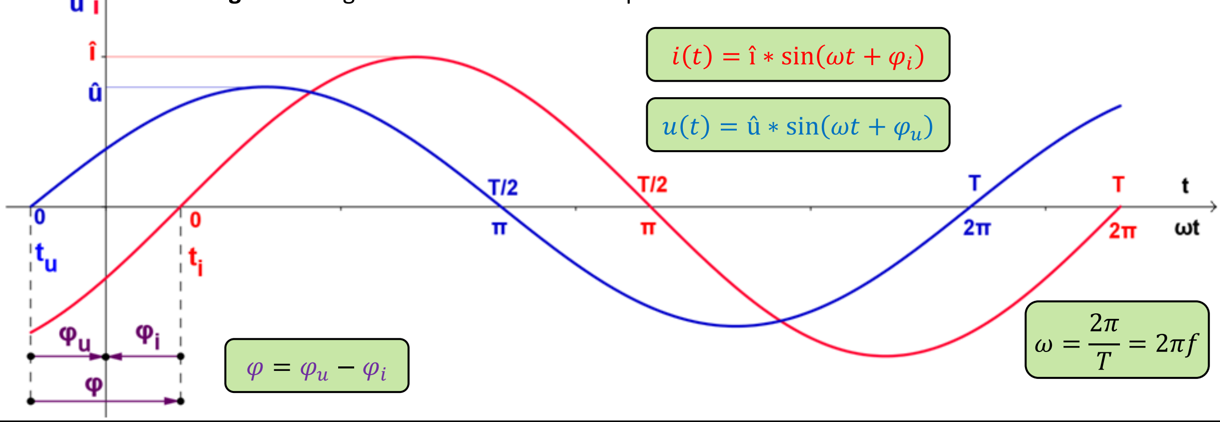
# WECHSELSTROMLEHRE

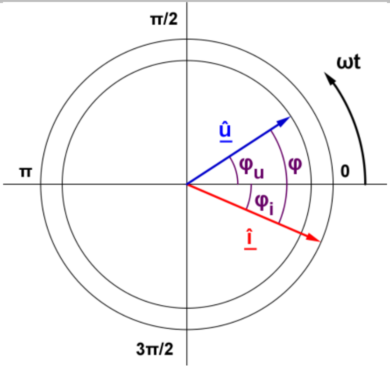
## Wechselgrössen

### Zeitlicher Verlauf

**Wechselgrösse:** Augenblickswert ändert sich periodisch und der zeitliche Mittelwert ist Null.

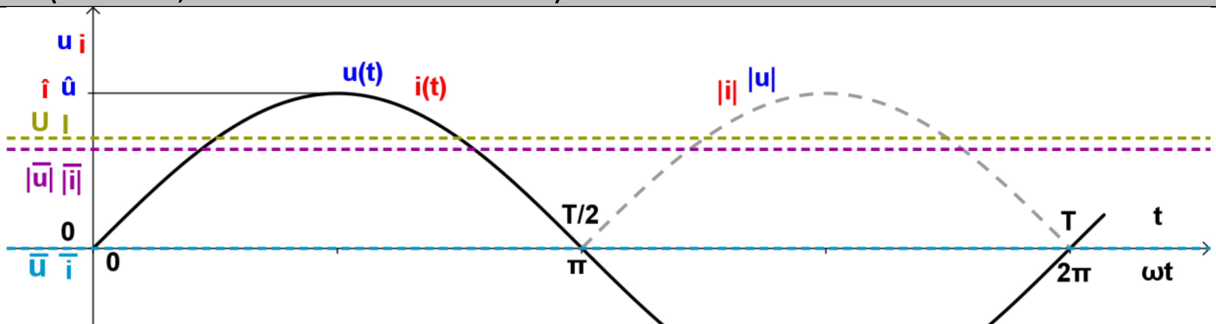



### Zeigerdarstellung




| | | |
|---|---|---|
| $u(t)$ | Spannung | $[V]$ |
| $\hat{u}$ | Scheitelwert, Amplitude | $[V]$ |
| $\underline{\hat{u}}$ | Spannungszeiger | $[V]$ |
| $i(t)$ | Strom | $[A]$ |
| $\hat{\imath}$ | Scheitelwert, Amplitude | $[A]$ |
| $\underline{\hat{\imath}}$ | Stromzeiger | $[A]$ |
| $\omega$ | Kreisfrequenz | $[s^{-1}]$ ~~Hz~~ |
| $T$ | Periodendauer | $[s]$ |
| $f$ | Frequenz | $[s^{-1}]$ $[Hz]$ |
| $\varphi$ | Phasenverschiebungswinkel | $[rad]$ |
| $\varphi_u, \varphi_i$ | Nullphasenwinkel | $[rad]$ |
| $t_u, t_i$ | Nullphasenzeit | $[s]$ |

