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Discrete event simulation model for selecting optimal substation transformers for offshore wind power plants

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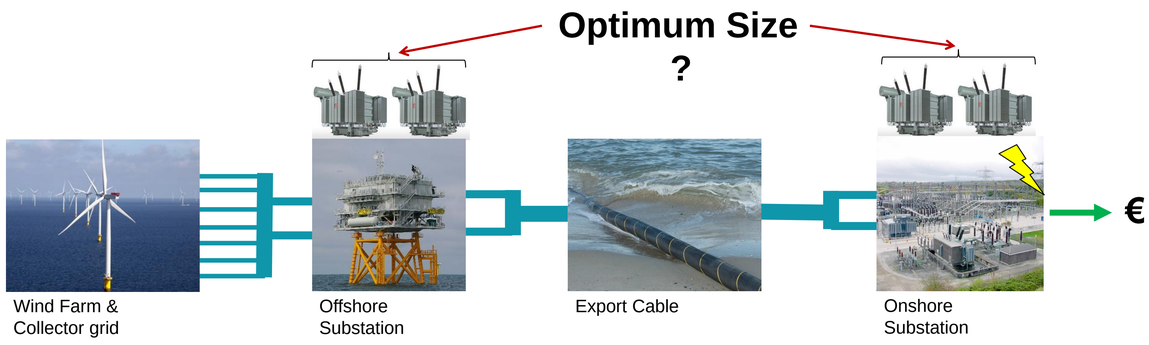
Introduction

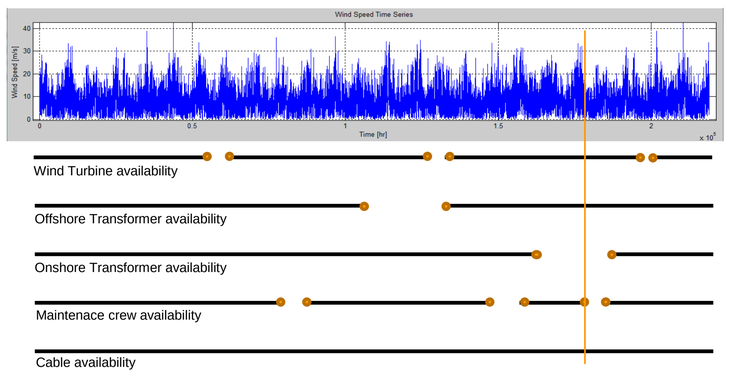


Selecting substation transformers with an optimal power rating could support the offshore wind industry in the effort to reduce the cost of electricity. The challenge stands on how to analyse and assess the project's life time effects on costs and production for different substation power capacities, when the system is heavily dependant on stochastic variables such as wind speed and downtime events

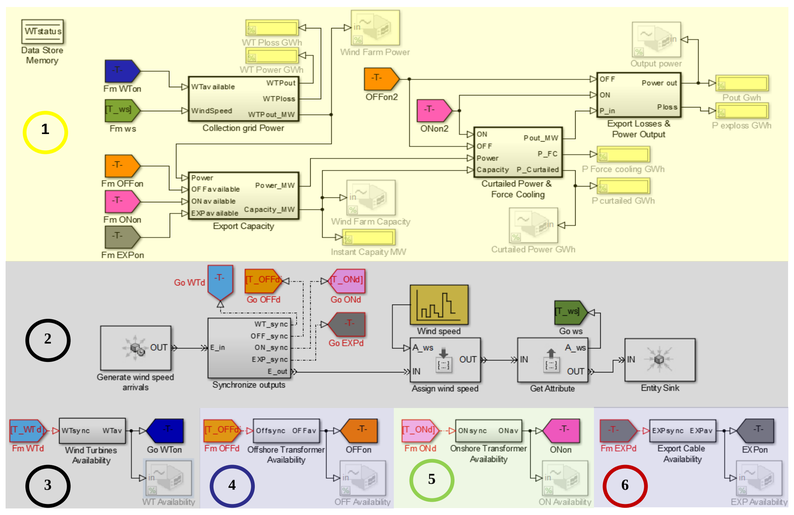
Methodology

Discrete event simulation (DES)

- Time-domain method that models a system in a natural manner
- Can be regarded as timelines of resources running in parallel which change status due to event occurrences
- Made possible thanks to computational advances



Graphical computational model



- Commercial platform: Matlab Simulink
- Programmed in modules to add flexibility: Wind turbines, export cables, onshore and offshore substation, wind speed resource
- Other variables: NPV, price of electricity (cfd and OFTO), cost of OSS, electrical losses (DC power flow).

