Baltic InteGrid
Integrated Baltic Offshore Wind Electricity Grid Development

Wind Farms Collection System Design and Optimization

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DTU

EU STRATEGY FOR THE BALTIC SEA REGION FLAGSHIP

Interreg Baltic Sea Region

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

Agenda

1 MOTIVATION

2 PROBLEM DEFINITION

3 METAHEURISTICS: GENETIC ALGORITHMS

4 RESULTS

5 DISCUSSION

Motivation – Collection system within the OWFESDO

OWFESDO: Offshore Wind Farm Electrical System Design Optimization

Given a large-scale offshore wind farm with coordinates location of WTs, geographical and meteorological information of the site under study

↓

1) Determine the number and location of OSSs and allocate each WT to a OSS

↓

2) For each sub-group optimize the CS (Collection System)

↓

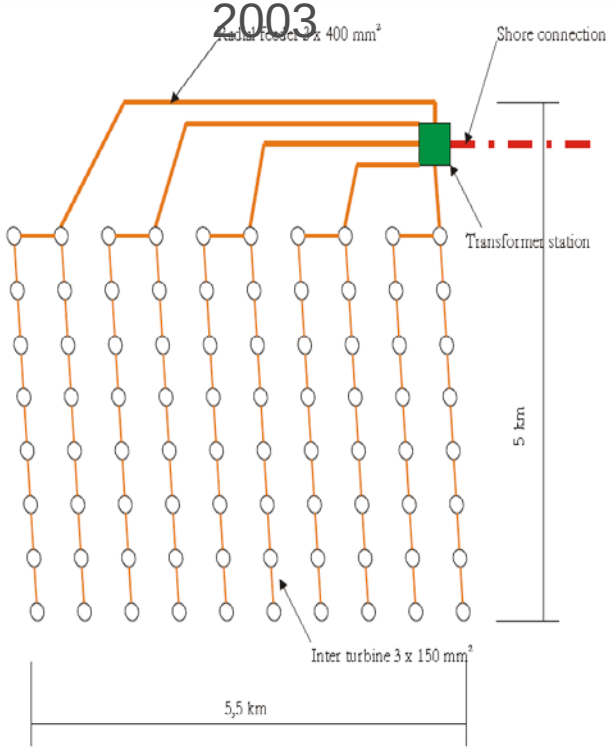
3) For each sub-group optimize the TS (Transmission System)

↓

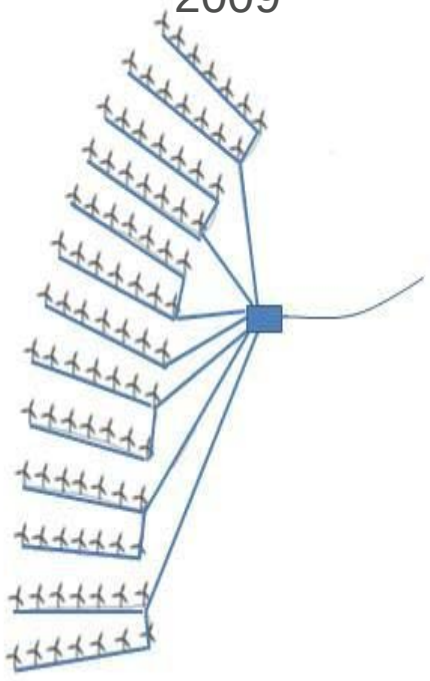
4) Determination of the optimal connection between OSSs

Motivation – Collection system within the OWFESDO (II)