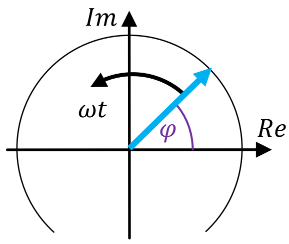
### Mittelwerte (Gleichwert, Gleichrichtwert und Effektivwert)




| | Spannung | Strom | bei Sinus | |
|---|---|---|---|---|
| Gleichwert<br>=arithmetischer Mittelwert | $\overline{u} = \frac{1}{T}\int_0^T u\,dt$ | $\overline{i} = \frac{1}{T}\int_0^T i\,dt$ | $\overline{u} = 0$ | $\overline{i} = 0$ |
| **Gleichrichtwert** | $\overline{\lvert u\rvert} = \frac{1}{T}\int_0^T \lvert u\rvert\,dt$ | $\overline{\lvert i\rvert} = \frac{1}{T}\int_0^T \lvert i\rvert\,dt$ | $\overline{\lvert u\rvert} = \frac{2}{\pi}\hat{u}$ | $\overline{\lvert i\rvert} = \frac{2}{\pi}\hat{\imath}$ |
| **Effektivwert**<br>= gleich dem Wert des Gleichstroms | $U\_ = \sqrt{\frac{1}{T}\int_0^T u^2\,dt}$ | $I\_ = \sqrt{\frac{1}{T}\int_0^T i^2\,dt}$ | $U\_ = \frac{\hat{u}}{\sqrt{2}}$ | $I\_ = \frac{\hat{\imath}}{\sqrt{2}}$ |
| Formfaktor | $F = \frac{U\_}{\overline{\lvert u\rvert}} = \frac{I\_}{\overline{\lvert i\rvert}}$ | | $F = \frac{\sqrt{2} * \pi}{2} = 1.11$ | |
| Scheitelfaktor | $\sigma = \frac{\hat{u}}{U} = \frac{\hat{\imath}}{I}$ | | $\sigma = \sqrt{2}$ | |

## Komplexe Darstellung von Sinusgrössen

### Komplexe Zeiger




**Polarform** Drehzeiger

$\underline{u}(t) = \hat{u} * e^{j(\omega t+\varphi_u)}$

$\underline{i}(t) = \hat{\imath} * e^{j(\omega t+\varphi_i)}$

**Polarform** Festzeiger

$\underline{u} = \hat{u} * e^{j\varphi_u}$

$\underline{i} = \hat{\imath} * e^{j\varphi_i}$

**Komponentenform** Drehzeiger

$\underline{u}(t) = \hat{u}\cos(\omega t + \varphi_u) + j * \hat{u}\sin(\omega t + \varphi_u)$

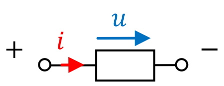
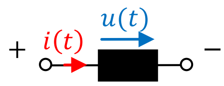
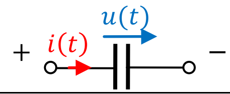
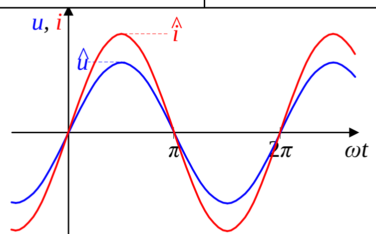
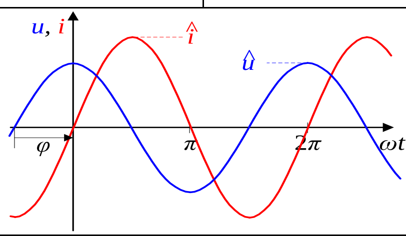
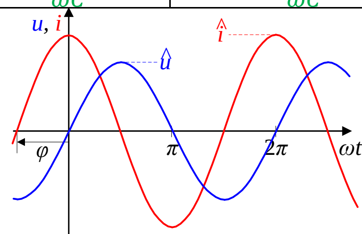
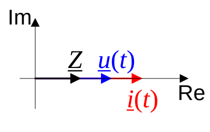
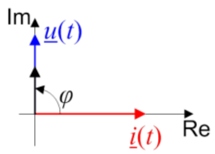
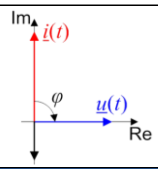
$\underline{i}(t) = \hat{\imath}\cos(\omega t + \varphi_i) + j * \hat{\imath}\sin(\omega t + \varphi_i)$

| | | |
|---|---|---|
| $\underline{u}(t)$ | $\underline{i}(t)$ | Effektivwert |
| $\underline{\hat{u}}$ | $\underline{\hat{\imath}}$ | Scheitelwert |
| $\varphi_u$ | $\varphi_i$ | Startwinkel |
| $e^{j(\omega t)}$ | | Drehfaktor |

