Wind Power Grid Connection

25th Nov 2022

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Content

- Wind turbines & generator/drive-train concepts
- The Nordic power system and transmission grid in Finland
- Connecting wind power production units to the network in Finland
- Requirements for wind power plants for grid connection, Grid Codes
- Grid Code in Finland
- Electrical design of a wind power plant
- Simulation studies
- Offshore wind power plants

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Terminology

- Wind turbine – individual wind power production unit structure
- Wind power plant (WPP) – a group of several wind turbines at a location (a.k.a. wind farm)
- Voltage, the unit is volt V → kV
- Power (active power, P), the unit is watt W (J/s) → MW, i.e. the rate at which energy is being used/produced/transmitted
- Reactive power (Q), the unit is Var – imaginary component of apparent power, whereas active power is the real component
- (Electric) network = grid
- Grid Code – requirements set by grid operators

Wind turbine general electrical components

Typical WT today 5-6 MW

generator

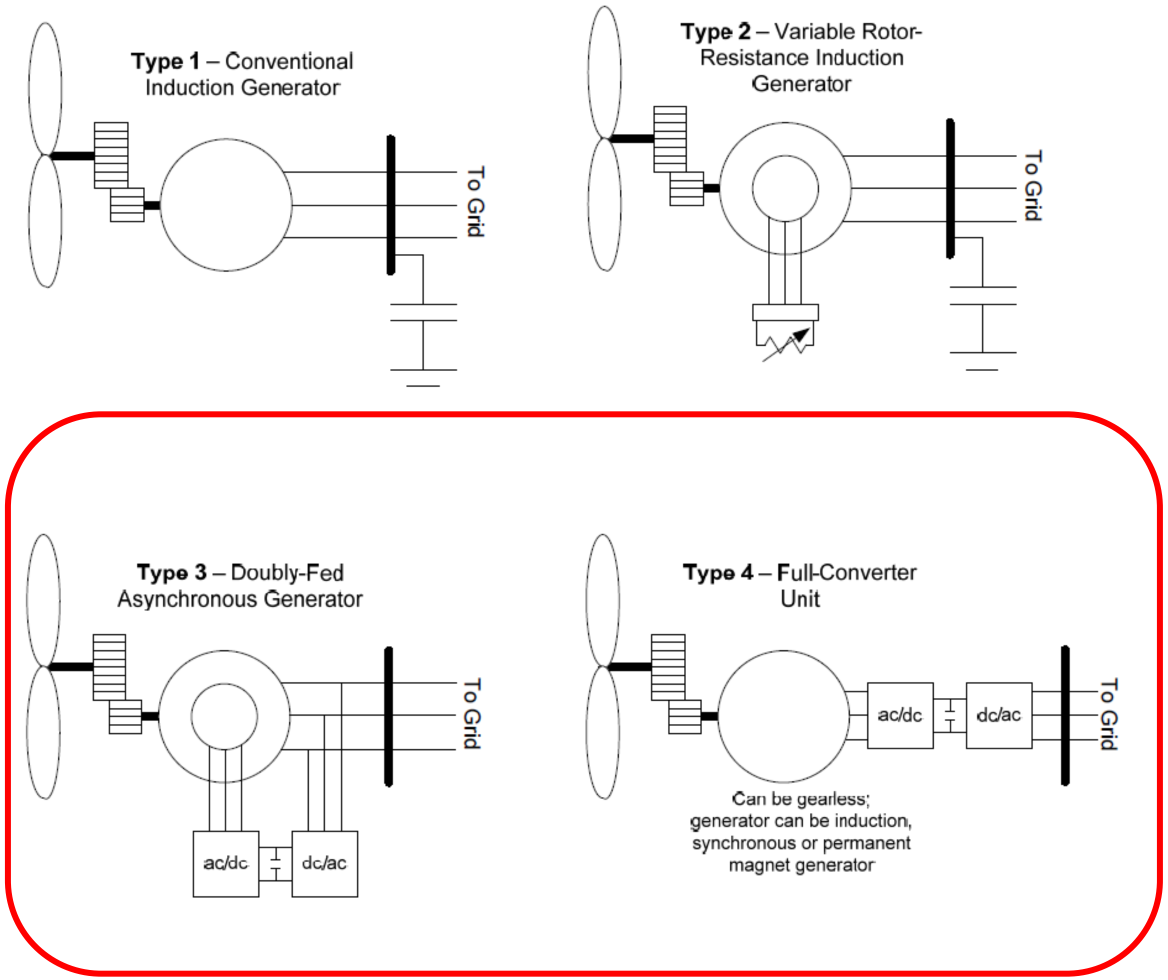
(gearbox)

converters

transformer

Component pictures source ABB

Wind Turbine Electrical Drive Trains



- three MW-class basic concepts (+ several variations)

  Type 1: Fixed speed, induction generator connected directly to the network

  Type 3: Variable speed, doubly-fed induction generator (DFIG) (or rotor resistance control, OptiSlip, Type 2)

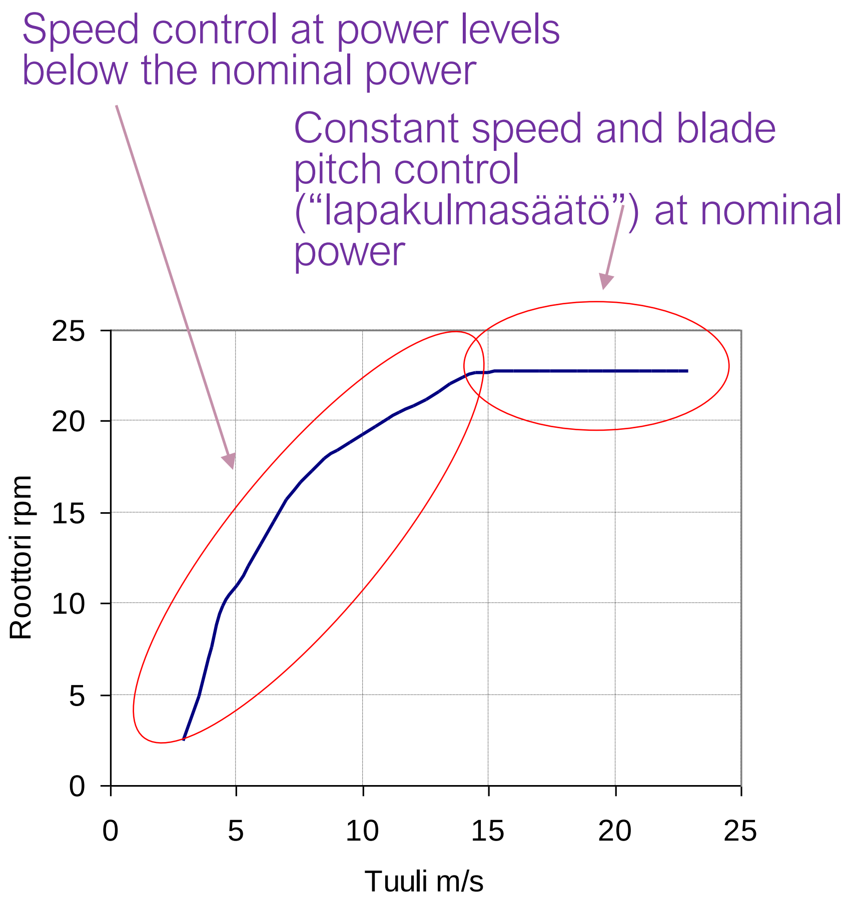
  Type 4: Variable speed, full power converter equipped generator

  (Types 1-4 according to IEC Strd 61400-27-1)

- Rotor speed slow (~10 rpm 4 MW unit), power system frequency 50 Hz (1500 rpm). There's needed
  - gear
  - or more poles in the generator
  - or power converter
  - or combination of these

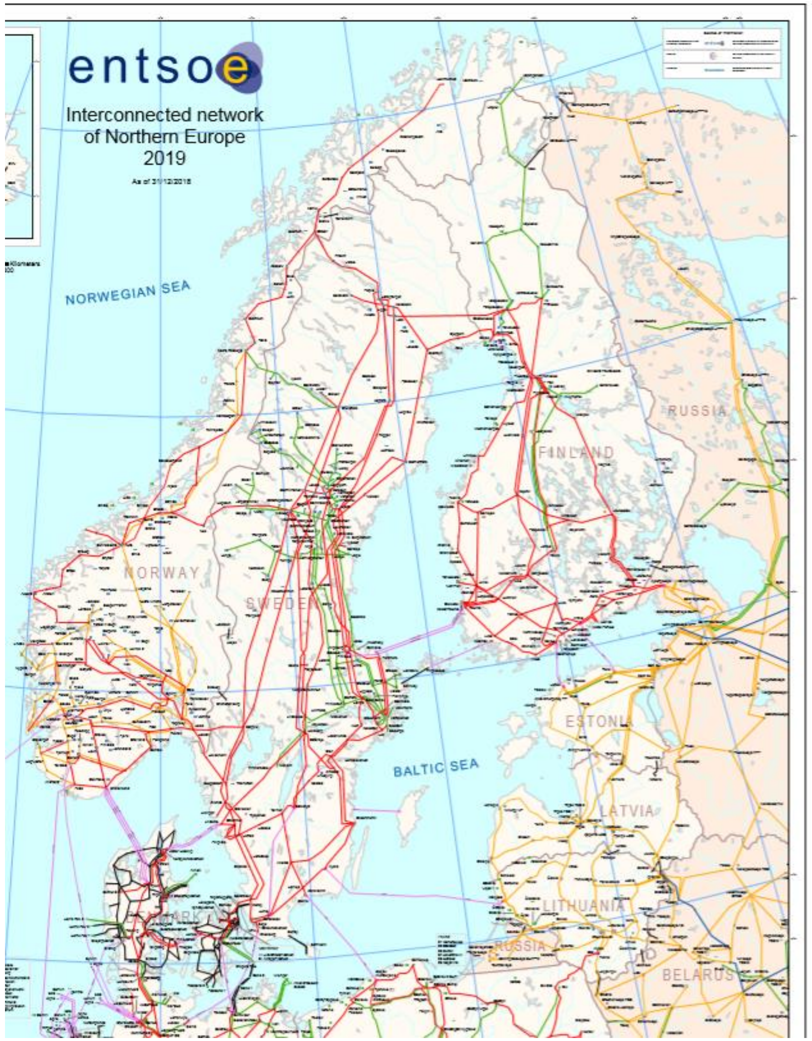
Variable speed generators – Common to Type 3 and Type 4 concepts

- Type 3 - Double-fed (or doubly-fed) induction generator (DFIG) (“kaksoissyötetty generaattori”)
- Type 4 - Full power converter equipped generator
- DFIG converter is about 1/3 of the size of the converter in full power converter WT
- Features
  - Converter enables speed control of the turbine
  - Operating range even 20 – 100 % of nominal speed
  - Reactive power is controllable
  - Causes harmonics (“yliaaltoja”) to the grid
- Benefits compared to the fixed speed turbines
  - Better aerodynamics efficiency at larger wind speed range
  - Reduction of turbine loads and stresses, especially at nominal speed
  - Reduction of aerodynamic noise
  - More flexible electrical control
  - Better possibilities for supporting the grid



The Nordic power system

- The Nordic synchronous power system consists of Finland, Sweden, Norway, and the eastern part of Denmark
- Alternating current (AC) 3-phase transmission system with 50 Hz frequency
- Fingrid is the transmission system operator (TSO) of the Finnish system
- AC-connections from Finland to
  - Sweden
  - Norway
- DC-connections (direct current) from Finland to
  - Sweden
  - Russia (IPS/UPS-system)
  - Estonia (IPS/UPS-system)
- Fingrid is a member of ENTSO-E, organization of the European (EU) TSOs



The Finnish transmission system

- National transmission system ("kantaverkko")
  - High-voltage transmission system
  - Meshed structure, as well as operation practice
  - 400 kV, 220 kV and meshed (operated) 110 kV lines
- Local high voltage networks ("alueverkot")
  - Radial or meshed structure
  - Radially operated 110 kV power lines
- Distribution networks ("jakeluverkot")
  - <110 kV networks of the local network companies
  - Medium-voltage network (mainly 20 kV)
  - Low-voltage networks (typically 400 V)
  - Radial or meshed structure, radial operation
- Lines
  - High-voltage lines > 20 000 km
  - Medium-voltage lines > 130 000 km
  - Low-voltage lines > 220 000 km

Source: Fingrid

The nominal voltage levels are:
110 kV, 220 kV, 400 kV

The normal operating voltages for the PP design are:
118 kV, 233 kV, **410 kV**

The normal voltage range in the grid at nominal levels:
400 kV: **395–420 kV**,
220 kV: **215–245 kV**,
110 kV: **105–123 kV**

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WPPs connected & connecting to grid

- Grid connected WPPs:
  - the older, the smaller: single unit or a few units, small unit size
  - over past few years:
    - turbine capacity 4.2 → 5.7 MW
    - power plants 25…150 MW, 4..28 turbines

Suomen Tuulivoimayhdistys

tuulivoima_vuositilastot_1_6_2022_julkaisuun-2.xlsx (live.com)

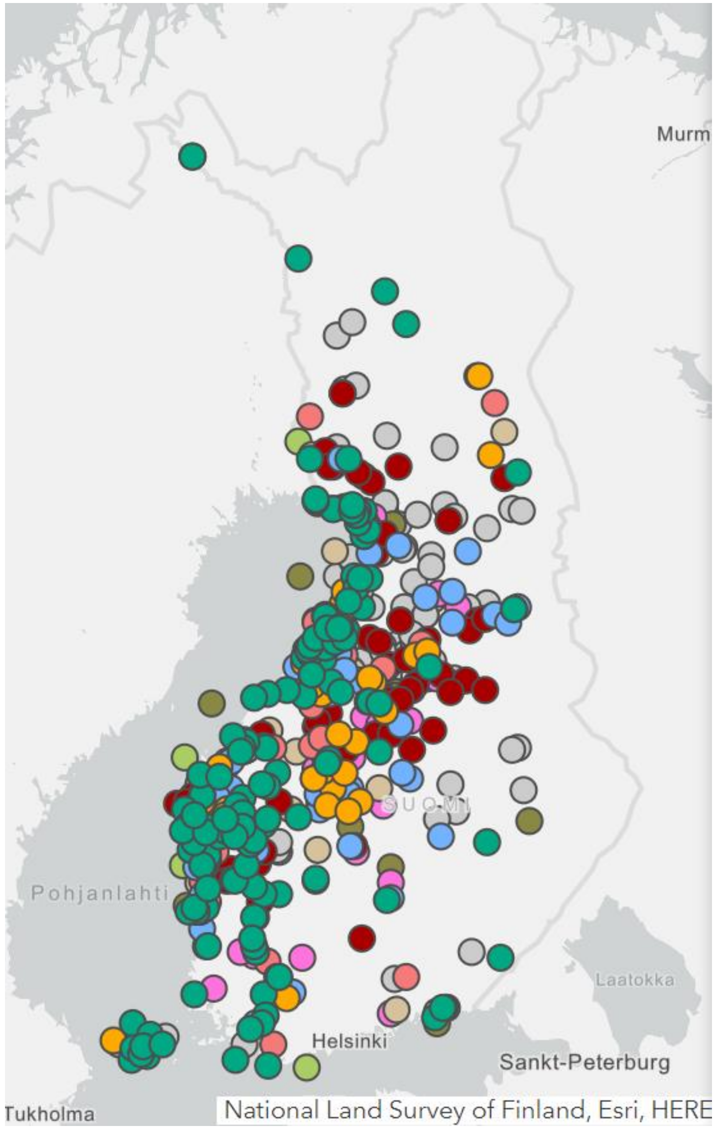
- In the grid connection process now
  - Bigger turbines, 5…6 MW
  - Power plants 30…450 MW, 5…69 turbines

