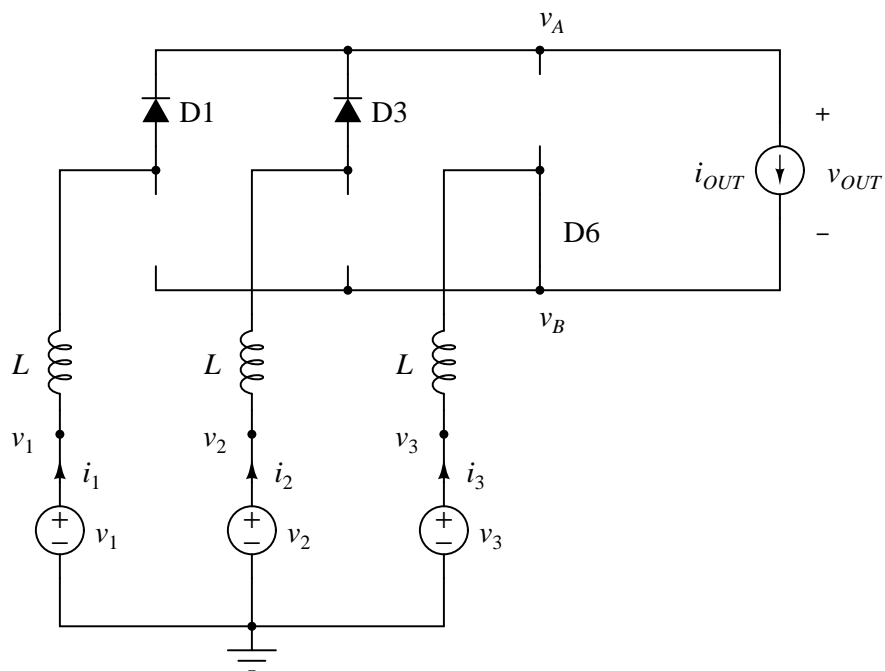
Slika 10: Strujom opterećen trofazni diodni most, napon i struja jedne faze.



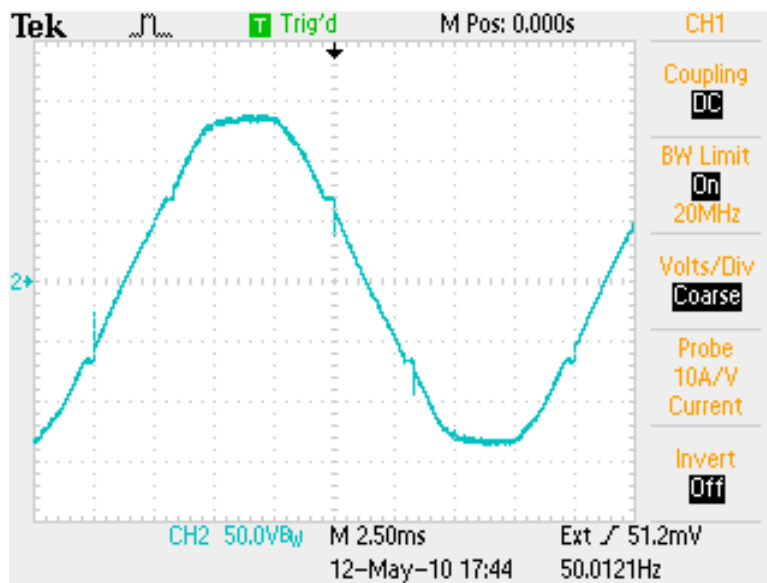


Slika 11: Strujom opterećen trofazni diodni most, izlazni napon i izlazna struja diodnog mosta.

## Komutacija u diodnom mostu



Slika 12: Komutacija u diodnom mostu, prenos provođenja sa D1 na D3.



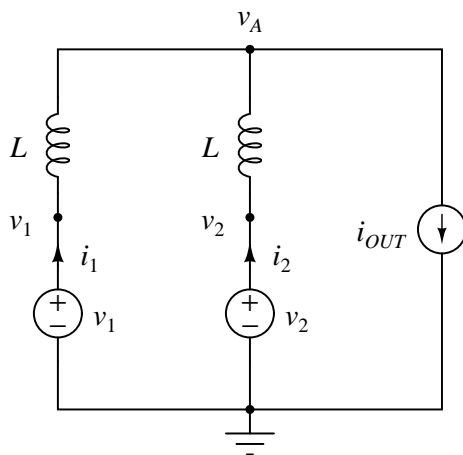
Slika 13: Čvorovi (notches) u naponu prve faze ispravljača.

$$v_{12} = -\sqrt{3} V_m \sin \omega_0 t$$

$$i_1(0) = I_{OUT}$$

$$i_2(0) = 0$$

$$i_1 + i_2 = I_{OUT}$$



Slika 14: Komutacija u diodnom mostu, ekvivalentno kolo tokom prenosa provođenja sa D1 na D3.

$$\frac{di_1}{dt} + \frac{di_2}{dt} = 0$$

$$v_1 - v_2 - L \frac{di_1}{dt} + L \frac{di_2}{dt} = 0$$

$$v_{12} - 2L \frac{di_1}{dt} = 0$$

$$\frac{di_1}{dt} = -\frac{\sqrt{3} V_m}{2L} \sin \omega_0 t$$

$$i_1 = I_{OUT} - \frac{\sqrt{3} V_m}{2\omega_0 L} (1 - \cos \omega_0 t)$$

$$i_2 = \frac{\sqrt{3} V_m}{2\omega_0 L} (1 - \cos \omega_0 t)$$

$$v_A = v_1 - L \frac{di_1}{dt} = v_2 - L \frac{di_2}{dt} = \frac{v_1 + v_2}{2} = -\frac{1}{2} v_3$$

$$i_2(\Delta t) = I_{OUT}$$

$$I_{OUT} = \frac{\sqrt{3} V_m}{2\omega_0 L} (1 - \cos(\omega_0 \Delta t))$$

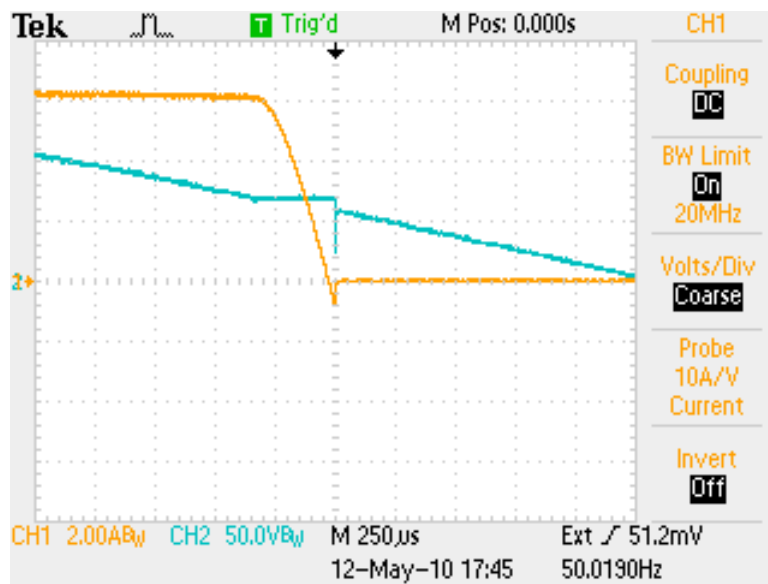
$$\cos(\omega_0 \Delta t) = 1 - \frac{2\omega_0 L I_{OUT}}{\sqrt{3} V_m}$$

