Cost effective solutions for offshore transmission

Supervisors: Kristof van Brusselen (CG Holdings).
Prof. Dr Dirk Van Hertem and Dr Hakan Ergun (KU Leuven).

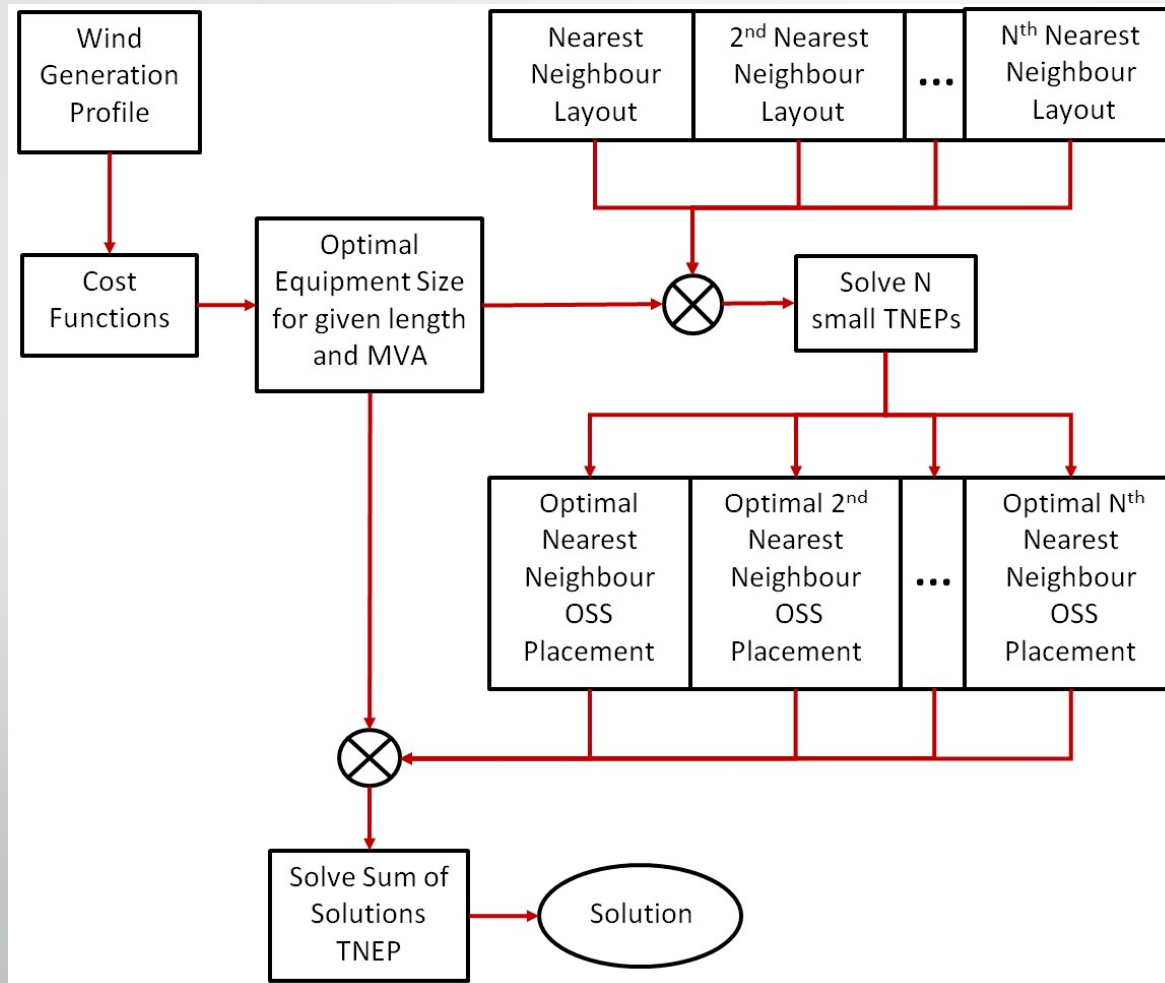# A Techno-Economic MILP Optimization of Multiple Offshore Wind Concessions

- **Written in Julia to leverage the DC optimal power flow TNEP formulation of PowerModels.jl**

  - C Coffrin, R Bent, K Sundar, Y Ng, M Lubin. PowerModels.jl: An Open- Source Framework for Exploring Power Flow Formulations. Los   Alamos National Laboratory, 2018. Report number: LA-UR-17-29326

- **Utilizes DTU Wind Energy's CorWind software to generate realistic geographic and technology dependant wind profiles.**

  - Koivisto, M, Das, K, Guo, F, et al. Using time series simulation tools for assessing the effects of variable renewable energy generation on power and energy systems. *WIREs Energy Environ*. 2019; 8:e329. https://doi.org/10.1002/wene.329

