Strategies for Offshore Wind Park Clustering and Cluster Grid Connection

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Abstract**-- This paper describes one method of finding an economically optimized planning strategy for interconnecting offshore wind parks to the onshore transmission grid. Depending on the strategy of placing HVDC converter platforms within a wind park cluster different total cost for investment and losses arise. A sensitivity analysis shows the influence of the variety of the used assumptions.**

Index Terms**-- Offshore, wind park cluster, grid connection, losses, investment, sensitivity analysis**

I. INTRODUCTION

In the area of the German North Sea a lot of offshore wind power activity takes place. There are around 58 offshore wind parks (OWP) planned with a total number of more than 4500 wind turbine generators (WTG). The most wind parks will have a distance to the nearest suitable grid connection point of around 120 to 250 kilometer and a water depth of 20 to 50 meters. The first parks to be built are the test site 'Alpha Ventus' and the first commercial one 'BARD Offshore 1', both started construction in 2009.

Because of their location the OWP were combined into four clusters. Cluster DolWin, BorWin, SylWin and HelWin.

The Cluster with the far most planned wind turbine generators is the cluster BorWin (Fig. 1). It is located around 120 kilometer from shoreline in the north of the German island Borkum and consists of more than 30 planned offshore wind parks in an area of approximately 5000 square kilometers. To examine the strategy of planning the grid connection it is reasonable to choose the cluster with the highest number of wind turbine generators. At BorWin more than 2000 wind turbine generators were planned. Based on the published information of the wind park planers, the transmission system operators and the German Federal Environment Ministry a maximum scenario for the wind turbine generator installation in the cluster was created [3,5].

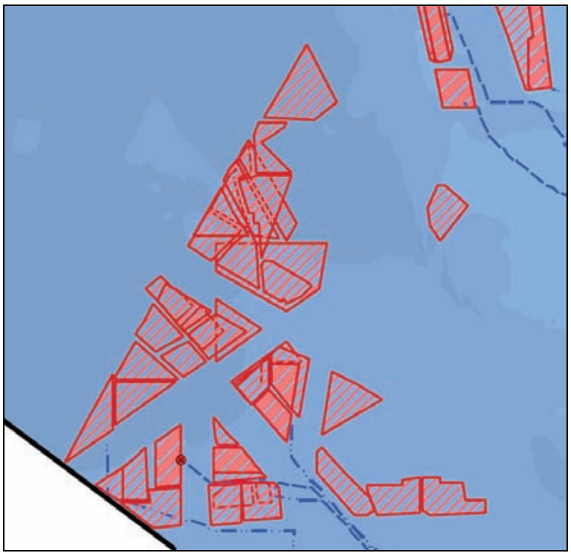

Fig. 1. Planned offshore wind parks and transmission traces in the German North Sea wind park cluster BorWin. [1]

II. MAXIMUM SCENARIO FOR THE WIND TURBINE GENERATOR INSTALLATION

Based on the assumption that all offshore wind parks in the cluster (see Fig. 1) will erect all the wind turbine generators at the time they have announced the number of installations exceeds 2000 up to the year 2020. Figure 2 shows the accumulated number of installed wind turbine generators, each with a lifecycle time of 20 years. Because of the forecast uncertainty a ±10 % bandwidth is assumed. New installed generators after the year 2021 are not included in this scenario. Possible bottlenecks in the supply of components are also not considered. It is assumed that all necessary equipment is available when needed. The third uncertainty besides the total number of wind turbine generators and their date of initial operation is the rated power of the generators.

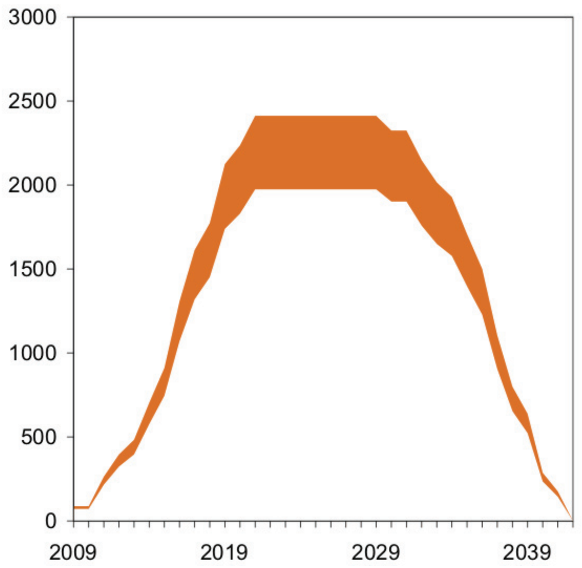

Fig. 2: Assumed number of installed wind turbine generators in the cluster BorWin.

