PO.ID 211

Optimisation of offshore wind farm collection systems

Dr Mircea Scutariu, Dr. Xiao Yi
Mott MacDonald, Glasgow, United Kingdom

Abstract

Offshore wind is at the forefront of energy generation technologies reducing carbon emissions. However it is expensive for large scale deployment (more than £140/MWh for a typical UK Round 2 site). The costs of Round 3 projects are set to escalate because of remote location and deep-water sitting.

For typical offshore wind farms the submarine cable procurement costs are up to 7% of total capital expenditure with the installation costing another 4%. Efficient inter-array cable layouts could achieve up to 10% of total savings in offshore wind.

An optimisation tool for offshore inter-array cable layout design was developed. It takes into account the seabed geo-tech constraints, identifying the locations of multiple offshore collector platforms in large wind farms while minimising the overall capital and operational expenditure of the wind farm collection system.

Objectives

- To minimise the combined CapEx (cable procurement and installation costs) and the net present value of OpEx over the operational years (costs of maintenance, energy losses during normal operation and energy not delivered due to equipment unavailability).
- The number of wind turbines connected to a collector string is constrained by the cable ampacity depending on installation conditions (J-tube, burial depth).
- The construction and installation of offshore collector platforms limits the number of incoming collector strings.
- Inter-array cable crossings are strictly avoided.
- Inter-array cable crossing of exclusion zones, defined using the seabed geo-tech features and the ability to install cables, is strictly avoided.

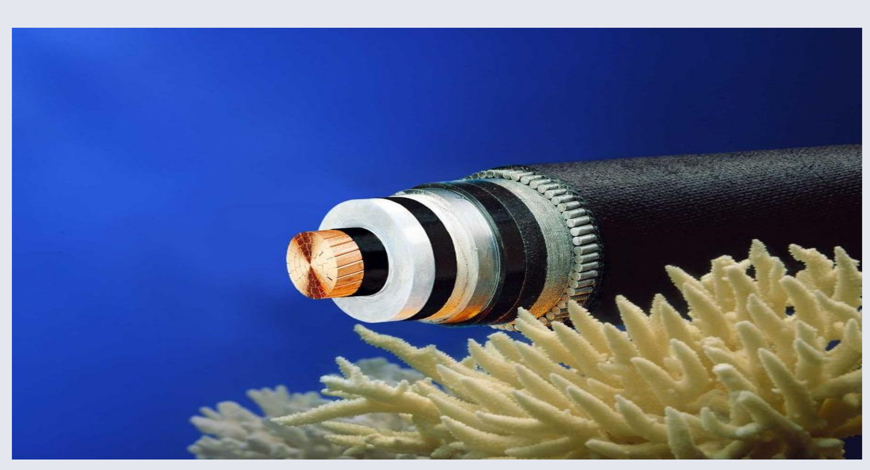


Image sources: http://www.nvnom.com/investment-opportunities/offshore-wind/
http://subseaworldnews.com/2011/12/26/litc-activates-new-enhanced-submarine-cable-system-between-libya-and-italy/

Methodology

Stochastic methods to find the near optimum connectivity

It is impossible to find the-best-of-all out of the enormous number of connectivity combinations; therefore, this tool uses stochastic approach to find the near optimum solution within given computation time.

Greedy algorithm is employed to generate the initial cable connectivity. It randomly chooses one of the incomplete strings and extends it to the nearest unconnected wind turbine. *Genetic algorithm* is used to further improve the connectivity. It randomly takes the turbines off the connectivity for further shuffling. It then randomly picks up one of the unconnected turbines and identifies the route to the nearest connected turbines.

Kmeans++ algorithm to optimise the locations of multiple substations

It classifies the wind turbines into several clusters according to geographical metrics and then it finds the *centre of gravity* for each cluster. This approach allows the minimisation of costs for connecting the wind turbines within the cluster.

Graham' scanning algorithm to bypass exclusion zones

It is applied to find the shortest *zigzag* path between two turbines when the connection route has to avoid exclusion zones. The *visibility graphs,* composed by the edges and vertices of the exclusion zones, are firstly identified between any pair of wind turbines and then the shortest zigzag cable route is found using a greedy algorithm.

References

1. US Energy Information Administration, "Levelized cost of new generation resources in teh annual energy outlook" 2011.
2. Low Carbon Innovation Coordination Group, "Technology innovation needs assessment-offshore wind power summary report," 2012.
3. A. Jenkins, M. Scutariu, and K.S. Smith, "Offshore wind farm inter-array cable layout," in IEEE PowerTech 2013, Grenoble.
4. http://en.wikipedia.org/wiki/K-means%2B%2B.
5. M. de Berg, O. Cheong, M. van Kreveld, M. Overmars, "Visibility graphs," in Computational geometry-algorithms and applications (3rd edition), Springer, 2008, pp. 326-330.
6. A. Sannino, H. Breder, E.K. Nielsen, "Reliability of collection grids for large offshore wind parks," in International Conference on Probabilistic Methods Applied to Power Systems (PMAPS 2006), 2006.