## Ideal Bauelemente

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $L$ | *Induktivität* | $[L] = H = \frac{Vs}{A}$ | $R$ | *Widerstand* | $[R] = \Omega$ | $\underline{Z} = \frac{\underline{U}}{\underline{I}} = \frac{1}{\underline{Y}} = \frac{\hat{u}}{\hat{\imath}}$ | *Impedanz* |
| $C$ | *Kapazität* | $[C] = F = \frac{As}{V}$ | $G$ | *Leitwert* | $[G] = S$ | $\underline{Y} = \frac{\underline{I}}{\underline{U}} = \frac{1}{\underline{Z}} = \frac{\hat{\imath}}{\hat{u}}$ | *Admittanz* |

### Übersicht

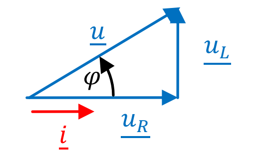
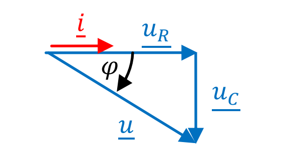
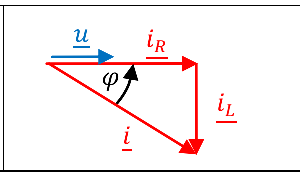
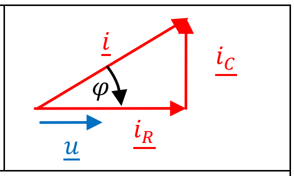
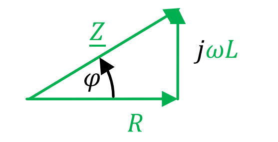
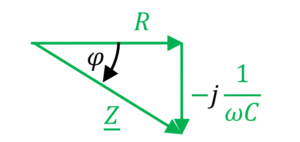
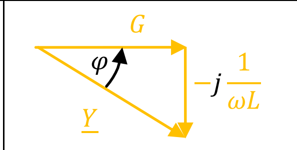
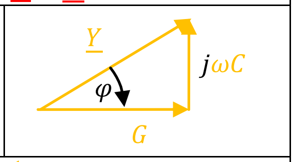
| Ohmscher Widerstand, R | | Ideale Spule, L | | Idealer Kondensator, C | |
|---|---|---|---|---|---|
|   | |   | |   | |
| $R(Widerstand)$ | | $x_L(Blindwiderstand) = \omega L$ | | $x_C(Blindwiderstand) = \frac{-1}{\omega C}$ | |
| $G(Leitwert) = {}^{1}/_{R}$ | | $B_L(Blindleitwert) = -{}^{1}/_{\omega L}$ | | $B_C(Blindleitwert) = \omega C$ | |
| $B = 0\ (ohmisch) = 1/x$ | | $B < 0\ (induktiv)$ | | $B > 0\ (kapazitiv)$ | |
| $u(t) = \hat{u} * \sin(\omega t)$<br>$i(t) = \hat{\imath} * \sin(\omega t)$ | | $u(t) = \hat{u} * \sin(\omega t + \varphi_u)$<br>$i(t) = \hat{\imath} * \sin(\omega t)$ | | $u(t) = \hat{u} * \sin(\omega t)$<br>$i(t) = \hat{\imath} * \sin(\omega t + \varphi_i)$ | |
| $u(t) = R * i(t)$ | | $u(t) = L * \frac{di(t)}{dt}$ | | $i(t) = C * \frac{du(t)}{dt}$ | |
| $\hat{u} = R * \hat{\imath}$ | $\underline{U} = R * \underline{I}$ | $\hat{u} = \omega L * \hat{\imath}$ | $\underline{U} = \omega L * \underline{I}$ | $\hat{u} = \frac{1}{\omega C} * \hat{\imath}$ | $\underline{U} = \frac{1}{\omega C} * \underline{I}$ |
|   | |   | |   | |
| $\varphi_u = \varphi_i$<br>$\varphi = 0$ | $\underline{u}(t) = R * \underline{i}(t)$ | $\varphi = \varphi_u - \varphi_i = \frac{\pi}{2}$ | $\underline{u}(t) = j\omega L * \underline{i}(t)$ | $\varphi_u - \varphi_i = -\frac{\pi}{2}$ | $\underline{u}(t) = j\omega C * \underline{i}(t)$ |
| $\underline{u}(t) = \hat{u} * e^{j\omega t}$ | $\underline{i}(t) = \hat{\imath} * e^{j\omega t}$ | $\underline{u}(t) = L * \frac{d\underline{i}(t)}{dt}$ | $\underline{i}(t) = \hat{\imath} * e^{j\omega t}$ | $\underline{u}(t) = \hat{u} * e^{j\omega t}$ | $\underline{i}(t) = C * \frac{d\underline{u}(t)}{dt}$ |
|   | $\underline{Z} = R = \frac{1}{G}$<br>$\underline{Y} = G = \frac{1}{R}$ |   | $\underline{Z} = jx_L = j\omega L$<br>$\underline{Y} = jB_L = -\frac{j}{\omega L}$ |   | $\underline{Z} = jx_C = -j\frac{1}{\omega C}$<br>$\underline{Y} = jB_C = j\omega C$ |

