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Electrical Power Systems

State-of-the Art of Wind Turbine Electrical Systems and Grid Interconnection

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- ⇒ Usable wind power
- ⇒ Fixed and variable speed WT
- ⇒ Generator types
- ⇒ Grid interconnection
- ⇒ Offshore designed WT
- ⇒ Medium voltage equipment
- ⇒ Power electronic connection
- ⇒ Power quality
- ⇒ Wind park structure
- ⇒ Summary

Grid connected Wind Turbine

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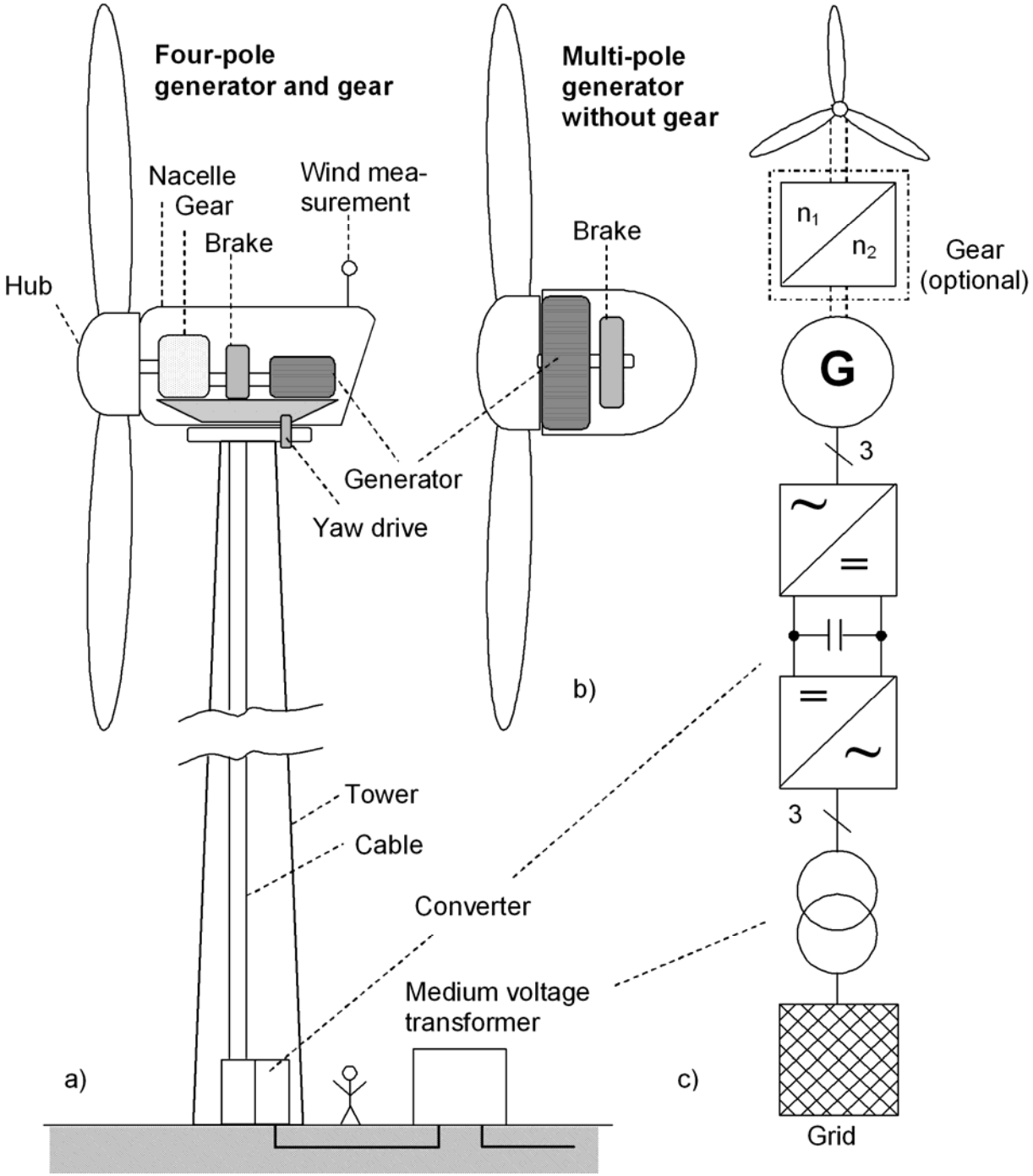

a) Four-pole generator with gear

b) Multi-pole generator without gear

c) Schematic drawing

Usable wind power

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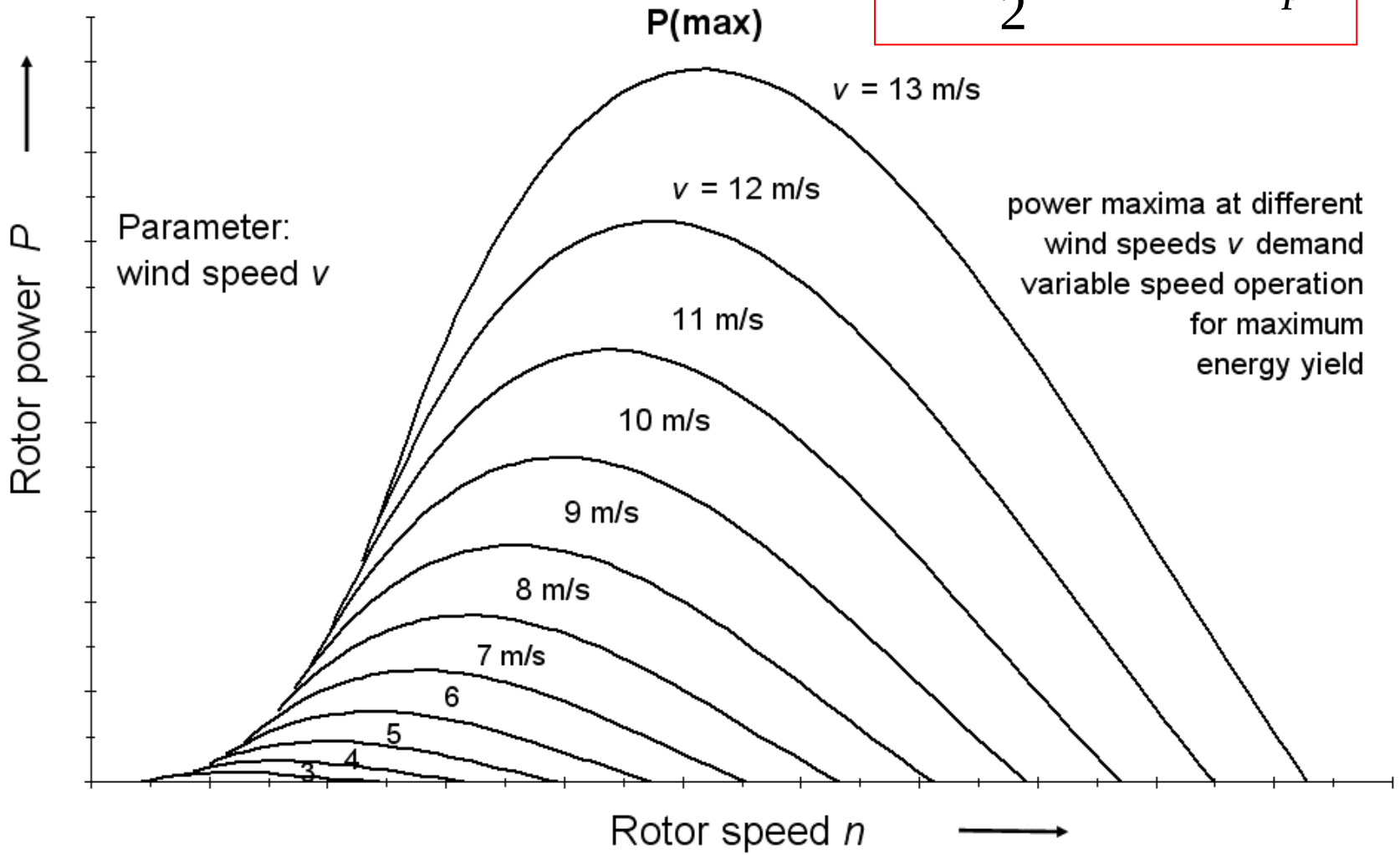
$$P = \frac{1}{2}\rho \cdot A \cdot v^3 \cdot c_p$$



