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EUROPÄISCHES INSTITUT FÜR ENERGIEFORSCHUNG  
INSTITUT EUROPEEN DE RECHERCHE SUR L'ENERGIE  
EUROPEAN INSTITUTE FOR ENERGY RESEARCH

# Elektrisches System

KIT

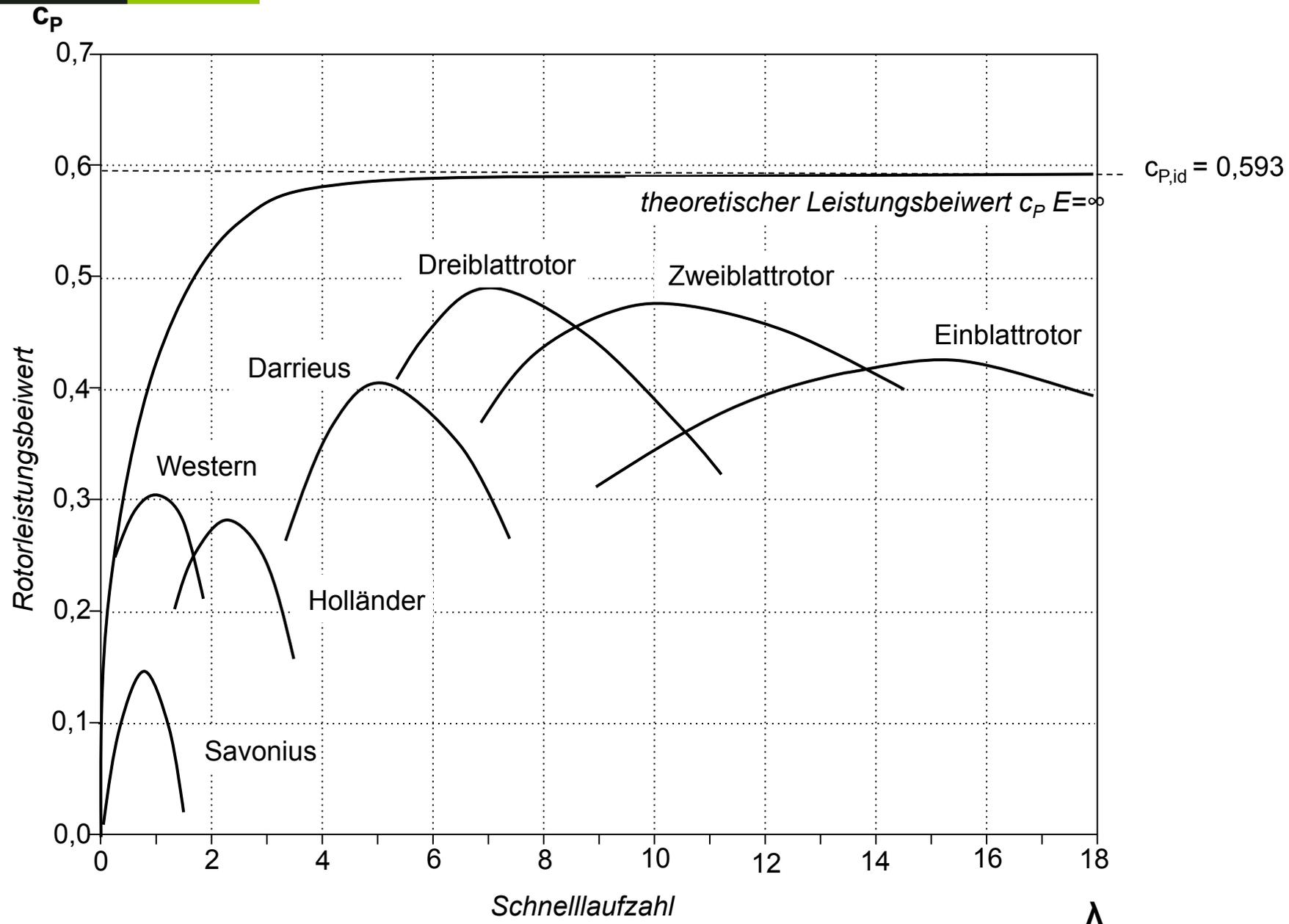




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# Betz

Leistungsbeiwerte / Lamda

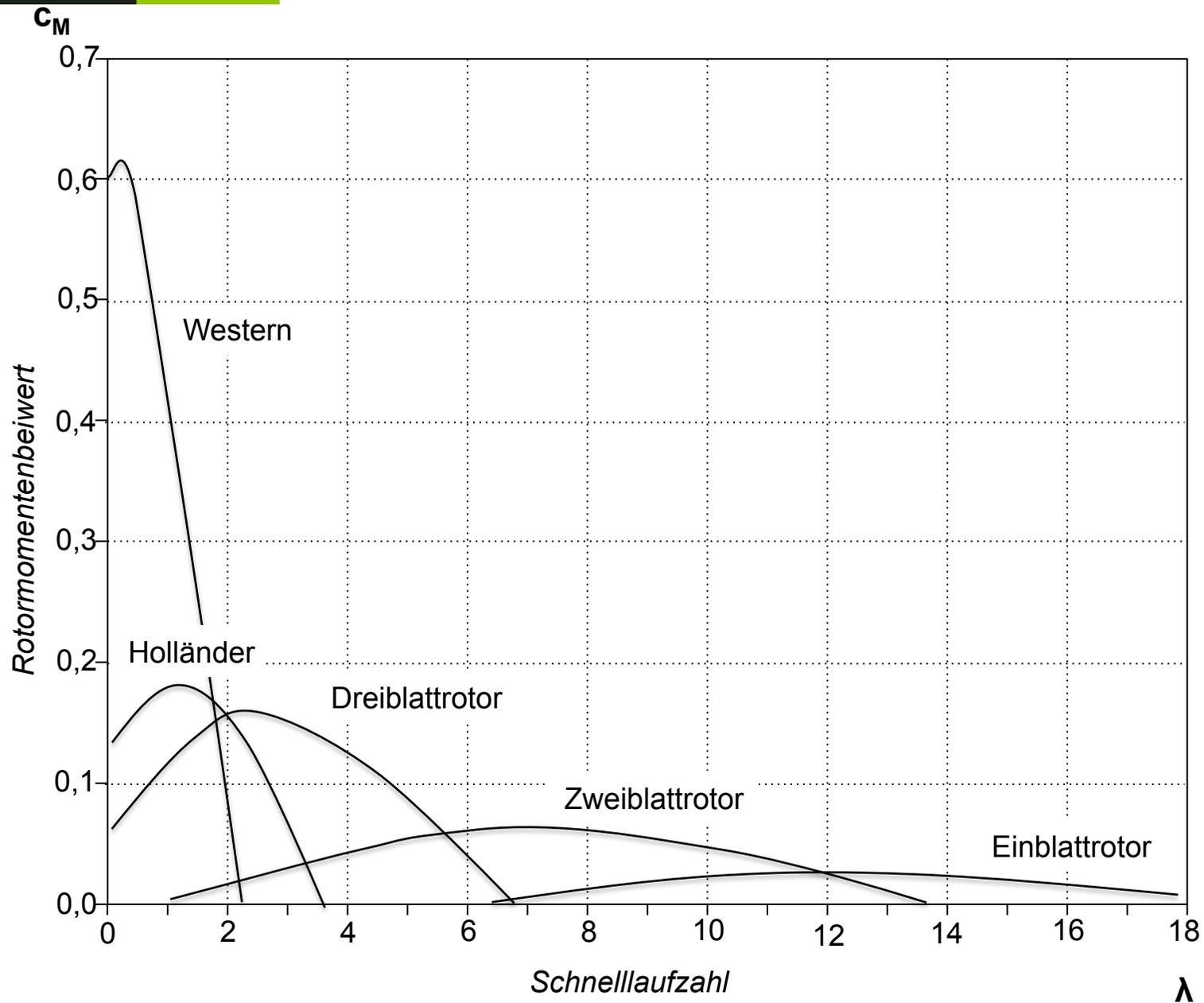




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# Betz

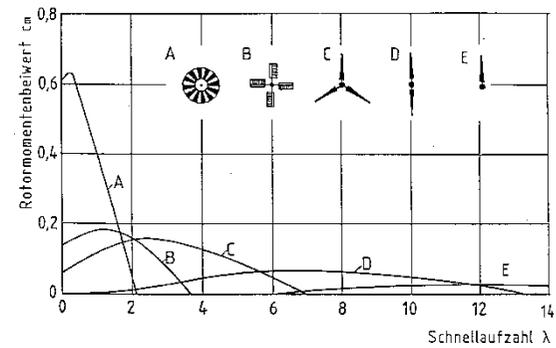
Momentenbeiwerte

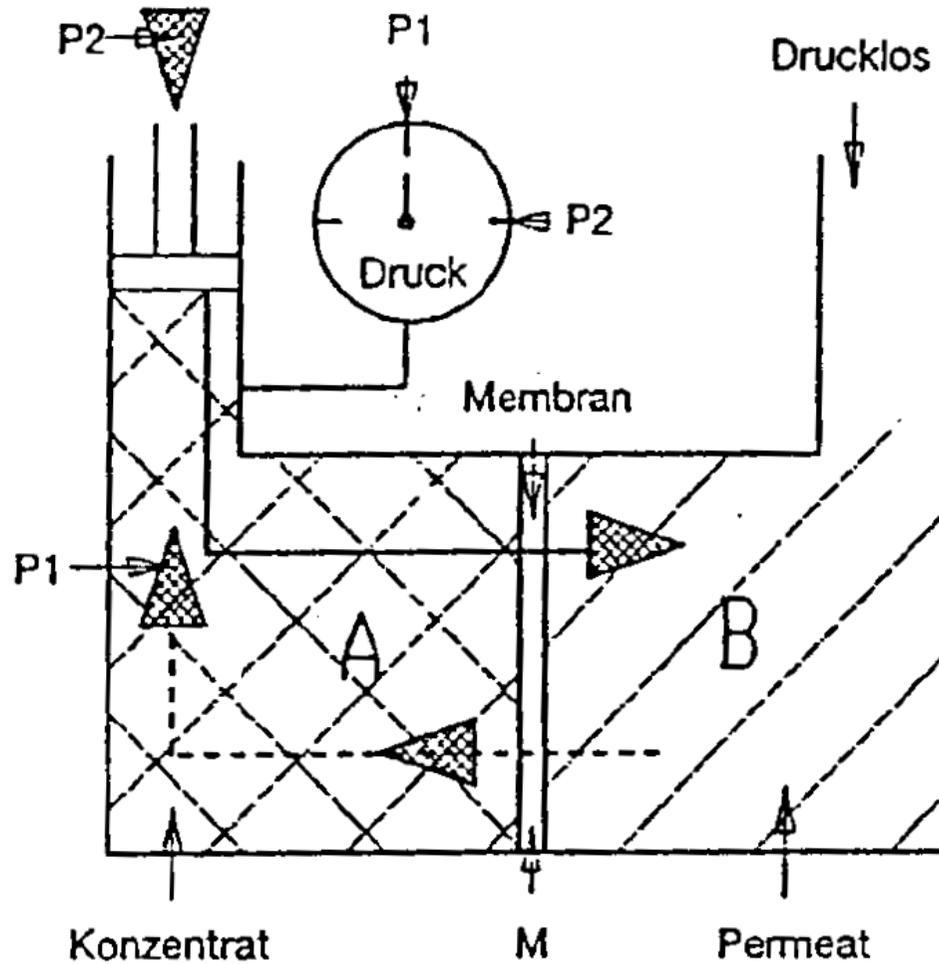




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# Anwendung Pumpen



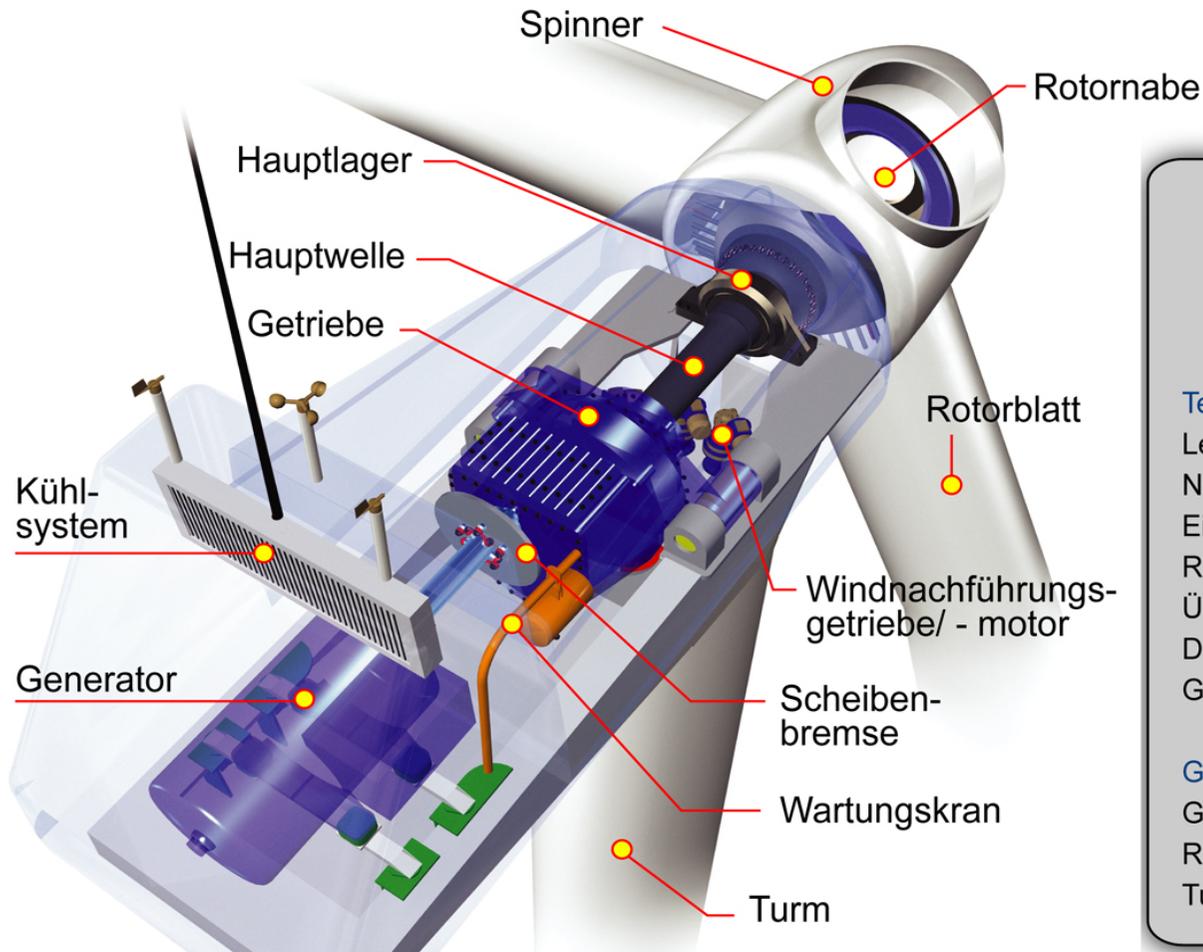




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# Aufbau

## Triebstrang – Klassischer Aufbau



### Modell NEG Micon 52/900 - technische Daten -

#### Technik

|                         |                        |
|-------------------------|------------------------|
| Leistung                | : 900 kw               |
| Nennwindgeschwindigkeit | : 16,0 m/s             |
| Einschaltwindgeschw.    | : 3,5 m/s              |
| Rotordurchmesser        | : 52,0 m               |
| Überstrichene Fläche    | : 2.140 m <sup>2</sup> |
| Drehzahl                | : 15-22 U/min          |
| Generator               | : asynchron            |

#### Gewicht

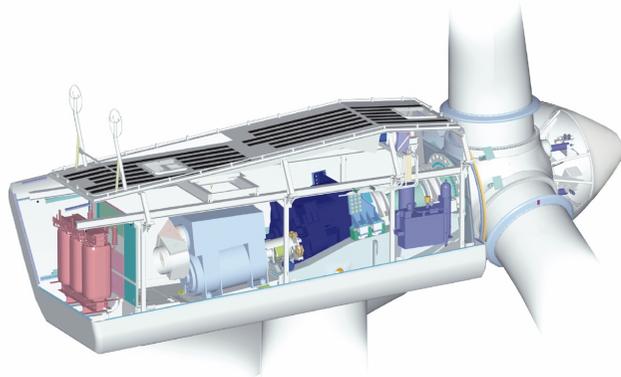
|                       |          |
|-----------------------|----------|
| Gondel                | : 26,5 t |
| Rotor (incl. Nabe)    | : 16,5 t |
| Turm (74m, Stahlrohr) | : 97,0 t |