$$L = \frac{\sqrt{3} V_m}{2\omega_0 I_{OUT}} (1 - \cos(\omega_0 \Delta t))$$

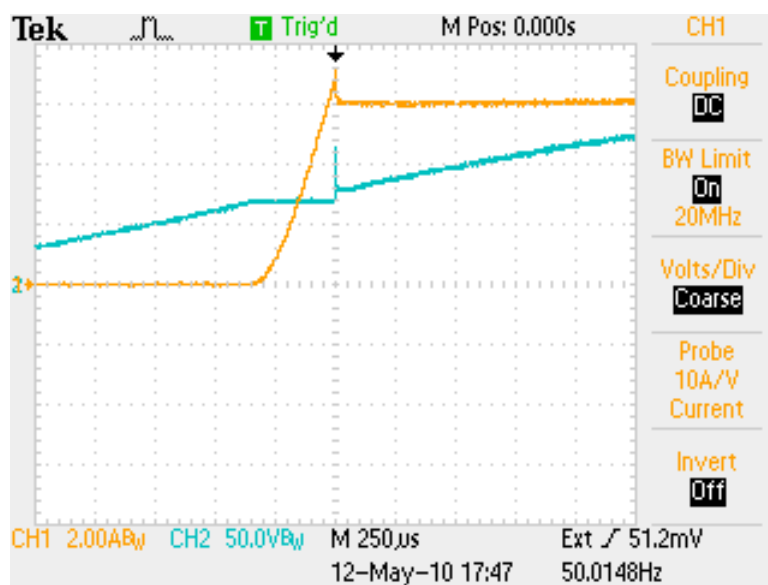
$$\Delta t = 350 \mu s$$

$$V_m = 140 \text{ V}$$

$$L = 388 \mu H$$

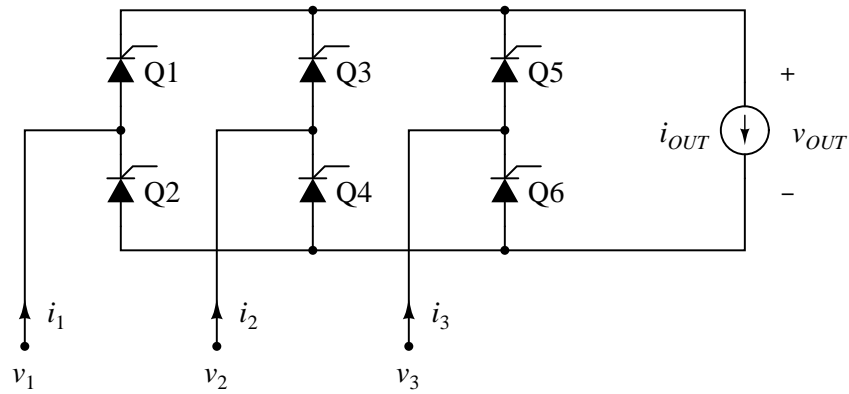


Slika 15: Prenos provođenja sa D1 na D3, faza 1.

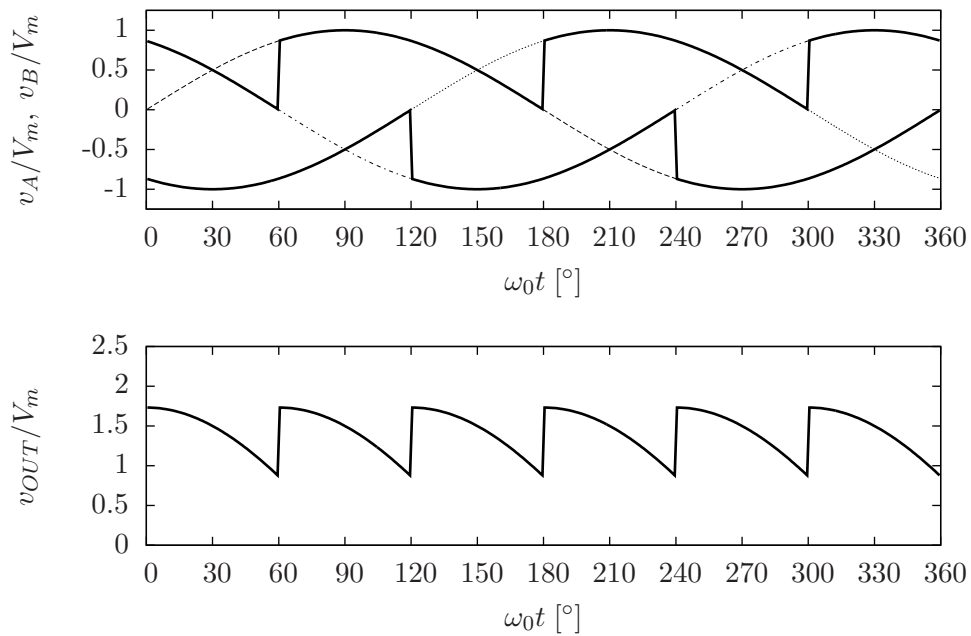


Slika 16: Prenos provođenja sa D1 na D3, faza 2.

## Potpuno kontrolisan trofazni tiristorski most



Slika 17: Potpuno kontrolisan trofazni tiristorski most.



Slika 18: Potpuno kontrolisan trofazni tiristorski most, potencijali izlaznih terminala mosta i izlazni napon,  $\alpha = 30^\circ$ .

