Offshore wind power plants and Electrical infrastructure

TWind Project

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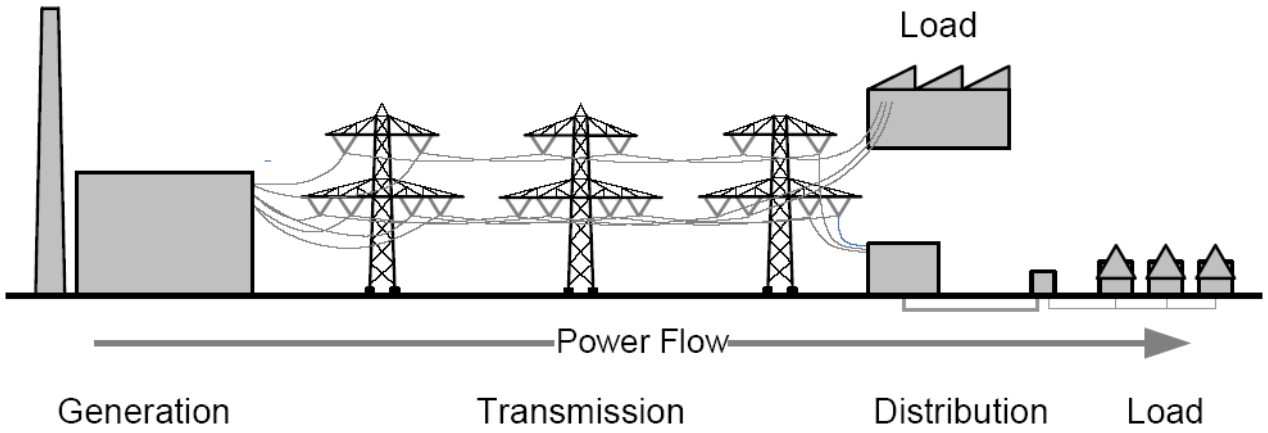
Learning objectives

- Explain basic design considerations for offshore wind electrical infrastructure
- Explain the main impact of large-scale (offshore) wind power on power systems

- Dare to ask questions!

Power System Objectives

- Conversion of primary energy forms into electrical energy
- Transmission and distribution of electrical energy to consumers
- Safe, reliable, economically efficient... and clean



Power System Objectives

- Safe
- Reliable
- Efficient

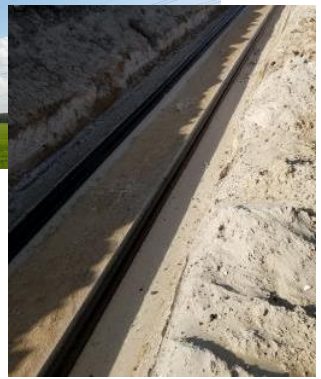
Electrical Design Objectives

- Safe
  - Safety by design
  - Limit impact of electrical faults
- Reliable
  - Very high quality: standardized components
  - Redundant design (‘N-1’)
- Efficient
  - CAPEX: component costs
  - OPEX: electrical losses → **use of high voltage**

Overhead vs. Underground

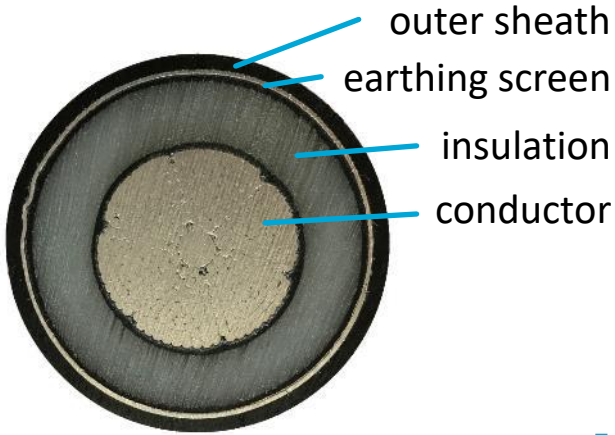
What are considerations for choosing overhead or underground?

Overhead vs. Underground



- Overhead lines
  - Air-insulated conductor, air-cooled
  - Visual impact, electrical and magnetic fields, wind, ice
  - Reliable and affordable

- Underground cables
  - XPLE-insulated conductor and earthing screen
  - Thermal insulation of soil, magnetic fields, installation
  - Reliable but costly: material and installation



Impacts of Wind Power on Power System Operation

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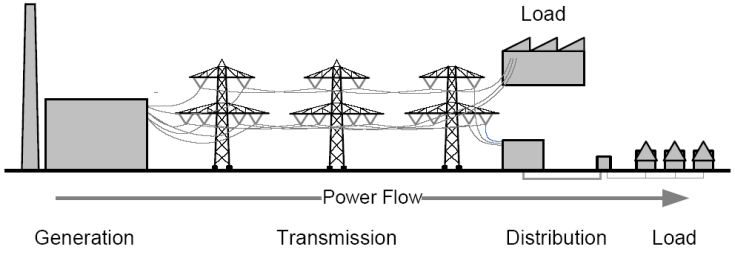
Power Balancing

- Electric energy cannot be stored inside the grid

- Power balance equation:

  Generation = Load + Losses



- Kinetic energy stored in coupled rotating masses - immediate buffer
- Power reserves are continuously needed and used

