Computational Tool Development for Offshore Wind and Renewables

Bahri Uzunoglu

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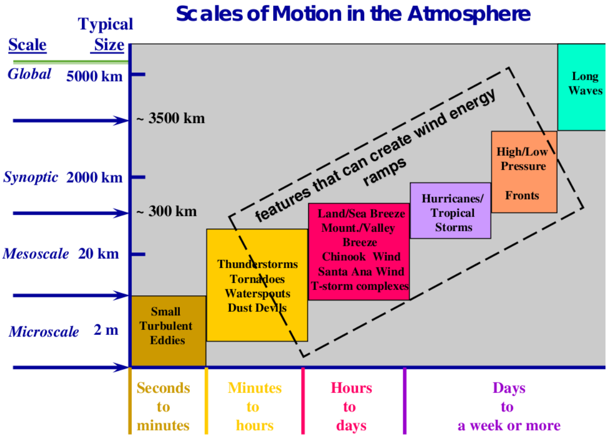
Objectives

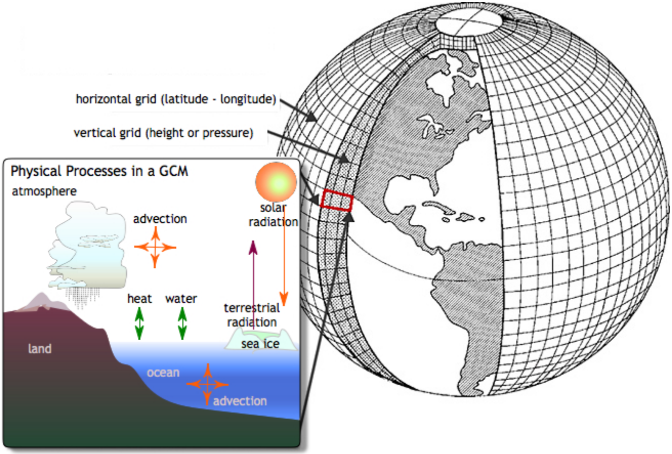
The problem formulation:

- Several large scale offshore wind farms are planned to be built far from the shores in the future.
- Several computational approaches can improve the business and risk decision on these projects. Modeling is essential part of project cycle.

