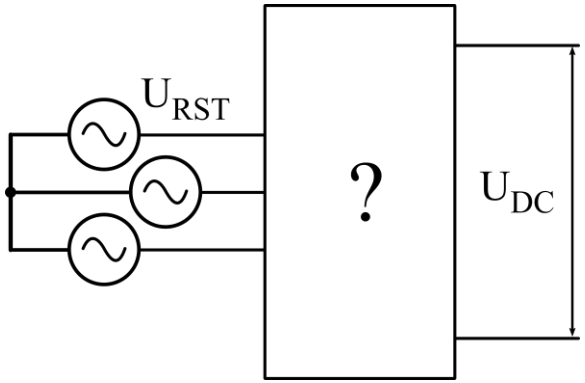
THREE-PHASE RECTIFIERS

- Three-phase diode rectifiers.
- Three-phase thyristor rectifiers.

RECTIFIERS

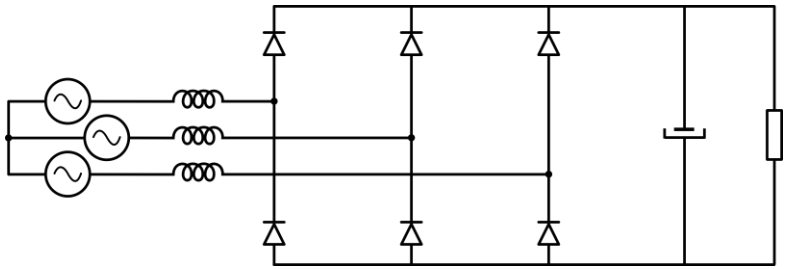
Diode vs thyristor rectifiers

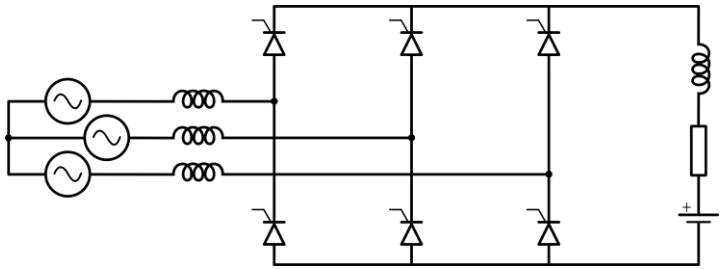


These rectifiers provide “either” small ΔU_{DC} “or” small ΔI_{DC}.

Types of three-phase rectifiers:

- Uncontrolled vs Controlled (vs Half/semi-controlled)
- Half-wave vs Full-wave





RECTIFIERS

Three-phase diode (uncontrolled) rectifier

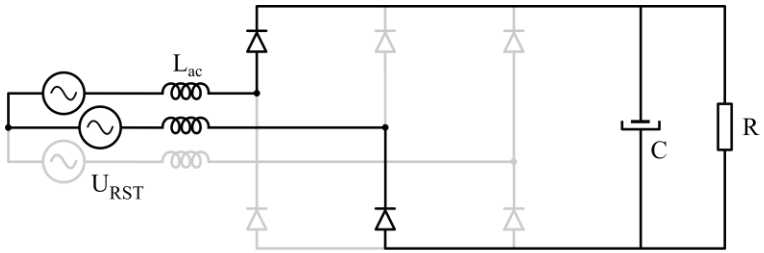
$U_{LDmax} = \sqrt{2} \cdot U_L$

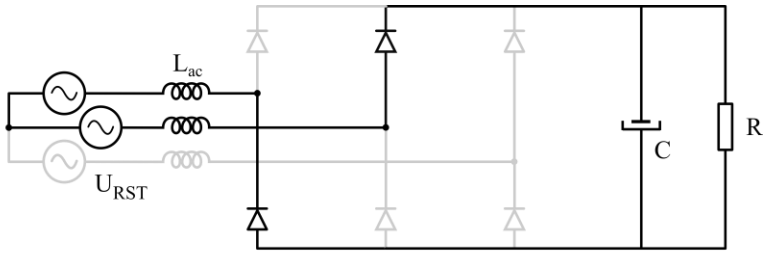
$u_{-N} \approx u_R$, $u_{+N} \approx u_S$