A Demo Case

This optimisation tool was applied for the inter-array layout design of one demo wind farm with 119 turbines rated at 6 MW. The seabed within the wind farm boundary was classified into 5 installation zones and several exclusion zones were also defined. The collector system will use 33 kV subsea cables with two HVAC collector platforms. It was assumed that the price of wind energy is £150/MWh, the annual discount rate is 8% and the designed operational life is 20 yrs.

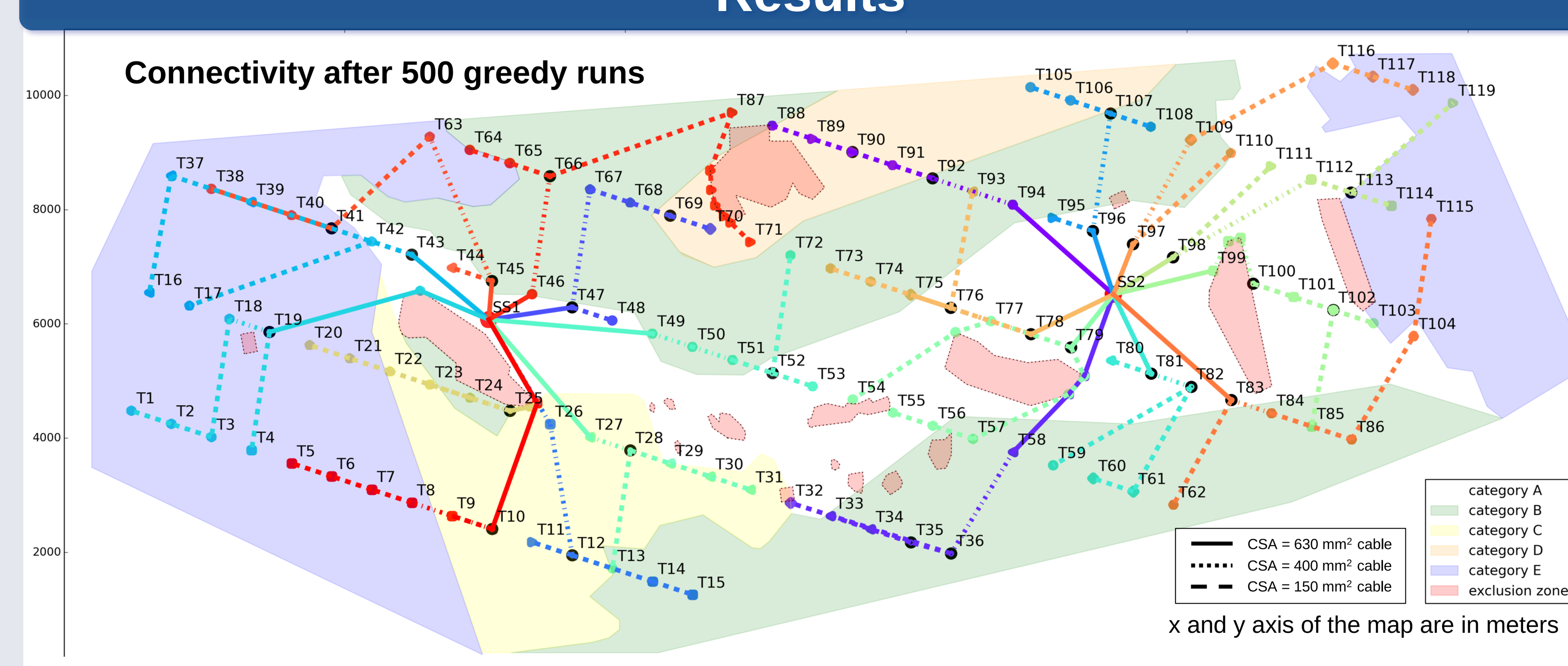
CSA (mm^2)	Cable cost (£/m)	R (Ω/km)	X (Ω/km)	B (uF/km)	Maximum number of 6 MW turbines to be connected downstream (in J-tube or seabed areas)					
					J-tube	category A	category B	category C	category D	category E
150	200	0.1589	0.1384	0.2264	3	3	3	3	3	3
400	250	0.0625	0.1206	0.3177	5	5	5	5	4	4
630	350	0.0405	0.1132	0.3836	7	7	7	6	6	6