## Reihenschaltung von R, L und C

| | Ohmscher Widerstand | Ideal Spule | Idealer Kondensator |
|---|---|---|---|
| **Reihenschaltung Serienschaltung** | $u = u_1 + u_2 + \cdots$<br>$i = i_1 = i_2 = \cdots$<br>$R = R_1 + R_2 + \cdots$ | $u(t) = u_1(t) + u_2(t) + \cdots$<br>$L = L_1 + L_2 + \cdots$ | $\frac{du(t)}{dt} = \frac{du_1(t)}{dt} + \frac{du_2(t)}{dt}$<br>$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots$ |
| **Parallelschaltung** | $u = u_1 = u_2 = \cdots$<br>$i = i_1 + i_2 + \cdots$<br>$G = G_1 + G_2 + \cdots$ | $i(t) = i_1(t) + i_2(t) + \cdots$<br>$\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} + \cdots$ | $\frac{dQ(t)}{dt} = \frac{dQ_1(t)}{dt} + \frac{dQ_2(t)}{dt}$<br>$C = C_1 + C_2 + \cdots$ |

### Berechnung von Kreisen mit Widerstand, Spule und Kondensator

| | Reihenschaltung / Serienschaltung $\underline{Z_1} = \underline{Z_2}$ | | Parallelschaltung $\underline{Y_1} = \underline{Y_2}$ | |
|---|---|---|---|---|
| Vergleich | **R + L** | **R + C** | **R + L** | **R + C** |

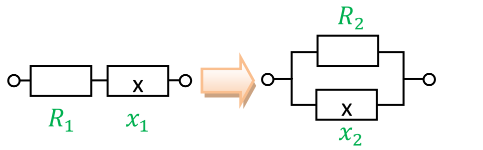
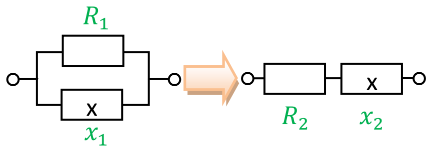
| | | | | |
|---|---|---|---|---|
| Zeigerdiagramm der Spannung der Ströme |  |  |  |  |
| | $\underline{u} = \underline{u}_R + \underline{u}_L + \underline{u}_C$ | | $\underline{i} = \underline{i}_R + \underline{i}_L + \underline{i}_C$ | |
| Widerstands -dreieck<br><br>Leitwert -dreieck |  |  |  |  |
| | $\underline{Z} = R + j\omega L - j\frac{1}{\omega C}$ | | $\underline{Y} = G - j\frac{1}{\omega L} + j\omega C$ | |