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# Aufbau

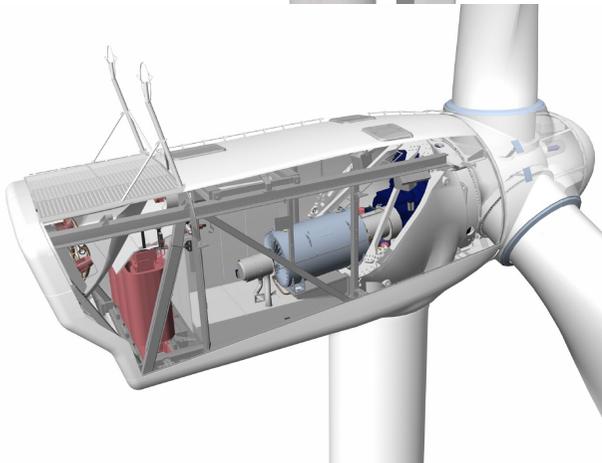
## Triebstrang - Integration



Vestas V80 - aufgelöst



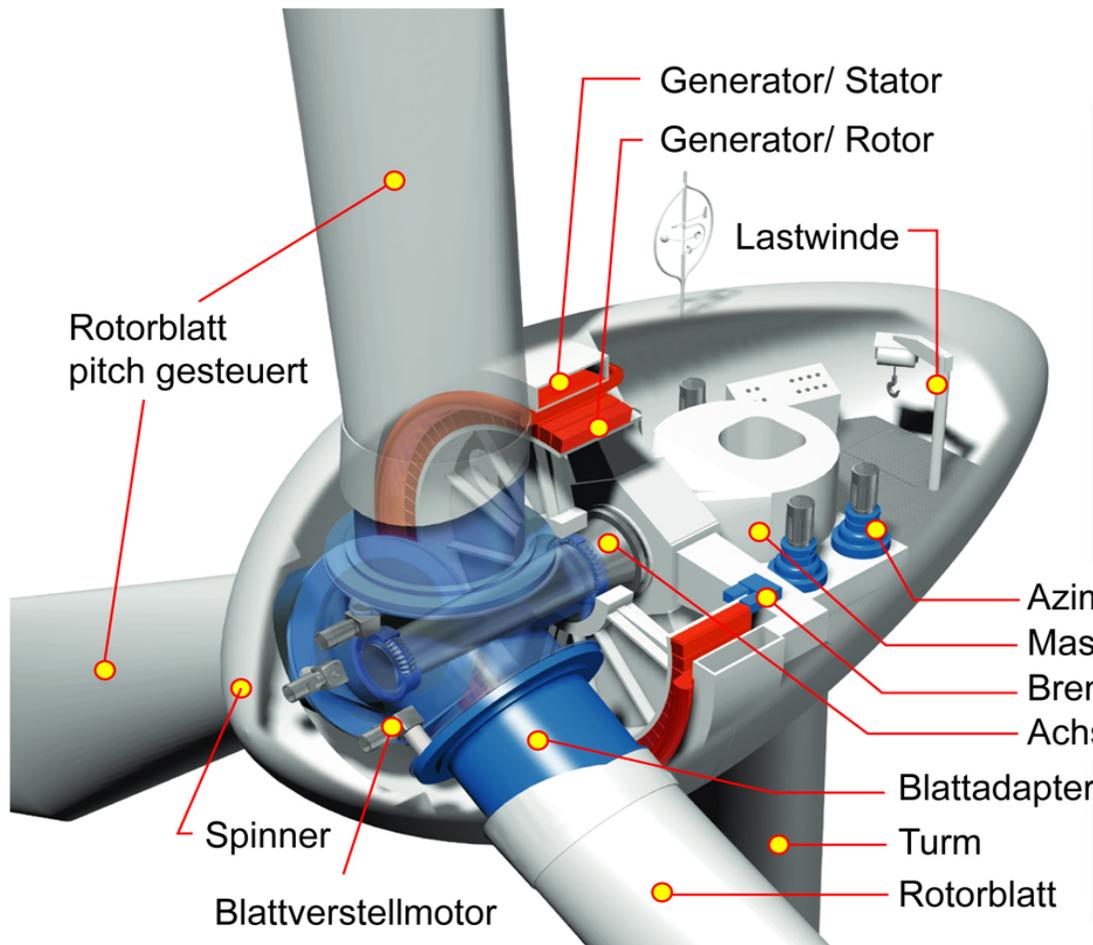
Nordex N54 - teilintegriert



Vestas V90 - integriert



# Aufbau Triebstrang - Getriebeles



## Modell Enercon E-66 - technische Daten -

### Technik

|                         |                        |
|-------------------------|------------------------|
| Leistung                | : 1,8 MW               |
| Nennwindgeschwindigkeit | : 12,0 m/s             |
| Einschaltwindgeschw.    | : 2,5 m/s              |
| Rotordurchmesser        | : 70,0 m               |
| Überstrichene Fläche    | : 3.848 m <sup>2</sup> |
| Drehzahl                | : 10-22 U/min          |

|           |                           |
|-----------|---------------------------|
| Generator | : synchron, Ringgenerator |
| Getriebe  | : ohne                    |

### Gewicht

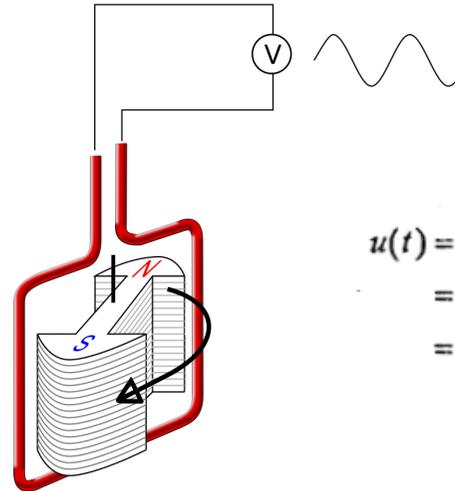
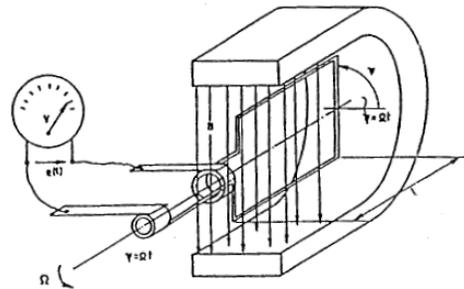
|                       |          |
|-----------------------|----------|
| Gondel                | : 68,8 t |
| Rotor (incl. Nabe)    | : 31,7 t |
| Turm (98m, Beton)     | : 861 t  |
| Turm (86m, Stahlrohr) | : 219 t  |



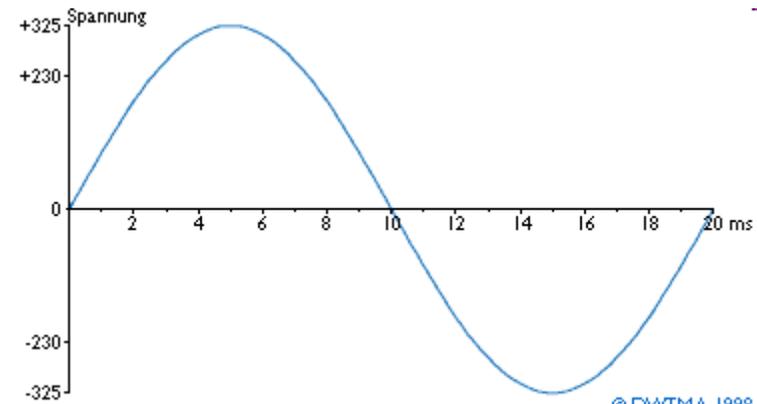
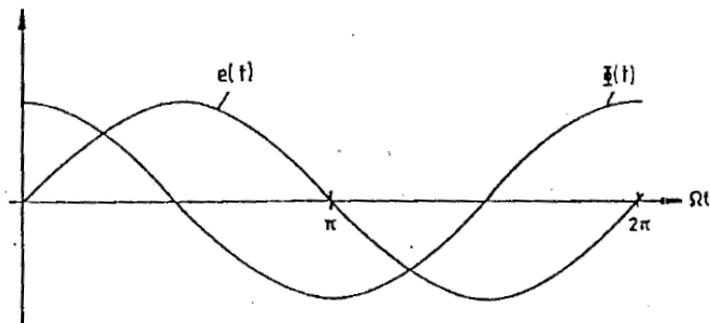
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# Elektrisches System

## Dynamomaschine



$$\begin{aligned}u(t) &= B \cdot \ell \cdot v(t) \\ &= B \cdot 2\ell \cdot r \cdot \omega \cdot \sin \omega t \\ &= U_s \cdot \sin \omega t\end{aligned}$$





