UNIVERSITY of TASMANIA

School of Engineering

ENG333 Power Systems 1
Semester 1, 2022

Major Project: New Wind Farm Connection Design

Design Brief

You are required to design the connection of a new wind farm to an existing 132 kV power system. You should determine the best point to connect into the existing 132 kV sub-transmission system, including consideration of the cost of connection, and must perform the following as part of the connection design:

1. Select the most suitable substation to connect the new wind farm to the existing 132 kV system
2. Specify new connection transmission line design: conductor type, bundling configuration, tower type, phase spacing
3. Determine transmission line model ABCD parameters and per unit lumped line parameters
4. Verify that line thermal and dynamic power flow limits will be sufficient for the specified application
5. Perform power flow (load flow) studies: by modelling the range of possible generation and load conditions in the sub-transmission, verify that there are no violations of line power flow limits or voltage outside of specified limits on part of the 132 kV system; design suitable mitigation strategies to avoid any such violation. As part of your load flow studies you should determine the increase or decrease in overall network losses as a result of the operation of the wind farm.
6. Perform system security studies: verify that any single line out of service (except for the new line) will not overload other lines and will thus ensure supply is maintained to existing load centres.
7. Perform fault studies: calculate fault currents supplied into the line under conditions of 3-phase faults at either end or at middle of the new transmission line, and with and without the existing hydro generator operating; determine fault current that is required to be supplied by the hydro generator in the system (if applicable) and the EHV transmission system
8. Calculate the total cost of the new wind farm connection, including all new transmission line costs, substation upgrades at existing buses and cost of augmenting the existing network if required.

You should prepare a Connection Design Report, containing an executive summary of the design, followed by sections containing detailed design calculations and addressing each of the requirements listed above.

Assignment submission requirements

- This assignment is an individual assignment
- The assignment due date is **Friday 27 May 2021, at 6 pm**
- Your assignment should consist of a well-written and well-structured report addressing the requirements of the design brief.
- Report length should be approximately 15 – 20 pages, including important figures and tables. Design calculations should be described in the report, but any detailed calculations or methodologies used (for example, design calculation code if used) may be included as appendices; additional figures may be included as appendices.
- Assignment submission should be made via MyLO assignment submission link
- Submission should include all relevant network model files, so as to enable any described power flow study scenario to be easily reviewed.

Design requirements, parameters, costings and any other relevant background information

1. Existing 132 kV sub-transmission network & requirements

You are required to design a new connection of a proposed wind farm, including design of a new 132 kV transmission line, selection of connection point into the existing 132 kV network, specification of any required substation upgrades and any augmentations of existing network as required. You are also required to specify to the system operator any new operating constraints or requirements.

A map of the existing 132 kV transmission infrastructure, for the region where the wind farm will be built, is shown in Figure 1. Each node or bus represents a major load centre (city, town or industrial zone). The corresponding network model file is also provided (and shown in Figure 2), with network impedances all based on a base power of 100 MVA and base voltage of 132 kV.

Integration with the main power system's extra high voltage (EHV) transmission network is via two separate connection points (bus 2 and bus 3), each connection being with existing double circuits. The EHV network is able to supply any amount of power and reactive power required by the 132 kV network. The main power system is represented, in the network model, by an EHV connection bus which operates in simulations as a slack bus with regulated voltage of 1 pu.