## Berechnung mit komplexer Darstellung

| Reelle Funktion aufstellen | in kompl. Darst. umwandeln | Abspaltung des Zeitfaktors $e^{j\omega t}$ |
|---|---|---|
| $u(t) = \hat{u} * \sin(\omega t + \varphi_u)$<br>$i(t) = \hat{\imath} * \sin(\omega t + \varphi_i)$<br>$\sin(\varphi) = \cos\left(\varphi + \frac{\pi}{2}\right)$ | $\underline{u}(t) = \hat{u} * e^{j\omega t + \varphi_u}$<br>$\underline{i}(t) = \hat{\imath} * e^{j\omega t + \varphi_i}$ | $\underline{\hat{u}}(t) = \hat{u} * e^{j\varphi_u}$<br>$\underline{\hat{\imath}}(t) = \hat{\imath} * e^{j\varphi_i}$ |
| **Berechnung der ges. Grösse** | **komplexen Scheitelwert mit Zeitfaktor ergänzen** | **Abspaltung des Imaginär-Teiles** |
| $A = \sqrt{R^2 + X^2}$<br>$\varphi = \tan^{-1}\left(\frac{X}{R}\right)$ | $\underline{u}(t) = \hat{u} * e^{j\omega t + \varphi_u}$<br>$\underline{i}(t) = \hat{\imath} * e^{j\omega t + \varphi_i}$<br>$\underline{u}(t) = A * e^{j\omega t + \varphi}$ | $u(t) = \hat{u} * \sin(\omega t + \varphi_u)$<br>$i(t) = \hat{\imath} * \sin(\omega t + \varphi_i)$<br>$u(t) = A * \sin(\omega t + \varphi)$ |

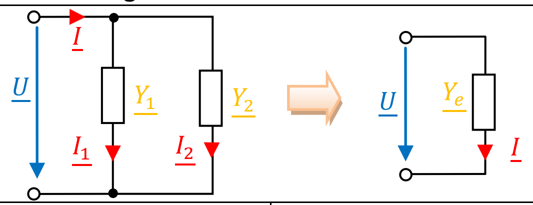
## Umwandlung von Reihen- und Parallelschaltung

**Ansatz: Impedanz und Admittanz bleiben gleich**

| Reihen- in Parallelschaltung | | | Parallel- in Reihenschaltung | | |
|---|---|---|---|---|---|
| Schaltbild |  | | Schaltbild |  | |
| Impedanz | $\underline{Z}_1 = R_1 + jx_1$ | | Admittanz | $\underline{Y}_1 = G_1 + jB_1$ | |
| Admittanz | $\underline{Y}_1 = \frac{1}{\underline{Z}_1} = \frac{1}{R_1 + jx_1}$ | $\underline{Y}_2 = G_2 + jB_2$ | Impedanz | $\underline{Z}_1 = \frac{1}{\underline{Y}_1} = \frac{1}{G_1 + jB_1}$ | $\underline{Z}_2 = R_2 + jx_2$ |
| Admittanz gleichsetzen | $\underline{Y}_1 = \underline{Y}_2$<br>$R_2$ und $x_2$ mit Im() und Re() berechnen | | Impedanz gleichsetzen | $\underline{Z}_1 = \underline{Z}_2$<br>$R_2$ und $x_2$ mit Im() und Re() berechnen | |

### Ersatzschaltung

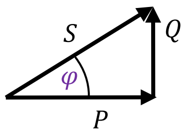
**Allgemeine Parallelschaltung**




$\underline{I} = \underline{I}_1 + \underline{I}_2 = \underline{U} * \underline{Y}_1 + \underline{U} * \underline{Y}_2$

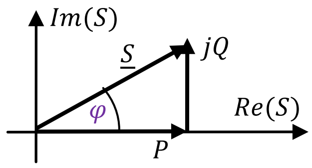
| | | |
|---|---|---|
| $\underline{Y}_1 = G_1 + jB_1$<br>$\underline{Y}_2 = G_2 + jB_2$ | $\underline{Y}_e = G + jB$ | $G = G_1 + G_2$<br>$B = B_1 + B_2$ |

## Leistung im Wechselstromkreis

| | | | |
|---|---|---|---|
| ohmsch-induktiv $Q > 0$  ohmsch-kapazitiv $Q < 0$ | **Leistung** | $p(t) = U * I(\cos\varphi_U - \cos(2\omega t + \varphi))$ | $[p] = W$ |
| | **Wirkleistung** | $P = U * I * \cos\varphi = S * \cos\varphi$ | $[P] = W$ |
| | **Blindleistung** | $Q = U * I * \sin\varphi = S * \sin\varphi$ | $[Q] = 1var$ $(\boldsymbol{v}olt\ \boldsymbol{a}mpere\ \boldsymbol{r}eactive)$ |
| | **Scheinleistung** | $S = U * I = \sqrt{P^2 + Q^2}$ | $[S] = 1VA$ |
| | **Leistungsfaktor** | $\cos\varphi = \frac{P}{S}$ | $[\varphi] = rad$ |

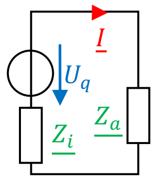


### komplexe Scheinleistung

| Leistungsdreieck | komplexe Scheinleistung |
|---|---|
|  | $\underline{S} = \underline{U} * \underline{I}^* = U * I * e^{-j\varphi_i}$<br>$\underline{S} = S\cos\varphi + j * S\sin\varphi$<br>$\underline{S} = P + jQ$ |

