# Influence of Transmission Lines on Grid Connection

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## Summary:

Long transmission lines have influence on the electrical charactistics of wind farms concerning their grid connection. The influence depends on the layout and on the type of the transmission line. This presentation show results of investigations of transmission lines concerning their influence on power quality parameter. With compensation units not only the reactive power can be compensated, also the electrical losses of the cable can be reduced. Harmonic currents are damped by the cables, but resonances can occur at the wind farm.

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### 1 Introduction

The specifics of an offshore wind farm concerning grid connection are as follows:

- Size and dimension of the wind farm
- Concentrated grid connection
- Long transmission line

There is already some experience from onshore installations of large wind farms. In some cases several onshore wind farms are connected together to one substation, which is connected to the high voltage network. In some cases the size of such systems are more than 200 MW, comparable to the size of the first stages of the Offshore farms.

In Germany the offshore wind farms will be connected to grid connection points in the northern part of Germany. Here we have already a lot of onshore installations of wind farms. Thus the possibility for the grid connection must be investigated in detail, which is done for example in /1/.

The grid connection of a wind farm is not only influenced by the electrical characteristics of the wind farm itself, also the transmission line between the wind farm and the grid connection point gives influence. Especially long transmission lines, as it is for offshore wind farms, give significant influence on the power quality and stability. But also for onshore installations in rural areas long transmission lines are often necessary. For the planned offshore installations in Germany the length of the transmission lines will be up to about 150 km.

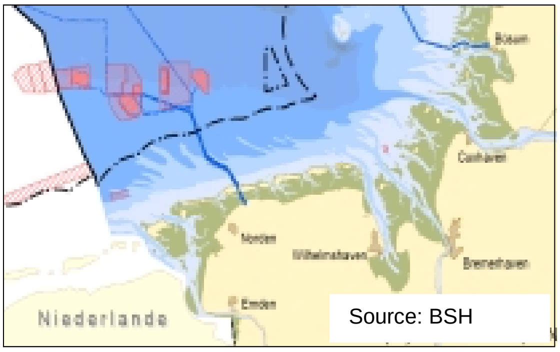



Figure 1: Sites of the investigated offshore wind farm in the Northern Sea.

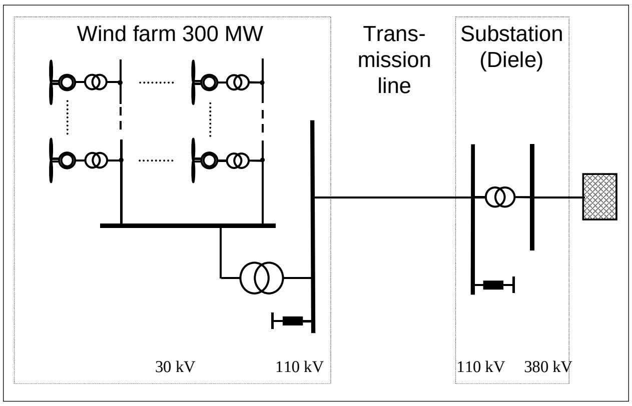



Figure 2: Overview of the simulation model of a 300 MW wind farm, the reactive power compensators, the transmission line and the onshore substation.

The DEWI performed some investigations of the influence of the transmission lines of offshore projects in the north of Borkum, Germany. The size of these planned wind farms shall be 60 MW up to 400 MW for the single wind farm in their first stages. Probably these wind farms will be connected to the substations at Conneforde or Diele in the north-west part of Germany. Figure 1 gives an overview of the sites of the wind farms. The distances between the wind farms and the onshore substations are about 120 km bee-line.

The investigations include a simulation of an offshore wind farm with the offshore substation and the transmission line to the onshore substation. An overview of the simulation model is given in figure 2. The chosen size of the wind farm is 300 MW. For the investigation of the influence of the transmission line the length of this line is varied up to 150 km. Compensators for reactive power are included at both sides of the transmission line. The voltage level within the wind farm network is 30 kV, the voltage level of the transmission line is 110 kV. At the onshore substation this 110 kV is transformed to 380 kV.