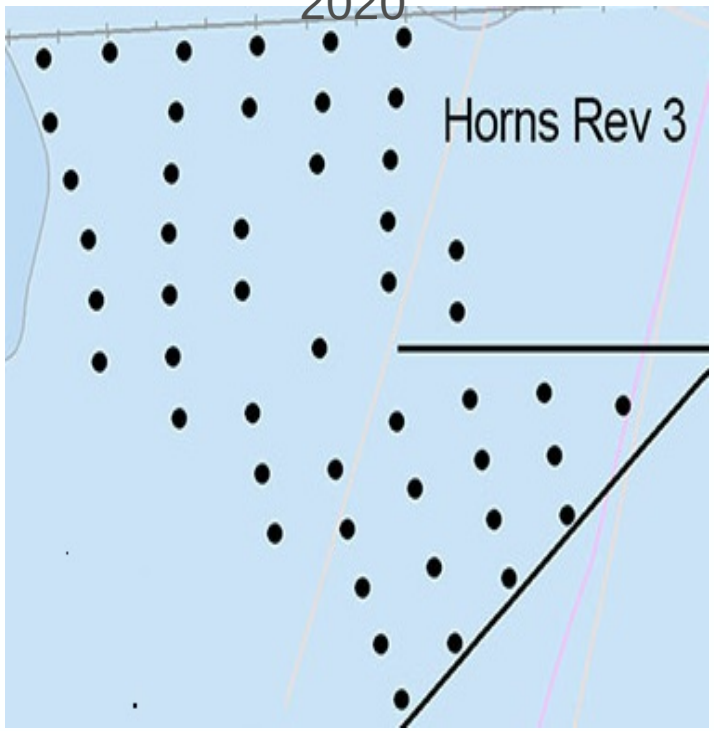
Horns Rev 1
2003



Horns Rev 2
2009

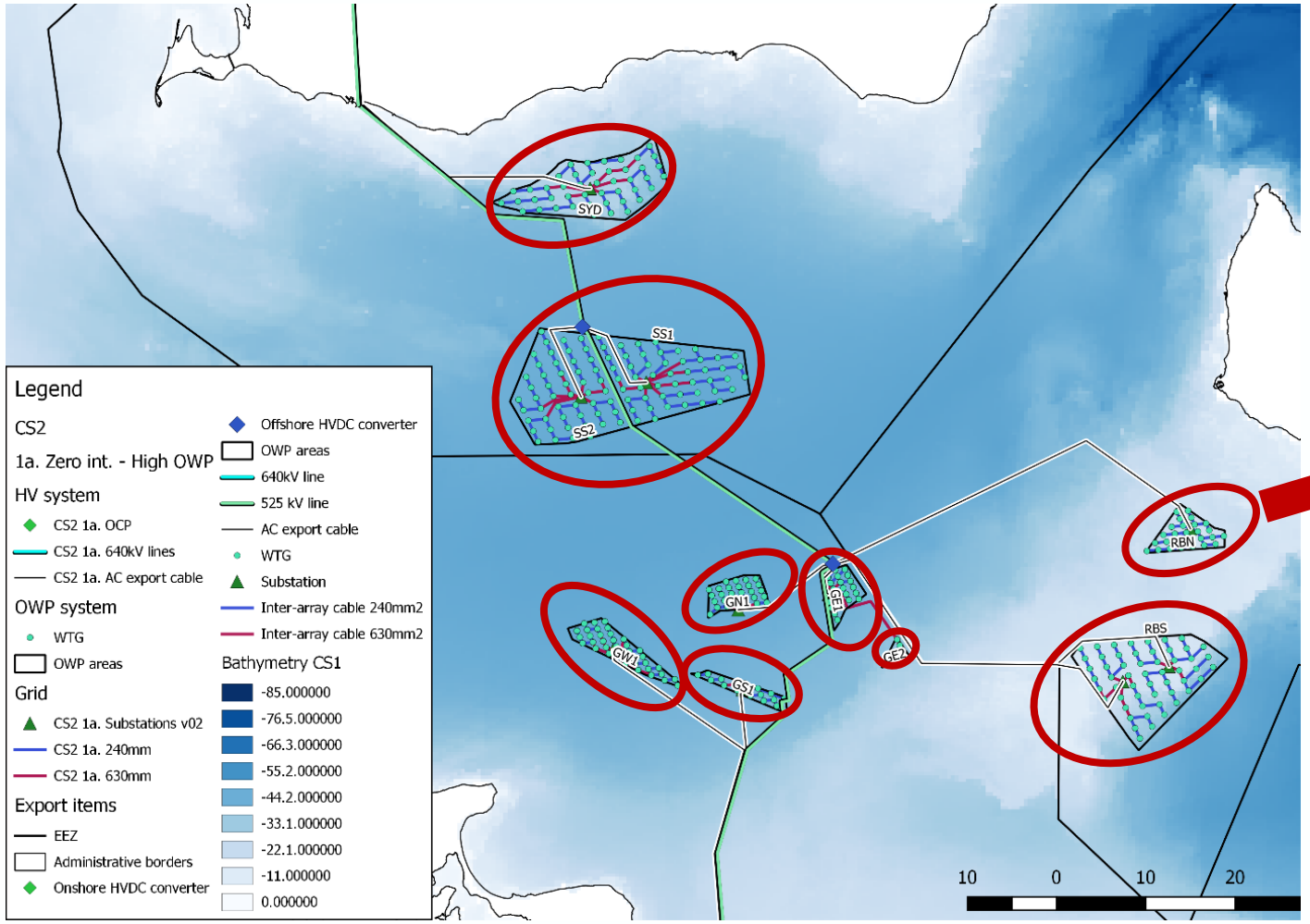


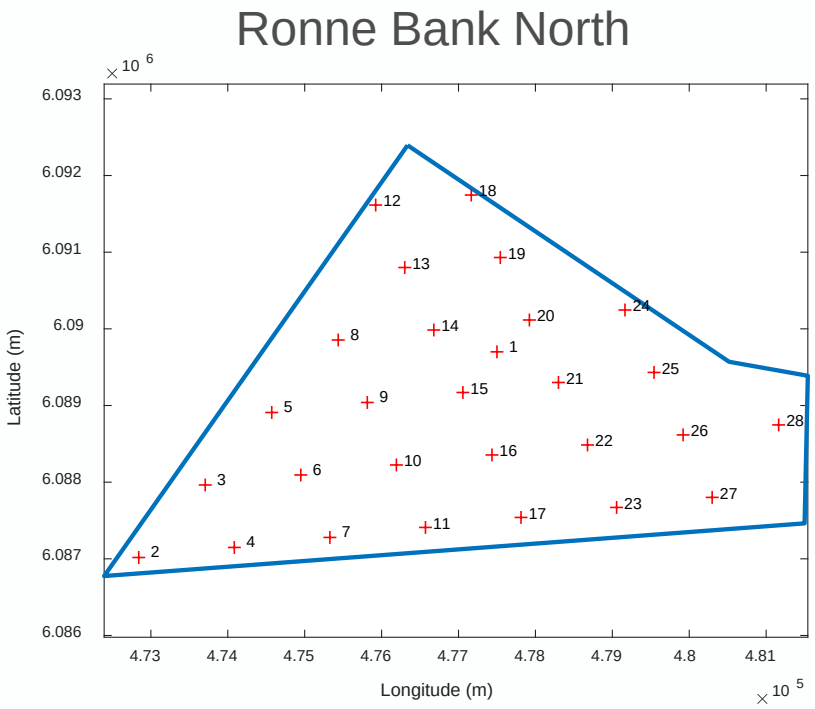
Horns Rev 3
2020



Optimal array cable layout not so apparent anymore

Motivation – Case from Baltic InteGrid Project





Installed power (MW)	240
Turbine size (MW)	8
Turbines	27
Project area (km^2)	26.77

