# Elektro Assignment for 46300 for 2025

## Problem formulation and tasks:

Your group is hired as a consultant to assist with the wind farm commission project. Your group needs to perform electrical study of operation of multi-MW variable speed offshore wind turbines. The offshore wind farm layout (including the connection to the grid) is illustrated in the figure below.

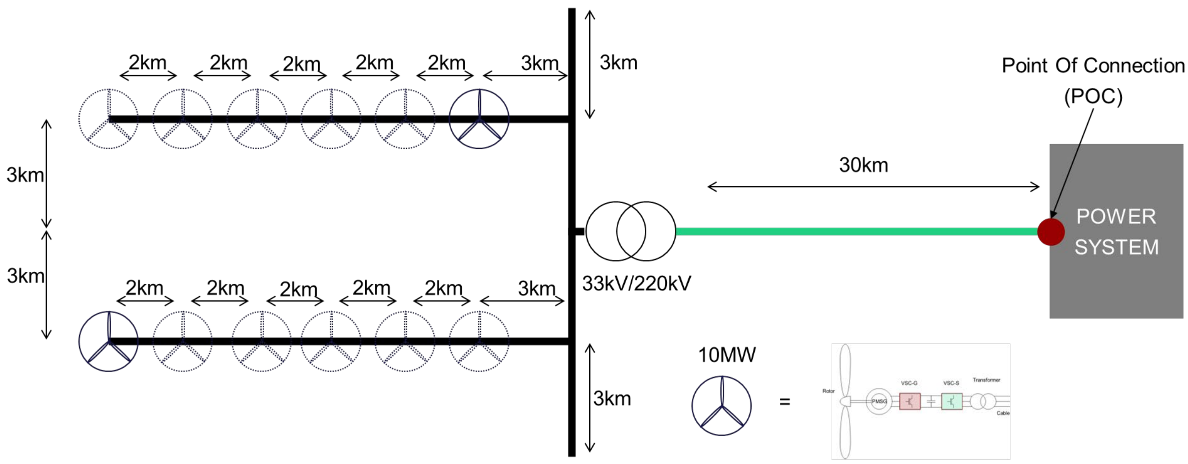


Figure 1: Wind farm layout with main components and spacing indication

The phase 1 of the wind farm development comprises from two strings of six 10MW wind turbines for total capacity of 120MW. Due to supplies chain delays, 10 wind turbines that are installed are not operational and are parked waiting for missing components. Only two installed wind turbines are operational at the time of commissioning. The non-operational wind turbines are indicated with dashed turbine symbols while operational wind turbines have turbine symbols with solid line.

**Your consultancy tasks:**
**Task A:**

1. Find the exported power (at the power system) as a function of the wind speed in the range from 1m/s to 12m/s, for both
   1.1. *Zero Power Factor Angle* MPPT wind turbine generator control and
   1.2. *Zero Beta Angle* MPPT wind turbine generator control

*Note: VSC-S power factor is assumed to be unity for this task*

2. Find the efficiency of the wind farm as a function of the wind speed in the range from 1m/s to 12m/s.
   2.1. At what wind speed does the wind farm have the highest efficiency?
   2.2. What is more efficient MPPT control of WT: *Zero Power Factor* or *Zero Beta Angle?*

## Technical description of the system

The rated mechanical power of each wind turbine is 10$MW$ developed at a rated wind speed 12m/s while turbine rotates at rated rotation speed of 12$RPM$. The cut-in wind speed is 1m/s.

*Note: The turbines are controlled using Maximum Power Point Tracking (MPPT) when turbines are in variable speed range, while for wind speeds above rated wind speed of 12m/s, the wind turbines limit the power production by pitching and maintain the rotating speed at 12.0 rpm. The MPPT control ensures that the wind turbine generator torque is controlled as quadratic function of the wind speed.*

### Wind turbine drivetrain

The drivetrain layout of the wind turbine is shown in Figure 2 (symbol on the left and the block diagram on the right). The turbine rotor is connected to the wind turbine generator (WTG) rotor directly (Direct Drive). The WTG three phase stator is connected to generator-side converter (VSC-G). The power system-side converter (VSC-S) is connected to the grid via a step-up transformer and cable connection.

