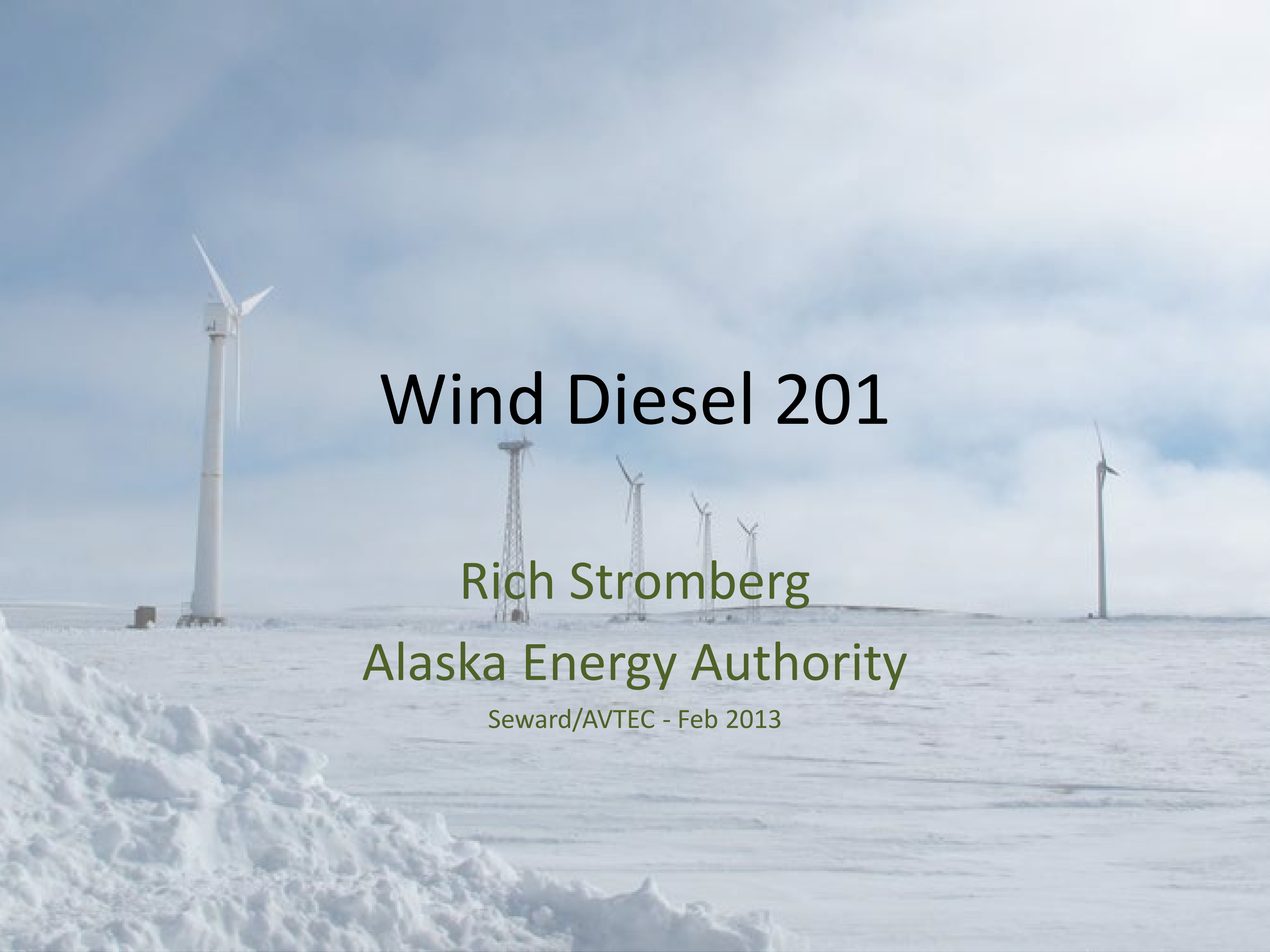


Wind Diesel 201

Rich Stromberg
Alaska Energy Authority

Seward/AVTEC - Feb 2013

Highlights from WD 101

AEA Wind Program Values

http://www.akenergyauthority.org/programwind.html

- Involve the local community throughout all aspects of the project to increase local ownership.
- Be kind when judging our predecessors. They didn’t have the benefit of the hindsight we now possess.
- Make data-driven decisions.
- Admit when we’re wrong.
- Approach problems and projects holistically. Developed integrated solutions.
- There is great opportunity to increase cost savings and learning when we improve existing wind systems.
- Think and plan for the long term.
- Understand that wind energy isn’t always the best solution.

This will be on the test!

First Law of Thermodynamics: Energy can be changed from one form to another, but it cannot be created or destroyed.

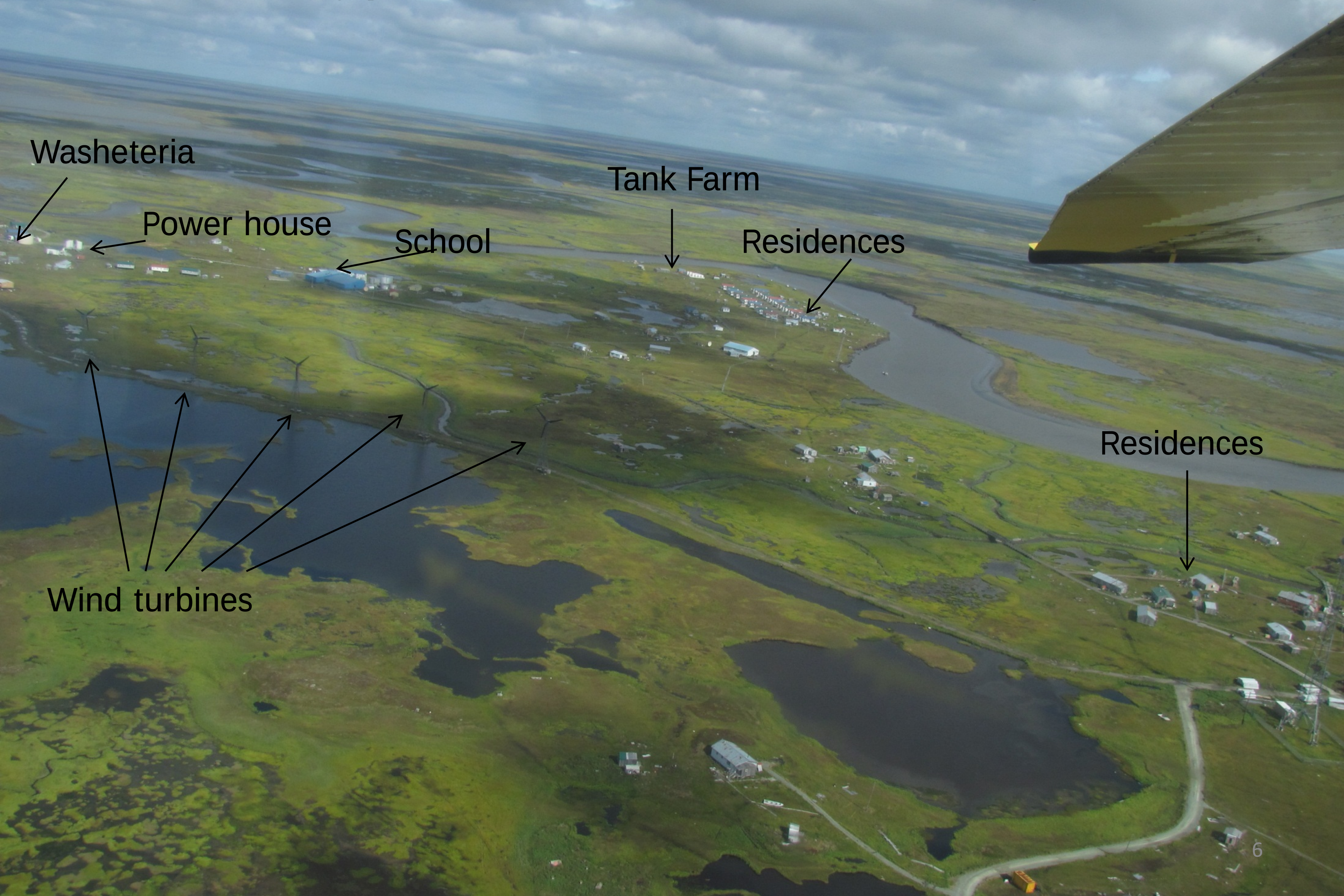
Everything we do with village energy systems is based on these two concepts.

An important facet of the Second Law of Thermodynamics (which deals with entropy): In the process of energy transfer, some energy will dissipate as heat.

Wind Classifications

- Class 1/Poor: Pursue options other than wind
- Class 2/Marginal: High costs of development in rural Alaska prevent an economical project.
- Class 3/Fair: A large project on the Railbelt may be cost effective. Remote village projects may have a payback longer than the 20-year life of wind turbines.
- Class 4/Good: A well-designed project will have a payback of 15-20 years.
- Class 5/Excellent: A well-designed project will have a payback of 12-15 years.
- Class 6/Outstanding: A well-designed project will have a payback of 10-12 years, but damaging high-wind events may be a concern.
- Class 7/Superb: Project developer may want to use a smaller rotor or find a sheltered site to protect turbines from periodic damaging winds.

