Topic 6: Superconductivity, Networks and System Integration

A Simulated-Annealing-Based Approach for Wind Farm Cabling

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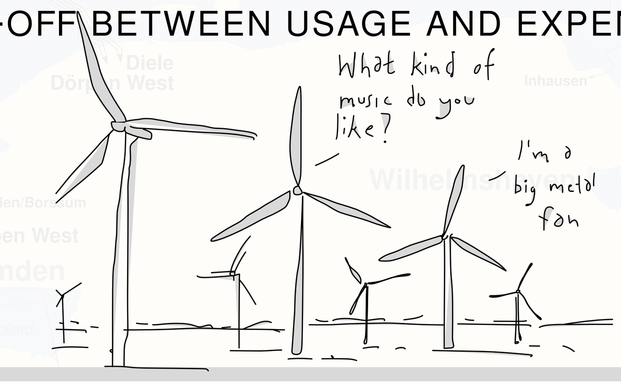
Motivation

	2015		2014		2015		—
					Elec. Cons.	Total Energy	Max. Pot.
	in MW	$\lvert V_T \rvert$	in MW	$\lvert V_T \rvert$	in TWh/a	in PWh/a	in TWh/a
World	12 100	3362	8800	2444	20 568	160.24	36 990
Europe	11 000	3056	8050	2237	3291	20.93	8480
UK	5100	1417	4500	1250	312	2.08	986
Germany	3300	917	1050	292	521	3.55	237
Denmark	1300	362	1300	362	—	—	550
North America	0	—	0	—	4342	28.45	9860
South America	0	—	0	—	1279	9.85	5660
Asia	1100	306	710	198	8608	65.42	7210
Australia	0	—	0	—	220	1.47	4110

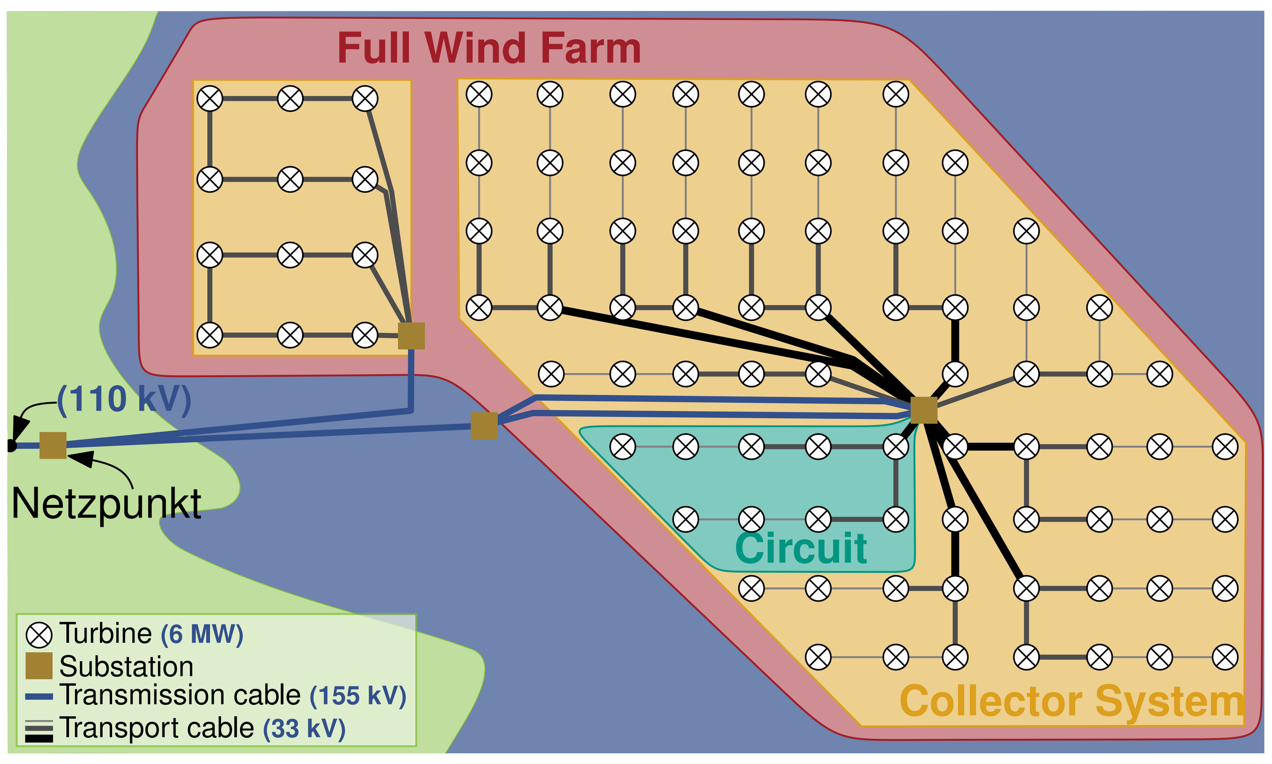
Roughly installed offshore wind power increases from 2014 to 2015 significantly [2]. The number of turbines $\lvert V_T \rvert$ is based on the total power and assumes that all wind turbines have a power rating of 3.6 MW, which matches the today's dominating Siemens SWT-3.6 turbines. In the last three columns the annual consumption of electricity (Elec. Cons.) and total energy consumption is compared to the maximum potential offshore wind energy (Max. Pot.), respectively [3,4].