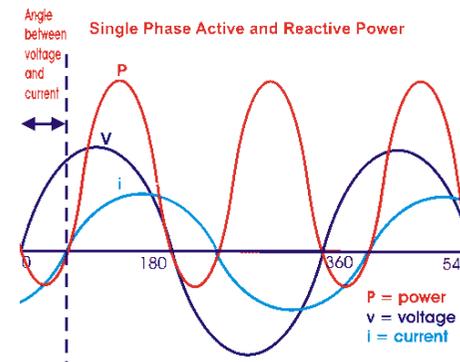
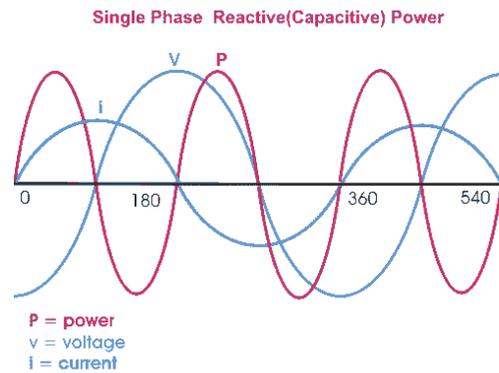
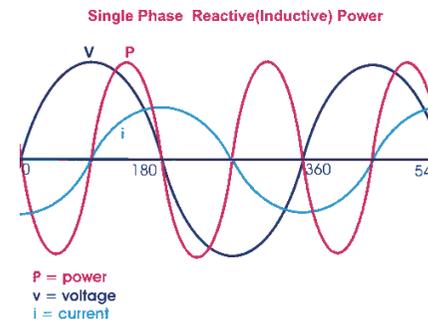
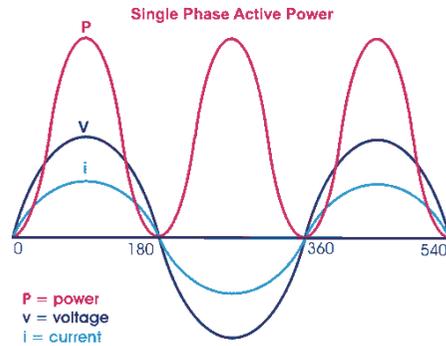
# Elektrisches Systeme

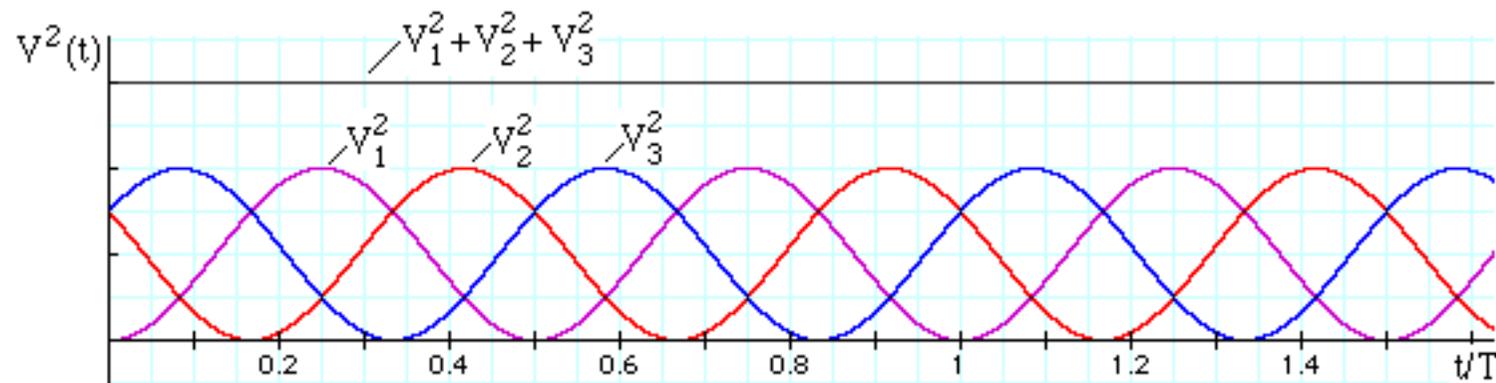
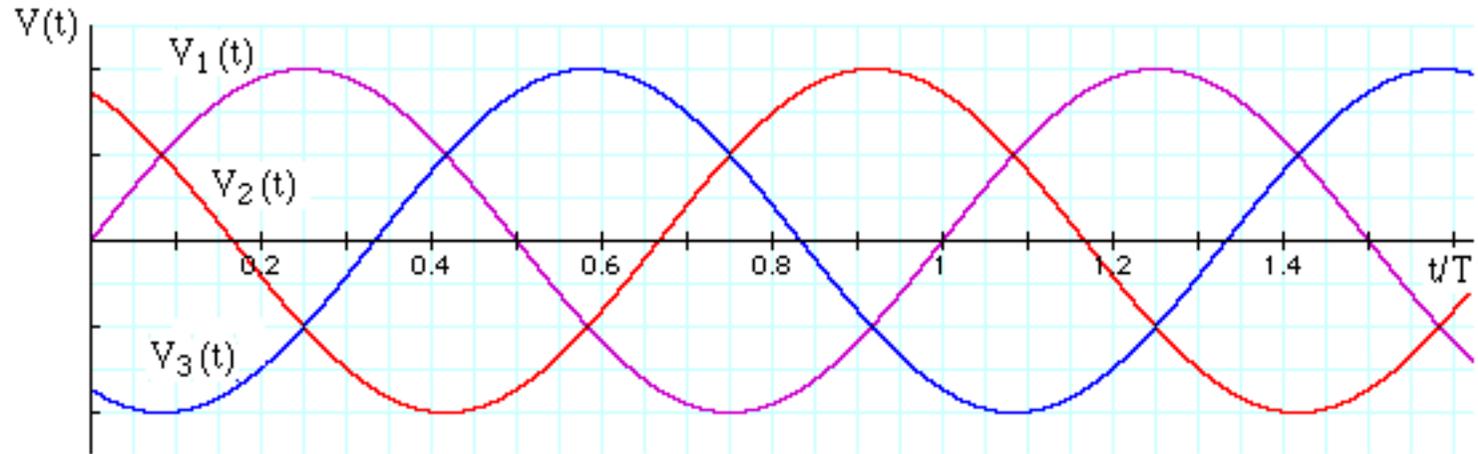
## Quellspannung und magnetischer Fluss (Wirk- Blindleistung)

$$u(t) = U_s \cdot \sin \omega t$$

$$i(t) = I_W \cdot \sin \omega t + I_B \cdot \cos \omega t$$

$$P(t) = U_s \cdot I_W \cdot \sin^2 \omega t + U_s \cdot I_B \cdot \sin \omega t \cdot \cos \omega t$$

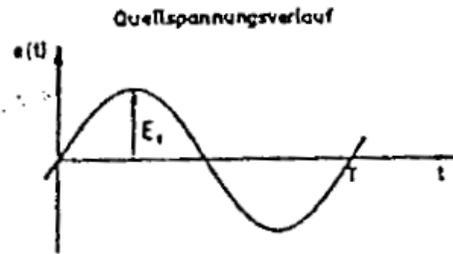






# Elektrisches System

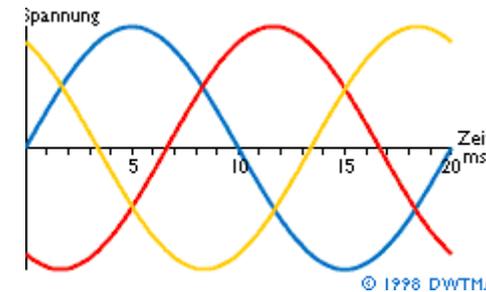
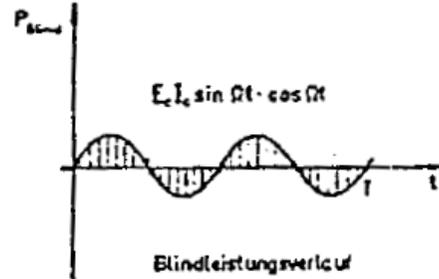
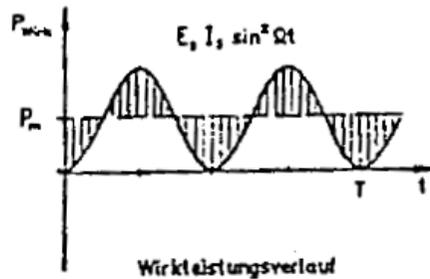
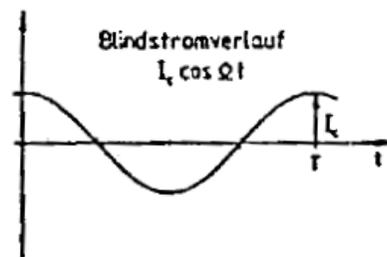
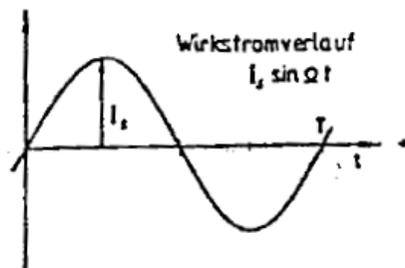
## Wirk- und Blindleistung / Drehstrom



$$u(t) = U_S \cdot \sin \omega t$$

$$i(t) = I_W \cdot \sin \omega t + I_B \cdot \cos \omega t$$

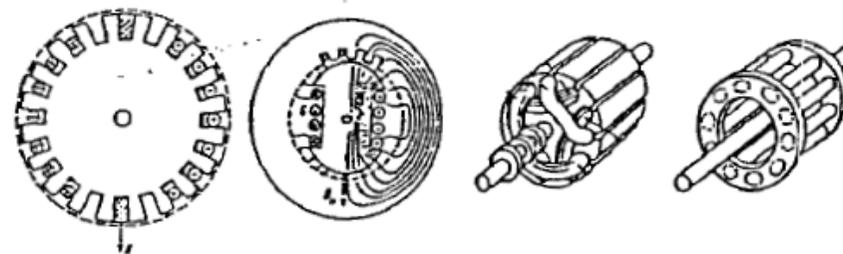
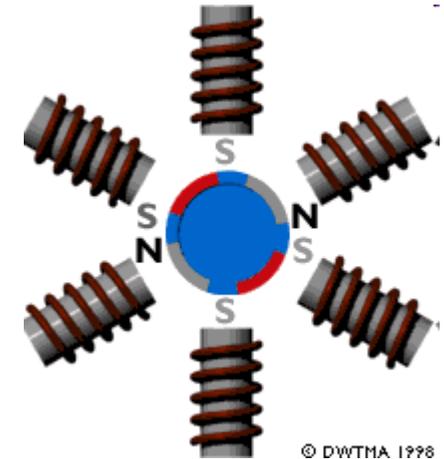
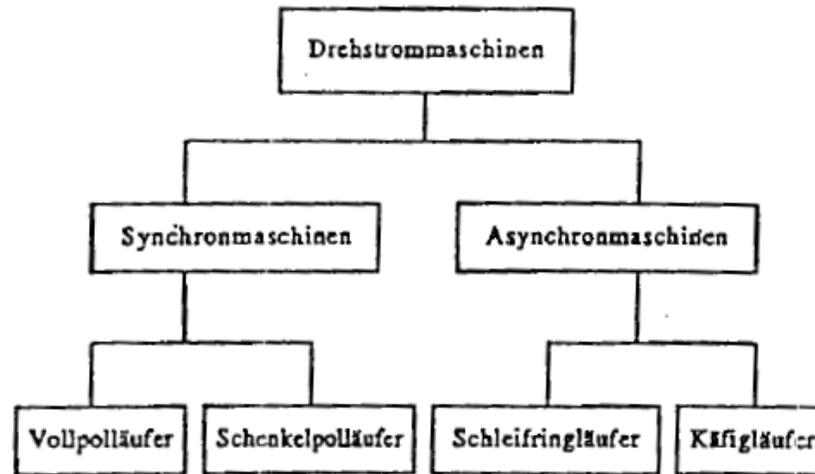
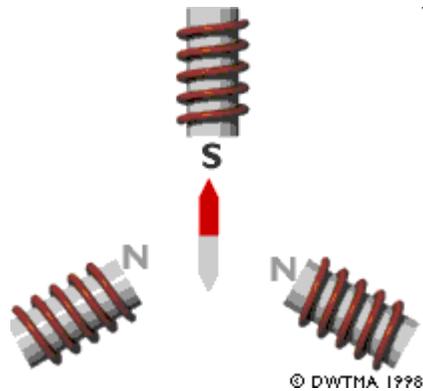
$$P(t) = U_S \cdot I_W \cdot \sin^2 \omega t + U_S \cdot I_B \cdot \sin \omega t \cdot \cos \omega t$$





