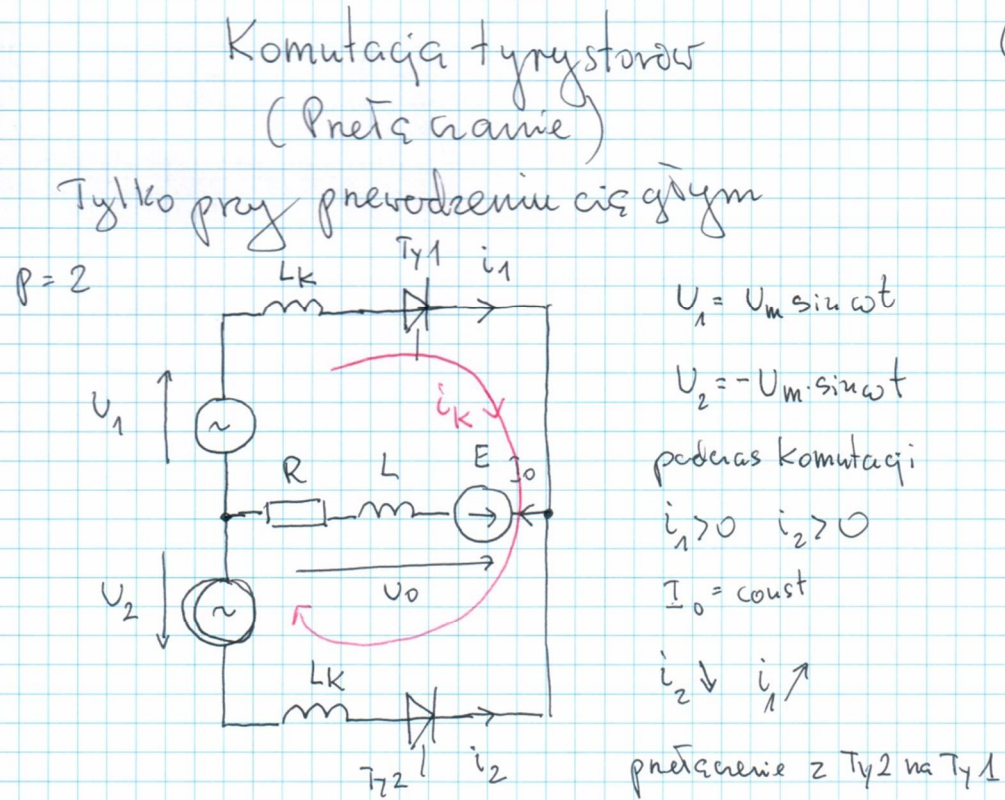


# Prostowniki tyrystorowe

## cz. 3

# Prostowniki tyrystorowe

## Komutacja



$$U_1 - U_2 = 2 L_k \cdot \frac{di_k}{dt}$$

$$U_m \cdot \sin \omega t - (-U_m \cdot \sin \omega t) = 2 L_k \frac{di_k}{dt}$$

$$2 U_m \cdot \sin \omega t = 2 L_k \frac{di_k}{dt}$$

$$\frac{di_k}{dt} = \frac{U_m}{L_k} \cdot \sin \omega t$$

$$di_k = \frac{U_m}{L_k} \cdot \sin \omega t \cdot dt \cdot \frac{\omega}{\omega}$$

$$\int_0^{v_z} di_k = \frac{U_m}{\omega L_k} \int_{v_z}^{\omega t} \sin \omega t \cdot d\omega t$$

$$i_k(t) = \frac{\sqrt{2} |U|}{\omega L_k} \left[ -\cos \omega t \right]_{v_z}^{\omega t}$$

# Prostowniki tyrystorowe

## Komutacja

$$di_k = \frac{U_m}{L_k} \cdot \sin \omega t \cdot dt \cdot \frac{\omega}{\omega}$$

$$\int_0^{U_2} di_k = \frac{U_m}{\omega L_k} \int_{U_2}^{\omega t} \sin \omega t \cdot d\omega t$$

$$i_k(t) = \frac{\sqrt{2}|U|}{\omega L_k} \left[ -\cos \omega t \right]_{U_2}^{\omega t}$$

$$i_k(t) = \frac{\sqrt{2}|U|}{\omega L_k} (\cos \vartheta_2 - \cos \omega t)$$

koniec komutacji dla  $\omega t = \vartheta_2 + \mu$   $i_k(\vartheta_2 + \mu) = I_0$   
 $\mu$  - kąt komutacji

$$I_0 = \frac{\sqrt{2}|U|}{\omega L_k} [\cos \vartheta_2 - \cos(\vartheta_2 + \mu)] \quad \frac{|U|}{\omega L_k} = I_k$$