Objective:

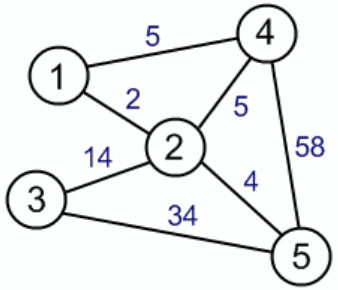
- Reduce investment cost by optimizing the length and the section of the cables.

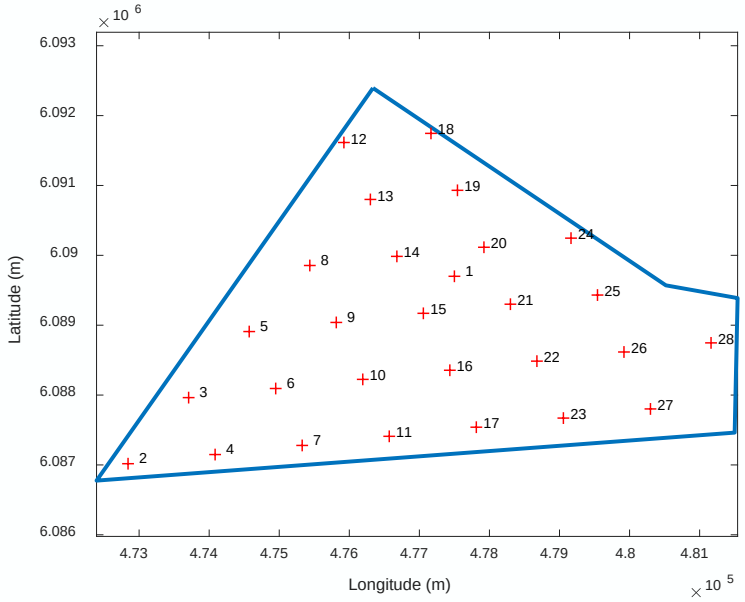
Defining the problem by using graph theory:

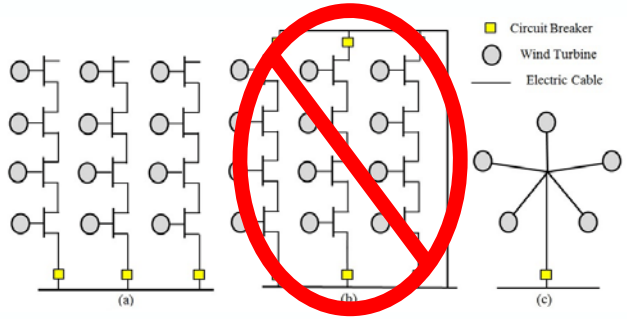
- Nodes -> Wind turbines and Offshore Substation (OSS)
- Edges -> Cables

Assumptions:

- One offshore substation (OSS).
- Location of the wind turbines and OSS are known.
- Star and radial topologies only.