Fixed and variable speed WTs

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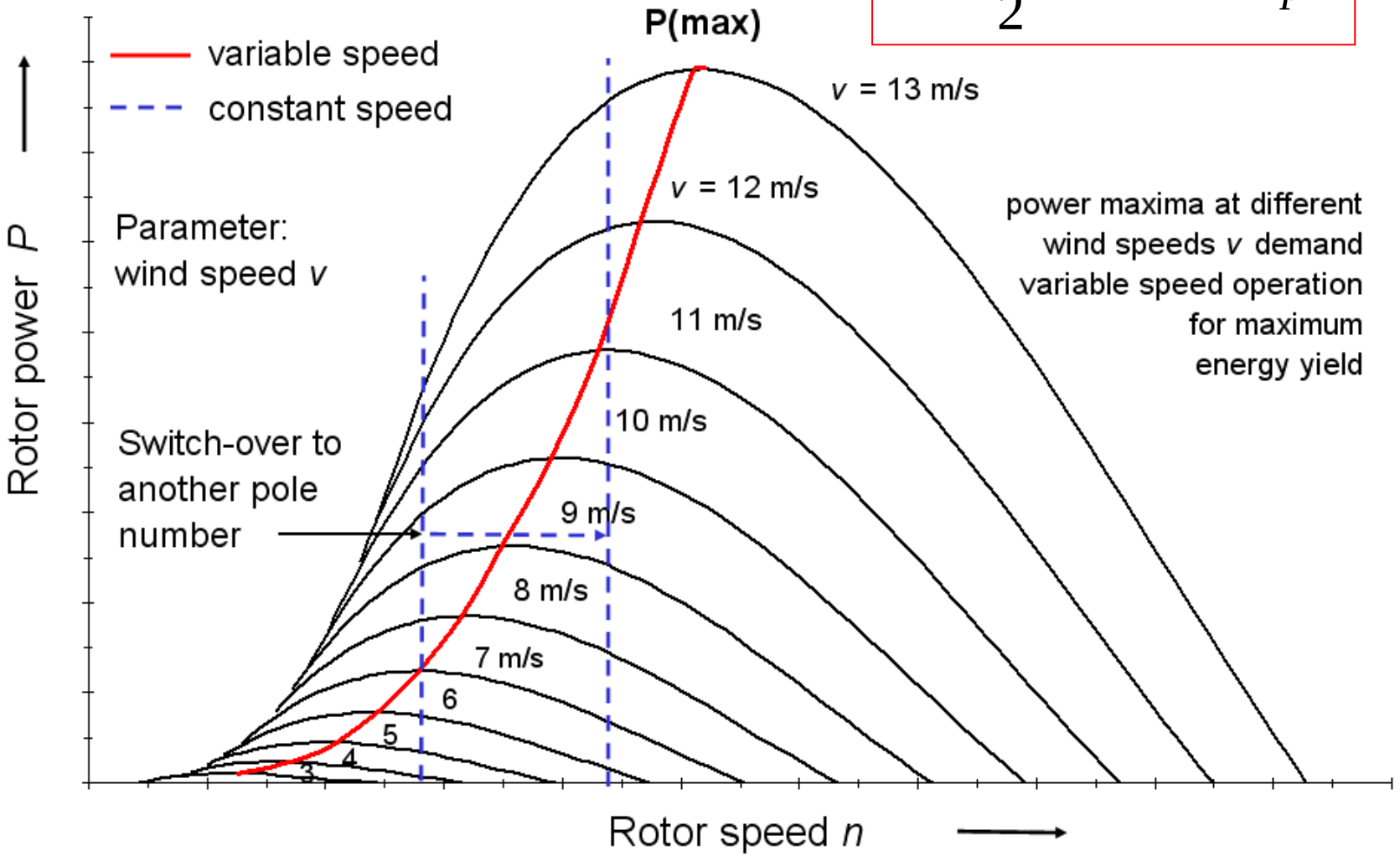
Usable wind power

$$P = \frac{1}{2}\rho \cdot A \cdot v^3 \cdot c_p$$



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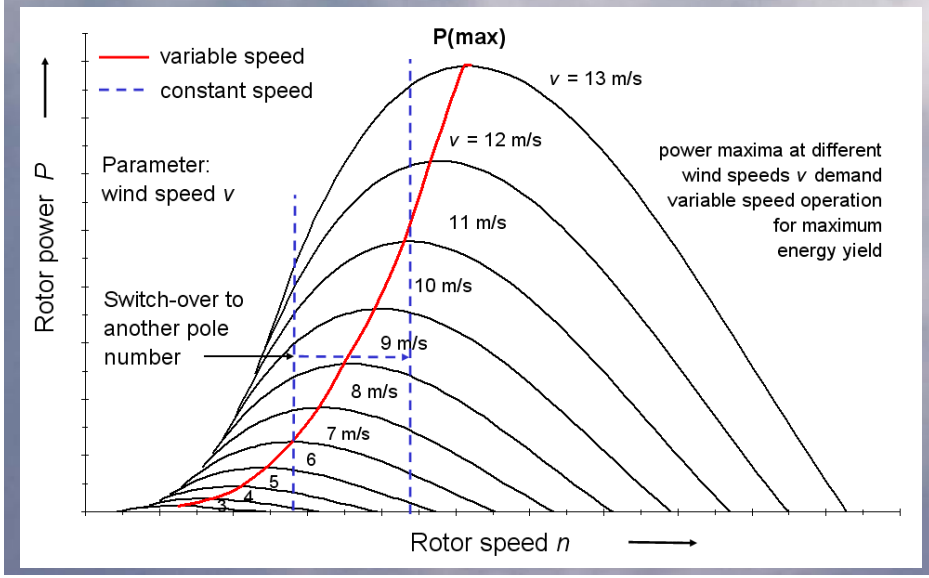
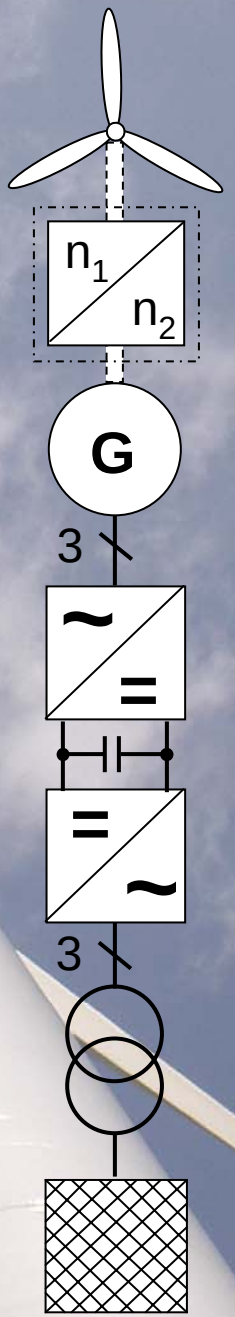

P(max)
variable speed
constant speed
v = 13 m/s
v = 12 m/s
11 m/s
10 m/s
9 m/s
8 m/s
7 m/s
6
5
4
3
Parameter:
wind speed v
Switch-over to
another pole
number
power maxima at different
wind speeds v demand
variable speed operation
for maximum
energy yield
Rotor power P
Rotor speed n


n1
n2
G
3
3

Grid coupling: generator types

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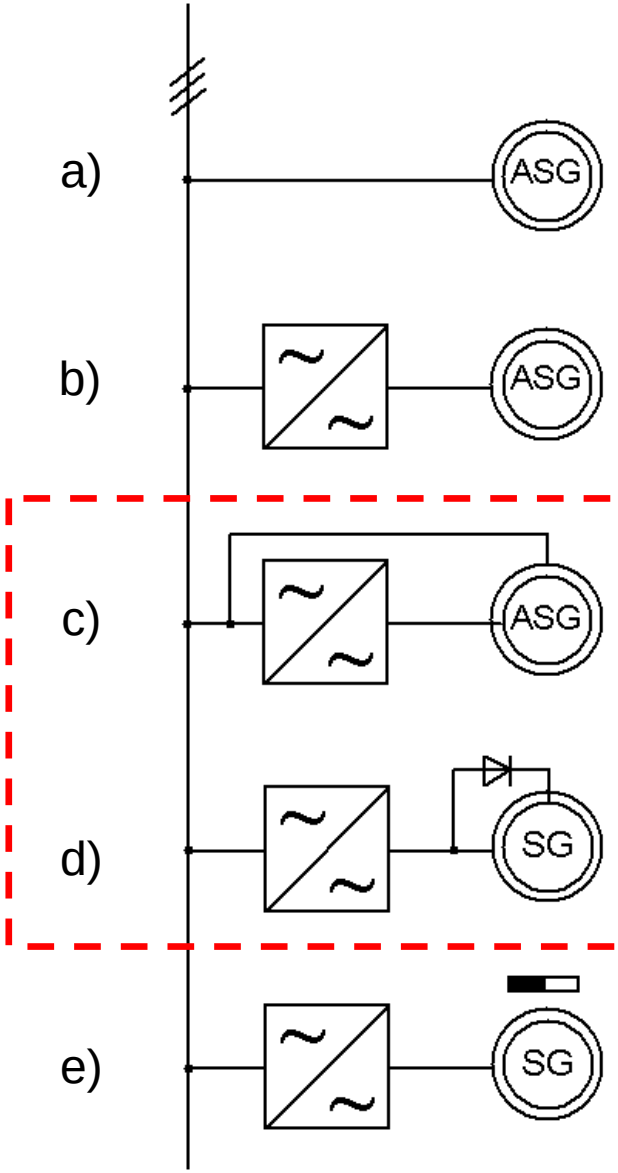