# Elektrisches System

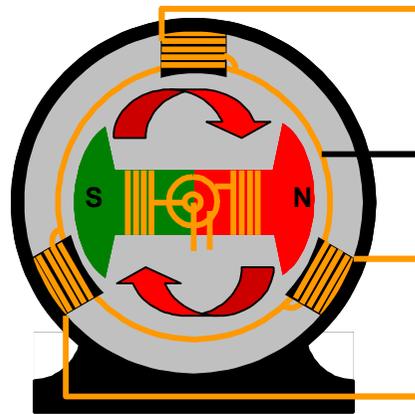
## Generatortypen



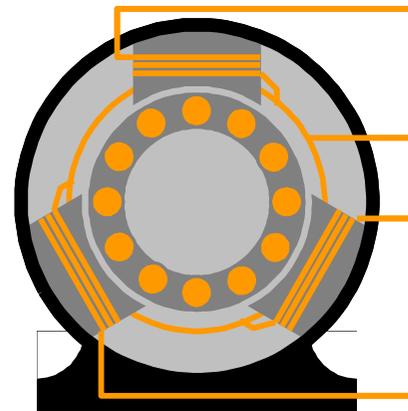


# Elektrisches System

## Generatoren



synchron



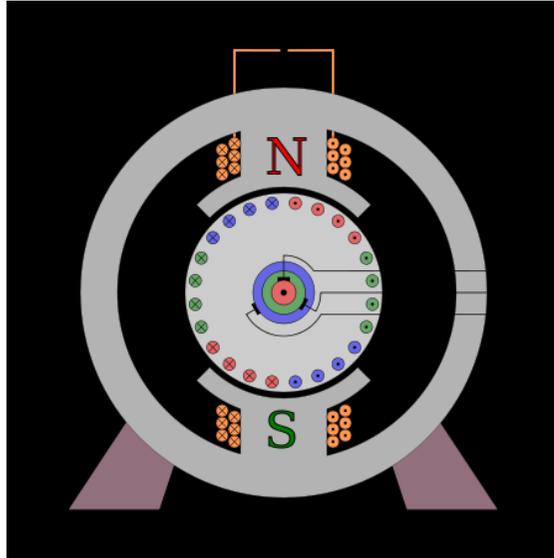
asynchron



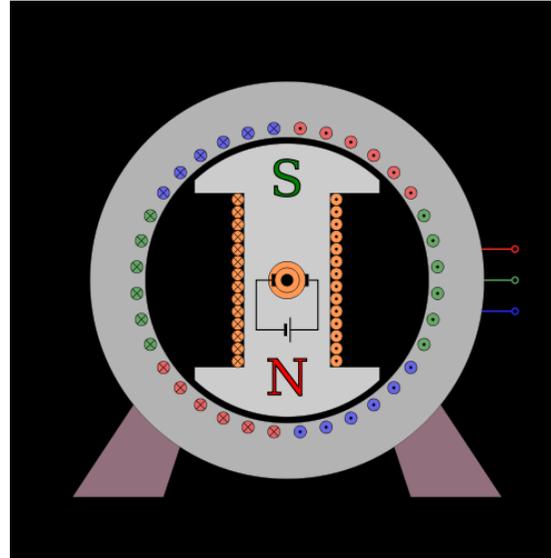
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# Elektrisches System

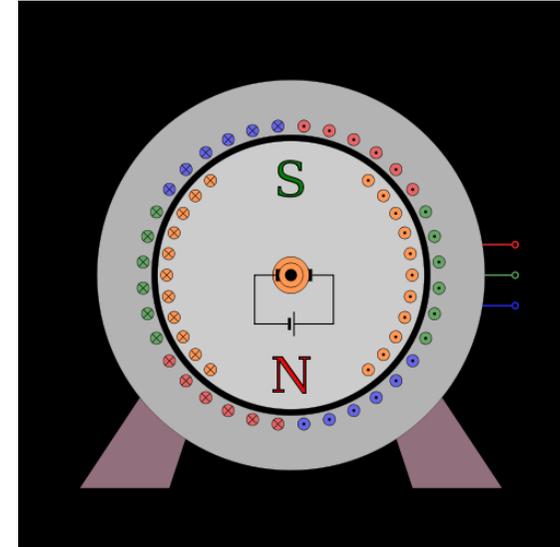
## Synchrongeneratoren



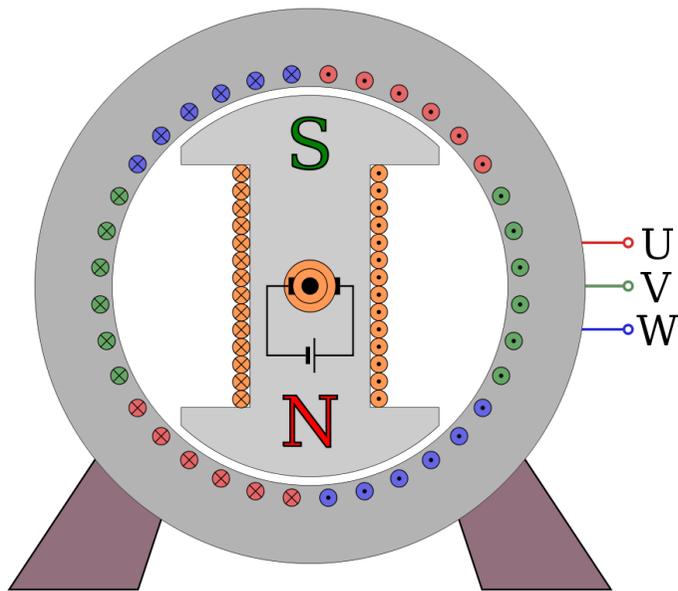
Außenpolmaschine  
Schenkelpol



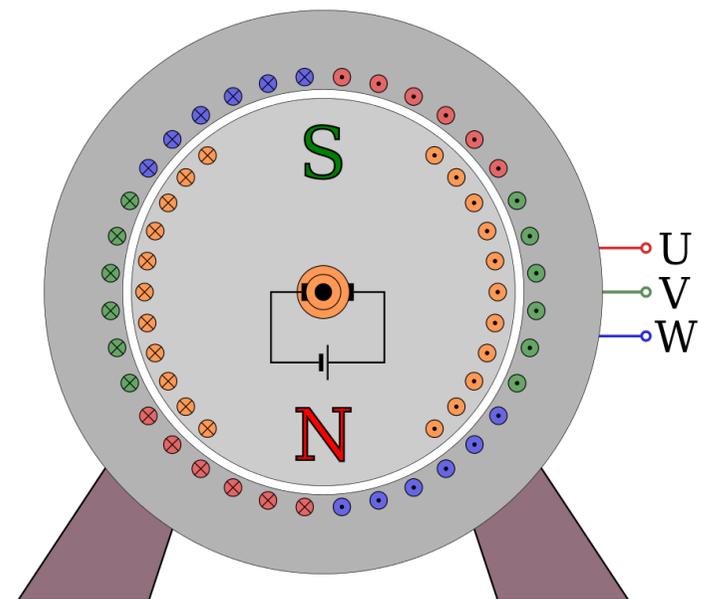
Innenpolmaschine  
Schenkelpol



Innenpolmaschine  
Vollpol



Innenpolmaschine  
Schenkelpol

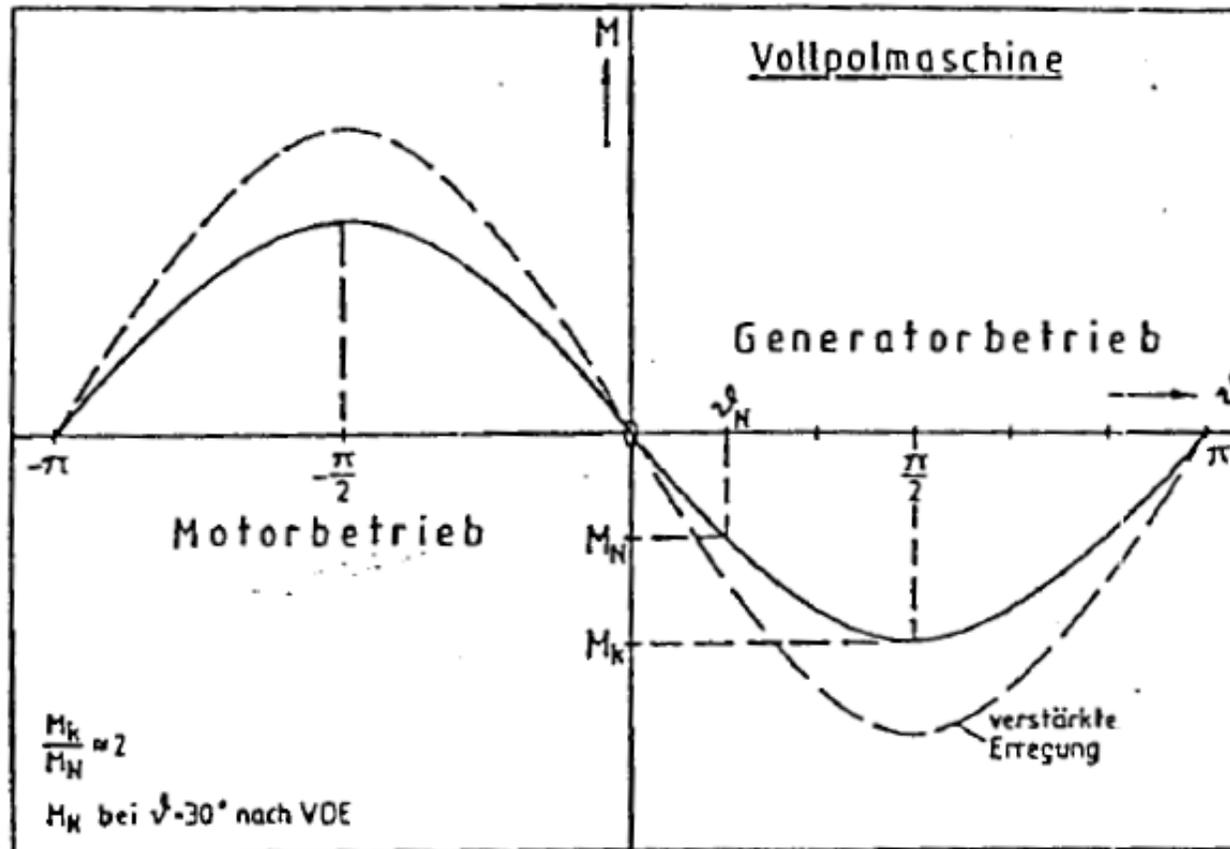


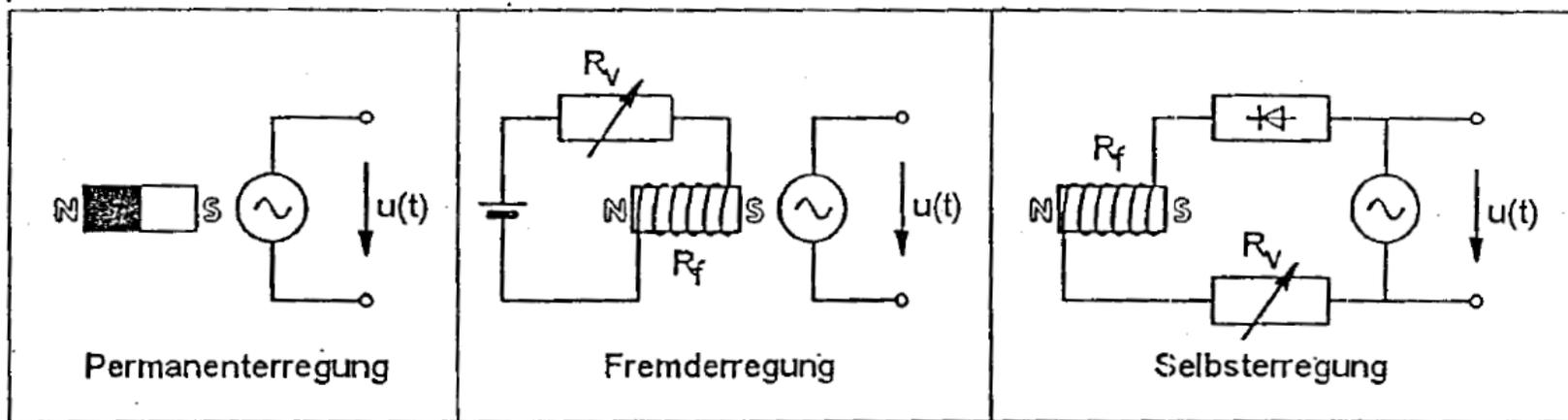
Innenpolmaschine  
Vollpol



# Elektrisches System

## Synchronmaschine - Momentenkurve







- **Getriebe ?**

$$n_s = \frac{60 \cdot f}{p}$$

$n_s$  = Rotordrehzahl [U / min]