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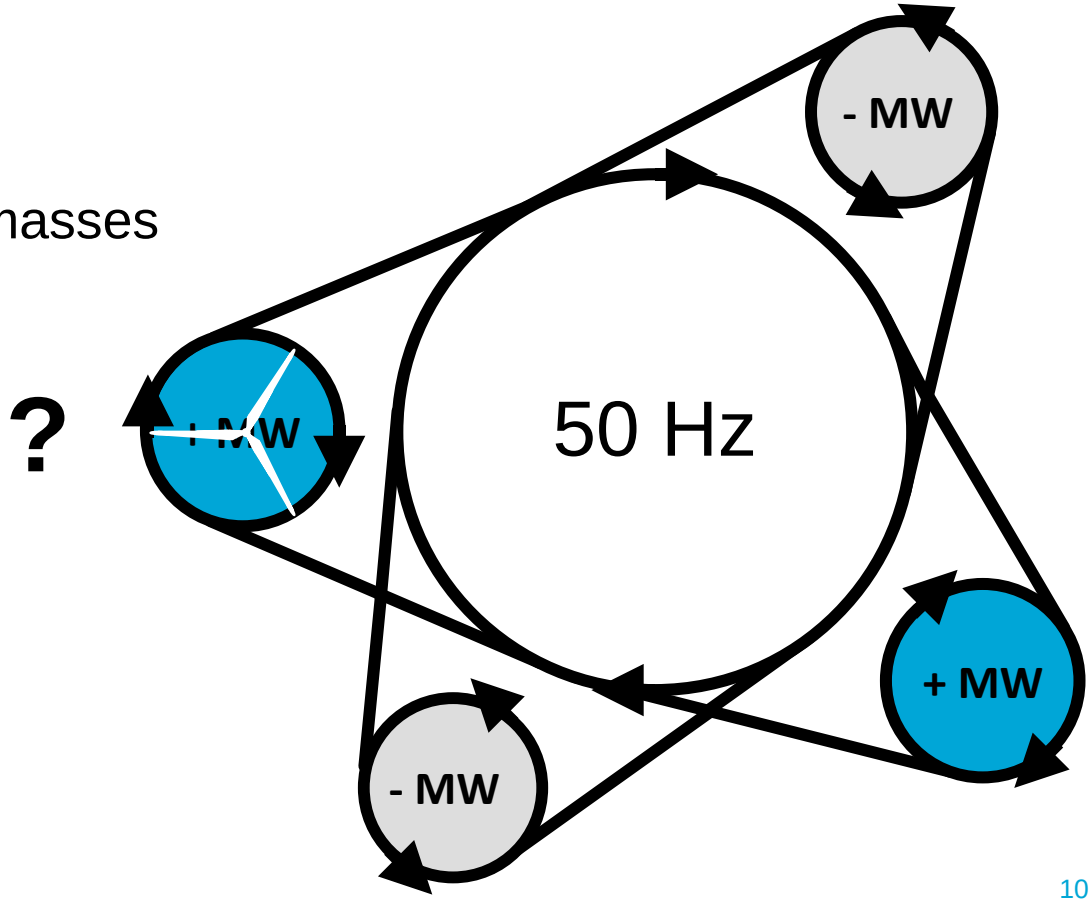
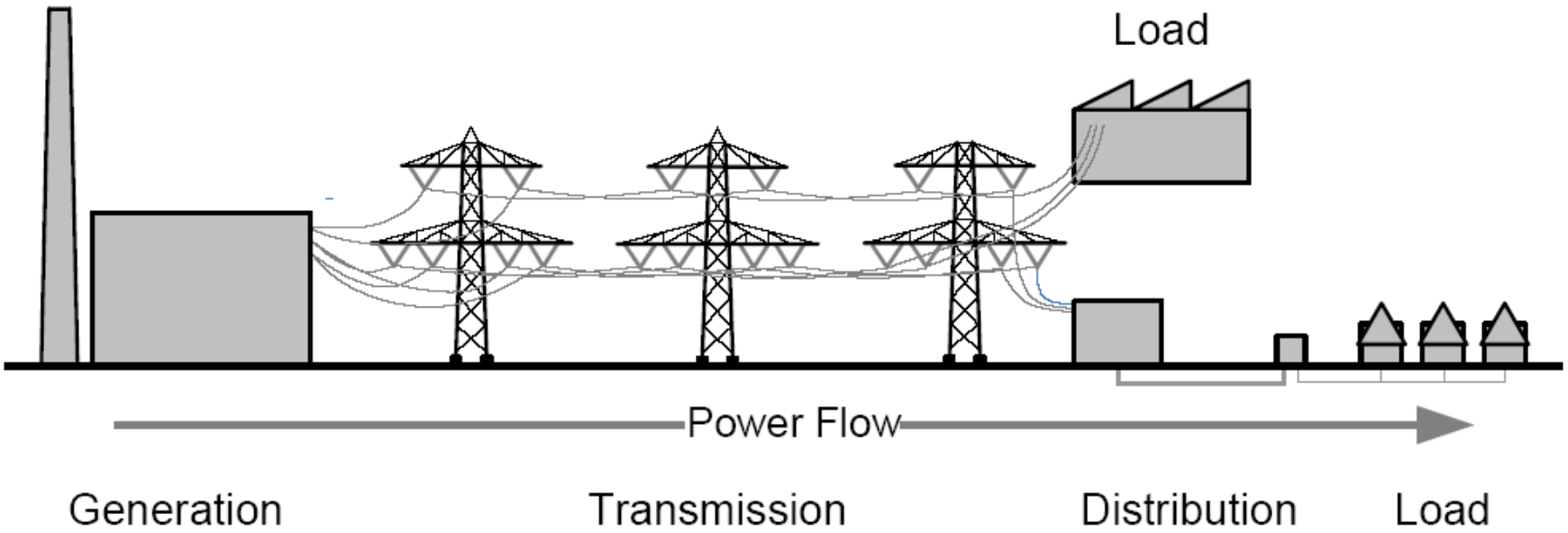
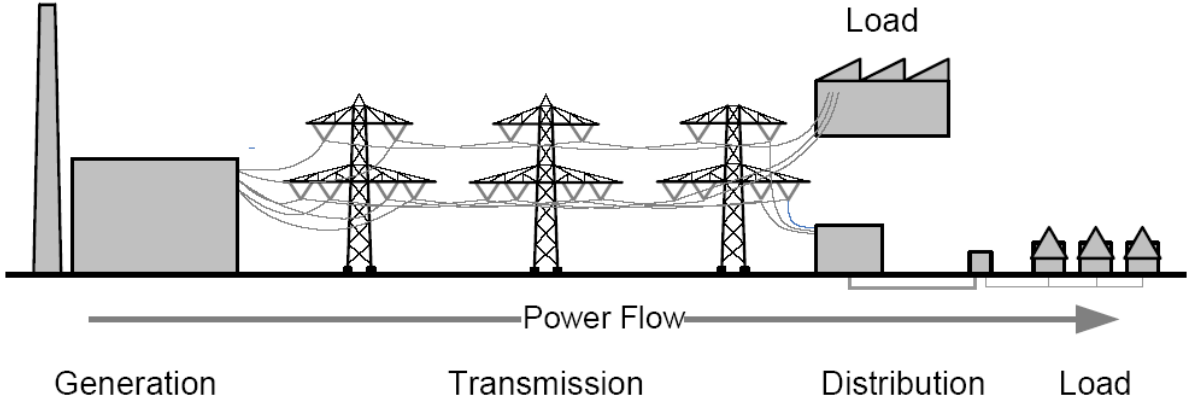
Power Balancing

- Generation = Consumption
- Inertia of coupled rotating masses




Load
Power Flow
Generation
Transmission
Distribution
Load



How do we balance generation and consumption at all times?