Today offshore wind turbine generators are available with rated power between 2 and 6 megawatt but in future maybe even larger turbines will be on the market. Due to that reason an offshore wind park with 80 wind turbine generators could have a total rated power in a range of 160 megawatt (2 MW each) up to 480 MW (6 MW each). For the study a rated power of 5 megawatt for all generators was chosen as a base case. Together with the installed generators a maximum of around 12000 megawatt will be reached in 2021 (see Fig. 3).

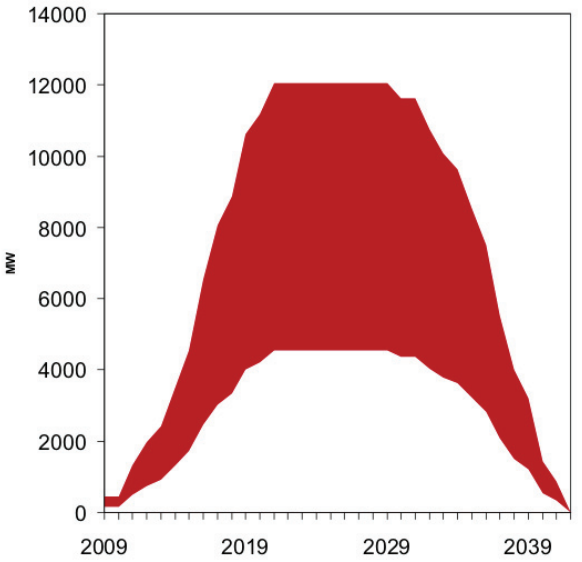

Fig. 3: Possible bandwidth of the installed power in the cluster BorWin.

III. TRANSMISSION TECHNOLOGY

Because of the distances between the OWP and the onshore connection point all grid connections were assumed to be in HVDC technology. Because of the positive features provided by the voltage source converter high voltage direct current (VSC HVDC) technology this type of HVDC is assumed for all interconnections. These features are [2]:

- Inherent startup capability
- Stable power transmission together with long cables
- Dynamic control of the AC voltage in the offshore grid
- Independent active and reactive power control on both converters (within ratings)
- Decoupling the offshore and the onshore grid resulting in maximum support of the wind generators during fault condition
- No synchronous compensator in the offshore grid is necessary
- Compact site area
- Lower losses in the transmission cables compared to AC transmission due to the lack of dielectric losses

The potential high number of needed HVDC systems in the whole North Sea area results in the need of standardization of the offshore DC links and their block size to reduce engineering costs. Two block sizes are used in this study: one with 400 megawatt and the second with 1000 megawatt.

IV. HVDC PLACING STRATEGY

Depending on the strategy of placing the HVDC platforms and connecting the wind parks to the converter stations via AC cables, there are more or less synergy effects in utilization, length of AC cables, losses and date of investment. The three strategies investigated in this paper are single connection of every wind park, central placing of all DC converter platforms and sub clustering.

Single connection

Figure 4 (left) shows the concept of single connection of every wind park. The green areas are the wind parks and the black dots represent the HVDC converter stations. The aim is to minimize the losses in the transmission cables. To reach this goal each DC converter platform is placed right next to the platform of the corresponding wind park in order to minimize the AC cable length and use DC instead of AC transmission. There are no interconnections between the wind parks. From the planning point of view this seems to be an easy solution because of the lack of interaction between the parks. But at the same time there are no synergy effects during construction and operation possible.