$f$  = Netzfrequenz [Hz]

$p$  = Anzahl **Polpaare**

- **Beispiele:**

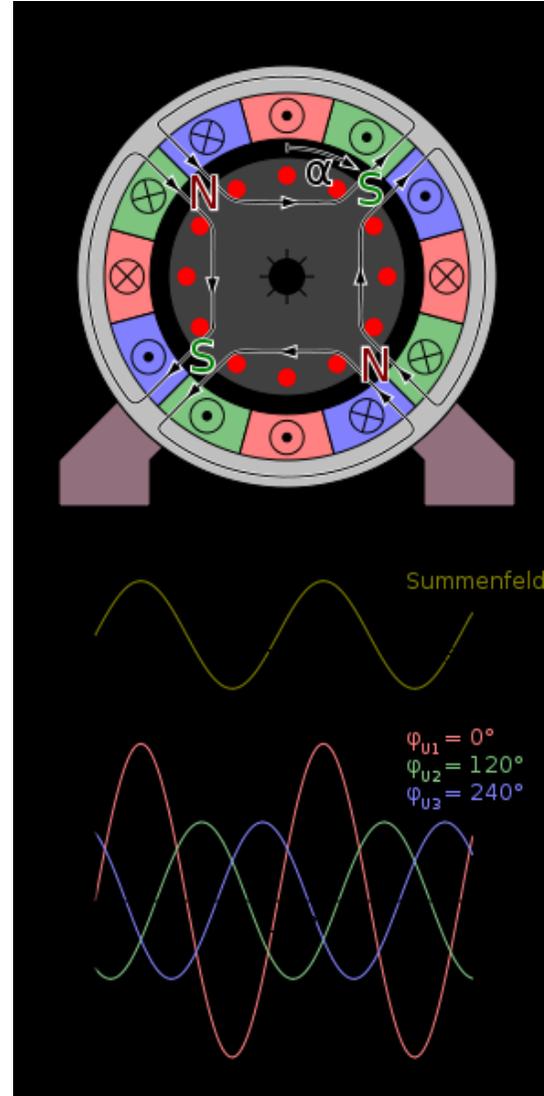
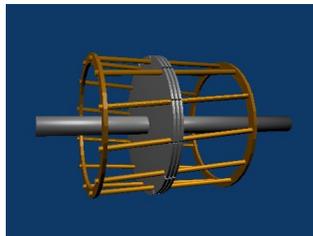
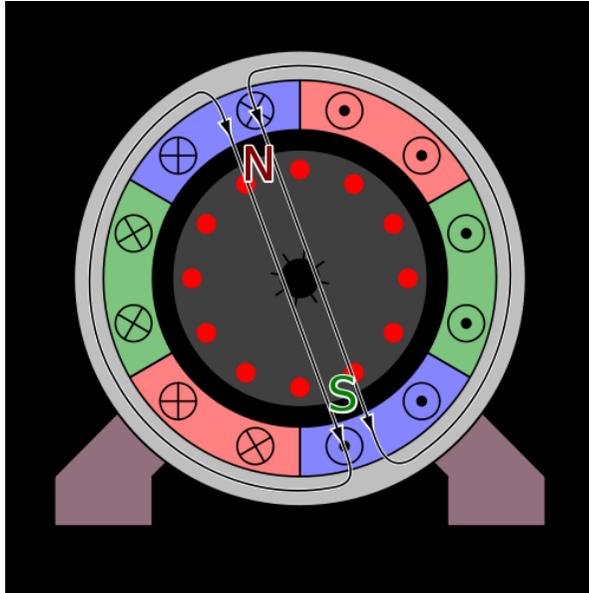
- 1 Polpaar und 50 Hz resultieren in 3.000 U/min
- 1 Polpaar und 60 Hz resultieren in 3.600 U/min
- Rotorrehzahl ca. 15-35 U/min



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# Elektrisches System

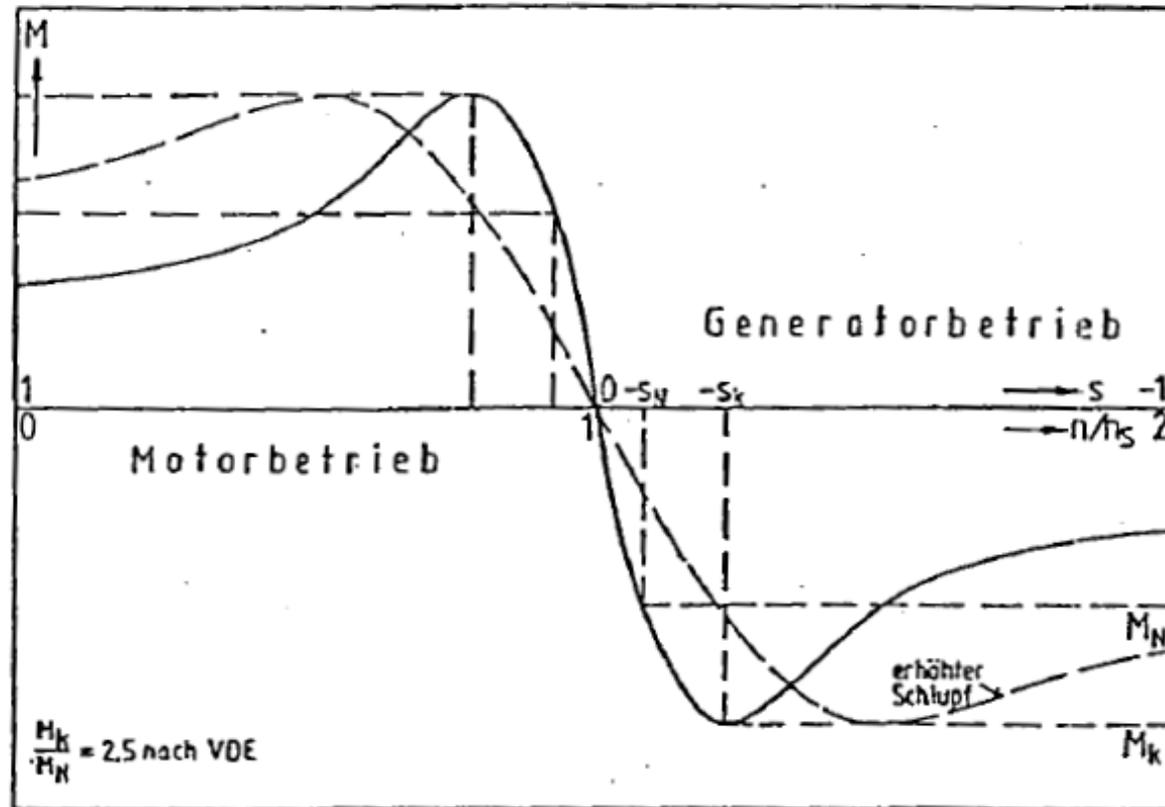
## Asynchrongeneratoren





# Elektrisches System

## Asynchronmaschine - Momentenkurve



$$\text{Schlupf } s = \frac{n_s}{n_f} = \frac{n_f - n}{n_f} \quad [100\%]$$

$$n_{sym} = \frac{f_{Netz}}{p} = \frac{50 \text{ Hz}}{2} = 25 \frac{1}{s} = 1500 \frac{U}{min}$$



# Elektrisches System

## Synchron – Asynchron / Vor- Nachteile

|                     | <i>synchronous</i> | <i>asynchronous</i> | <i>remark</i>                               |
|---------------------|--------------------|---------------------|---|
| Effizienz           | ++                 | +                   | <i>ASG Schlupf</i>                          |
| Kosten              | +                  | ++                  | <i>ASG Massenprodukt</i>                    |
| Wartung             | o                  | ++                  | <i>ASG Käfigläufer</i>                      |
| Blindleistung       | ++                 | -                   | <i>ASG benötigt Blindleistung</i>           |
| Netz Kopplung       | o                  | +                   | <i>SG Synchronisierereinrichtung</i>        |
| Netzaufbau          | ++                 | -                   | <i>SG Bereitsstellung von Blindleistung</i> |
| Leistungselektronik | ++                 | o                   | <i>SG einfachere Leistungselektronik</i>    |

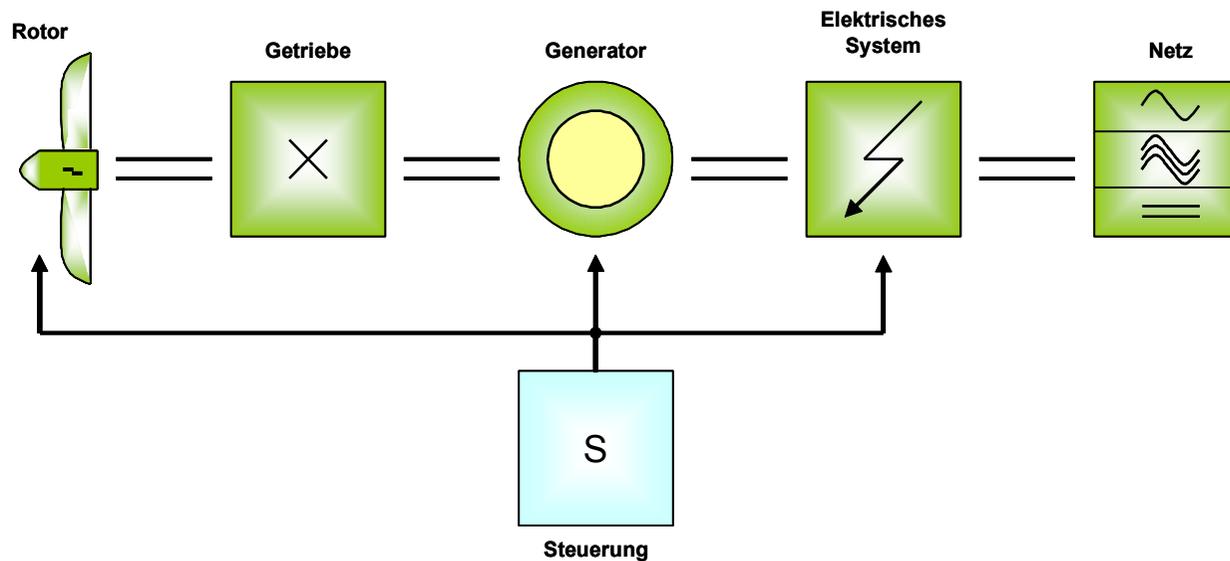
- Der Einsatz von Leistungselektronik kann die Vor- und Nachteile der einzelnen Generatortypen relativieren, wenn nicht gar aufheben.



# Elektrisches System

## Allgemeiner Aufbau

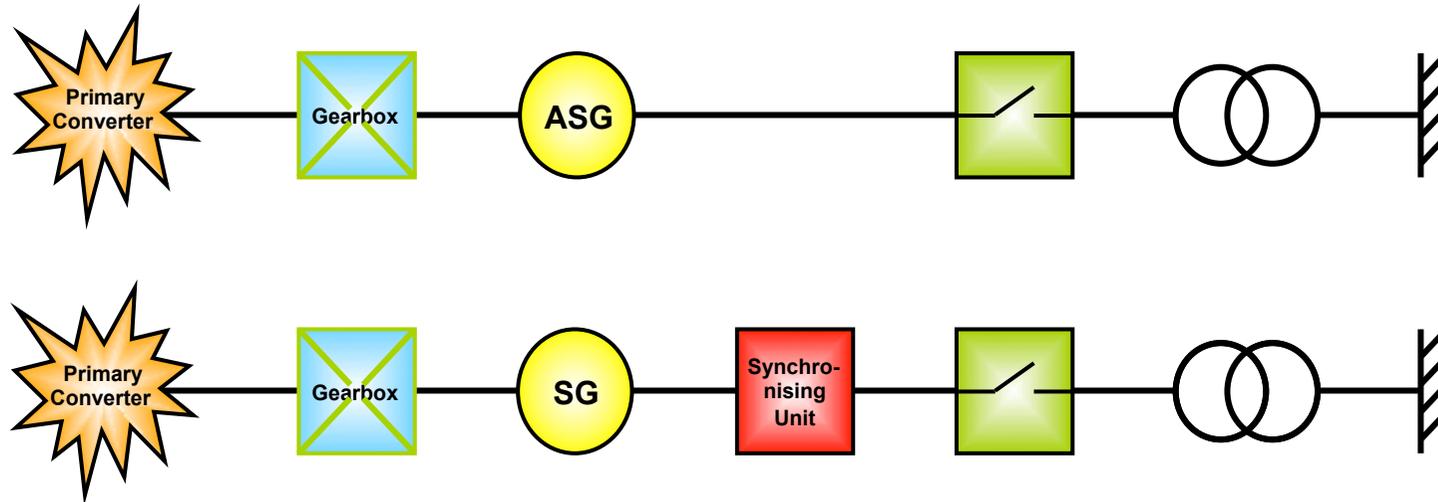
| $v \geq 5 \text{ m/s}$                       | <i>min</i> | <i>max</i> |
|--|------------|------------|
| Spezifische Investitionskosten               | 800 €/kW   | 1300 €/kW  |
| Spezifische Investitionskosten (Kleinanlage) | 1100 €/kW  | 2500 €/kW  |
| Volllaststunden (Küste, Bergkuppe)           | 2000 h     | 2500 h     |
| Volllaststunden (Binnenland)                 | 1000 h     | 1500 h     |
| Spezifische Energiekosten (Küste)            | 0.04 €/kWh | 0.08 €/kWh |
| Spezifische Energiekosten (Binnenland)       | 0.11 €/kWh | 0.13 €/kWh |
| Spezifische Energiekosten (Kleinanlage)      | 0.12 €/kWh | 0.20 €/kWh |