Suomen Tuulivoimayhdistys

rakenteilla_2022_2025_olevat_hankkeet-5.10..2022.xlsx (live.com)

- the majority of existing the wind power plants are connected to 110 kV level
- the largest wind power plant (to be commissioned in 2024-25) Lestijärvi, 455 MW, connecting to 400 kV by 400 kV power line

Kartta - Suomen Tuulivoimayhdistys



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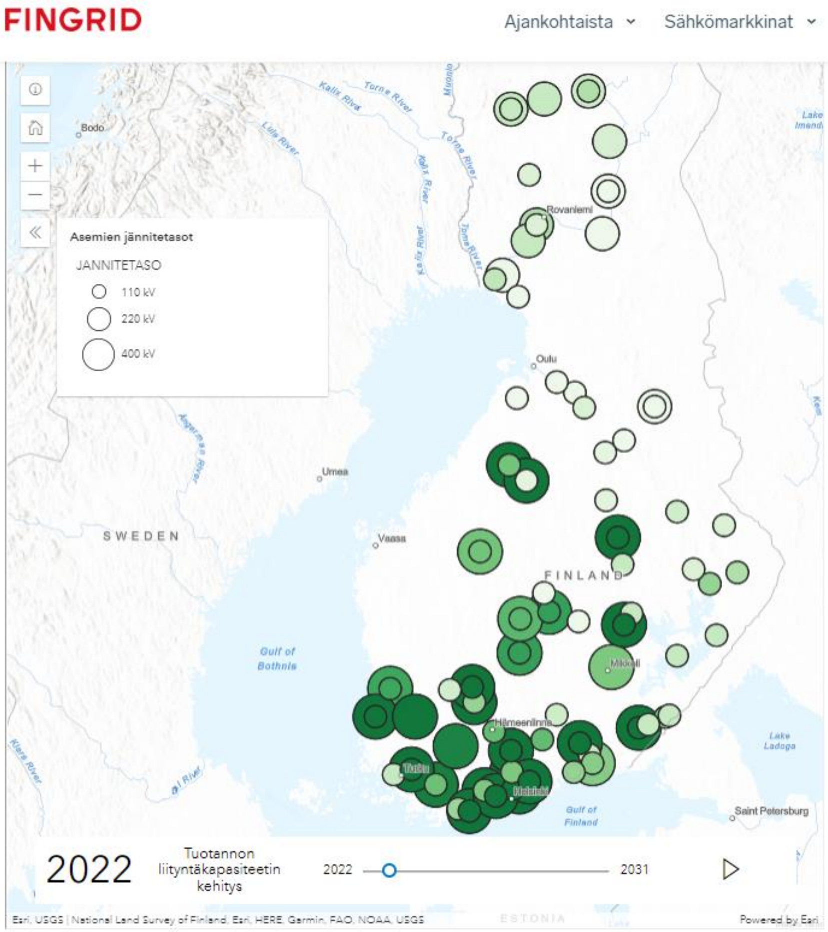
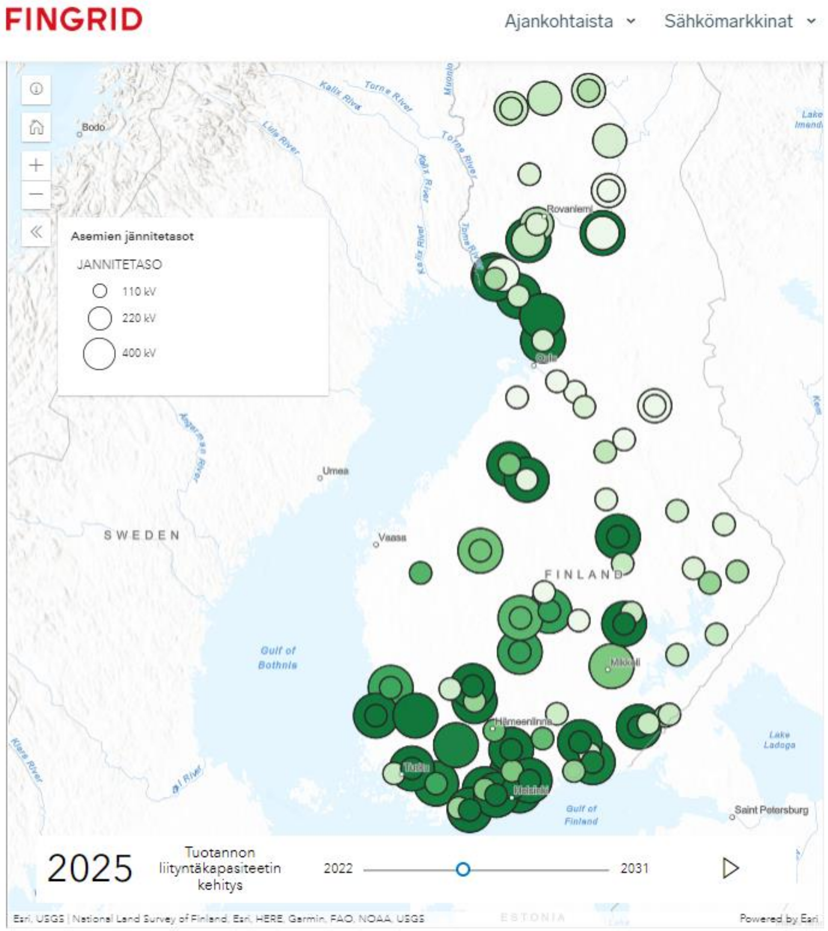
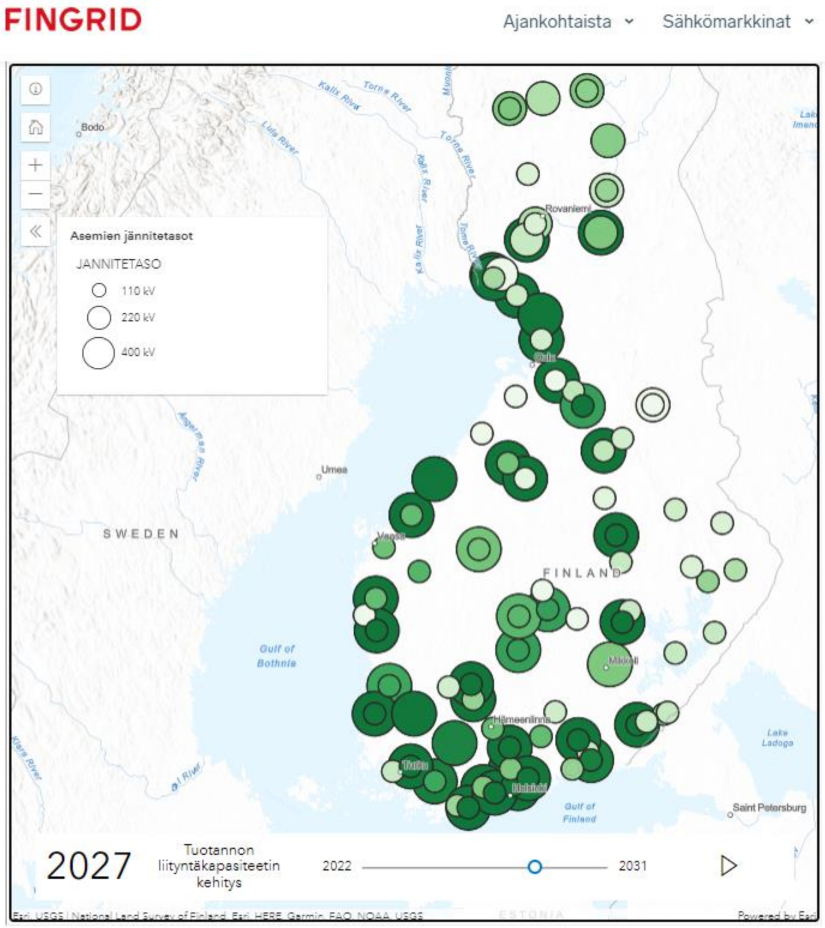
Grid connection possibilities

- Grid practically full in the west cost, connections on hold for a few years until Fingrid grid reinforcements ready

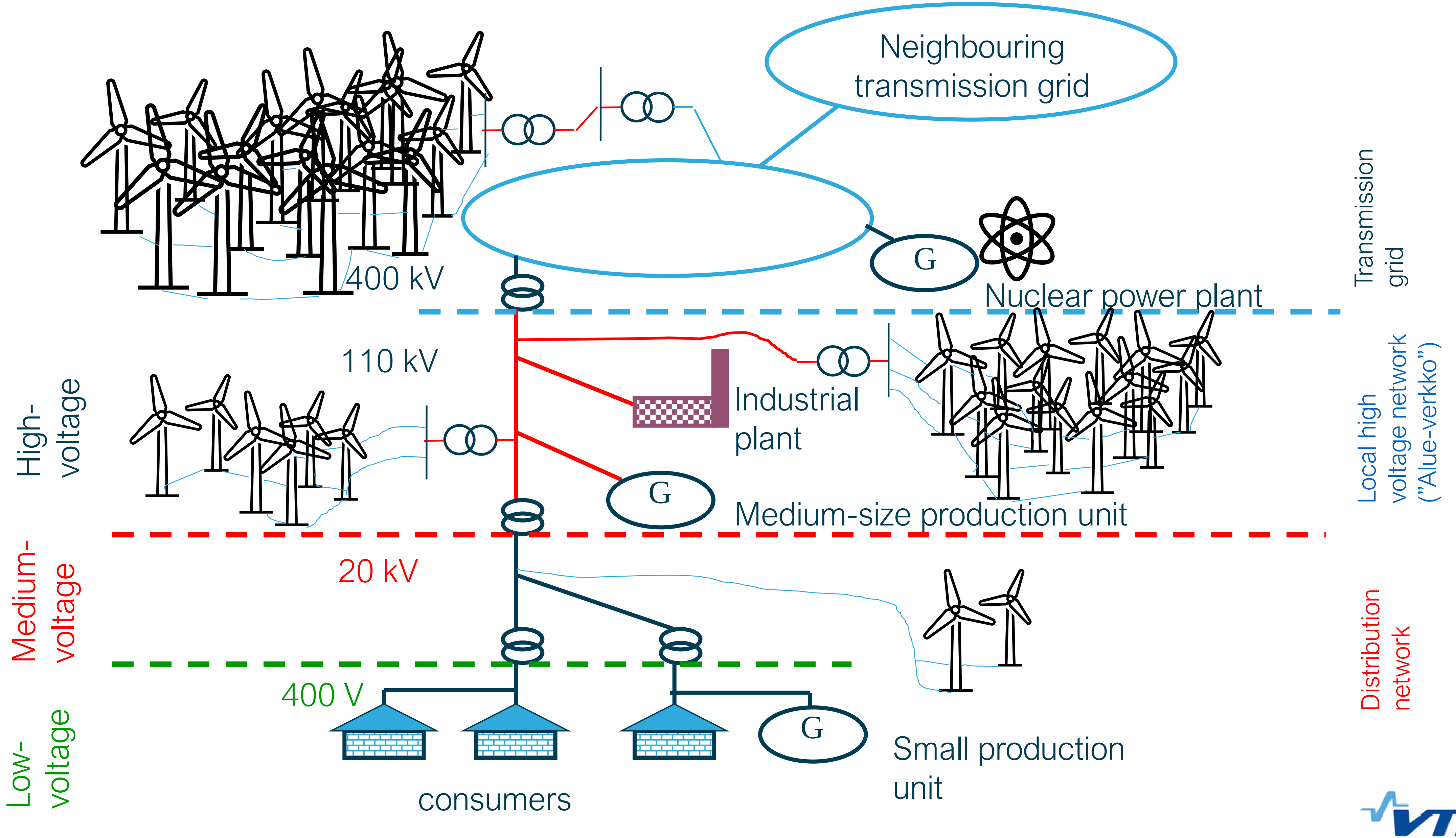
Verkkokiikari - Fingrid





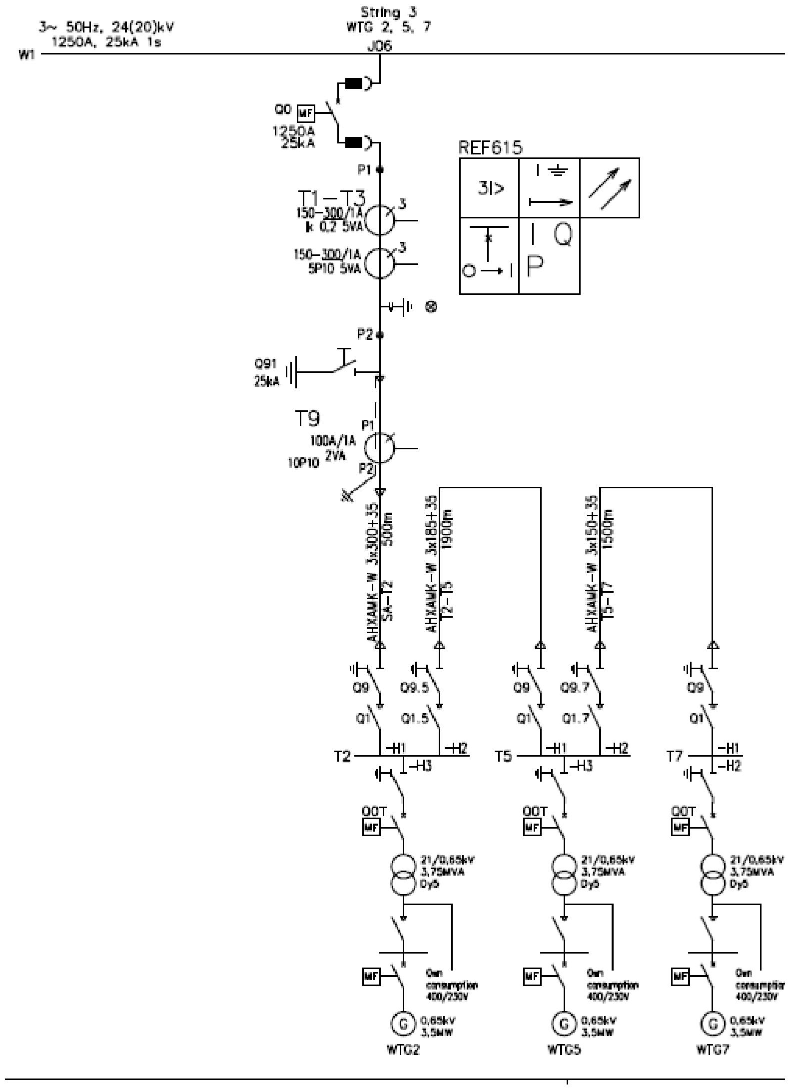


General overview of grid connection locations:



Electrical design of a wind power plant

- Consider the grid code requirements and other relevant regulations and standards throughout the WPP electrical planning & design
- Also consider the costs, e.g.
  - Material/component/work expenses
  - Operating costs, e.g. internal power transmission losses, potential loss of production due to component outages
- Electrical design of a WPP consists of, e.g.
  - Cabling dimensioning & design (typically 33 kV)
  - Main transformer selection
  - Instrumentation design & dimensioning
    (e.g. breakers, relays, metering…)
  - Determining the protection settings
  - Design of additional components /arrangements to comply with the grid code requirements, e.g.
    - Capacitor bank
    - Communication arrangements to the power plant operating center, grid operator(s), internal power plant communication…



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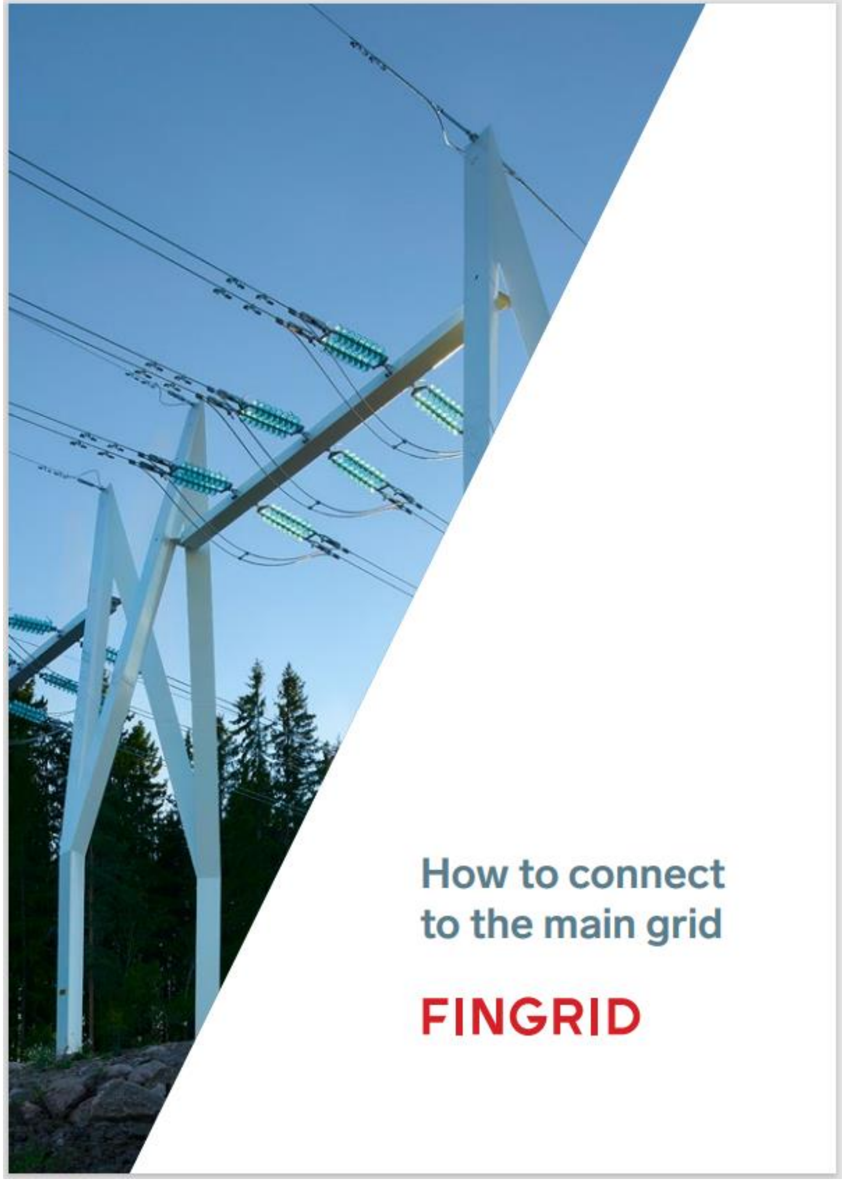
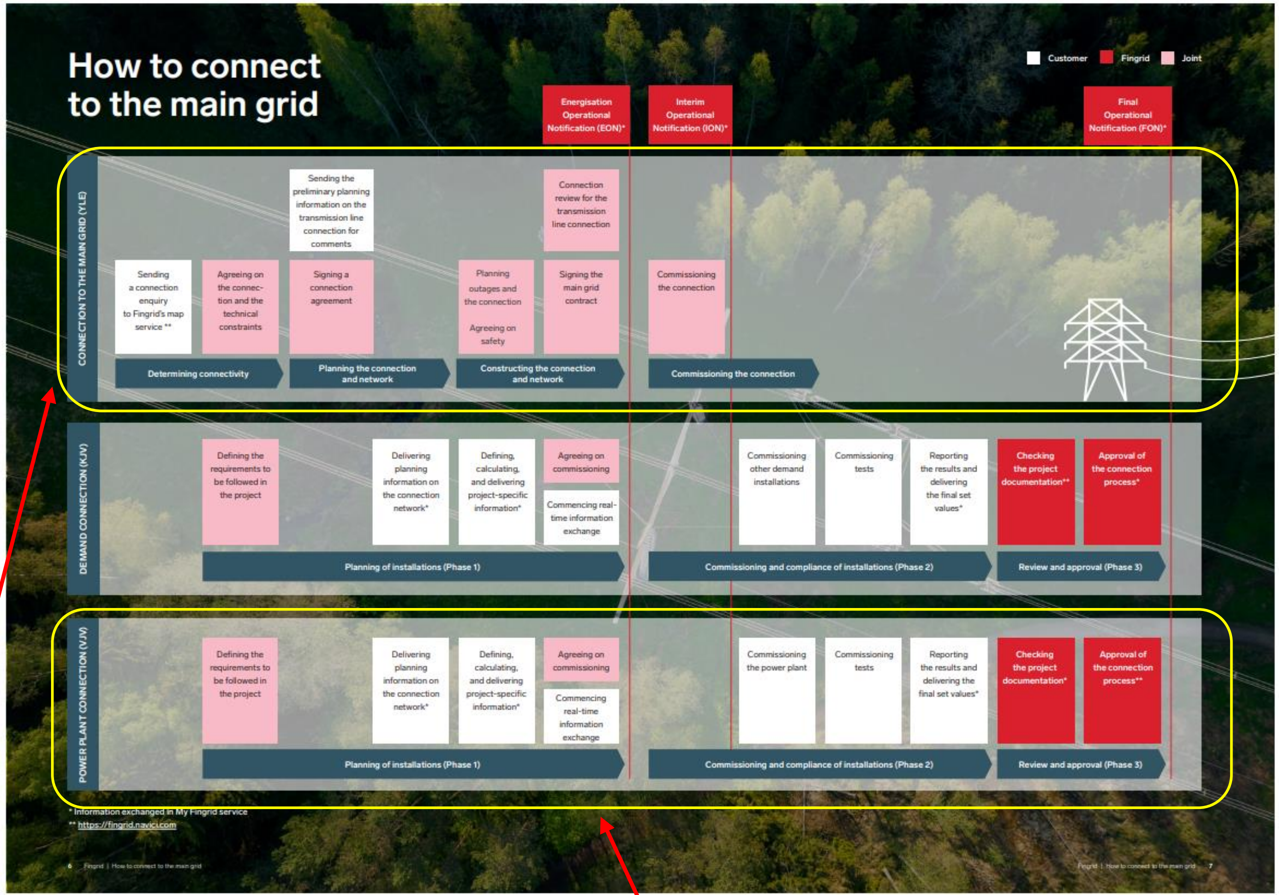
[how-to-connect-to-the-main-grid.pdf (fingrid.fi)](how-to-connect-to-the-main-grid.pdf)





Procedure for the physical connection of power plants (~"technical" requirements)

Grid Code compliance procedure for power plants (~"operational" requirements)

FINGRID UNOFFICIAL TRANSLATION 1 (15)

28.12.2021

FINGRID OYJ'S
GENERAL CONNECTION TERMS YLE2021

Multiple relevant documents!

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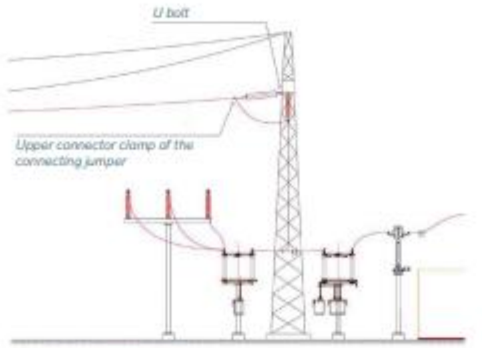
Connecting wind turbines and wind power plants to the network

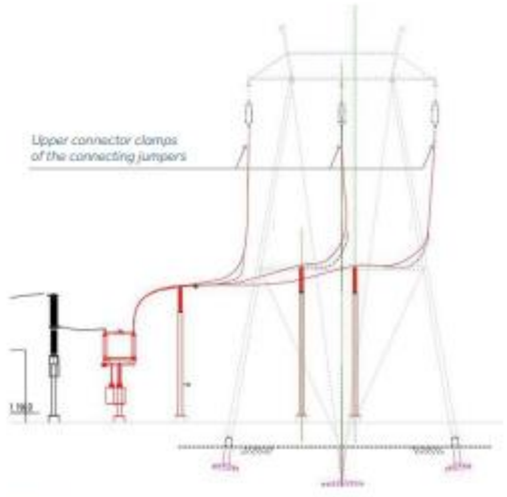
- The wind power plant **MW-capacity** and **location** determine the connection options
  - → existing grid in the area?
  - → discussion with the network operators (local and/or Fingrid)
- Network operators are obliged to grant network access upon request by law – but they determine the appropriate location and conditions
- Connection voltage level
  - 110 kV typically nowadays
  - medium-voltage network possible for small wind power plants or individual wind turbines
  - 400 kV in case of very large power plants (>250 MW)
- Connection to a power line, existing substation or new substation?
- Cheaper to connect at lower voltage level
  Connection fees (payable to network owner):
  - E.g. Fingrid connection fees on 110…400 kV levels 0.6…2 M€
  - Medium and low voltage grid connections are usually determined case-by-case

→ Connection agreement & fixed price settlement

- Distance to the connection point, need to build own HV line or cable also?



Switchyard connection
The ownership and administrative limits are the U-bolts on the terminal tower and the upper connector clamps of the connecting jumpers.



110 kV transmission line connection
The connection point and the limit of ownership are the upper connector clamps in the customer's connecting jumpers in the main grid line.

how-to-connect-to-the-main-grid.pdf (fingrid.fi)

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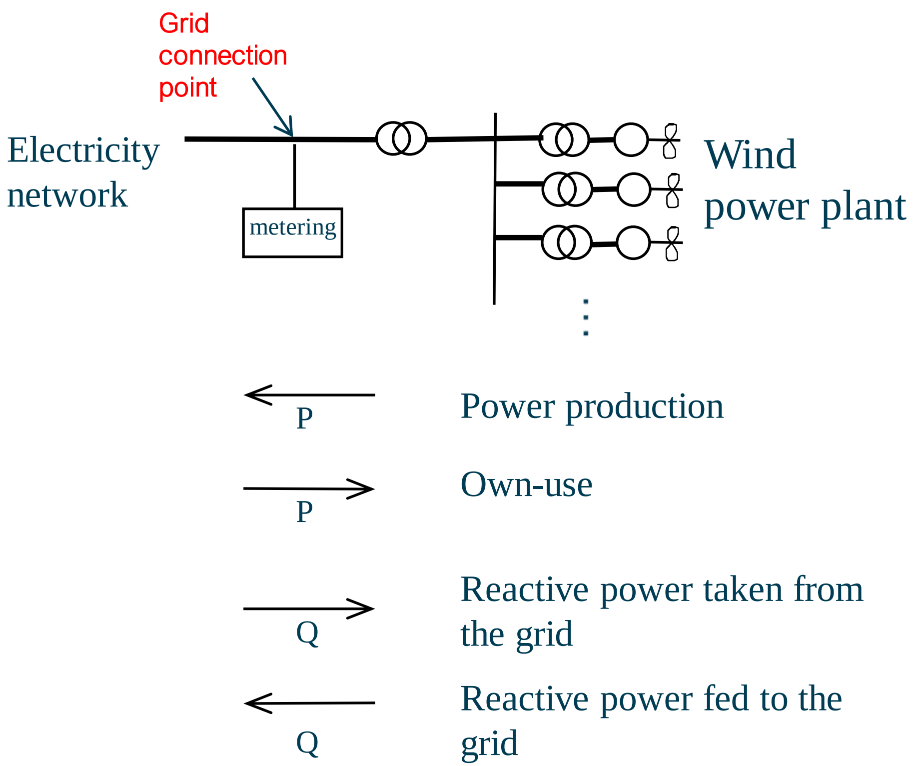
Energy metering and tariffs

- Produced electricity can be **sold freely** to anybody in Finland (e.g. by power purchase agreement, PPA) or to the electricity market ("sähköpörssiin")
- Electricity **transmission** is charged by the local grid company
- When production is smaller than own-use, the needed **electricity is bought** from somebody or the market
- Certain amount of reactive power ("loisteho") is usually **free**, but generally reactive power is expensive. Reactive power is also used to support the grid on voltage control



- Different tariff structures by different network companies, tariffs may be comprised of different components (fixed or energy/power based, seasonal differences…)

Variable costs payable to the usage of network depend on metering

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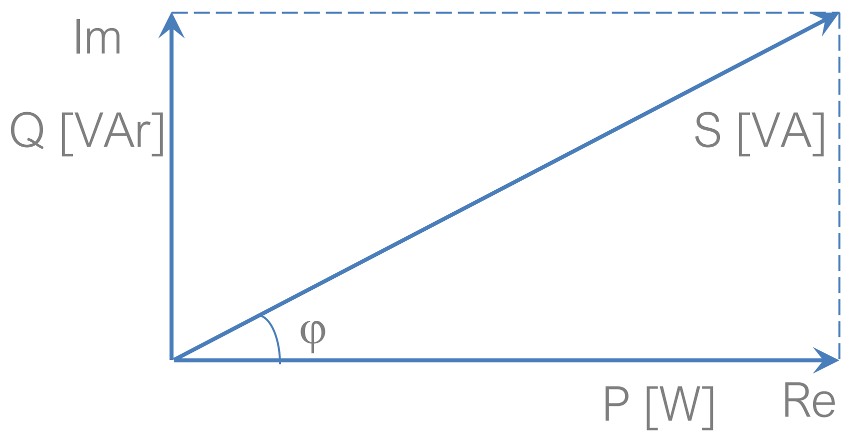
Active power, reactive power and apparent power
What are MW, MVAr & MVA?