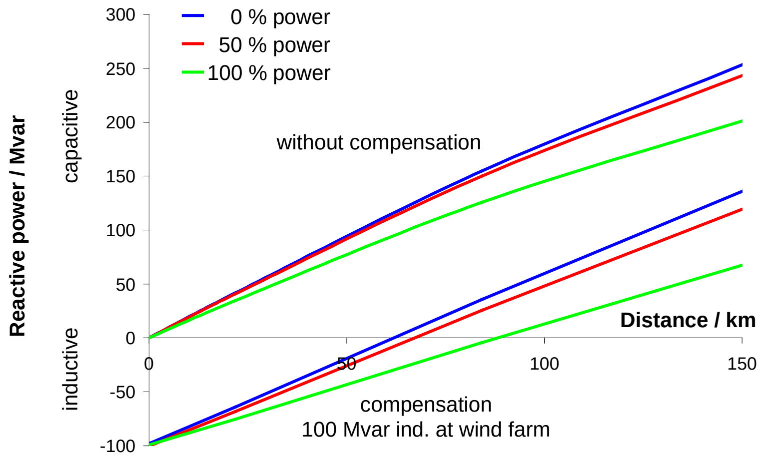



Figure 3: Reactive Power of the cable, measured at the grid connection point at the onshore substation. With increasing active power the reactance of the cable is partly compensated by the inductance of the cable. Including of a 100 Mvar compensation unit at the wind farm side gives a shifting of the curves.

## 2 Reactive power

The transmission line acts more or less as a capacitor. This means that the capacitive reactive power increases with the length of the cable. The manufacturer of the cable gives the capacitance as µF per km. But for the resulting reactive power further influence is given by the inductive component of the cable, which leads to the effect, that the reactive power is not increasing linear with the increasing length of the cable, as it can be seen in figure 3. With increasing active power and thus with increasing current, the curve gets more and more nonlinear. But also for no-load operation of the cable there is already an influence of the inductive component due to the charging current of the capacitance of the cable.

Mainly the reactive power compensation means a shifting of the curves, as it can be seen in figure 3 for a compensation of 100 Mvar at the wind farm side.

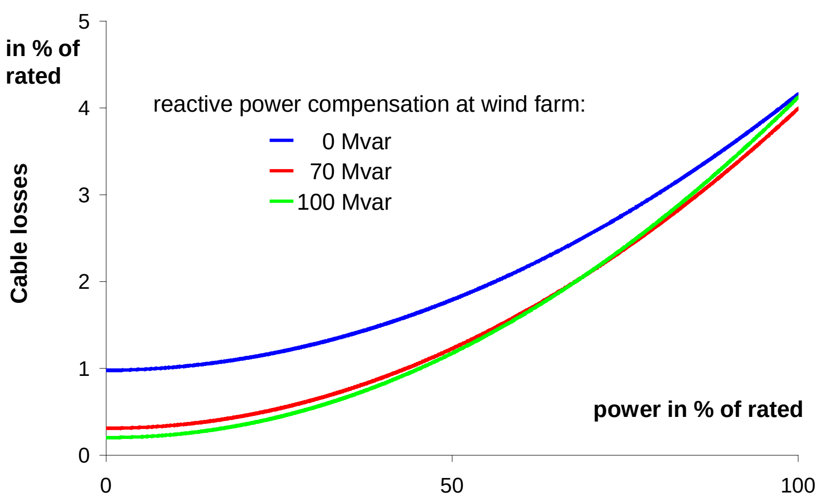



Figure 4: Electrical losses of the cable for a cable length of 150 km. The losses depend on the size of the reactive power compensation at the wind farm site.

## 3 Electrical losses

The electrical losses of the cable depend on the current of the cable. Thus the cable has already losses when there is no active power from the wind farm. Only due to the reactive power of the cable there is a current, which lead to electrical losses. This effect can be seen in figure 4 at no-load (active power =0) Especially when there is no reactive power compensation at the wind farm the losses are already 1 % of the rated capacity of the wind farm, although the wind farm does not produce any power.

With increasing active power of the wind farm the losses increase up to about 4 % of rated power of the wind farm.

The reactive power compensation at the wind farm site reduces the electrical losses on the cable. In the example of figure 4 the electrical losses at no-load are reduced from 1% down to 0.2 – 0.3 % of rated power of the wind farm, which has of course an enormous influence on the efficiency of the wind farm. Thus with an adequate layout of the compensation unit the economy of the wind farm can be improved.

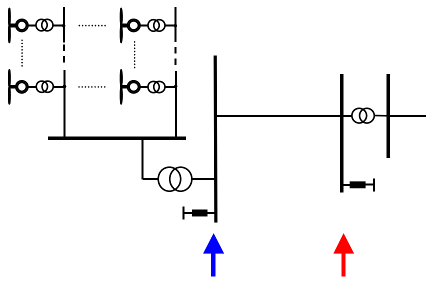
## 4 Harmonics

The Harmonic current emission of wind farms are often a limiting factor for grid connection. Thus the damping effect of the transmission line has large influence. But in addition there are also other effects, which lead to resonances as it can be seen in figure 5 until figure 7. In these figures a transmission ratio is shown, which is defined as follows:

$$\text{transmission ratio} = \frac{\text{harmonic current at beginning (or end) of cable}}{\text{sum of harmonic current emission of all WTs}}$$

This means the transmission ratio is equal 1, if the currents at the examined site (which is in this case the beginning and the end of the transmission cable) are equal to the generated harmonic currents of all of the wind turbines. If the transmission ratio is below 1, then there is a damping of harmonic currents.