- the German renewable energy act EEG 2017 targets 40–45% of electricity from renewable energy producers to gross electricity consumption until 2025 and 55–60% until 2035
- the design includes a lot of decisions that influence the construction and operation costs [5]
- a large fraction of the investment for the cables, cable laying and substations, e.g., Horns Reef in Denmark had costs for the cabling of 10–15% [6]

REDUCE THE TRADE-OFF BETWEEN USAGE AND EXPENSES FOR WIND FARMS!



Model

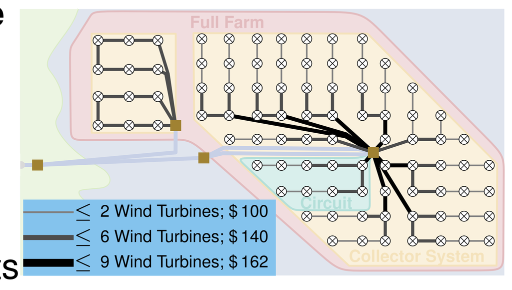


Given V_S set of substations, V_T set of turbines (each with **capacity**), for each edge: cable types (each with **cost** and **capacity**)

find for each edge: the **cable type**

minimizing **total cable cost**

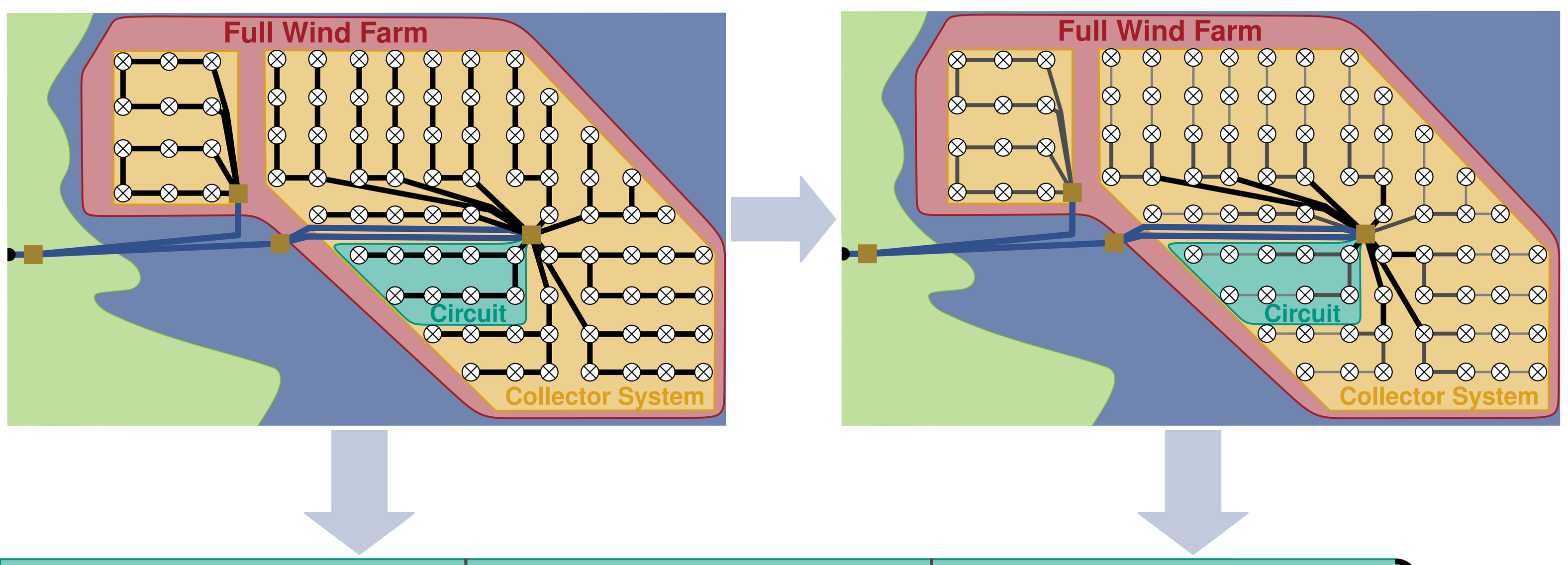
subject to cable capacity constraints, substation capacity constraints, flow conservation constraints