- **Solved using Gurobi 's MILP branch and bound based algorithm**

  - http://www.gurobi.com/
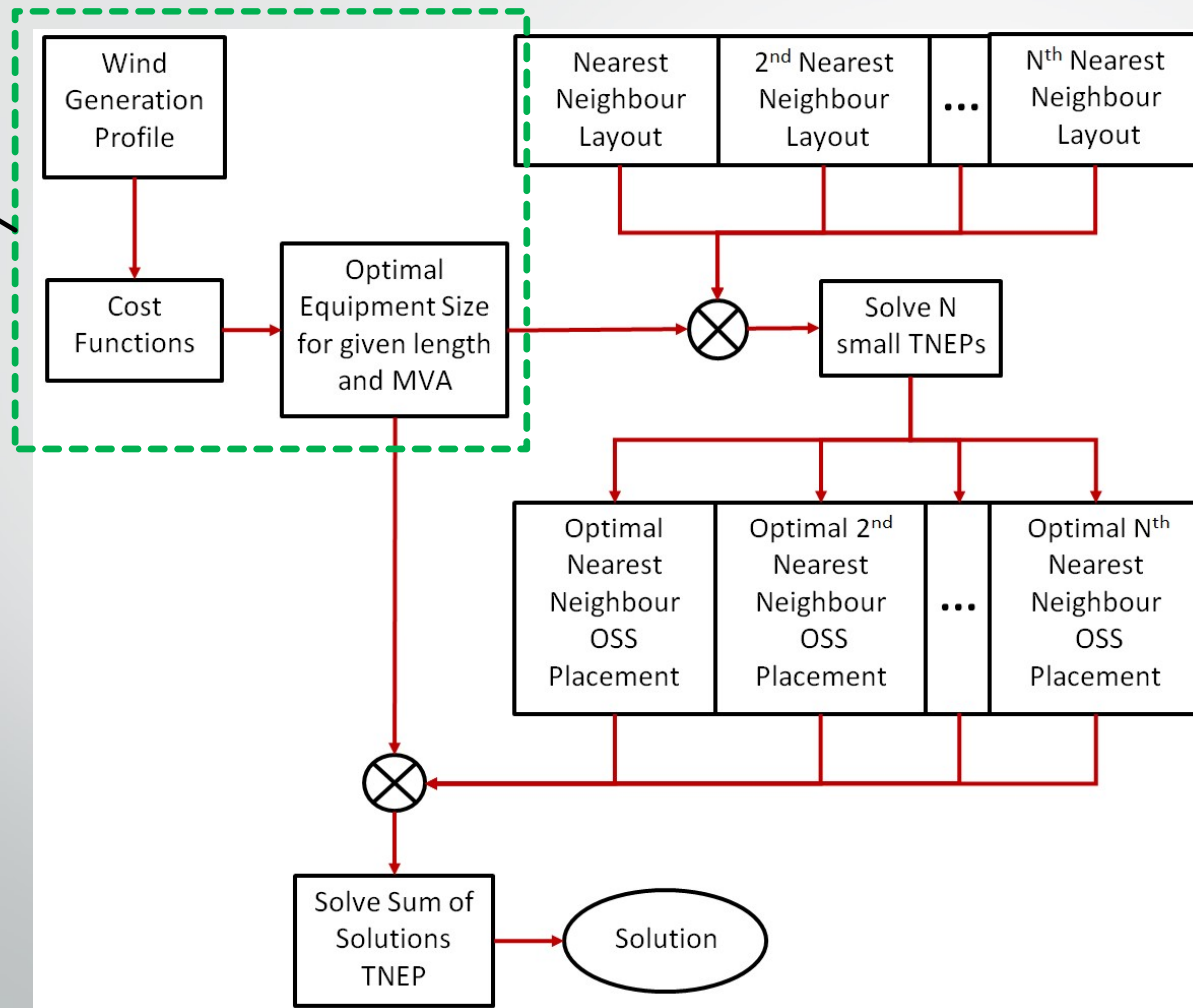
Optimization Overview
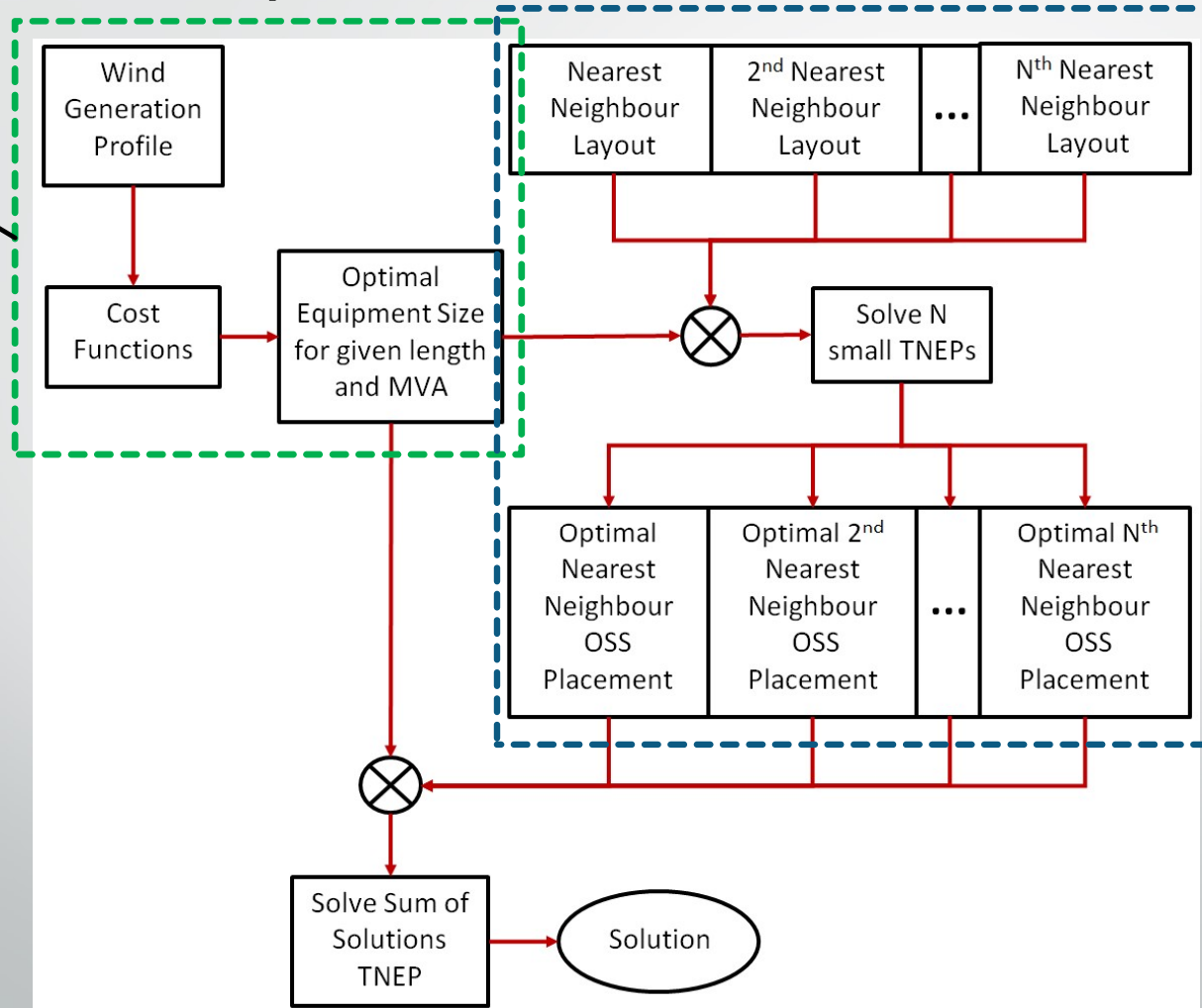
Optimization Overview
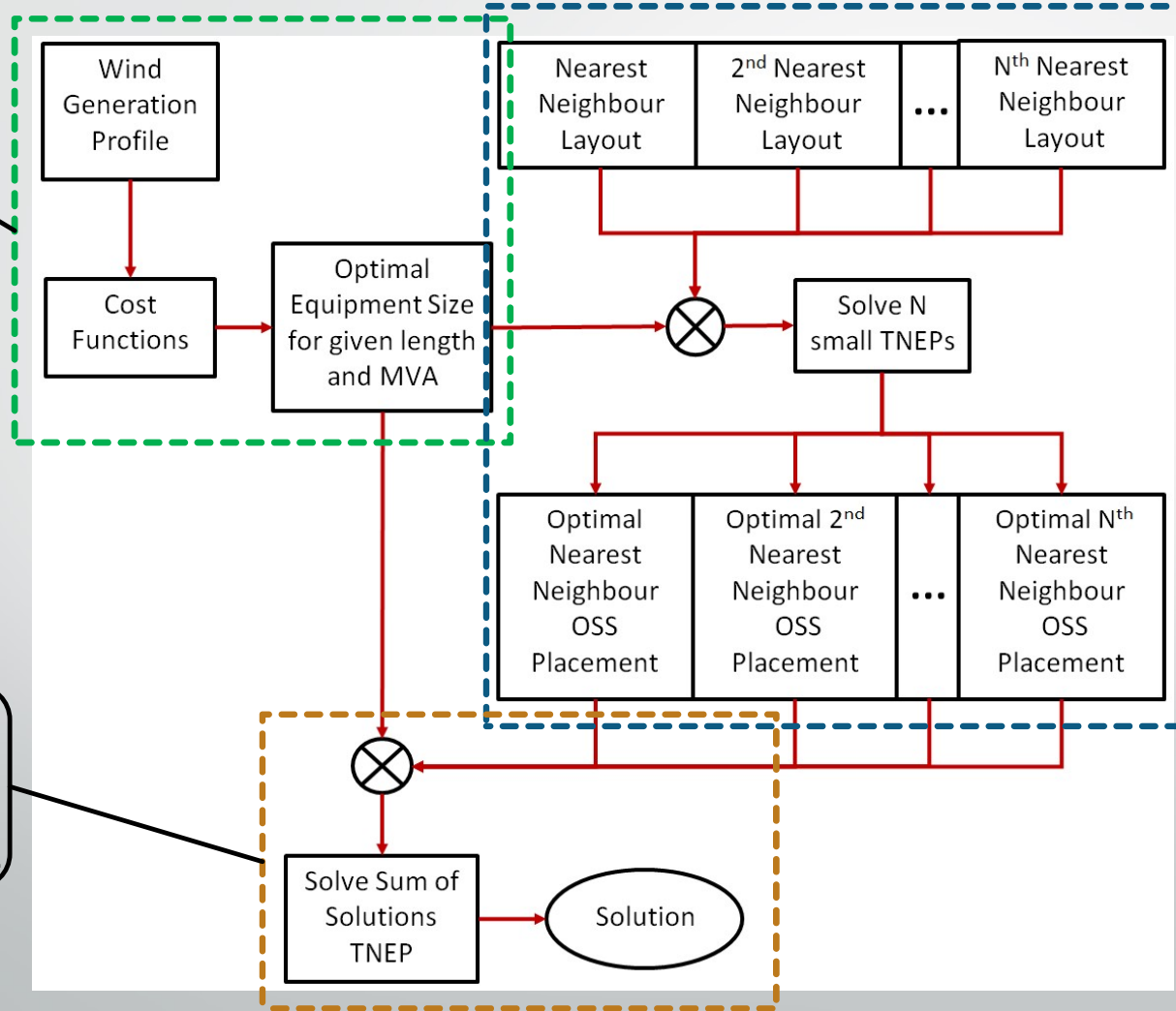
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Stage 1:
Finds the optimal equipment given distance and MVA.
- Both AC/DC options
- CAPEX, OPEX, Losses, CM and EENS over 25 year lifetime.

Stage 2:
Finds the optimal placement of OSSs for connections between nearest N neighbours.

Wind Generation Profile

Cost Functions

Optimal Equipment Size for given length and MVA

Nearest Neighbour Layout

2nd Nearest Neighbour Layout

...

Nth Nearest Neighbour Layout

Solve N small TNEPs

Optimal Nearest Neighbour OSS Placement

Optimal 2nd Nearest Neighbour OSS Placement

...

Optimal Nth Nearest Neighbour OSS Placement

Solve Sum of Solutions TNEP

Solution

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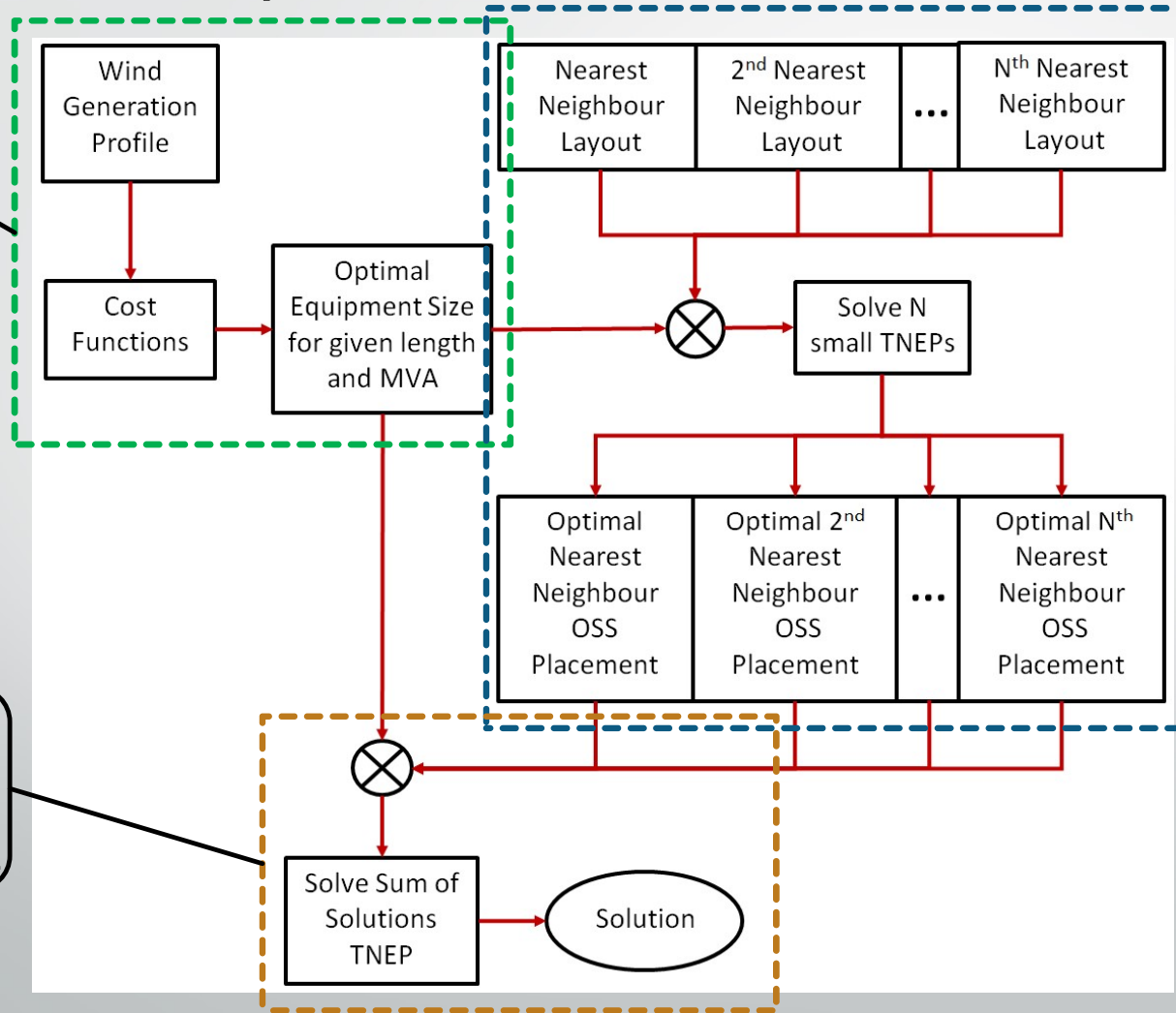- CAPEX, OPEX, Losses, CM and EENS over 25 year lifetime.