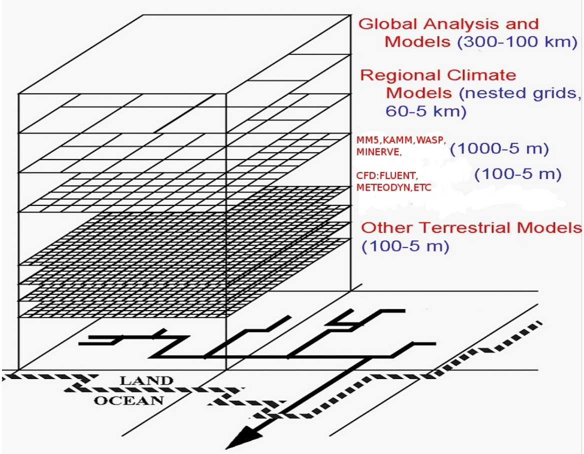
Scales of the Atmosphere



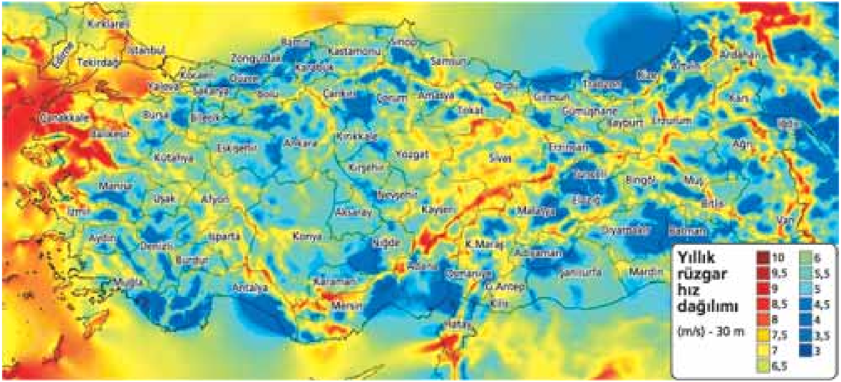
Atmospheric Model



Atmospheric Model

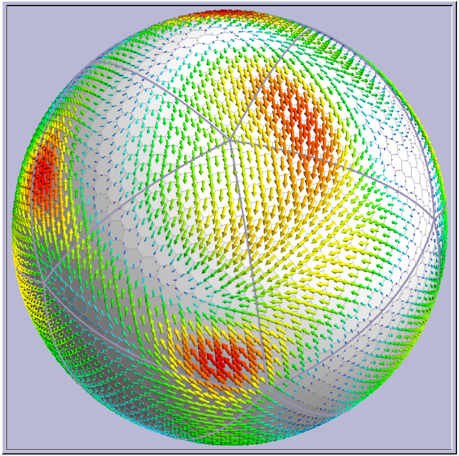


Atmospheric Model

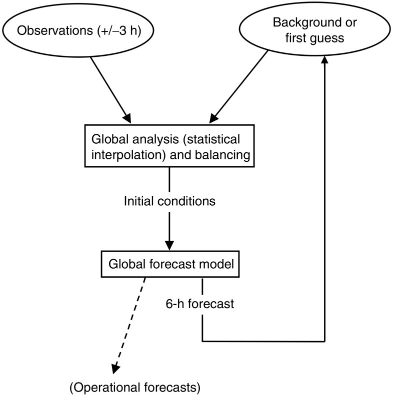


- The forecasts are computed using mathematical equations for the physics and dynamics of the atmosphere.
- These equations are nonlinear and are impossible to solve exactly. Therefore, numerical methods obtain approximate solutions.
- Global models often use spectral methods for the horizontal dimensions and finite-difference methods for the vertical dimension, while regional models usually use finite-difference methods in all three dimensions.
- Poles usually needed to be treated seperately unless it is using geodesic grids and icosahedral grids, which (being more uniform) do not have pole-problems.

CCoSM: Coupled Colorado State University Model

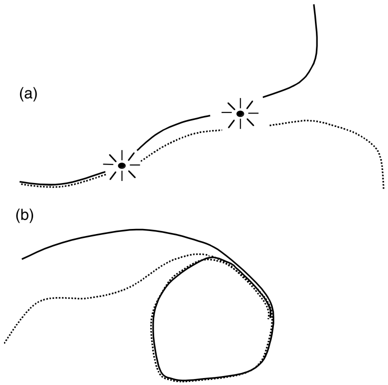


Data Assimilation



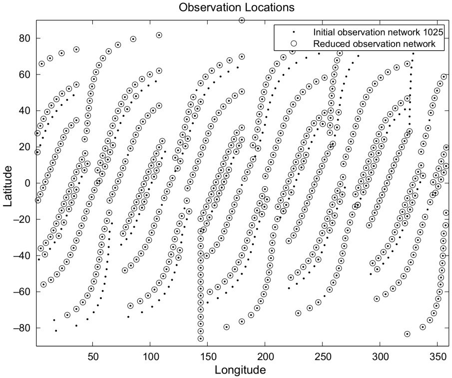
All the data assimilation methods; filter and nonlinear filters, ensemble data assimilation methods follow the similar procedure.4-D Var, Ensemble Kalman filter, Reduced Kalman filter, Particle Filter, etc.

Ensemble Data Assimilation



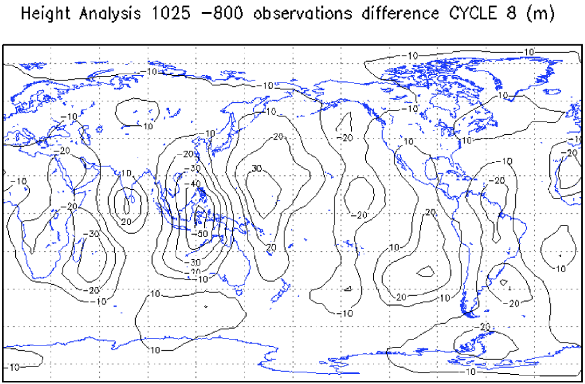
a) Chaotic system b) Stable system; It can be combination of different runs or different NWPs.

Macroscale: Met Tower Optimization



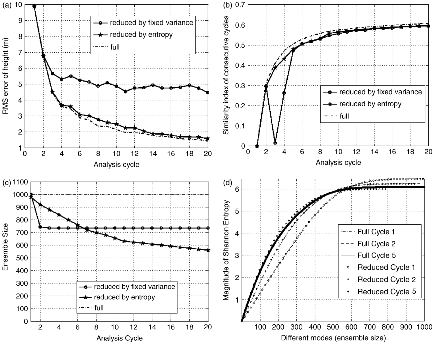
The method is feasible for both macroscale and mesoscale wind prediction. (Uzunoglu,B., Computer Methods in Applied Mechanics and Engineering 196, 4207-4221, (2007))

Macroscale: Met Tower Optimization



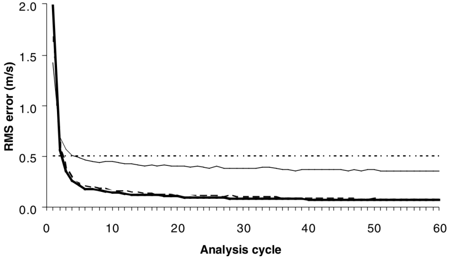
Errors involved for the full network and optimized network are minimal.

Macroscale: Ensemble Data Assimilation and Control



Ensemble size control; initial investigation shows significant reduction in ensemble size control for computational cost of wind prediction. Uzunoglu,B. et al., Adaptive ensemble member size reduction and inflation, Quarterly Journal of Royal Meteorological Society Vol 133, Issue 626, Pages 12811294, July Part A (2007).

Macroscale: Initiation of Ensemble Data Assimilation



Analysis RMS error for: east-west wind component (ms1),The results are obtained using three different methods: Correlated-KPZ method gave better results. The observation error standard analysis cycle deviation is indicated by a dotted line. Zupanski,, M., Fletcher. F, Navon., I.M, Uzunoglu,B., Heikes,R.P. , Randall, D.A, and Ringler, T.D., Tellus 58 A, 159-170 (2006).