Wind farm planning problem ⇔ Minimum cost flow problem
using [Leibfried et al., 2015]

$$\mathrm{OPT}(\mathcal{N}_{\mathrm{FFP}}) \leq \sum_{j \in V_S} \mathrm{OPT}(\mathcal{N}_{\mathrm{SP}}(j)) \leq \sum_{j \in V_S} \sum_{i \in \mathbb{N}} \mathrm{OPT}(\mathcal{N}_{\mathrm{CP}}(j, i))$$

Windfarm Cabling Problem

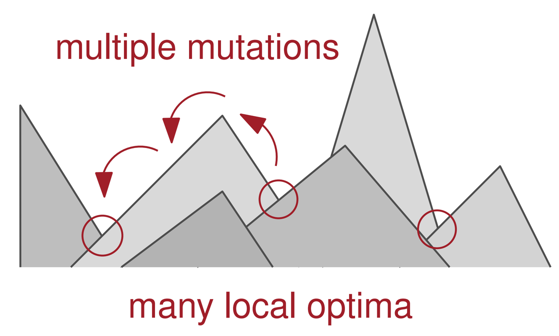


P (MST)	Circuit Problem	NP-hard (Clustering)
NP-hard (CMST)	Substation Problem	NP-hard
NP-hard (Heuristics)	Full Farm Problem	NP-hard

