AC Transmission Systems for Large and Remote Offshore Wind Farms

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ABSTRACT

Today the majority of large scale and remote OWF's (800 – 1200 MW and more than 100 km from the onshore connection point) are planned with HVDC solutions in mind. This paper presents various AC configurations and their limitations for use in large scale offshore wind farms. There are also some thoughts of the voltage level for the export transmission system. Cable parameters and thermal loading are discussed.

KEYWORDS

HVAC, Low Frequency AC (LFAC); Transmission length, Offshore windfarms, Intermittent load, Dynamic Rating, Armour Losses.

INTRODUCTION

Today the majority of large scale and remote offshore wind farms (OWF's) in the range of say 800 – 1200 MW and more than 100 km from the onshore connection point are planned with HVDC solutions in mind. These are HVDC schemes with VSC converters and extruded XLPE DC export cables.

This paper gives a presentation of the opportunity to use AC transmission in various forms for these large scale offshore wind farms. The paper highlights and discusses the following main topics:

- i) 50 Hz AC with different compensation schemes
- ii) Low frequency AC (LFAC)
- iii) AC transmission without offshore transformer station
- iv) Extra High Voltage (EHV) AC transmission solutions

The various options are evaluated and give an indication of maximum transmission capabilities with respect to transmission lengths and rated power.

In addition some central topics are discussed to identify the cables parameters and the stress they are exposed to:

- Cable losses; including armour losses
- Intermittent loading; wind power output is not constant
- Dynamic rating; thermal time constants

LIMITATIONS OF THE AC SYSTEM

It is well known that an AC transmission system with predominance of cable connections has its limitations. This is because the cable) act as large capacitors which requires a certain amount of reactive power (Q, [VAr]) to charge/discharge when applied in an AC system. The reactive power demand is both length and frequency dependent and will occupy a certain portion of the cable's transmission capability. When the transmission length is increasing the reactive power will be more and more dominant and at some point there is no transmission capacity left for the active power (P, [W]).

When dealing with AC transmission systems the following equations should be used (also referred to as the "Telegrapher's equations"):

$$U_{send} = U_{load} \cdot \cosh(g \cdot l) + \sqrt{3} \cdot I_{load} \cdot Z \cdot \sinh(g \cdot l) \qquad (1)$$

where *l* is the cable length and *g* the propagation constant:

$$g = \sqrt{(R + j \cdot \omega \cdot L)(G + j \cdot \omega C)} \qquad (2)$$

and *Z* is the characteristic impedance of the cable.

Thus the current in the sending end is derived from:

$$I_{send} = I_{load} \cdot \cosh(g \cdot l) + \frac{U_{load}}{\sqrt{3} \cdot Z} \cdot \sinh(g \cdot l) \qquad (3)$$

and the sending power:

$$P_{send} = \sqrt{3} \cdot |I_{send}| \cdot |U_{send}| \cdot \cos(\phi_{send}) \qquad (4)$$

These equations form the basis for the calculations performed throughout in this document.

CABLE MODEL

Inter-array cables (cables between turbines) have got no attention in this document. This paper focuses on AC export cables and their transmission capabilities. It is however assumed that the voltage in the inter-array grid is 66 kV as expected to be the output level for the next generation of WTG's.

The export cable used for simulations in this document is a 1200 mm^2 Cu 3-phase cable at various voltage levels.

It is of similar designs for all alternatives discussed in this paper, but with different insulation thickness corresponding to the different voltage classes.

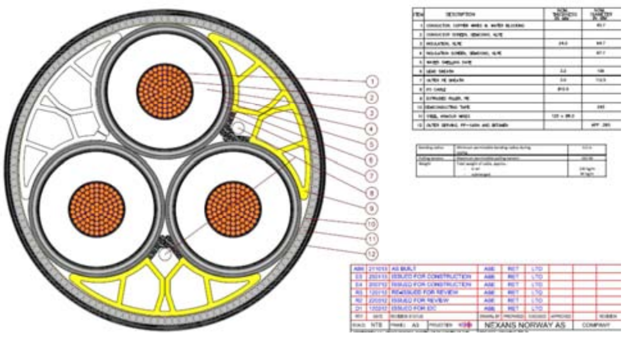

FIGURE 1: Cross section, typical export cable, 230 kV 1200 mm^2 Cu