Macroscale: Nonlinear Ensemble Data Assimilation

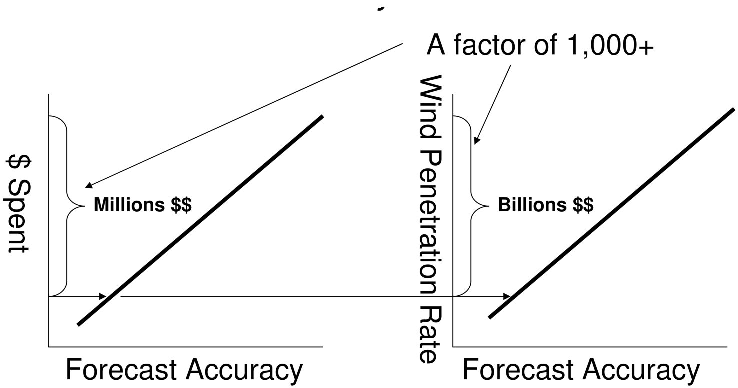
1000-member Model error variance	EnKF mean rms x	EnKF mean rms y	EnKF mean rms z	PFGR mean rms x	PFGR mean rms y	PFGR mean rms z
0	2.16	3.49	3.49	1.69	2.71	2.87
2	2.29	3.75	3.81	2.20	3.56	3.55
4	2.40	3.87	3.73	2.15	3.46	3.28
6	3.00	4.95	4.89	2.40	3.90	3.85
8	2.67	4.40	4.17	2.33	3.85	3.21
10	3.55	5.67	5.32	2.56	4.22	4.17
0	2.03	3.27	3.23	1.64	2.65	2.77
2	2.34	3.84	3.87	2.22	3.60	3.68
4	2.51	4.06	3.98	2.23	3.59	3.59
6	3.09	5.15	5.02	2.26	3.79	3.68
8	2.61	4.31	4.11	3.28	5.08	4.57
10	3.46	5.75	5.54	2.95	4.85	4.67

Nonlinear filters can perform better but they are computationally limited: Results for Lorenz equation. Xiong,X., Navon., I.M and Uzunoglu,B, A Particle Filter with Posterior Gaussian Resampling; Tellus 58 A, 456460 (2006).

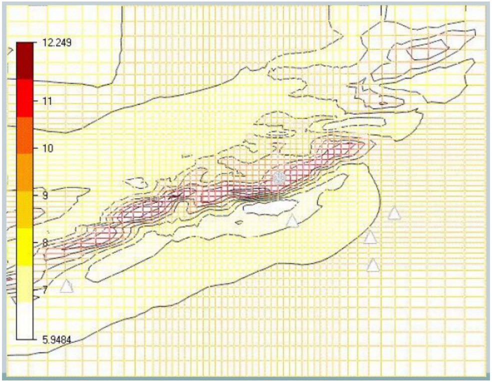
Ensembles in Wind Industry

- Transmission congestion forecast.
- System balancing forecast.
- Short term spot market prediction.
- Ramp prediction and uncertainty.
- Energy risk management.
- Good forecasts minimize reductions in spot forecast prices and reduce overall energy cost; Perfect forecast to less over-commitment.
- GL forecaster, Predictor, Anemos, Zephyr, Previento are some tools that already employ ensembles for prediction.

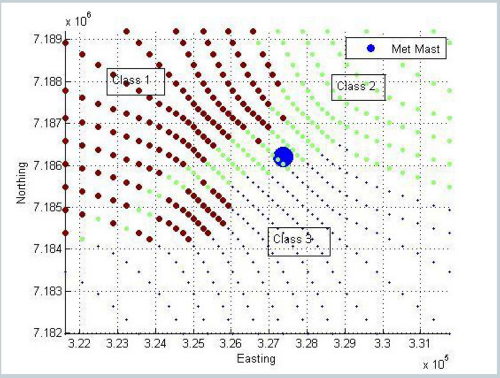
Cost of Forecast.