Direct coupled asynchronous generator

Converter coupled asynchronous generator

Double-fed asynchronous generator

standard MW power class

Converter coupled synchronous generator

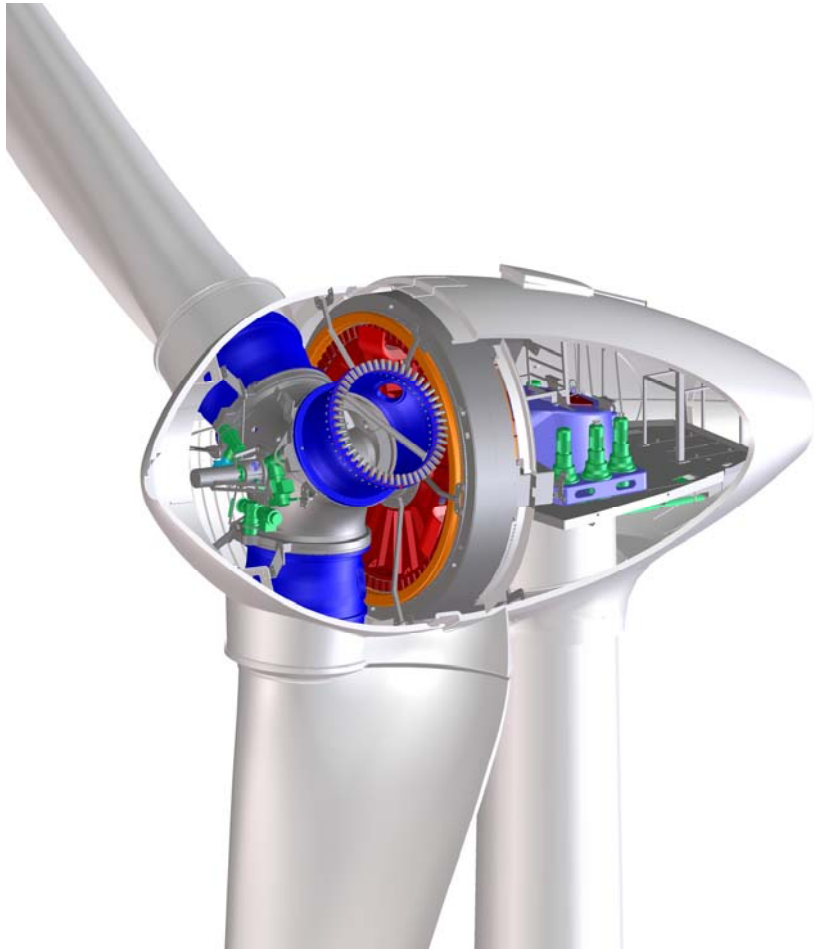
Converter coupled synchronous generator with permanent excitation