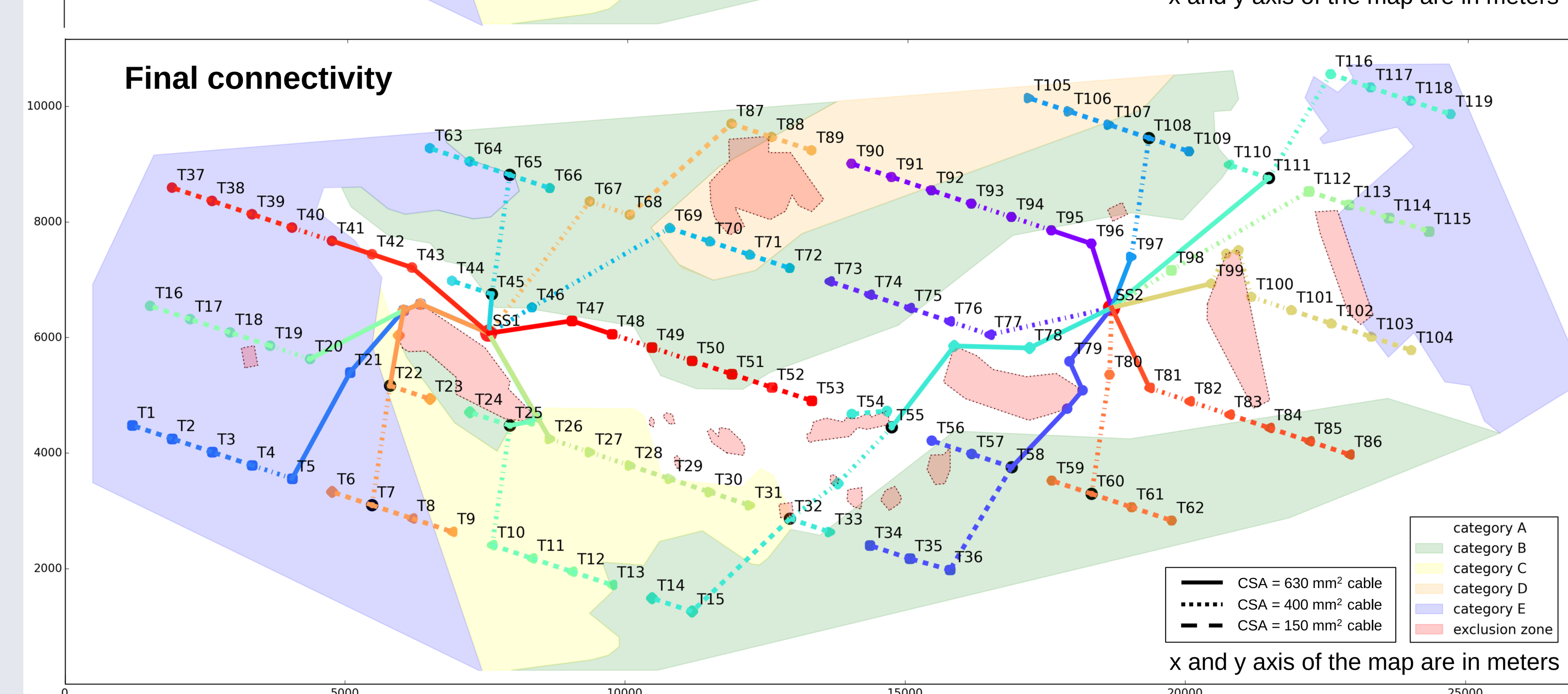
Seabed categories	Cable installation costs (£/m)	Cable maintenance costs (£/m/yr)
A	300	5.3
B	600	5.7
C	600	6.2
D	600	7.0
E	750	7.3

Cable electrical and thermal data (above), cable installation and maintenance costs associated with seabed categories (left) and equipment reliability data for collection system (below)

Equipment	Forced outage rate	Mean time to repair
Subsea cables	0. 015/km/yr	2160 hours
MV breaker	0.025/yr	120 hours

Results





Result summary		after 500 greedy runs	final result
CAPEX + NPV(OPEX)	[£m]	310.3	268.6
Unconstrained annual production	[GWh]	3021.9	3021.9
Annual energy losses due to normal operation	[GWh]	38.8	38.2
Annual unrealised energy output due to unavailability	[GWh]	46.1	46.6
Aggregate MV AC cable length	[km]	201.4	154.6
Total 150 mm^2 cable	[km]	124.5	65.3
Total 400 mm^2 cable	[km]	34.7	45.4
Total 630 mm^2 cable	[km]	42.2	43.9
MV AC supply cable cost	[£m]	47.1	38.5
MV AC installation cost	[£m]	114.3	84.5
Annual maintenance cost (maintenance activities only)	[£m/year]	1.3	1.0
Monetary equivalent of annual energy losses due to normal operation	[£m/year]	5.0	5.0
Monetary equivalent of annual unrealised energy output due to unavailability	[£m/year]	6.0	6.1
Power losses at 25% of rated power	[MW]	0.8	0.7
Power losses at 50% of rated power	[MW]	3.0	3.0
Power losses at 75% of rated power	[MW]	6.6	6.6
Power losses at rated power	[MW]	11.6	11.5
Annual energy losses in MVAC cables due to normal operation	[GWh]	19.0	18.5
Annual energy losses in step-up transformers due to normal operation	[GWh]	19.8	19.8

Conclusions

An optimisation tool is developed for inter-array cable layout design. Employing stochastic approaches this tool can quickly find a near optimal cable connectivity solution using one of several criteria including CAPEX, OPEX, system availability or combinations thereof. The seabed geo-tech information is taken into account to minimise cable routes across difficult to install seabed areas and to avoid cable routes through seabed exclusion zones. The tool employs self-start identification of locations of multiple offshore collector platforms for large wind farms.

OFFSHORE 2015 COPENHAGEN
ORGANISED BY EWEA

EWEA Offshore 2015 – Copenhagen – 10-12 March 2015