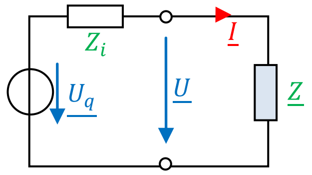
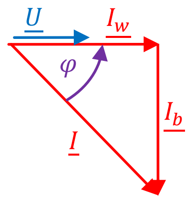
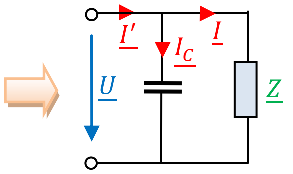
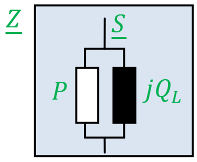
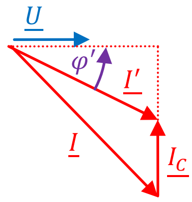


### Wirkleistungsanpassung

| max. Leistung | | |
|---|---|---|
| $\underline{Z_a} = \underline{Z_i}^*$<br>$\underline{Y_a} = \underline{Y_i}^*$ |  | $\underline{Z_i} = R_i + jX_i$ |
| $R_i = R_a$<br>$-X_i = X_a$ | | $\underline{Z_a} = R_a + jX_a$ |

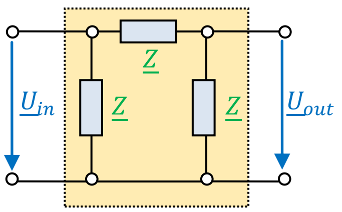


### Blindleistungskompensation

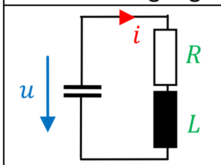
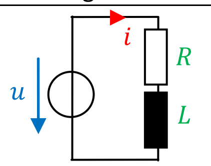
| | | | |
|---|---|---|---|
|  |  | $\underline{I_w}$ | Wirkstrom |
| | | $\underline{I_b}$ | Blindstrom |
| | | $\underline{I}$ (wird kleiner zu) $\underline{I'}$<br>$P = R_i * I^2$ (wird kleiner)<br>$\varphi$ (wird kleiner zu) $\varphi'$ | |
| Parallelschaltung eines Kondensators   |  | $C = \frac{I_w(\tan\varphi - \tan\varphi')}{U * \omega}$<br>$P = I_w * U$ | |



## Tief- und Hochpass, Übertragungsfunktionen

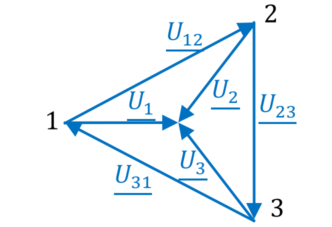
| **Vierpol** | | | | |
|---|---|---|---|---|
|  | $\underline{G}(f) = \frac{\underline{U}_{out}}{\underline{U}_{in}}$ | $\underline{G}(f)$ | Übertragungsfunktion | $[\underline{G}(f)] = (\dots)$ |
| | $VdB = 20\log\left\lvert\frac{\underline{U}_{out}}{\underline{U}_{in}}\right\rvert$ | $VdB$ | Übertragungsmass | $[VdB] = dB$ |
| | $G(f_g) = \frac{1}{\sqrt{2}} * G(f_{max})$ | $f_g$ | Grenzfrequenz | $[f_g] = Hz$ |
| **Tiefpass** | lässt tiefe Frequenzen passieren | | | |
| **Hochpass** | lässt hohe Frequenzen passieren | | | |
| **Bandpass** | (Kombination) lässt nur ein gewisse Bandbreite passieren | | | |

## Schwingkreise

| Freie Schwingung | Erzwungene Schwingung |
|---|---|
|  |  |

# Drehstromtechnik

## Zeigerdiagramm

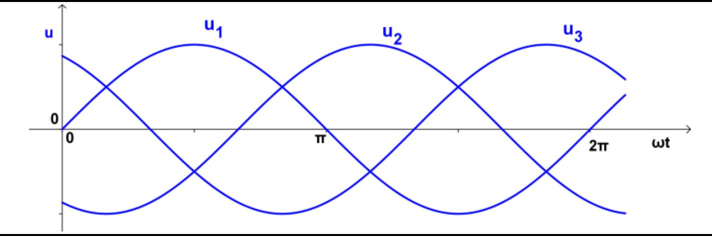



$$\underline{U}_{12} = \underline{U}_1 - \underline{U}_2$$
$$\underline{U}_{23} = \underline{U}_2 - \underline{U}_3$$
$$\underline{U}_{31} = \underline{U}_3 - \underline{U}_1$$