As it can be seen in figure 5 the cable (in this case with a length of 150 kW) damps the harmonic currents. At the onshore substation the harmonic currents at 1 kHz are already damped down to 1 % of the harmonic currents, generated by the wind turbines. Higher frequencies than 1 kHz are damped even more by the cable.



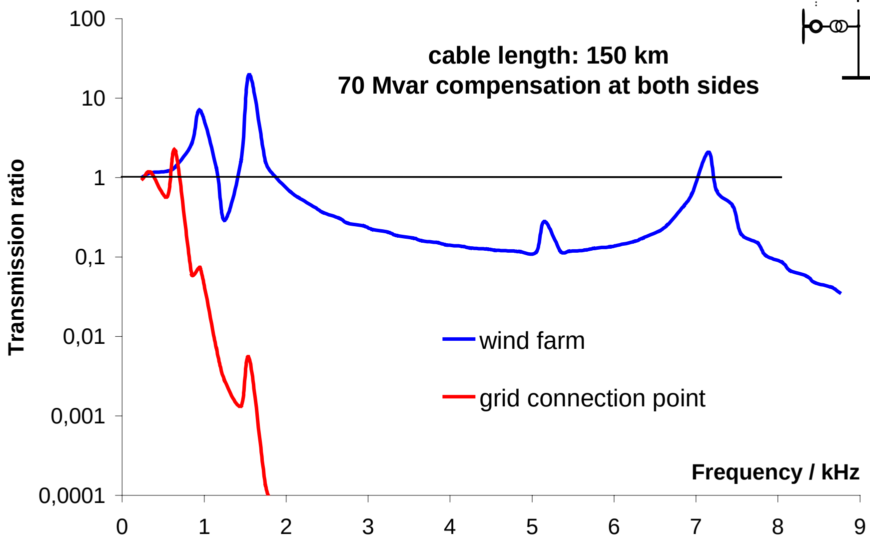



Figure 5: Transmission ratio at both sides of the cable for a cable length of 150 km.

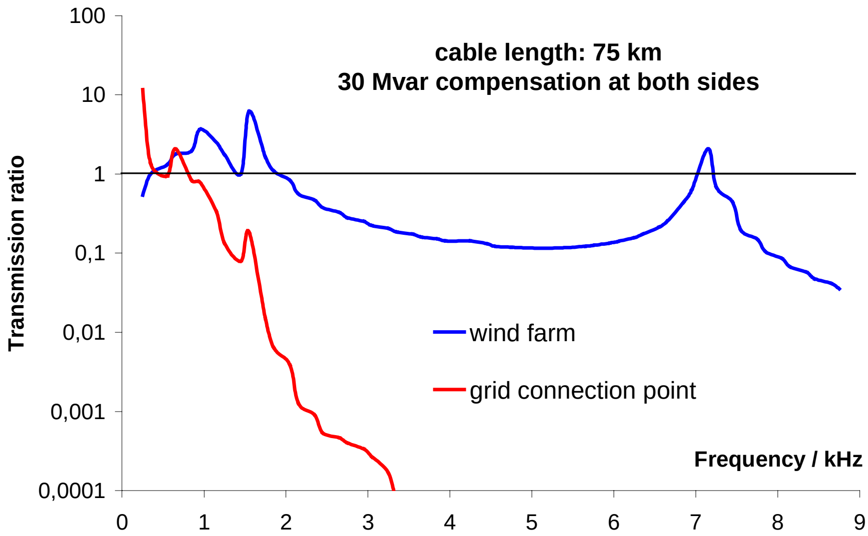



Figure 6: Transmission ratio at both sides of the cable for a cable length of 75 km.