Central placing

The best solution in terms of synergy effects and flexibility is the central placing of all DC converters close together (Fig. 4, right). During construction of the wind parks the date of first operation of the HVDC links is more flexible and at normal operation a lot of operation modes are possible e.g. complete shutdown of DC links during times with low wind or for maintenance without the need of forced

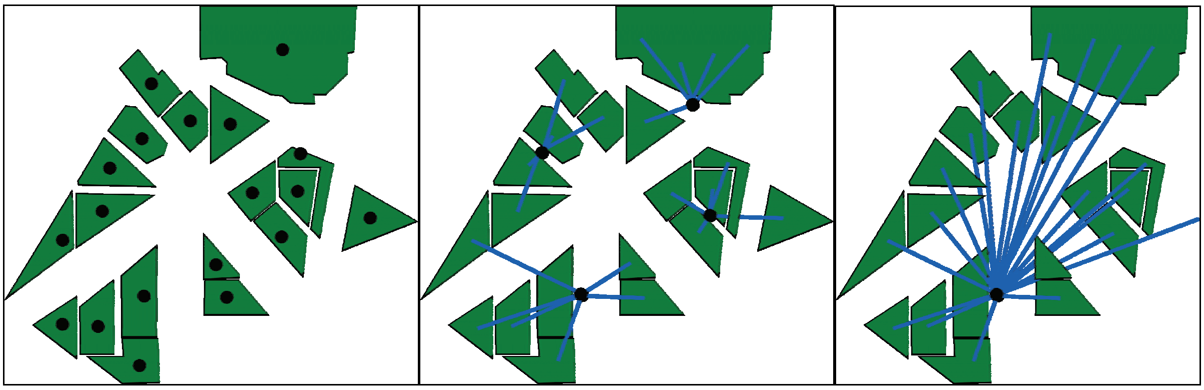

Fig. 4: Strategy of placing HVDC links. Green areas: Offshore wind parks. Black dots: HVDC converter station. Blue lines: AC cables.

power infeed reduction. It is necessary to connect the wind parks to this central busbar with AC cables and with that additional losses occur. The total length of AC cable is more than 1000 system kilometers (see Fig. 5).

Sub clustering

A combination of the above mentioned strategies is the sub clustering (Fig. 4, middle). The wind park cluster is divided in four independent sub clusters, each with a common busbar to connect the wind parks and the DC links of the sub cluster together. This strategy has the flexibility of a centralized bus bar but around 60 % shorter AC cables.

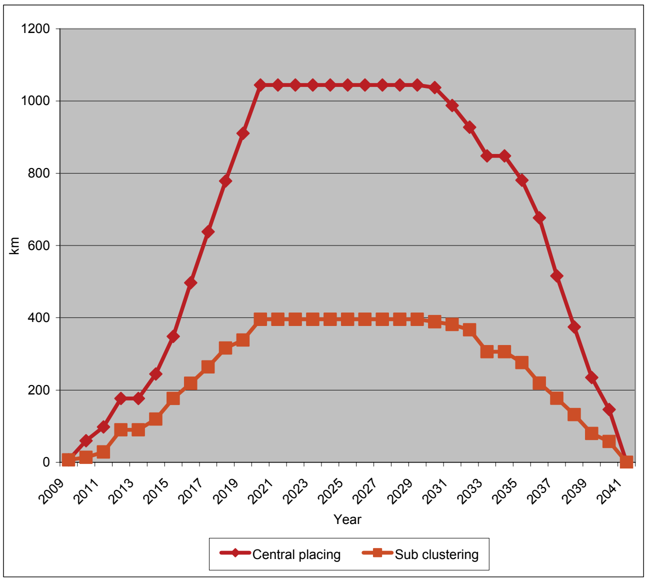

Fig. 5: AC cable length for the strategies single connection and sub clustering.

V. COMPARING THE STRATEGIES

To compare the three strategies the total investment costs and the total costs due to losses during the lifetime of 20 years were calculated as net present value in the year 2009. The procedure is described in the following and illustrated in figure 6.

For each year the location and the rated power of the DC converters were chosen and the number of AC respectively DC cable systems and their total length were calculated depending on the strategy and the WTG installation scenario.

After the specification of the topology, the total net present value of all investment costs was calculated based on the assumed values presented in table 1. Included in the investment costs are the costs for deconstruction after the lifetime.