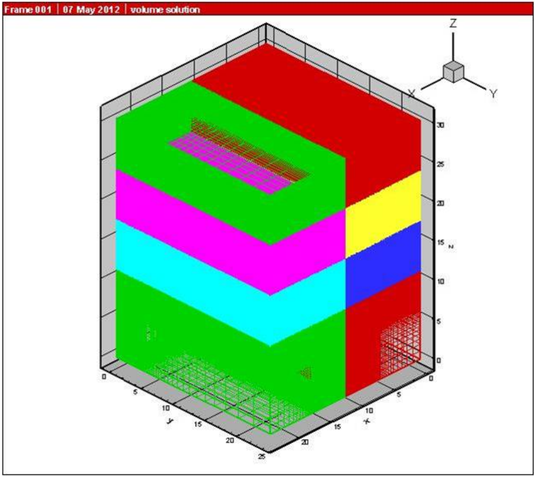
Data Mining



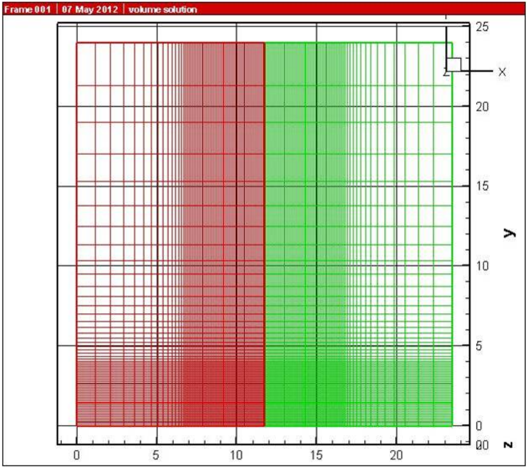
Data Mining

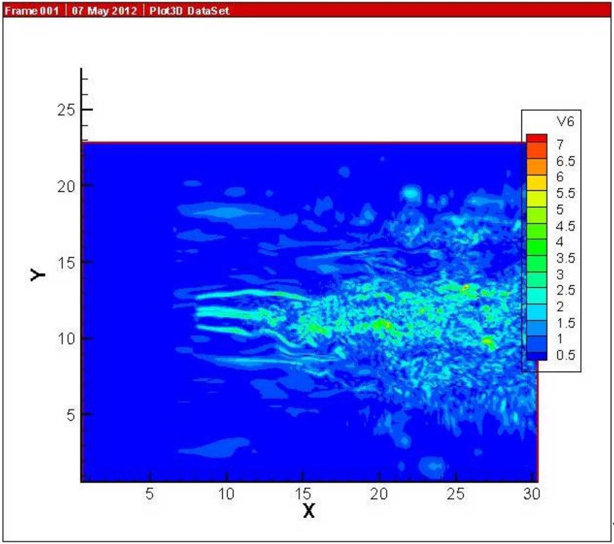

x 10^6
7.189
7.188
7.187
7.186
7.185
7.184
7.183
7.182
Northing
3.22
3.23
3.24
3.25
3.26
3.27
3.28
3.29
3.3
3.31
Easting
x 10^5
Met Mast
Class 1
Class 2
Class 3

Large Eddy Simulation



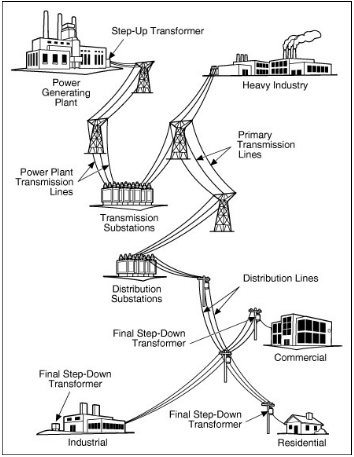
Large Eddy Simulation



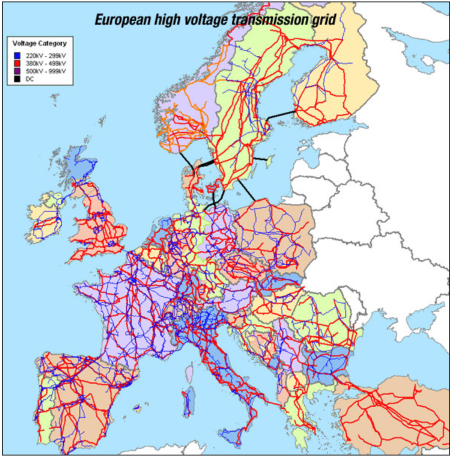


Vorticity field for two turbine configuration. Time 120; U=10m/s: LES result: Ambient turbulence introduced