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Modelling Belgium Offshore EEZ

Fig. from https://www.4coffshore.com/offshorewind/
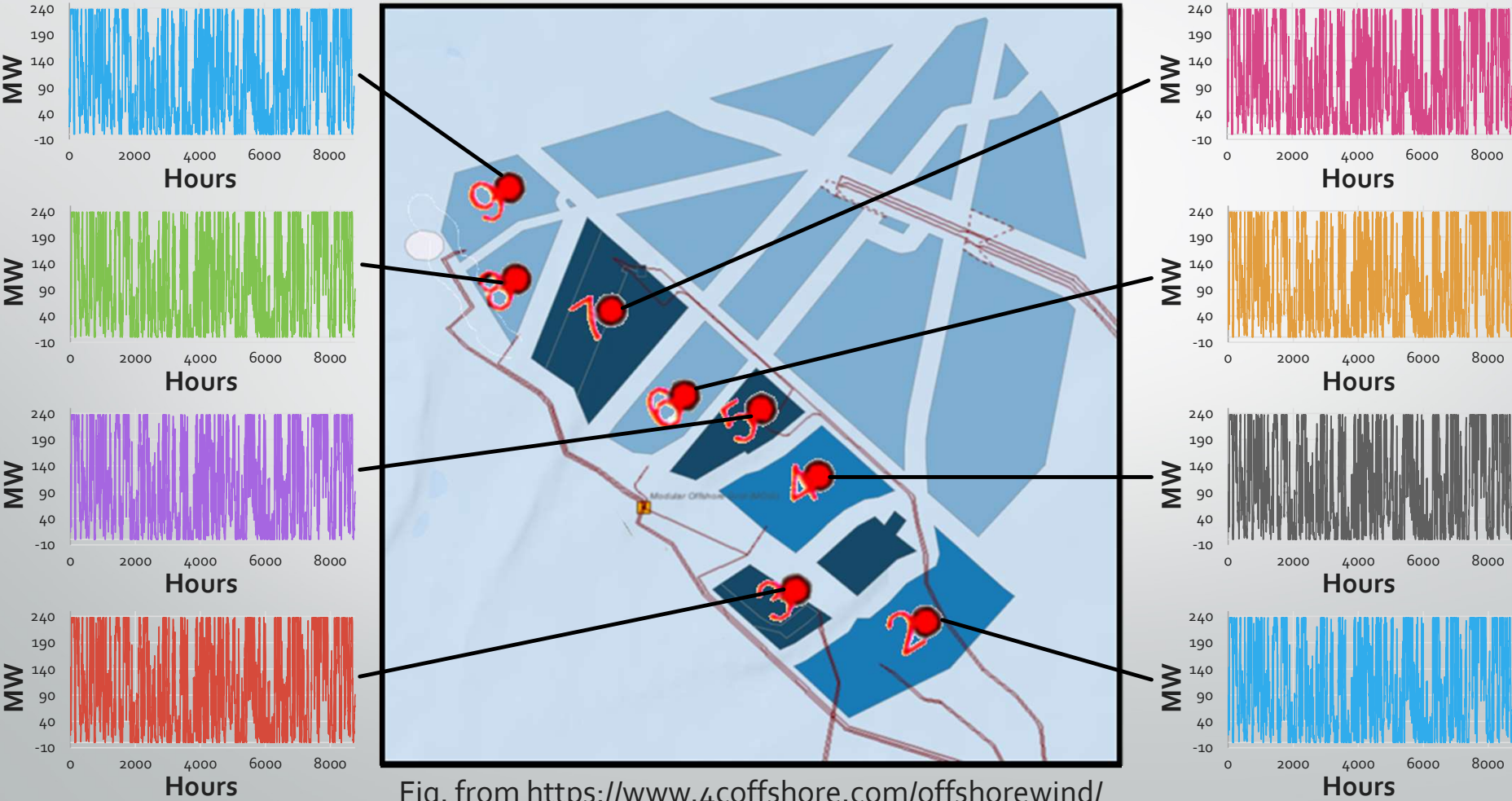
CorWind Generation Profile

Fig. from https://www.4coffshore.com/offshorewind/

CorWind Generation Profile

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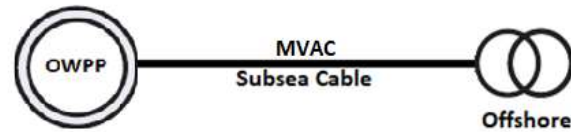
Cost Model

$$= \text{CPX}_{cbl,xfm} + \text{Q}_{cbl} + \text{CU}_{cbl,xfm} + \text{FE}_{xfm} + \text{CM}_{cbl,xfm} + \text{EENS}_{cbl,xfm}$$
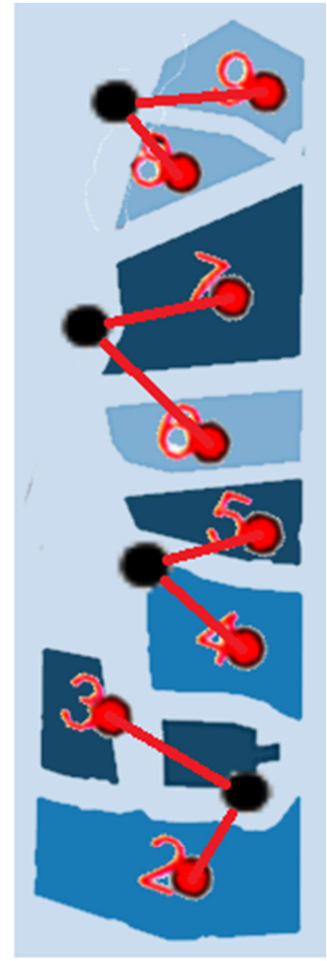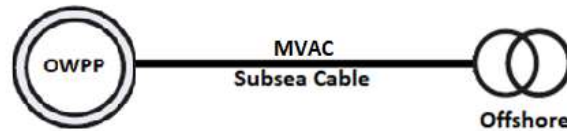
Cost Model

$$= CPX_{cbl,xfm} + Q_{cbl} + CU_{cbl,xfm} + FE_{xfm} + CM_{cbl,xfm} + EENS_{cbl,xfm}$$
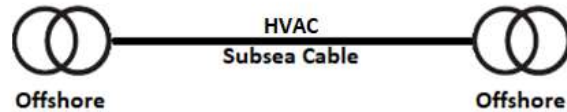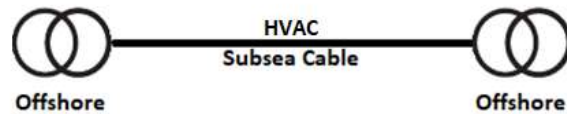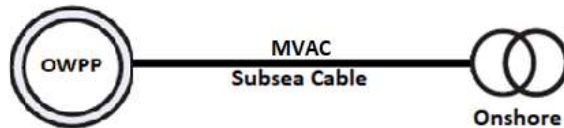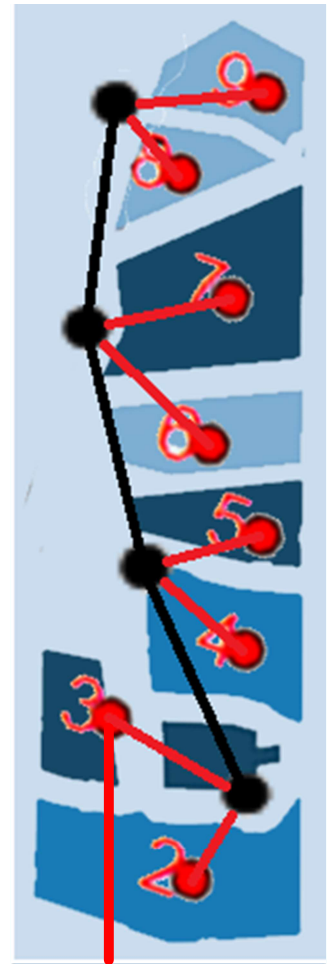

$$= CPX_{cbl} + Q_{cbl} + CU_{cbl} + CM_{cbl} + EENS_{cbl} + 2FC_{oss}$$
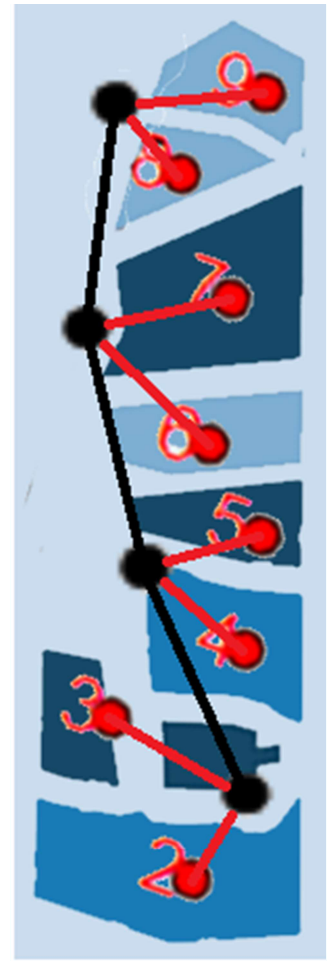
Cost Model
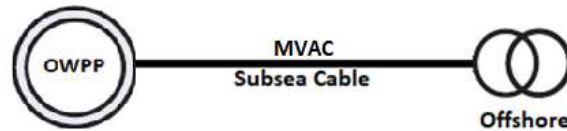
$$= CPX_{cbl,xfm} + Q_{cbl} + CU_{cbl,xfm} + FE_{xfm} + CM_{cbl,xfm} + EENS_{cbl,xfm}$$
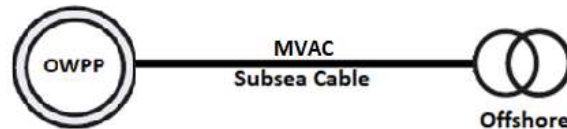

$$= CPX_{cbl} + Q_{cbl} + CU_{cbl} + CM_{cbl} + EENS_{cbl} + 2FC_{oss}$$
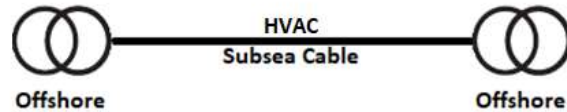

$$= CPX_{cbl,xfm} + Q_{cbl} + CU_{cbl,xfm} + FE_{xfm} + CM_{cbl,xfm} + EENS_{cbl,xfm}$$
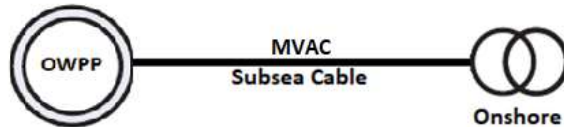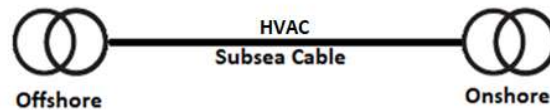
Cost Model