$u_{LD} = u_{+N} - u_{-N} \approx u_{RS}$

$i_R = i_{LD}$, $i_S = -i_{LD}$

$i_C = i_D - i_{LD}$,





$u_{-N} \approx$ $u_{+N} \approx$

$u_{LD} =$

$i_R =$ $i_S =$

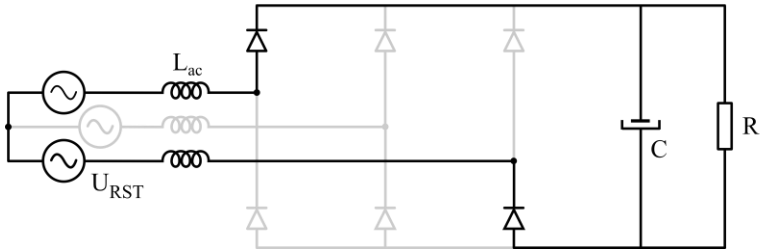
$i_C =$

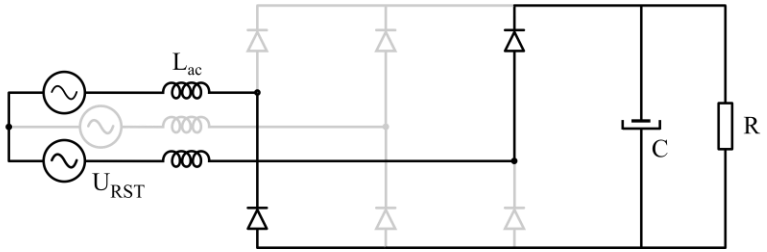
$u_{-N} \approx$ $u_{+N} \approx$

$u_{LD} =$

$i_R =$ $i_S =$

$i_C =$





$u_{-N} \approx$ $u_{+N} \approx$

$u_{LD} =$

$i_R =$ $i_S =$

$i_C =$

$u_{-N} \approx$ $u_{+N} \approx$

$u_{LD} =$

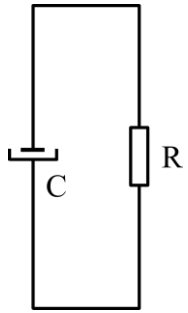
$i_R =$ $i_S =$

$i_C =$

$u_{LD} \approx U_{LDmax} \cdot e^{-\frac{\omega t - \frac{\pi}{2}}{\omega \cdot \tau_{LD}}}$, $\tau_{LD} = C \cdot R$