A Typical Remote Alaska Village



Wind-Diesel system challenges

- The design and integration of power systems is a complex matter and although the models make it look simple, it is never that easy.
- By their nature, renewable generation are stochastic (uncontrolled) and vary with the resource.
- The amount of variation and thus the amount of system control to handle the variation depends on the
  - Renewable resource being used
  - The load
  - Power system design

Can your existing electrical distribution system support wind technology?

- Do you have newer diesel gensets with fast, electronic injection controls or mechanical governors?
- Are your gensets sized so that you can run at optimum fuel efficiency both when the wind is blowing and when it's calm?
- Are your distribution lines, transformers and meters up to code?
- Are your phases balanced?

- If you can't answer "yes" to all of these questions, you could save more money by fixing your existing power system.

Cooling System

Current diesel plants have many different types of cooling systems – some integrated, some not, but all provide primary heat to the power plant and sometimes other buildings as well.

In almost all cases the operation of the diesels provide more than enough heat for the plants needs, but in high penetration systems we would like to shut off the diesels

- Plant goes from heat surplus to heat deficit.
- To allow fast starting of the diesel engines, diesels in fast start mode must be kept warm

May require revamping of the cooling systems

- Implementation of electric boilers to allow use of wind energy
- Allow specific engine cooling systems to be separated
- Better energy management
- Different or conflicting pumping requirements.
- Heat efficiency of plant buildings may need to be considered

System Stability

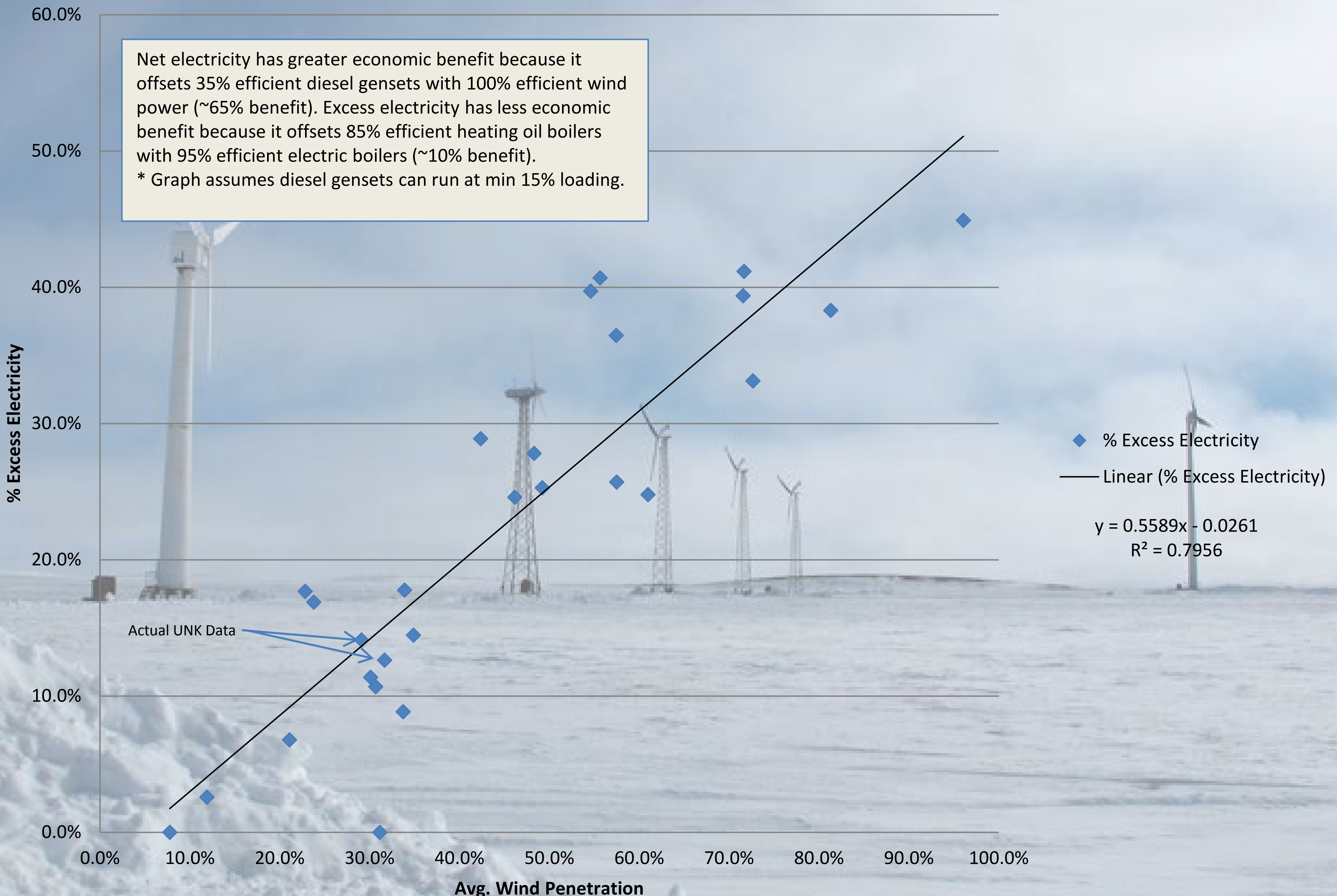
Driven by maintaining system voltage, frequency and reactive power supply.

- Voltage: Currently uses an active controller on the diesel. Alternatives are synchronous condensers or a battery bank and solid state or rotary power converter.
- Frequency: A balance of power supply and demand, controlled by the throttle of the diesel. Can be solved through the use of dump loads or power converters.
- Power Factor: Balancing active and reactive power as needed by the inductive motors and electronics on the system. Capacitor banks, motors or advanced solid state power converters.

Old Wind Penetration Classes

Penetration Class	Operating Characteristics	Penetration	
		Instantaneous	Average
LOW	• Diesel runs full-time • Wind power reduces net load on diesel • All wind energy goes to primary load • No supervisory control system	< 50%	< 20%
MEDIUM	• Diesel runs full-time • At high wind power levels, secondary loads are dispatched to insure sufficient diesel loading or wind generation is curtailed • Requires relatively simple control system	50% – 100%	20% – 50%
HIGH	• Diesels may be shut down during high wind availability • Auxiliary components are required to regulate voltage and frequency • Requires sophisticated control system	100% – 400%	50% – 150%

Excess Electricity vs. Wind Penetration Level - Alaska Village Systems



New Wind Penetration Classes

Penetration Class	Operating Characteristics	Instantaneous Penetration	Average Penetration
Very Low	Diesel runs full time	<60%	<8%
	Wind power reduces net load on diesel		
	All wind energy goes to primary load		
	No supervisory control system		
Low	Diesel runs full time	60% - 120%	8%-20%
	At high wind power levels, secondary loads are dispatched to insure sufficient diesel loading or wind generation is curtailed.		
	Requires relatively simple control system		
Medium	Diesel runs full-time	120%-300%	20%-50%
	At medium to high wind power levels, secondary loads are dispatched to insure sufficient diesel loading.		
	More complex secondary load control system is needed to ensure that heat loads do not become saturated during extended windy periods.		
High	Diesels may be shut down during high wind availability	300%-900%	50%-150%
	Auxiliary components are required to regulate voltage and frequency		
	Requires sophisticated control system		

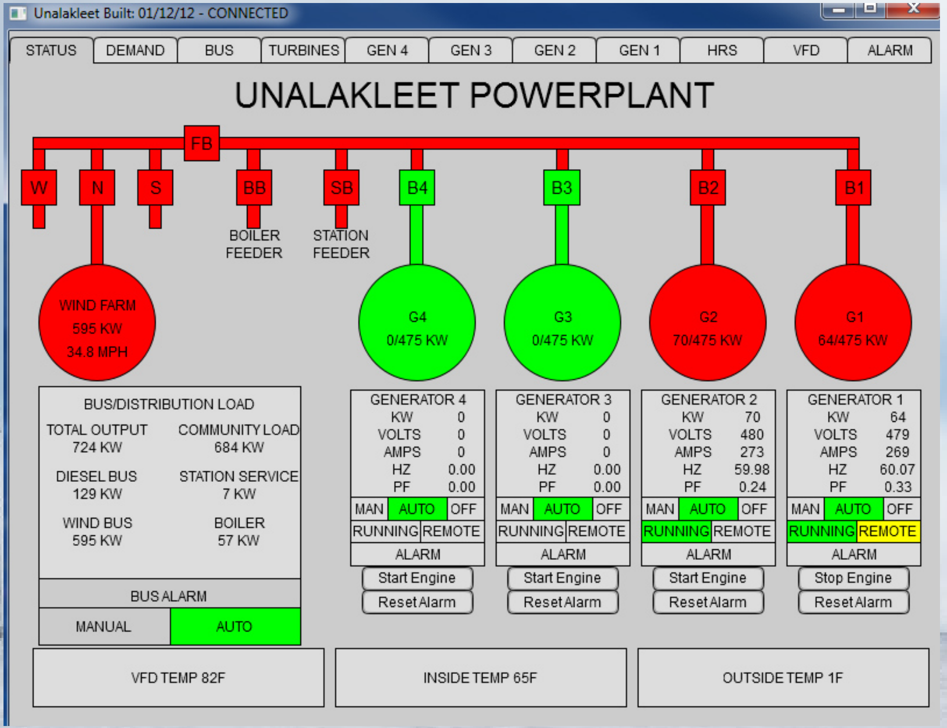
Exact numbers are not sacrosanct.