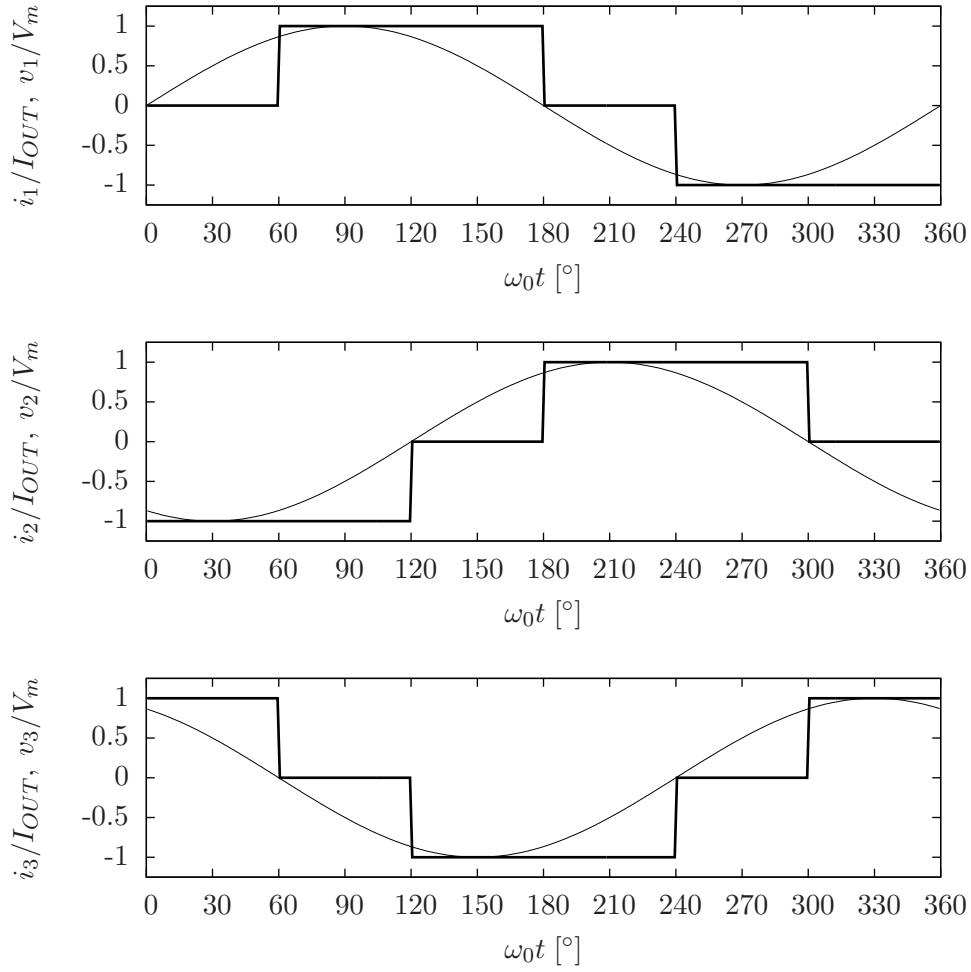
$$v_{OUT} = v_A - v_B$$

$$V_{OUT} = \overline{v_{OUT}} = \langle v_{OUT} \rangle = \frac{6}{T_0} \int_{t_0}^{t_0+T_0/6} v_{OUT}(t) dt$$

$$V_{OUT} = \frac{3}{\pi} V_m \int_{\pi/6+\alpha}^{\pi/2+\alpha} \left( \sin(\omega_0 t) - \sin\left(\omega_0 t - \frac{2\pi}{3}\right) \right) d\omega_0 t$$

$$V_{OUT} = \frac{3\sqrt{3}}{\pi} V_m \cos \alpha \approx 1.65 V_m \cos \alpha \approx 2.34 V_{RMS} \cos \alpha$$

$$V_{OUT} = \frac{3}{\pi} V_m \int_{-\pi/6+\alpha}^{\pi/6+\alpha} \cos(\omega_0 t) d\omega_0 t = \frac{3\sqrt{3}}{\pi} V_m \cos \alpha$$



Slika 19: Potpuno kontrolisan trofazni tiristorski most, ulazne struje i njima odgovarajući ulazni naponi,  $\alpha = 30^\circ$ .

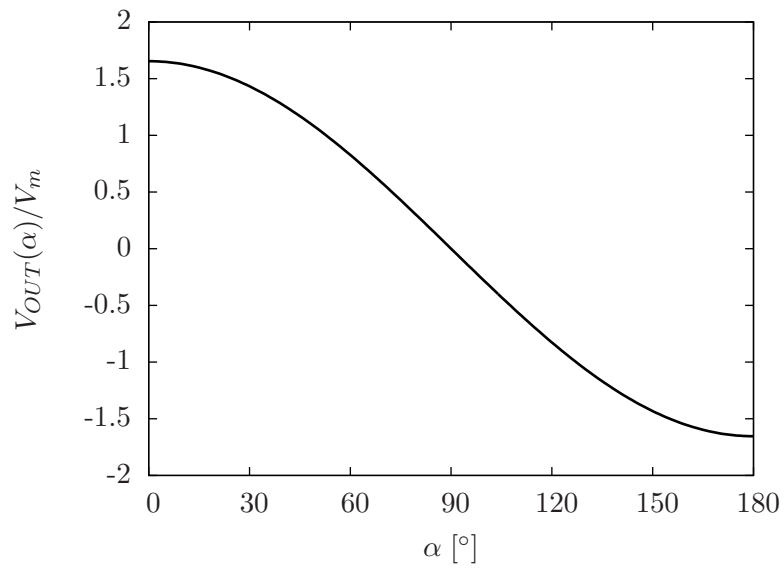
$$V_{OUT} = \frac{3}{\pi} \int_{-\frac{\pi}{6} + \alpha}^{\frac{\pi}{6} + \alpha} \sqrt{3} V_m \cos(\omega_0 t) d\omega_0 t = \frac{3\sqrt{3}}{\pi} V_m \cos \alpha$$