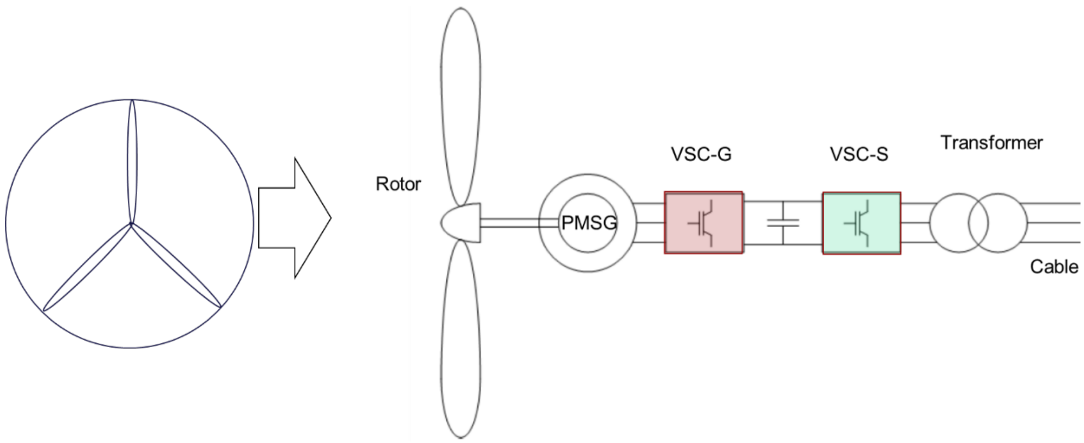


Figure 2: Schematic representation of wind turbine drivetrain and the WT system

### Power electronic converters

The converter system consists of two three phase power electronic Voltage Source Converters (VSCs) referred to as generator (VSC-G) and the system side converters (VSC-S), respectively. The objective of VSC-G converter is to control the terminal voltage of WTG to achieve MPPT control.

The VSC-G will adjust the generator stator voltage to ensure the MPPT, i.e the generator mechanical power is proportional to cubic of the rotational speed. In addition, the MPPT control can be realized by one of the following strategies, ensuring that:

a) *MPPT – Zero Power Angle (Unity Power Factor):* phase current is in phase with terminal voltage or
b) *MPPT – Zero Beta Angle:* the phase current is in phase with induce voltage

The objective of VSC-S converter is to control the terminal voltage of step-up transformer low voltage side. The control is done in such a way that the active power of the VSC-S matches the active power coming from the wind turbine i.e. VSC-G (i.e. $P_{VSC-G} = P_{VSC-S}$). In addition to active power balance, the reactive power of VSC-S can be controlled independently (or in other words VSC-G reactive power does not need to be equal to VSC-S reactive power, i.e. $Q_{VSC-G} \neq Q_{VSC-S}$ ). The losses in converters can be neglected.

*Note: Each converter is modeled as an ideal voltage source, where RMS and phase of the source can be controlled independently and is a function of the control objective of each converter. In practice, the two converters are connected by DC link, the consequence of which is that converters* ***must have the same active power, i.e $P_{(VSC-G)} = P_{(VSC-S)}$, i.e the active power conservation is maintained (only active power !!!)****.*

## Generator WTG (Permanent Magnet Synchronous Generator):

The per-phase equivalent circuit diagram of permanent magnet synchronous generator can be found in lecture notes / slides. Parameters of equivalent circuit of the generator, connected in a star, are as follows:

- Number of poles: 266
- Stator synchronous inductance is $L_s = 7.8mH$
- Stator resistance is $R_s = 254mOhm$
- Nominal rotor flux linkage is $19.5Wb$

Due to core loss and friction, generator has rotating power loss scaling as a quadratic function of speed and can be estimated to be 225kW at nominal rotating speed of 12RPM.

## Wind turbine transformer

The transformer with YY connection and line to line voltage ratio of 4kV/33kV, can be presented with equivalent circuit diagram shown in Figure 3. The leakage inductances are $L_1 = L'_2 = 10\mu H$, the winding resistances are $R_1 = R'_2 = 42mOhm$, while the magnetizing inductance is $L_m = 55mH$ and the iron loss resistance is $R_c = 55\ Ohm$. All parameter and values are referred to the low voltage side (4kV).