Batteries in Medium Penetration W/D Systems

- Batteries can play a role in medium penetration systems
- Used for short periods of load/supply time shifting
- Not intended for diesel-off operation
- An option to be weighed against/with more secondary loads, synchronous condensers

Monitoring and Remote Access

- Remote access allows oversight of system performance
- Enables real time system interrogation and troubleshooting even when off site
- With expert analysis system reduces maintenance and down time
- Small incremental cost



Has become a required component of any remote power system

Financial Impacts of PCE on W-D

Village name:	Anuqamute	
Total kWh produced:	3,202,657	
kWh sold:	3,065,046	
Station service:	137,611	4.49%
PCE eligible residential kWh:	747,592	24.39%
PCE eligible community facilities kWh:	514,346	16.78%
Non PCE and commercial kWh:	1,803,108	58.83%
Diesel kWh:	2,202,657	68.78%
Wind kWh:	1,000,000	31.22%
Non fuel expenses:	$777,960	
Fuel expenses	$622,165	
Calculated res/comm rate - before PCE	$0.4568	Without wind energy
Calculated PCE reduction	$0.2973	Without wind energy
Calculated residential rate after PCE	$0.1595	Without wind energy
Fuel expense with wind energy	$436,460	
Drop in fuel cost per kWh with wind	$0.0606	
Calculated res/comm rate with wind	$0.3962	With wind energy
Drop in Calculated residential rate	$0.0606	
Calculated PCE reduction with wind	$0.2397	With wind energy
Drop in PCE discount with wind	$0.0576	
Calculated residential post PCE rate	$0.1565	With wind energy
Actual change to residential rate after PCE----->	**$0.0030**	
Actual change to commercial rate with wind energy	**$0.0606**	
* Actual rates will be higher when residential customers exceed the 500kWh per month PCE limit.		

You’re caught up on Wind-Diesel 101

NOW FOR THE WIND-DIESEL 201 PRESENTATION

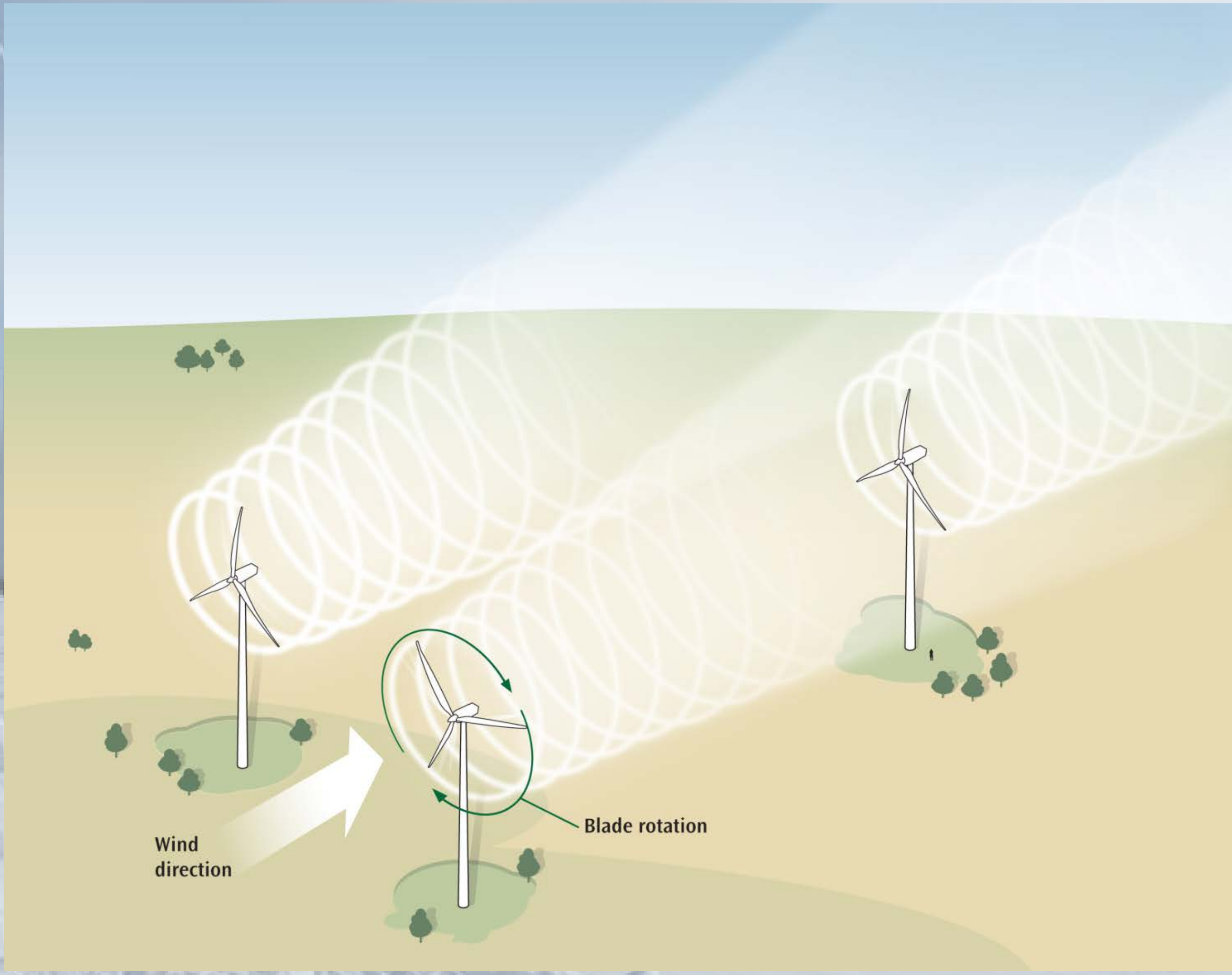
Wake Losses

- The space behind a wind turbine that is marked by decreased wind power capacity due to the fact that the turbine itself used the energy in turning the blades. The wind behind the turbine, in its wake, is less effective at generating energy for a certain distance in the downwind direction due to turbulence created by the upwind machine. Thus, when siting a wind farm, it is important to space turbines as to minimize the impact each has on the others' power production capacity, taking into account additional costs for laying of electrical cable and other infrastructure required when machines are spaced further apart. (http://www.windustry.org/resources/wake-losses)

Horns Rev offshore wind farm - Denmark

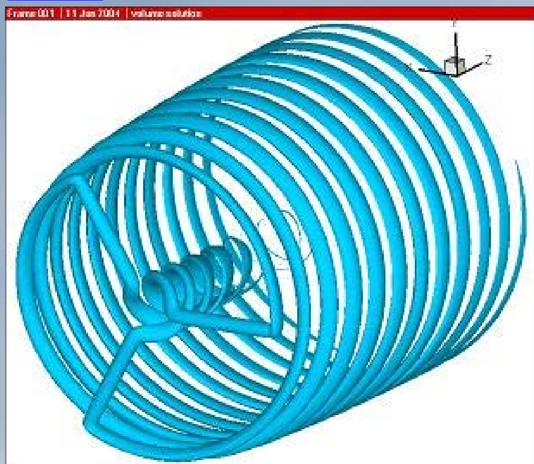
- Horns Rev 1 owned by Vattenfall. Photographer Christian Steiness