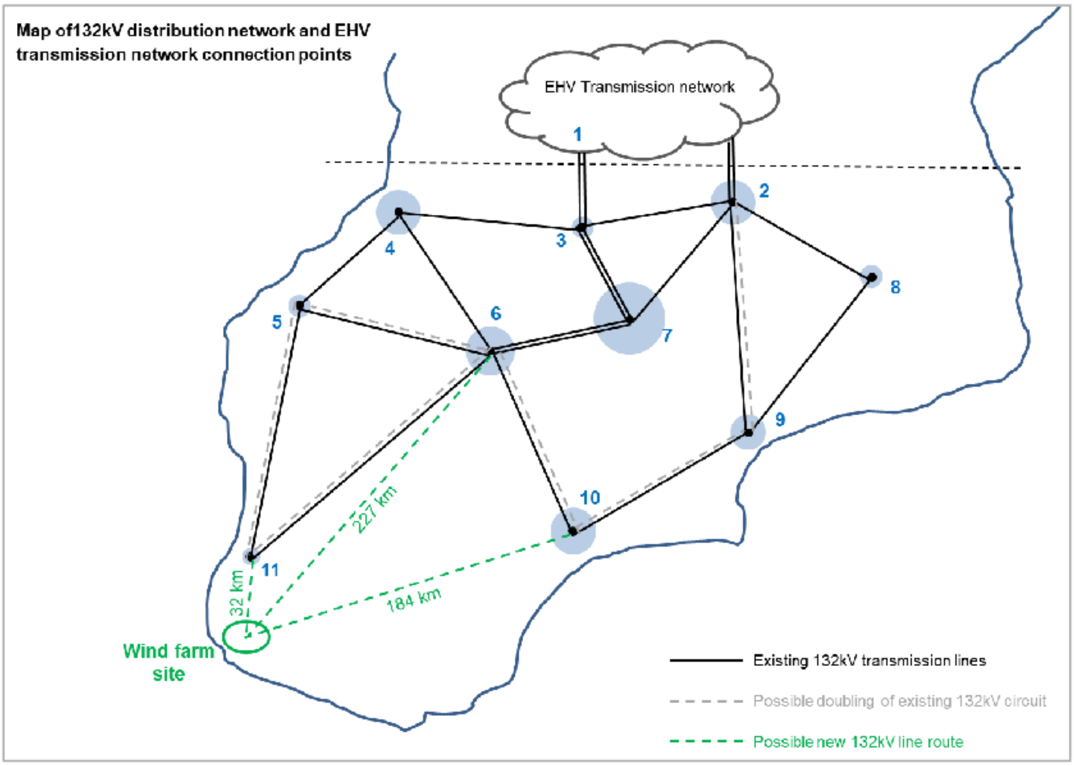


Figure 1. Map of region showing current 132 kV transmission network

A number of existing transmission lines are built on towers which allow easy 'doubling'. Doubling consists of adding a second circuit in parallel, by adding cross arms / supports and a second set of conductors. Doubled circuits are connected in parallel and must only use the same conductor configuration, that is will have the same line impedance characteristics and power flow limits as the existing circuit. Lines which are able to be doubled are shown in the map of Figure 1 and are also listed in Table 1, along with the cost of doubling.

Table 1. Existing transmission lines available for doubling

Line	Cost to 'Double' the circuit
2-9	$4,500,000
5-6	$2,650,000
5-11	$5,300,000
6-10	$3,400,000
6-11	$7,600,000
9-10	$3,200,000