$$P_{OUT} = V_{OUT} I_{OUT} = \frac{3\sqrt{3}}{\pi} V_m I_{OUT} \cos \alpha$$

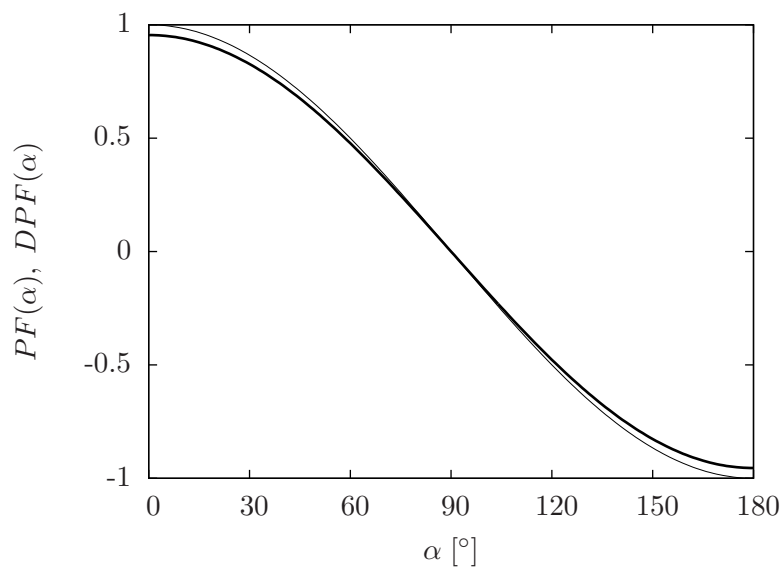
$$S = \sqrt{3} V_m I_{OUT}$$

$$PF = \frac{3}{\pi} \cos \alpha$$

$$THD = \sqrt{\frac{\pi^2}{9} - 1} \approx 31.08\%$$

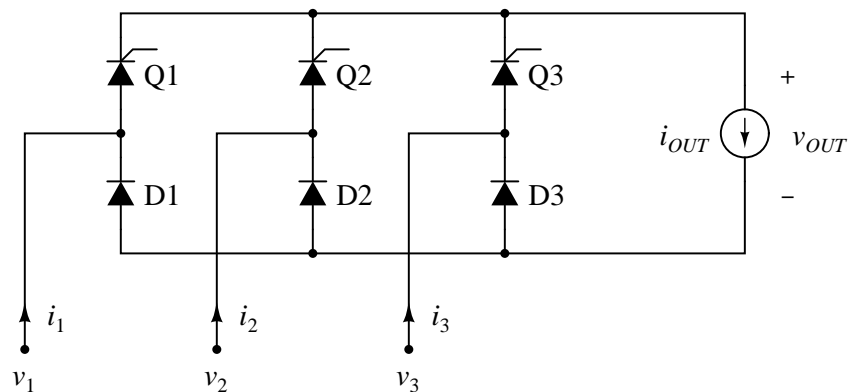


Slika 20: Potpuno kontrolisan trofazni tiristorski most, zavisnost  $V_{OUT}$  od  $\alpha$ .

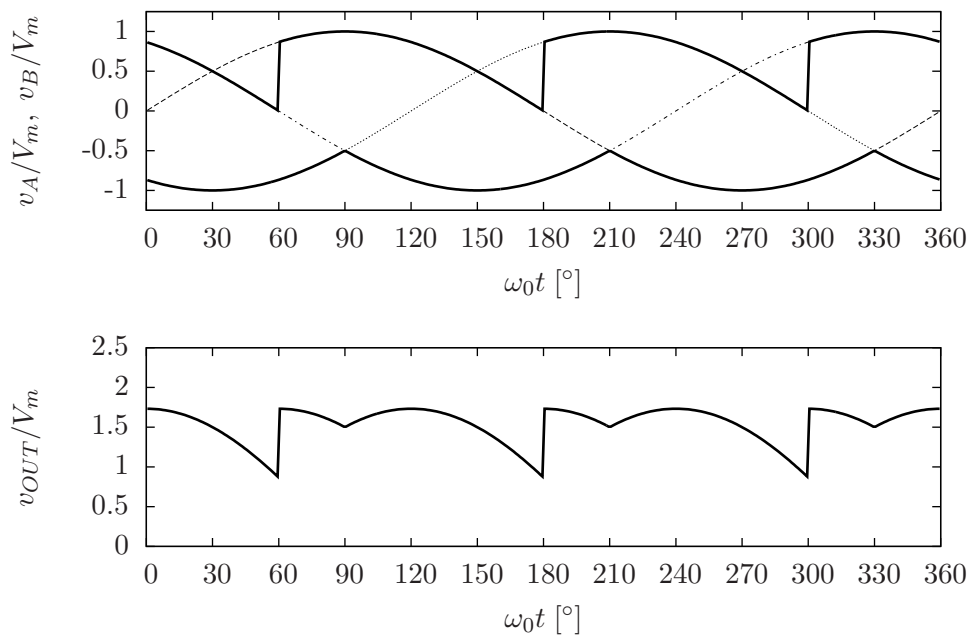


Slika 21: Potpuno kontrolisan trofazni tiristorski most, zavisnost  $PF$  i  $DPF$  od  $\alpha$ .

## Polukontrolisan trofazni tiristorski most

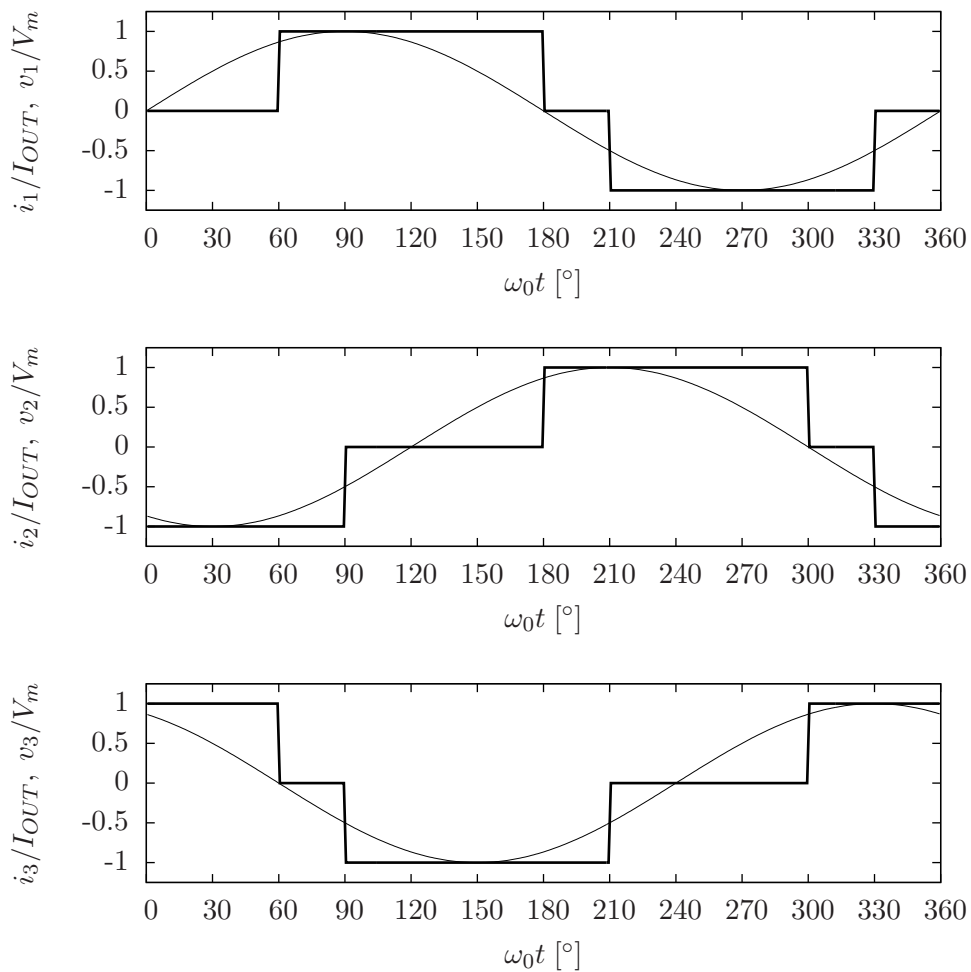


Slika 22: Polukontrolisan trofazni tiristorski most.