Drive train concepts

Generator and gear

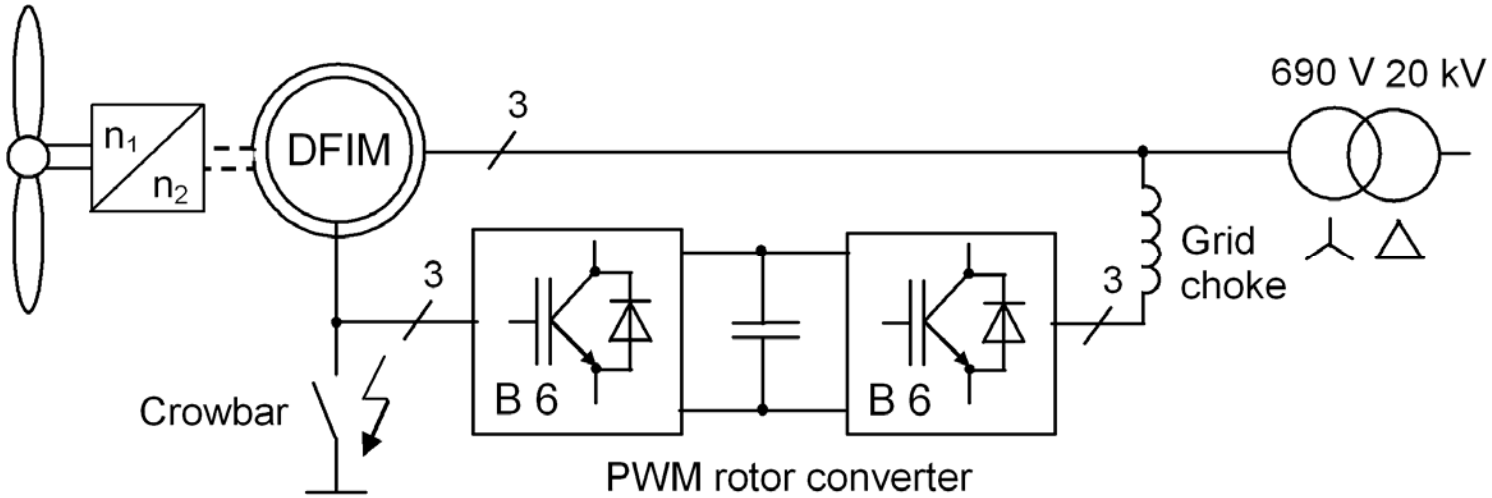
Picture: Nordex

Gearless, multi pole generator

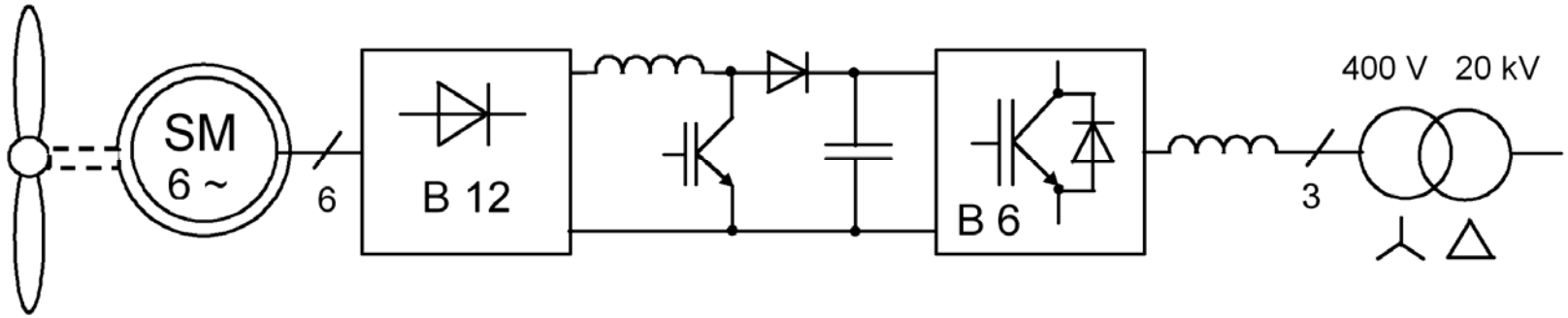


Picture: Enercon

Drive train details



Doubly-fed induction machine



Synchronous machine with full-size VSI

WT-types with grid interconnection

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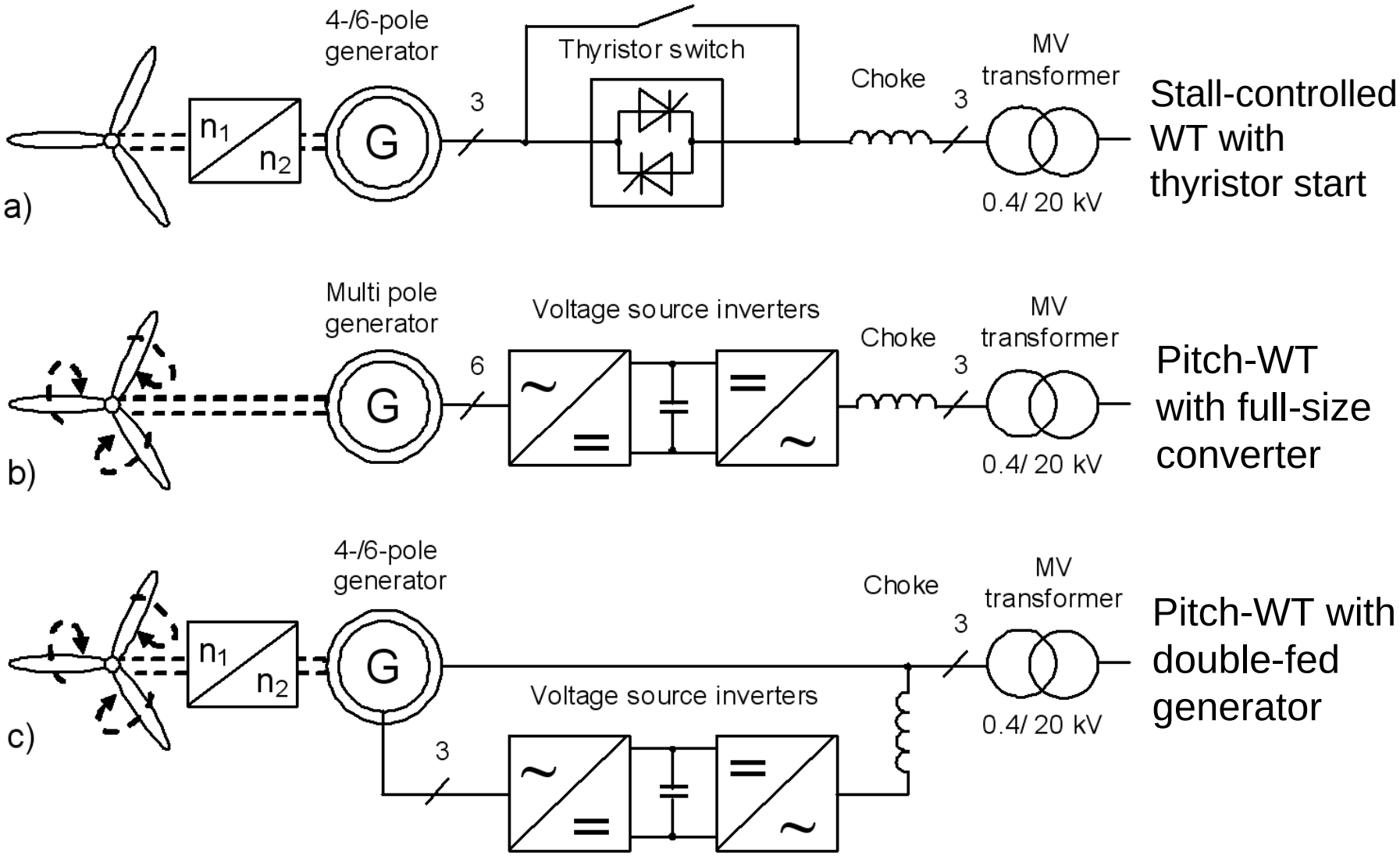

WT with 5 MW power in offshore design

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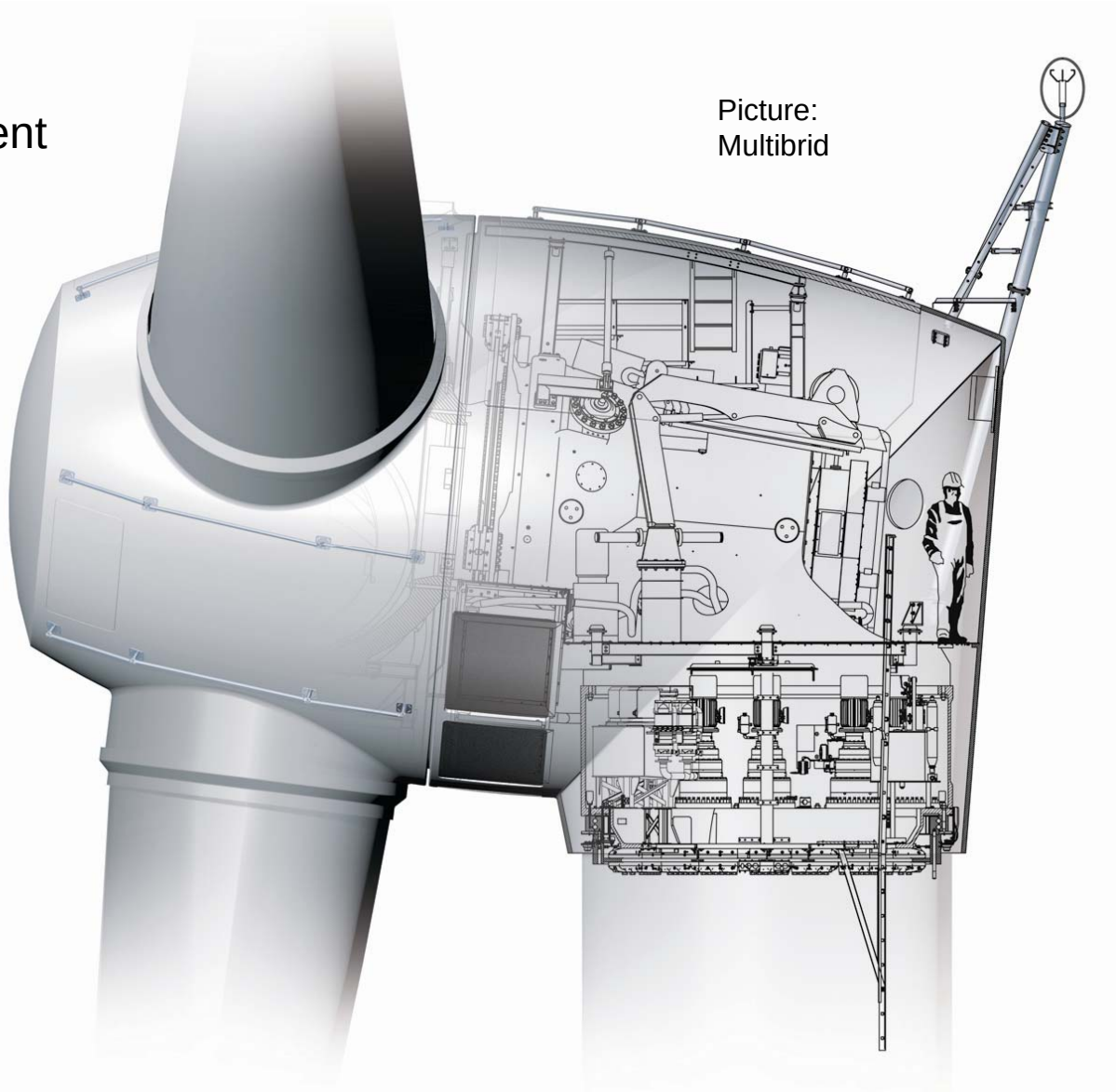
Multi-pole synchronous generator with permanent magnet excitation, slow-speed gear

Special design for offshore-installation

Low weight of the generator

Generator and inverter: medium voltage 3.3 kV

Two prototypes, six offshore WTs next year



Picture: Multibrid

Medium voltage equipment for WT

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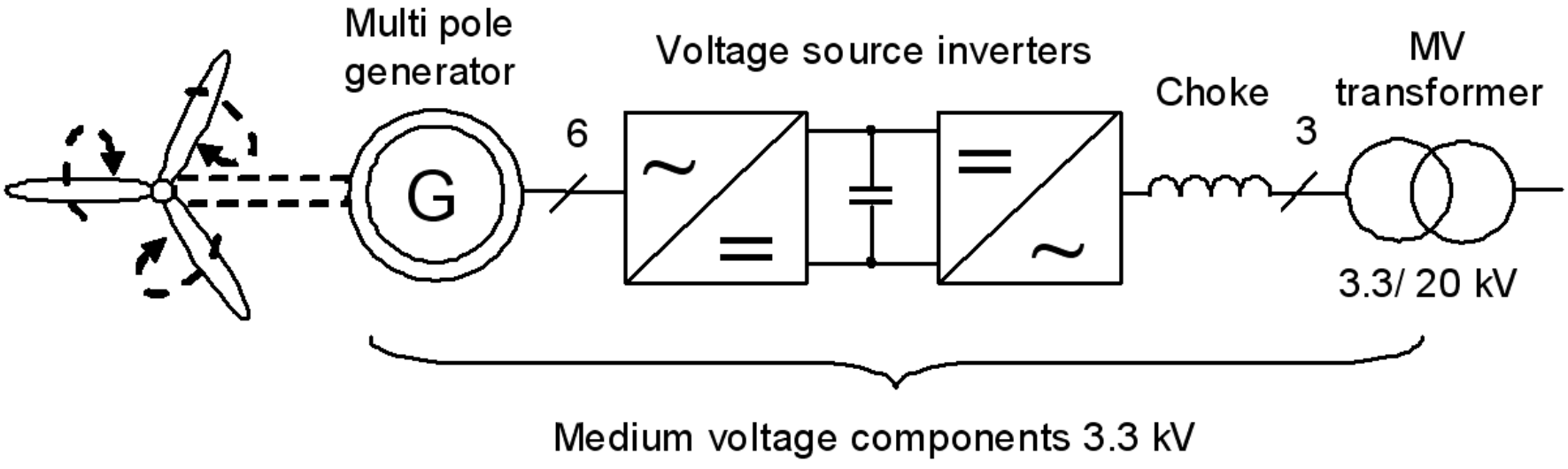