Wake effect – Sandia Labs

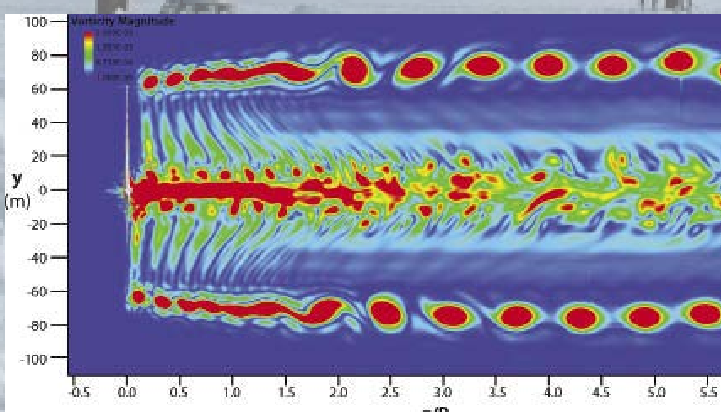


Graphical representation of wind turbine wakes

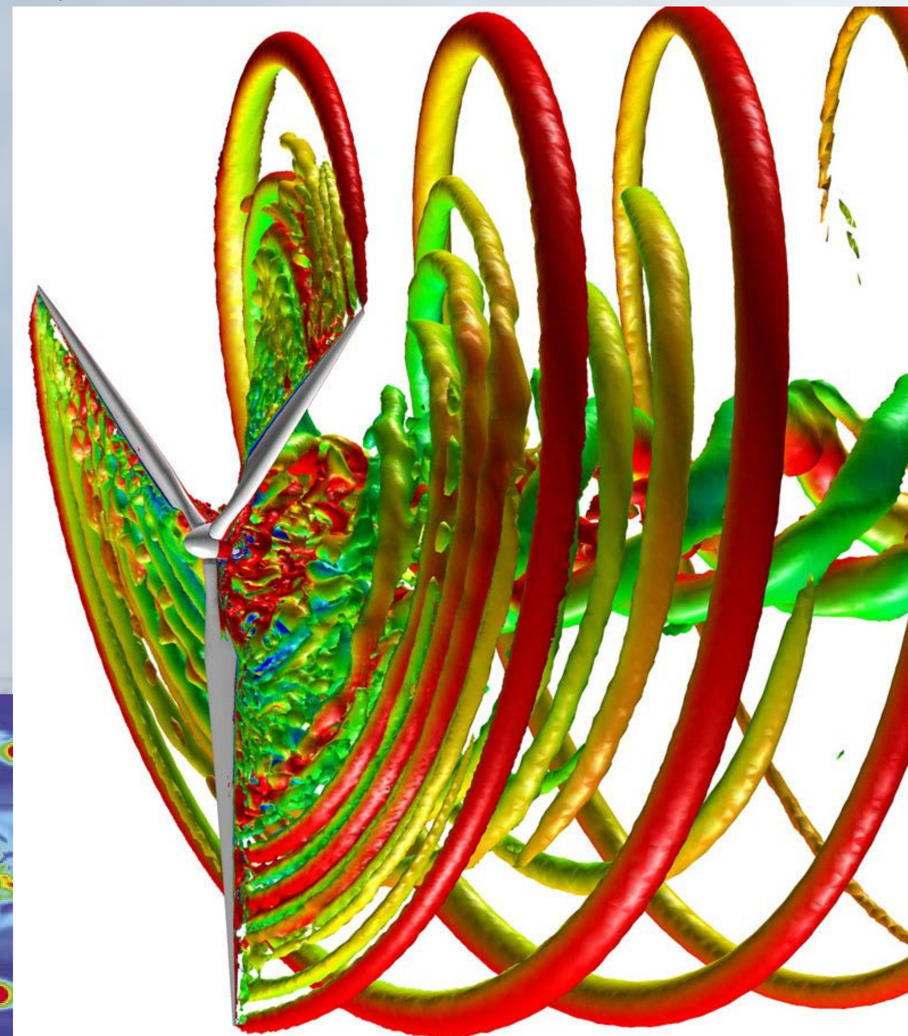
http://www.eps.ee.kth.se/windpower/images/wakesim.jpg



http://www.windpowerengineering.com/construction/simulation/seeing-the-unseeable-in-a-rotor-wake/

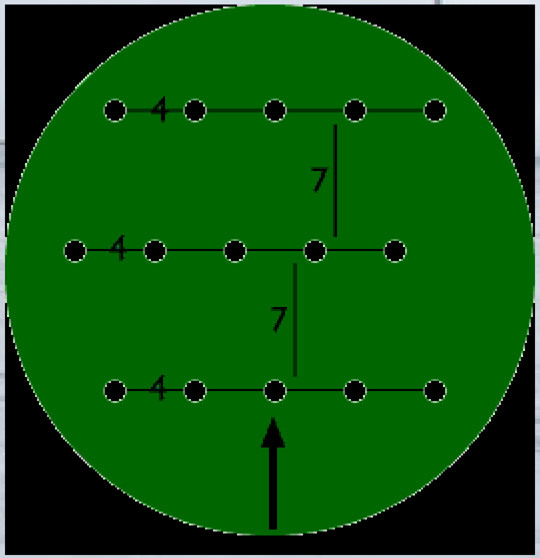


- http://www.nvidia.com



Wake and the Park Effect

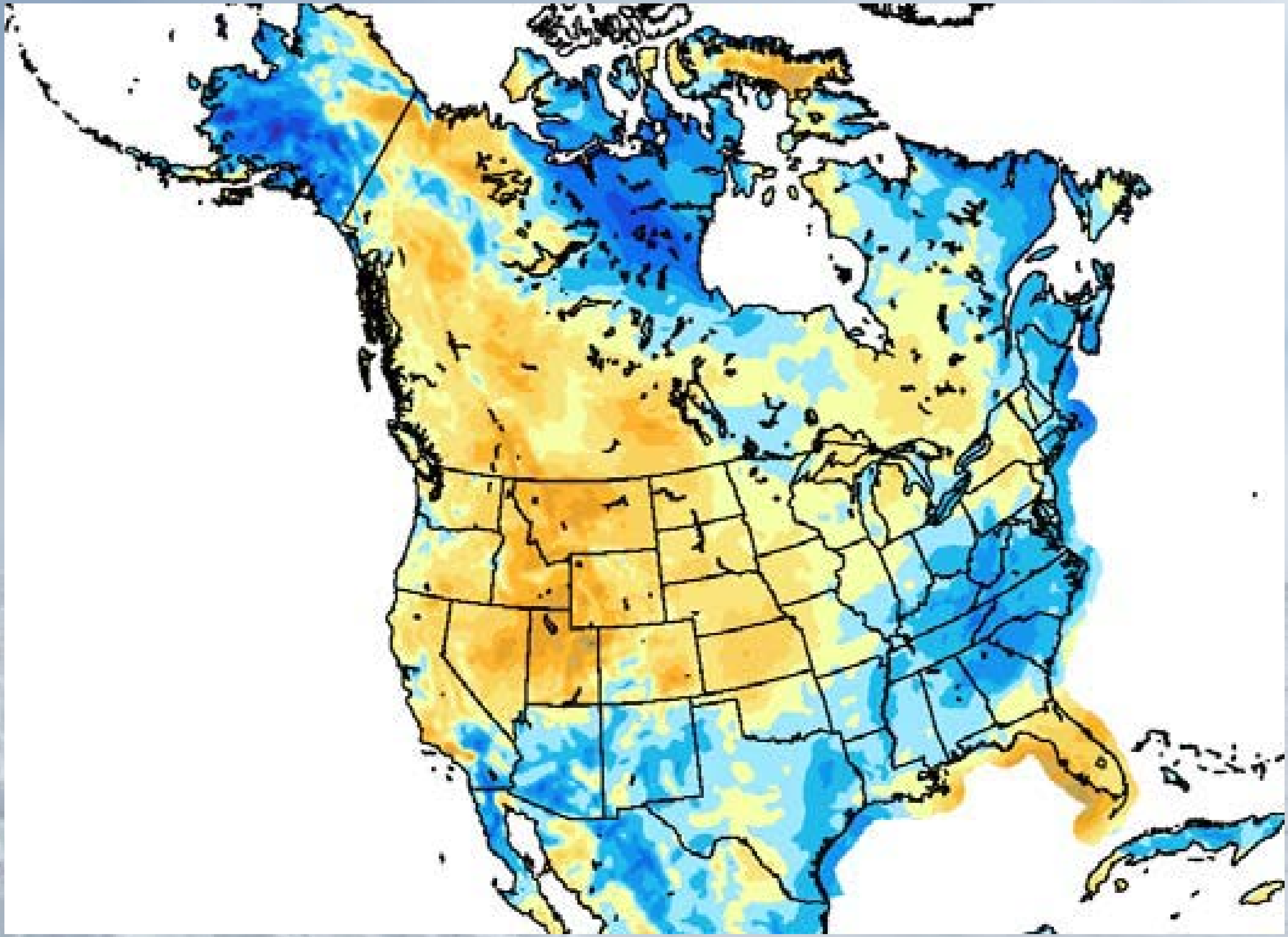
- Ideally, we would space turbines as far apart as possible in the prevailing wind direction. But land use and the cost of connecting wind turbines to the electrical grid would indicate spacing them closer together.
- As a rule of thumb, turbines in wind parks are usually spaced somewhere between 5 and 9 rotor diameters apart in the prevailing wind direction, and between 3 and 5 diameters apart in the direction perpendicular to the prevailing winds.
- Typical park losses are ~ 5%.

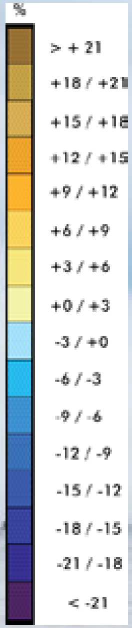


Seasonal changes in wind resources

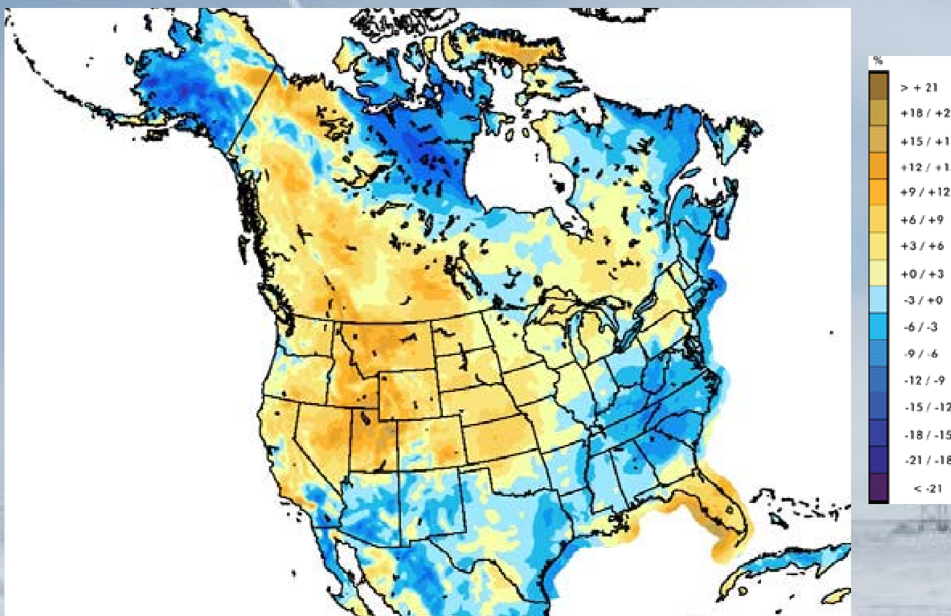
- One year of quality wind data is the minimum required to assess the local wind resource.
- Multiple years give a better representation of variation and the potential resource.
- Secondary load systems can be better designed with multiple years of data.
- Move forward with a project design, but leave the met tower up to improve project confidence.