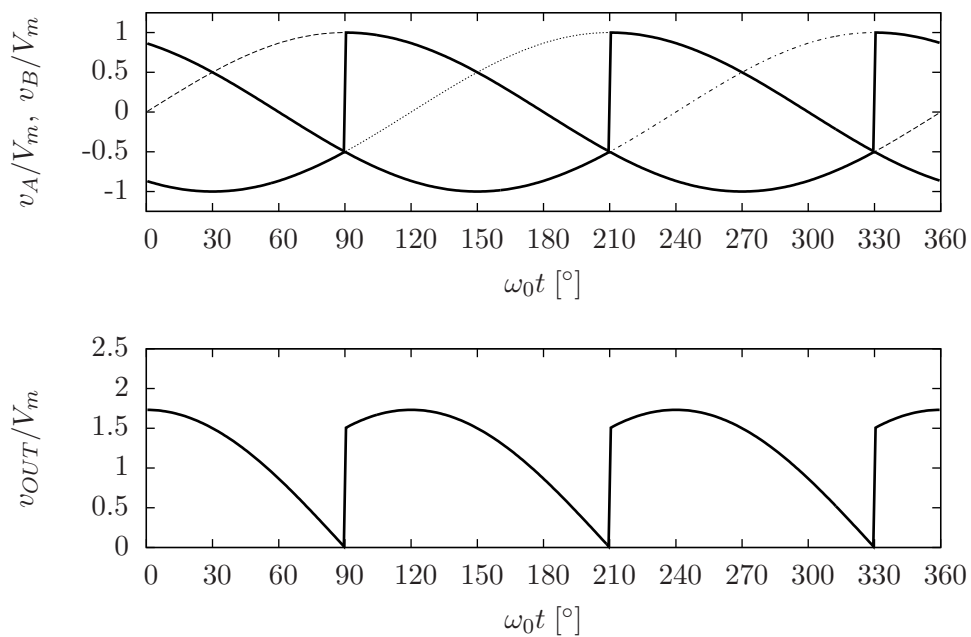


Slika 23: Polukontrolisan trofazni tiristorski most, potencijali izlaznih terminala mosta i izlazni napon,  $\alpha = 30^\circ$ .

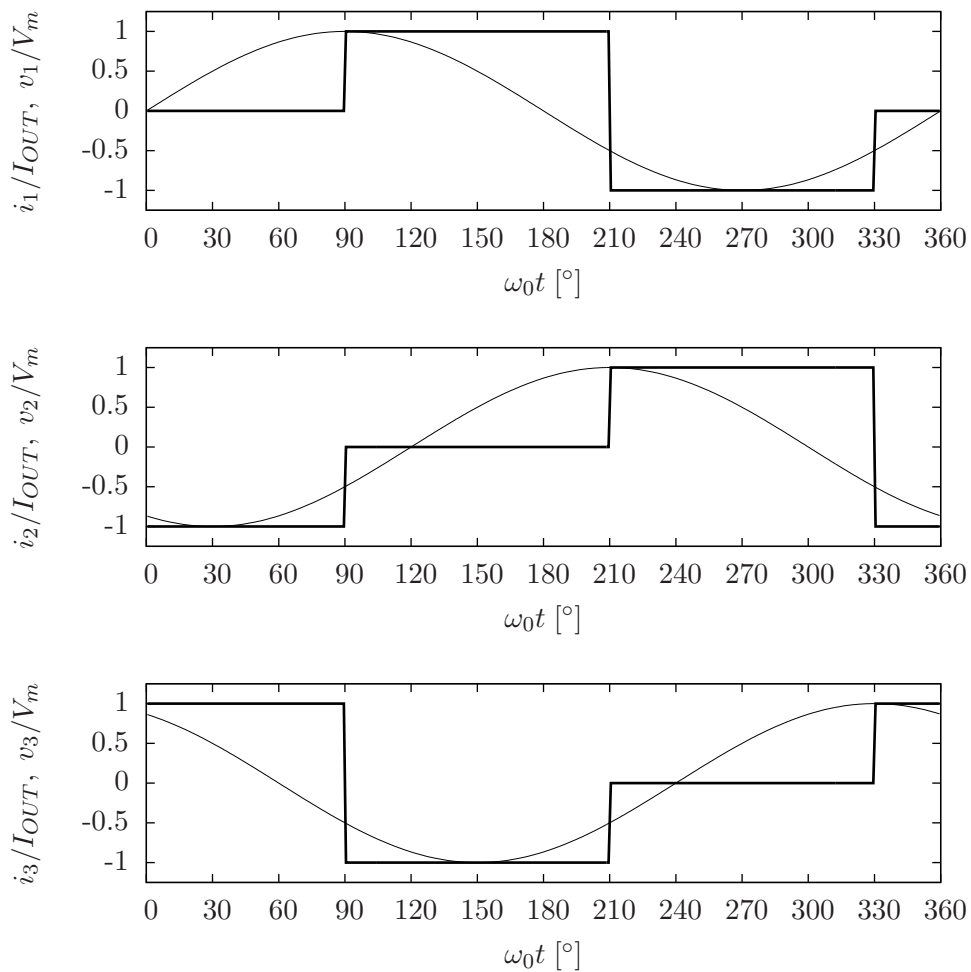




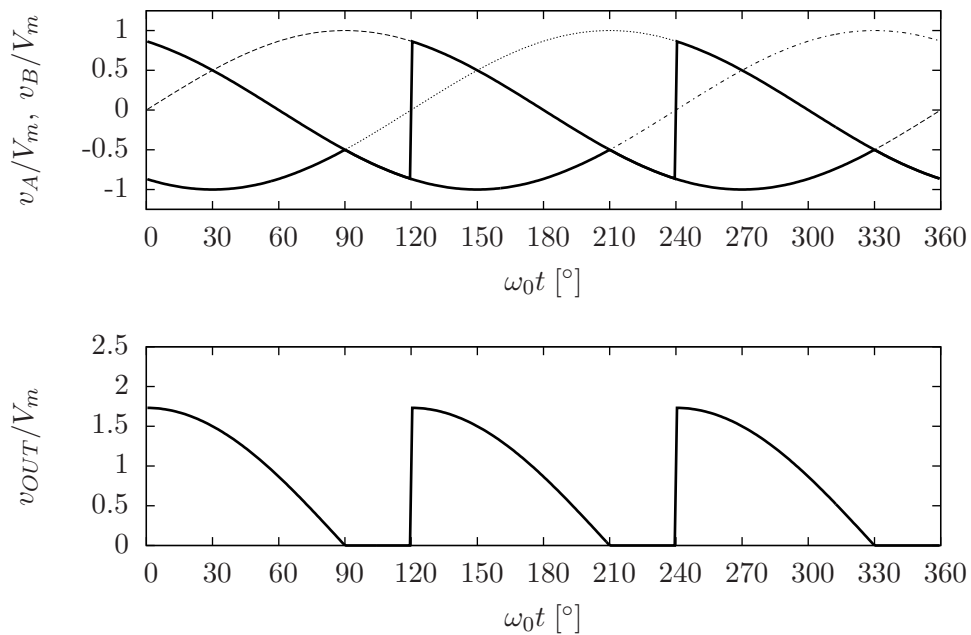
Slika 24: Polukontrolisan trofazni tiristorski most, ulazne struje i njima odgovarajući ulazni naponi,  $\alpha = 30^\circ$ .