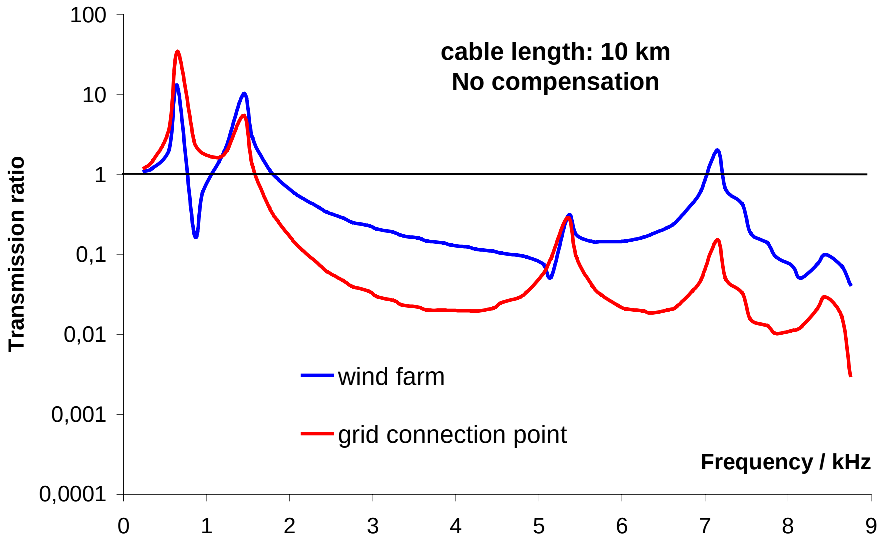



Figure 7: Transmission ratio at both sides of the cable for a cable length of 10 km.

As it can also be seen in figure 5 there are some resonances at the wind farm side. For some frequencies the harmonic currents at the beginning of the cable (at the wind farm) are higher than the produced harmonic currents by the wind turbines. The reason are these resonances, which occur at about 1 kHz, 1.5 kHz and 7.5 kHz in this case.

Figure 6 shows a similar behaviour, but here the investigated cable had a length of 75 km. Of course the damping effect of a 75 km cable is lower than for a 150 km cable. Thus only for frequencies above about 2 kHz the harmonic currents are damped down to 1 % (or below) of the generated harmonic currents by the wind turbines.

In figure 6 resonance effects also occur at the wind farm site. At about 1 kHz, 1.5 kHz and 7.5 kHz the harmonic currents at the beginning of the cable at the wind farm are higher than the harmonic currents, produced by the wind turbines.

For comparison also a system was investigated, where the cable length was only 10 km, see figure 7. This case may be similar to the grid connection of large onshore wind farms. As expected the damping effect of the short cable is much smaller, but there is still an effect for higher frequencies. But for the low frequencies there is also a resonance effect at the grid connection point, so that the harmonic currents at the grid connection point can be higher than the sum of the harmonic currents, produced by the wind turbines.

## 5 Conclusion

The investigations at the offshore wind farm with a grid connection by a long transmission cable show the following results:

- The reactive power of the cable depends not only on the capacitive component of the cable, also the inductive component has influence. Thus the reactive power depends also on current resp. on active power output of the wind farm
- If the reactive power of the cable is compensated at the wind farm site, then the electrical losses of the cables are reduced. In the shown example the power losses of the cable are up to 1 % of rated power of the wind farm at no-load of the wind farm without any compensation. Adequate compensation could reduce these cable losses at no-load of the wind farm down to about 0.2 % of rated power.
- The harmonic currents of the wind farm are damped by the transmission cable. For a frequency at 1 kHz the harmonic currents are already damped down to 1 % of the harmonic currents, produced by the wind turbines, for a cable length of 150 km. Shorter cables of course give lower effect for the damping.
- For the case, that the transmission line is very short, as it is in often cases for large onshore wind farms, resonance effects can occur. These resonances lead to the effect, that the harmonic currents can be higher at the grid connection point, than produced by the wind turbines. In the shown example this effect happened at about 1 and 1.5 kHz.

For the assessment of the grid connection of wind farms the present method to calculate the harmonics of a wind farm is performed by summation laws, where the harmonic currents of the wind turbines are arithmetically or geometrically added, see [2], [3]. The investigations have shown, that already relatively short cables have a damping effect for higher frequencies, so that higher frequency harmonic currents can be much lower at the grid connection point than the harmonic currents, produced by the wind turbines. At the other hand resonance effects can occur, especially in the range of 1 or 2 kHz. Due to these resonances the harmonic currents at the grid connection point can be higher than the produced harmonic currents. Thus for a correct assessment of the grid connection of a wind farm, a detailed frequency analysis should be performed for each project.

## 6 Literature


[1] Energiewirtschaftliche Planung für die Netzintegration von Windenergie in Deutschland an Land und Offshore bis zum Jahr 2020. Deutsche Energie-Agentur GmbH (dena). Febr. 2005

[2] IEC 61400-21: Wind turbine generator systems – Part 21: Measurement and assessment of power quality characteristics of grid connected wind turbines. First edition 12.2001.

[3] Eigenerzeugungsanlagen am Mittelspannungsnetz. Richtlinie für Anschluss und Parallelbetrieb von Eigenerzeugungsanlagen am Mittelspannungsnetz
2.. Ausgabe 1998, Hrsg.: VDEW e.V.; VWEW-Verlag, Frankfurt