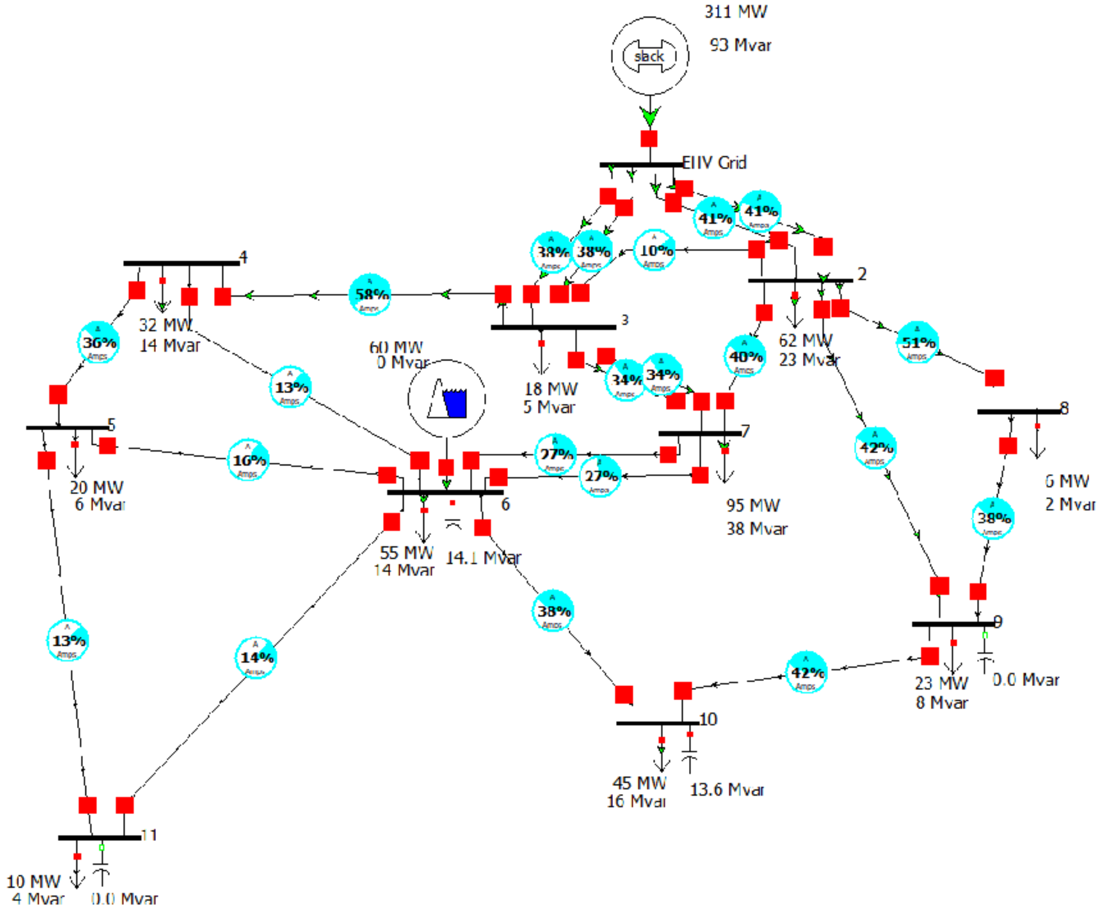


Figure 2. Network model for 132 kV transmission network

Voltage at every bus in the network, including the new wind farm bus, should be between 0.95 and 1.05 pu at all times (under all possible operating conditions).

2. Existing hydro generator and shunt capacitors

The large town connected to bus 6 features an old hydro power station with 60 MW total generation capacity. The hydro plant has only a relatively small storage reservoir associated with it, and therefore tends to be somewhat dependent upon the seasonality of rainfall patterns; it essentially runs about 50% of the time, when water is available, but is disconnected at other times. The transmission system must therefore always be operated so as to handle the case where the hydro generator is running and producing 60 MW output or when it is not running at all (and everything in between of course). The generator is a synchronous generator and is capable of outputting reactive power within its capability curves and up to a maximum output of 60 MVA. Currently it is not used for regulating voltage when it is operating.

The network has a number of shunt capacitor banks available for use to help manage voltage. These are connected as shown in the network model, and are listed in Table 2. Each of these existing shunt capacitor banks are capable only of being switched into the circuit or out of the circuit (there is no continuous control available).

Table 2. Buses with existing shunt capacitors in operation

Bus	Shunt Capacitor Size
6	15 MVAr
9	15 MVAr
10	15 MVAr
11	10 MVAr

Power flow studies as part of this wind farm connection design must specify under which conditions each of these shunt capacitors should be turned on or off, to ensure voltages are within specified limits.

New shunt capacitors or shunt reactors are able to be constructed as part of the wind farm connection design, at any bus required. The cost of capacitor or reactor banks is as shown in Table 3. You may specify these as needed.

Table 3. Cost of shunt reactors and shunt capacitors

Type	Cost
Shunt Capacitor	$1,000,000 per 25 MVAr
Shunt Reactor	$1,000,000 per 20 MVAr

3. Wind farm location, connection options and operation overview

An excellent site with very good wind resource has been selected for a new 160 MW wind farm. Wind turbine layout and the internal electrical system design is well underway. The wind farm will have a new substation built, which will step voltage distribution around the wind farm from 11 kV to 132 kV. The location of this 132 kV wind farm substation has been selected and is shown on the map of Figure 1. Three options for connection into the 132 kV network are available, with distances to each substation / bus indicated on the map.

The wind farm may at any time produce between 0 and 160 MW, dependent upon wind conditions. The wind farm operator would like a connection which guarantees that the full 160 MW output can be delivered under any scenario. However, if you feel that there are certain conditions under your proposed connection design that would require the wind farm to curtail its output owing to network constraints, then you may specify these conditions and justify this choice.