U – voltage
I – current
cos φ – power factor
S – apparent power
P – active power (power that ”does work”)
Q – reactive power

Reactive power: Considering active power (P), the power that ”does work”, as real, reactive power (Q) is the imaginary part of total power, i.e. the apparent power (S). Reactive power is produced and/or consumed on power lines and cables, as well as electric machines. It can be produced e.g. by capacitors and consumed by shunts reactors (coils). Reactive power transmission must be avoided, because it causes losses whereas active power transmission does. By reactive power, the voltage can be controlled, which in some cases may be needed.

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Grid Code - Why?

- Grid Code Requirements are set in order to guarantee that
  - the production unit can handle the occuring voltage and frequency variations on normal voltage and frequency operating range
  - the production unit supports the power system in the case of disturbances and abnormal situations, and operates reliably during and after these situations
  - the production unit does not disturb or cause harm to other equipment connected to the grid
  - the owner of the connection grid and TSO (Fingrid in Finland) has all necessary information of the production unit for power system planning and operation planning purposes.

https://www.entsoe.eu/network_codes/

entsoe

What are Network Codes?

Network codes are a set of rules drafted by ENTSO-E, with guidance from the Agency for the Cooperation of Energy Regulators (ACER), to facilitate the harmonisation, integration and efficiency of the European electricity market. Each network code is an integral part of the drive towards completion of the internal energy market, and achieving the European Union's energy objectives

...

One of the Codes

Requirements for Generators

The Network Code on Requirements for Generators is harmonising standards that generators must respect to connect to the grid. These harmonised standards across Europe will boost the market of generation technology and increase competitiveness.

CURRENT STATUS
✓ Entered into force
Read the guideline

= NC RfG

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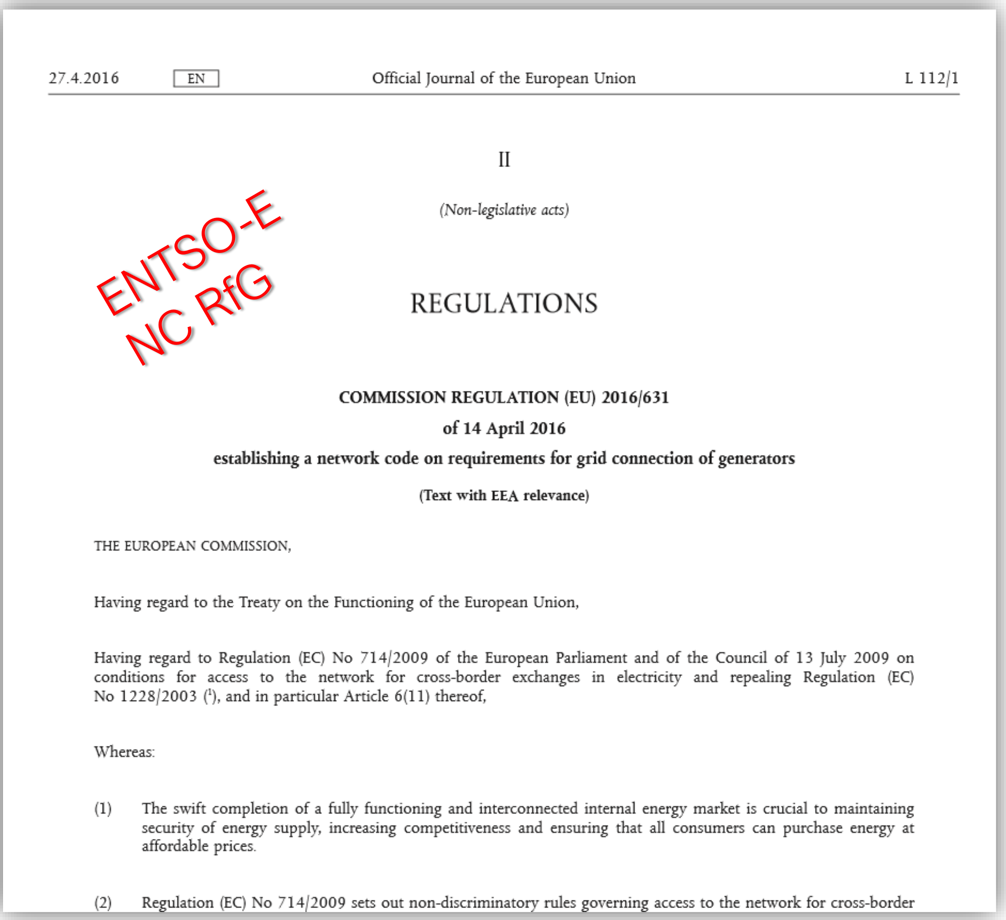
ENTSO-E Grid Code(s) and National GC(s) in Finland


ENTSO-E NC RfG

27.4.2016 EN Official Journal of the European Union L 112/1

II

(Non-legislative acts)

REGULATIONS

COMMISSION REGULATION (EU) 2016/631

of 14 April 2016

establishing a network code on requirements for grid connection of generators

(Text with EEA relevance)

THE EUROPEAN COMMISSION,

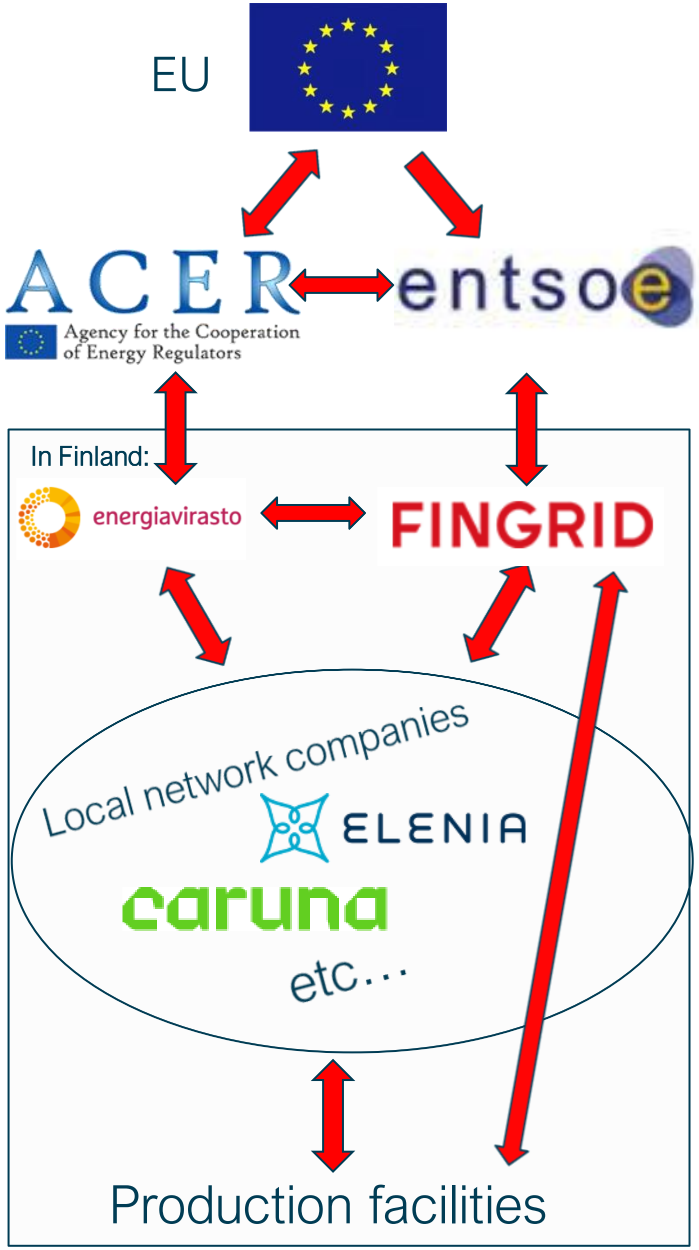
Having regard to the Treaty on the Functioning of the European Union,

Having regard to Regulation (EC) No 714/2009 of the European Parliament and of the Council of 13 July 2009 on conditions for access to the network for cross-border exchanges in electricity and repealing Regulation (EC) No 1228/2003 ([1]), and in particular Article 6(11) thereof,

Whereas:

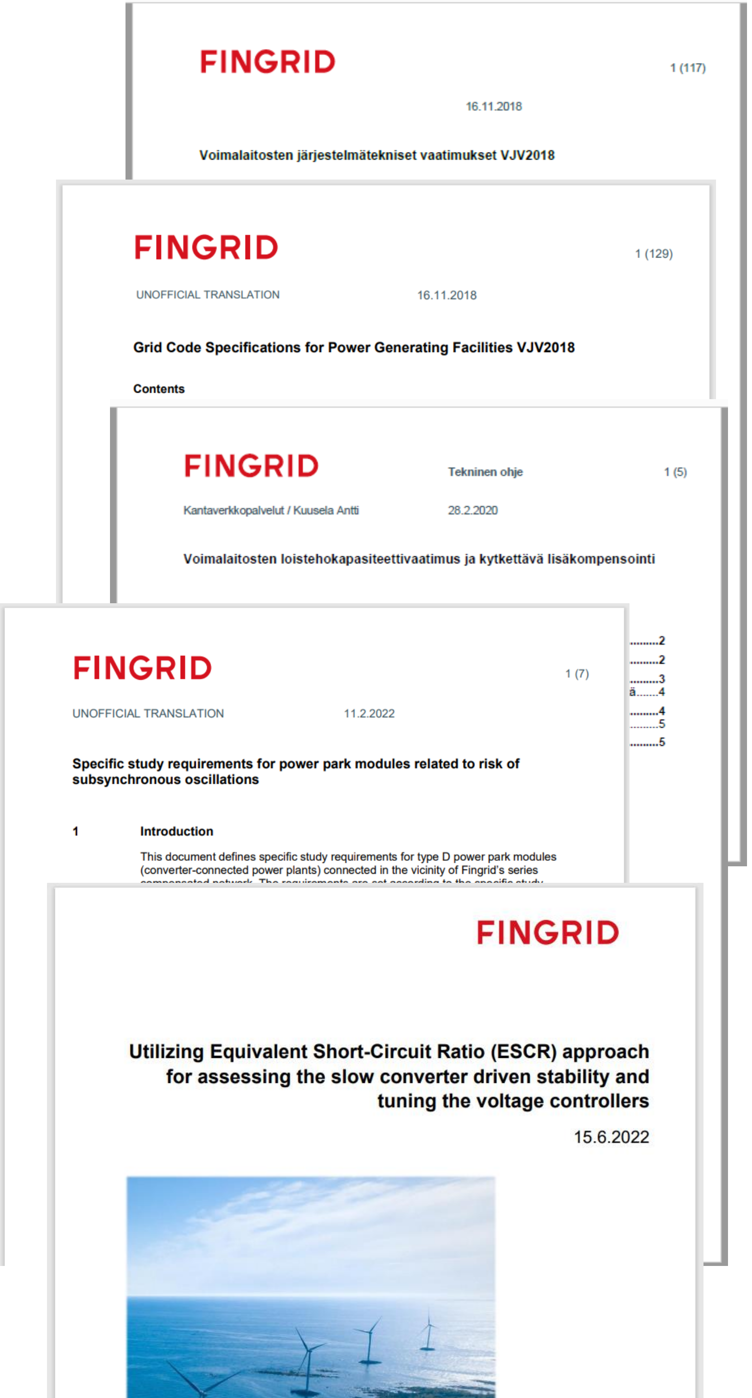
(1) The swift completion of a fully functioning and interconnected internal energy market is crucial to maintaining security of energy supply, increasing competitiveness and ensuring that all consumers can purchase energy at affordable prices.

(2) Regulation (EC) No 714/2009 sets out non-discriminatory rules governing access to the network for cross-border



Grid Code in Finland - VJV2018

- VJV2018 in force since Nov 2018
  - prepared and issued by Fingrid, approved by Energy authority (“Energiavirasto”)
  - based on ENTSO-E RfG (Network Code on Requirements for Generators)
  - applies to new power plants with generating facility procurement agreement signed after May 19th, 2018, and existing power plants when their electrical characteristics are changed
- earlier VJV2013 since Nov. 2013
  - A share of the existing WPPs in Finland commissioned based on VJV2013
- Official and binding requirements in the Finnish version VJV2018
  - English translation available
  - Several guidance documents specifying in more detail the requirements and providing additional technical information
- National VJV update estimated in 2024


FINGRID 1 (117)
16.11.2018
Voimalaitosten järjestelmätekniset vaatimukset VJV2018

FINGRID 1 (129)
UNOFFICIAL TRANSLATION 16.11.2018
Grid Code Specifications for Power Generating Facilities VJV2018
Contents

FINGRID Tekninen ohje 1 (5)
Kantaverkkopalvelut / Kuusela Antti 28.2.2020
Voimalaitosten loistehokapasiteettivaatimus ja kytkettävä lisäkompensointi

FINGRID 1 (7)
UNOFFICIAL TRANSLATION 11.2.2022
Specific study requirements for power park modules related to risk of subsynchronous oscillations
1 Introduction
This document defines specific study requirements for type D power park modules (converter-connected power plants) connected in the vicinity of Fingrid's series

FINGRID
Utilizing Equivalent Short-Circuit Ratio (ESCR) approach for assessing the slow converter driven stability and tuning the voltage controllers
15.6.2022

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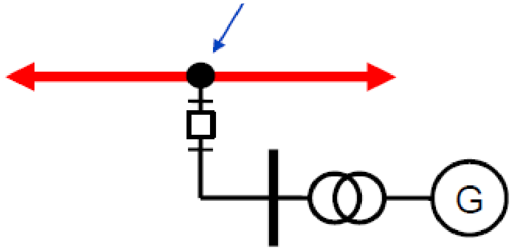
Fingrid VJV2018 – Content outline

- VJV2018 specifies the national requirements in more detail within ENTSO-E RfG framework requirements
- Requirements specified separately for
  - synchronous (conventional) generation units and for power park modules, e.g. wind power plants, and
  - different requirements for different sizes of power plants & location of connection (voltage level) – A,B,C,D
- Technical requirements must be fulfilled at the grid connection point (in any grid in Finland)
- Includes a requirement to verify the fulfillment of the requirements (”vaatimusten täyttymisen todentaminen”) and commissioning tests (“käyttöönottokokeet”)
- Documentation of the power plant to Fingrid
- Requirement to exchange information with Fingrid
- Requirement to provide simulation models and some specific simulation results to Fingrid

Connection point



Rated power / Connection point voltage	0,8 kW – < 1 MW	1 MW – < 10 MW	10 MW – < 30 MW	30 MW ≤
U < 110 kV	A	B	C	
110 kV ≤ U	D	D	D	D

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Examples of the technical requirements in VJV2018

"The Specifications shall be fulfilled at the connection point or at a point defined separately by a specific requirement."