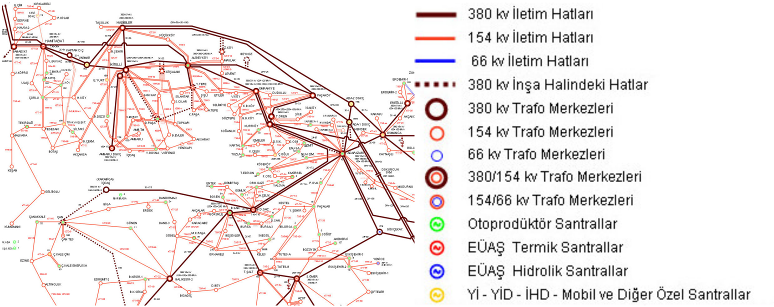
Scales of Electricity Grid



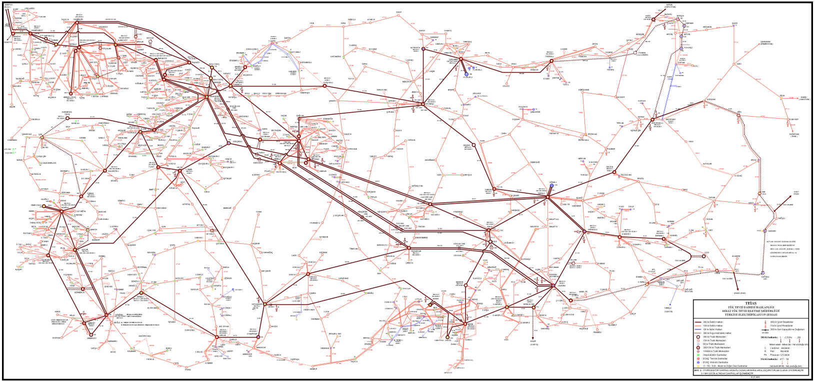
Scales of Electricity Grid Europe



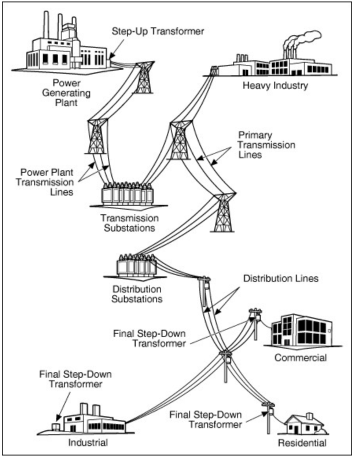
Scales of Electricity Grid Turkiye



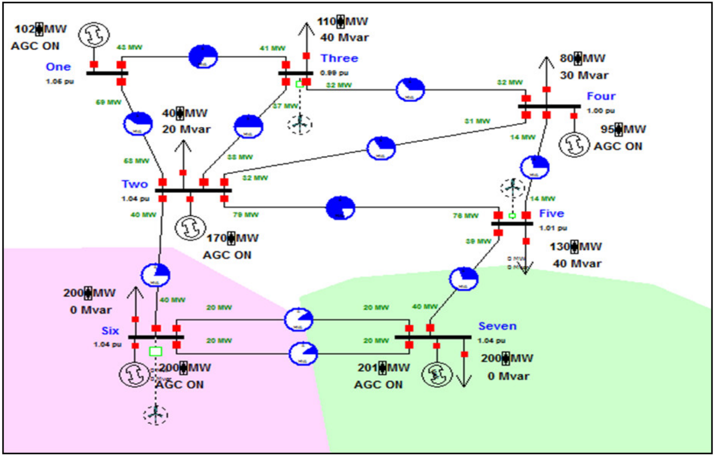
Scales of Electricity Grid Turkiye



Scales of Electricity Grid



Security and Contingency analysis



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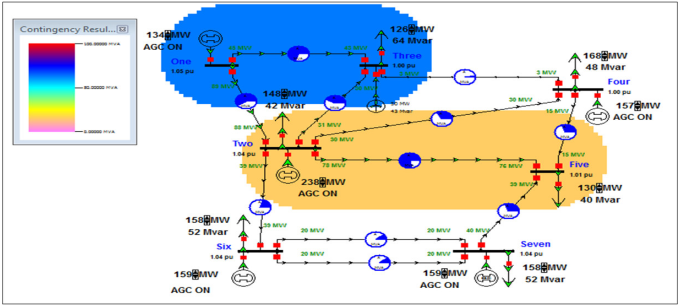

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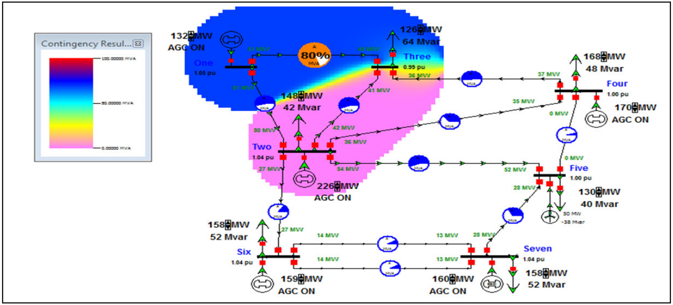
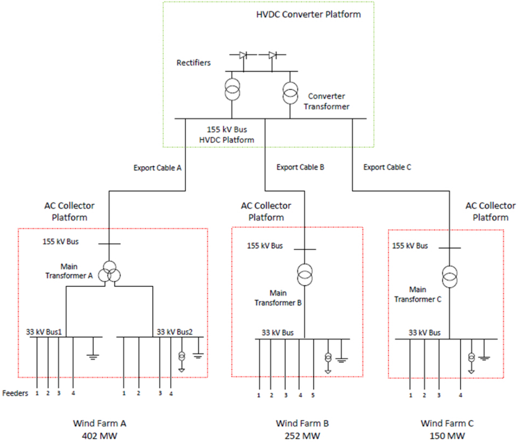


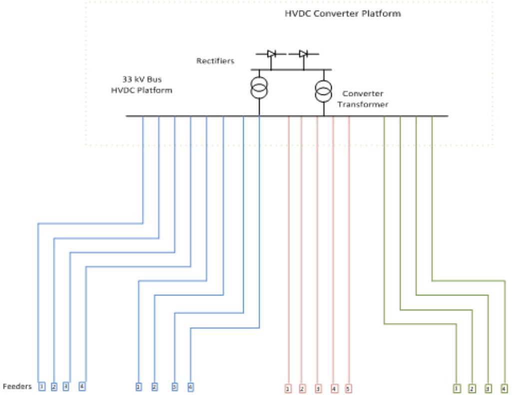
The first topology

In the first topology, the offshore wind farms are connected to an HVDC converter platform through offshore AC collector platforms.



The second topology

In the second topology, the offshore AC collector platform is removed from the circuit and the offshore wind farms are connected directly to offshore HVDC converter platform.



Wind Turbine Configuration DFIG

Siemens 6 MW offshore wind turbine model is used for this study. Two types of wind turbine generators i.e. DFIG and FC generators are investigated. These are the some of the most common wind turbine generators which are currently being used in the market. The 6 MW DFIG is selected with following specifications:

Specifications	
Apparent Power(MVA)	6.667
Rated Voltage(kV)	0.69
Nominal Frequency(Hz)	50
Stator Resistance(p.u)	0.01
Stator Reactance(p.u)	0.1

Table : Specifications of DFIG from DIgSILENT

Wind Turbine Configuration FC

- The short circuit contribution from HVDC (from grid side) is chosen as 150% of apparent power of the wind farms cluster initially and 50% thermally.
- Two cases are investigated for short circuit analysis. In the first case, short circuit analysis of an offshore wind farm cluster connection to HVDC converter platform with and without using offshore AC collector platforms is simulated. In the second case, short circuit analysis at the feeders in the absence of offshore AC collector platform is simulated.