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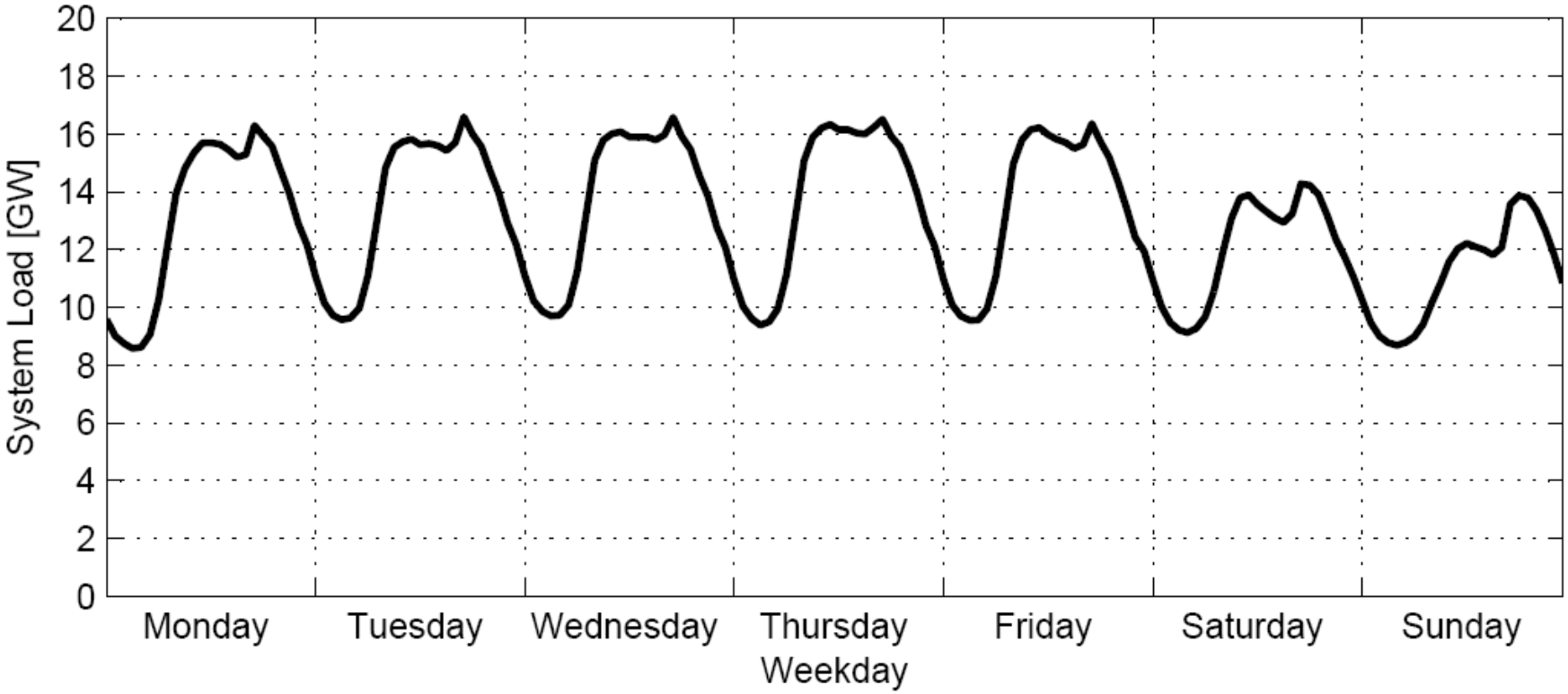
System Load [GW]
20
18
16
14
12
10
8
6
4
2
0
Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Weekday

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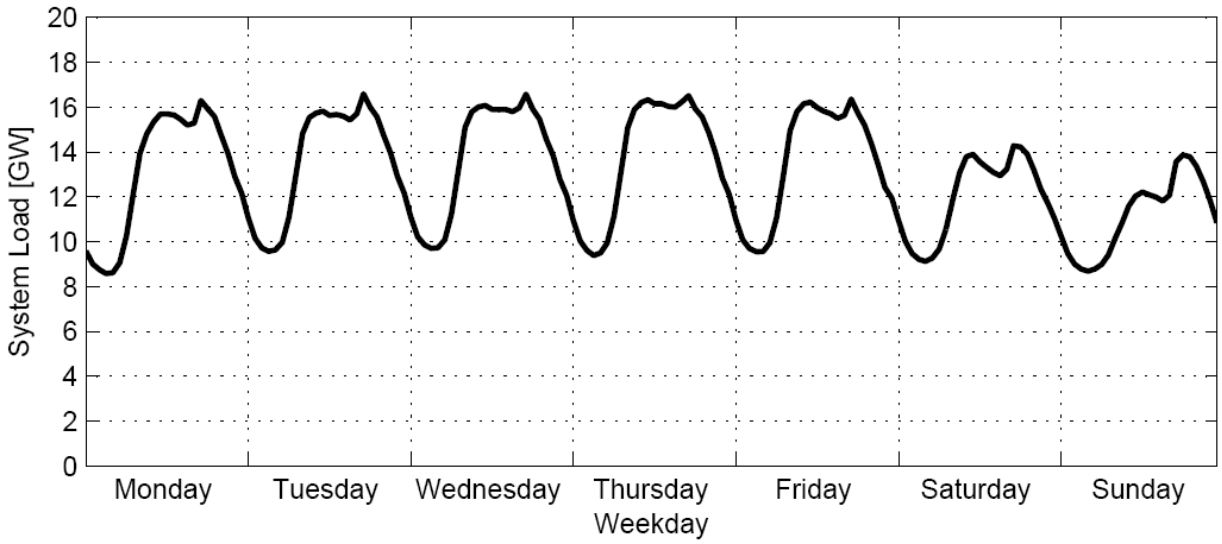

What will happen if we add wind power to the mix?