$$I_0 = \sqrt{2} I_k [\cos \vartheta_2 - \cos(\vartheta_2 + \mu)]$$

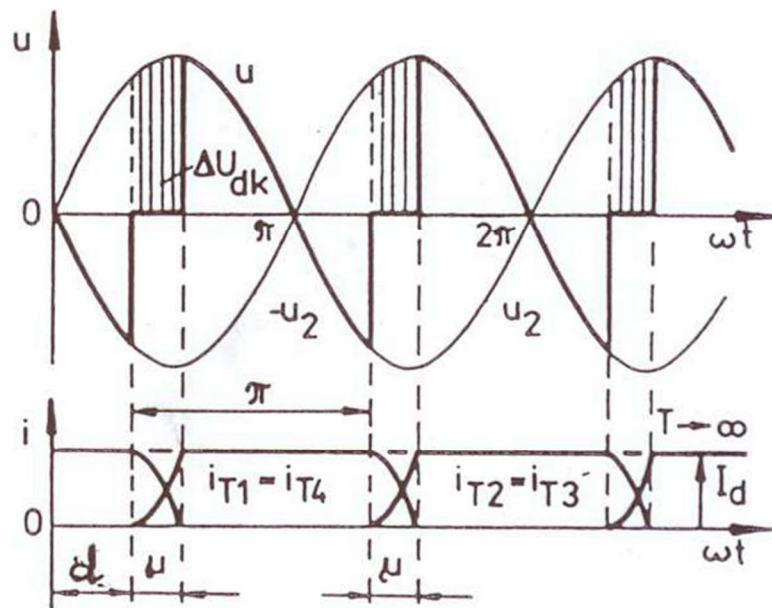
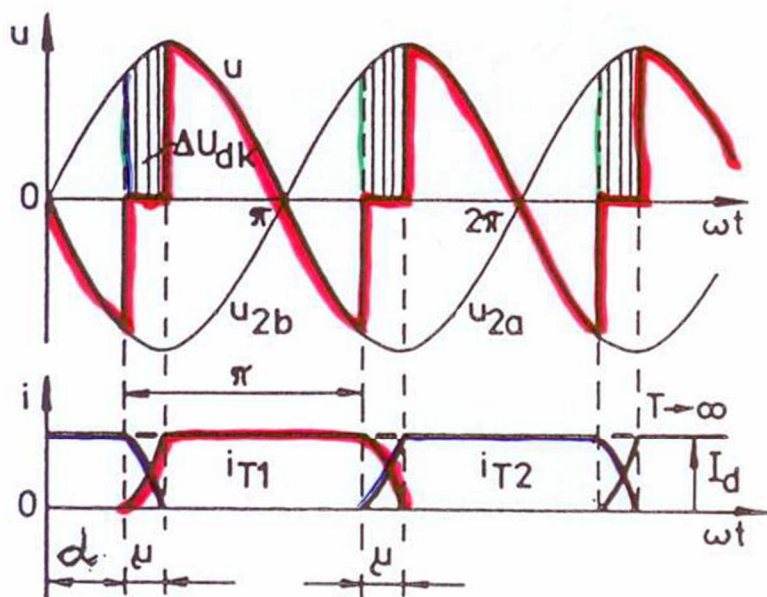
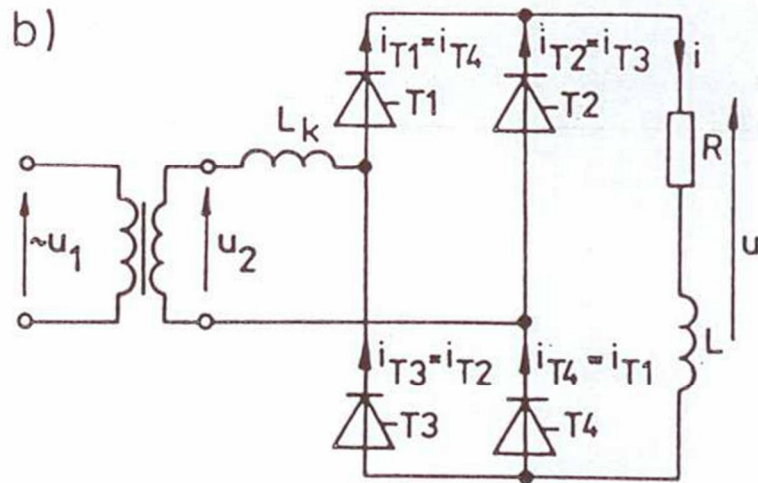
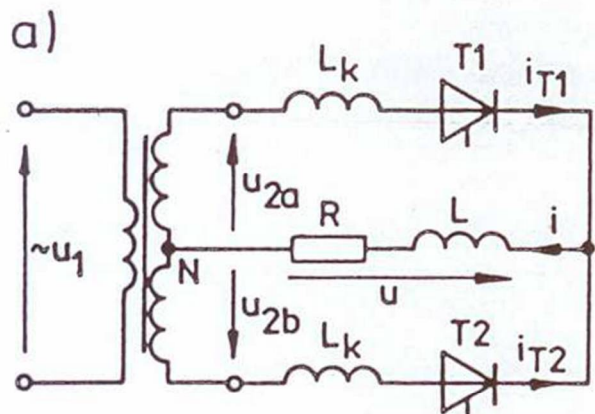
$$\mu = ?$$

$$\frac{I_0}{\sqrt{2} I_k} = \cos \vartheta_2 - \cos(\vartheta_2 + \mu)$$

$$\mu = \arccos\left(\cos \vartheta_2 - \frac{I_0}{\sqrt{2} I_k}\right) - \vartheta_2$$