The wind turbines are not designed and configured to be able to provide controllable reactive power, and so the wind farm only outputs real power. Part of your new connection design may need to include specification of shunt reactors and/or shunt capacitors connected at the new 132 kV wind farm substations, in order manage voltage. Voltage at the wind farm bus should be kept within the voltage limits specified for the 132 kV network.

4. Existing load centre demand profiles

For ease of performing load flow and system security studies the load profiles for each load centre (bus) in the 132 kV network can be assumed to be similar. That is, minimum load occurs at the same time at all load centres, with peak load also occurring simultaneously. Minimum and maximum loads for each bus are provided in Table 4.

Table 4. Minimum and maximum bus loads

Bus number	Minimum load	Maximum load	Load power factor
2	24 MW	62 MW	0.94 lagging
3	7 MW	18 MW	0.97 lagging
4	12 MW	32 MW	0.92 lagging
5	8 MW	20 MW	0.96 lagging
6	21 MW	55 MW	0.97 lagging
7	37 MW	95 MW	0.93 lagging
8	2 MW	6 MW	0.95 lagging
9	9 MW	23 MW	0.95 lagging
10	17 MW	45 MW	0.94 lagging
11	4 MW	10 MW	0.93 lagging

5. Available transmission line components

Your new transmission line design must be based on one of the available tower designs (Table 5 and Figure 3). You may choose a tower which can either accommodate one or two parallel circuits. That is, if you choose tower 'Type B – Double', then you may use it to build two parallel circuits using the same conductor type.

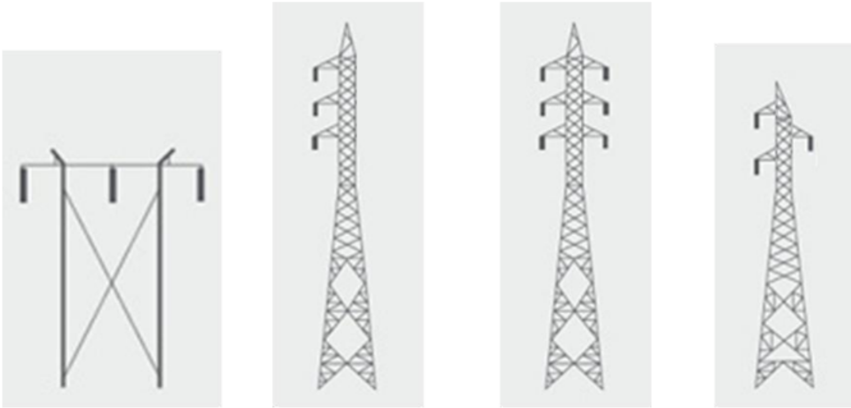


Figure 3. Available 132 kV transmission tower types

Table 5. Available tower designs, spacing and installed costs

Component	Phase layout	Phase spacing	Cost
Tower Type A1	Horizontal phasing	2.2 m	$62,000 per km
Tower Type A2	Horizontal phasing	2.7 m	$76,000 per km
Tower Type B1	Vertical phasing	2.4 m	$75,000 per km
Tower Type B2	Vertical phasing	3.2 m	$86,000 per km
Tower Type B1 – Double	Vertical phasing x 2	2.3 m & 5.5 m between ccts	$82,000 per km
Tower Type B2 – Double	Vertical phasing x 2	3.1 m & 7 m between ccts	$95,000 per km
Tower Type C	Triangle	3.2 m	$76,000 per km

Your new transmission line must use one of the available conductor types provided in Table 6, taking into account the current ratings as shown. The costs quoted are per km of a single length of conductor, delivered to site. Note that the diameter provided is the nominal outer diameter of the conductor. However, each conductor consists of several strands and, for purposes of calculating resistance, has a packing factor of 90%. Resistance of conductors for network modelling purposes should be calculated assuming an average normal operating temperature of 50°C, with a skin effect resistance increase of 10%.

Table 6. Available conductor diameters, current ratings and costs

Conductor type / diameter	Current Rating (summer, no wind)	Current Rating (winter, wind > 2 ms^{-1})	Conductor cost
AAC 9.0 mm diameter	110 A	308 A	$4,300 per km
AAC 16.3 mm diameter	216 A	636 A	$6,700 per km
AAC 21.0 mm diameter	299 A	875 A	$9,000 per km
AAC 26.3 mm diameter	405 A	997 A	$12,300 per km
AAC 31.5 mm diameter	495 A	1224 A	$16,300 per km

You may choose to use more than one conductor per phase, by employing a bundling arrangement. Available bundling arrangements are shown in Table 7, along with the total cost per km of installing transmission line conductors for each arrangement (for all three phases, including cost of the bundling spacers).