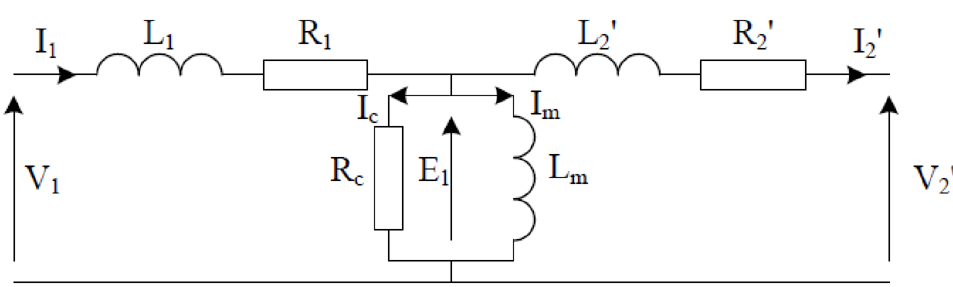


Figure 3 Equivalent circuit of the power transformer (per phase, and referred to primary (Low Voltage side))

## Wind farm transformer

The transformer with YY connection and line to line voltage ratio of 33kV/220kV, can be presented with equivalent circuit diagram shown in Figure 4. The leakage inductances are $L_1 = L'_2 = 2154\mu H$, the winding resistances are $R_1 = R'_2 = 834mOhm$, while the impact of magnetizing inductance $L_m$

and core loss resistance is $R_c$ can be neglected. All parameter and values are referred to the low voltage side (33kV).

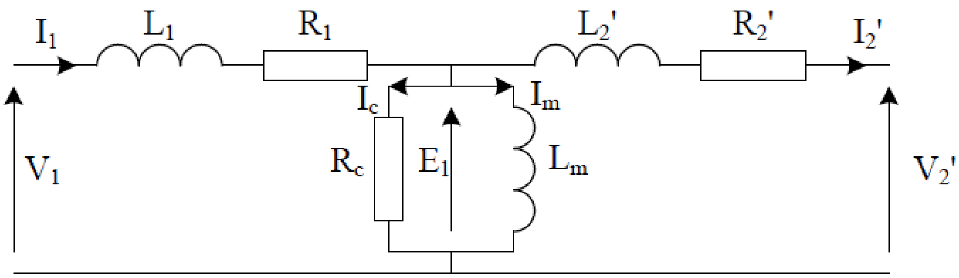


Figure 4 Equivalent circuit of the power transformer (per phase, and referred to primary (Low Voltage side))

## 33kV collection cable connection

Wind turbines are connected to the wind farm transformer with 33kV phase cable with following (per-phase) parameters: $r_{cable}$ = 0.1 *Ohm/km*, $l_{cable}$ = 0.6 mH/km and $c_{cable}$= 0.3 *uF/km*. The equivalent circuit of a cable is presented in the Figure. 4.

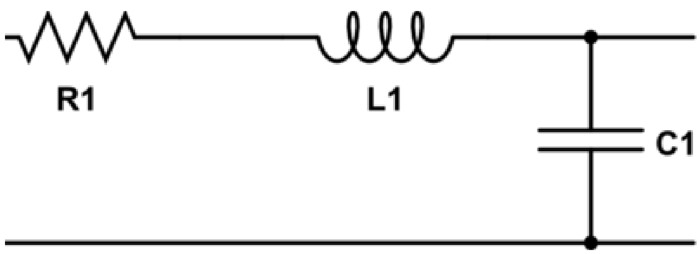


Figure 4: Equivalent circuit of the power cable (per phase)

## 220kV export cable connection

Wind farm is connected to shore with 3 phase cable with following parameters: $r_{cable}$ = 0.25 *Ohm/km*, $l_{cable}$ = 2.5 mH/km and $c_{cable}$= 0.05 *uF/km*. The equivalent circuit of a cable is presented in the Figure. 5.

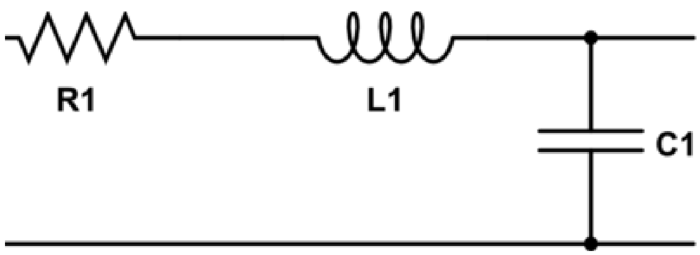


Figure 5: Equivalent circuit of the power cable (per phase)

## Grid

The wind farm is located ~30km from shore (and power system connection). The voltage at the POC is constant at nominal value of 220*kV (note: that this is line-line voltage).*

*Note: Since the power system is very large, this can be represented with constant voltage source*