POSITION
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1. Background material

Literature used:
• N.A.

2. Scope and considerations

The *Figure **1*** below shows a schematic cross section of the connection of an offshore wind farm to the onshore electricity grid. Wind turbines are connected through “inter-array” cables (in orange) to the offshore Connection Point (CP)[1] at the offshore substation, from which electricity is transported to shore. TenneT is responsible for the grid connection up to, and including, the offshore substation and will take care for the supply and installation.

The wind park, including the wind turbines and the array cables, up to the offshore CP at the switchgear installation on the offshore substation of TenneT, is to be supplied and installed by the owner of the Power Park Module (PPM[2]).

TenneT intends to standardise the offshore substations as much as possible for all five wind areas to be realised in the coming years in line with the Energy Agreement.

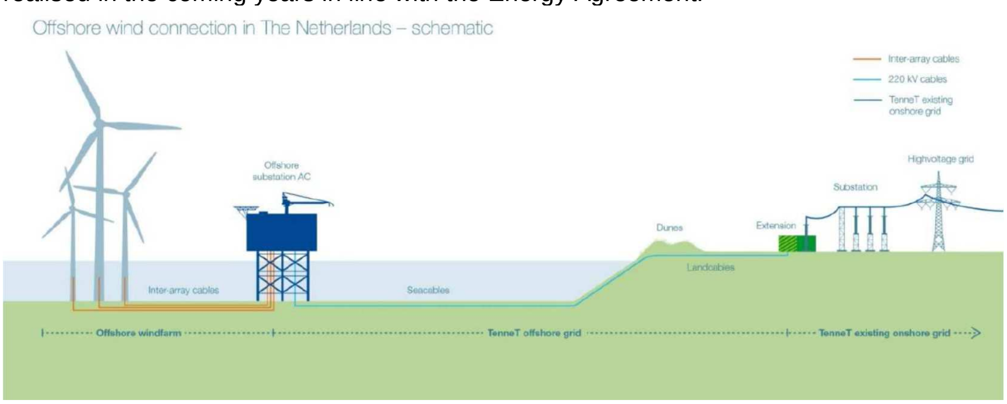

Figure 1 - Schematic of the offshore electrical grid. Source: TenneT

[1] The connection point (CP) between the offshore power park module (PPM) and TenneT is specified [TenneT position paper ONL 15-061 T.3 Point of Common Coupling] at the cable termination of the inter-array cables and the switchgear installation on the platform.
[2] TenneT, position paper ONL 15-079 T.5 Operation of Bays

3. Reactive power infield cables

3.1 Introduction

At the onshore grid connection point in the 380kV substation, the offshore grid connection has to comply to the TenneT TSO grid requirements. One of these grid requirements concerns the reactive power produced or consumed. The normal operation requirement will be: no exchange of reactive power i.e. cos(phi)=1. To be able to comply to this, TenneT will install reactors and capacitor banks in their onshore substations. These “static” compensation can only be switched on or off (compensation in big steps). A dynamic way of compensating is actually needed. This can be achieved by making use of the WTG reactive power capabilities.

Under no-load conditions the reactive power is mostly determined by the HV power cables (producing reactive power). Under full-load conditions also the transformers will consume reactive power. Hence, the reactive power consumed or produced by the total offshore grid depends on the transmitted active power (MW). For each operating point (in MW transmitted to TenneT TSO), TenneT will determine what amount of reactive power compensation is needed by the offshore grid. The main part will be produced/consumed by the onshore capacitors/reactors. The remaining part of the reactive power (the fine tuning) shall be compensated (production or consumption) by the PPM. The contribution by the PPM should be determined at the PPM grid connection point at the 66 kV busbar on the platform. To prevent extreme reactive power values for the PPM, TenneT will dimension their system (capabilities) in a way that the reactive power exchange between TenneT and the PPMs at the 66 kV connection point will be well within 0,1 pu (for a 350 MW i.e. 1 pu wind farm, within 35 MVAr i.e. 0,1 pu).