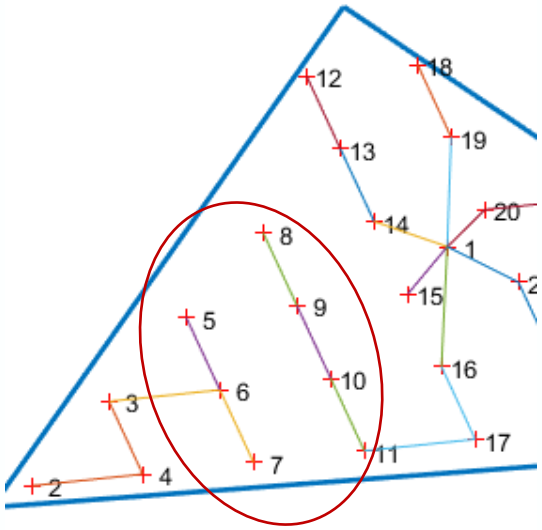


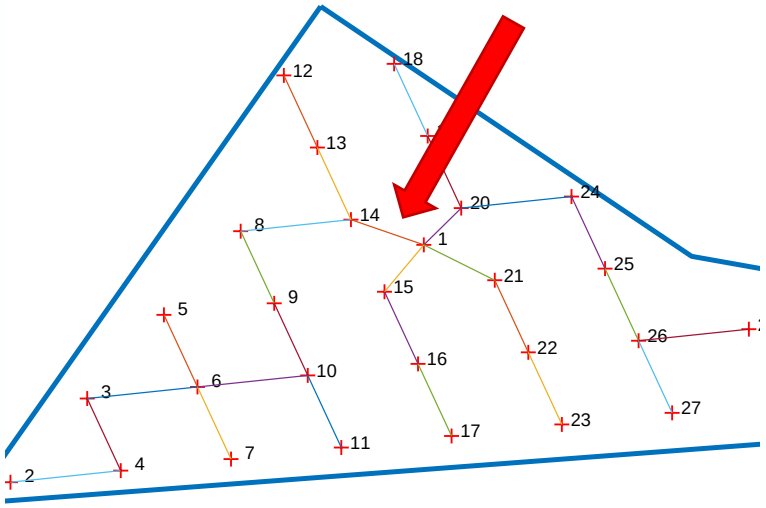


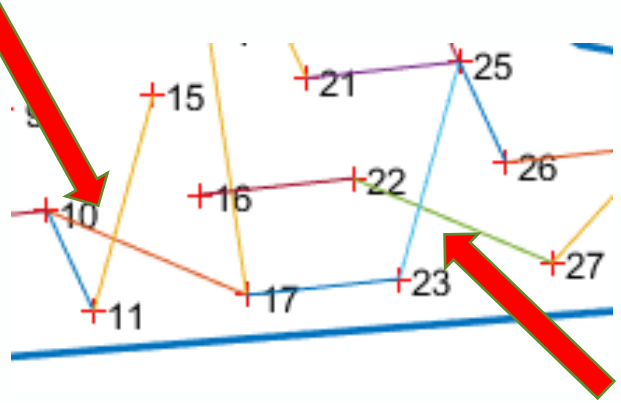


- 0 = Constraint is not met
- 1 = Constraint is met

- Possibilities:
  1. [1 0 0 0] – Complete connectivity: All wind turbines are connected to the OSS.
  2. [1 1 0 0] – # Cables < # Wind turbines: There are no loops in the layout.
  3. [1 1 1 0] – Cable capacity: The cables have enough capacity.
  4. [1 1 1 1] – Cable crossing detection: No cables cross each other.







The constraints grow exponentially with the number of nodes -> Increased computational time.

Method	Advantages	Disadvantages
Heuristics	• Fast (seconds). • Generally provide a good solution	• Can fail to find a feasible solution • Struggle in complex layouts • Do not take into account cable sizing
Metaheuristics	• Always finds a feasible solution. • Explores different feasible solutions. • Takes into account cable sizing	• Slow (hours)

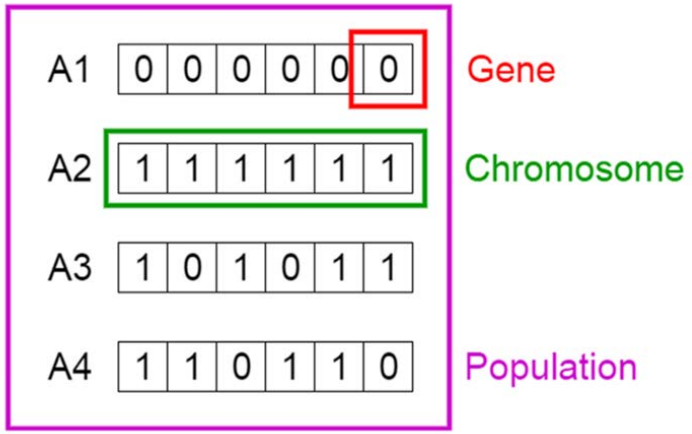
- Heuristics: Prim, Kruskal, Esau – Williams, VAM.
- Metaheuristics: Genetic algorithms.

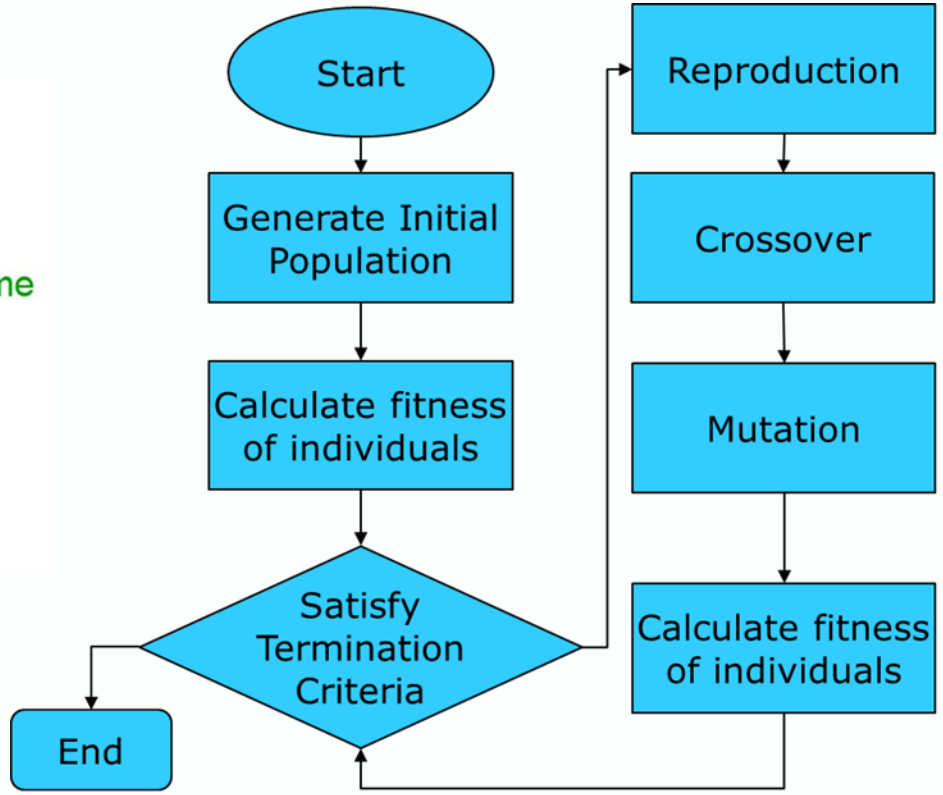
Genetic algorithms – What?