State-of-the Art

- **Power electronic devices for medium voltage design: up to 6 kV**
- **Press-pack IGBTs (Insulated Gate Bipolar Transistor) and IGCTs (Integrated Gate Commutated Thyristor)**
- **Power electronic converters in the range of 4 MW up to 33 MW**
- **Medium voltage level: good power/volume-ratio**
- **Advantages: small generator design, low nacelle weight, small cables**
- **Disadvantages of medium voltage components: only few supplier**

Power electronic grid connection of WT

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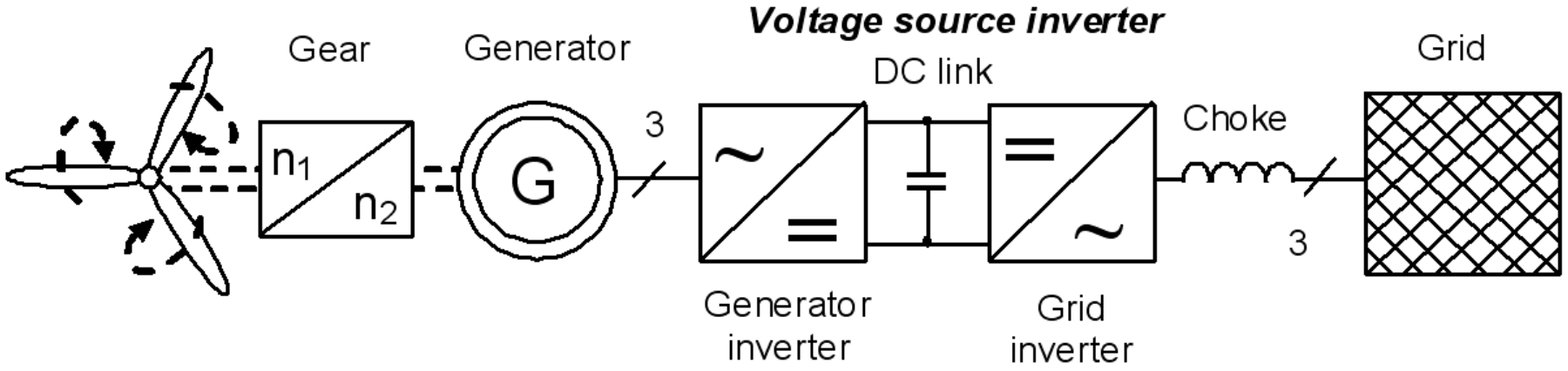
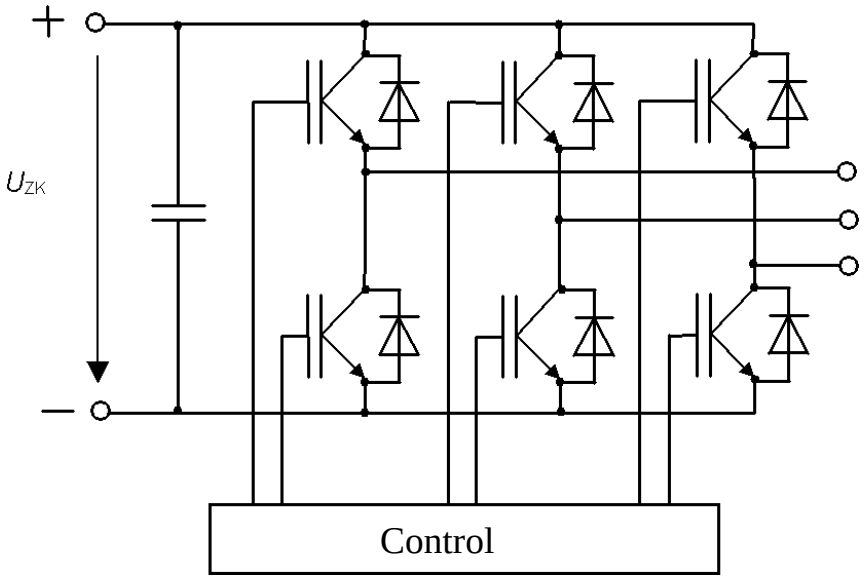
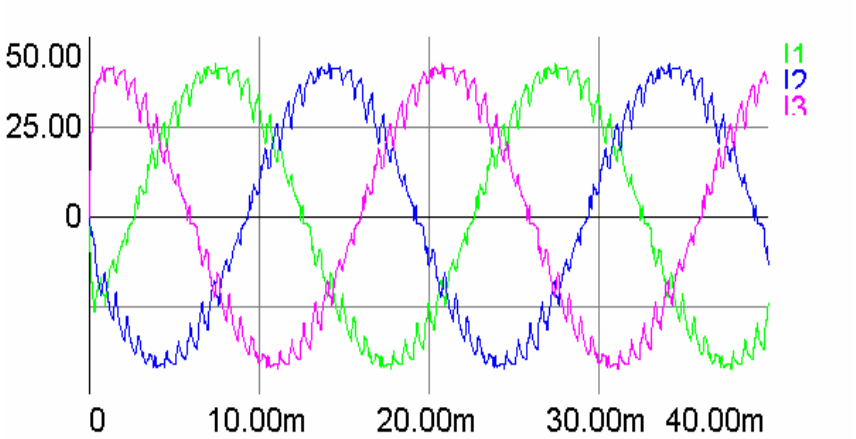


IGBT six pack



Current ripples due to inverter switching



Typical switching frequencies: 2,5 …3 kHz

Voltage shape PWM modulation

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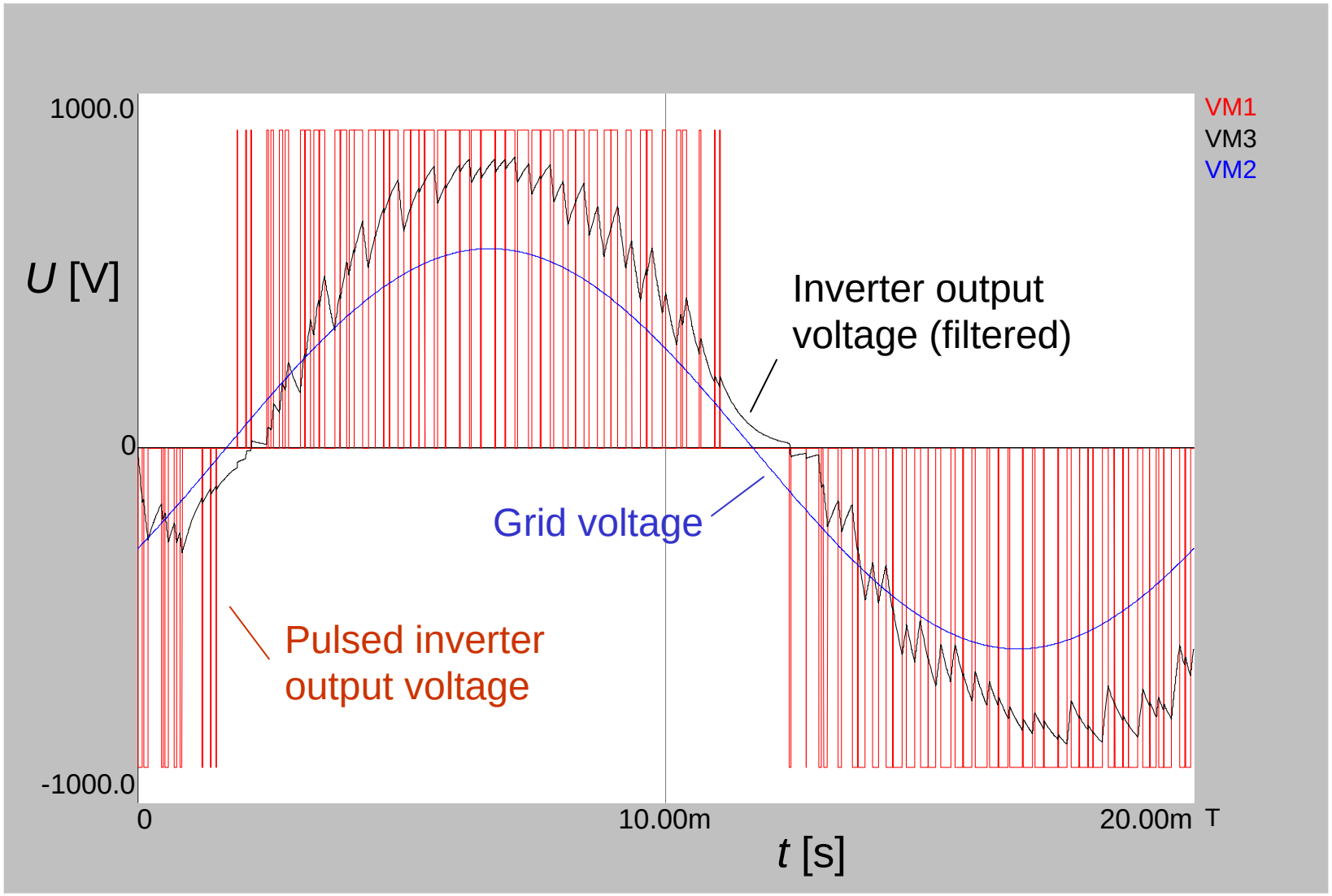