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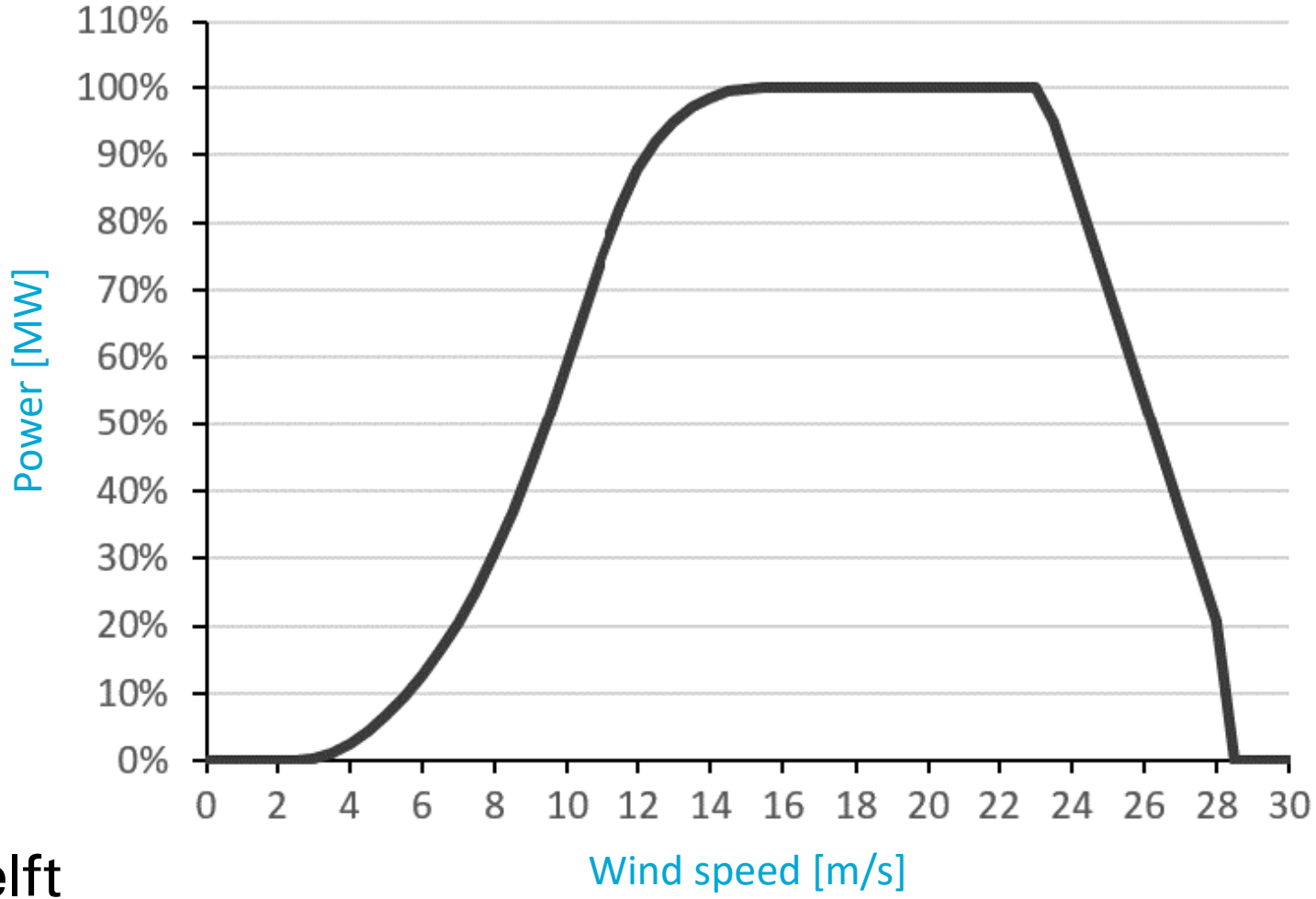
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Power [MW]
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Wind speed [m/s]

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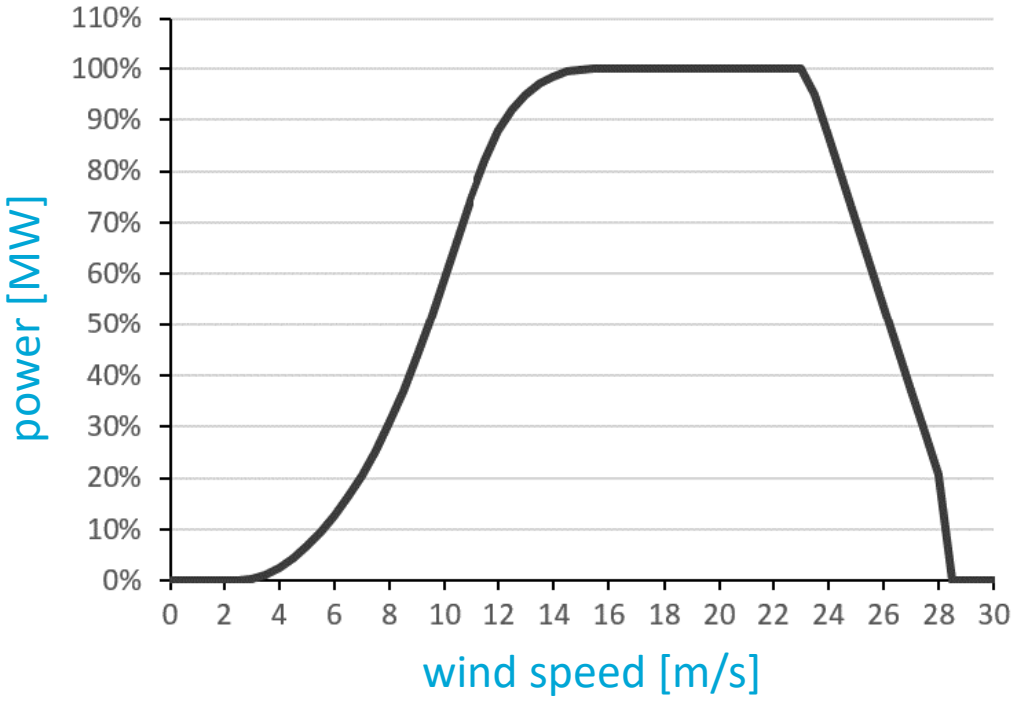

Which wind speed ranges are most challenging for the power system?