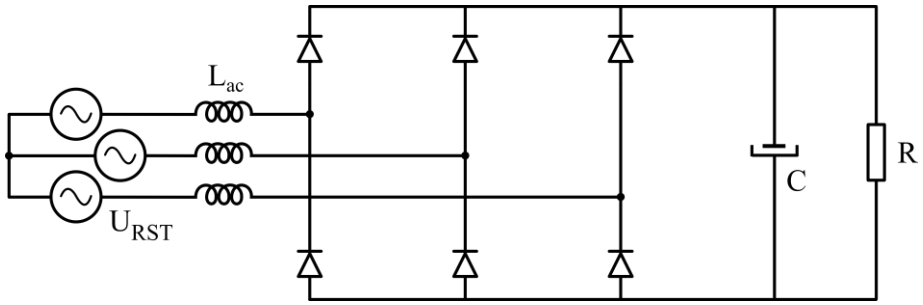
$i_R = 0A$

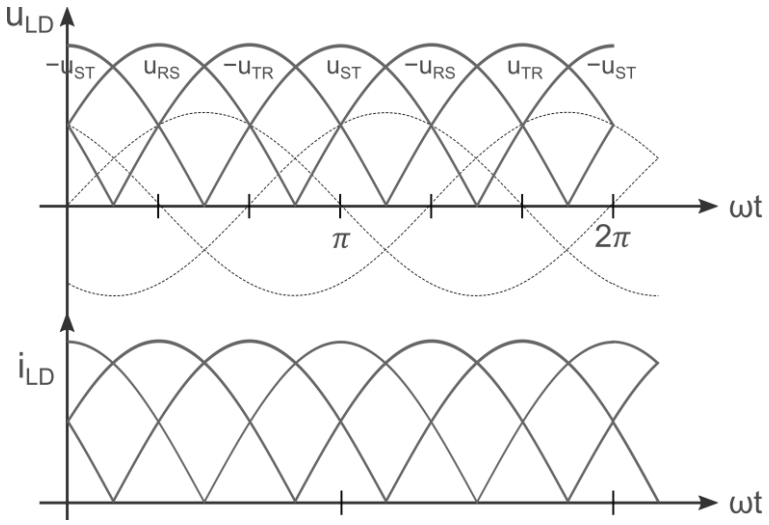
$i_C = -i_{LD}$

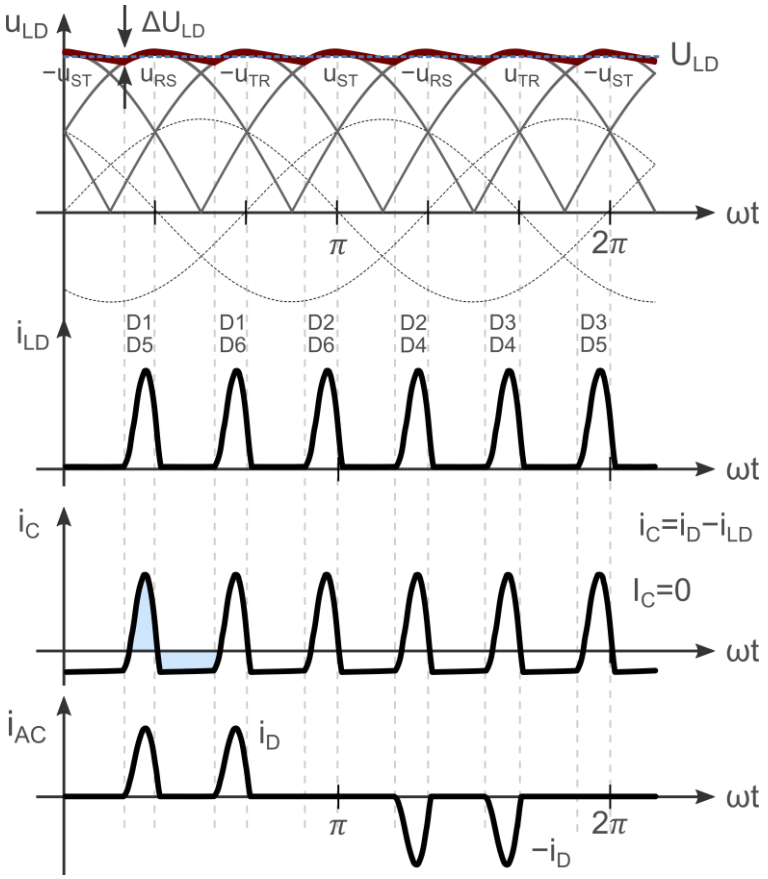


RECTIFIERS

Three-phase diode (uncontrolled) rectifier



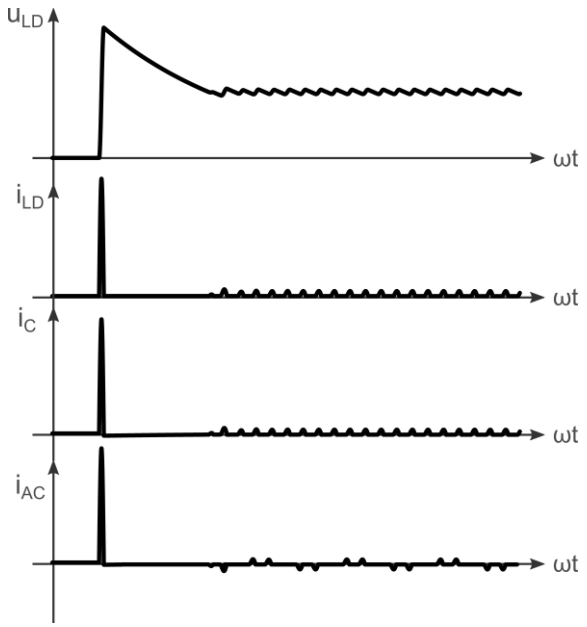


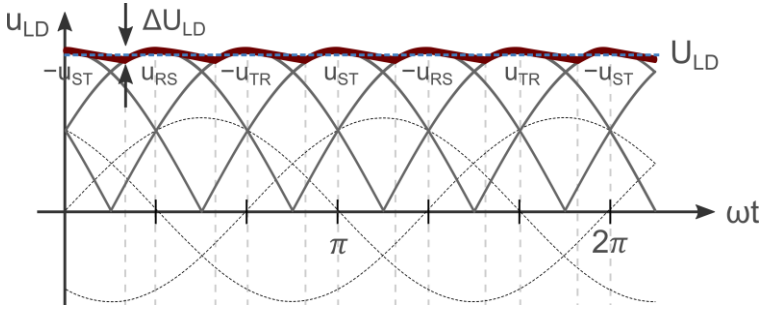


RECTIFIERS

Three-phase diode (uncontrolled) rectifier

Direct start with a discharged capacitor:





Capacitor sizing:

Assumption - $\Delta U_{LD} \ll U_{LD}$ $(\Delta U_{LD} \approx 0)$

=> $i_{LD} \approx I_{LD}$ and the discharge time is (whole) 10/3 ms.