$$\underline{U}_{12} + \underline{U}_{23} + \underline{U}_{31} = 0$$

$$U_{12} + U_{23} + U_{31} \neq 0$$

## Liniendiagramm



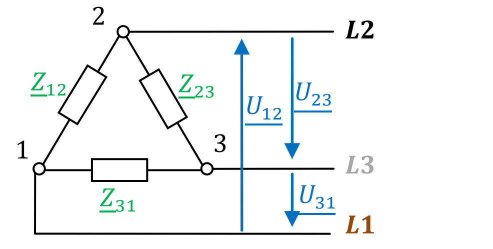

$$U_1 = U_2 = U_3 = U_{st} = 230V$$
$$U_{12} = U_{23} = U_{31} = U = 400V$$

$$\underline{U}_1 = U_1 * e^{j0}$$
$$\underline{U}_2 = U_2 * e^{j-\frac{2\pi}{3}}$$
$$\underline{U}_3 = U_3 * e^{j\frac{2\pi}{3}}$$

$$u_1 = \hat{u}_1 * \sin(\omega t)$$
$$u_2 = \hat{u}_2 * \sin(\omega t - 120°)$$
$$u_3 = \hat{u}_3 * \sin(\omega t - 240°)$$

$$\hat{u} = 230V * \sqrt{2}$$
$$\omega = 314s^{-1}$$

## Dreieckschaltung




| | |
|---|---|
| N | Knotenpunkt |
| N | Neutralleiter |
| $L1, L2, L3$ | Aussenleiter |
| $U_1, U_2, U_3$ | Strangspannungen |
| $U_{St}$ | Sternspannungen |
| $U_{12}, U_{23}, U_{31}, U$ | Aussenleiter-spannungen |

| | |
|---|---|
| Verkettete Spannung<br>$U_L$ | = Strangspannungen<br>$= U_\Delta = U_{Str}$ |
| Aussenleiterstrom<br>$I_L$ | $= \sqrt{3}$ Strangstrom<br>$= \sqrt{3} * I_\Delta = \sqrt{3} * I_{Str}$ |

### Symmetrische Last

$$\underline{Z}_{12} = \underline{Z}_{23} = \underline{Z}_{31} = \underline{Z} = \frac{1}{\underline{Y}}$$
$$\underline{I}_{12} = \underline{U}_{12} * \underline{Y}$$

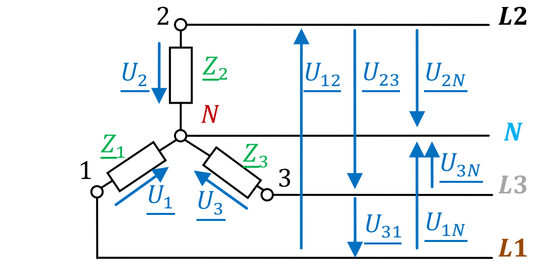
$$I_{12} = I_{23} = I_{31} = I_{Str}$$
$$I_1 = I_2 = I_3 = \sqrt{3} * I_{str}$$
$$\underline{I}_1 = \underline{I}_{12} - \underline{I}_{31}$$

### Unsymmetrische Last

$$\underline{I}_{12} = \underline{U}_{12} * \underline{Y}_{12}$$
$$\underline{I}_{23} = \underline{U}_{23} * \underline{Y}_{23}$$
$$\underline{I}_{31} = \underline{U}_{31} * \underline{Y}_{31}$$

$$\underline{I}_1 = \underline{I}_{12} - \underline{I}_{31}$$
$$\underline{I}_2 = \underline{I}_{23} - \underline{I}_{12}$$
$$\underline{I}_3 = \underline{I}_{31} - \underline{I}_{23}$$

## Sternschaltung




| | |
|---|---|
| Verkettete Spannung<br>$U_L$ | $= \sqrt{3}$ Strangspannungen<br>$= \sqrt{3} * U_\curlywedge$ |
| Aussenleiterstrom<br>$I_L$ | = Strangstrom<br>$= I_\curlywedge = I_{Str}$ |

### Mit Neutralleiter

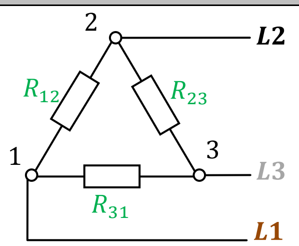
| symmetrisch | unsymmetrisch |
|---|---|
| $\underline{Z}_1 = \underline{Z}_2 = \underline{Z}_3 = \underline{Z}$<br>$\underline{I}_1 + \underline{I}_2 + \underline{I}_3 = \underline{I}_N = 0$ | $\underline{I}_1 = \underline{U}_1 * \underline{Y}_1$<br>$\underline{I}_1 + \underline{I}_2 + \underline{I}_3 = \underline{I}_N$ |