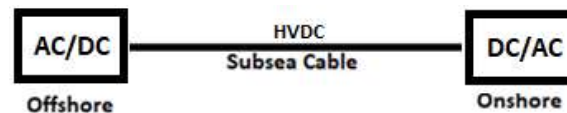$$= CPX_{cbl,xfm} + Q_{cbl} + CU_{cbl,xfm} + FE_{xfm} + CM_{cbl,xfm} + EENS_{cbl,xfm}$$

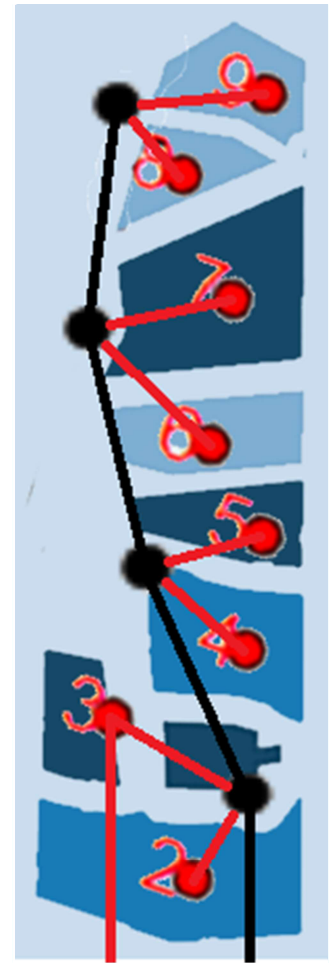$$= CPX_{cbl} + Q_{cbl} + CU_{cbl} + CM_{cbl} + EENS_{cbl} + 2FC_{oss}$$

$$= CPX_{cbl,xfm} + Q_{cbl} + CU_{cbl,xfm} + FE_{xfm} + CM_{cbl,xfm} + EENS_{cbl,xfm}$$

$$= CPX_{cbl,xfm} + Q_{cbl} + CU_{cbl,xfm} + FE_{xfm} + CM_{cbl,xfm} + EENS_{cbl,xfm} + FC_{oss}$$
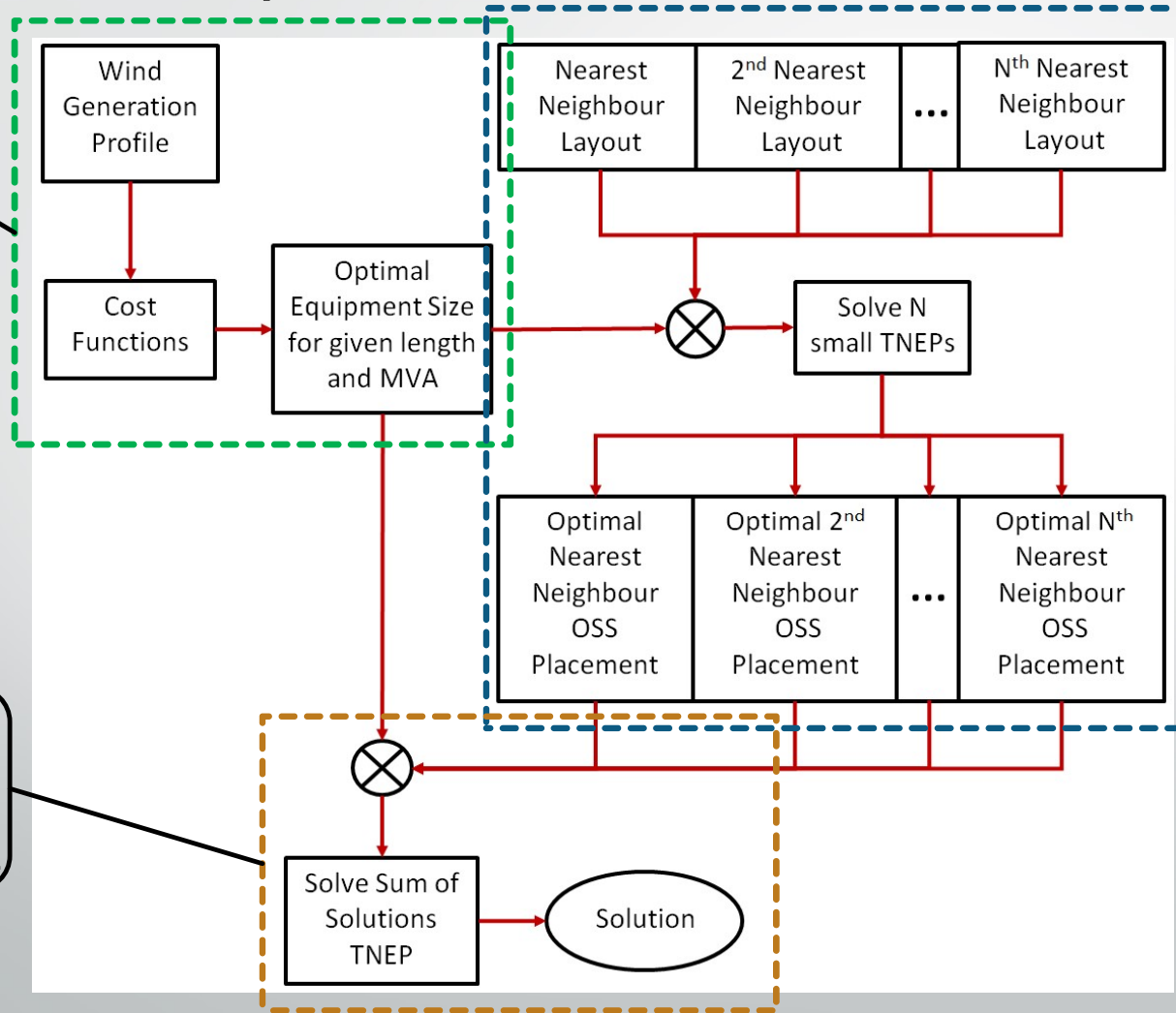
$$= CPX_{cbl,con} + CU_{cbl} + LS_{con} + CM_{cbl,con} + EENS_{cbl,con} + FC_{oss}$$
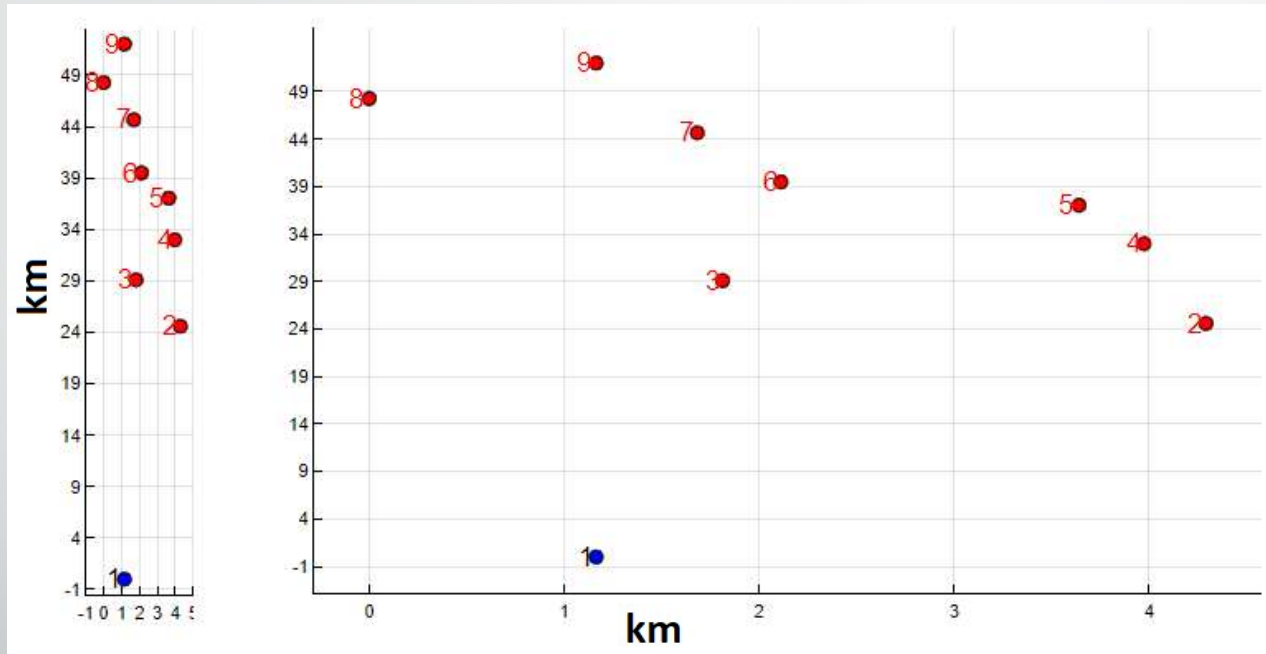
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Wind Generation Profile

Cost Functions

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2nd Nearest Neighbour Layout

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Nth Nearest Neighbour Layout