The reason for calculating the OWP’s reactive power compensation at the 66 kV grid connection point is, that the only possible point for a measuring and regulating loop as at the 66kV busbar on the platform. The consequence is that the PPMs shall compensate their “own” infield grid reactive power, either with reactors on the platform and/or making use of the reactive power capabilities of the WTG.

3.2 Main capacitors and reactors within infield grid

The main contributors of reactive power within an infield grid are the infield cables and the WTG step-up transformers. The 66 kV infield cables for a 350 MW wind farm will produce approx. 21–26 MVAr. This reactive power production does not vary much over the transmitted wind power (no-load or full-load). Further calculations are based on a virtual OWP grid with 26 MVAr produced by the infield cables.

The WTG step-up transformers for a 350 MW wind farm all together will consume approx. 24 MVAr. This reactive power consumption is very much depending on the transmitted wind power, however. The 24 MVAr will only be consumed under full-load conditions. Under no-load conditions this consumption will be close to 0 MVAr. From 0 to 24 MVAr is a quadratic function of MW.

3.3 Options for reactive power compensation

Basically, there are 2 possibilities to compensate the reactive power of the infield grid: making use of the WTG capabilities or placing equipment (reactor) on platform.
Making use of the WTG capabilities will introduce slightly higher converter losses. Placing a reactor on the platform raises the question: what MVAr size?

- The reactor can be dimensioned in such way that full compensation is obtained under no-load condition (QR=26 MVAr). Under full-load condition the total infield grid system will then be “over-compensated”, because of the consumption by the WTG step-up transformers (24 MVAr). This overcompensation must thus be levelled by the WTG converters.
- The reactor can be dimensioned in such way that full compensation is obtained under full-load condition (QR=2 MVAr). Under no-load condition the total infield grid system will then be “under-compensated”, because the WTG step-up transformers (24 MVAr) are not consuming anymore. This under-compensation must thus be levelled by the WTG converters.

Like making use of the WTG capabilities, a reactor will also introduce some losses.

So basically, there are 3 options for the compensation of the reactive power of the infield grid:

1) Reactor of 26 MVAr (QR) on platform,
2) Reactor of 2 MVAr (QR) on platform,
3) No reactor on platform, only WTG converter compensation.

3.4 Options for reactive power compensation

Since the needed reactive power capabilities of the WTGs for all 3 options are well within +/– 0,1 pu band, it is deemed not to be an issue. The WTG should be very well capable to fulfil these needs. The comparison of the 3 options can therefore mainly focus on the losses.

The losses for each option are calculated, as shown in the table below.

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35 = convertor losses MW at full load