Turnkey investment 400 MW VSC HVDC	400 Million €
Turnkey investment 1000 MW VSC HVDC	680 Million €
Investment AC cable [4]	1.05 Million € per km
Cost rate for transmission losses	6 ct/kWh
Imputed interest rate	8 %
Deconstruction factor	0.25

Table 1: Assumptions for cost calculation.

The calculation of the costs caused by losses is more complicated. The system losses consist of a current dependent and a voltage dependent (current invariant) part. For the calculation of the current dependent losses the power infeed of the wind parks is needed. Based on the wind speed measurements of the year 2006 [3] (FINO I platform) and typical wind speed – power – characteristics of windmills the power infeed was determined as 35000 – 15 minutes average values. The wind profile of the year 2006 is assumed as typical and is used for all years of operation.

With these power infeed profile together with the loss characteristics of the converters and cables and the system topology (which defines the type and length of cables, the number of parallel cable systems, the number and size of HVDC converters) the total loss energy was calculated and accumulated for each year. To get the costs for transmission losses the yearly amount of loss energy was multiplied with a constant cost rate for transmission losses and annualized to the year 2009.

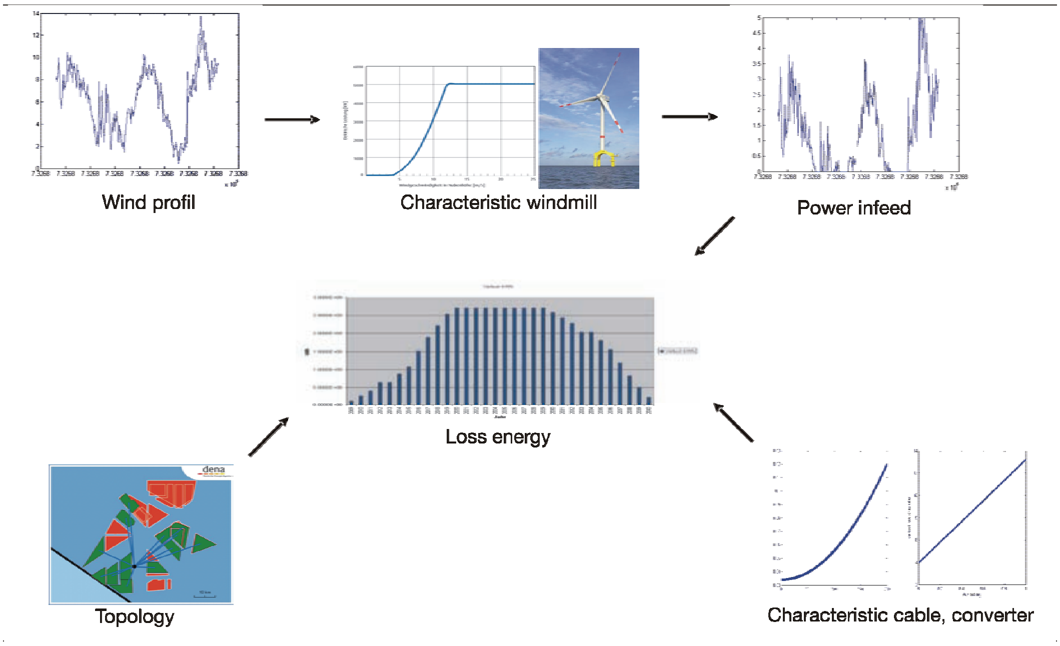

Fig. 6: Procedure for loss energy calculation.

VI. RESULTS

The single connection strategy causes the highest investment costs, mainly because almost all wind parks have a rated power of 400 megawatt so there is no use for the bigger links with 1000 megawatt transmission capacity. But the specific costs per megawatt are higher (by 47 %) for the 400 megawatt link. The total system losses are smaller than with the other strategies due to the very short AC cables.

Sub clustering and central placing generate nearly the same investment costs. The net present value of the investment costs with sub clustering is 4507 million euro and with the central placing strategy 4480 million euro (fig. 7).