# Prostowniki tyrystorowe

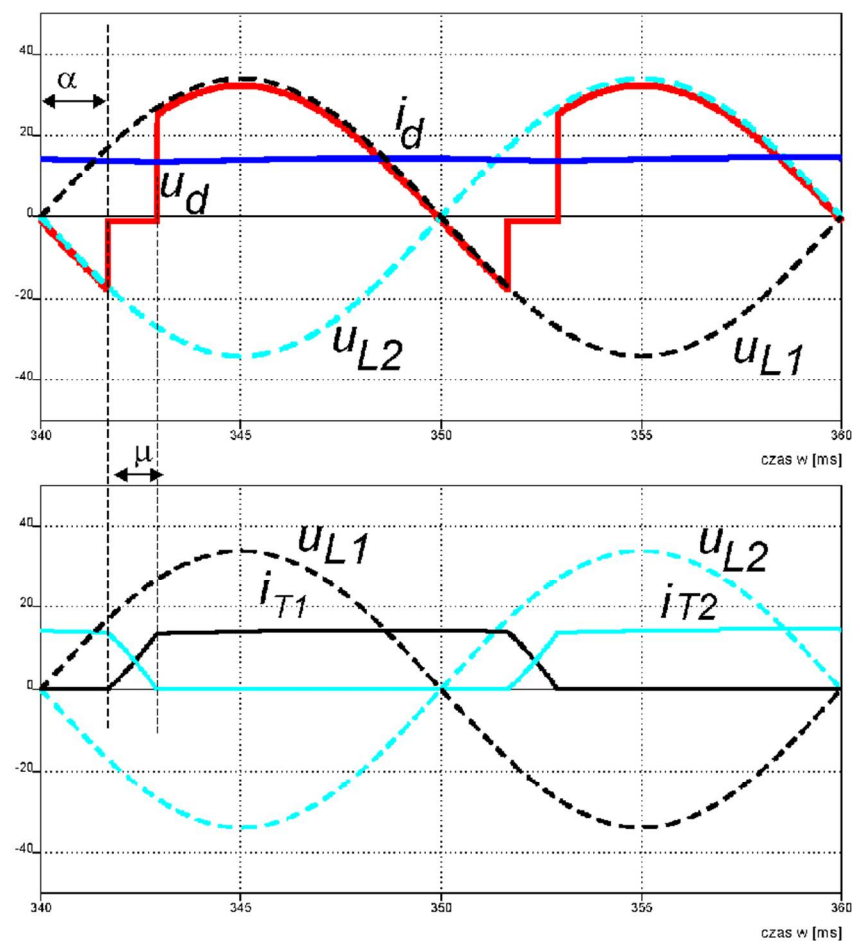
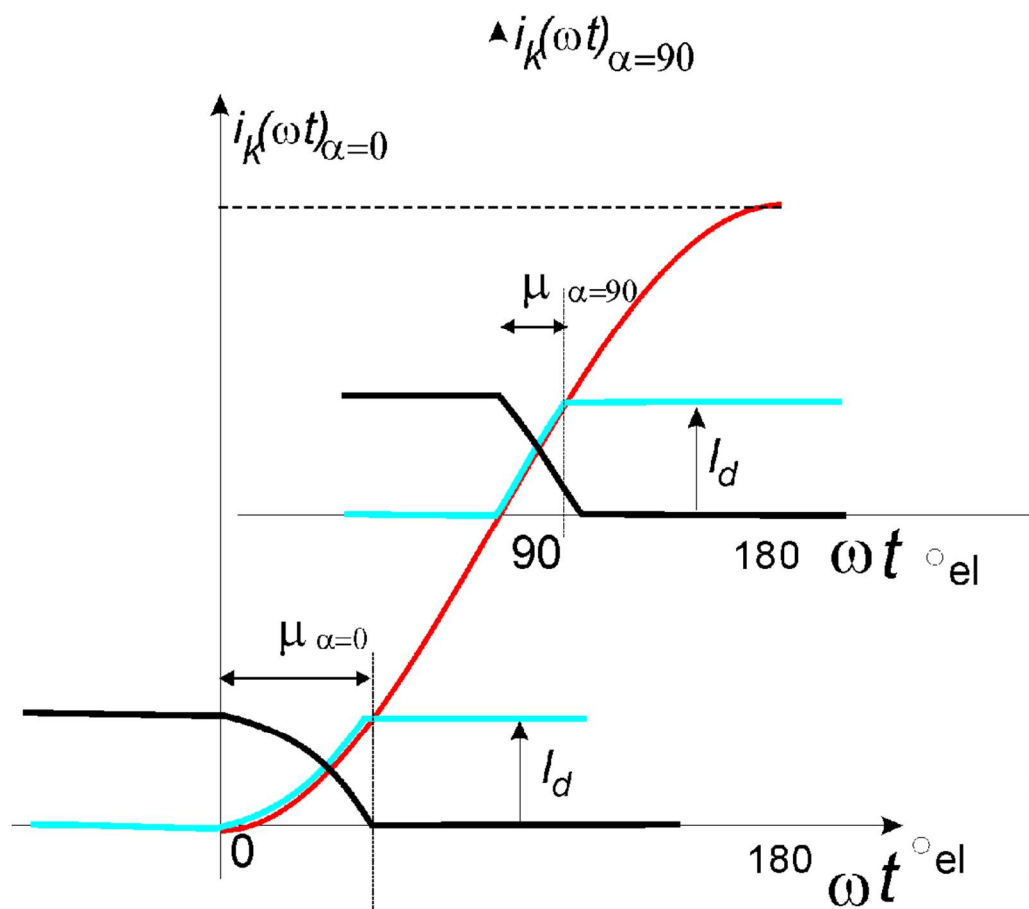
## Komutacja