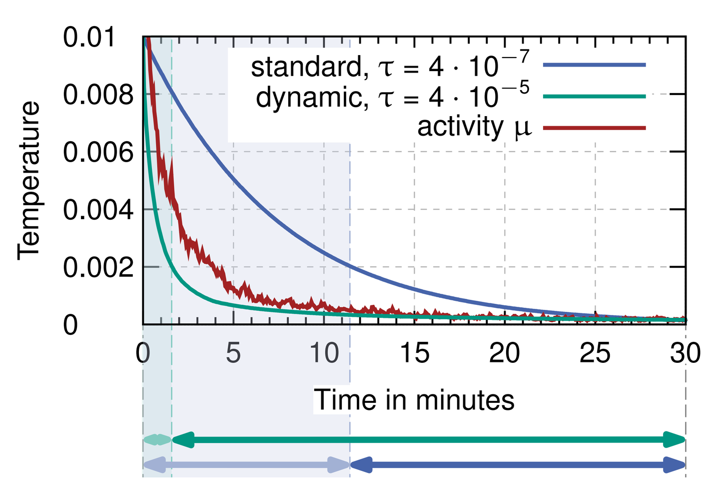
} Simulated Annealing

Simulated Annealing (SA) Algorithm

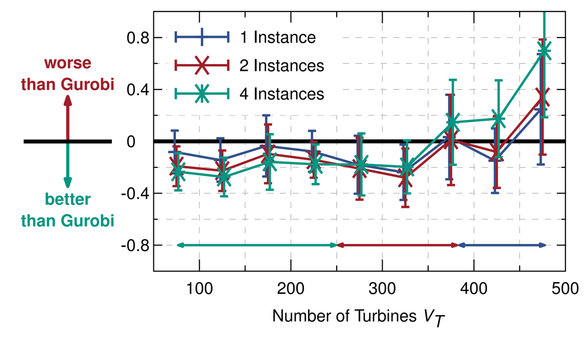
Metropolis Algorithm



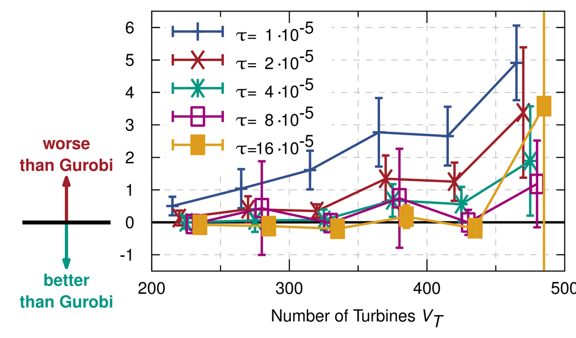
Cooling Schedule



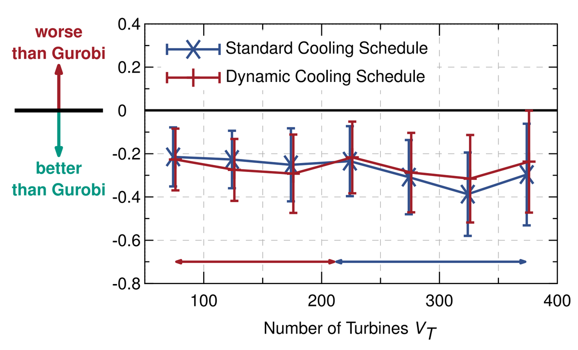
Results & Future Work



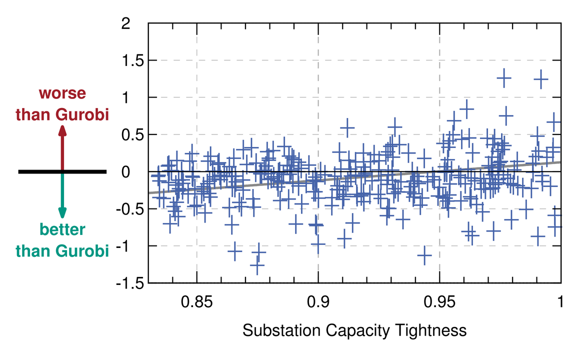
Multiple instances reduce the overall computation time. This causes a reduced time spend for the intensification phase.



Parameter tuning is difficult for the cooling schedule.

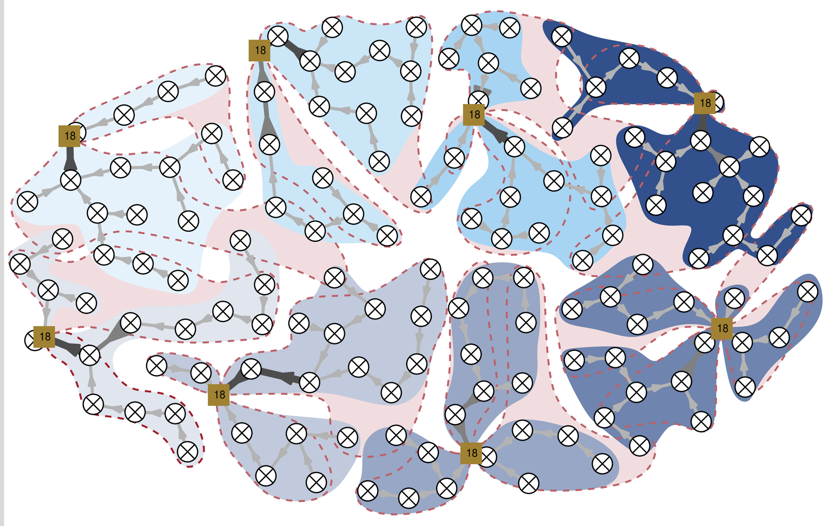


The **dynamic** outperorms the **standard** one without parameter tuning. Parameter tuning improve the standard one for larger instances.



The **tighter** the substation capacity or the **more** substations the harder the instance is to solve. Thus, the solution quality reduces with same duration.

Example



The *instance properties* and *SA parameters* are defined by

- the shape aspect ratio $\beta = 0.727$,
- the number of turbines $\lvert V_T \rvert = 93$,
- the number of substations $\lvert V_S \rvert = 5$,
- the capacity tightness $\gamma = 0.886$.
- the number of instances $\lvert \mathcal{I} \rvert = 2$,
- the dynamic cooling schedule,
- the initial temperature $T(0) = 0.01$,
- the thermal conductivity and capacity $\tau = 16 \cdot 10^{-5}$,
- the recover iteration threshold is set to 10 000.

After 60 min the number of circuits in the best solution of the SA approach are 15 ($1 \times 4; 3 \times 3; 1 \times 2$ circuits), whereas for the MILP the number of circuits are 13 ($3 \times 3; 2 \times 2$ circuits).

Literature

[1] S. Lehmann, I. Rutter, D. Wagner, and F. Wegner. 2017. *A Simulated-Annealing-Based Approach for Wind Farm Cabling.* In Proceedings of the Eighth International Conference on Future Energy Systems (e-Energy '17). ACM, pp. 203–215.

[2] *Global Energy Statistical Yearbook 2016.* @ONLINE, 2016. https://yearbook.enerdata.net, Accessed: 2016-11-17.

[3] A. Garrad and H. Matthies. *Study of Offshore Wind Energy in the EC.* JOULE I. Executive Summary. Offshore Wind Turbines. 1993.

[4] *Windparks.* @ONLINE, 2016. http://www.offshore-windindustrie.de/windparks, Accessed: 2016-10-25.

[5] S. Lundberg. *Evaluation of wind farm layouts.* EPE Journal, 16(1):14–21, 2006.

[6] B. Frankén, H. Breder, M. Dahlgren, and E. K. Nielsen. *Collection grid topologies for off-shore wind parks.* In Electricity Distribution, 2005. CIRED 2005. 18th International Conference and Exhibition on, pages 1–5, 2005.