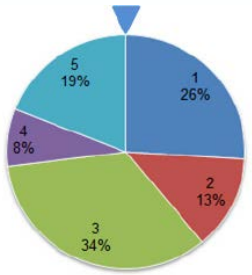
What are genetic algorithms?

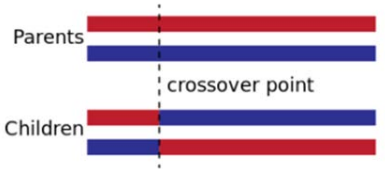
- Metaheuristic method inspired in the process of natural selection
- Invented in the 1970s
- Iterates through fitness assessment, selection and breeding, and population reassembly.

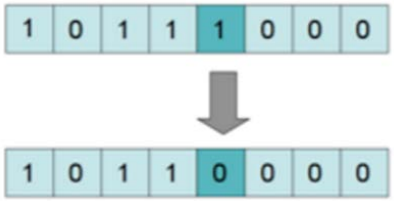
Genetic algorithms – How?





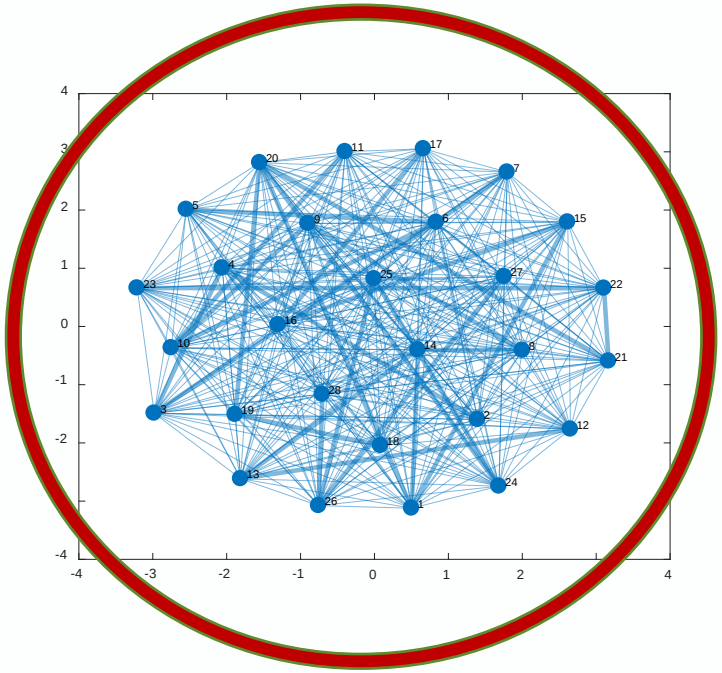






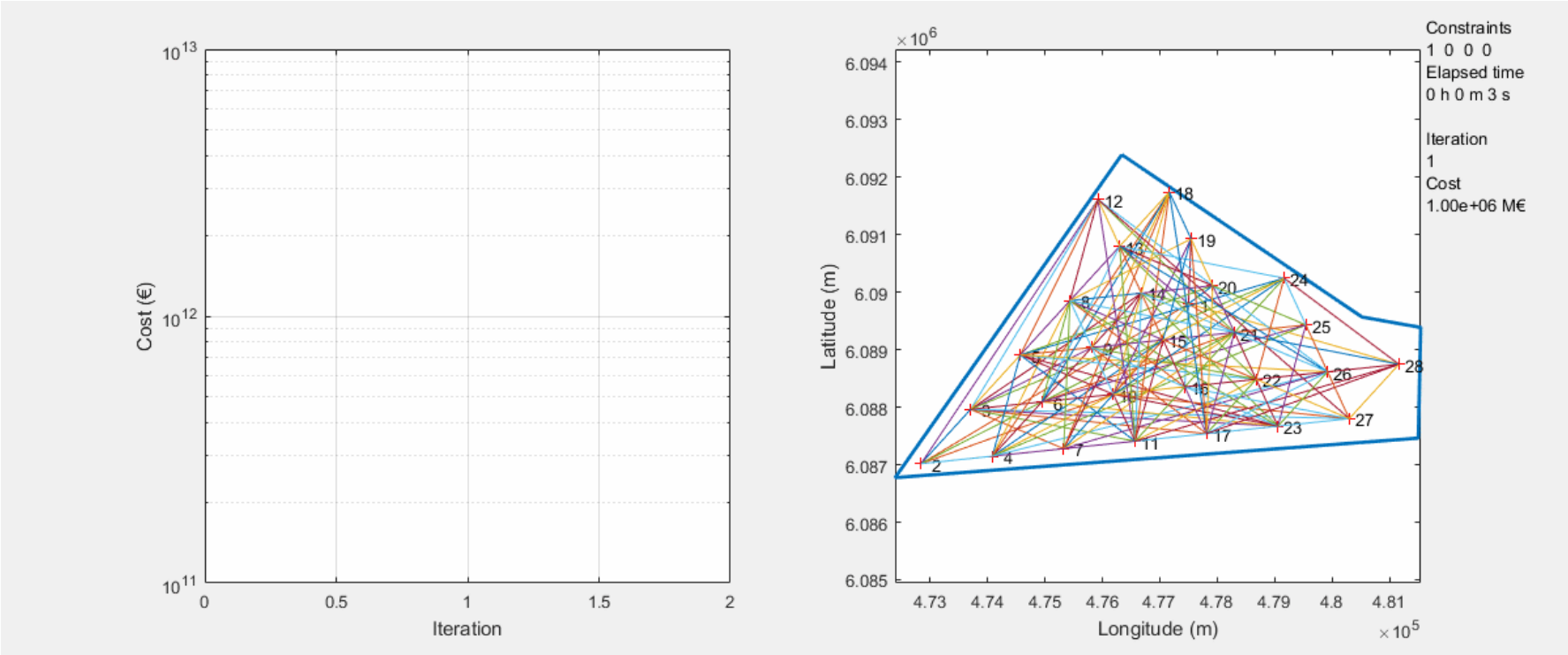
Key characteristics:

- Calculate all possible edges between nodes and weight them by distance.
- Variables: 1 – Edge active, 0 – Edge not active.
- Cable selection: Sizes the cable for each branch.
- Fitness function = Distance x Cost + Penalization (if constraints are not met).

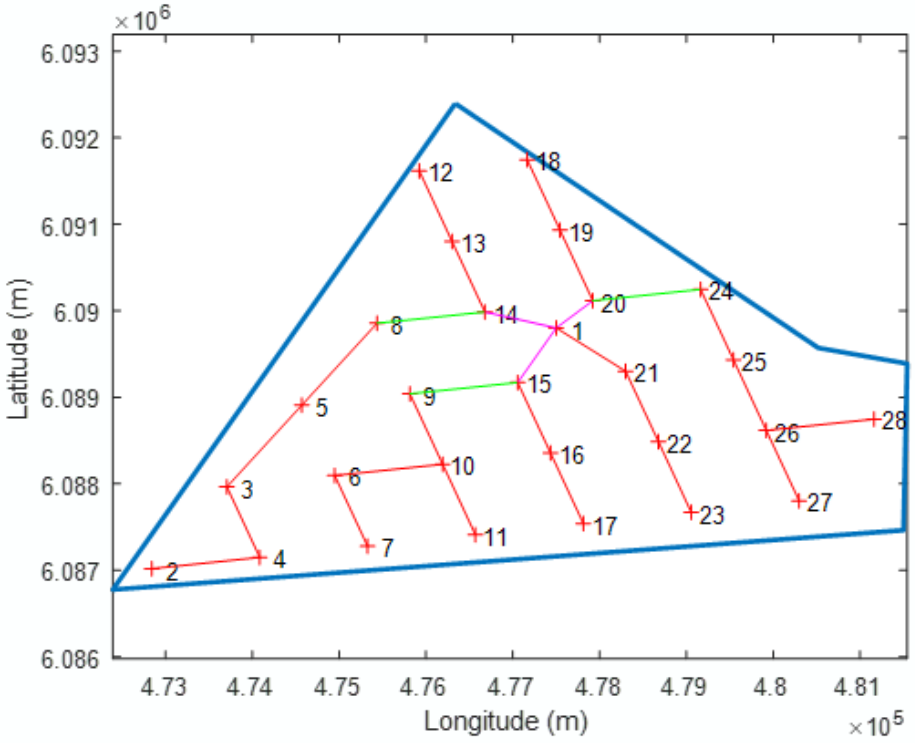


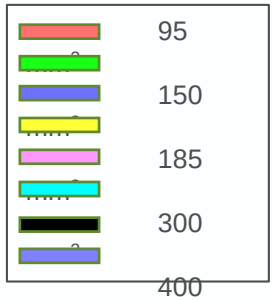
Node 1	Node 2	Distance (m)	Variable	Cable (€/m)
5	20	10	1	270237
5	24	1000	0	287426