# Prostownniki tyrystorowe

## Komutacja

$$i_K(t) = \frac{\sqrt{2}U}{\omega L_K} (\cos \vartheta_2 - \cos \omega t)$$

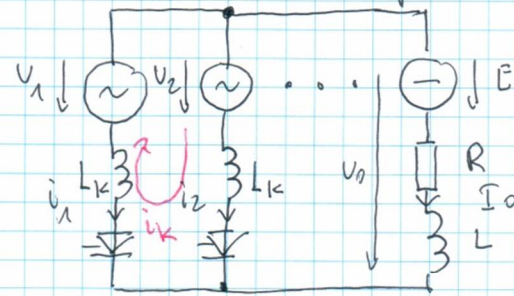


$$\mu = \arccos\left(\cos \vartheta_2 - \frac{I_o}{\sqrt{2} I_K}\right) - \vartheta_2$$

# Prostowniki tyrystorowe

## Komutacja

Komutacja dla  $p = 2, 3, 6$



$$U_2 - U_1 = 2 L_k \frac{di_k}{dt}$$

$$U_1 = U_m \sin\left(\omega t + \frac{2\pi}{p}\right)$$

$$U_2 = U_m \sin \omega t$$

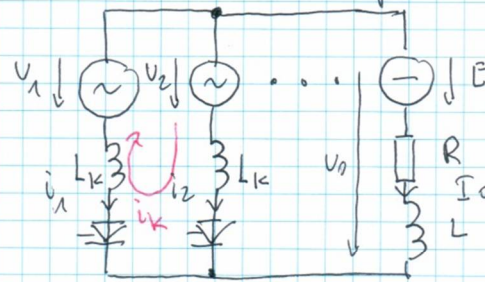
$$\frac{di_k}{dt} = \frac{U_m}{2 L_k} \left[ \sin \omega t - \sin\left(\omega t + \frac{2\pi}{p}\right) \right]$$

$$\frac{di_k}{dt} = \frac{U_m}{2 L_k} 2 \sin \frac{\pi}{p} \sin\left[\omega t - \left(\frac{\pi}{2} - \frac{\pi}{p}\right)\right]$$

# Prostowniki tyrystorowe

## Komutacja

Komutacja dla  $p = 2, 3, 6$



$$U_2 - U_1 = 2 L_k \frac{di_k}{dt}$$

$$U_1 = U_m \sin\left(\omega t + \frac{2\pi}{p}\right)$$

$$U_2 = U_m \sin \omega t$$

$$\frac{di_k}{dt} = \frac{U_m}{2 L_k} \left[ \sin \omega t - \sin\left(\omega t + \frac{2\pi}{p}\right) \right]$$

$$\frac{di_k}{dt} = \frac{U_m}{2 L_k} \cdot 2 \sin \frac{\pi}{p} \cdot \sin\left[\omega t - \left(\frac{\pi}{2} - \frac{\pi}{p}\right)\right]$$

$$\sin \gamma - \sin \delta = 2 \cos \frac{\gamma + \delta}{2} \sin \frac{\gamma - \delta}{2}$$

$$\sin \omega t - \sin\left(\omega t + \frac{2\pi}{p}\right) = 2 \cos \frac{\omega t + \omega t + \frac{2\pi}{p}}{2} \sin \frac{\omega t - \omega t - \frac{2\pi}{p}}{2} =$$

$$= 2 \cos\left(\omega t + \frac{\pi}{p}\right) \cdot \sin\left(-\frac{\pi}{p}\right) \quad \cos \gamma = \sin\left(\frac{\pi}{2} - \gamma\right)$$

$$= 2 \sin\left(\frac{\pi}{2} - \omega t - \frac{\pi}{p}\right) \cdot \sin\left(-\frac{\pi}{p}\right) = 2 \sin\left[\omega t - \left(\frac{\pi}{2} - \frac{\pi}{p}\right)\right] \cdot \sin \frac{\pi}{p}$$

$$di_k = \frac{\sqrt{2} U \cdot \sin \frac{\pi}{p}}{L_k} \sin\left[\omega t - \left(\frac{\pi}{2} - \frac{\pi}{p}\right)\right] \cdot dt \cdot \frac{\omega}{\omega}$$

# Prostowniki tyrystorowe

## Komutacja

$$di_k = \frac{\sqrt{2}|U| \cdot \sin \frac{\pi}{p}}{L_k} \sin \left[ \omega t - \left( \frac{\pi}{2} - \frac{\pi}{p} \right) \right] \cdot dt \cdot \frac{\omega}{\omega}$$

$$\int_0^{i_k} di_k = \frac{\sqrt{2}|U| \cdot \sin \frac{\pi}{p}}{\omega L_k} \int_{\vartheta_2}^{\omega t} \sin \left[ \omega t - \left( \frac{\pi}{2} - \frac{\pi}{p} \right) \right] d\omega t$$

$$i_k(t) = \frac{\sqrt{2}|U|}{\omega L_k} \cdot \sin \frac{\pi}{p} \left[ -\cos \left[ \omega t - \left( \frac{\pi}{2} - \frac{\pi}{p} \right) \right] \right]_{\vartheta_2}^{\omega t}$$

$$i_k(t) = \frac{\sqrt{2}|U|}{\omega L_k} \cdot \sin \frac{\pi}{p} \left[ \cos \left( \vartheta_2 - \frac{\pi}{2} + \frac{\pi}{p} \right) - \cos \left( \omega t - \left( \frac{\pi}{2} - \frac{\pi}{p} \right) \right) \right]$$