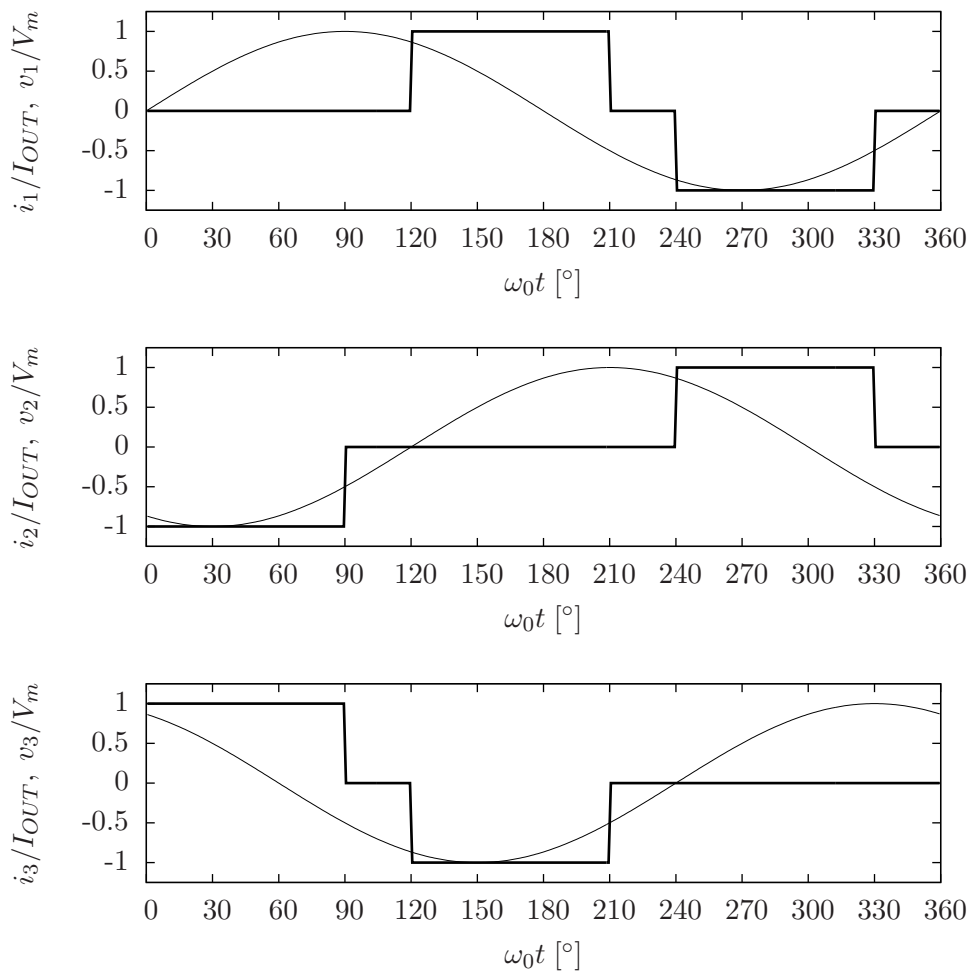
Slika 25: Polukontrolisan trofazni tiristorski most, potencijali izlaznih terminala mosta i izlazni napon,  $\alpha = 60^\circ$ .



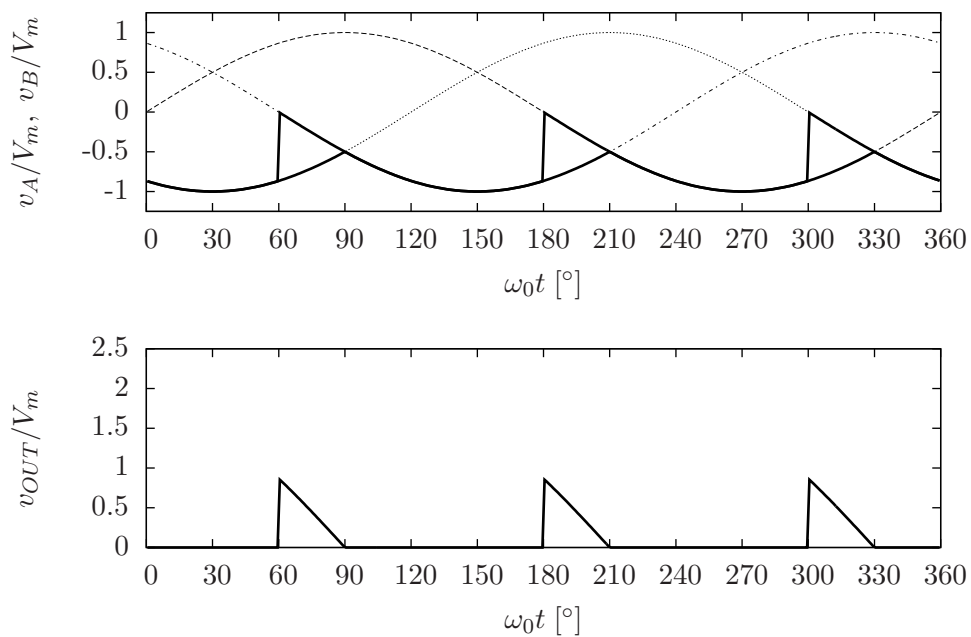
Slika 26: Polukontrolisan trofazni tiristorski most, ulazne struje i njima odgovarajući ulazni naponi,  $\alpha = 60^\circ$ .



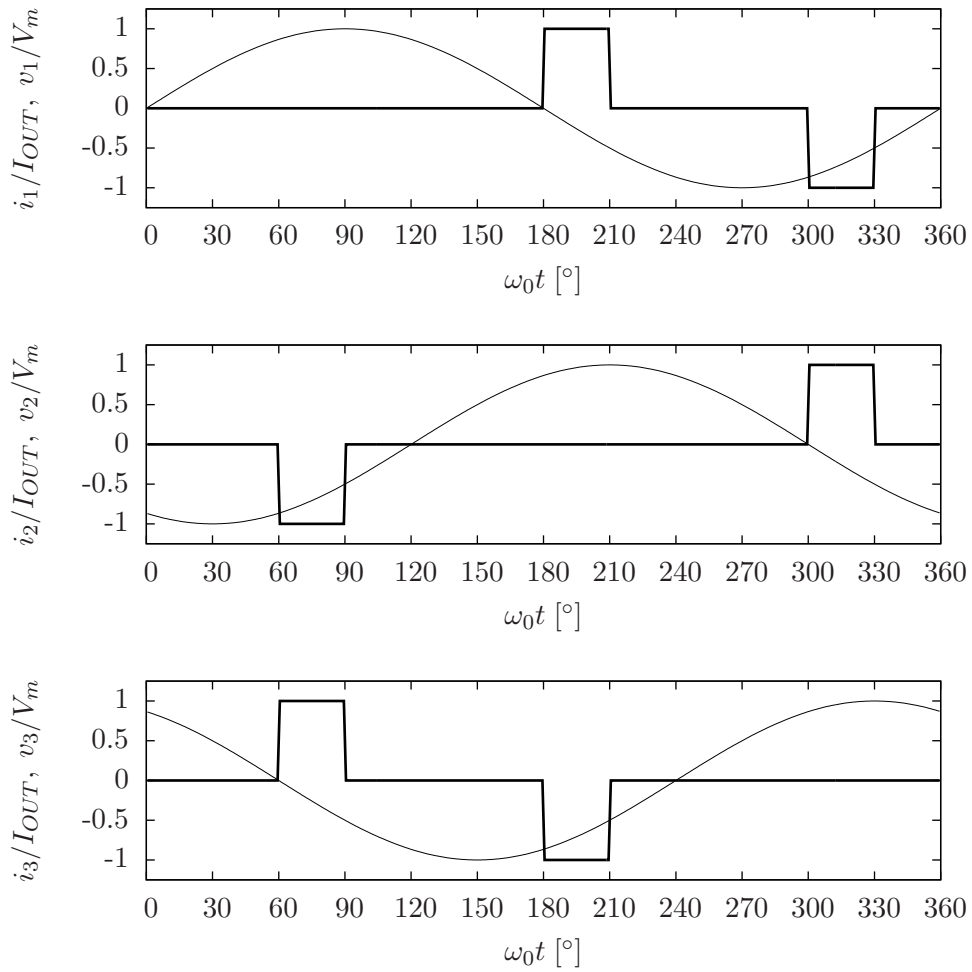
Slika 27: Polukontrolisan trofazni tiristorski most, potencijali izlaznih terminala mosta i izlazni napon,  $\alpha = 90^\circ$ .