=> $\Delta U_{LDmax} = \frac{Q}{C} = \frac{I_{DC} \cdot \frac{10}{3} ms}{C}$ or $C = \frac{I_{DC} \cdot \frac{10}{3} ms}{\Delta U_{LD}}$

Example:

$U_{ACL} = 400V\ (50Hz), P_{LD} = 5kW, \Delta U_{LDmax} \leq 10\% \cdot U_{LD}$

$U_{LD} \approx U_{LDmax} = \sqrt{2} \cdot U_L = \sqrt{2} \cdot 400 = 566V$

$I_{LD} = \frac{5kW}{566V} = 8.84A\ ,\ \Delta U_{DC} = 57V$

$C = \frac{8.84 \cdot 3.33ms}{57} = 516\mu F$

RECTIFIERS

Three-phase thyristor (controlled) rectifier

$L >> L_{AC}$ => $u_{LAC} <<$

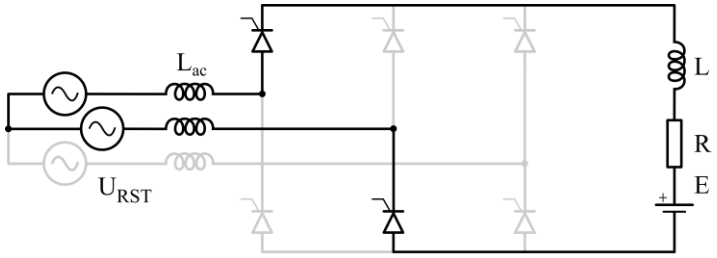