$$\omega t = \vartheta_2 + \mu \quad (\text{koniec komutacji})$$

$$i_k(\vartheta_2 + \mu) = I_0 = I_d$$

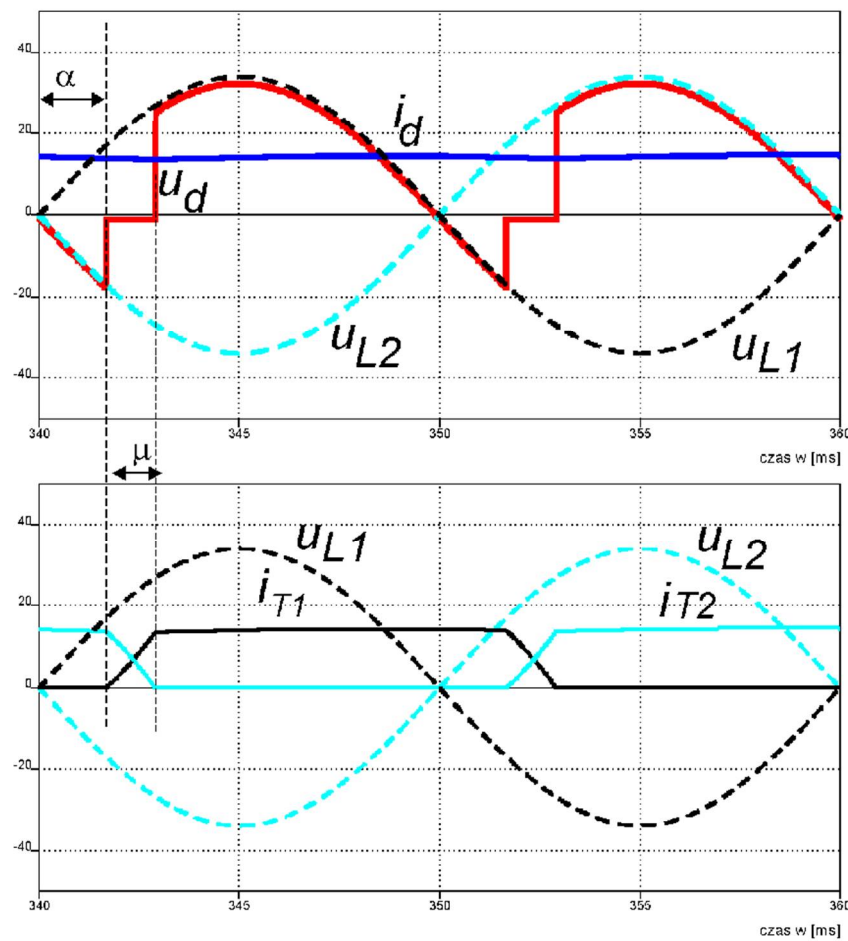
$$I_0 = \frac{\sqrt{2}|U|}{\omega L_k} \sin \frac{\pi}{p} \left[ \cos \alpha - \cos(\alpha + \mu) \right]$$

$$\mu = \arccos \left[ \cos \alpha - \frac{\omega L_k \cdot I_0}{\sqrt{2}|U| \cdot \sin \frac{\pi}{p}} \right] - \alpha$$

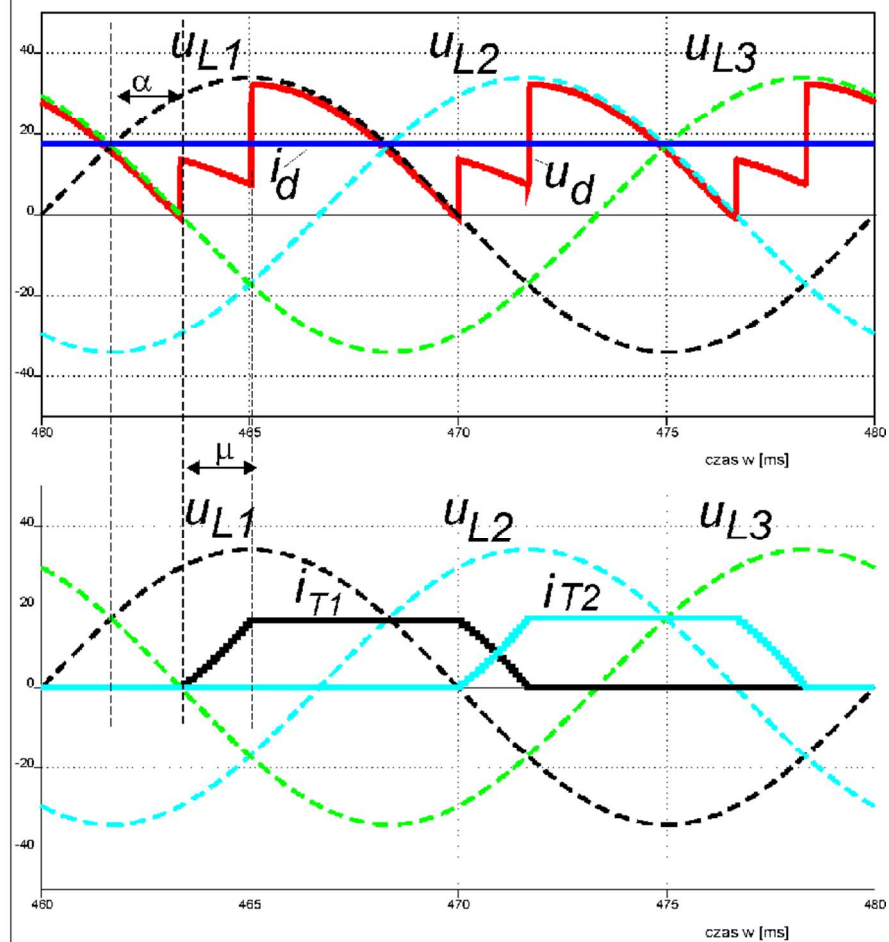
# Prostownniki tyrystorowe

## Komutacja

a)



b)