Slika 28: Polukontrolisan trofazni tiristorski most, ulazne struje i njima odgovarajući ulazni naponi,  $\alpha = 90^\circ$ .



Slika 29: Polukontrolisan trofazni tiristorski most, potencijali izlaznih terminala mosta i izlazni napon,  $\alpha = 150^\circ$ .



Slika 30: Polukontrolisan trofazni tiristorski most, ulazne struje i njima odgovarajući ulazni naponi,  $\alpha = 150^\circ$ .

$$V_A = \frac{3}{2\pi} \int_{-\frac{\pi}{3}+\alpha}^{\frac{\pi}{3}+\alpha} V_m \cos(\omega_0 t) d(\omega_0 t) = \frac{3\sqrt{3}}{2\pi} V_m \cos \alpha$$

$$V_B = \frac{3}{2\pi} \int_{-\frac{\pi}{3}}^{\frac{\pi}{3}} (-V_m \cos(\omega_0 t)) d(\omega_0 t) = -\frac{3\sqrt{3}}{2\pi} V_m$$

$$V_{OUT} = V_A - V_B = \frac{3\sqrt{3}}{2\pi} V_m (1 + \cos \alpha)$$

$$i_1 = i_{Q1} - i_{D1}$$

$$i_{Q1} = \begin{cases} I_{OUT}, & \frac{\pi}{6} + \alpha < \omega_0 t < \frac{5\pi}{6} + \alpha \\ 0, & \text{otherwise} \end{cases}$$

$$i_{D1} = \begin{cases} I_{OUT}, & \frac{7\pi}{6} < \omega_0 t < \frac{11\pi}{6} \\ 0, & \text{otherwise} \end{cases}$$

za  $0 < \alpha < \pi/3$

$$i_1 = \begin{cases} I_{OUT}, & \frac{\pi}{6} + \alpha < \omega_0 t < \frac{5\pi}{6} + \alpha \\ -I_{OUT}, & \frac{7\pi}{6} < \omega_0 t < \frac{11\pi}{6} \\ 0, & \text{otherwise} \end{cases}$$

$$I_{RMS} = \sqrt{\frac{2}{3}} I_{OUT}$$

za  $\pi/3 < \alpha < \pi$

$$i_1 = \begin{cases} I_{OUT}, & \frac{\pi}{6} + \alpha < \omega_0 t < \frac{7\pi}{6} \\ -I_{OUT}, & \frac{5\pi}{6} + \alpha < \omega_0 t < \frac{11\pi}{6} \\ 0, & \text{otherwise} \end{cases}$$

$$I_{RMS} = \sqrt{1 - \frac{\alpha}{\pi}} I_{OUT}$$

u oba slučaja

$$I_{1S} = \frac{\sqrt{3}}{\pi} (1 + \cos \alpha) I_{OUT}$$

$$I_{1C} = -\frac{\sqrt{3}}{\pi} \sin(\alpha) I_{OUT}$$

$$I_{1m} = \frac{\sqrt{6}}{\pi} \sqrt{1 + \cos \alpha} I_{OUT} = \frac{\sqrt{12}}{\pi} \cos \frac{\alpha}{2} I_{OUT}$$

$$I_{1RMS} = \frac{\sqrt{3}}{\pi} \sqrt{1 + \cos \alpha} I_{OUT} = \frac{\sqrt{6}}{\pi} \cos \frac{\alpha}{2} I_{OUT}$$

$$DPF = \cos \varphi_1 = \frac{I_{1S}}{I_{1m}} = \sqrt{\frac{1 + \cos \alpha}{2}} = \cos \frac{\alpha}{2}$$

za  $0 < \alpha < \pi/3$ :

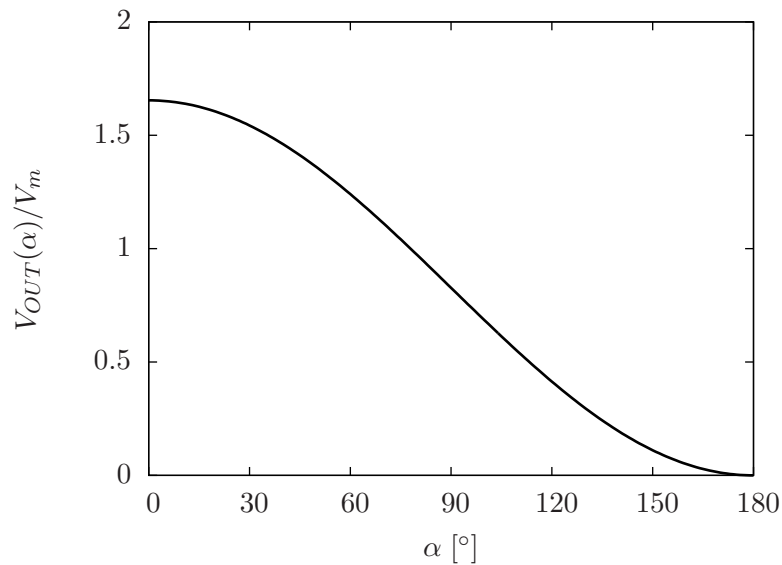
$$PF = \frac{3}{2\pi} (1 + \cos \alpha) = \frac{3}{\pi} \cos^2 \frac{\alpha}{2}$$

$$THD = \sqrt{\frac{2\pi^2}{9(1 + \cos \alpha)} - 1} = \sqrt{\left(\frac{\pi}{3 \cos \frac{\alpha}{2}}\right)^2 - 1}$$