Current shape for different switching frequencies

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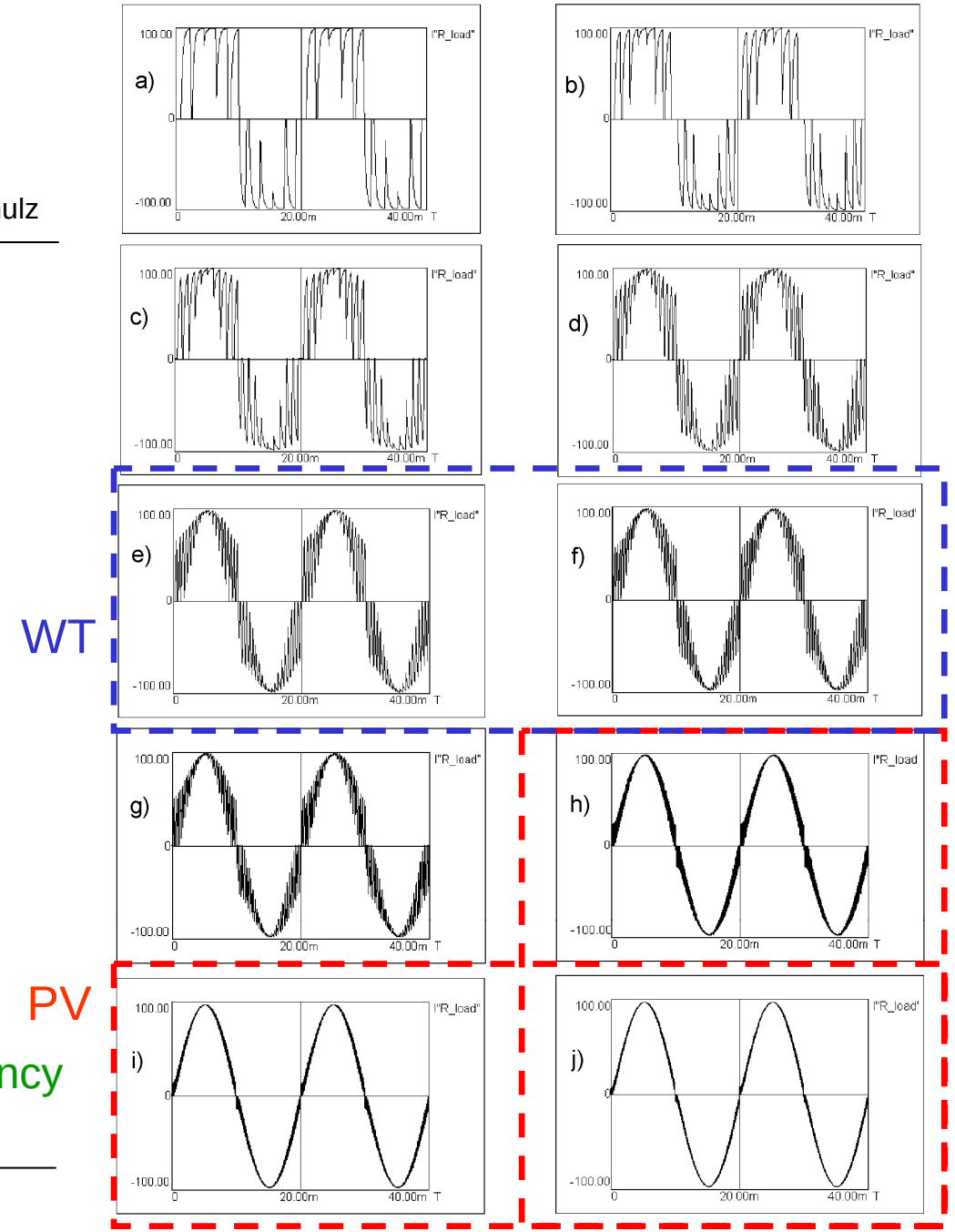
Simulation results:
Current over time at a switching frequency of

a) 500 Hz
b) 750 Hz
c) 1 kHz
d) 1.5 kHz
e) 2 kHz,
f) 2.5 kHz
g) 3 kHz
h) 8 kHz
i) 15 kHz
j) 25 kHz

Limitation of the switching frequency by switching losses



Power quality parameters

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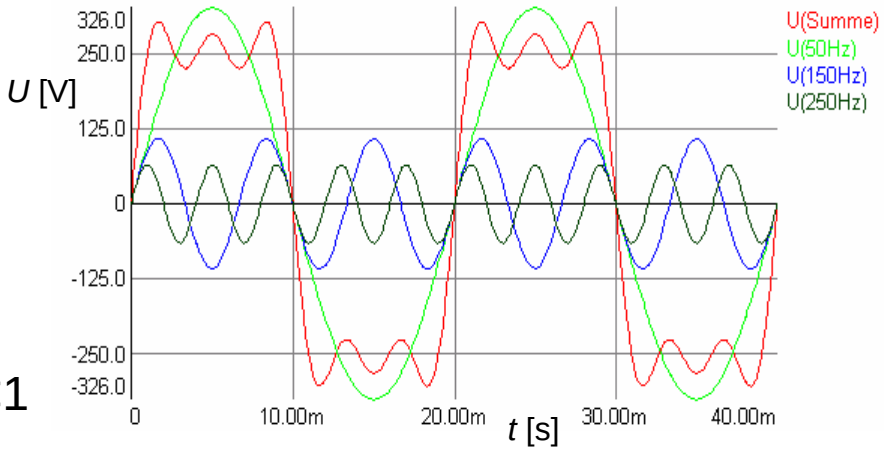
Description	p[1]	np[2]	Frequency range	Cause
Harmonics	x		> 50 Hz	Non-linear consumers, switching events
Interharmonics	x		0...> 50 Hz	
Subharmonics		x	< 50 Hz	
Voltage deviations		x	< 0.01 Hz	Power changes
Flicker	x	x	(0.001 – 35) Hz	Power changes
Transients		x	> 50 Hz, accidental	Switching events

[1]periodic, [2]non-periodic

Harmonics: whole-numbered multiples *n* of the basic frequency

Interharmonics: real-numbered multiples *n/m* of the basic frequency

Subharmonics: non-whole-numbered parts below the basic frequency (*n/m*)<1



Medium voltage transformer

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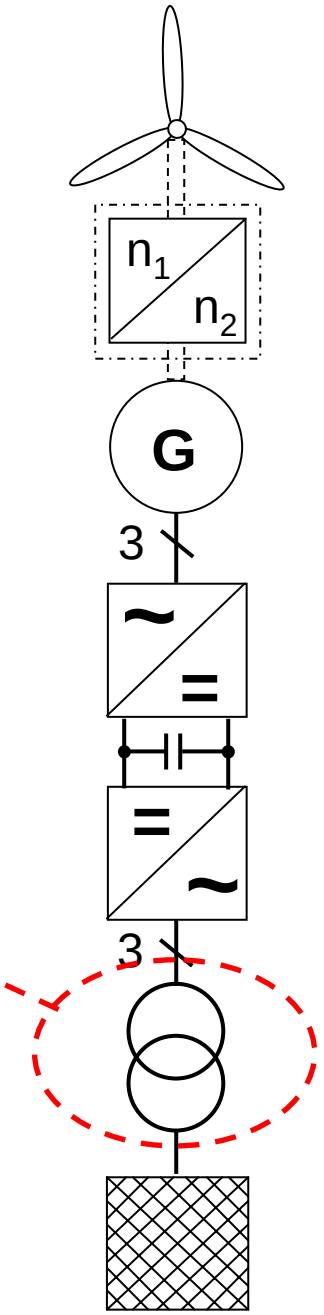