AWS Truepower Wind Speed Anomaly Map: Q2 2012



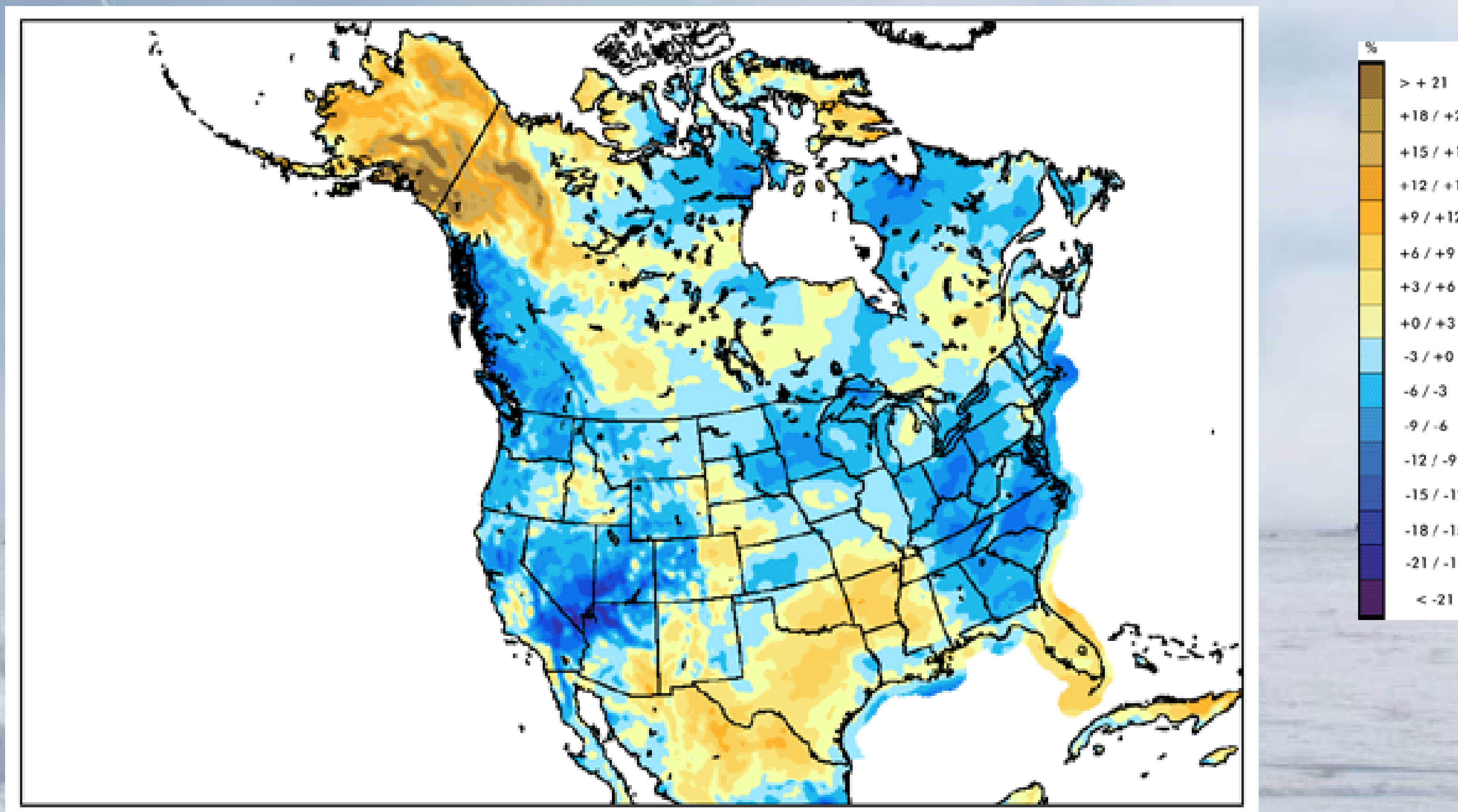


AWS Truepower Wind Speed Anomaly Map: Q2 2012

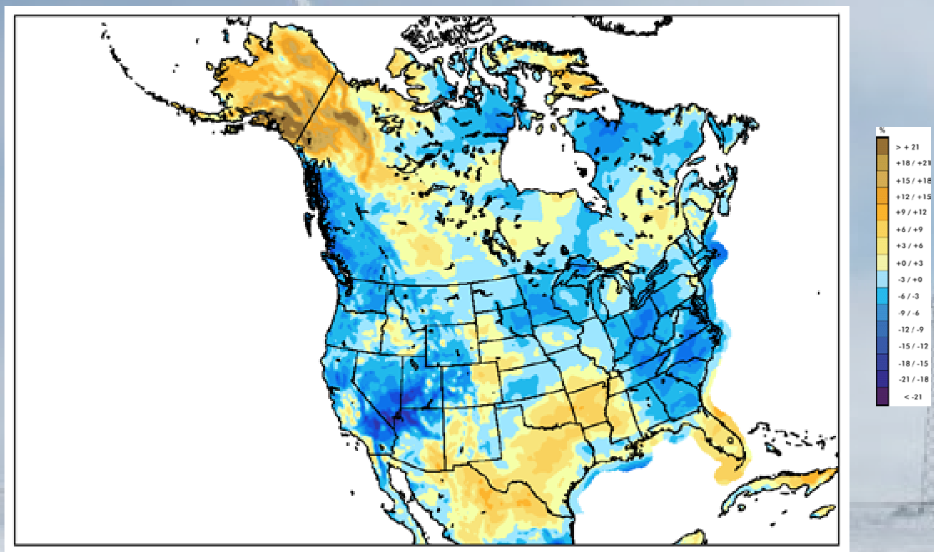


A strong pressure gradient between a persistent low over Alaska and a high over the Canadian Archipelago resulted in anomalously strong winds (+10% or more) over Western Canada, while winds were below-average (-10% or less) in Alaska and Nunavut.

AWS Truepower Wind Speed Anomaly Map: Q3 2012

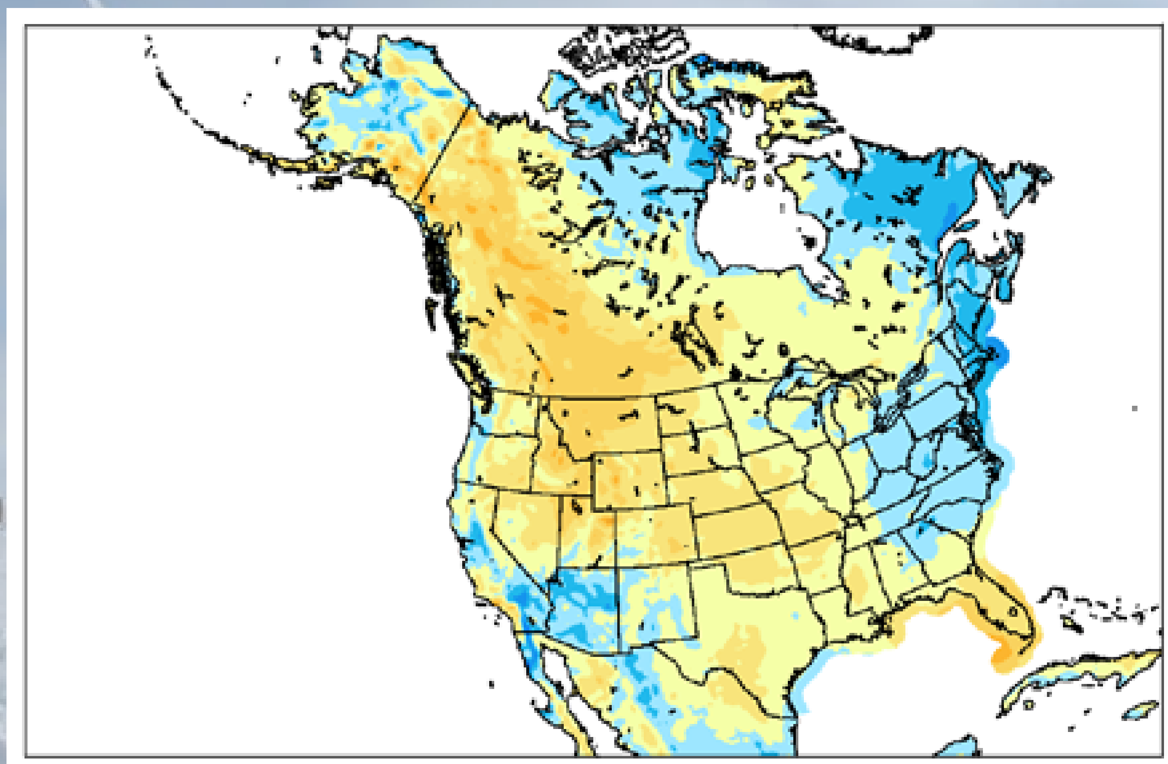


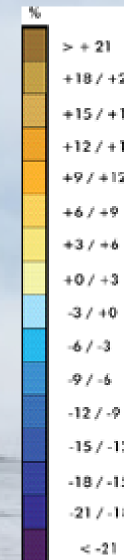
AWS Truepower Wind Speed Anomaly Map: Q3 2012