The inner array and export cable specifications

- The inner array cables connect the individual wind turbines, in each feeder, to AC collector platform of each wind farm. The length of the cable between two wind turbines is kept at 0.9 km. The length of the cable between the wind turbine and offshore AC collector platform is kept at 2.5 km while in the absence of offshore AC collector platform; three different lengths are chosen i.e. 1 km, 5 km and 10 km.
- Three export cables are used to connect three different offshore wind farms to offshore HVDC converter platform. Three different lengths i.e 1 km, 5 km and 10 km is chosen.

The main transformer configuration.

The offshore wind farms are connected to the main transformers placed on offshore AC collector platforms. Each wind farm has its own step up transformer which raises the voltage from 33 kV to 155 kV.

- The eight feeders of the offshore wind farm A are connected to a three winding transformer having 444/222/222 MVA capacity and voltage transformation 155/33/33 kV.
- The five feeders of the offshore wind farm B are connected to a two winding transformer having 280 MVA capacity and voltage transformation 155/33 kV.
- The four feeders of the offshore wind farm C are connected to a two winding transformer having 170 MVA capacity and voltage transformation 155/33 kV.

Loss Analysis

- The offshore wind farm connection contains cables, bus bars, transformers, shunt reactors and offshore AC platform which contribute to the electrical losses.
- Following assumptions were made. 70 kW losses are assumed at low loads for shunt reactors having 15 MVAr. The capacitor losses can be neglected. The zero load losses for main transformers are approximately 0.026% of the apparent power for large transformers and 0.08% of the apparent power for small transformers. The offshore AC collector platform losses are considered to be 100 kW. The load losses and zero load losses add up to make total losses of the connection.

Loss Analysis

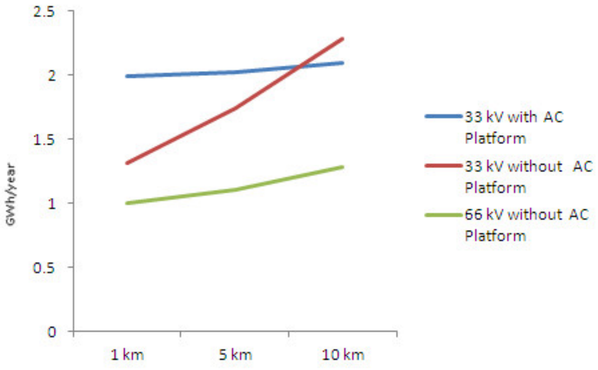


Figure : (a) Comparison of the total energy loss (normalized) GWh/year of the offshore wind farm cluster link for different distances between wind farms and HVDC platform

Loss Analysis

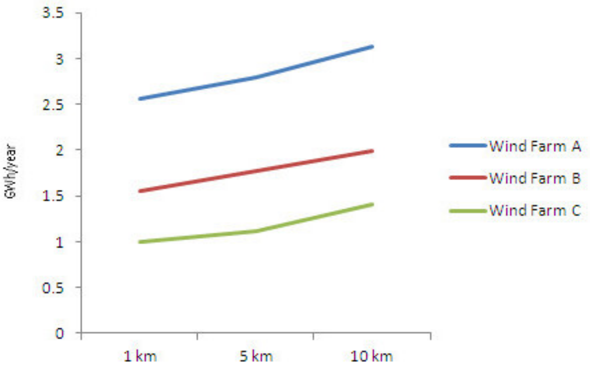


Figure : (b) Comparison of energy loss (normalized)in GWh/year of three wind farms for different distances between wind farms and HVDC converter platform for 66 kV without AC collector platform

Short Circuit Analysis

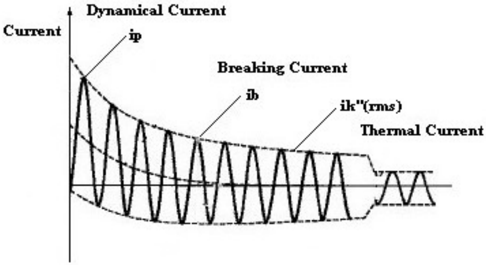


Figure : Short circuit current oscillogram

Short Circuit Analysis

- Several different methods for short circuit analysis. Some methods like IEC 60909/VDE 0102 method, the ANSI method and the IEC 61363 method require less detailed network modeling i.e. require no load information.
- The superposition method which is also known as complete short circuit method is used for the precise evaluation of the fault currents in a specific situation.

Short Circuit Analysis

The short circuit contribution from HVDC (from grid side) is chosen as 150% of apparent power of the wind farms cluster initially and 50% thermally.