# Elektrisches System

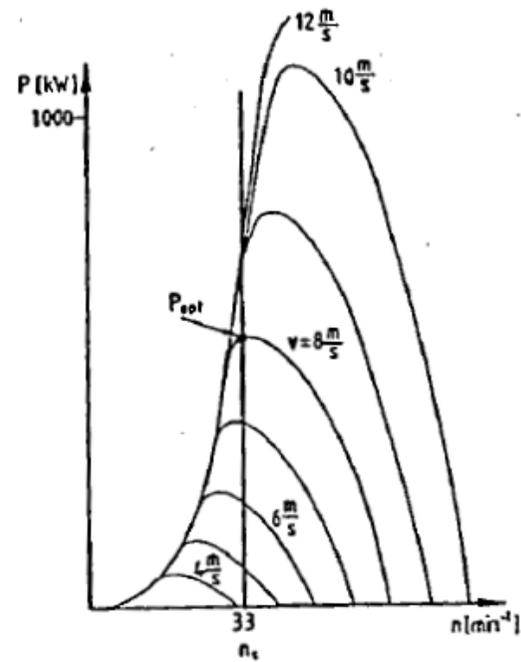
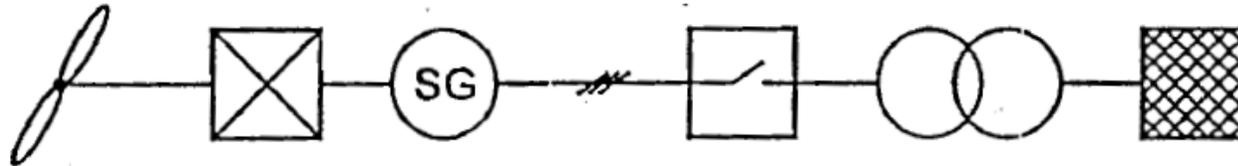
## Netzanbindung





# Elektrisches System

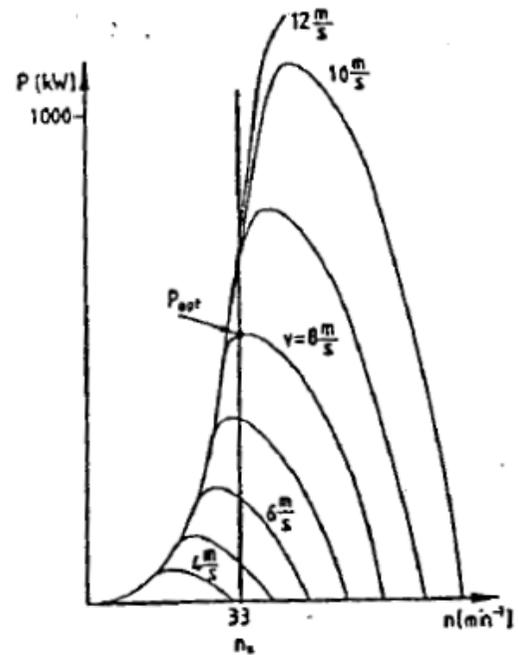
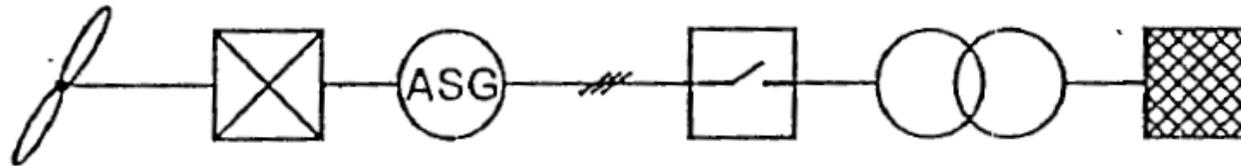
## Drehzahlfeste Kopplung - Synchronmaschine





# Elektrisches System

## Drehzahlfeste Kopplung - Asynchronmaschine

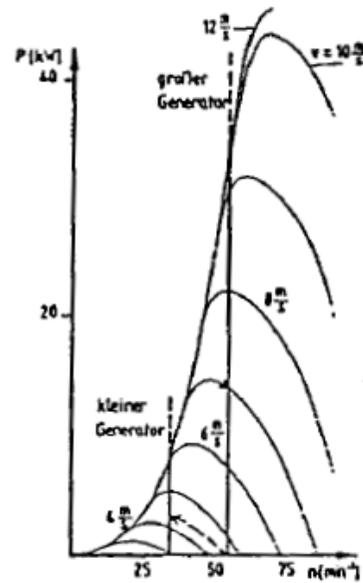
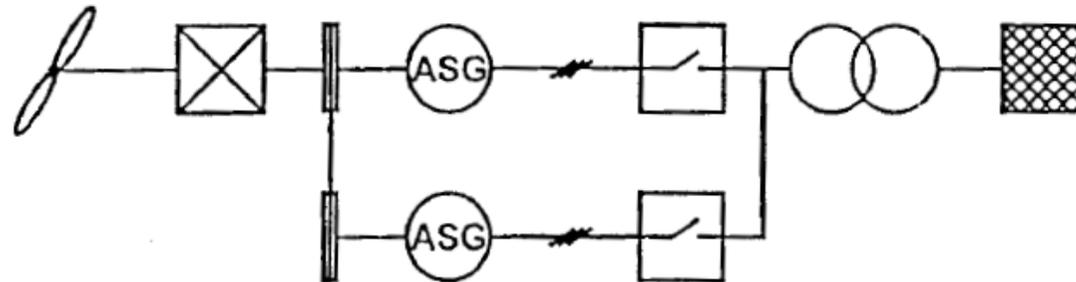




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# Elektrisches System

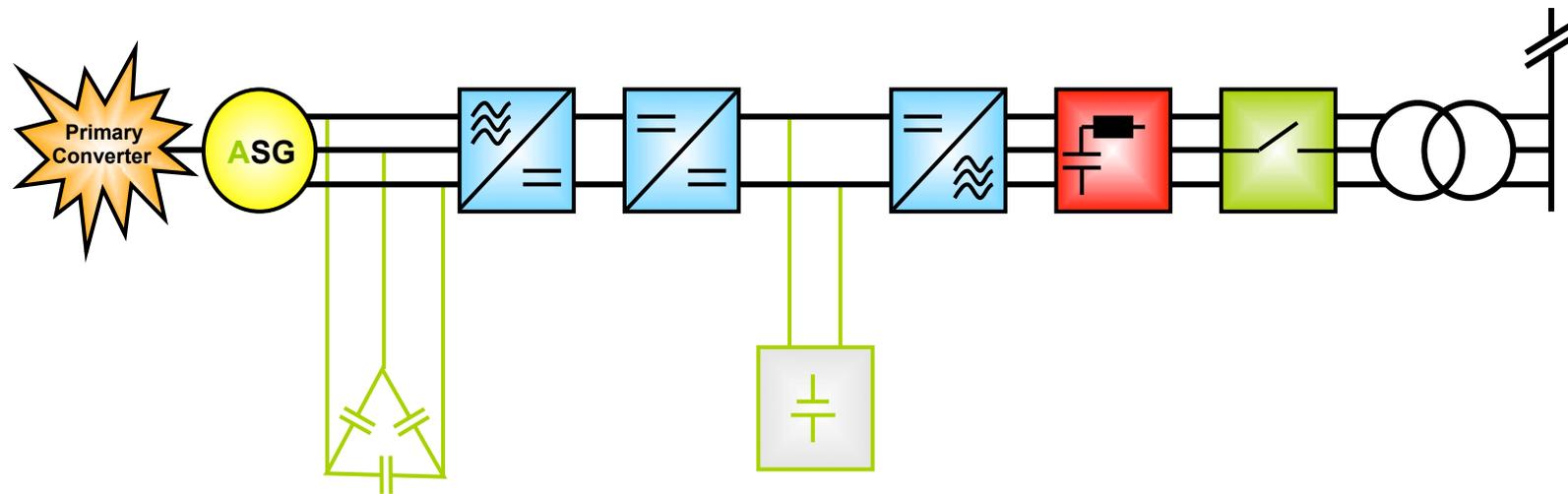
Drehzahlgestufte Kopplung – Dänisches Modell