# Prostowniki tyrystorowe

## Komutacja

Skutki komutacji -  $\Delta U_d$

$$i_k = \frac{U_2 - U_1}{2\omega L_k} \quad U_{wy}' = U_o' = U_2 - \omega L_k \cdot i_k$$

$$U_o' = U_2 - \frac{U_2 - U_1}{2\omega L_k} \cdot \omega L_k = U_2 - \frac{U_2}{2} + \frac{U_1}{2} = \frac{U_2 + U_1}{2}$$

$$U_o = U_{wy} = U_2 \quad \Delta U = U_o - U_o' = U_2 - \frac{U_2 + U_1}{2} = \frac{U_2 - U_1}{2}$$

$$\Delta U_o \cdot i_k \cdot \Delta U_d = \frac{P}{2\pi} \int_{\theta_2}^{\theta_2+\mu} \Delta U_o \cdot d\omega t =$$

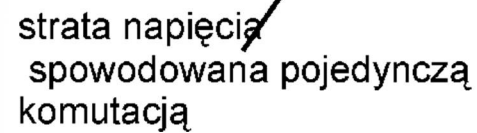
$$\Delta U_d = \frac{P}{2\pi} \int_{\theta_2}^{\theta_2+\mu} \frac{U_2 - U_1}{2} d\omega t = \frac{P}{2\pi} \int_{\theta_2}^{\theta_2+\mu} \frac{1}{2} \left( 2L_k \frac{di_k}{d\omega t} \right) \cdot d\omega t \cdot \frac{\omega}{\omega}$$

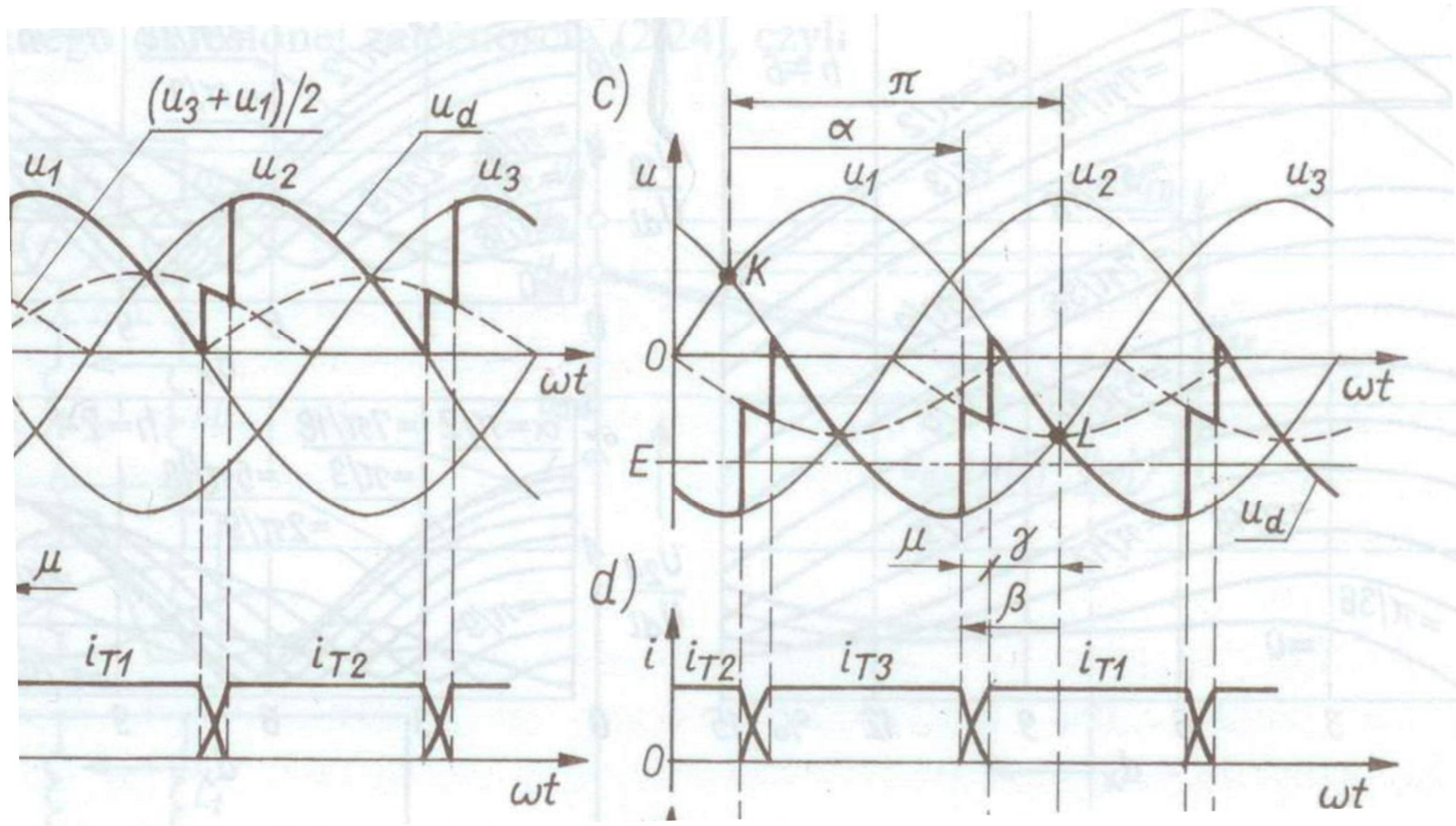
$$\Delta U_d = \frac{P}{2\pi} \omega L_k \int_0^{I_o} di_k = \frac{P \cdot \omega L_k}{2\pi} \cdot I_o$$