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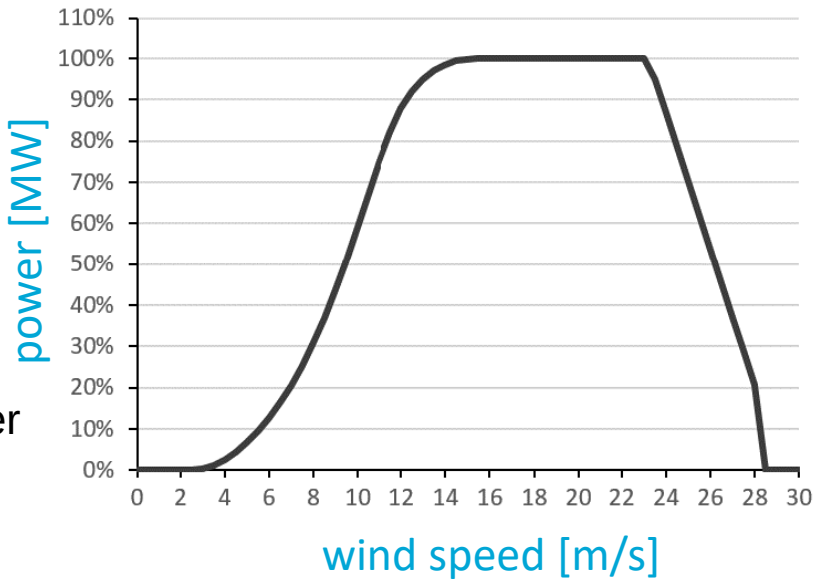
Wind Turbines

- Nature of energy source
  - Variable
  - Predictable to a limited extent
  - Only downward regulation possible
- Power curve characteristics
  - Non-linear relationship wind speed vs. power
  - Loss of production when $V > V_{\text{cut-out}}$
- Variable RPM vs. fixed grid frequency
  - WTG Converters



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Offshore Wind Power Plants

- More wind, higher capacity factor
- Wake: wind speed, direction, layout
- Short-term variations balance out
- Large distance to shore/grid
- Electrical infrastructure offshore

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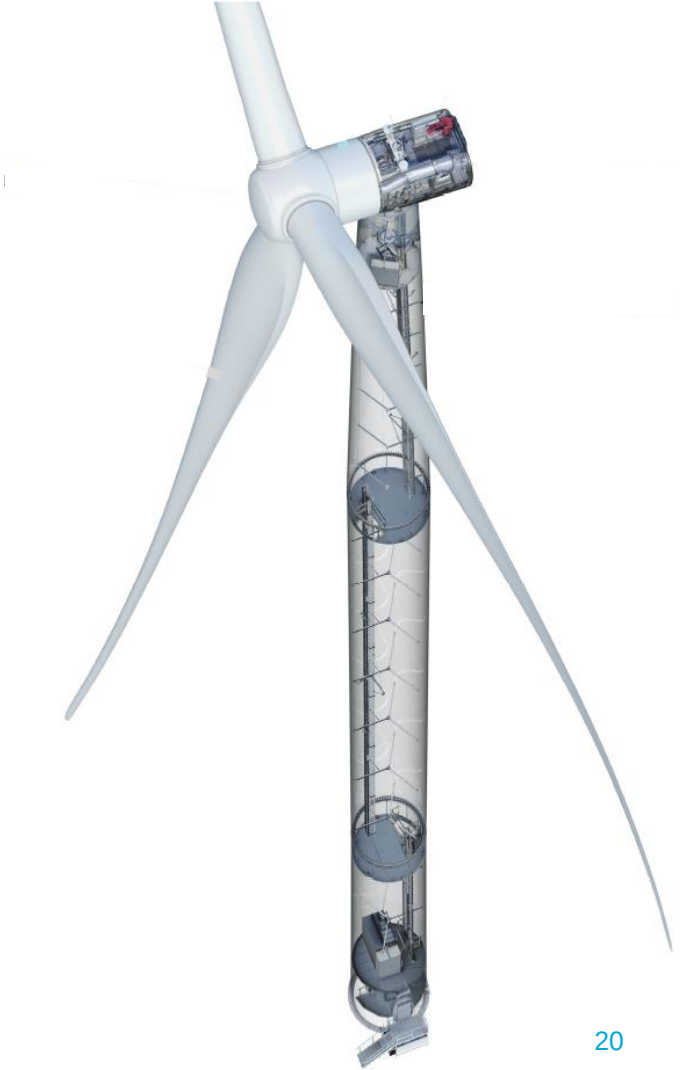
Offshore wind electrical infrastructure

Offshore Wind Turbines

- Wind speed
- RPM and blade pitch angle: MW control
- LV Generator (< 1 kV)
- Power converter: fixed 50 Hz output

- MV transformer (66 kV → 132 kV)
- MV switchgear (66 kV)



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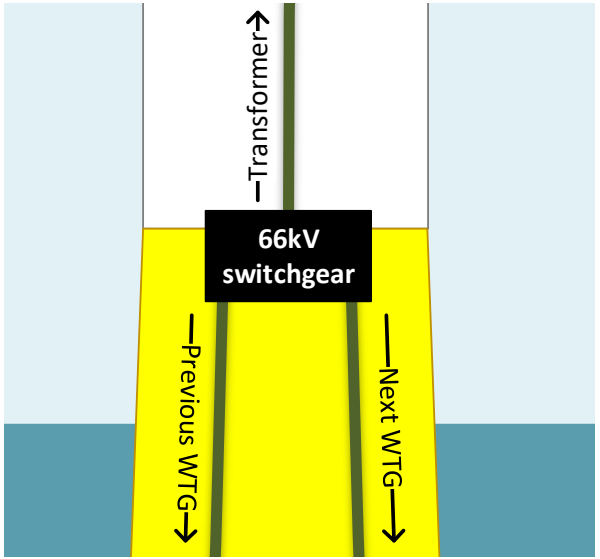
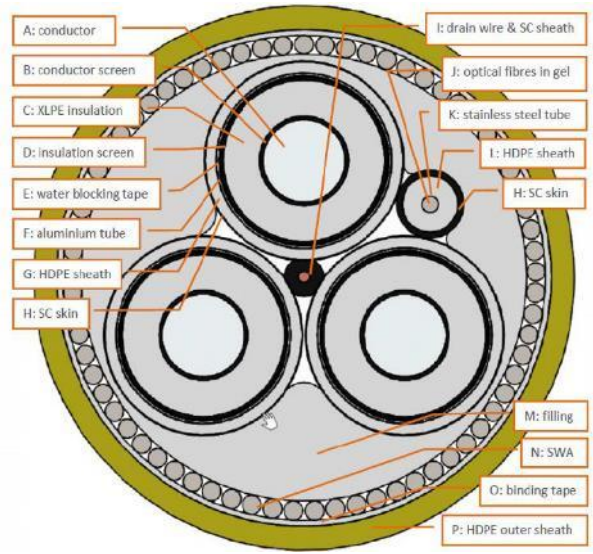
Switchgear and Inter-Array Cabling