$u_{+N} \approx u_R$

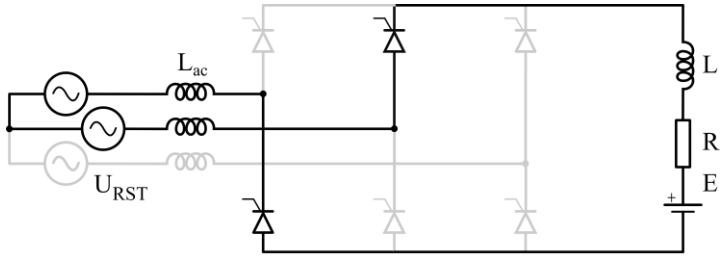
$u_{-N} \approx u_S$

$u_{LD} = u_{+N} - u_{-N} \approx u_{RS}$

$i_R = i_{LD}$, $i_S = -i_{LD}$

π/6+α < ωt < π/2+α





$u_{+N} \approx$

$u_{-N} \approx$

$u_{LD} =$

$i_R =$

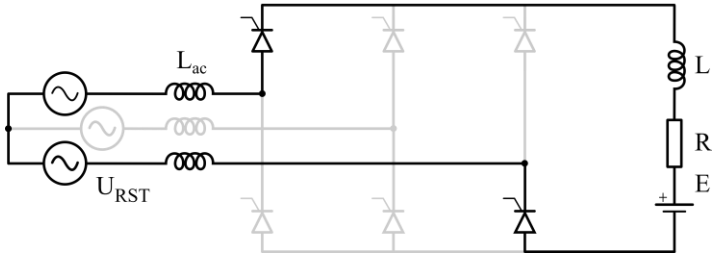
$u_{+N} \approx$

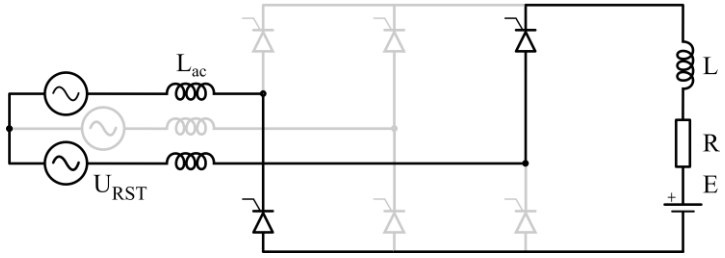
$u_{-N} \approx$

$u_{LD} =$

$i_R =$

π/2+α+μ < t < 5π/6+α





$u_{+N} \approx$

$u_{-N} \approx$

$u_{LD} =$

$i_R =$

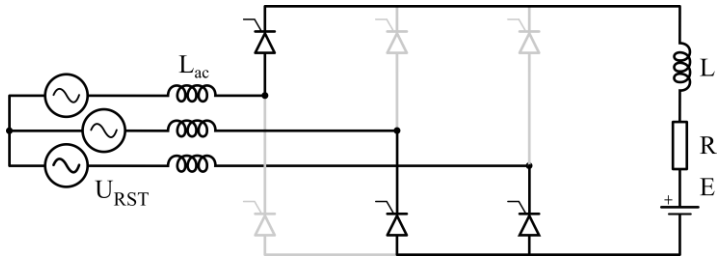
$u_{+N} \approx u_R$