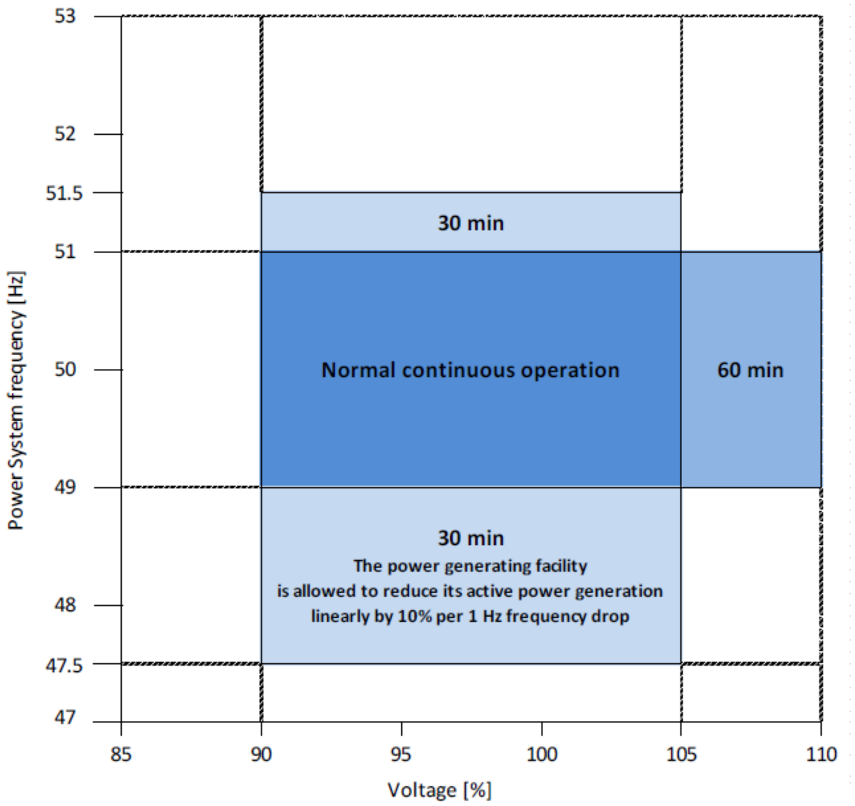

Figure 10.5. The power generating facility must remain connected to the network at the different frequencies and voltages at the connection point set out in the figure. The 100% voltage of the continuous operating range in the 400 kV grid is always 400 kV. At other voltages, the voltage corresponding to the 100% value shall be inquired from the relevant network operator.

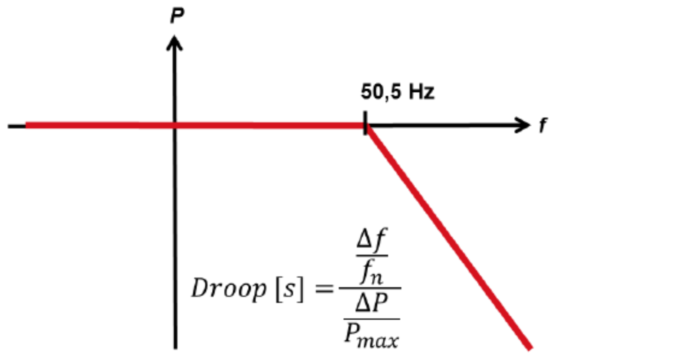

Figure 10.1. In LFSM-O operation, the power generating facility must be capable of reducing its active power production as a linear function of frequency when the electricity system's frequency exceeds 50.5 Hz. It shall be possible to adjust the droop to between 2 and 12 per cent. In the figure, f is the frequency, f_n is the nominal frequency (50 Hz), P is the power generating facility's active power, P_{max} is the power generating facility's rated capacity.

Table 20.1. Verification obligation of modelling data on wind power park modules by type.

Item to be verified	Type C	Type D
Step response of voltage control of the power generating facility using two different slope values (both the increase and decrease in voltage)	X	X
Reactive power capacity of the power generating facility and the functioning of limiters that restrict the capacity	X	X
Operation of additional control functions, such as POD (Section 18.3).		X
Fault-ride-through test [1]	X	X

[1] To be agreed on a case-by-case basis. If a fault-ride-through test for the power generating facility is not carried out, the functioning of the power generating facility in a local fault shall be demonstrated by means of simulation calculations.

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A BREAK

?

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Electrical simulation studies for a WPP

Primarily for WPP planning

Primarily to fulfill the requirements

- Steady state
  - Load flow
    - System dimensioning
    - Reactive power capability
  - Short circuit calculation
    - System dimensioning
    - Protection settings and co-ordination
- Dynamic simulations (RMS, EMT)
  - Grid Code Compliance
    - Voltage/Reactive Power Control
    - Fault ride-through
    - (Active Power and Frequency Control)
    - Simulation studies for Subsynchronous Oscillation risk
  - Model validation
  - Controller tuning/development

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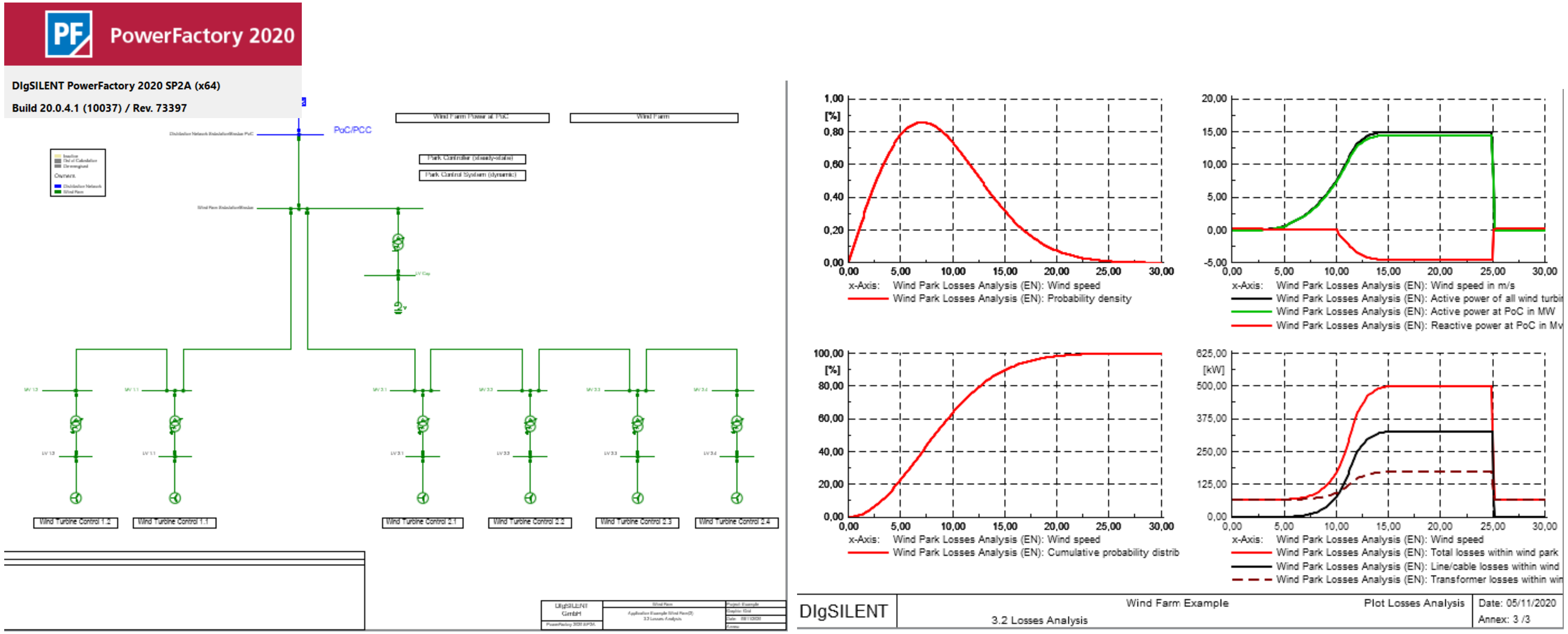
Dimensioning of WPP internal network
Example: loss analysis



Electrical energy losses per year

	Total	In feed-in operation	In consumption operation	losses in feed-in operation:
Total:	1755,19 MWh	1704,26 MWh	50,93 MWh	85212,87 USD/a
Cables:	885,24 MWh	885,23 MWh	0,02 MWh	44261,26 USD/a
Cables, HV:	0,00 MWh	0,00 MWh	0,00 MWh	0,00 USD/a
Cables, MV:	885,24 MWh	885,23 MWh	0,02 MWh	44261,26 USD/a
Cables, LV:	0,00 MWh	0,00 MWh	0,00 MWh	0,00 USD/a
Transformers:	869,94 MWh	819,03 MWh	50,91 MWh	40951,61 USD/a
Transformers, HV-MV:	0,00 MWh	0,00 MWh	0,00 MWh	0,00 USD/a
Transformers, MV-LV:	869,94 MWh	819,03 MWh	50,91 MWh	40951,61 USD/a
Transformers, LV-LV:	0,00 MWh	0,00 MWh	0,00 MWh	0,00 USD/a

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Protection ("suojaus") 1/2

Generally & roughly about network and production unit protection

- Background: There occur faults (e.g. short circuits) in electricity networks at times. The faulted part of the network must be disconnected and the fault needs to be cleared. Large fault currents could brake equipment, and the operation at a low voltage during the fault could be difficult.
- Solution: Network protection could be based on detecting the large fault currents to locate the fault in order separate the faulted part of the network and attempt to clear the fault (e.g. disconnect and reconnect very soon). False disconnections need to be avoided.
  - Protection implemented by relays and breakers
- Other features: There are also other quantities (e.g. frequency) related to protection issues and different use of, and protection settings of voltages, currents, rates of changes in quantities… in order to identify abnormal operation and implement the protection.

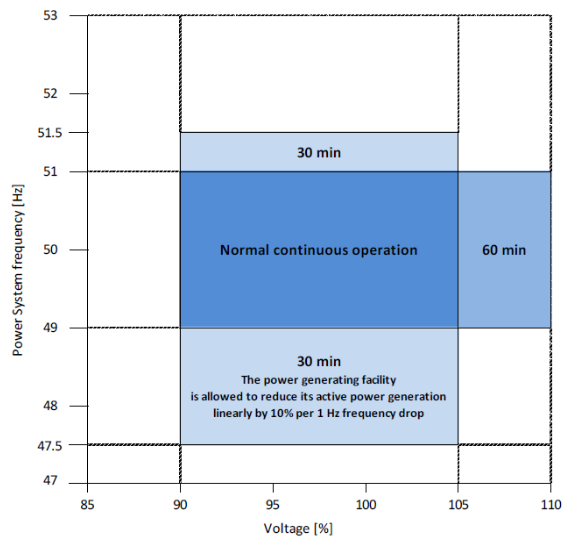

Figure 10.5. The power generating facility must remain connected to the network at the different frequencies and voltages at the connection point set out in the figure. The 100% voltage of the continuous operating range in the 400 kV grid is always 400 kV. At other voltages, the voltage corresponding to the 100% value shall be inquired from the relevant network operator.

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Protection (“suojaus”) 2/2

Network and production unit protection related to wind power

- The goal is to guarantee operation of relay protection – this is a challenge especially in the distribution networks, where there’s normally only power consumption, no production
- Generally, the protection is based on over-currents (i.e. short-circuit currents)
- In protection planning it is important to know electrical properties of the production unit, which depend on the generator / electrical drive type of the unit
- There are differences especially in the units’ abilities to feed short-circuit current
- Full power converter equipped turbines:
  - Converters’ (with power electronic devices) ability to feed short-circuit current is limited (approximately up to the nominal current or slightly above)
- Wind turbine / power plant protection:
  - Must disconnect sufficiently fast from the grid in case of grid fault (the fault is on the same radial line the unit is connected to, in case the fault is on different line, the units should not disconnect), i.e. during the high-speed auto-reclosure (HSAR, “pikajälleenkytkentä”, PJK)
  - Island operation must be avoided
  - But there are requirements for the unit to remain connected during a fault that is cleared (a short duration, low voltage dip), i.e. to ride-through the fault

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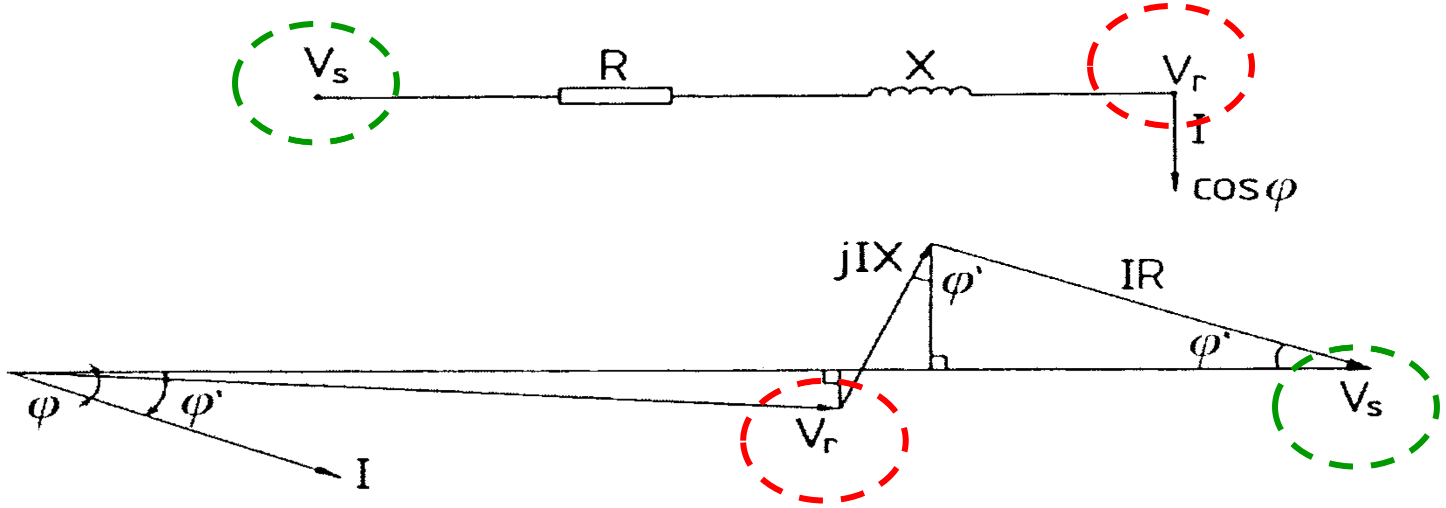
Voltage impacts of power production



- Current flowing on a conductor decreases voltage on the line
- Absolute value of the voltage is what we look at
- Decrease in voltage Vh = Vs - Vr ≈ I R cosφ + I X sinφ

Sufficient assumption when X/R is reasonable and cosφ is close to 1, i.e. reactive power transmitted is low

- Basic rule of thumb: power production increases voltage & power consumption decreases voltage at the point the production/consumption is located