Genetic algorithm – Results



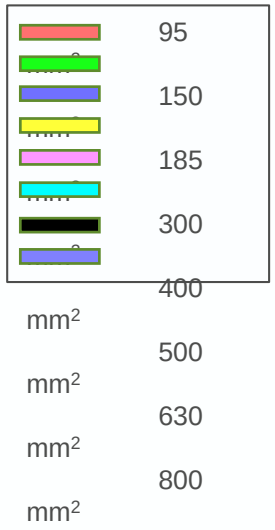
Final layout and results

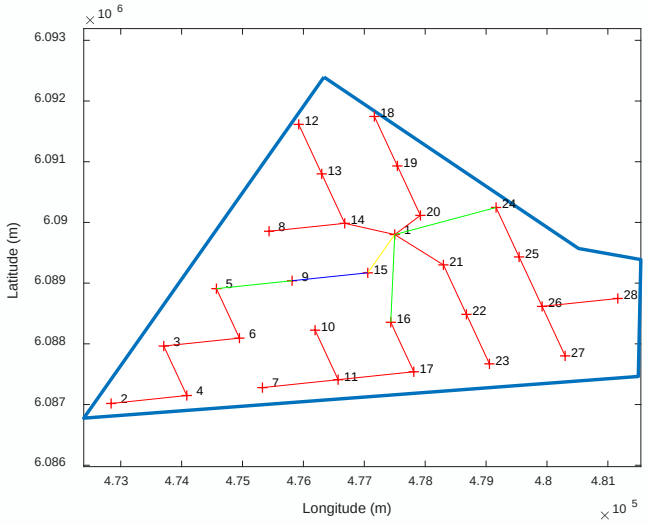


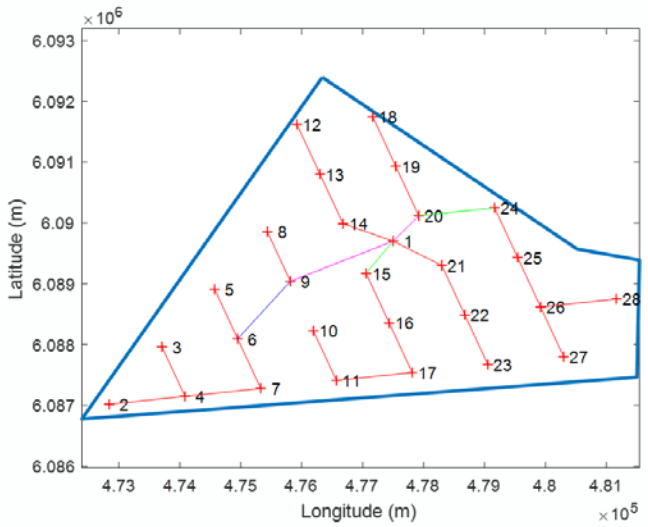


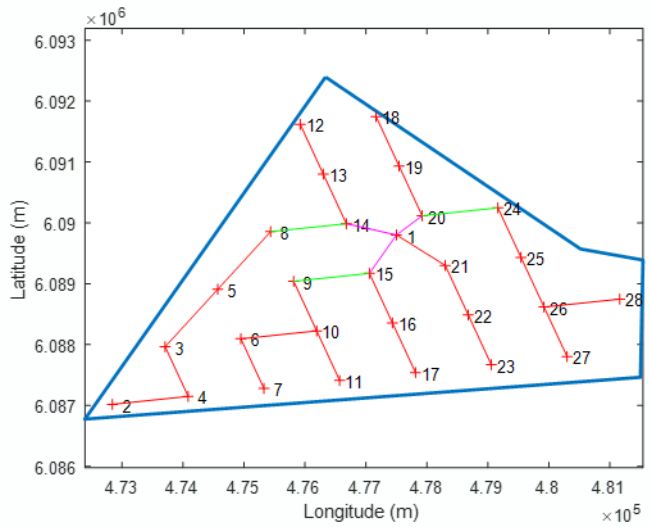
Cost	7,682,576 €
Iterations	3000
Time	3 h 51 min
Constraints	[1 1 1 1]

Different simulations yield different results





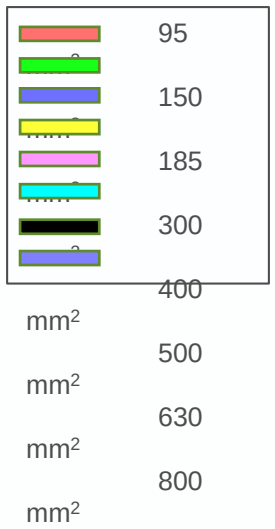


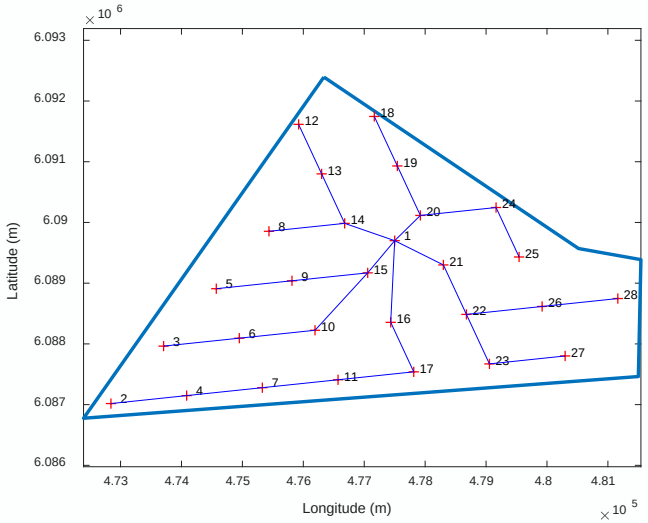


Cost	7,862,079 €	7,778,070 €	7,682,576 €
Time	4 h 56 min	4 h 3 min	3 h 51 min
Iterations	1000	1462	3000