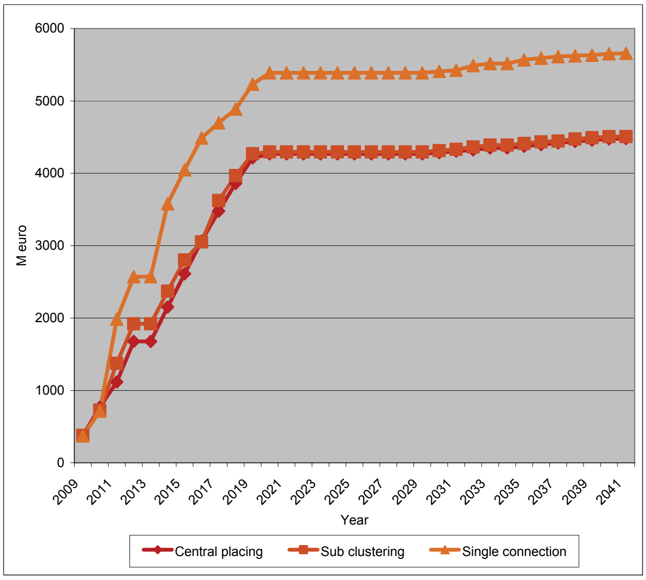

Fig. 7: Net present value of investment costs for single connection, central placing and sub clustering in million euro.

In terms of system losses the sub clustering is the better concept. Over lifetime the net present value of the costs for system losses is 893 million euro, about 123 million euro less than central placing (see fig. 8). The costs due to transmission losses are five times smaller compared to the investment costs.

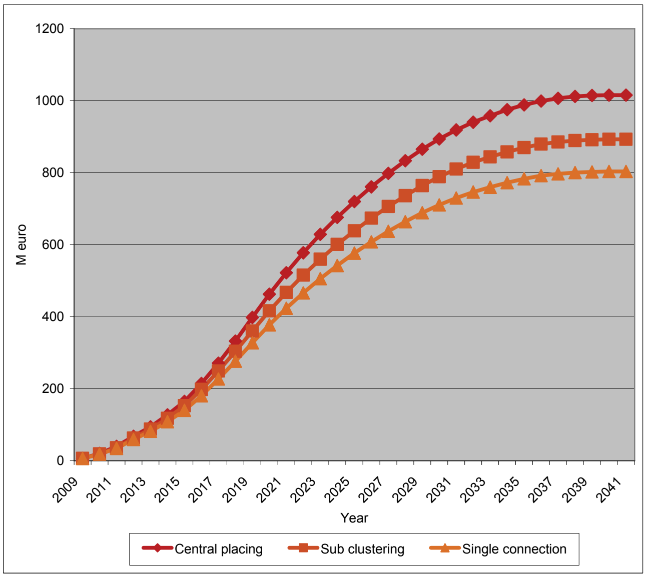

Fig. 8: Net present value of costs caused by transmission losses for single connection, central placing and sub clustering in million euro.

Figure 9 shows the net present value of the total costs of all three strategies. At the beginning of the offshore development the sub clustering strategy is a little more expensive but over lifetime cheaper than central placing because of lower system losses. Single connection causes around 16 % more expenses than the other strategies.

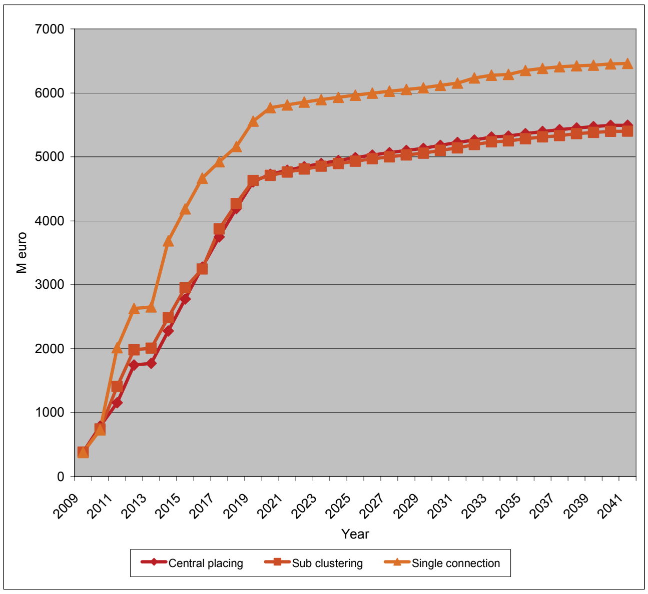

Fig. 9: Net present value of total costs for single connection, central placing and sub clustering in million euro.