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Solve N small TNEPs

Optimal Nearest Neighbour OSS Placement

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$\cdots$

Optimal Nth Nearest Neighbour OSS Placement

$\otimes$

Solve Sum of Solutions TNEP

Solution

Finding Optimal OSS Placement
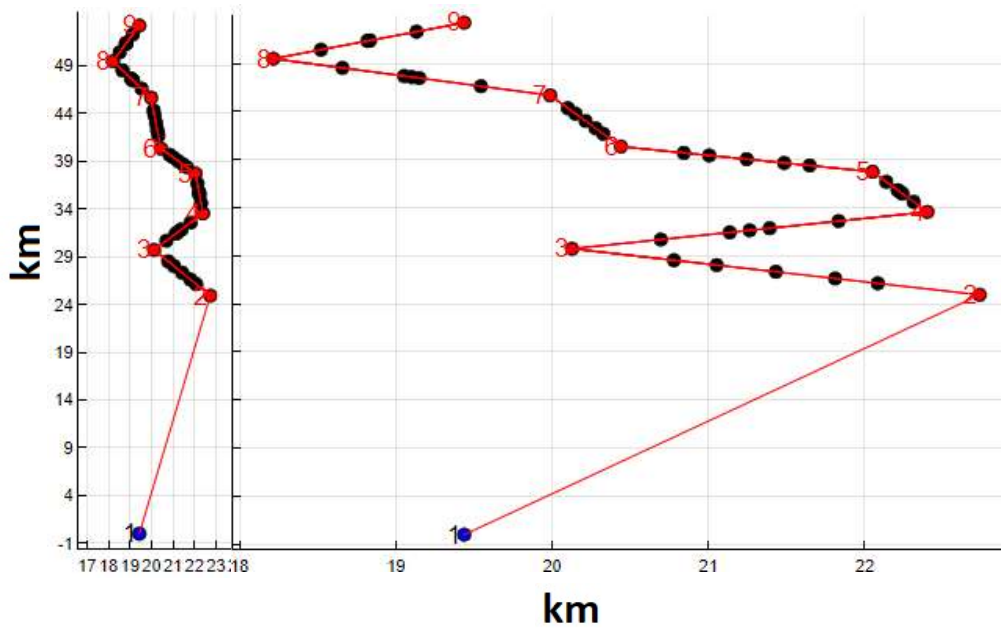
Finding Optimal OSS Placement
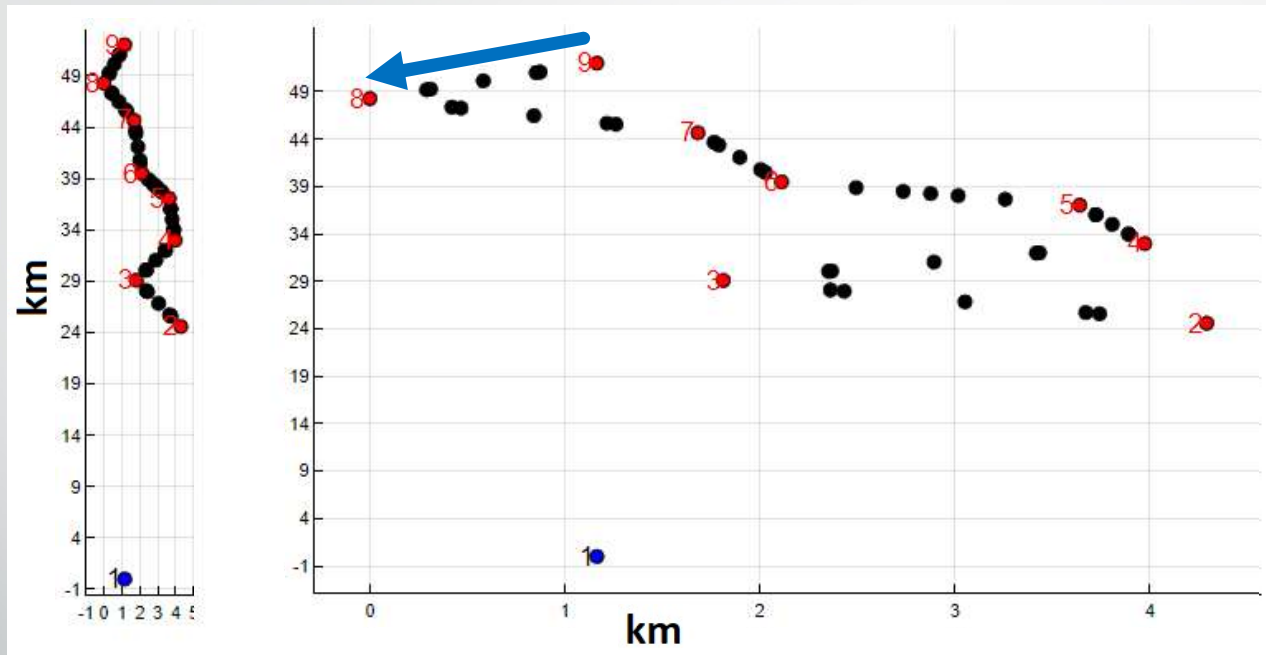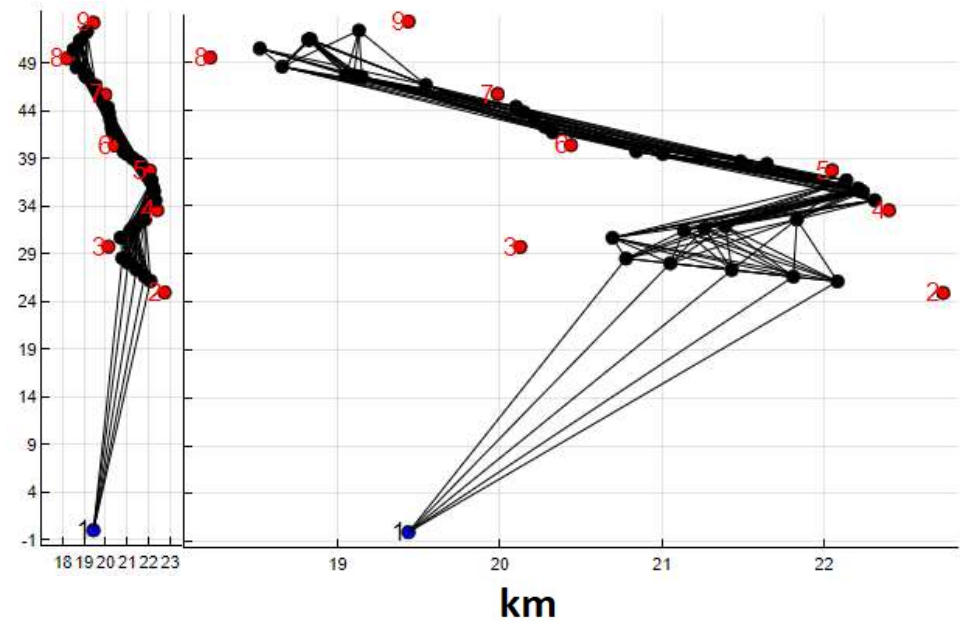
Nearest Neighbour

Finding Optimal OSS Placement
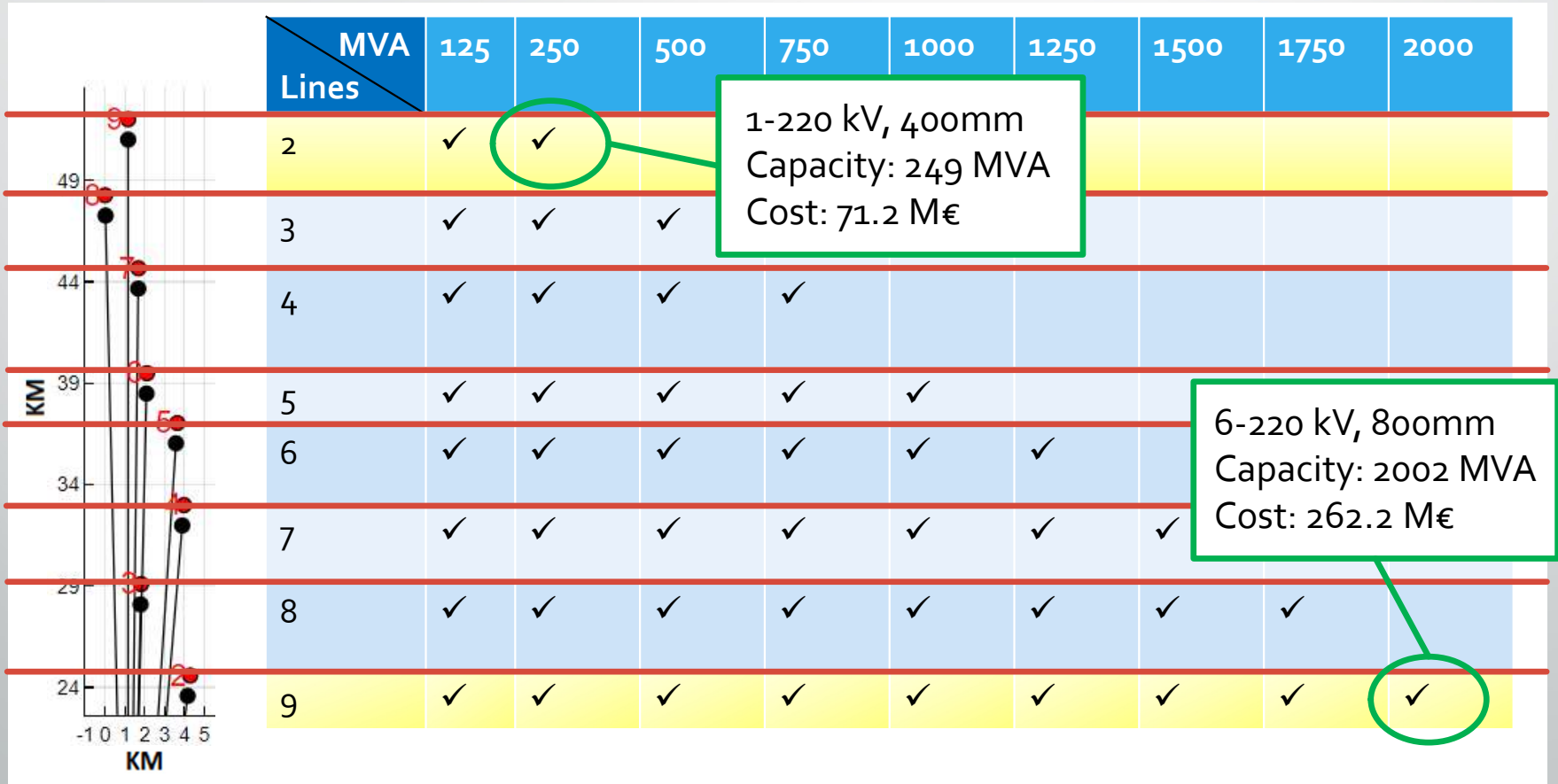
Nearest Neighbour

MVAC Cable Paths

HV AC/DC Cable Paths

Finding Optimal OSS Placement

Candidate Cable Capacity Selection

MVA / Lines	125	250	500	750	1000	1250	1500	1750	2000
2	✓	✓							
3	✓	✓	✓						
4	✓	✓	✓	✓					
5	✓	✓	✓	✓	✓				
6	✓	✓	✓	✓	✓	✓			
7	✓	✓	✓	✓	✓	✓	✓		
8	✓	✓	✓	✓	✓	✓	✓	✓	
9	✓	✓	✓	✓	✓	✓	✓	✓	✓

