Collection Grid Optimization of a Floating Offshore Wind Farm using Particle Swarm Theory

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Introduction

Floating substructures for offshore wind turbines are a promising solution that enable to harness the abundant wind resources of deep water sites [1]. Floating offshore wind (FOW) is now reaching a pre-commercial phase where first multi-unit FOW farms are being constructed in European waters [2]. Recently, WindEurope has announced the large potential of FOW and the ability to reach a LCOE of about 40€/MWh to 60€/MWh by 2030 [3]. However, this is only achievable by significant cost reductions along the whole supply chain. The cost of the electrical system of offshore wind farms can take up to 15 % to 30% of the total investment [4]. For FOW farms the costs might be even higher since new technologies and installations procedures are applied. Besides that, commercial scale FOW farms will likely include wind turbines with power ratings up to 10MW or more, which require dynamic power cables with higher voltage levels. Hence, it is desirable to optimize the cable connection layout to obtain the most cost-effective solution.

Objectives

- Develop a model to solve the problem of optimizing the electrical collection grid of a floating offshore wind farm
- Base the model on particle swarm theory (PSO) and adapt appropriately
- Increase complexity of the problem by including:
  - All wind turbine connection possibilities
  - Stochasticity of wind speed and wind direction
  - Acquisition and installation costs of dynamic power cables
  - A number of different power cable cross sections
  - Power losses in the cables
  - A comprehensive wake effect model
- Apply the model to a large floating offshore wind farm
- Study the effect of a quantity discount

Methodology

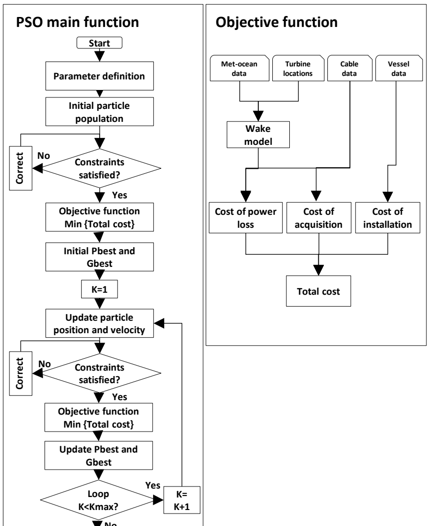

Figure 1: Optimization model algorithm

Objective function

The objective function for a single particle solution:

$$\text{Min}\ (C_{acquisition} + C_{installation} + C_{loss})$$

The acquisition cost takes into account:

$$C_{acquisition} = \left(\sum_{1}^{N_{iac}} C_{iac} * L_{iac} + \sum_{1}^{N_{exc}} C_{exc} * L_{exc}\right) * \left(T \frac{i(1+i)^T}{(1+i)^T - 1}\right)$$

The installation cost is obtained by:

$$C_{installation} = \left(\sum_{1}^{N_{iac}} L_{iac} + \sum_{1}^{N_{exc}} L_{exc}\right) * C_{vessel} * r_{install} \left(T \frac{i(1+i)^T}{(1+i)^T - 1}\right)$$

The cost of energy loss is calculated by:

$$C_{loss} = \sum_{v_{min}}^{v_{max}} \sum_{0°}^{360°} \left[\left(\sum_{1}^{N_{iac}} Ploss_{iac} + \sum_{1}^{N_{exc}} Ploss_{exc}\right) H_{ws} * H_{wd} * T\right] * C_{energy}$$

The power loss is computed as following:

$$P_{loss} = 3\left(\frac{P_{gen} + P_{trans}}{\sqrt{3} * U}\right)^2 * R_{cable} * L_{cable}$$

with

$$P_{gen} = \frac{1}{2} * p_a * A_{rotor} * C_p(\lambda, \beta) * v_{ws}^3$$

Constraints

- The energy leaving a turbine must be supported by a single cable.
- A maximum of one cable can be placed between two turbines.
- The crossing of power cables is not allowed.
- The building of a ring connection is not permitted.
- The power transmitted by a cable cannot exceed the capacity of the installed cable.

Wake model

A comprehensive wake effect model has been included considering [5]:

- Single wake
- Partial wakes
- Multiple wakes

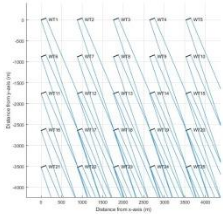

Figure 2: Wake model illustration

Application

Study case

- 500MW floating offshore wind farm
- DTU 10-MW reference wind turbine
- Golfe de Fos offshore location in France
- Reference water depth is 70m
- Collection grid operated at 66kV
- Transmission voltage is 220kV

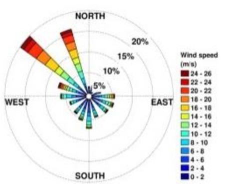

Figure 3: Wind rose

	Inter-array cables	Export cables	Total
Acquisition cost (M€)	91.92	69.09	161.01
Installation cost (M€)	19.71	8.12	27.83
Cost of energy loss (M€)	27.38	3.34	30.72
Total cost (M€)	139.01	80.55	219.56
Annual energy loss (GWh)	17.11	2086.85	19199.1
Length of cables (km)	155.73	64.20	219.93

Table 1: Cost and power losses of actual layout

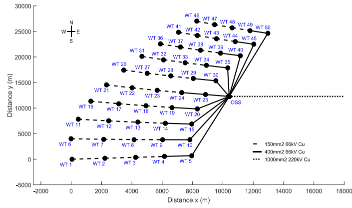

Figure 4: Actual layout

Optimized layout results

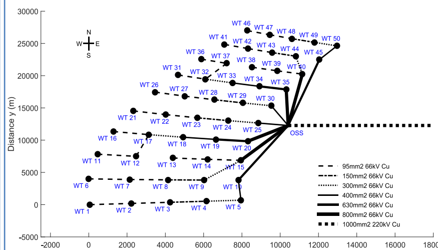

Figure 5: Optimized layout

	Acquisition cost (M€)	Installation cost (M€)	Cost of energy loss (M€)	Total cost (M€)	Annual energy loss (GWh)	Length of cables (km)
Optimized layout	86.34	18.06	25.15	129.55	15.72	142.73
Difference (%)	-6.07	-9.56	-8.15	-6.81	-8.12	-8.35

Table 2: Inter-array cable costs and losses of optimized layout

Quantity discount effect

- Discount of 15% on C_{iac}
- Use of the 2 largest cross sections only

	Cross section (mm²)	Resistance (Ω/km)	Unit cost (€/m)	Power capacity (MW)
66kV IAC	95	0.25	220	26
	150	0.158	300	31
	300	0.078	423	44
	400	0.059	475	51
	630	0.037	554	62
	800	0.029	683	71
220kV EXC	1000	0.0243	740	269

Table 3: Power cable data (without discount)

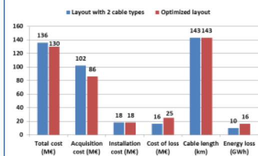

Figure 6: Comparison of inter-array costs and losses

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For more information:
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