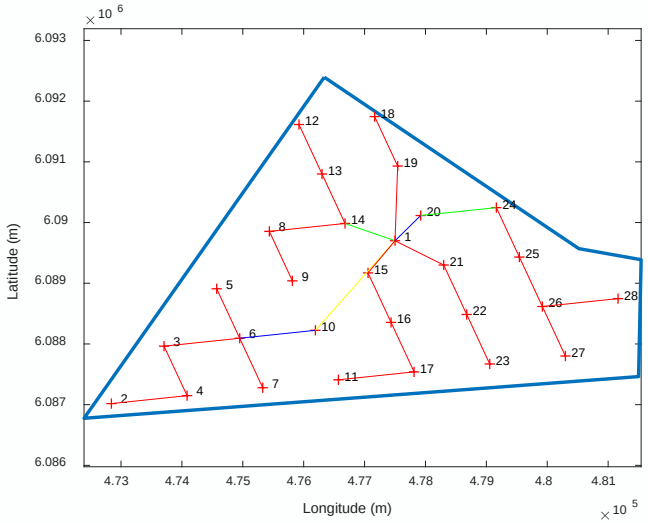
Results – Comparison different methods

Manual

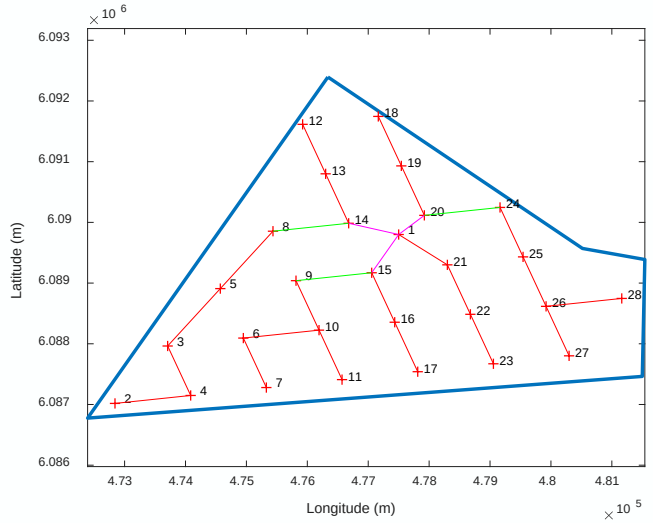




Heuristic (Esau-Williams)

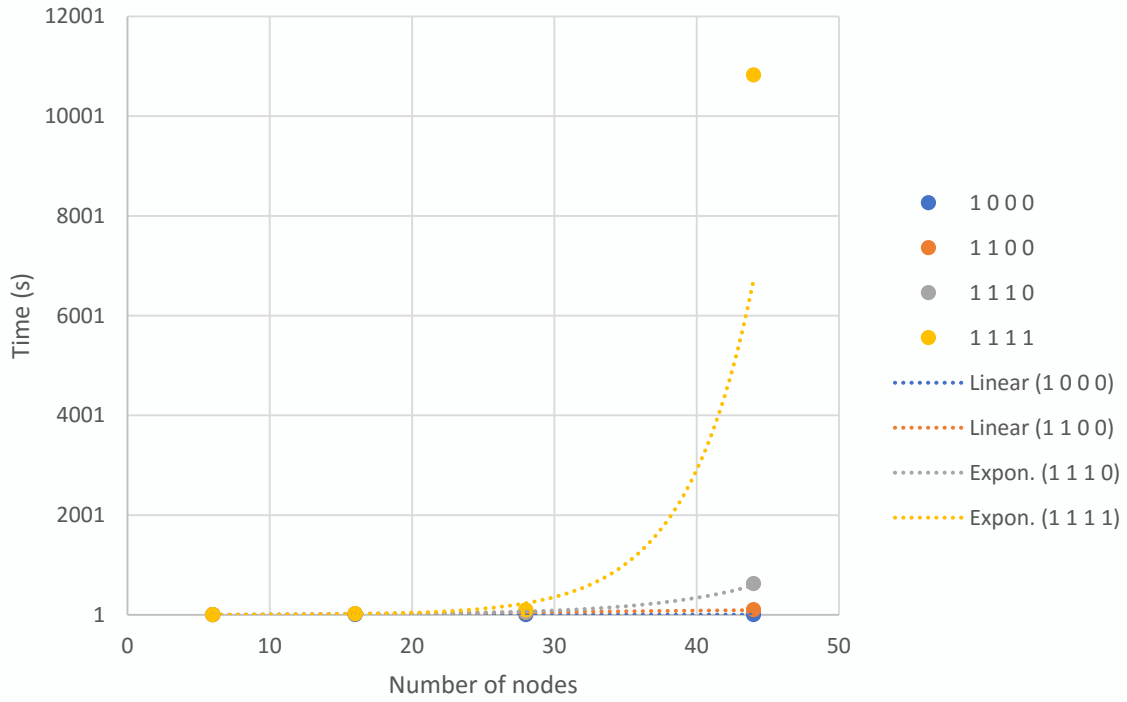


Metaheuristic (GA)



Cost	9,655,099 €	7,873,108 €	7,682,576 €
Time	-	0.33 s	3 h 51 min
Difference	-	-18 %	-20 %

Results – Time analysis for meeting the constraints



Main takeaways

- Complete connectivity is always achieved in the first iteration.
- Star/radial layout restriction increase computational time linearly .
- Capacity and crossings of cables increase the computational time exponentially.

Discussion – Wrap up

- Heuristics provides a fast and great solutions for overall length of cable.
- Metaheuristics generally provides a better overall cost solution as it takes into cable costs.
- Metaheuristics is more flexible towards constraints and complex layouts.

Discussion – Next steps

Speed up the metaheuristics:

- Use the heuristic as an initial guess to the metaheuristics to speed up the solution.
- Optimize the cable crossings detection.
- Optimize the genetic algorithm operators.

Additional features:

- Complete the cost function: depth of each wind turbine, cable bending, etc.
- Losses sensitivity analysis by calculating the power flow in the cables.
- Reliability sensitivity analysis by including loops to the branches and calculating the power flow.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Questions & discussion

Thank you

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