# Elektrisches System

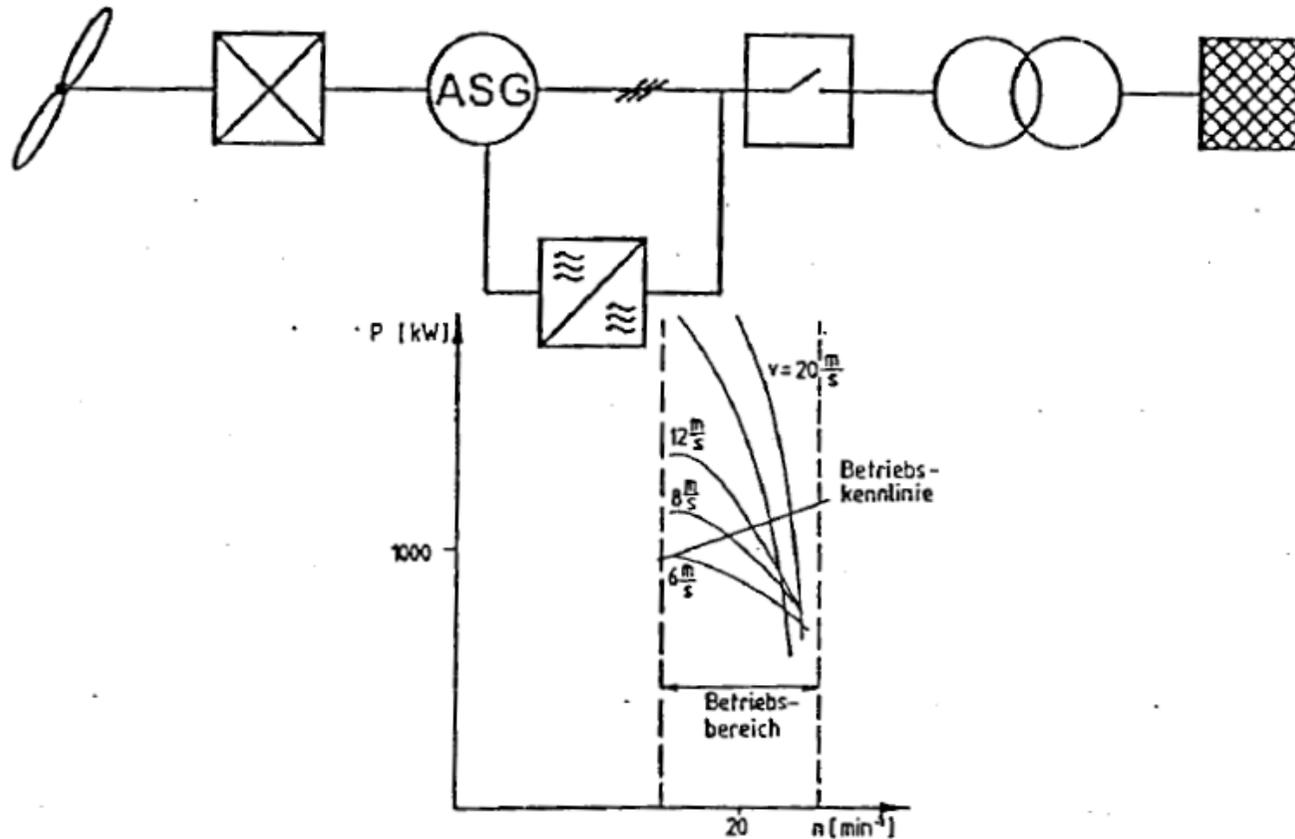
Komplexe Kopplung





# Elektrisches System

## Drehzahlvariabel – Doppelt gespeister Asynchrongenerator

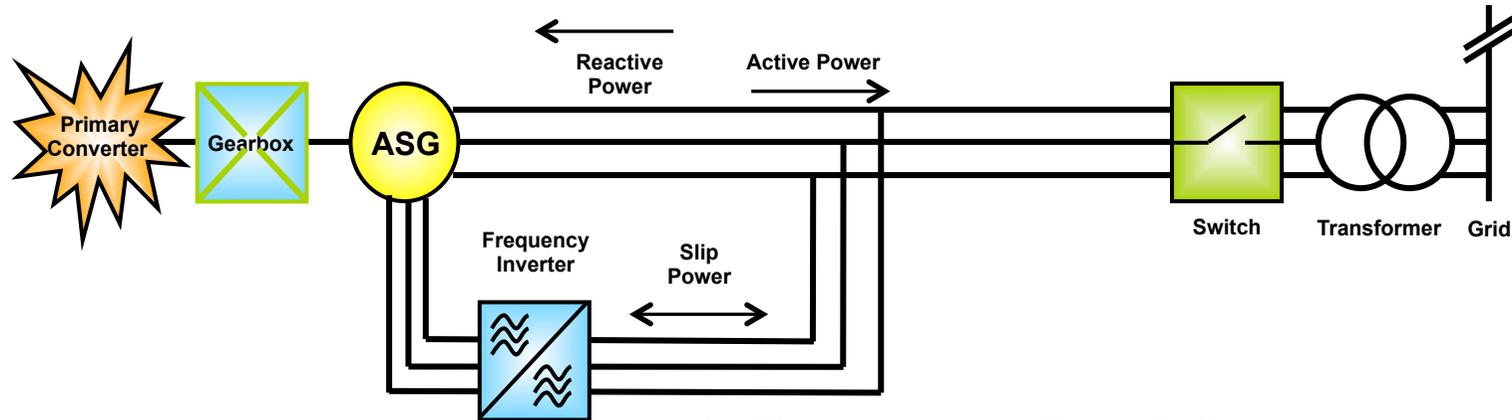




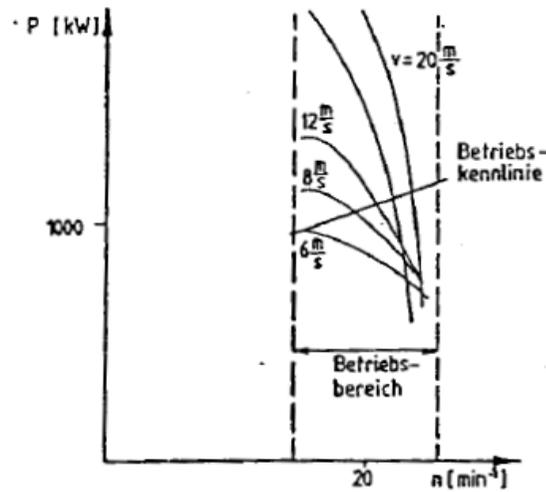
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# Elektrisches System

Drehzahlvariabel – Doppelt gespeister Asynchrongenerator



## Aufbau einer Gondel - mit Getriebe



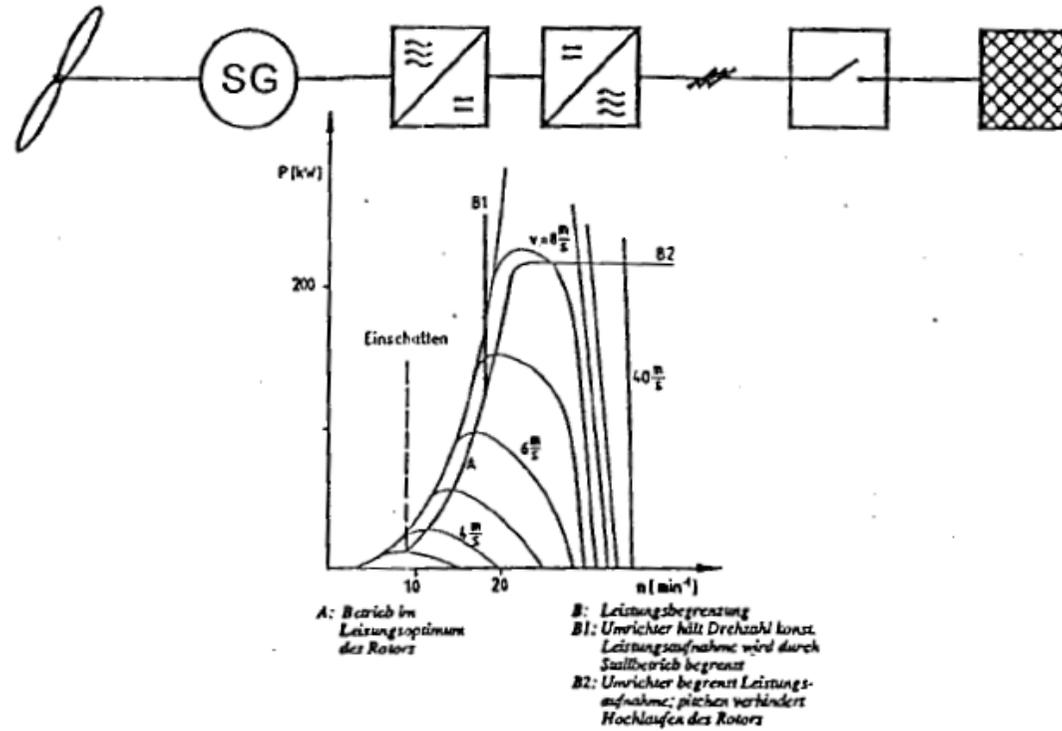
**Modell NEG Micon 52/900**  
- technische Daten -

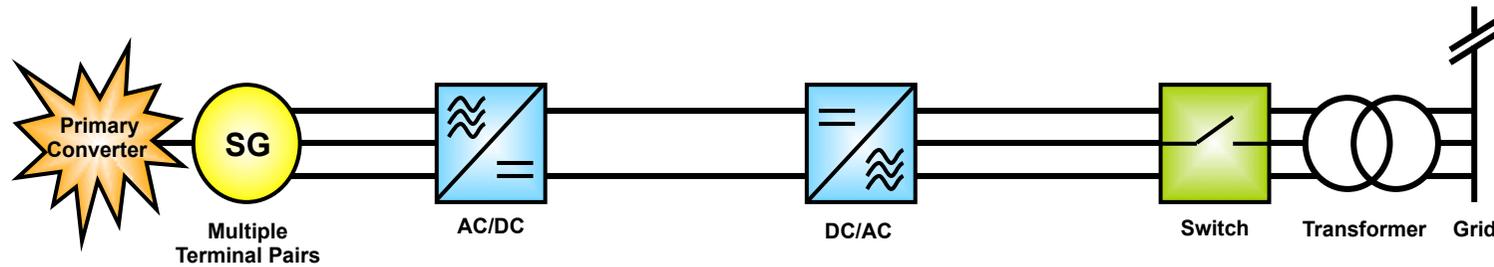
|                         |                        |
|-------------------------|------------------------|
| <b>Technik</b>          |                        |
| Leistung                | : 900 kW               |
| Nennwindgeschwindigkeit | : 16,0 m/s             |
| Einschaltwindgeschw.    | : 3,5 m/s              |
| Rotordurchmesser        | : 52,0 m               |
| Überstrichene Fläche    | : 2.140 m <sup>2</sup> |
| Drehzahl                | : 15-22 U/min          |
| Generator               | : asynchron            |
| <b>Gewicht</b>          |                        |
| Gondel                  | : 26,5 t               |
| Rotor (incl. Nabe)      | : 16,5 t               |
| Turm (74m, Stahlrohr)   | : 97,0 t               |



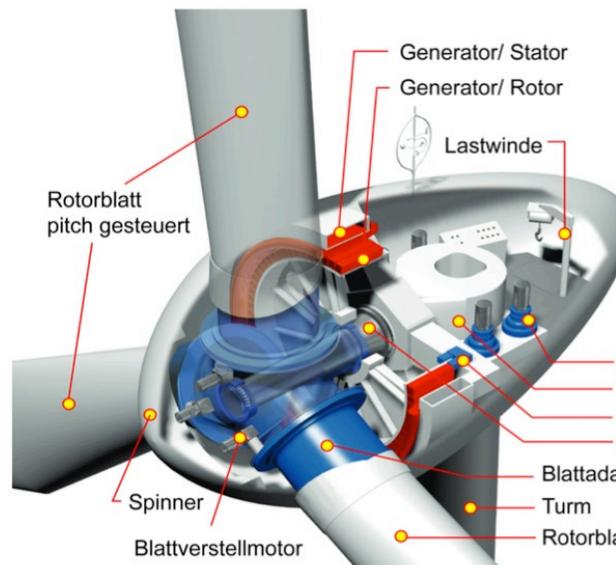
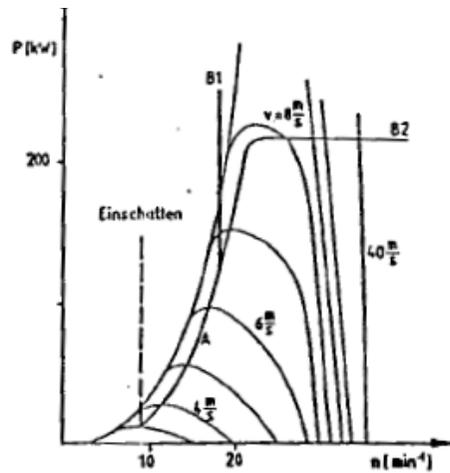
# Elektrisches System

## Drehzahlvariabel - Enercon





### Aufbau einer Gondel - getriebelos



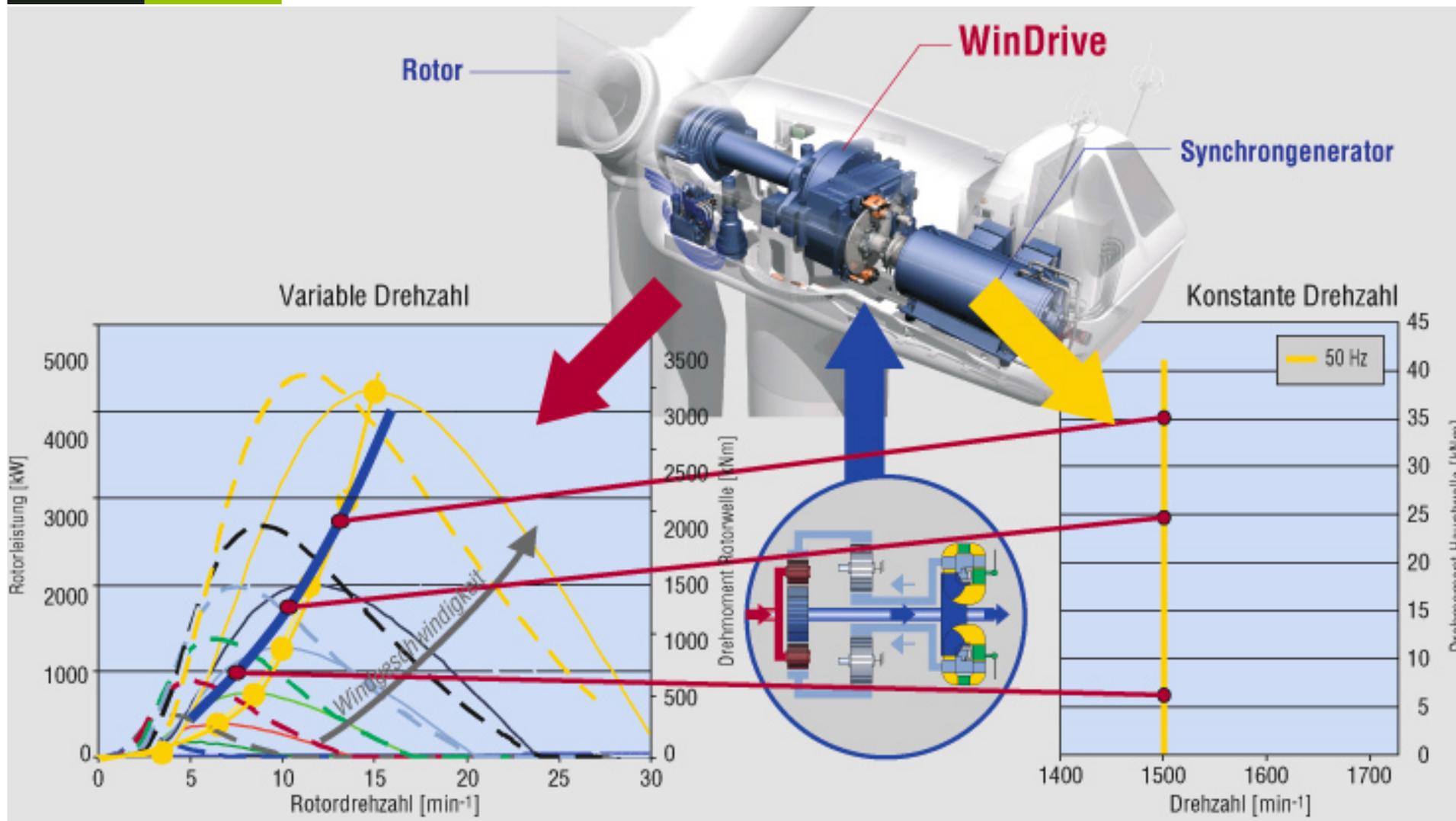
| Modell Enercon E-66<br>- technische Daten - |                           |
|---|---------------------------|
| <b>Technik</b>                              |                           |
| Leistung                                    | : 1,8 MW                  |
| Nennwindgeschwindigkeit                     | : 12,0 m/s                |
| Einschaltwindgeschw.                        | : 2,5 m/s                 |
| Rotordurchmesser                            | : 70,0 m                  |
| Überstrichene Fläche                        | : 3.848 m²                |
| Drehzahl                                    | : 10-22 U/min             |
| Generator                                   | : synchron, Ringgenerator |
| Getriebe                                    | : ohne                    |
| <b>Gewicht</b>                              |                           |
| Gondel                                      | : 68,8 t                  |
| Rotor (incl. Nabe)                          | : 31,7 t                  |
| Turm (98m, Beton)                           | : 861 t                   |
| Turm (86m, Stahlrohr)                       | : 219 t                   |