$u_{-N} \approx u_S - u_{ST}/2$

$u_{LD} = u_{RS} + u_{ST}/2$

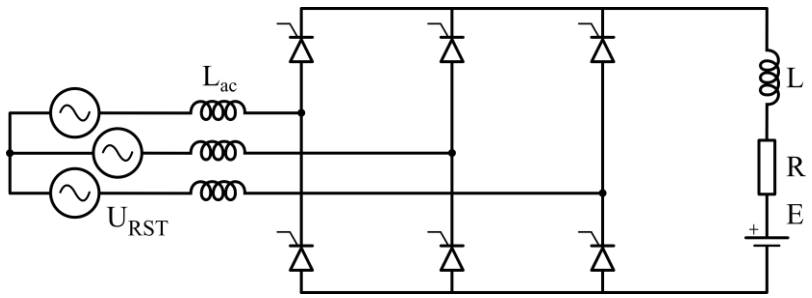
$i_R = i_{LD}$

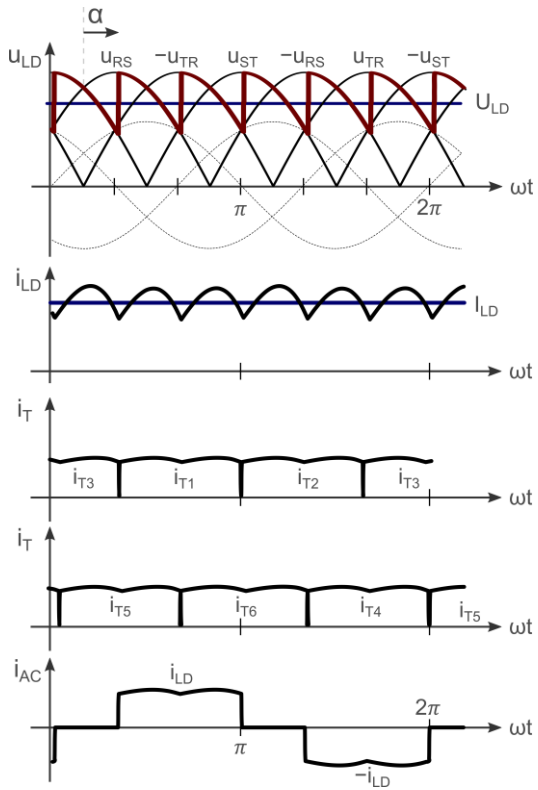
π/2+α < t < π/2+α+μ

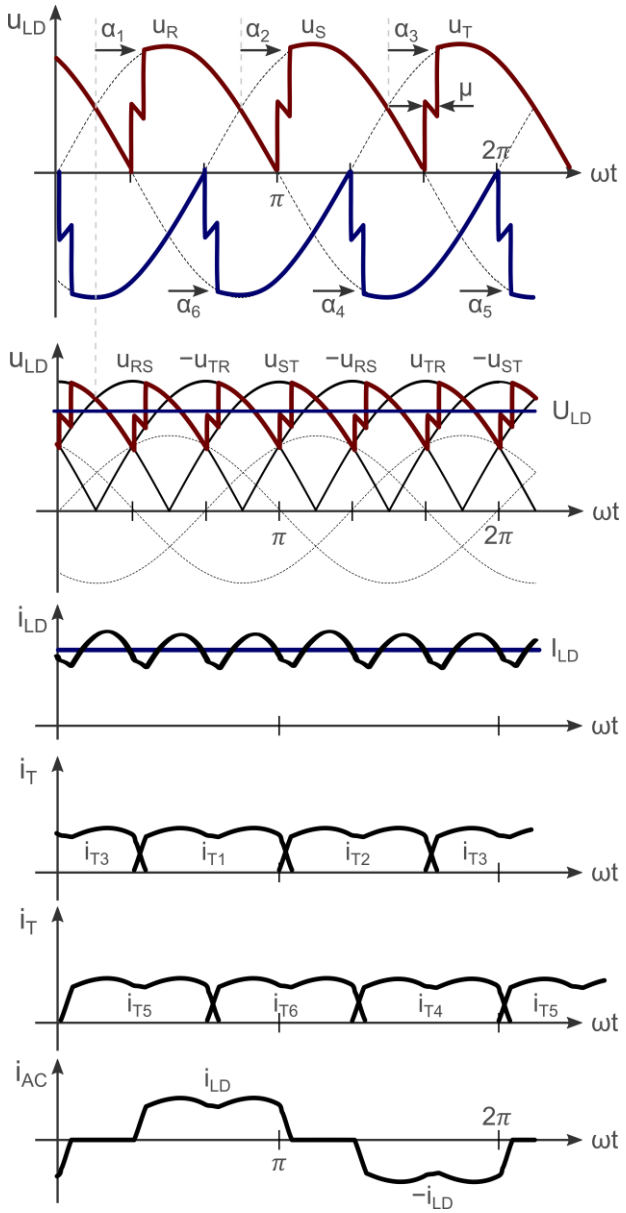


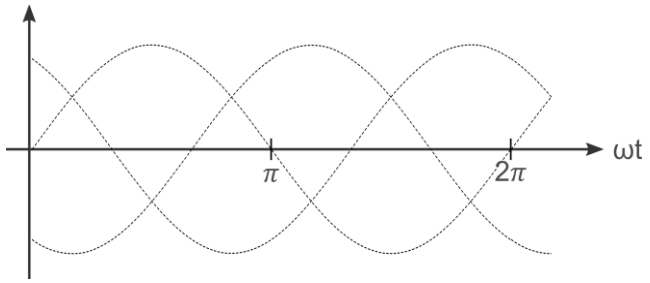
RECTIFIERS

Three-phase thyristor (controlled) rectifier





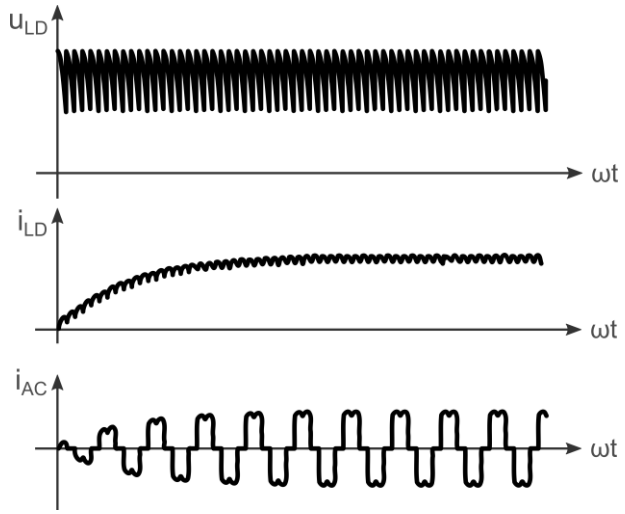




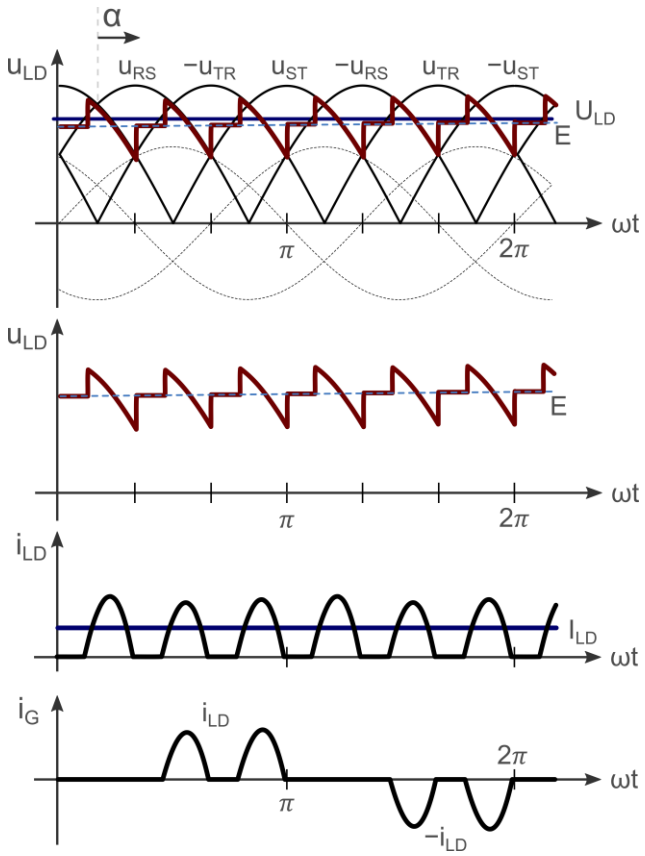
RECTIFIERS

Three-phase thyristor (controlled) rectifier

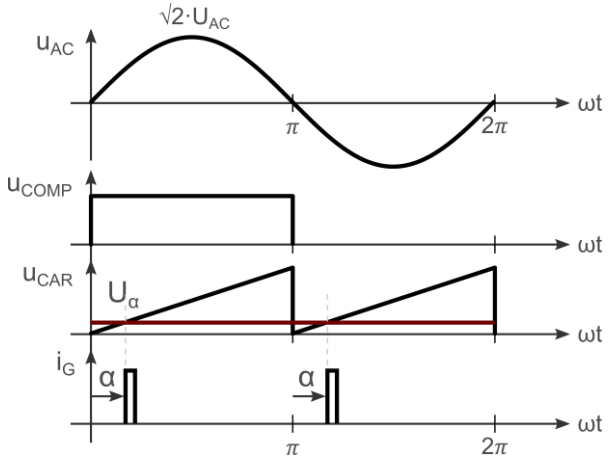
Direct start:



Discontinuous i_{LD}:



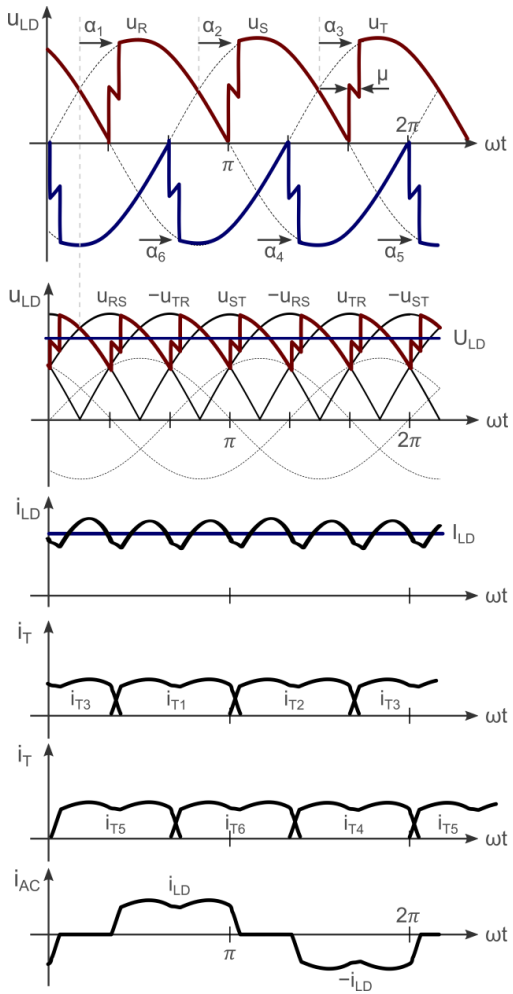
Synchronization:



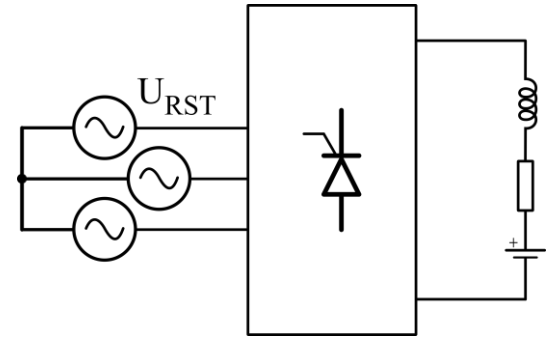
RECTIFIERS

Three-phase thyristor (controlled) rectifier

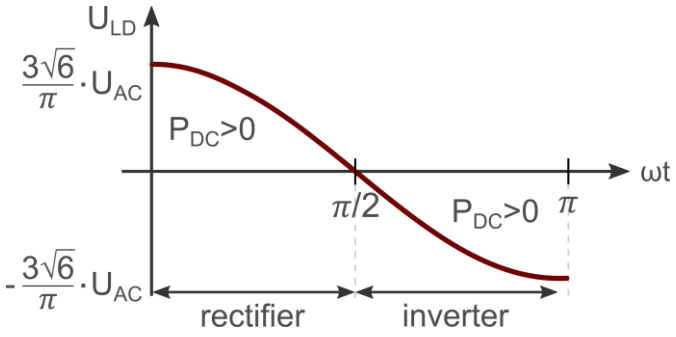
Continuous conduction mode (continuous i_{LD}):



Average load voltage (U_{LD}):



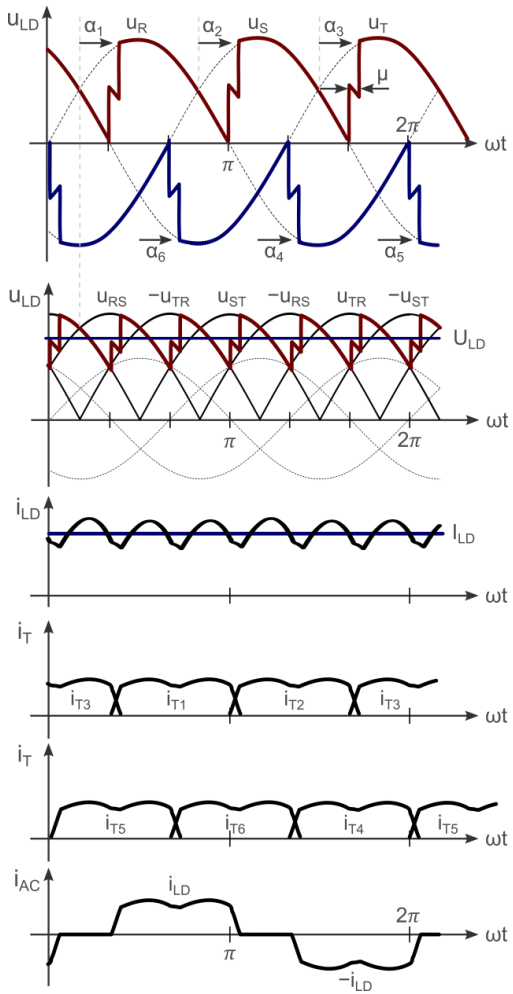
Average load current (I_{LD}):



RECTIFIERS

Three-phase thyristor (controlled) rectifier

Continuous conduction mode (continuous i_{LD}):