1-220 kV, 400mm
Capacity: 249 MVA
Cost: 71.2 M€

6-220 kV, 800mm
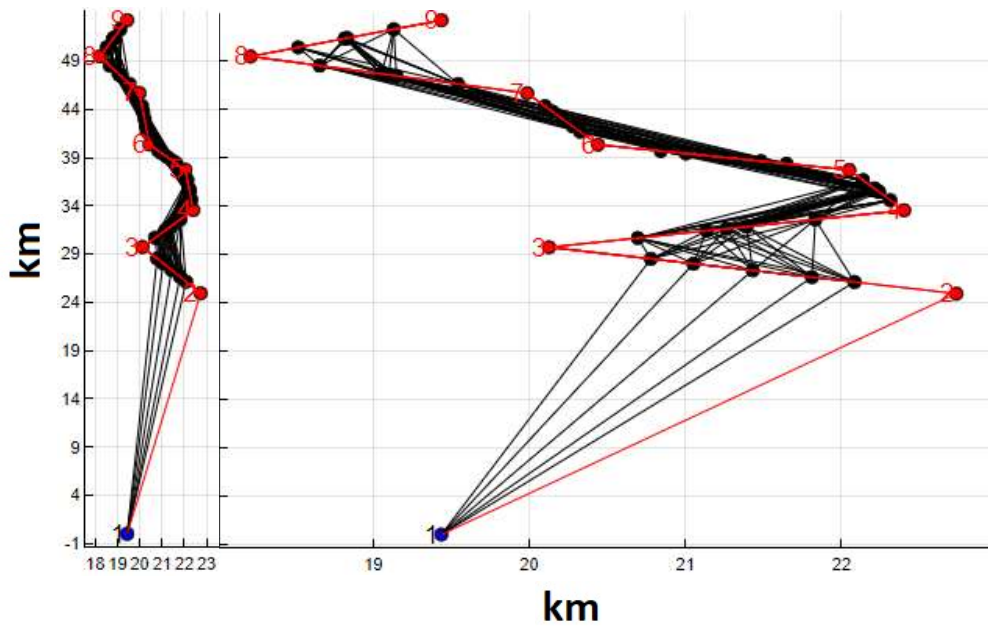Capacity: 2002 MVA
Cost: 262.2 M€

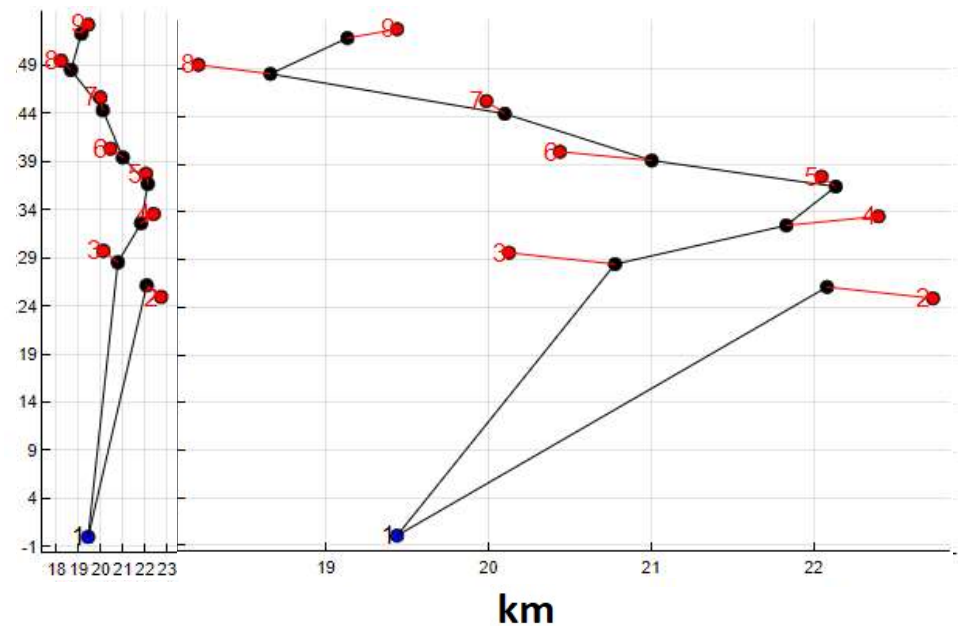Number of candidate lines per path increases