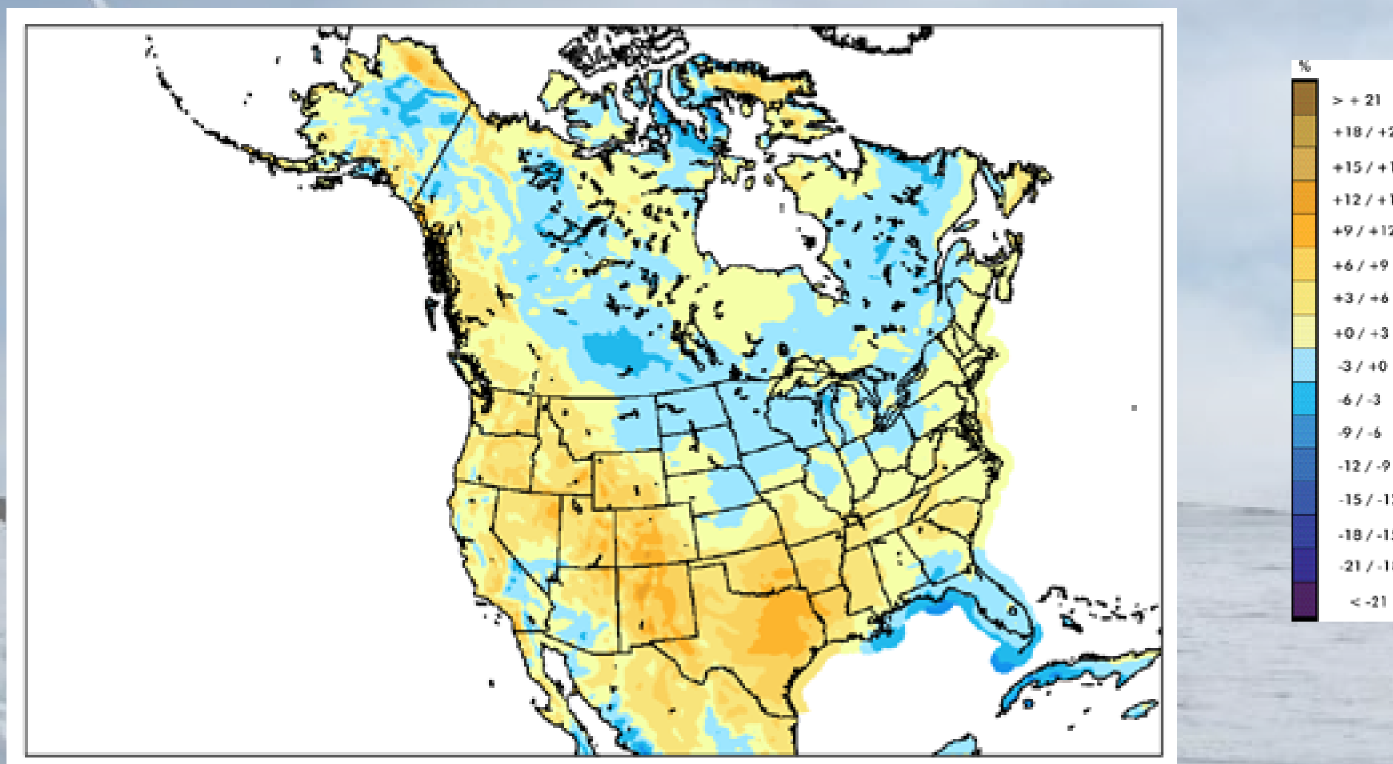
In September, a very strong pressure gradient developed between a ridge in the west and a trough in the Bering Sea, bringing high winds and numerous strong storms to the southern coast of Alaska. Wind speeds in southern Alaska and the Yukon were more than 35% above-average for the month as a result.

AWS Truepower Wind Speed Anomaly Map: Q4 2011 – Q3 2012





AWS Truepower Wind Speed Anomaly Map: Q4 2010 – Q3 2011



Turbulence

- Turbulence induces additional mechanical and vibration loads on wind turbines.
- IEC61400-1 edition 2 defines the characteristic turbulence intensity as the mean plus standard deviation of random ten-min measurements. Load cases are defined by the characteristic turbulence intensity at 15 m/s, called I15. A=0.18, B=0.16, no C classification.
- IEC61400-1 edition 3 defines the representative turbulence intensity as the mean + 1.28 times standard deviation of random ten-min measurements. *(The calculation has changed so it is important to understand which formula is used.)* Load cases are defined by the reference turbulence intensity Iref which is equal to the mean turbulence intensity at 15 m/s.

	WTG CLASS		I	II	III	S
PARAMETERS	V_{ref}	(m/s)	50	42.5	37.5	VALUES SPECIFIED BY DESIGNER
	A	I_{ref} (-)	0.16			
	B	I_{ref} (-)	0.14			
	C	I_{ref} (-)	0.12			

IEC 61400-1 ed. 2

IEC Wind Turbine Class

- It is critical to know what the expected maximum wind speeds are at your turbine site.
- Some turbines are designed for surviving high winds while others are designed to capture the most energy in calmer regimes.
- Ensure that your turbine can survive the environment while producing the most energy possible.

IEC Wind Turbine Classes

Wind Speed Parameters for Wind Turbine Classes

	I	II	III	IV
Reference Wind Speed, U_{ref} (m/s)	50	42.5	37.5	30
Annual Average Wind Speed U_{ave} (m/s)	10	8.5	7.5	6
50-year Return Gust Speed, 1.4 U_{ref} (m/s)	70	59.5	52.5	42
1-year Return Gust Speed, 1.05 U_{ref} (m/s)	52.5	44.6	39.4	31.5

Notes: 10-minute averages, hub height wind speed. Air density: 1.225 kg/m3.

Turbulence Intensity Classes	I		II		III		III	IV
	A	B	A	B	A	B	A	B
I_{15} (Turbulence Intensity at 15 m/s)	18%	16%	18%	16%	18%	16%	18%	16%
a	2	3	2	3	2	3	2	3
I_u (Turbulence Intensity)	0.210	0.180	0.226	0.191	0.240	0.200	0.270	0.220

I_u (Turbulence Intensity) = $I_{15}(a=15/U_{ave})/(a+1)$

Source: IEC 61400-1; cited in Wind Energy Handbook, Tony Burton, et al, John Wiley & Sons UK), 2001, ISBN: 0-471-48997-2, p. 210.

Caution: Verify with current IEC 61400-1 for all parameters and criteria.

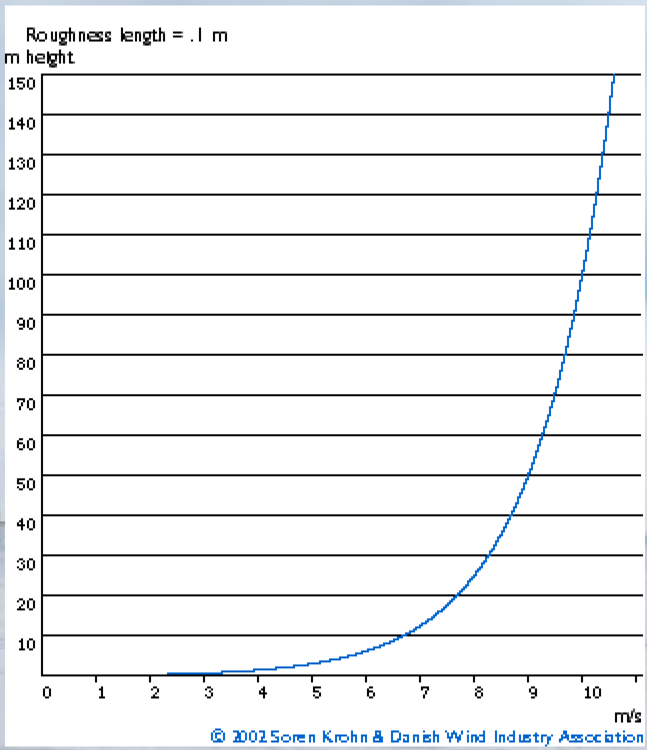
IEC 61400-1 ed. 3

Wind shear and roughness

- In general, the more pronounced the roughness of the earth's surface, the more the wind will be slowed down.
- In the wind industry, people usually refer to roughness classes or roughness lengths, when they evaluate wind conditions in a landscape. A high roughness class of 3 to 4 refers to landscapes with many trees and buildings, while a sea surface is in roughness class 0.
- Concrete runways in airports are in roughness class 0.5.

Wind shear and roughness

- Roughness and wind shear are directly correlated.
- This graph shows how wind speeds vary in roughness class 2 (agricultural land with some houses and sheltering hedgerows with some 500 m intervals), if we assume that the wind is blowing at 10 m/s at a height of 100 meters.