Transformer 690V/20kV, 1.8 MVA

Typical wind park structure

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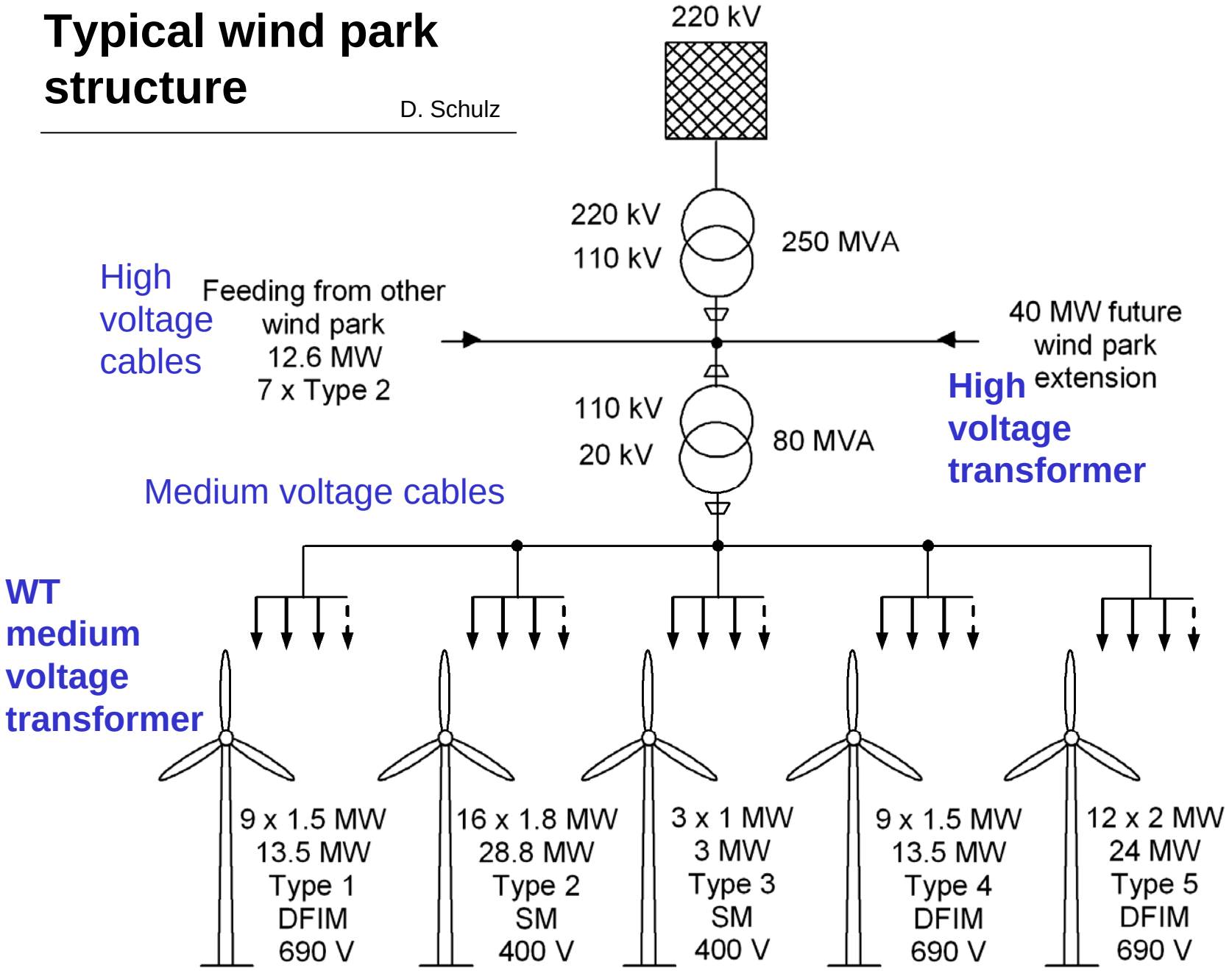

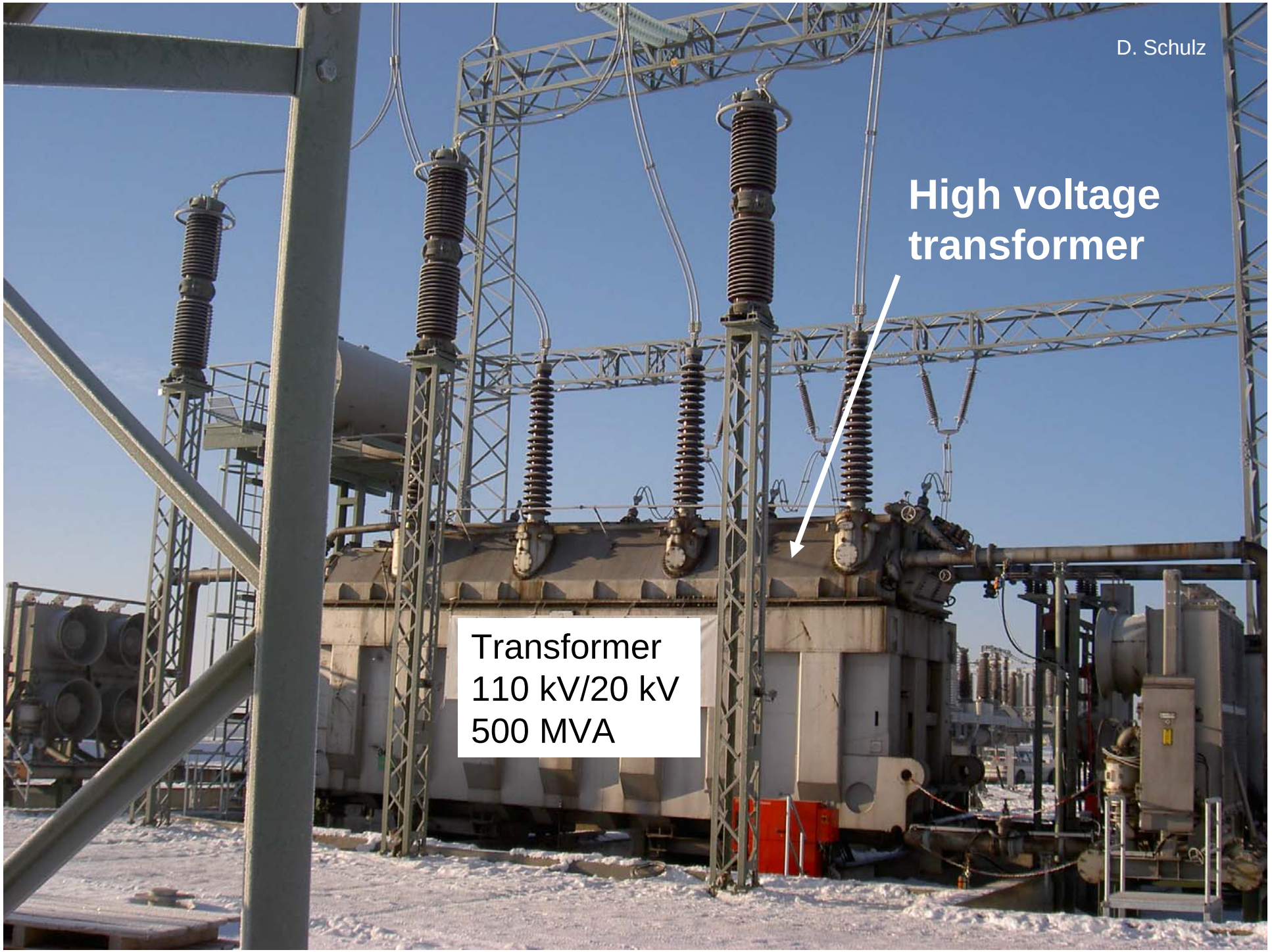
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High voltage transformer
Transformer
110 kV/20 kV
500 MVA

Cables in the wind park

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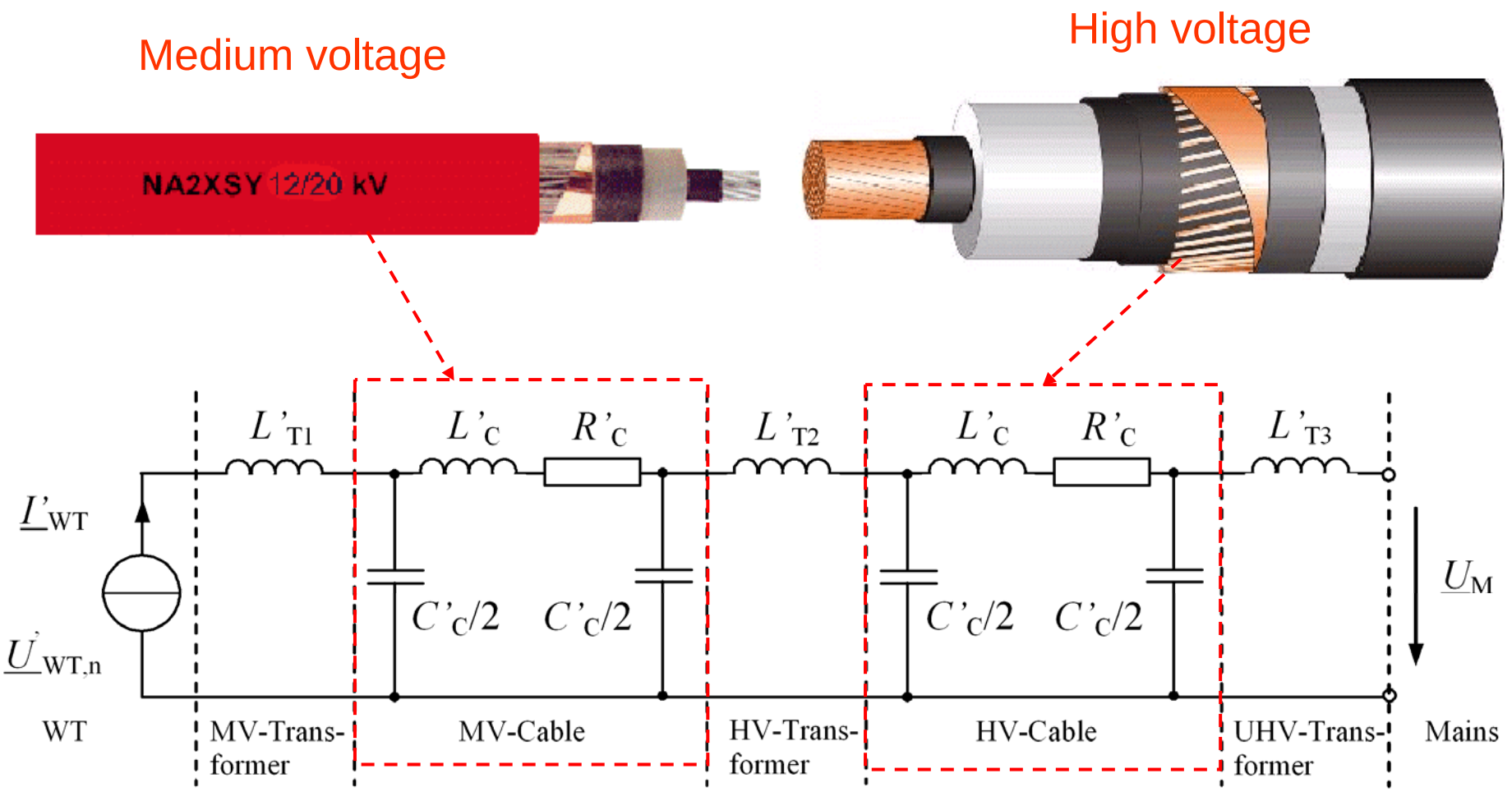