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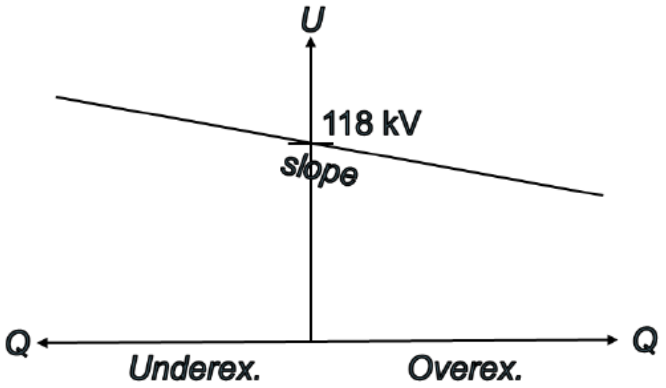
Voltage control

- Whereas *active power* (P) feed or power production increases voltage at the feeding point, *reactive power* (Q) can be used to control voltage
- Qcap (capacitive, feeding Q) to increase voltage
- Qind (inductive, absorbing Q) to decrease voltage
- Certain amount of reactive power capacity needed to enable voltage control according to the requirements
- In Finland, WPPs generally operate on voltage control (e.g. voltage setpoint 118 kV, and 4 % slope with Qn = 0.33 *Pn)

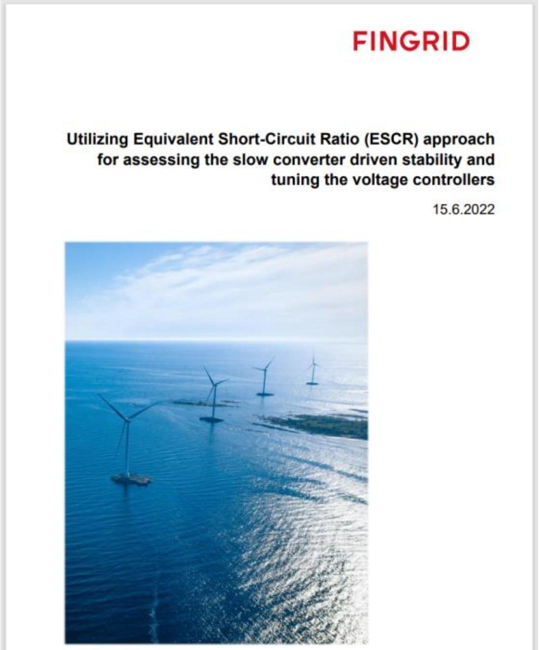


$$slope = \frac{\frac{\Delta U}{U_n}}{\frac{\Delta Q}{Q_n}}$$

Figure 22.1. Slope

Source: Fingrid VJV2018

- Since recently, a new controller tuning method to be applied as required by Fingrid:
  - To co-ordinate multiple inverter connected, voltage controlling power plants combined control
  - Fingrid defines equivalent “grid strength” at the connection point (ESCR = equivalent short-circuit ratio), based on which the WPP controller shall be tuned


FINGRID

Utilizing Equivalent Short-Circuit Ratio (ESCR) approach for assessing the slow converter driven stability and tuning the voltage controllers

15.6.2022

[Utilizing Equivalent Short-Circuit Ratio (ESCR) approach for assessing the slow converter driven stability and tuning the voltage controllers (fingrid.fi)]

Reactive power / voltage control capabilities of wind turbines

- Wind turbines (Type 3 and Type 4) have different possibilities to control reactive power / voltage in more flexible way than conventional generators

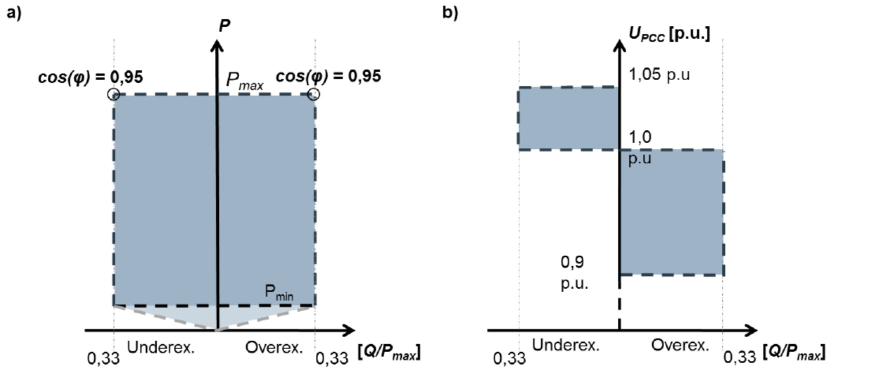
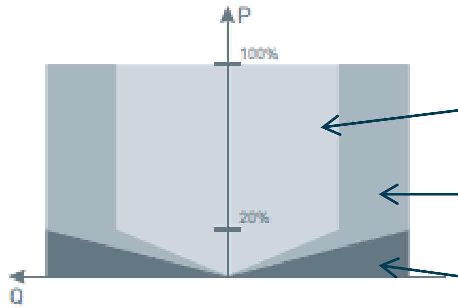


Figure 17.1. Reactive power capacity requirements for type C and D power park modules as the function of active power and the voltage at the connection point. In the figure, a voltage of 1.0 pu corresponds to the normal operating voltage specified by the relevant network operator.

Source: Fingrid VJV2018

If required, ENERCON wind turbines can also be equipped with a STATCOM option. Due to the extension of the reactive power range, it is also possible to provide the electrical power network with reactive power if no active power is being fed into the grid (standstill).

P/Q diagram of an E-82 E2 with extended reactive power range (Q+ option) and STATCOM option.



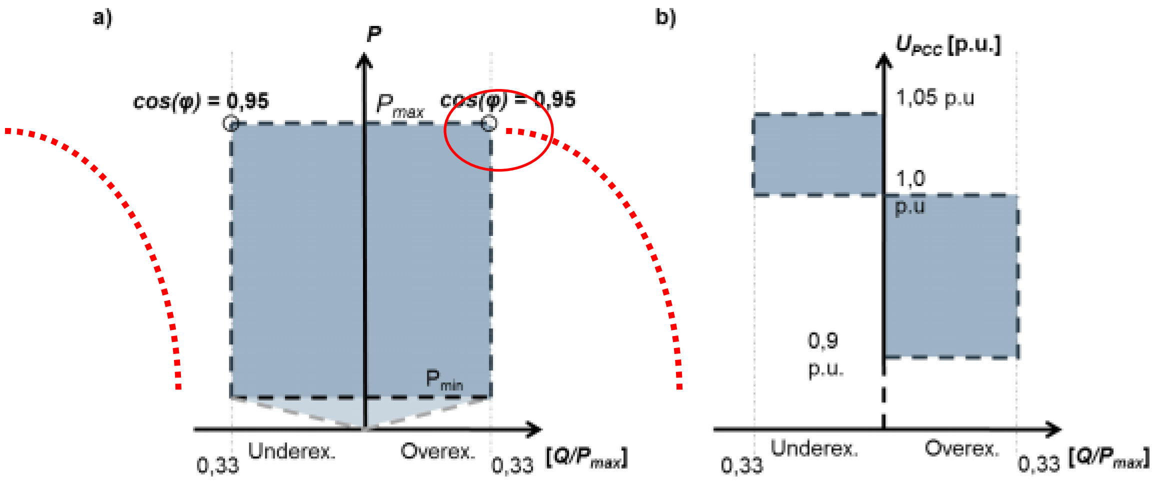
Normal PQ-operation range

Extended PQ-operation range if desired

Extended PQ-operation range as STATCOM if required

Reactive power capacity requirements

Reactive power capacity requirement for Type C and D synchronous generators and power plant modules (e.g., WPPs)



Reactive power capacity calculation points of Type C and D synchronous generators

Table 12.1. Operating points used in the reactive power capacity calculation.

Connection point's voltage [pu]	0.85*	0.90	1.00	1.10
Power level 1	Minimum output			
Power level 2	$P=0.75*P_{max}$			
Power level 3	Rated capacity			
*Operating point 0.85 pu is momentary, at this operating point reactive power shall be produced for a minimum of 10 seconds				

Reactive power capacity calculation points of Type C and D power plant modules (e.g., WPPs)

Table 17.1. Operating points used in the reactive power capacity calculation.

Connection point's voltage [pu]	0.85*	0.90	1.00	1.10
Power level 1	Minimum output			
Power level 2	$P=0.50*P_{max}$			
Power level 3	Rated capacity			
*Operating point 0.85 pu is momentary, at this operating point reactive power shall be produced for a minimum of 10 seconds				

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Dynamic simulations – general

- TSOs, DSOs, consultants, power generating facility owners, equipment manufacturers
- System operators: focus on features and values at point of connection
- Equipment manufacturers: focus on features and values related to the equipment
- Dynamic performance, limits on equipment and power plant controllers need to be included on the top of load flow model
  - User-built models by equipment manufacturers
  - Generic standard library models

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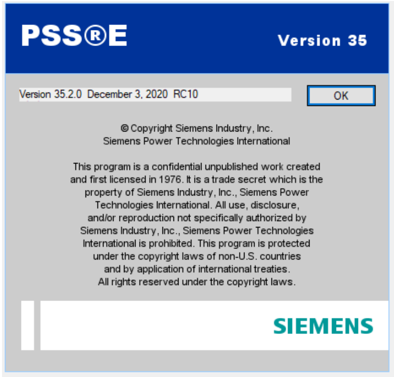
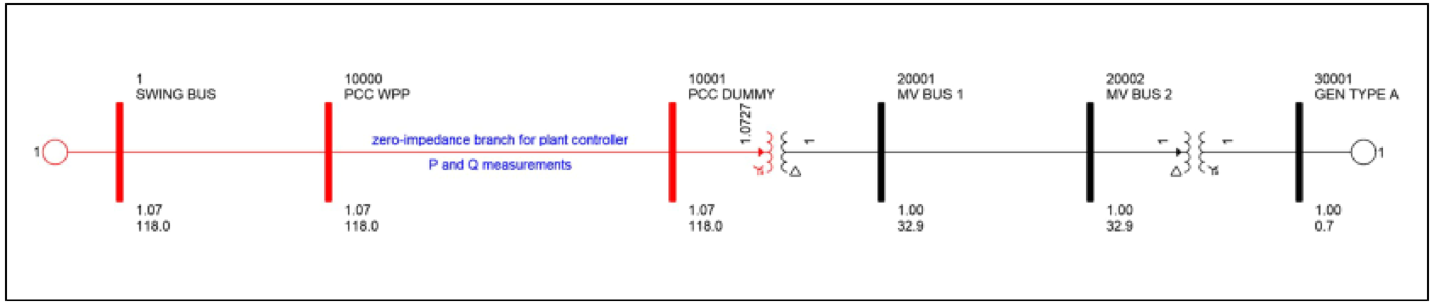
Power plant aggregation in models

- Simulations required/made by system operators are usually done with an aggregated power plant model
- MV-cabling, turbine step-up transformers, converters, generators presented as equivalent components
- Example topology of aggregation from Fingrid modeling instructions:





Source: modelling-instruction-for-psse-and-pscad-models.pdf (fingrid.fi)

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Dynamic simulation cases – Example: Fault ride-through

Voltage disturbance to be ride-through by converter connected power plants of Type D (i.e. ≥ 30 MW or connected to ≥ 110 kV grid) in accordance to Fingrid VJV2018:

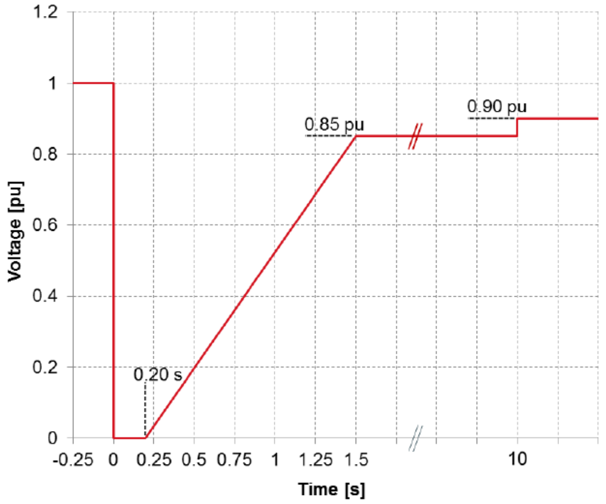

Figure 10.8. The voltage of a connection point corresponding to a momentary voltage disturbance, during and after which type D power park modules shall continue to operate normally. The per unit value 1.0 pu of voltage is the voltage before the disturbance. The voltage is 0.00 pu for 200 milliseconds.

- Ride-through the fault, i.e. continue operation without disconnection from grid
- Operational voltage envelope
- Reactive current injection during fault
- Active power restoration after fault
- P, Q settling time back to pre-fault state

Table 10.1. Input data used in the voltage disturbance calculation, when connection point voltage is less than 400 kV.

Input data	Fault 1	Fault 2
Fault time	*150 ms*	*250 ms*
Connection point's voltage during the fault	0.0 pu	0.25 pu
Connection point's short circuit current before the	Normal	Normal
Connection point's short circuit current after the fa	Minimum	Normal

Table 10.2. Input data used in the voltage disturbance calculation, when connection point voltage is at least 400 kV.

Input data	Fault 1	Fault 2
Fault time	200 ms	250 ms
Connection point's voltage during the fault	0.0 pu	0.25 pu
Connection point's short circuit current before the	Normal	Normal
Connection point's short circuit current after the fa	Minimum	Normal

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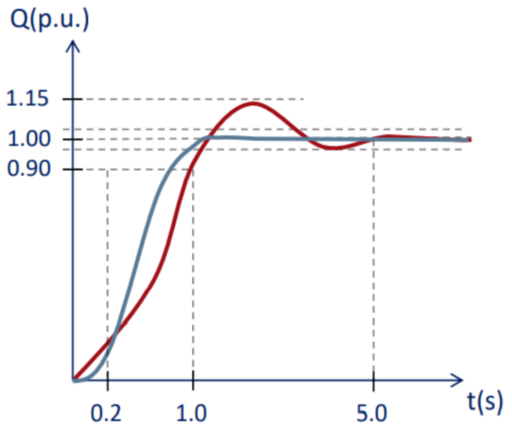
Dynamic simulation cases –
Constant voltage control performance calculation

Simulation cases to be covered according to VJV2018:

Slope setting	Vref setpoint sequence
2 %	1.00 pu; 1.01 pu; 1.00 pu; 0.99 pu; 1.00 pu; 1.02 pu: 1.00 pu; 0.98 pu; 1.00 pu
4 %	1.00 pu; 1.01 pu; 1.00 pu; 0.99 pu; 1.00 pu; 1.02 pu: 1.00 pu; 0.98 pu; 1.00 pu

To a step-change in voltage reference value, the response shall be:

1) the rise time of the reactive power response from 0 to 90 % of the measured total change in reactive power 0.2–1.0 s,
2) overshoot max. 15 % of the measured total change in reactive power,
3) settling to target level within 5 s from the stepwise excitation,
4) In achieved steady-state reactive power shall be within ±5% of the reactive power target value, with max. deviation ±1 Mvar



[Fingrid]

A description of the model used in the calculation, including the parameters used in the calculation and the block diagram presentations of the control systems, shall be delivered as part of the calculation to the relevant network operator.