Table 7. Available bundling arrangements, conductor diameters, current ratings and costs

Conductor bundling options	Bundle pattern	Line installation cost (incl. bundling spacers)
No bundling – 1 conductor	N/A	$30,000 per km
Bundling spacer – 2 conductor, 24 cm	Horizontal, 24 cm spacing	$35,000 per km
Bundling spacer – 2 conductor, 32 cm	Horizontal, 32 cm spacing	$36,000 per km
Bundling spacer – 3 conductor, 23 cm	Triangle, 23 cm sides	$40,000 per km
Bundling spacer – 3 conductor, 33 cm	Triangle, 33 cm sides	$42,000 per km

Bundling spacer – 4 conductor, 26 cm	Square, 25 cm sides	$45,000 per km

6. Transmission line model parameters

As part of the new connection design you are required to develop (and use) an accurate model of your proposed new transmission line. Regardless of the actual length of the line used, it is expected that you use the full long line approach to determine accurate lumped π model parameters (Z' and Y'/2) as well as ABCD parameters for your line (Note: if you use the short or medium line model for this part, you will miss out on being able to get all available marks for this bit). You are subsequently also required to calculate per unit line impedance parameters for purposes of modelling the network, noting that in Powerworld your π model per unit line parameters are represented as Z' = R + jX and Y' = G + jB.

The network model provided for the existing 132 kV system is based on a base power of 100 MVA and base voltage of 132 kV.

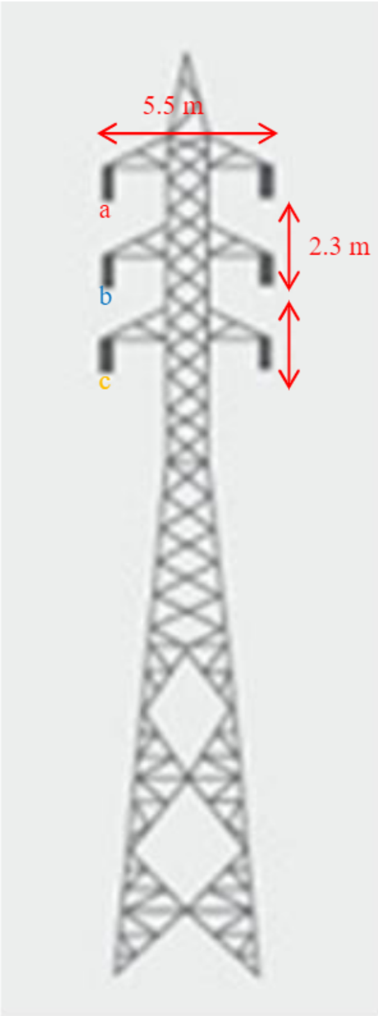
7. Upgrades of existing substations

Any substation which has a new line (or a newly doubled circuit) added to it will require additional power capacity to be built. Typically this might include a new transformer bay, new switchgear and protection equipment. This cost will be considerably less than building a brand new substation, but nonetheless you need to allow a cost of $1,000,000 per 15 MVA connection capacity added. Note that if you build a line (or doubled circuit) between two substations you will need to pay for upgrades at both substations, but that two new lines, one into and one out of the same substation will only the upgrade cost at that substation once.

8. Security and fault studies information

As part of the new connection design you are required to perform 'n-1' security studies to ensure that demand is still met at each major load centre. If you have chosen to double any of the 6 lines that can be doubled, you only need to consider one of the circuits being tripped out of service at any one time.

For purposes of fault studies, there are no major motor loads connected to the system that need to be considered. Furthermore, the connection to the main EHV grid is strong (consists of lots of parallel generators and a highly meshed network) and so has an effective reactance of 0.1 pu (at the system base of 100 MVA and 132 kV). The hydro generator at bus 6 has a reactance of 0.5 pu, on a base of 60 MVA and 132 kV.



Type B - Double