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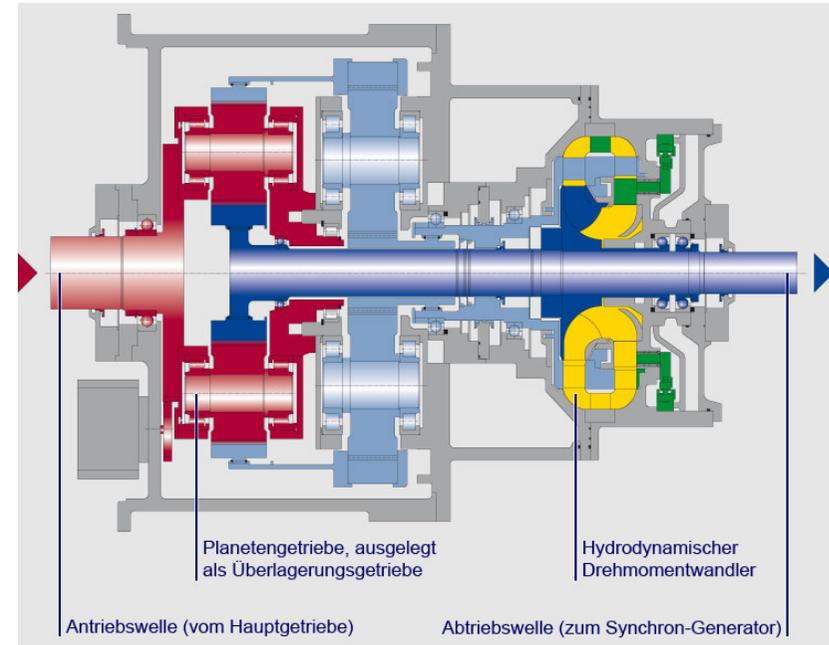
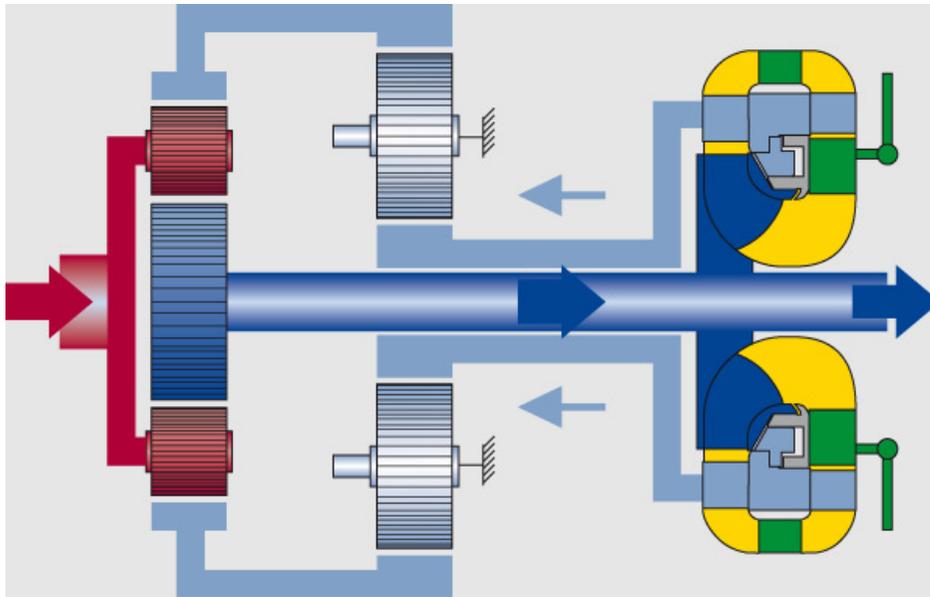
# Aufbau

## Voith - WinDrive





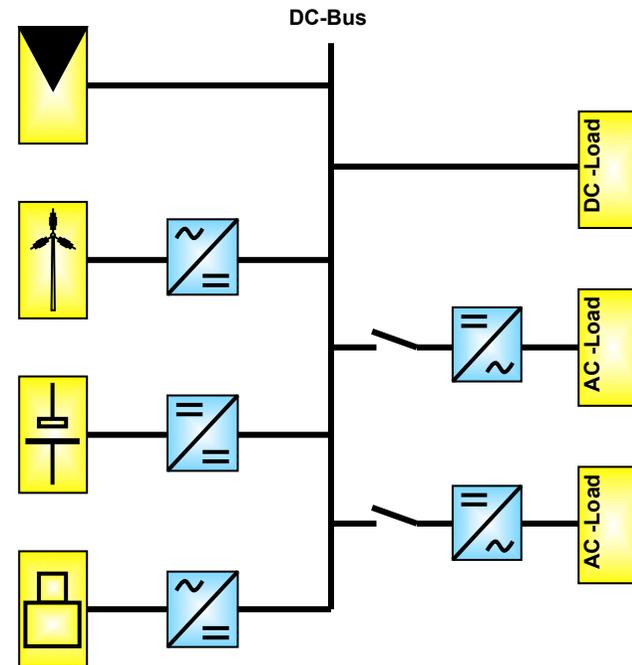
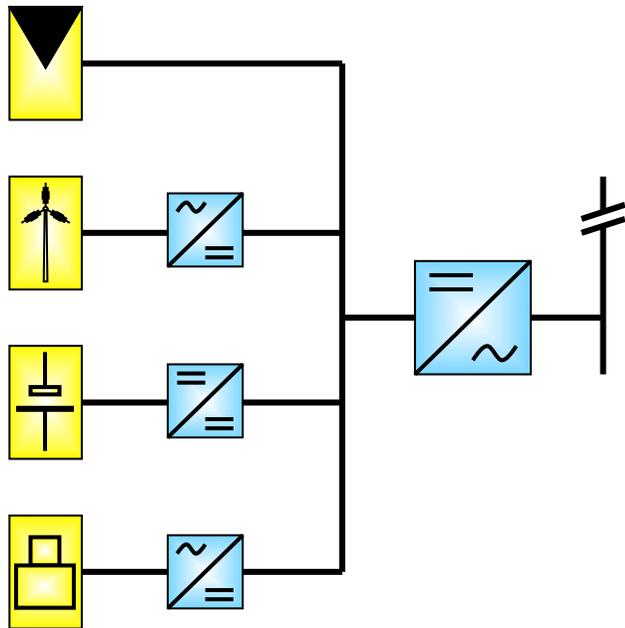
# Aufbau Voith – WinDrive - Drehmomentwandler





# Inselsysteme

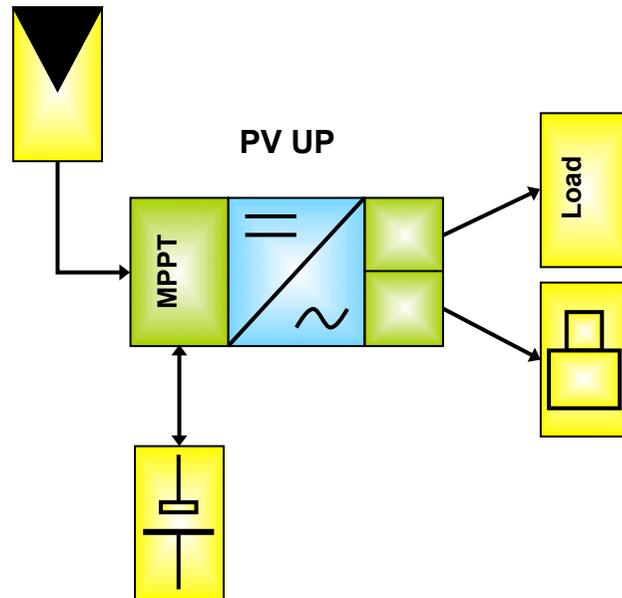
## DC Kopplung





# Inselsysteme

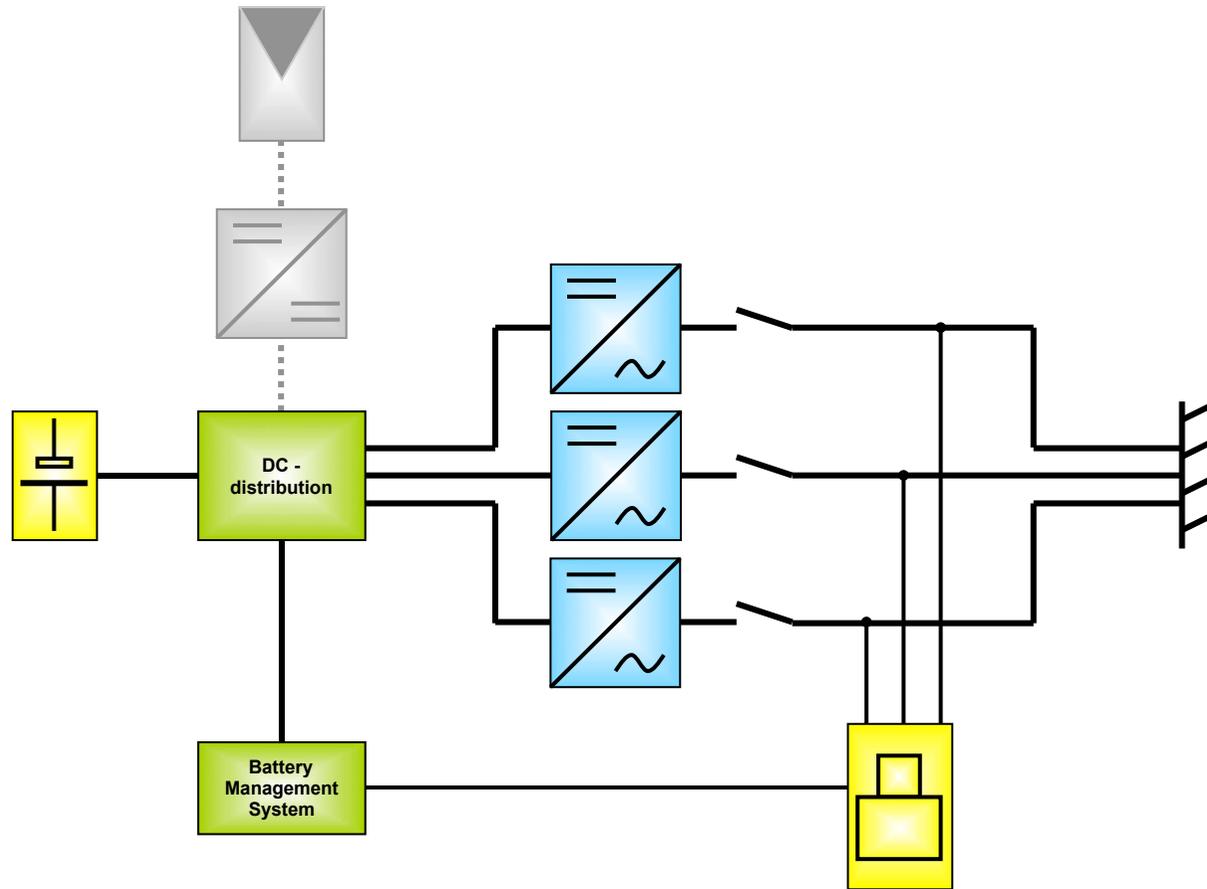
Integrierte Kopplung





# Inselsysteme

## Gemischte Kopplung





# Inselsysteme

## Wechselstromkopplung