Optimal OSS TNEP

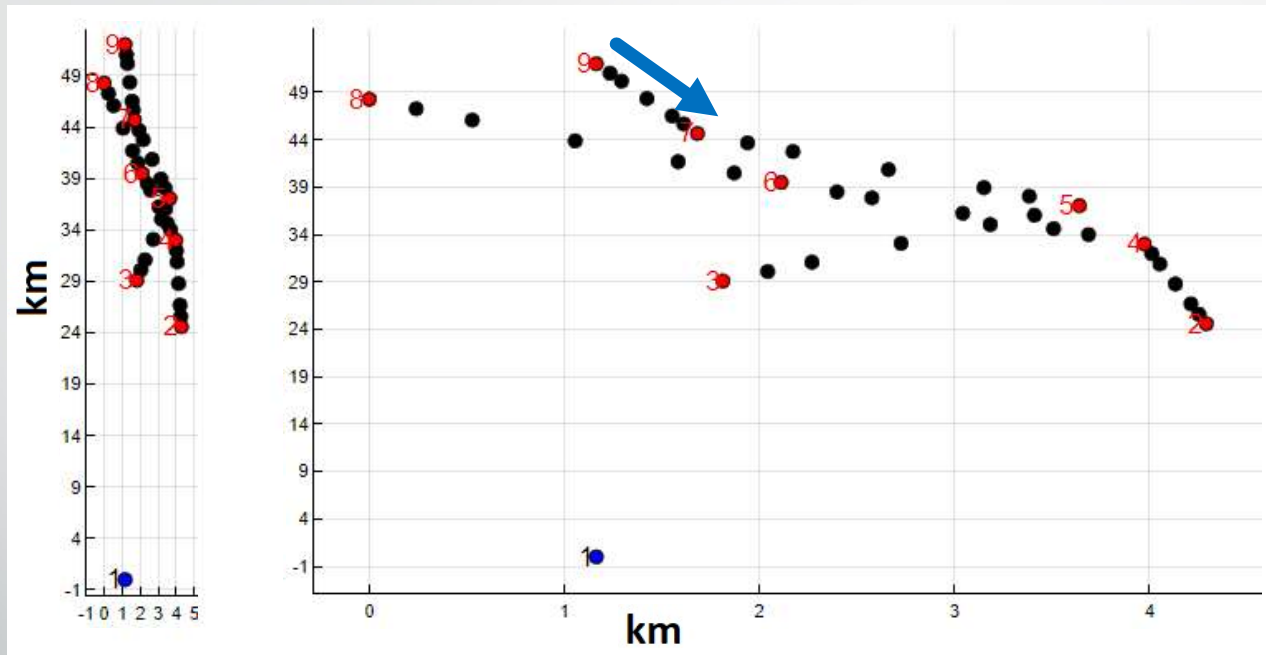Nearest Neighbour

Full Layout

Optimal Solution

Finding Optimal OSS Placement

2nd Nearest Neighbour

Finding Optimal OSS Placement

3rd Nearest Neighbour

Finding Optimal OSS Placement

4th Nearest Neighbour
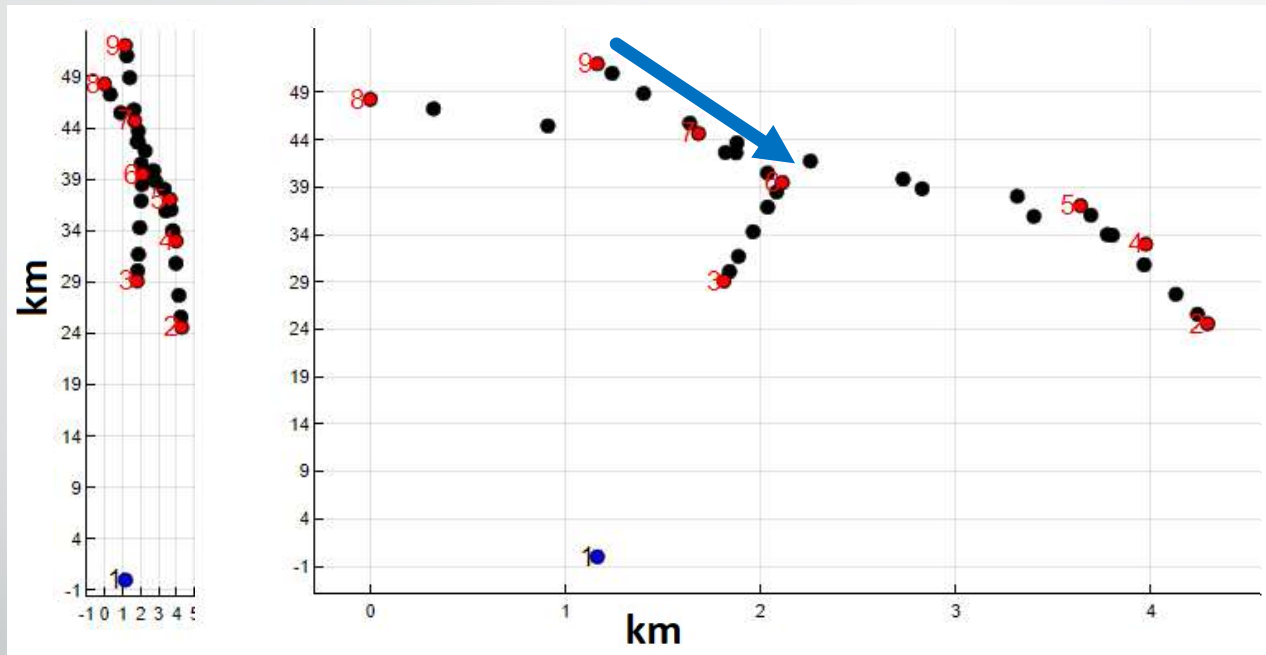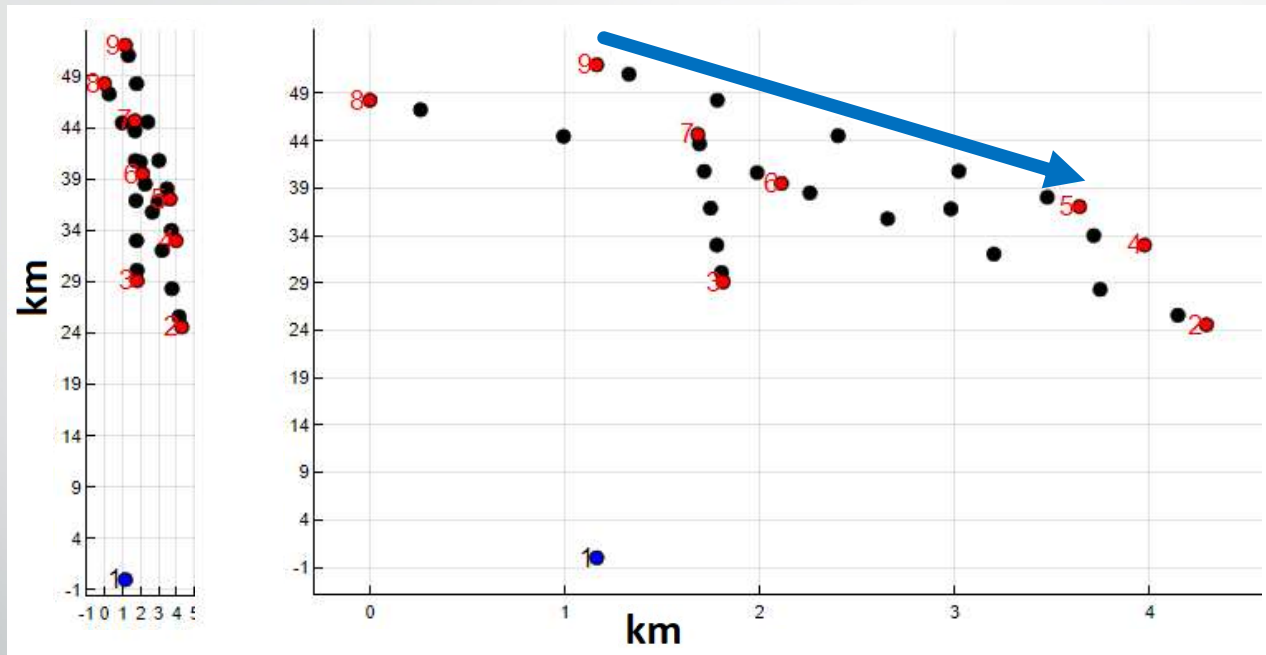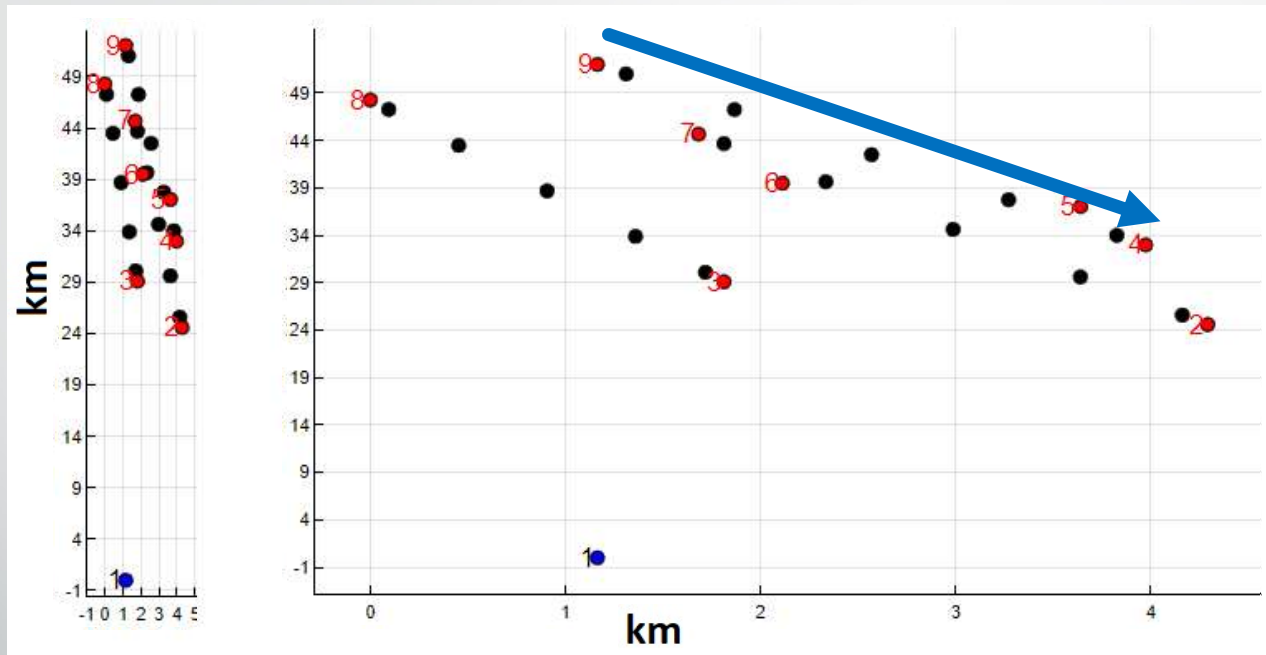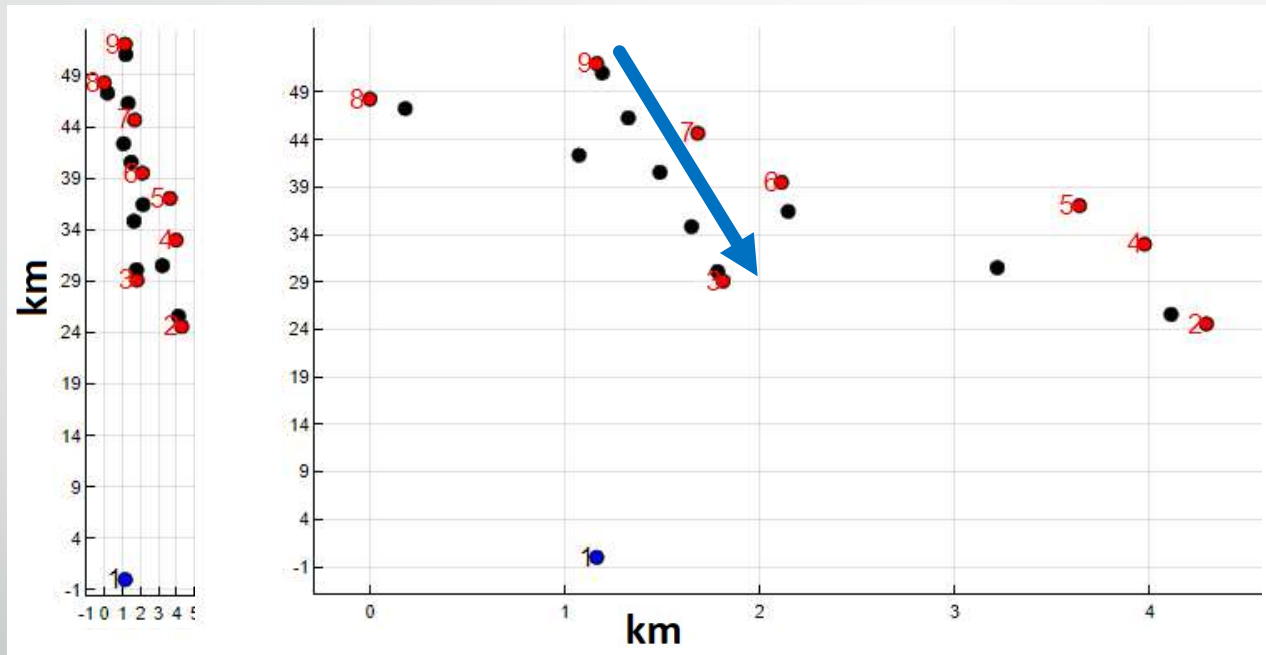
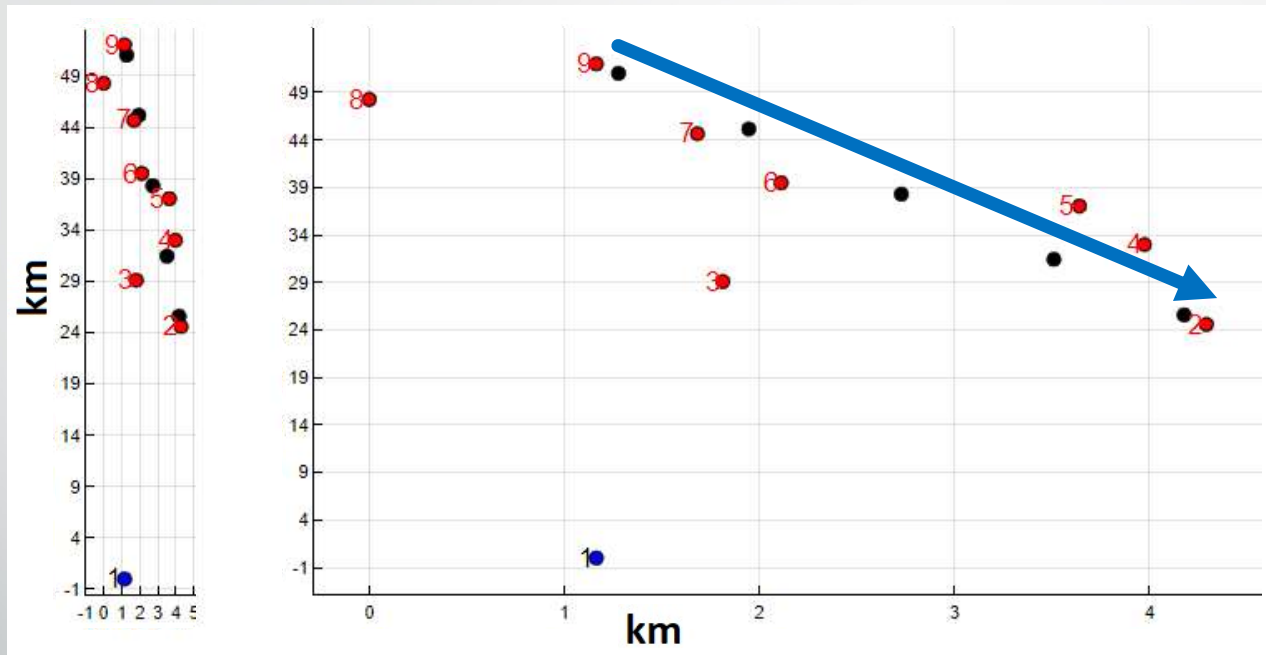# Finding Optimal OSS Placement