VII. SENSITIVITY ANALYSIS

As a result of this study the strategy of sub clustering seems to be the most advantageous concept based on the used assumptions. To find out how sensitive the result react on changes in the assumptions the parameters imputed interest rate, the cost rate for transmission losses, the investment costs for AC cables and the investment costs for the 400 megawatt VSC HVDC links were analyzed.

A change in the imputed interest rate by ±30 % results in no change in the recommendation in favor the sub cluster concept. Also a cost rate for transmission losses between 1 and 16 cent per kilowatt hour leads to no change in the recommendation.

A rise of the VSC HVDC link price above 500 million euro for a 400 megawatt link and a constant price for the 1000 megawatt link leads to a change and the central placing strategy has the lowest net present value of total costs. This scenario is very unlikely because normally the price decreases due to synergy effects in multiple manufacturing of the same HVDC converter station and savings in engineering costs.

More likely is a reduction of the AC cable costs. If the total cost of one kilometer cable decreases below 0.8 million euro, the central placing strategy will become the cheapest. Figure 10 shows the difference in net present value of total costs between central placing and sub clustering in million euro. Positive values indicate that central placing and negative that sub clustering is advantageous.

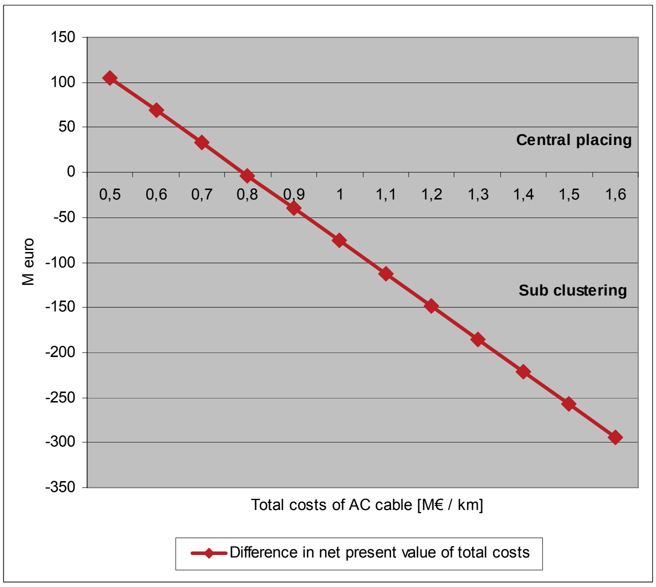

Fig. 10: Difference in net present value of total costs between central placing and sub clustering in million euro.

VIII. CONCLUSION

The strategies central placing the HVDC platforms and sub clustering are very similar in terms of total costs. The sensitivity analysis shows that a change in price for HVDC converters or AC cables lead to a shift in net present value of total costs. It is not possible to make a clear recommendation for one of these strategies but with the used assumption (maximum installation scenario, specific costs) sub clustering is a little bit more advantageous.

The study shows that single connection is not recommended because of the much higher costs and the lack of synergy effects.

In terms of system stability and system operation further investigations have to be done to decide which strategy is the best from technical and economical point of view.

IX. REFERENCES

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X. BIOGRAPHIES

Thomas Ahndorf received in 2004 his diploma in electrical power engineering and automation from the University of Applied Science in Karlsruhe, Germany. After this he started a postgraduate study also at the University of Applied Science in Karlsruhe and received his Master degree in Electrical Engineering in 2006 with distinction. Since 2006 Mr. Ahndorf worked at the Associated Institute of Power Transmission Systems of Technische Universität München as a Ph.D. student. His research is focused on the grid connection of large scale offshore wind power. Mr. Ahndorf is a member of the VDE

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