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# Transmission System Topology Optimization for Large-Scale Offshore Wind Integration — Source link

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# Optimal topology for offshore transmission system investments

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## I. EXTENDED ABSTRACT

Sustainable energy sources are becoming more important and reaching a higher penetration level to reduce $CO_2$ emissions. The goals set by the European Union require a fast development and integration of sustainable energy sources into the existing electricity network. Wind energy converters are well known and the generation technology has been developed rapidly in past years. Therefore the wind energy is predestinated to be integrated largely. To realize a large scale integration of wind power, offshore wind power plants are essential, because of the reduced visual and environmental impact and the higher and more constant wind speeds on the open seas. On the other hand the integration of wind power from offshore power plants creates new challenges for the transmission system planning.

To integrate large amounts of offshore wind power, an offshore transmission grid has to be designed, so that the power is transmitted to the main land in a cost effective way and the operational safety of the existing transmission grid is not endangered. The major difference and the big challenge of developing an offshore transmission grid is that high voltage submarine cables have to be used, which behave different than overhead lines used in the existing transmission grid.
Because of the high cable capacitances, which can reach values up to 25 times higher than these of overhead lines [1], the required charging currents are enormous and therefore the maximum transferable active power and the cable lengths are limited. In order to decrease the investment requirements, the offshore transmission system has to be optimized keeping the limited transfer capabilities in mind.

This work shows a method for the optimization of offshore transmission grid topologies in order to minimize the life cycle system costs of the transmission system. With this method, besides the grid topology also the optimal transmission technology (HVAC, HVDC or both) and the transmission voltage are determined. Additionally the number of the required cables (or overhead lines for onshore sections) and their cross sections for each branch are determined using an iterative approach.

The required equipment size for compensation is also determined and taken into account for the total system costs. The transmission losses, the maintenance as well as the unavailability of the used equipment are taken into account during the optimization process. Network reinforcements to the existing onshore grid are taken into consideration as they can help to reduce offshore transmission costs resulting in reduced total system costs. In the developed algorithm, the extent of the network reinforcements can be chosen. It is also possible to determine, whether the reinforcement is best realized with cables or overhead lines due to the differences in the investment costs.

The optimization process is divided in two levels. The upper level is the optimization of the topology and the technology (HVAC or HVDC) and the lower level is the optimization of the voltage level and the determination of the required number of lines/cables and the cross sections. The following paragraphs explain the optimization process in more detail and figure 1 shows a block diagram of the optimization process.


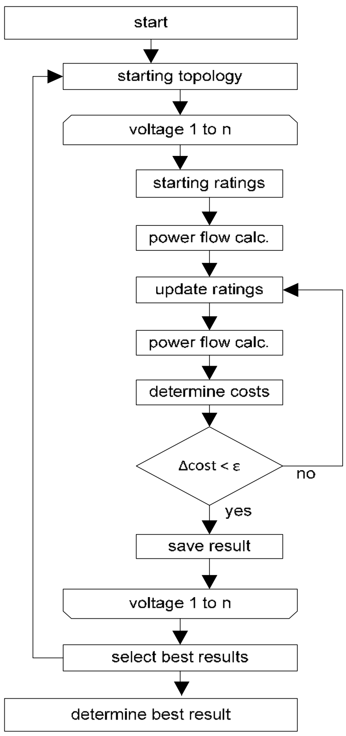


Fig. 1 Block diagram of the optimization process

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Starting with the given coordinates of the offshore wind farms (WF), the positions of the possible points of common coupling (PCC), the power which can be injected in each of the PCCs and the possibilities of grid reinforcement a starting offshore grid topology is defined. After defining the starting topology, the transmission technology is chosen using the transmitted power and the transmission distance of each branch. After defining transmission topology and technology starting power ratings for the branches are defined to perform load flow calculations. The results of the power flow calculations are needed for two reasons. First of all the results show if the technical constraints are fulfilled and second, if the chosen starting values were set to high. Depending on the power flow results, the ratings of the branches, hence their impedances are updated and a new power flow calculation performed. This is done iteratively until the change in the transmission system costs is smaller than a chosen threshold value. This procedure is repeated for all possible voltage levels to obtain the optimal voltage level for one transmission topology.

After obtaining the best voltage level for one topology, the topology is varied step by step, so that the best topology can be identified. Because the number of possible topologies increases exponentially with the number of WFs and PCCs, it is difficult to determine the best topology by analyzing all possibilities. Therefore an algorithm is used, which limits the number of the analyzed topologies. With the algorithm, new topologies are created, the life cycle costs of the topologies determined and the best solutions used as new starting solutions.

In this way a set of topologies is created iteratively, where the optimization algorithm decides automatically which connection topology is the best one for the analyzed wind farms, whether it is a meshed or a radial topology. The method can be used to plan offshore grids as well. It is also automatically decided, which single connections should be realized with HVAC and which connections should be realized with HVDC.

To get realistic results it is important to use realistic data for the costs of the used equipment. The cost functions used for the optimization are obtained from several publications such as [2-7]. Also the technical equipment data is obtained using manufacturer's data sheets [1, 8-9] in order to have reliable power (current) ratings. By analyzing several study cases from [10] the used cost data could be validated. Such a case is shown in figure 2. The study case includes 8 wind farms with a rated power of 550 MW for each wind farm. In the configuration given in [10], the HVAC connections are realized with 245 kV. For this case the total system costs determined in [10] are 2,160 M€. For the same topology and voltage levels, the costs determined with the developed tool are 2,080 M€. The best solution delivered by the optimization algorithm realizes the HVAC connections with 380 kV and replaces two HVAC connections (WF4 –WF3 and WF5 – WF6 in figure 2) with HVDC connections. The total system costs determined for the best solution are 1,550 M€.

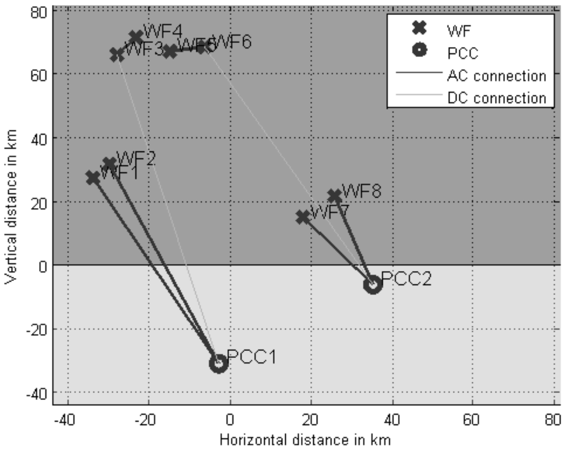


Fig. 2 Coordinates of the wind farms and the topology of the transmission system for a study case.

The optimization algorithm is implemented in MATLAB and the power flow calculations are performed with Matpower [11], a MATLAB based power flow calculation tool.

The full paper will contain a detailed description of the model and optimization techniques used, as well as some benchmarked examples which show the validity of the method.

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