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Dynamic simulations

Specific study requirements on PSCAD

PSCAD

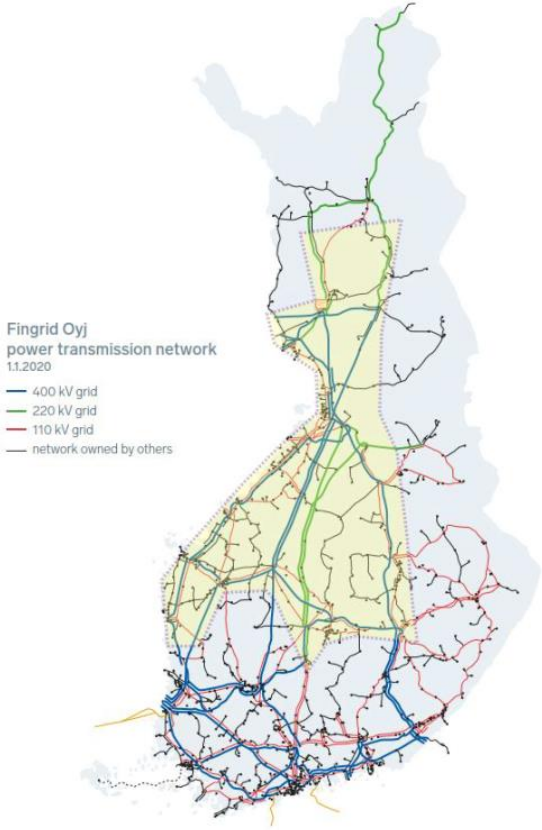
FINGRID

1 (7)

UNOFFICIAL TRANSLATION 11.2.2022

Specific study requirements for power park modules related to risk of subsynchronous oscillations

- Risk of Subsynchronous resonance (SSR)
  - Certain geographical area (grid)
- Protection requirements against SSR
- Instrumentation requirement (disturbance recording)
- Modeling & simulation requirements
  →Possible control tuning for sufficient damping



specific-study-requirements-for-power-park-modules-connected-in-vicinity-of.pdf (fingrid.fi)

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VJV2018 Stage 1 data deliveries

Table 7.2. Data to be delivered for type C and D power generating facilities. The data in the table for type D power generating facilities must be delivered in Stage 1 of the compliance monitoring process.

	Stage 1 (Planning)	Reference
1	**General data**	
1.1	Name and contact details of project, connection point, relevant network operator and contact details	
1.2	Single line diagram	
	The main components of the power generating facility and the electricity network that connects the components	
	Electric parameters of the components and conductors presented in the single line diagram	
1.3	Type data	
	Power generating facility's production type and fuel (e.g. wind power, hydropower, condensing power [coal])	
	Basic data (e.g. on wind power park module: tower height, rotor diameter, converter powered etc.)	
1.4	Location data (municipality, area, connection point, coordinates)	
2	**Technical data**	
2.1	Number, supplier and type details of power-generating units	
2.2	Documentation and data sheets of power-generating units	
	Production units' apparent power [MVA], rated capacity [MW], minimum output [MW], current [A], voltage [V], frequency [Hz]	
	Data specified in Table **7.4** on synchronous power generating modules	
	Water time constant of hydroelectric power plants (T_w)	
2.3	Documentation and data sheets of transformers	
	Power [MVA], current [A], transformation ratio [primary, secondary], short-circuit impedance [%], short-circuit resistance [%], vector group and earthing details, control range and step of on- or off-load tap-changer [%, %], number of steps of on- or off-load tap-changer and selected step [quantity, step]	
2.4	Documentation and data sheets of other components	
	Where applicable, the same data as on power generating units (section 2.2) and transformers (section 2.3) as well as all data that is relevant in terms of the Specifications (e.g. structure, filter tuning frequency)	
3	**Operating voltage and frequency range**	
3.1	Data on the power generating facility's ability to operate at undervoltage and overvoltage (section **10.2.1 or 10.5.1**)	
3.2	Data on the power generating facility's ability to operate at underfrequency and overfrequency (section **10.2.1 or 10.5.1**)	
3.3	Data on the power generating facility's rate of change of frequency withstand capability (section **10.2.2**)	
4	**Fault-ride-through capability**	
4.1	Calculation of the operation of the power generating facility during voltage disturbance (section **10.3.2 or 10.5.3**)	
4.2	Data on fault current injection of a power park module (section **10.3.3**)	
4.3	Data on active power recovery after a voltage disturbance (section **10.3.4**)	
5	**Active power control and frequency control**	
5.1	Documentation and description of active power control and frequency control (chapter **11 or 16**)	
	Documentation on the control system's implementation and technical characteristics.	
	Functional block diagram on the implementation of control described as transfer curves. (E.g. according to IEEE PES-TR1).	
5.2	Parameters and operating delays set for controllers	
6	**House load and changes in production power**	
6.1	Data on the operation of the power generating facility in house load operation (section **11.3.5**)	
	House load of the power generating facility, operating time in house load operation, potential delays in transition to house load operation and synchronisation with the grid, and restrictions in transition to house load operation	
6.2	Changes in production power	
	Changes in production power in conjunction with frequency and voltage fluctuations	
	Dependence of production power on operating conditions (e.g. temperature, wind velocity)	
	Operating conditions leading to the shutdown of production power (e.g. limit value of maximum wind velocity)	
	Rate of change of production power, functionality and constraints of limiters of rate of change	

Table 7.2 continues.

7	**Reactive power capacity of the power generating facility**	
7.1	Reactive power capacity calculation (section **12.2.4** or **17.2.4**)	
7.2	PQ diagrams	
	PQ diagrams of power generating units or generators and data on their voltage-frequency dependence. The setpoints used in the reactive power limiters shall be specified in the PQ diagrams.	
7.3	Other components influencing reactive power	
	Components that generate (e.g. capacitor or STATCOM) and consume reactive power, and their operation as a function of the variables (e.g. voltage, active power) influencing the components	
8	**Voltage control and reactive power control**	
8.1	Documentation and description of voltage control and reactive power control (chapter **13** or **18**)	
	Documentation on the control system's implementation and technical characteristics.	
	Functional block diagram on the implementation of control described as transfer curves. (e.g. according to IEEE 421.5).	
8.2	Parameters and operating delays set for controllers	
8.3	Voltage control performance calculation (section **13.2.3** or **18.2.2.1**)	
9	**Protection setpoints of the power generating facility and impact on power quality**	
9.1	Protection setpoints (section **10.3.5**)	
	Data on the relay protection diagram of the generators and at the facility level as well as on the setpoints of the described protection. Related data shall be submitted on protection which leads to the disconnection of the generator/facility from the grid and on protection whose activation leads to a restriction or automatic change in the generator's/power generating facility's active power, reactive power or voltage.	
9.2	The power generating facility's impact on power quality (section **10.4.4**).	
	Description of the change in power quality caused by the connection of the power generating facility to the grid, and potential reports of factory testing (e.g. according to IEC 61400-21).	
10	**Data required for dynamic modelling**	
	Project-specific data or simulation models required by the modelling of dynamic operation in accordance with the Specifications	
11	**Real-time measurement data and instrumentation**	
11.1	Method of delivery and verification of real-time measurement data (section **9.3**)	
11.2	Technical data on and the setpoints of disturbance and swing recorders	
12	**Specific study requirements**	
	Required specific studies related to the Specifications (chapter **5**)	
13	**Power generating facility project's schedule and commissioning**	
	Schedule of the power generating facility project and the planned timing of the commissioning tests relating to the Specifications. Possible options for expanding the project and known future expansion plans shall also be reported.	
	Statement of compliance	
	The power generating facility owner's representative confirms with a signature that the documents referred to in this table's reference details prove that the power generating facility meets the Specifications set for it. Place, date, signature and printed name:	

→ION, "interim operational notification"

VJV2018 Stage 2 data deliveries

Needed to get FON, "final operational notification"

Table 7.3. Data to be delivered for type C and D power generating facilities. The data in the table for type D power generating facilities must be delivered in Stage 2 of the compliance monitoring process.

	Stage 2 (Commissioning and compliance)	Reference
1	Changes and further specifications	
	Further specifications to the data delivered in stage 1 of the compliance verification process	
2	Data related to commissioning tests	
2.1	Commissioning test plan (section **14.3.1** or **19.3.1**)	
	The detailed commissioning testing plan, commissioning instructions provided by the power generating facility supplier and a description of the practical arrangements of the tests for verifying compliance with the Specifications shall be submitted to the relevant network operator **at the latest two months before the tests are started**.	
2.2	Commissioning schedule (section **14.3.1** or **19.3.1**)	
	Commissioning schedule; subsequent changes to the commissioning schedule shall be co-ordinated with the relevant network operator and Fingrid.	
2.3	Measurement arrangements (section **14.3.1** or **19.3.1**)	
	Plan of the execution of measurements for the tests related to the Specifications. Data on both fixed measuring equipment and measuring equipment only used during the commissioning tests.	
3	Results of commissioning tests	
3.1	Commissioning report on tests related to the Specifications (section **14.3.3** or **19.3.3**)	
3.2	Key results of commissioning tests in numerical format (Table **15.2** or **20.2**)	
4	Verified modelling data	
	Validated data required for the modelling of dynamic operation, or simulation models (chapter **15** or **20**)	
5	Final controller setpoint values	
	Final setpoint values of the controllers of active power and frequency as well as of the controllers of voltage and reactive power of the power generating facility/generators.	
6	Final protection setpoint values	
	Final protection setpoint values of the power generating facility/generators and the power generating facility connection.	
	Statement of compliance	
	The power generating facility owner's representative confirms with a signature that the documents referred to in this table's reference details prove that the power generating facility meets the Specifications set for it. Place, date, signature and printed name:	

But before this stage, VJV testing and model validation must be carried out…

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Compliance testng, i.e. VJV testing

- Official, planned measurements at the power plant site
- Testing takes about a day or two
- Planned a few months ahead (consider participants, needed operating conditions…)
- Relevant parties involved:
  - Executor of the tests (cover testing items, taking measurements)
  - Grid companies (TSO, DSO)
  - Facility owner
  - Power plant operator
  - Power plant supplier (e.g. WT manufacturer)
  - etc
- In case of discrepancies or uncompliance: checking/updating controller parameterization & repeating the relevant test
- Reporting the test results & delivering recorded data

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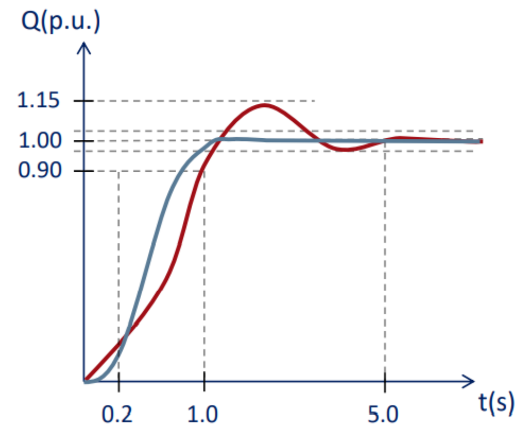
Model Validation

- Validation = comparing simulation results to measured test results
- Updating the models
- Replicating the corresponding test situations and events of compliance tests in simulations (actual grid short circuit level, actual initial power feed, voltage & reactive power, controller settings, Vref steps)
- Validation
  - In case of discrepancies, checking parameterization / finding out explanations
- Reporting the validation results

Table 20.1. Verification obligation of modelling data on wind power park modules by type.

Item to be verified	Type C	Type D
Step response of voltage control of the power generating facility using two different slope values (both the increase and decrease in voltage)	X	X
Reactive power capacity of the power generating facility and the functioning of limiters that restrict the capacity	X	X
Operation of additional control functions, such as POD (Section 18.3).		X
Fault-ride-through test [1)]	X	X

[1] To be agreed on a case-by-case basis. If a fault-ride-through test for the power generating facility is not carried out, the functioning of the power generating facility in a local fault shall be demonstrated by means of simulation calculations.



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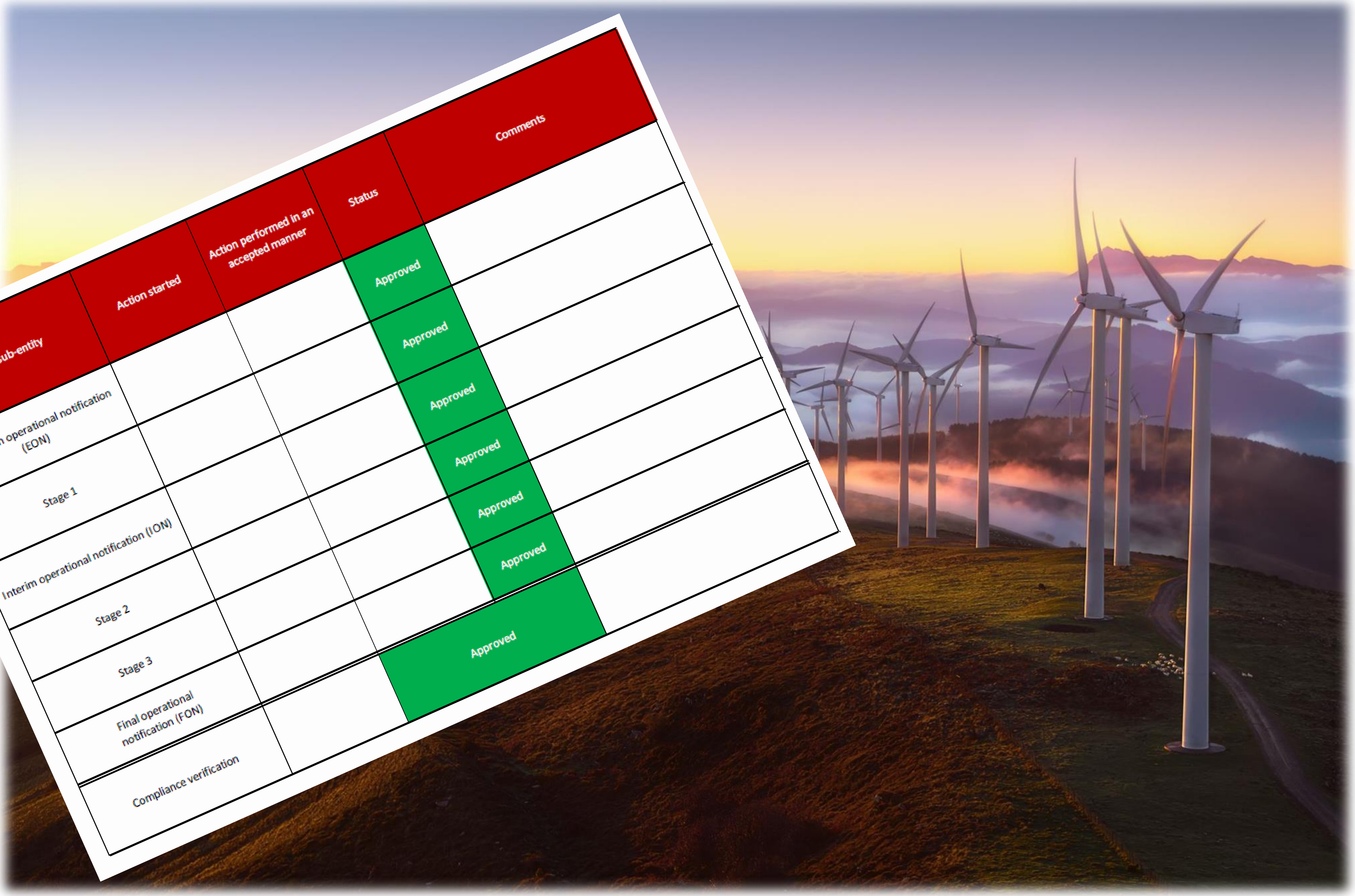

VJV2018 sub-entity	Action started	Action performed in an accepted manner	Status	Comments
Energisation operational notification (EON)			Approved	
Stage 1			Approved	
Interim operational notification (ION)			Approved	
Stage 2			Approved	
Stage 3			Approved	
Final operational notification (FON)			Approved	
Compliance verification			Approved	

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WIND EUROPE

WIND POWER NUMBERS DAILY

Currently displaying data from 23 November 2022

Looking for archive data?