### Ohne Neutralleiter

$$\underline{I}_N = \underline{I}_1 + \underline{I}_2 + \underline{I}_3 = 0$$
$$\underline{I}_1 = \left(\underline{U}_1 - \underline{U}_N\right) * \underline{Y}_1$$

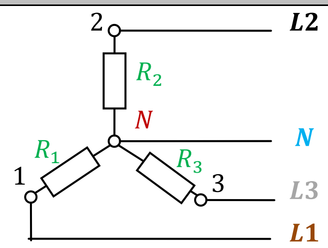
$$\underline{U}_N = \frac{\underline{U}_1 * \underline{Y}_1 + \underline{U}_2 * \underline{Y}_2 + \underline{U}_3 * \underline{Y}_3}{\underline{Y}_1 + \underline{Y}_2 + \underline{Y}_3}$$

## Stern in Dreieck




| unsymmetrisch | symmetrisch |
|---|---|
| $R_{12} = R_1 + R_2 + \frac{R_1 R_2}{R_3}$<br>$R_{23} = R_2 + R_3 + \frac{R_2 R_3}{R_1}$<br>$R_{31} = R_3 + R_1 + \frac{R_3 R_1}{R_2}$ | $R_{12} = R_{23} = R_{31} = R_\curlywedge$<br>$R_\Delta = 3 * R_\curlywedge$ |

## Dreieck in Stern




| unsymmetrisch | symmetrisch |
|---|---|
| $R_1 = \frac{R_{12} * R_{31}}{R_{12} + R_{23} + R_{31}}$<br>$R_2 = \frac{R_{23} * R_{12}}{R_{12} + R_{23} + R_{31}}$<br>$R_3 = \frac{R_{31} * R_{23}}{R_{12} + R_{23} + R_{31}}$ | $R_{12} = R_{23} = R_{31} = R_\Delta$<br>$R_\curlywedge = \frac{R_\Delta}{3}$ |

## Leistung im Dreiphasensystem

### Allgemein

| | |
|---|---|
| $\underline{S} = \sum (P_{Str} + jQ_{Str})$ | $\underline{S}_{Str} = \underline{U}_{Str} * \underline{I}_{Str}^*$ |

### Symmetrische Last

| | Dreieckschaltung | Sternschaltung |
|---|---|---|
| Strangwirkleistung | $P_{Str} = U_L * I_{Str} * \cos\varphi$ | $P_{Str} = U_{Str} * I_L * \cos\varphi$ |
| Gesamtwirkleistung | $P_{ges} = \sqrt{3} * U_L * I_L * \cos\varphi$ | |
| Gesamtscheinleistung | $S_{ges} = \sqrt{3} * U_L * I_L$ | |
| Gesamtblindleistung | $Q_{ges} = \sqrt{3} * U_L * I_L * \sin\varphi$ | |

### Unsymmetrische Last

| | |
|---|---|
| **Dreieckslast** | $\underline{S}_{ges} = \underline{U}_{12} * \underline{I}_{12}^* + \underline{U}_{23} * \underline{I}_{23}^* + \underline{U}_{31} * \underline{I}_{31}^*$<br>$P_{ges} = U_{12} * I_{12} * \cos\varphi_{12} + U_{23} * I_{23} * \cos\varphi_{23} + U_{31} * I_{31} * \cos\varphi_{31}$ |
| **Sternschaltung mit Neutralleiter** | $\underline{S}_{ges} = \underline{U}_1 * \underline{I}_1^* + \underline{U}_2 * \underline{I}_2^* + \underline{U}_3 * \underline{I}_3^*$<br>$P_{ges} = U_1 * I_1 * \cos\varphi_1 + U_2 * I_2 * \cos\varphi_2 + U_3 * I_3 * \cos\varphi_3$ |
| **Sternschaltung ohne Neutralleiter** | $\underline{S}_{ges} = \underline{U}_1' * \underline{I}_1^* + \underline{U}_2' * \underline{I}_2^* + \underline{U}_3' * \underline{I}_3^*$<br>$P_{ges} = U_1' * I_1 * \cos\varphi_1' + U_2' * I_2 * \cos\varphi_2' + U_3' * I_3 * \cos\varphi_3'$ |