$U_{AC} = 3x400V\ (50Hz),\ R = 1\Omega,\ L = 30mH,\ E = 417{,}8V,$

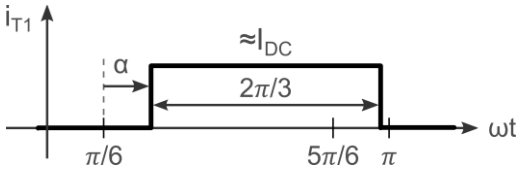
$L_{ac} = 100\mu H,\ \alpha = \frac{\pi}{6}$

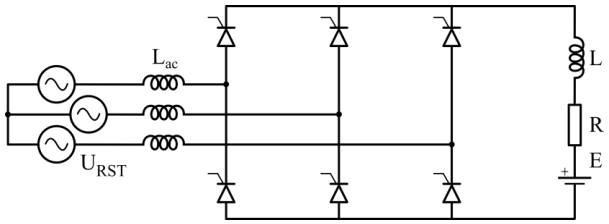
Average load voltage - example:

$$U_{LD} = \frac{3\sqrt{2}}{\pi} \cdot U_L \cdot cos\alpha = \frac{3\sqrt{2}}{\pi} \cdot 400 \cdot \cos\left(\frac{\pi}{6}\right) = 467{,}8V$$

Average load current – example:

$$I_{LD} = \frac{U_{LD} - E}{R} = \frac{467{,}8 - 417{,}8}{1} = 50A$$



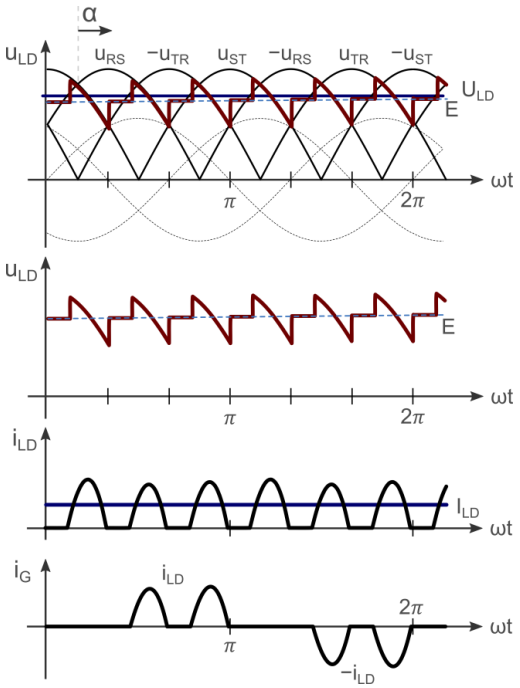


Choose thyristors:

RECTIFIERS

Single-phase thyristor (controlled) rectifier

Discontinuous conduction mode (discontinuous i_{LD}):

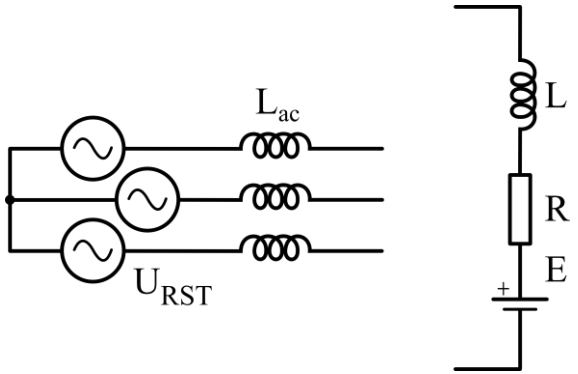


Average load voltage (U_{LD}):

$$U_{LD} = \frac{1}{\pi/3}\left[\int_{\frac{\pi}{6}+\alpha}^{\frac{\pi}{6}+\beta} \sqrt{2}\cdot U_L \cdot \sin\left(\omega t + \frac{\pi}{6}\right)\cdot d(\omega t) + + \int_{\frac{\pi}{6}+\beta}^{\frac{\pi}{2}+\alpha} E \cdot d(\omega t)\right] = \cdots$$

Average load current (I_{LD}):

$$I_{LD} = \frac{U_{LD} - E}{R}$$



RECTIFIERS

Three-phase rectifiers - important notes

- Three-phase rectifiers are used in higher power applications,
- There are controlled and uncontrolled rectifiers,
- Filtering is extensively used,
- Filters influence the semiconductor devices conduction times,
- Diode bridge secures output voltage with small ripple,
- Thyristor bridge secures output current with small ripple,
- They drive different types of load,
- Load current can be discontinuous in thyristor bridges,
- Thyristor bridges necessitate synchronization unit,
- Commutation is process of importance for thyristor bridges,
- For continuous load current, the thyristor bridge can behave both as a rectifier and as an inverter (depending on firing angle).