$$\Delta U_d = \frac{P \cdot \omega L_k}{2\pi} \cdot I_d \quad R_k = \frac{P \cdot \omega L_k}{2\pi}$$

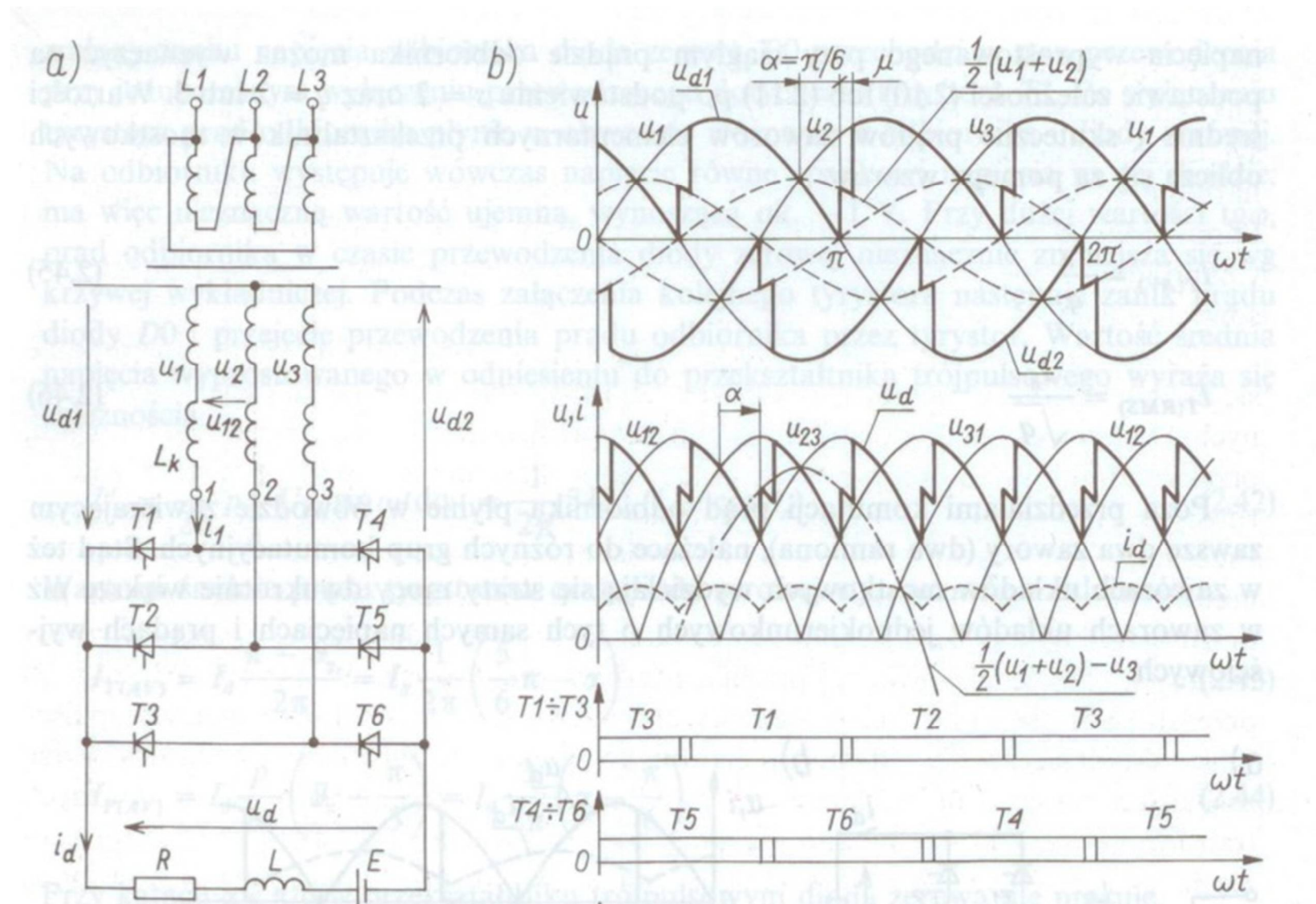
$R_k$  - rezystancja komutacji

# Ilustracja straty napięcia w wyniku komutacji

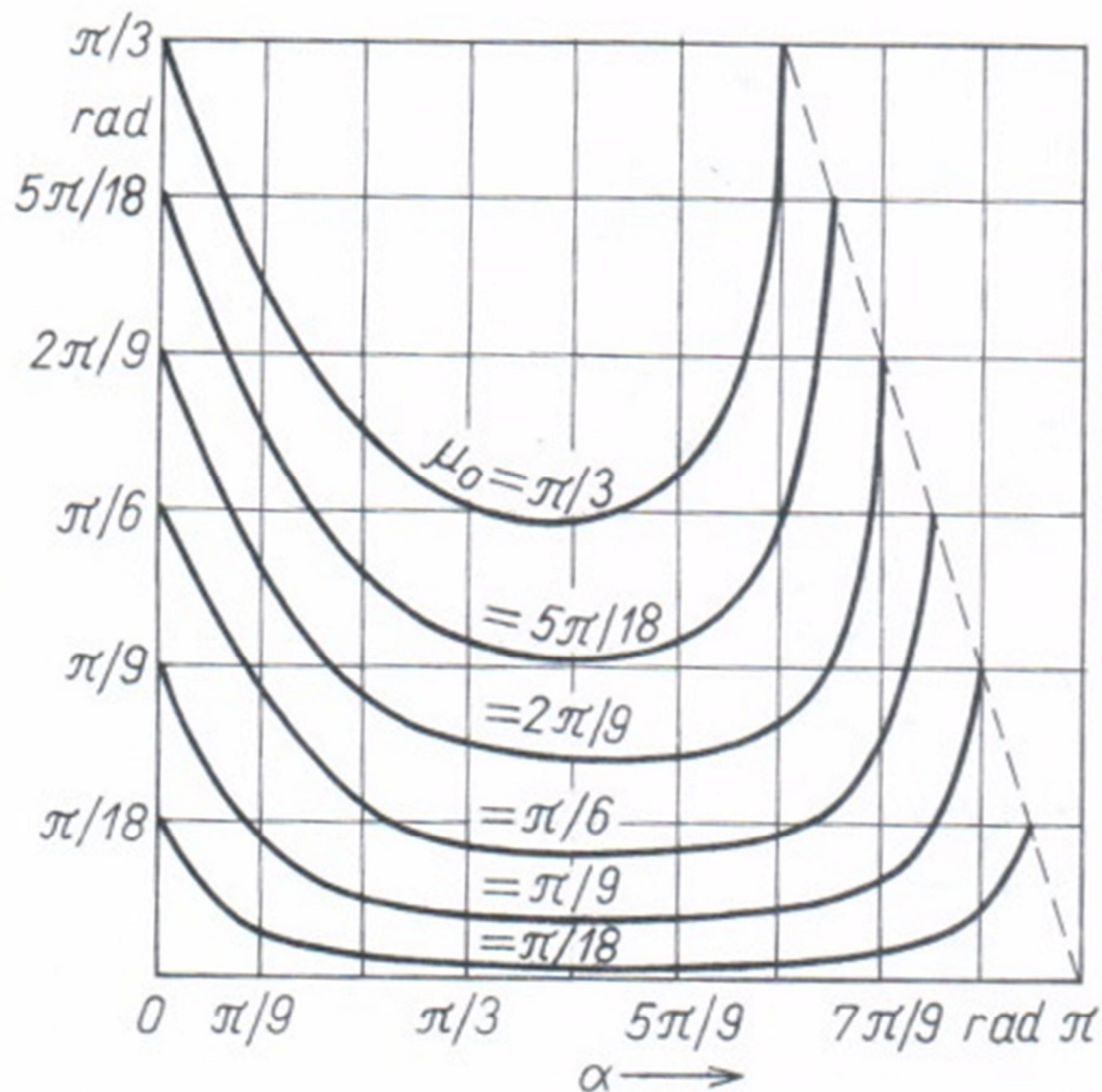
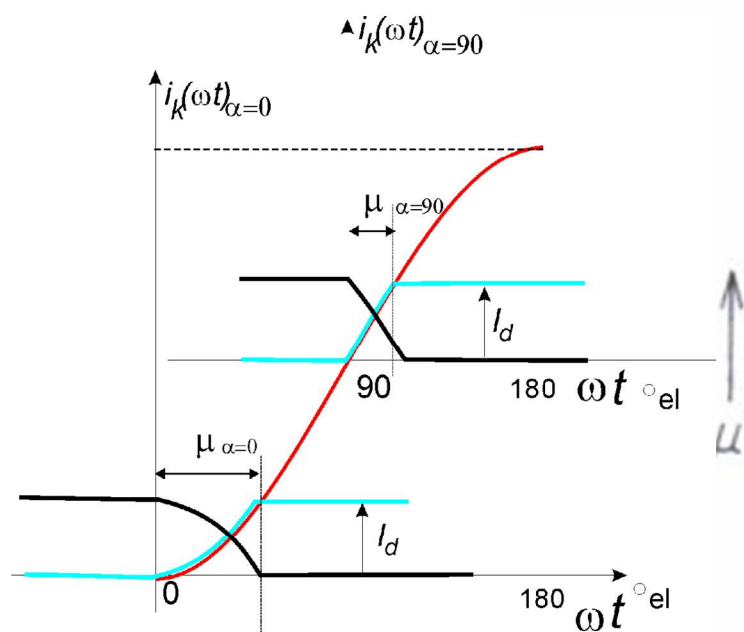




Przebiegi czasowe napięć i prądów prostownika 3-fazowego jednokierunkowego ( $p=3$ ) z uwzględnieniem zjawiska komutacji w pracy prostownikowej (a) i falownikowej (b)



Przebiegi czasowe napięć i prądów prostownika 3-fazowego mostkowego ( $p = 6$ ) z uwzględnieniem zjawiska komutacji; (a) schemat układu, (b) przebiegi czasowe napięć i prądów prostownika



**Zależność kąta komutacji  $\mu$  od kąta wysterowania tyrystorów  $\alpha$**