Measured power factors of WTs

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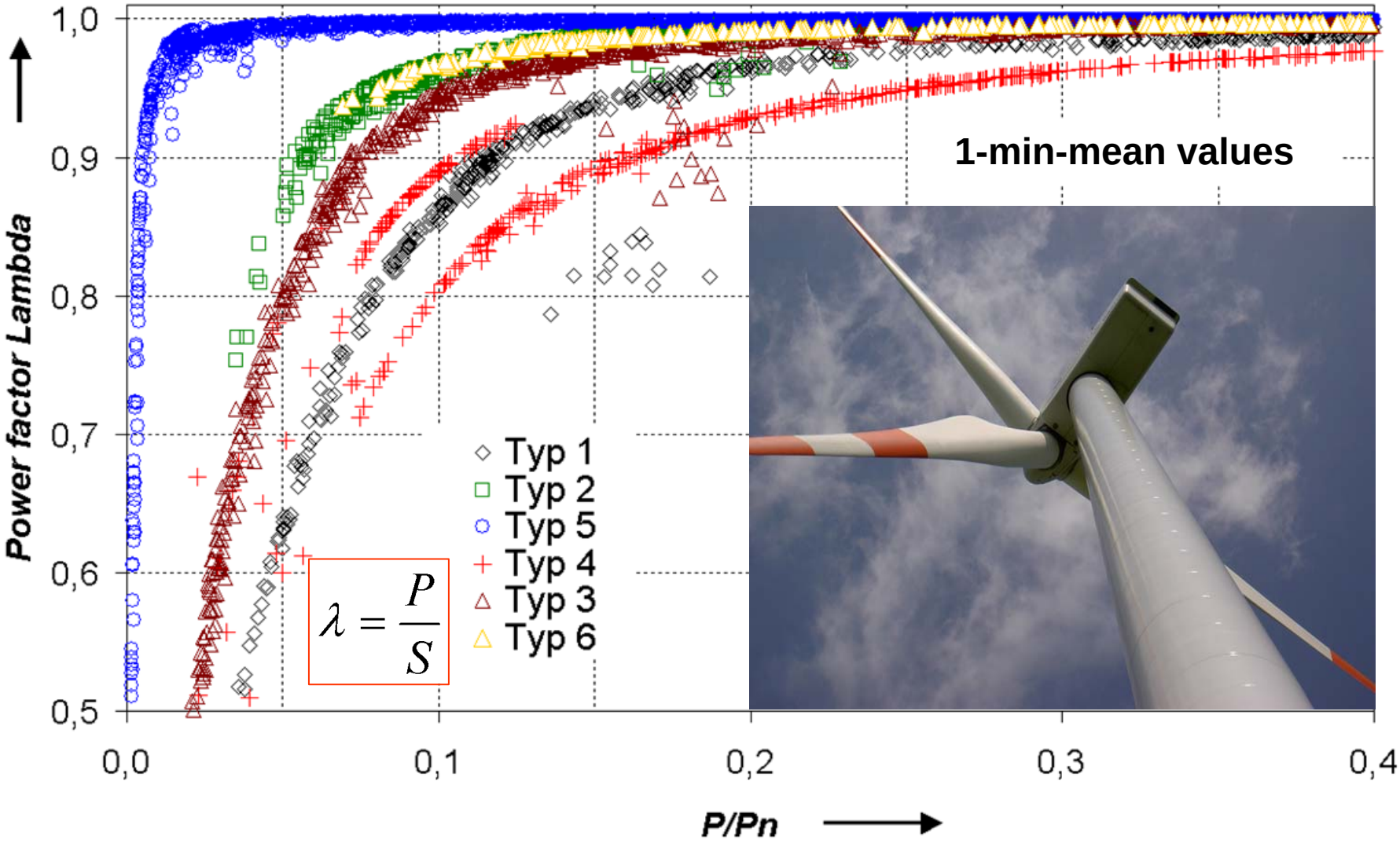
Measurement between VSI and WT transformer



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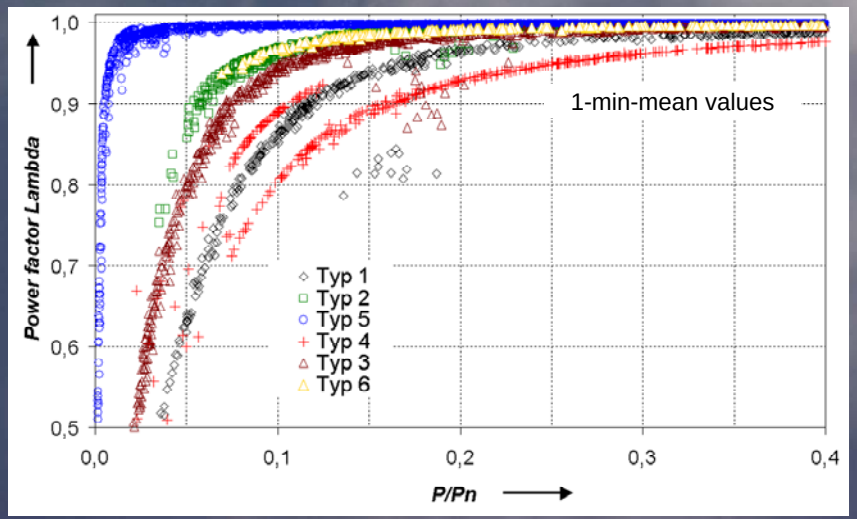
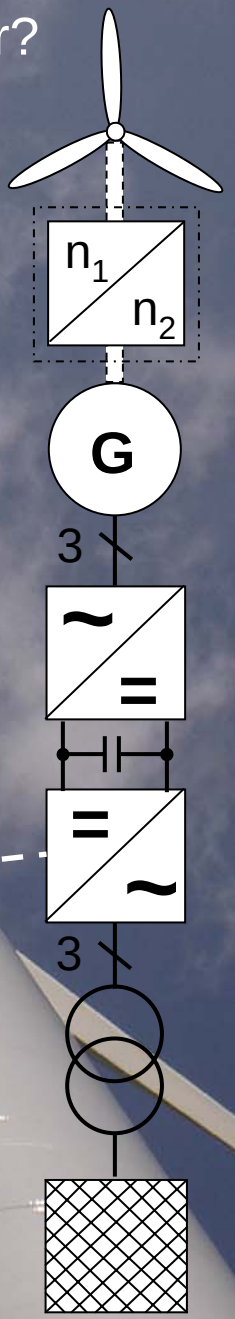
How can we adjust the WT power factor?





Summary

⇒ **Grid connected Wind Turbine (WT)**

⇒ **Usable wind power**

⇒ **Fixed and variable speed WT**

⇒ **Generator types**

⇒ **Grid interconnection**

⇒ **Offshore designed WT**

⇒ **Medium voltage equipment**

⇒ **Power electronic connection**

⇒ **Power quality**

⇒ **Wind park structure**

⇒ **Power factor adjustment**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n1
n2
G
3
~
=
=
~
3
Thank you for your attention!