			OPTION 1 (QR = 26 MVAr)			OPTION 2 (QR = 2 MVAr)			OPTION 3 (no QR)			COMBI 1-3 (switching 26 MVAr)		
active power	duration	active power	reactive power	apparent power	WTG convertor losses	reactive power	apparent power	WTG convertor losses	reactive power	apparent power	WTG convertor losses	reactive power	apparent power	WTG convertor losses
%	%	MW	MVAr	MVA	MW	MVAr	MVA	MW	MVAr	MVA	MW	MVAr	MVA	MW
0	17%	0	**0,0**	0,0	0,0	**-23,6**	23,6	0,0	**-25,4**	25,4	0,0	**0,0**	0,0	0,0
10	15%	35	**0,2**	35,0	0,1	**-23,6**	42,2	0,1	**-25,4**	43,2	0,1	**0,2**	35,0	0,1
20	10%	70	**1,0**	70,0	0,1	**-22,8**	73,6	0,2	**-24,6**	74,2	0,2	**1,0**	70,0	0,1
30	7%	105	**2,2**	105,0	0,2	**-21,6**	107,2	0,2	**-23,4**	107,6	0,2	**2,2**	105,0	0,2
40	5%	140	**3,8**	140,1	0,3	**-20,0**	141,4	0,3	**-21,8**	141,7	0,3	**3,8**	140,1	0,3
50	5%	175	**6,0**	175,1	0,4	**-17,8**	175,9	0,4	**-19,6**	176,1	0,4	**6,0**	175,1	0,4
60	5%	210	**8,6**	210,2	0,6	**-15,0**	210,5	0,6	**-16,8**	210,7	0,6	**8,6**	210,2	0,6
70	3%	245	**11,8**	245,3	0,5	**-11,8**	245,3	0,5	**-13,6**	245,4	0,5	**11,8**	245,3	0,5
80	5%	280	**15,6**	280,4	1,1	**-7,8**	280,1	1,1	**-9,6**	280,2	1,1	**-9,6**	280,2	1,1
90	6%	315	**19,2**	315,6	1,7	**-4,8**	315,0	1,7	**-6,6**	315,1	1,7	**-6,6**	315,1	1,7
100	22%	350	**24,0**	350,8	7,7	**0,0**	350,0	7,7	**-1,8**	350,0	7,7	**-1,8**	350,0	7,7
				WTG converter: MW	12,8			12,8			12,8			12,7
				platform reactor: MW	0,1			0,0			0,0			0,1
				total: MW	**12,88**			**12,83**			**12,84**			**12,81**
							k€ loss over 20 years (€30/MWh)				42.189			42.076
							difference in k€ (€30/MWh)				**113**			**0**
							k€ loss over 20 years (€120/MWh)				168.757			168.303
							difference in k€ (€120/MWh)				454			0

Beside the 3 options, a 4th option "Combi 1-3" has been calculated. This is a combination of option 1 and 3, which would be common practice if option 1 was chosen:

> As explained, option 1 fully compensates the infield cables. At full-load we have over-compensation, but it makes no sense to produce reactive power in the WTG and "burn" it in the reactor on the platform. In that case the reactor will be switched off..
> The optimal switch-off power is 75% (marked with bold red line).

The first 3 columns present the produced wind power and its duration. For each option, the first column presents the reactive power needed from the WTG converter in MVAr. The second column presents the corresponding apparent (total) power in MVA. The third column present the losses per hour (MWh per hour). This last calculation is based on 10% converter losses at full load i.e. 35 MWh (upper left corner) for a 350 MW wind farm. These converter losses are very pessimistic.

The losses per wind power produced are summarized, resulting in the losses per hour of the WTG converter. Depending on a reactor being switched on or off, also the losses of that reactor are estimated. Note that the losses of option 2, reactor of 2 MVAr, are neglected in the calculations. The costs of the total losses per hour are capitalized over 20 years using MWh prices of € 30 (market price) and € 120 (subsidised price).

3.5 Analysis

Option 3 (no reactor, only WTG converter compensation) shows slightly higher losses than the best option

with a platform reactor (being Combi 1-3). The difference between option 3 and the combi 1-3 capitalized to NPV is € 113.000 (with € 30 per MWh). As stated, 10% losses in all WTGs (35 MW for 350 MW wind park) is a rather high value. However, if the power generation is less than maximum, the losses decrease very rapidly. E.g. reducing to 30 MW the difference will already result in a difference of € 66.000.
Calculating with € 120 per MWh will result in a difference of € 454.000.

The costs of a platform reactor, a 66 kV bay, the 66 kV cable connection, the protection panel and also the extra space and weight on the platform will exceed this difference by far.

Option 3 (no reactor on platform, only WTG converter compensation) is the best overall option.

4. Position of TenneT

TenneT is inclined to have the reactive power of the infield grid compensated by the PPM, in order to regulate the reactive power of the offshore grid. The reactive power intended to be compensated only making use of the WTG reactive power capabilities.

5. Topic consultation

The expert meeting of 2-3 July, 2015 gives TenneT the opportunity to get feedback from developers on their position regarding reactive power compensation. The main goal of this meeting will be to assess whether TenneT's views as documented within this position paper, and background data above, are shared by the industry.