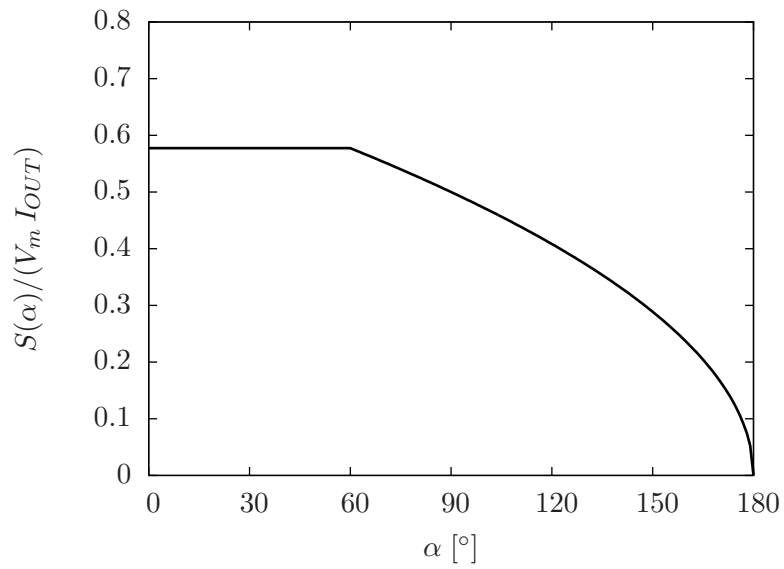
za  $\pi/3 < \alpha < \pi$ :

$$PF = \sqrt{\frac{6}{\pi(\pi - \alpha)}} \cos^2 \frac{\alpha}{2}$$

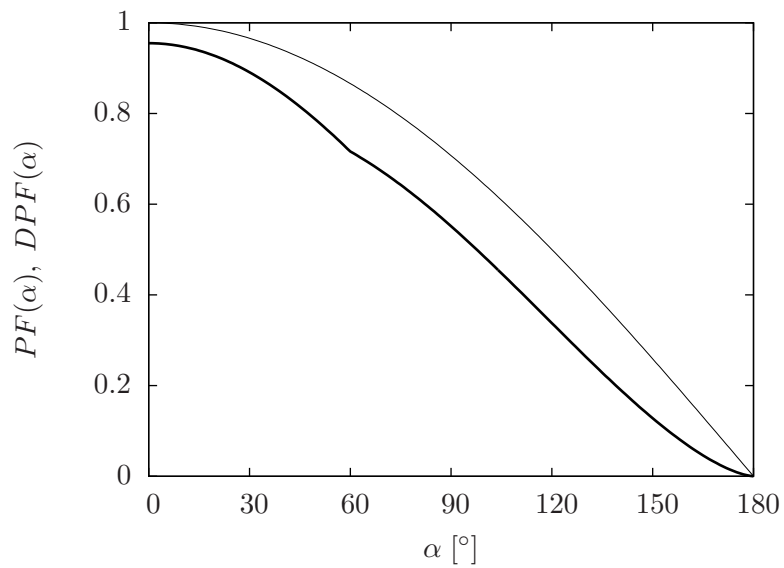
$$THD = \sqrt{\frac{\pi(\pi - \alpha)}{6 \cos^2 \frac{\alpha}{2}} - 1}$$



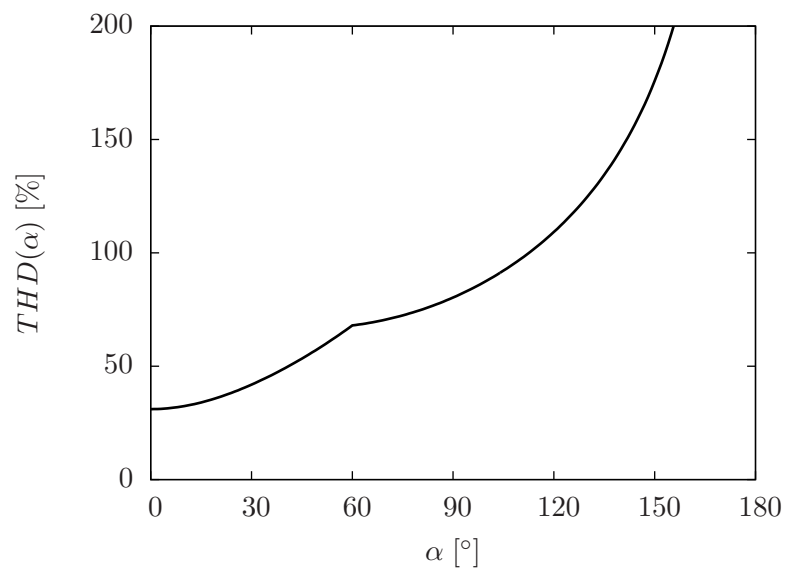
Slika 31: Polukontrolisan trofazni tiristorski most, zavisnost  $V_{OUT}$  od  $\alpha$ .



Slika 32: Polukontrolisan trofazni tiristorski most, zavisnost prividne snage od  $\alpha$ .



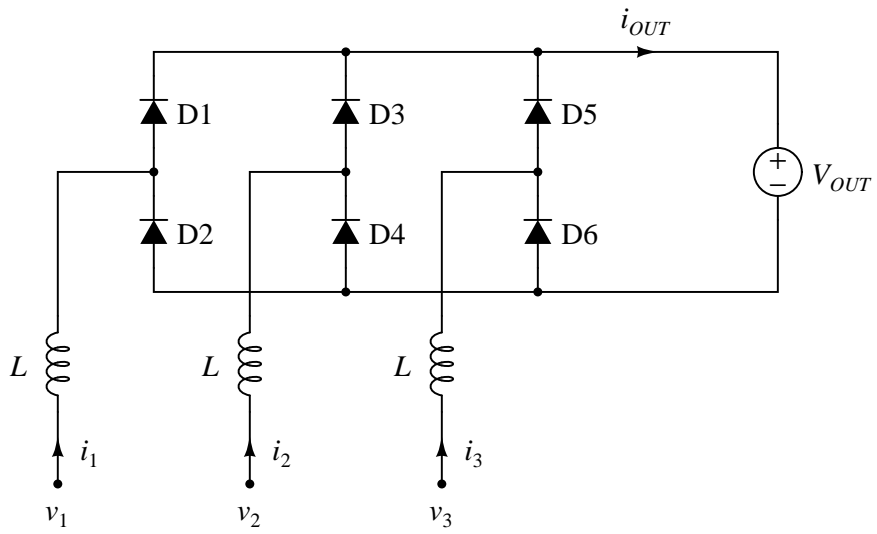
Slika 33: Polukontrolisan trofazni tiristorski most, zavisnost  $PF$  i  $DPF$  od  $\alpha$ .



Slika 34: Polukontrolisan trofazni tiristorski most, zavisnost  $THD$  od  $\alpha$ .



# Nekontrolisan naponom opterećen trofazni ispravljač



Slika 35: Nekontrolisan naponom opterećen trofazni ispravljač.