Wind shear formula

- The wind speed at a certain height above ground level is:

$$v = v_{ref} \ln(z/z_0)/\ln(z_{ref}/z_0)$$

- v = wind speed at height z above ground level.
- v_{ref} = reference speed, i.e. a wind speed we already know at height z_{ref}. ln(...) is the natural logarithm function.
- z = height above ground level for the desired velocity, v.
- z_0 = roughness length in the current wind direction.
- z_{ref} = reference height, i.e. the height where we know the exact wind speed v_{ref}.

Roughness Class and Length

For example, assume we know that the wind is blowing at 7.7 m/s at 20 m height. We wish to know the wind speed at 60 m height. If the roughness length is 0.1 m, then

v ref = 7.7

z = 60

z0 = 0.1

z ref = 20

Therefore:

v = 7.7 ln(60/0.1) / ln(20/0.1) = 9.2966 m/s

Rough- ness Class	Roughness Length m	Energy Index (per cent)	Landscape Type
0	0.0002	100	Water surface
0.5	0.0024	73	Completely open terrain with a smooth surface, e.g.concrete runways in airports, mowed grass, etc.
1	0.03	52	Open agricultural area without fences and hedgerows and very scattered buildings. Only softly rounded hills
1.5	0.055	45	Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approx. 1250 metres
2	0.1	39	Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approx. 500 metres
2.5	0.2	31	Agricultural land with many houses, shrubs and plants, or 8 metre tall sheltering hedgerows with a distance of approx. 250 metres
3	0.4	24	Villages, small towns, agricultural land with many or tall sheltering hedgerows, forests and very rough and uneven terrain
3.5	0.8	18	Larger cities with tall buildings
4	1.6	13	Very large cities with tall buildings and skycrapers

Wind shear – Power law

- The power law exponent is α. For fairly flat terrain, it is common to use the one-seventh power law, where α = 1/7.
- 1/7 power law for height adjustments

  for a known wind speed V1 at height H1, you can calculate V2 at height H2:

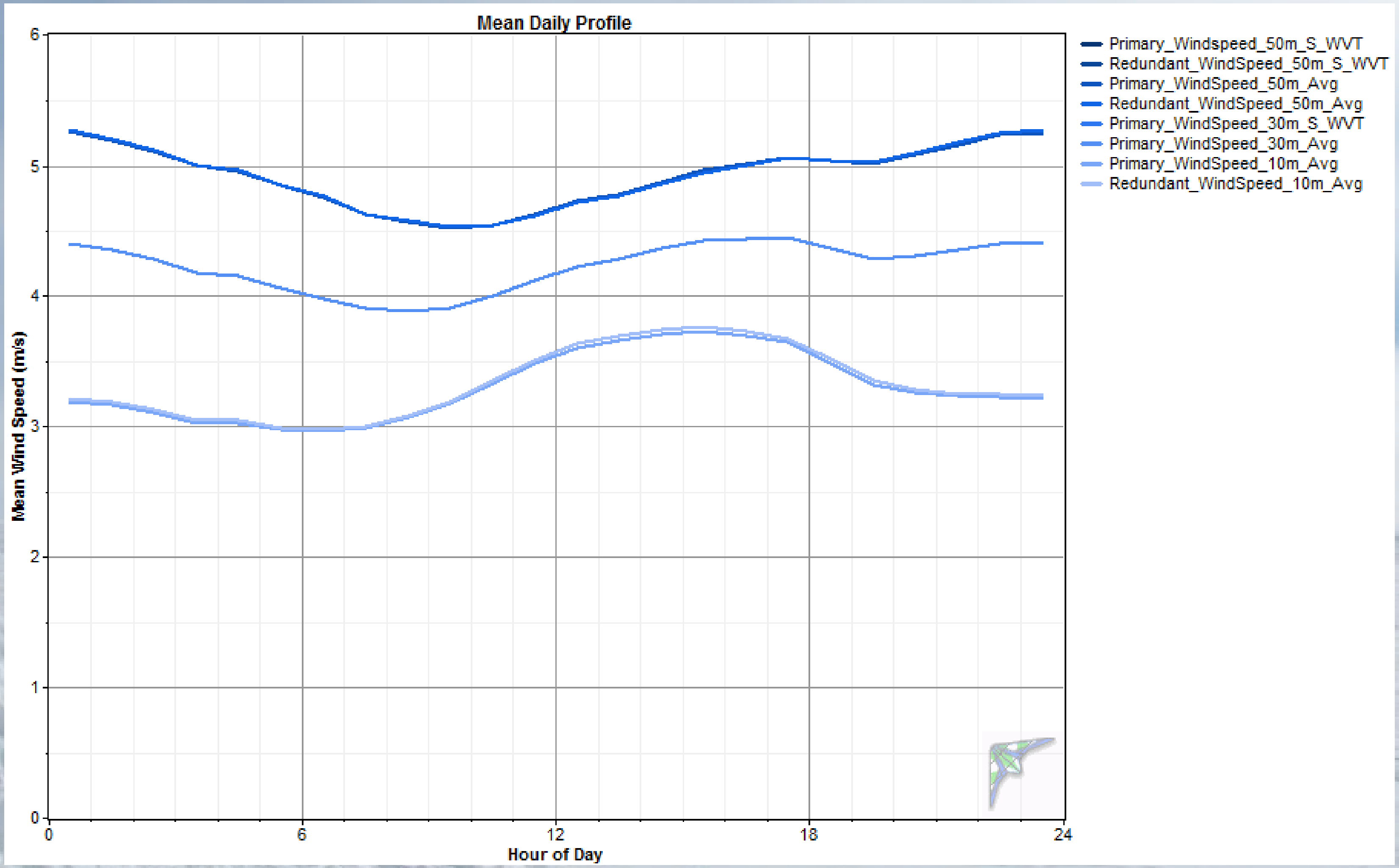
  $V2=V1*(h2/h1)^{(1/7)}$
- For example: $9.008=7.7*(60/20)^{(1/7)}$

Terrain Description	**Power law exponent,** α
Smooth, hard ground, lake or ocean	0.10
Short grass on untilled ground	0.14
Level country with foot-high grass, occasional tree	0.16
Tall row crops, hedges, a few trees	0.20
Many trees and occasional buildings	0.22 – 0.24
Wooded country – small towns and suburbs	0.28 – 0.30
Urban areas with tall buildings	0.4

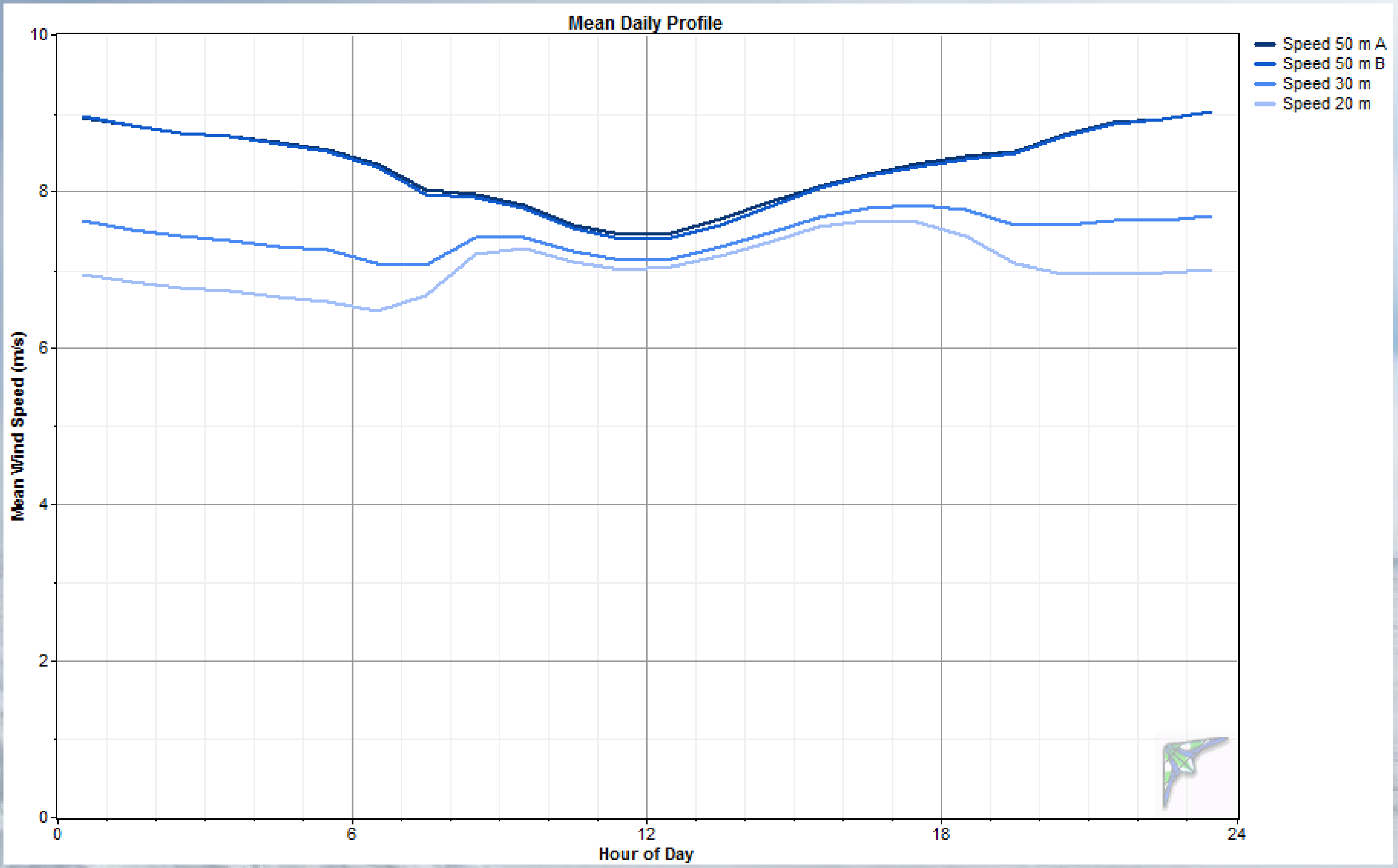
So, with wind shear you can predict the wind speed at higher elevations…sort of.