5th Nearest Neighbour

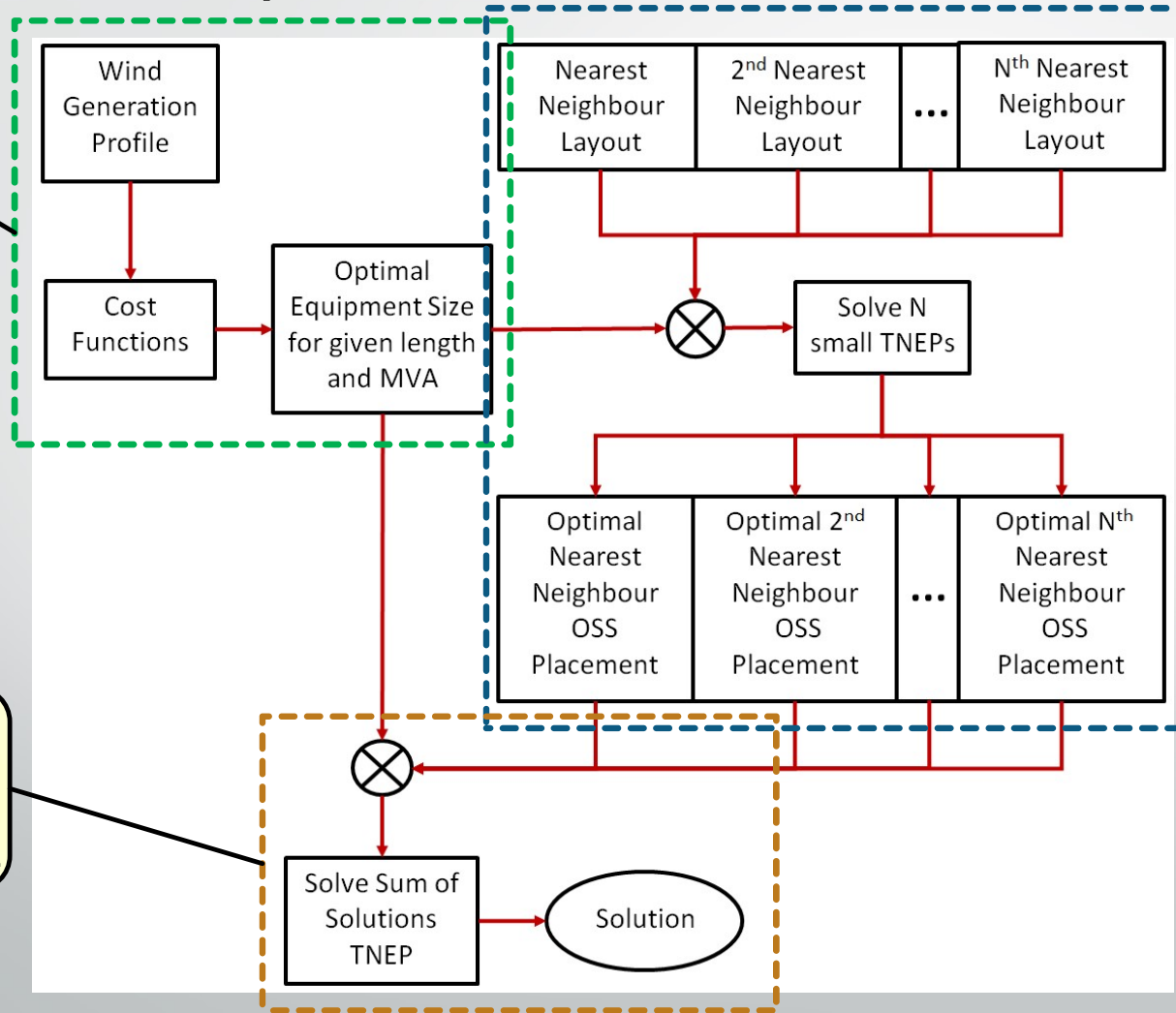# Finding Optimal OSS Placement

6th Nearest Neighbour

Finding Optimal OSS Placement

7th Nearest Neighbour

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Solve N small TNEPs

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Optimal Nth Nearest Neighbour OSS Placement

Solve Sum of Solutions TNEP

Solution

TNEP formulated as the sum of optimally placed OSSs

- OSS-OSS connections are a minimum of 2km.

- OSS connections are only with the nearest PCC.

- Max 12 cables are allowed in parallel.

- Only forward and horizontal paths.

TNEP formulated as the sum of optimally placed OSSs

Layout			Solution Cost [M€]		Gap [%]
Final Formulation			625.941 M€		0.0
START	END	KM	MVA	CABLE	
9	A	6	265	3-800mm, 66kV	
8	A	3	265	3-800mm, 66kV	
7	A	1	265	3-800mm, 66kV	
6	B	4	265	3-800mm, 66kV	
5	B	1	265	3-800mm, 66kV	
4	B	1	265	3-800mm, 66kV	
3	C	3	265	3-800mm, 66kV	
2	C	1	265	3-800mm, 66kV	
A	B	11	759	3-400mm, 220kV	
B	1	36	1526	5-630mm, 220kV	
C	1	26	504	2-400mm, 220kV	
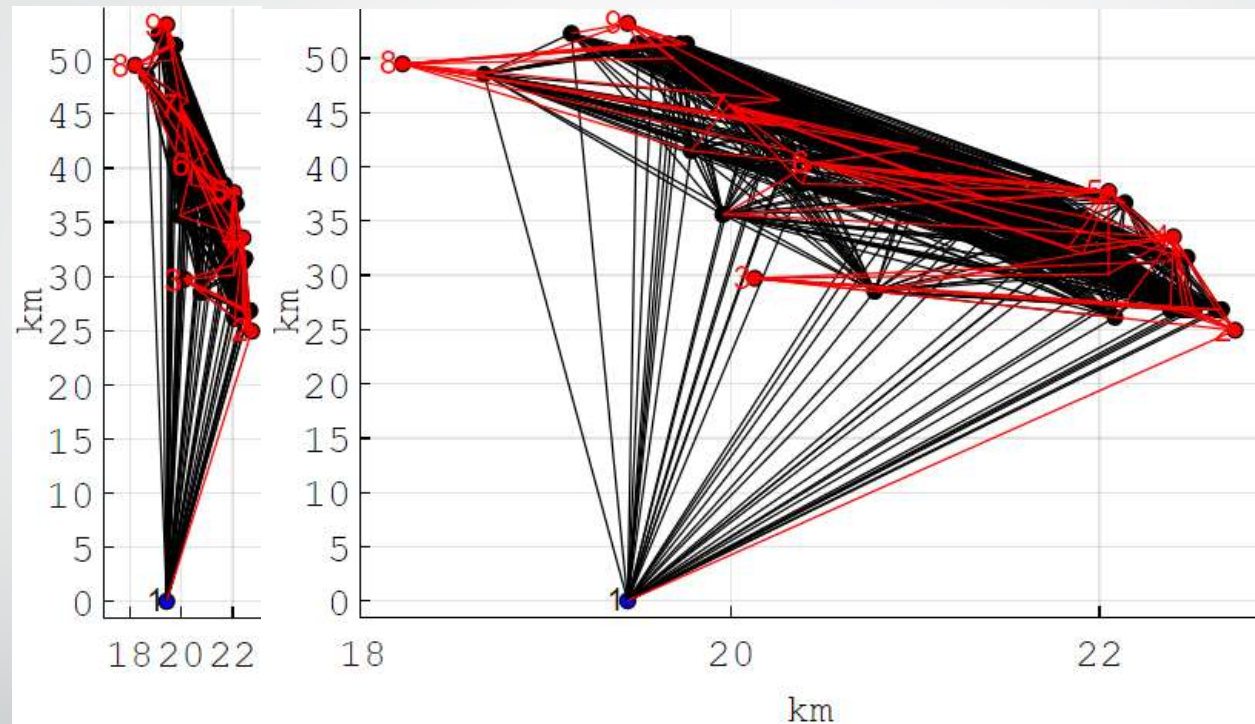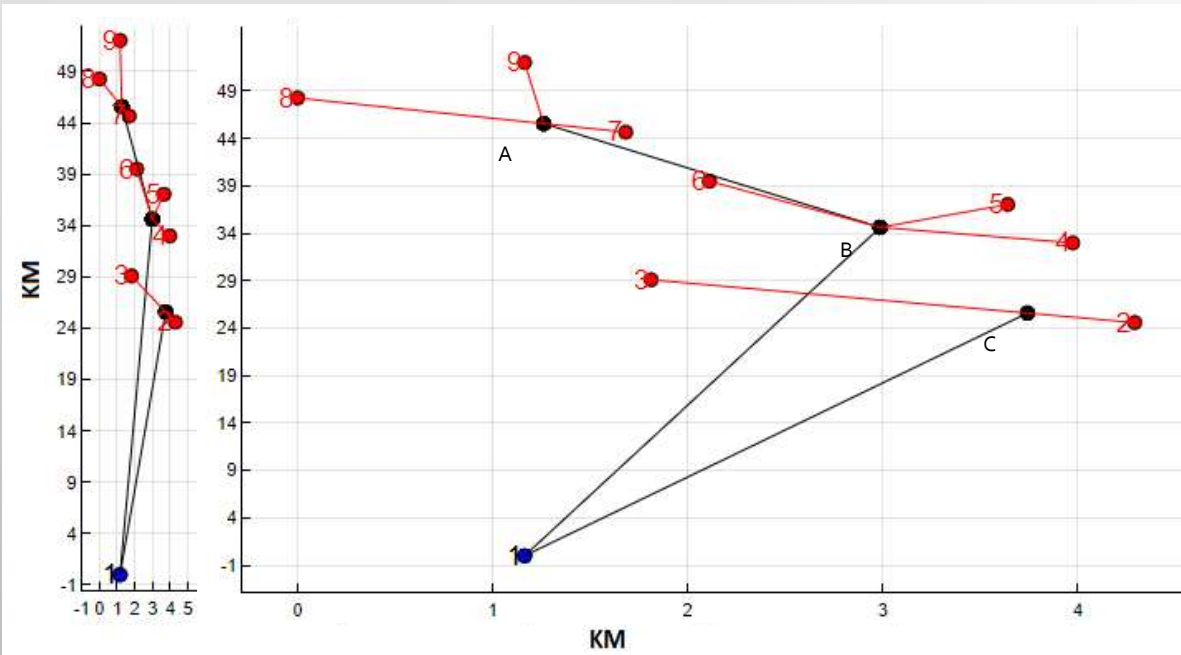
OSS	A	B	C
Latitude	51.67199	51.60145	51.53354
Longitude	2.80918	2.91818	2.99813
Transformers	3-350MVA	3-350MVA	3-240MVA

Thank You for your attention!

CG Holdings and KU Leuven Belgium