Parameters	
Method	Complete
Fault Type	3-phase Short Circuit
Calculate	Max. Short Circuit Current

Table : Parameters for short circuit method from DIgSILENT

Short Circuit Analysis

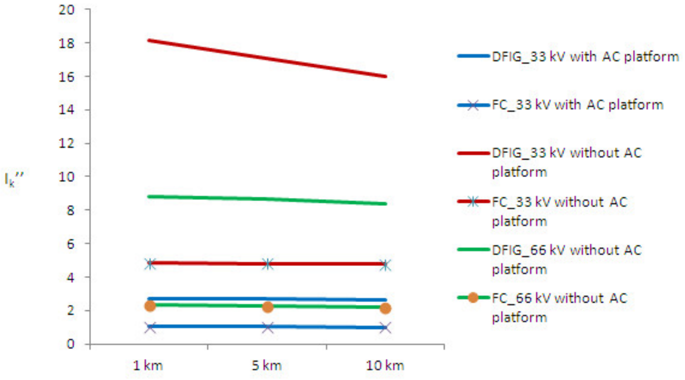


Figure : Short circuit currents(normalized)in kA at HVDC converter platform bus for different connection options and different types of wind turbine generators (a) $I_{k''}$ for a 804 MW Wind Farm

Short Circuit Analysis

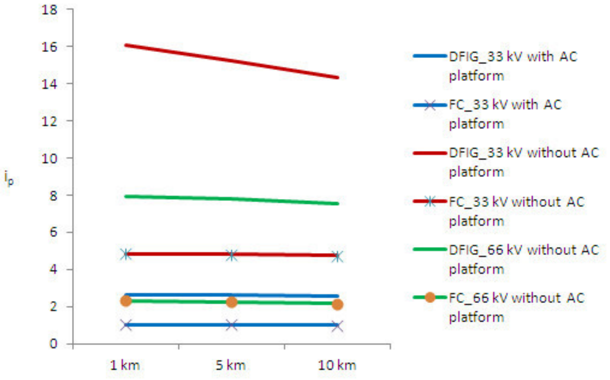


Figure : Short circuit currents(normalized)in kA at HVDC converter platform bus for different connection options and different types of wind turbine generators (b) i_p for a 804 MW Wind Farm

Short Circuit Analysis

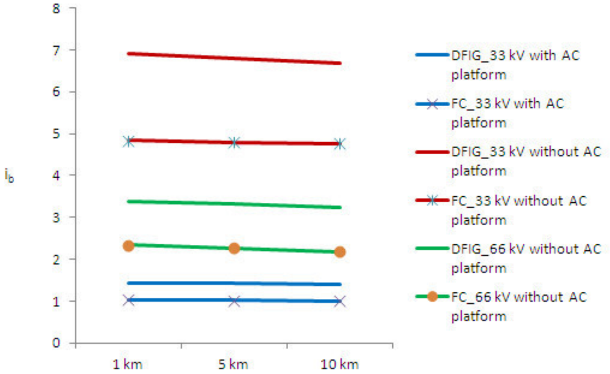
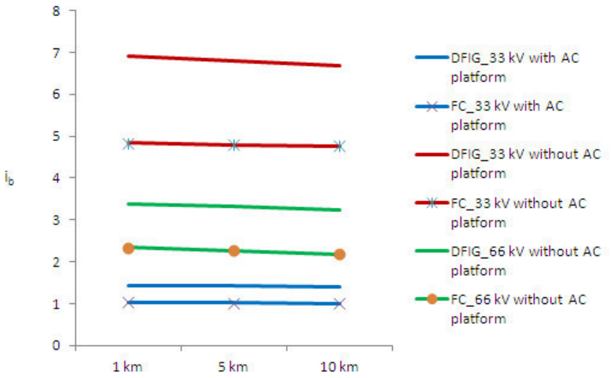


Figure : Short circuit currents(normalized)in kA at HVDC converter platform bus for different connection options and different types of wind turbine generators(c) i_b for a 804 MW Wind Farm

Short Circuit Analysis



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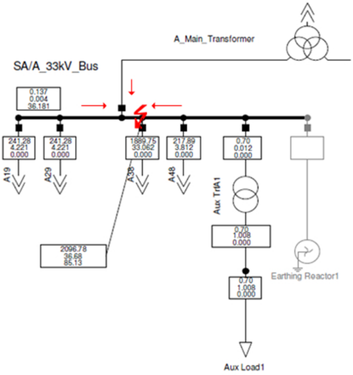
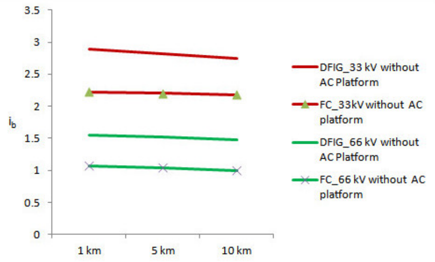


Figure : Peak short circuit breaking current (normalized) (i_b)in kA at individual feeders for two different types of wind turbine generators in the absence of AC collector platform