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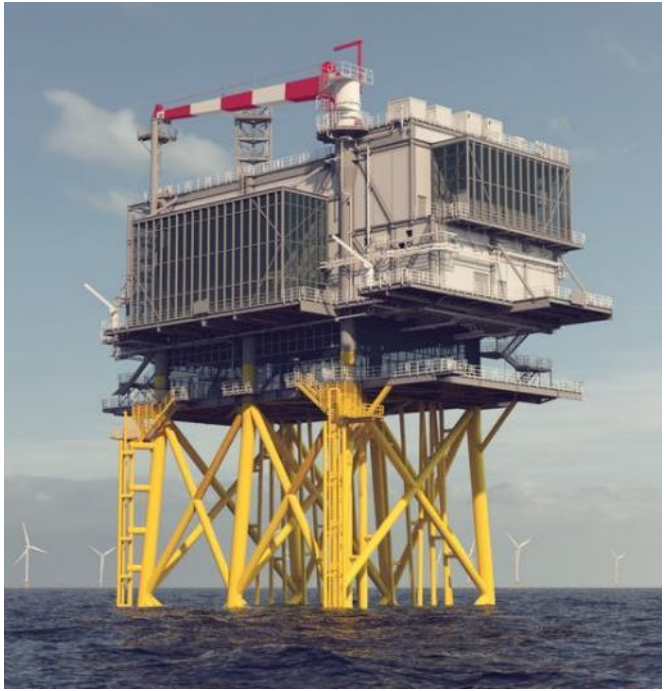
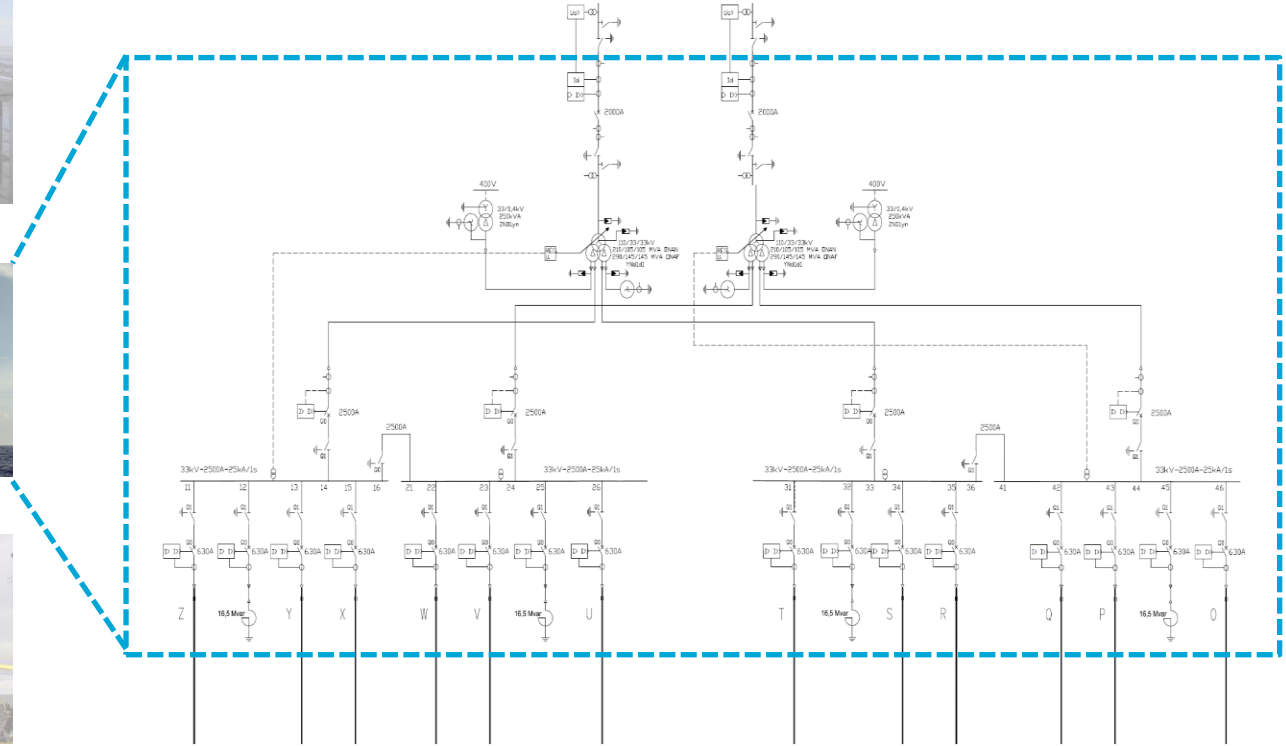
Transformer Substation

- Incoming inter-array cabling
- Switchgear
- Power transformers
- Outgoing export cabling
- HVS SCADA
- Auxiliary systems and metering