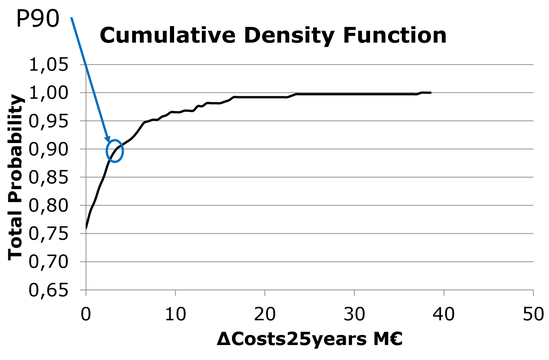
Randomly generated failures

- Failure rates based on CIGRE surveys
- Random number generator with variable seeds.
- Failure rate (FR) assumed constant using exponential distribution.
- Diverse probability distribution available to account for FR variations but not used.

$$f(t) = \lambda \cdot e^{-\lambda t} = \frac{1}{MTBF} \cdot e^{-\frac{t}{MTBF}}$$

	λ	MTTR
Substations transformers	0.0032 failure/yr	1.5 weeks to 8.5 weeks
Wind Turbine	1.5 failure/yr.	170 hr.
Export system combined*	0.049 failure/yr.	3.5 months

Decision making based Confidence Intervals



- Multiple computer simulation runs to construct a probability distribution of losses in electricity production and monetary units.
- Decision of optimum transformer ratings can be made based on confidence intervals such as 90%, 95% and 99% instead of the traditional use of average values.

Results

1. A reference wind farm was established based on realistic data.
2. The simulation model mimics the lifetime operation of the wind farm.
3. The model was validated using a reference case and the output compared to expected values.
4. Sensitivity analysis was run to examine the effects of specific parameters.
5. Qualitative analysis was carried out to determine which factors have greater effects on the economics of the wind farm.
6. Optimization loop is run to find the optimum transformer power rating.

Variable	Reference value		Sensitivity	Min. likelihood	Max. severity	Std. dev.	Min. ΔCost
Iterations	375	+		N/A	N/A		
		-		N/A	N/A		
MTTF	312,5 yr	+					
		-					
MTTR	8.5 weeks	+					
		-					
MTTR Distribution	Exponential	Uniform					
		Triangular					
Forced Cooling	OFF	ON					
Forced cooling Reliability	100%	≥ 50%					
		< 50%					
Power Rating	50%	+					
	50% + Forced	+					
		-					
WT Availability	100%	O&M					
		97%					
		98.5%					
Export cable Availability	100%	MTTR / MTTF					

P.rating/transf. [%]	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	83	100
P. Rating [MVA]	114	120	126	131	137	143	148	154	160	156	171	177	183	188	194	200	237	285
ΔCAPEX [M€]	-1.52	-1.02	-0.52	-0.11	0.37	0.85	1.24	1.71	2.18	2.56	3.02	3.47	3.92	4.3	4.74	5.18	7.82	11.1
Mean Costs [M€]	51.539	40.438	40.634	40.748	40.662	40.662	40.851	41.155	41.416	41.685	42.009	42.291	42.63	42.89	43.231	43.543	45.737	48.845
Std. dev. Costs [M€]	2.83	2.59	2.42	2.28	2.09	1.94	1.79	1.65	1.47	1.36	1.22	1.06	0.94	0.82	0.71	0.57	0.17	0.17
P90 Costs [M€]	53.68	42.58	42.58	42.59	42.37	42.25	42.24	42.51	42.58	42.76	42.92	43.17	43.32	43.5	43.74	43.98	45.72	48.9
P95 Costs [M€]	56.48	45.28	45.08	44.89	44.37	44.05	43.94	43.91	43.78	43.76	43.82	43.77	43.92	44	44.14	44.28	45.82	48.9
P99 Costs [M€]	65.68	53.48	52.68	52.09	51.07	50.35	49.84	49.41	48.78	48.46	48.02	47.57	47.22	46.9	46.64	46.28	45.92	49

Potential Application

1 Prepare Tenders

- Asses optimum power rating
  - Adjust model to wind farm
  - Use reference inputs
  - Decide confidence interval
- Request proposal from manufacturer

2 Select Suppliers

- Evaluate proposals
- Use manufacturers input
  - Price
  - Failure rate
  - Forced cooling capabilities
  - Equipment weight

Future Work

- Test different configurations of wind farms
- Optimize other components of transmission system
- Develop a user friendly interface
- Add module to consider maintenance parameter
  - Weather delays
  - Crew, vessel and spare parts costs

References

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