Short Circuit Analysis



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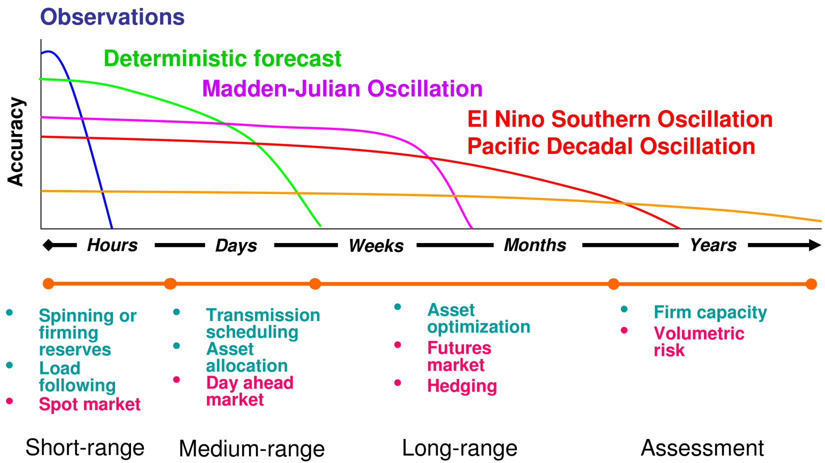
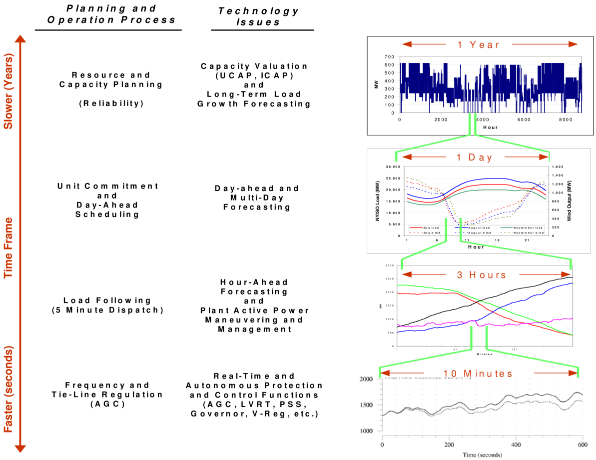
Electricity Market



Electricity Grid/Power System



Electricity market price estimation

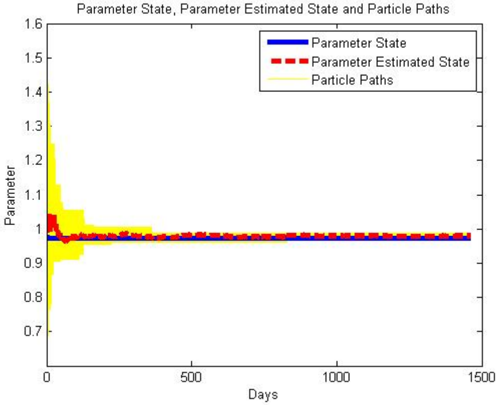


Figure : Daily electricity prices for Alberta simulated.

Electricity market price estimation

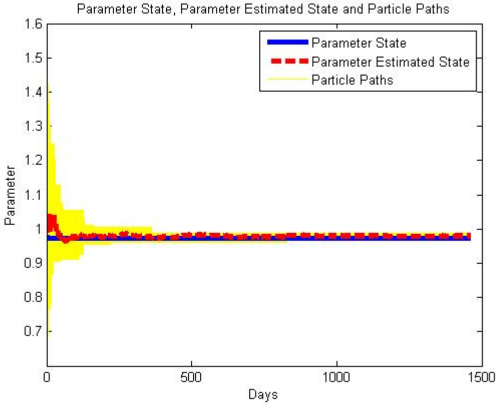


Figure : Exponential of estimated parameter versus exponentials of parameter state and particle paths of 10000 particles.

Electricity market price estimation

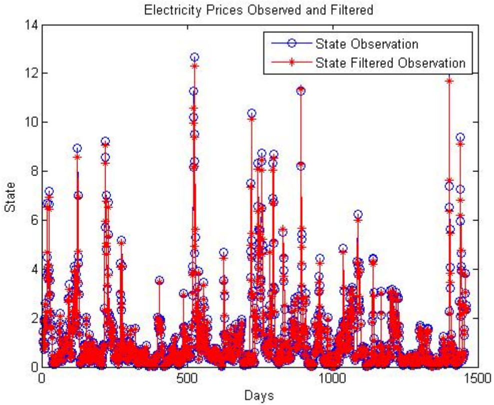


Figure : Exponentials of daily electricity prices for Alberta observed versus filtered.

Electricity market price estimation

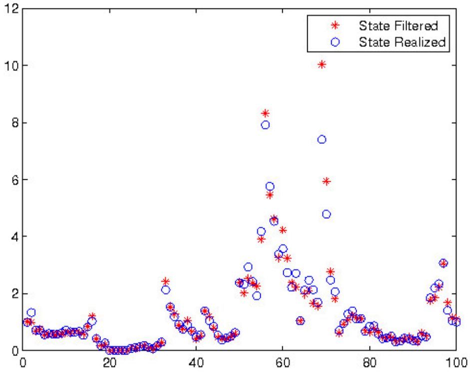


Figure : State filtered by using optimum parameter set.

Conclusions

The problem formulation:

- Several computational possibilities in different disciplines present themselves. There is a spectrum of numerical methods which can be used for different needs of industry.
- The transformer removal possibility in an offshore wind farm has been investigated.
- Data mining is a tool that has been introduced.
- Particle filter to electricity price models have been introduced.
- Observation stations can be optimized.
- Optimization of wind farms needs attention and validation.
- Operation and Maintenance work and SCADA data analysis is being developed.