Export Cabling to Shore

Offshore Substation



Offshore Substation

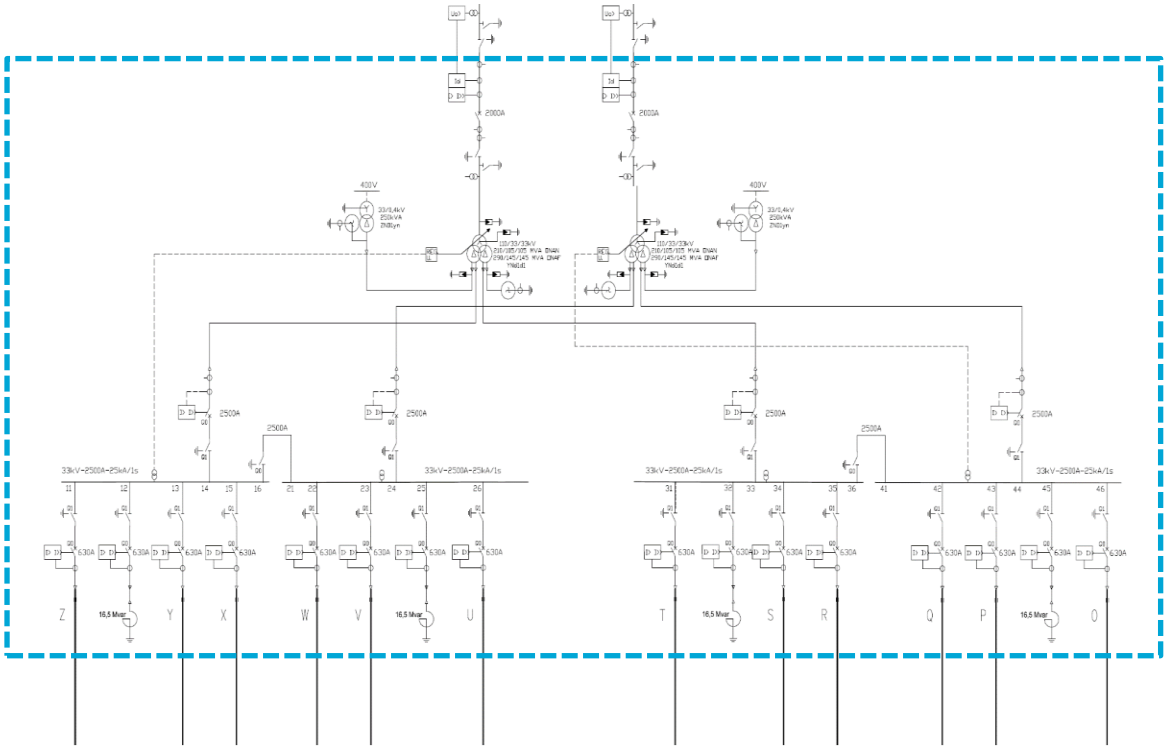
Export Cabling

Switchgear

Power Transformers

Switchgear

Inter Array Cabling

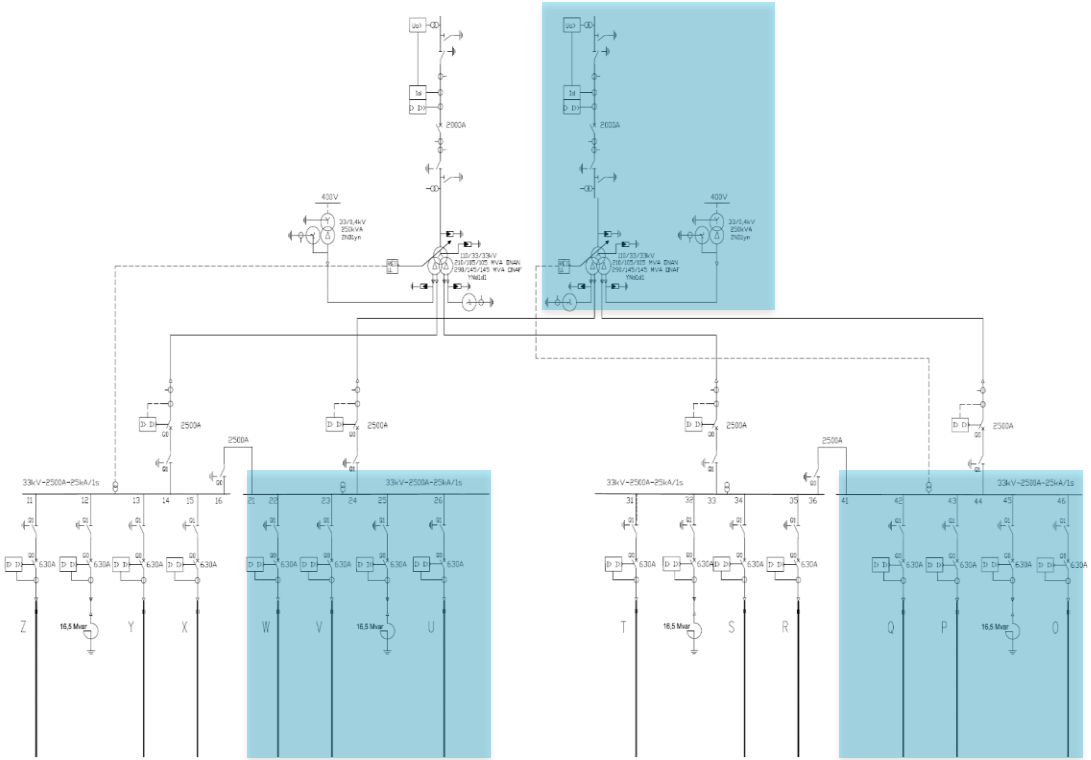


WTG Strings

WTG Strings

Redundancy

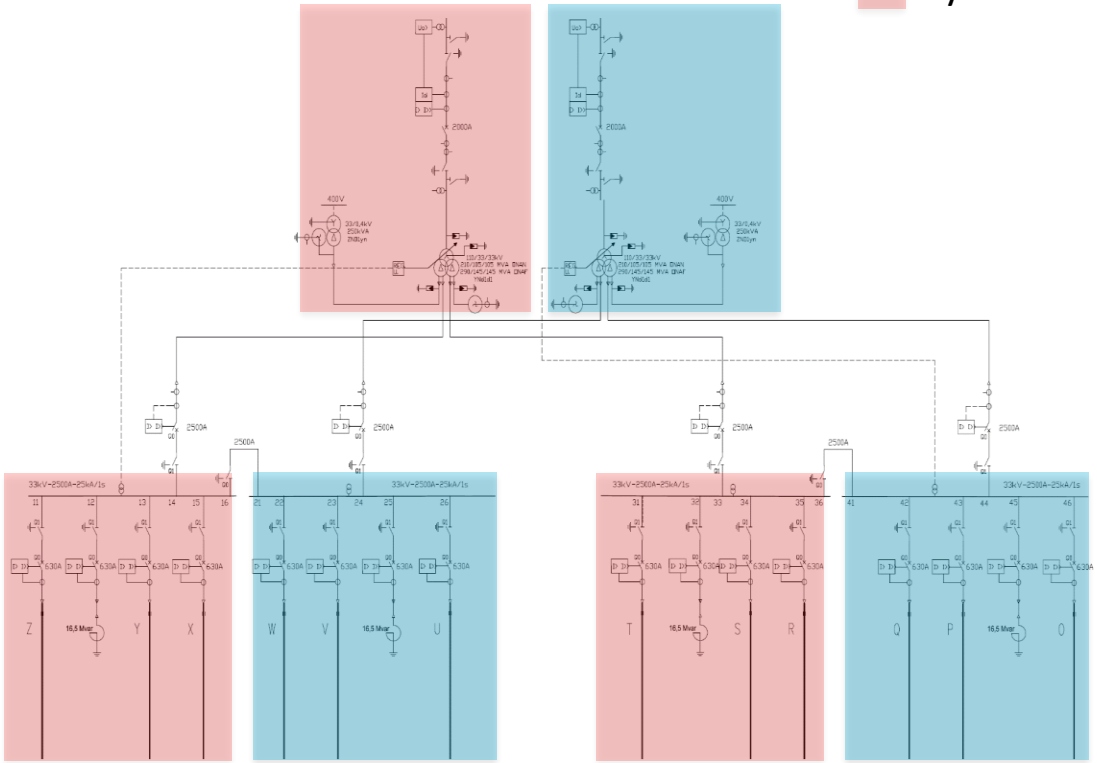
System A



Redundancy

System A

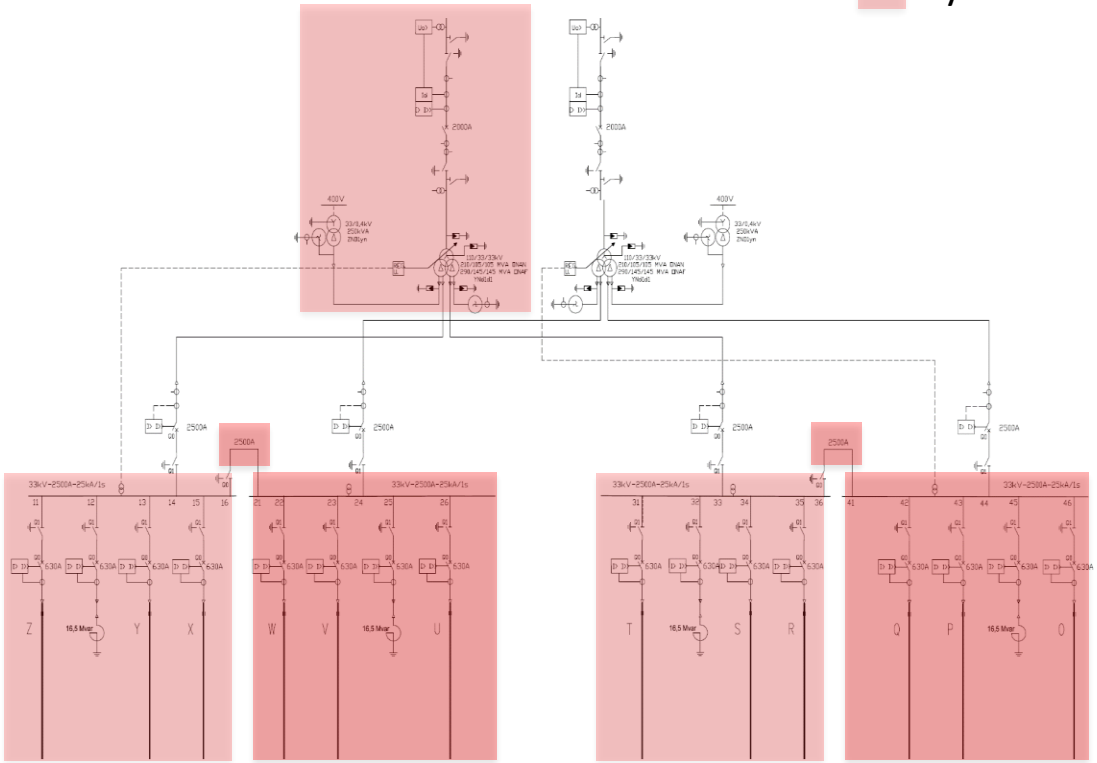
System B



Redundancy

A → B

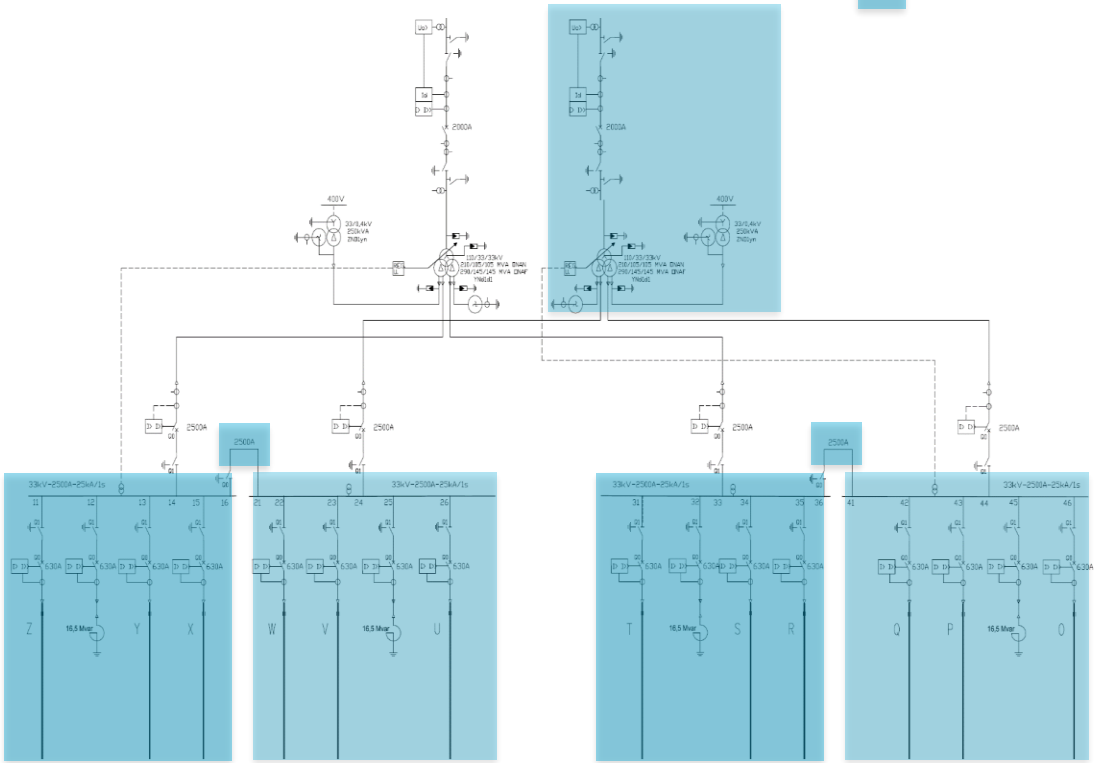
System B



Redundancy

System A

B → A



Summary

- Power system objectives: safe, reliable, efficient
- Generation = Load + Losses
- High voltage → low currents → low^2 losses
- CAPEX, OPEX, redundancy
- Offshore Wind: higher capacity factor
- Short-term power variations balance out
- Variability, unpredictability vs. power balance
- Electrical infrastructure for offshore wind parks

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Thank you!

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