How much wind was in Europe's electricity yesterday?

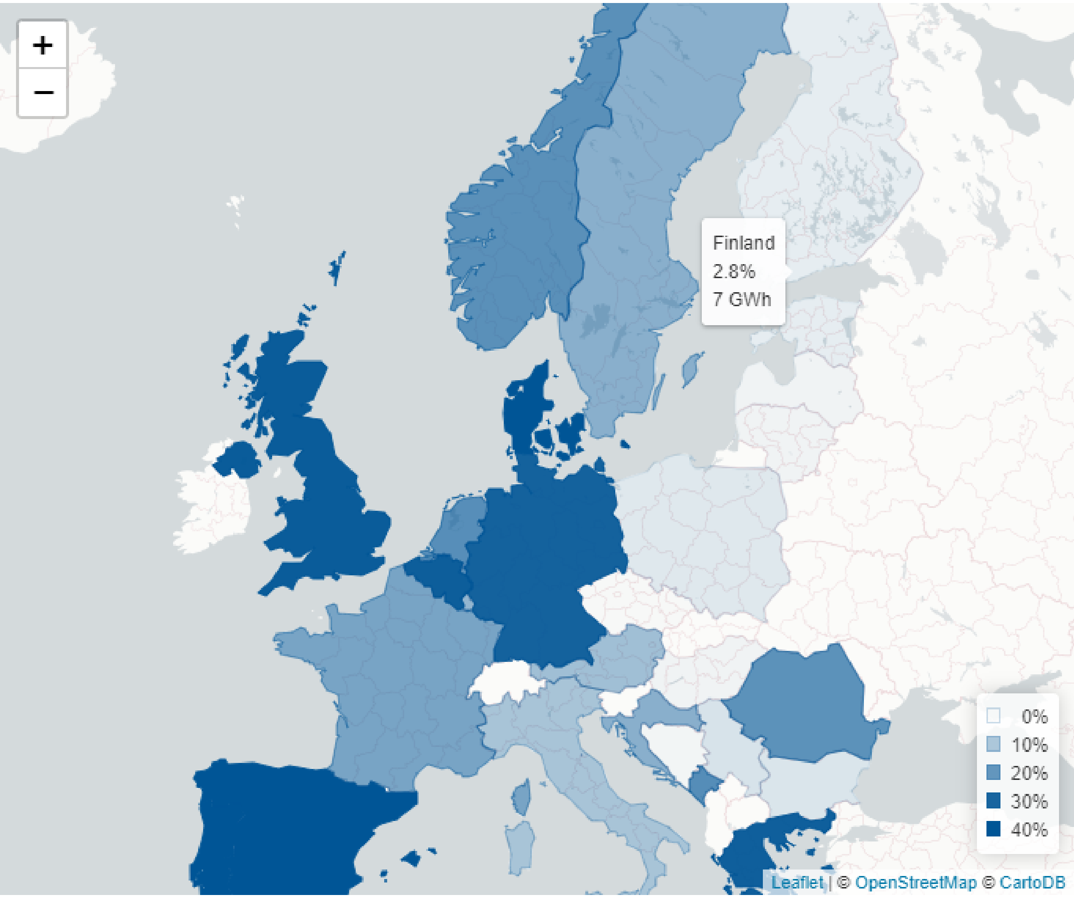
DAILY WIND ENERGY

YESTERDAY'S TOP 20 COUNTRIES

HOURLY ELECTRICITY MIX

HOURLY WIND ENERGY GENERATION

CAPACITY FACTORS



Share of wind energy in electricity demand

21.7%

17.8%
1,605 GWh
onshore wind

3.9%
355 GWh
offshore wind

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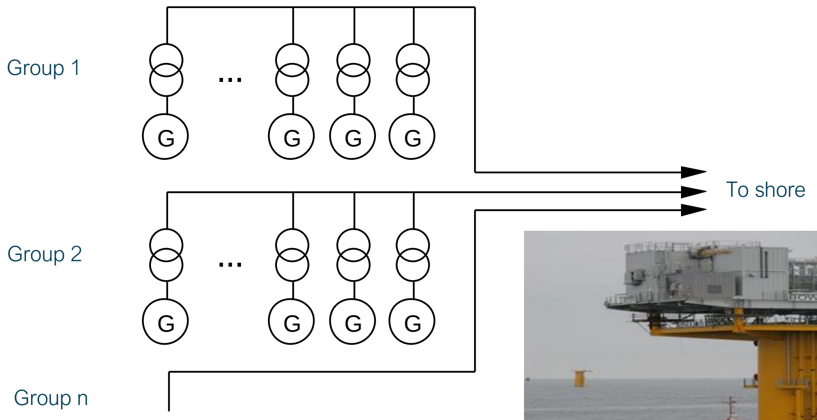
Offshore wind power plants

- Grid connection at sea is expensive
  - Distances may be long
  - Sea cable
  - Possibly separate transformer platform at sea
- Back-up connections?
  - Groups/blocks of units
  - E.g. separate AC-connection cables for unit blocks near the shore
  - In case of cable outage, not whole WPP production is lost

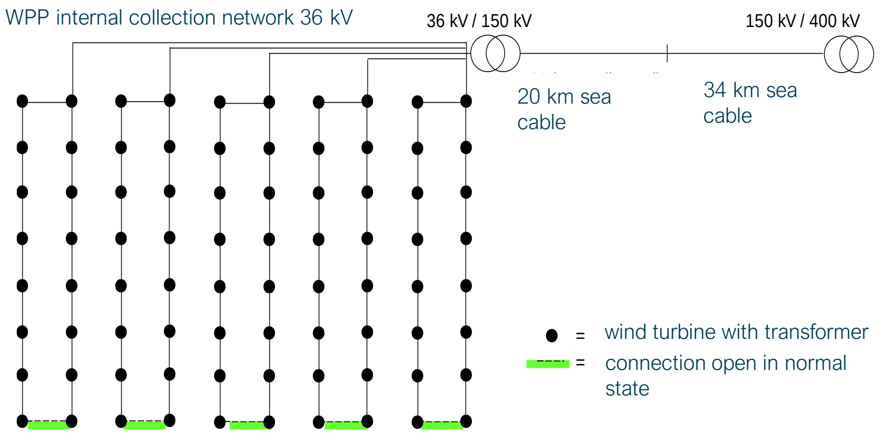


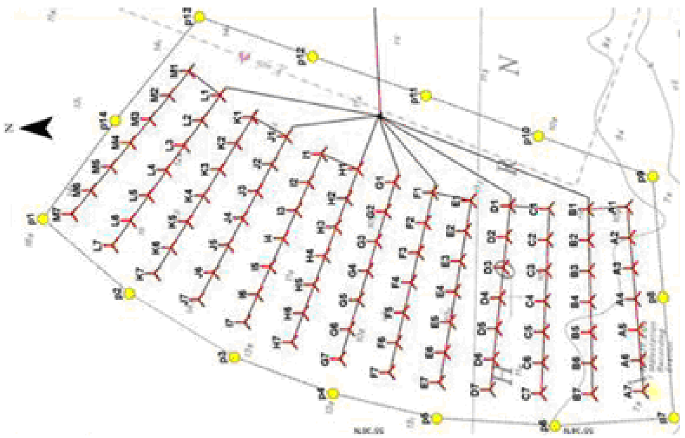
Offshore wind power plants

Example from Denmark:

- Horns Rev I 160 MW (80 x 2 MW DFIG)
  - In operation since 2002
  - Total construction costs of the wind power plant approximately 278 M€, of which substation at sea and connection cable costs appr. 40 M€
- Horns Rev II 209 MW (90 x 2.3 MW full power converter equipped WTs)
  - In operation since 2009
  - Total construction costs of the wind power plant approximately 470 M €, of which grid connection costs with grid reinforcements appr.110 M€
  - Estimated yearly production 800 GWh

- www.hornsrev.dk





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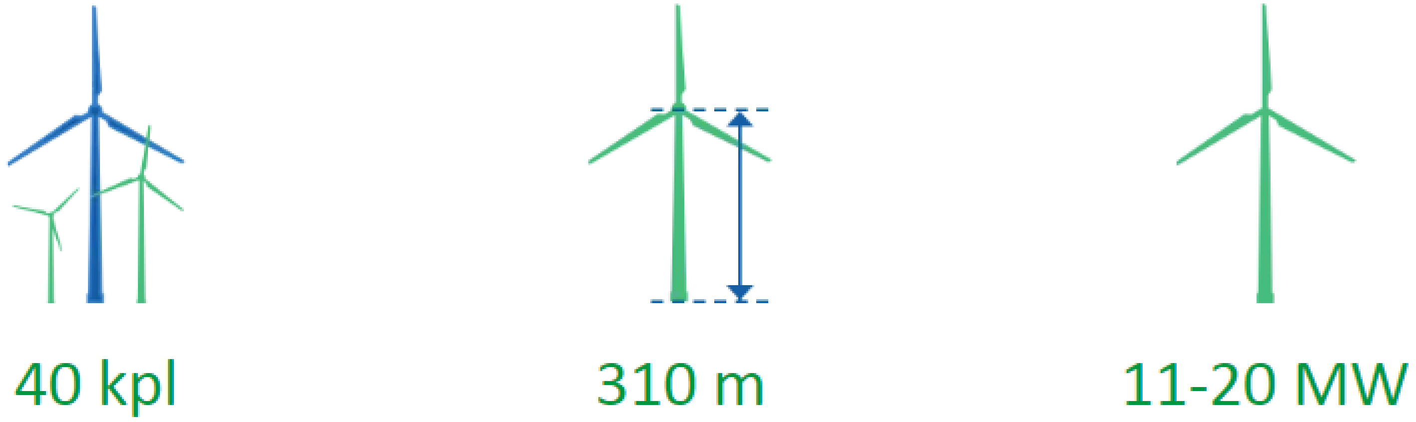
Offshore wind power plants in Finland

- Hyötytuuli / offshore demonstration power plant in Tahkoluoto, Pori:
  - In operation since 2017
  - 10 x 4.2 MW
  - Substation at land
  - 157 GWh/a
- Extension plan:



[Tahkoluodon merituulivoimahankkeen laajennus | Suomen Hyötytuuli Oy (hyotytuuli.fi)](https://hyotytuuli.fi)

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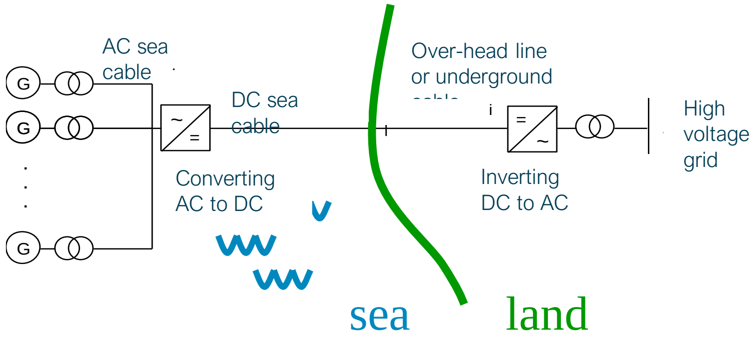
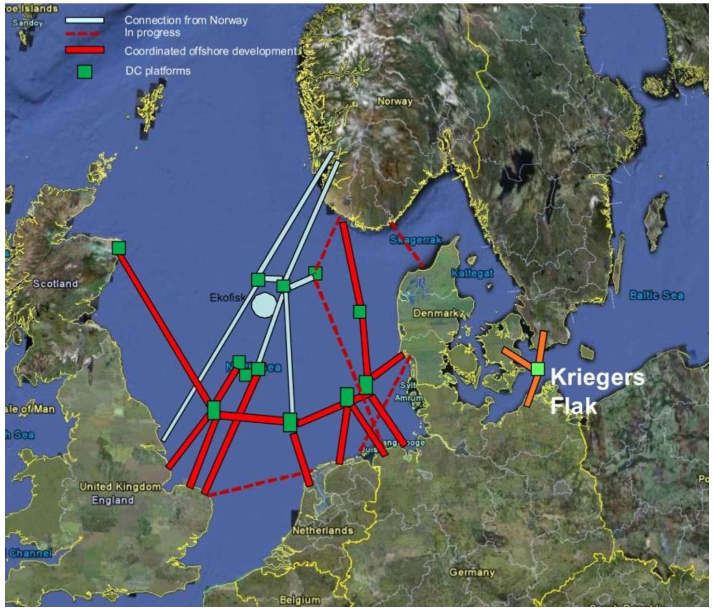
Offshore grids

- Using HVDC (high voltage direct current) connections to connect the wind power plants to the grid at land may become more common
- Transformation AC ↔ DC is expensive, but getting cheaper
- HVDC connection is profitable if the WPP is large enough and/or the distance to the shore is long
- HVDC connection is the only option in case of long sea cables
- Possibility to connect offshore wind power plants to so-called offshore grids, i.e. the HVAC or HVDC grid built at sea (no radial connection) will be used for both electricity transmission between countries/areas and for connecting wind power plants to the power system

→Kriegers Flak offshore wind power plants (German, Danish and Swedish areas) --- German & Danish TSOs' Kriegers Flak Combined Grid Solution (CGS) inaugurated *in October 2020*, connecting two offshore substations to enable cross-border electricity trading in addition to offshore WPP power transmission to the home-land





Source: Joined Pre-feasibility Study by Energinet.dk, Svenska Kraftnät and Vattenfall Europe Transmission, An analysis of Offshore Grid Connection at Kriegers Flak in the Baltic Sea.

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