- Estimating performance for a turbine with a 40-meter hub height off of 20m and 30m anemometers has lower risk than estimating the performance of a turbine with a hub height of 70 or 80 meters.
- Wind shear formulas estimate annual averages – not diurnal patterns.

Delta Wind Farm Diurnal Pattern



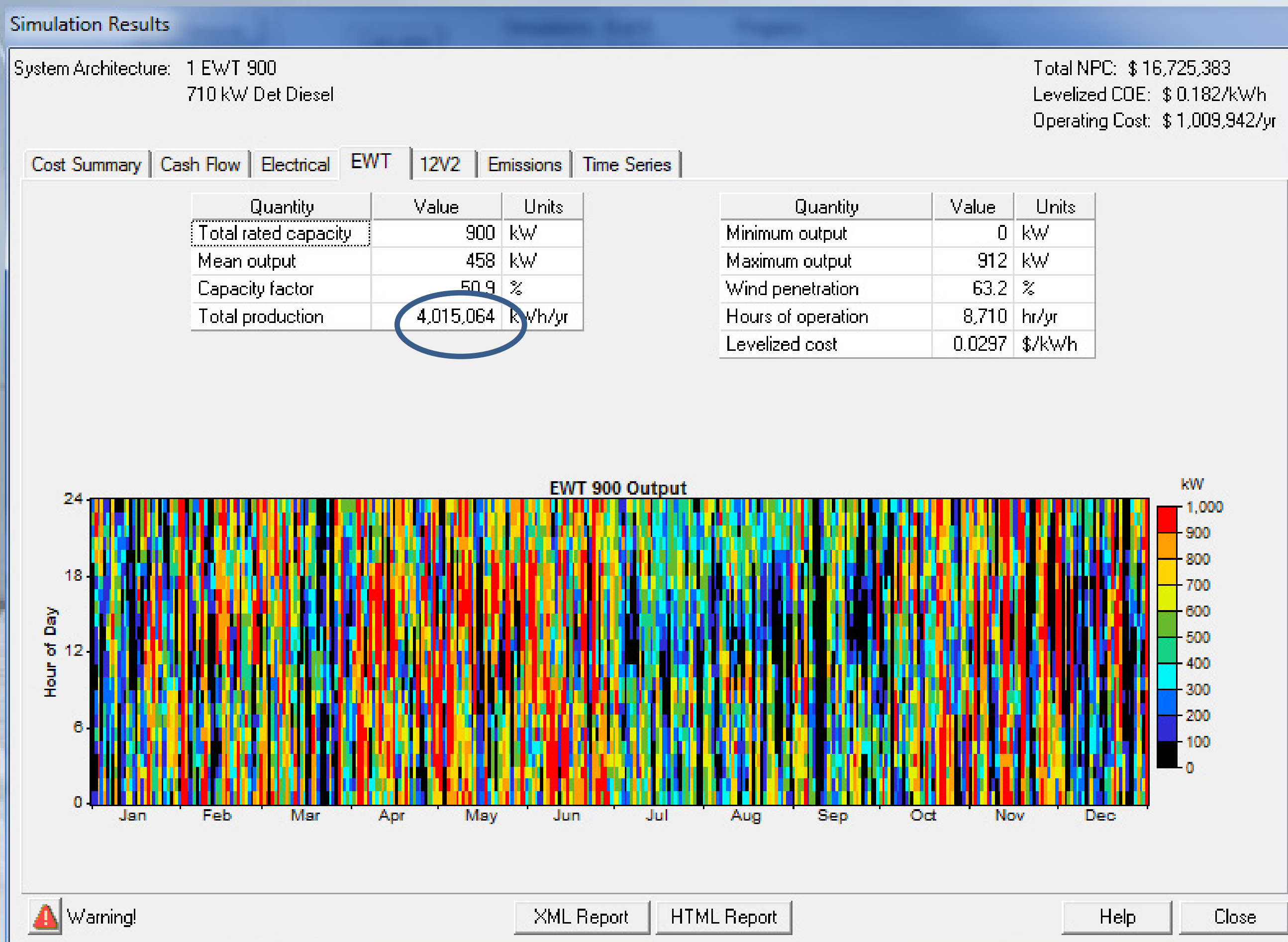
West TX A&M Diurnal Pattern



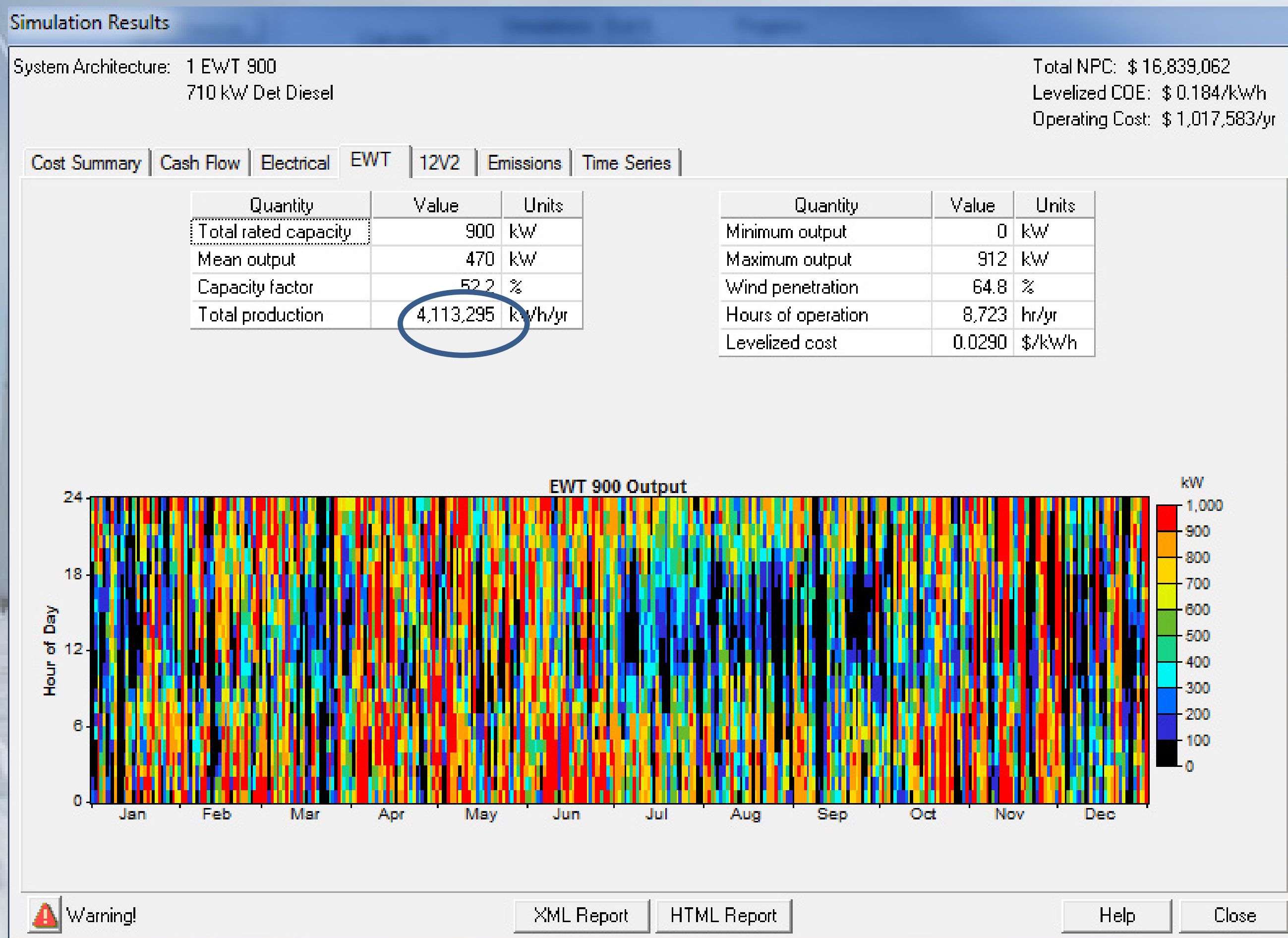
Drivers of winds at different heights

- Lower level winds are driven by solar heating of the Earth's surface, so winds increase throughout the day and subside at night.
- Higher-level winds are dominated by stably stratified flows that sink down at night into the rotor swept area, but get pushed higher during the day as solar-induced turbulence picks up.
- **Knowing the true diurnal pattern at your hub height is critical when designing secondary load systems on moderate and high penetration wind-diesel systems.**

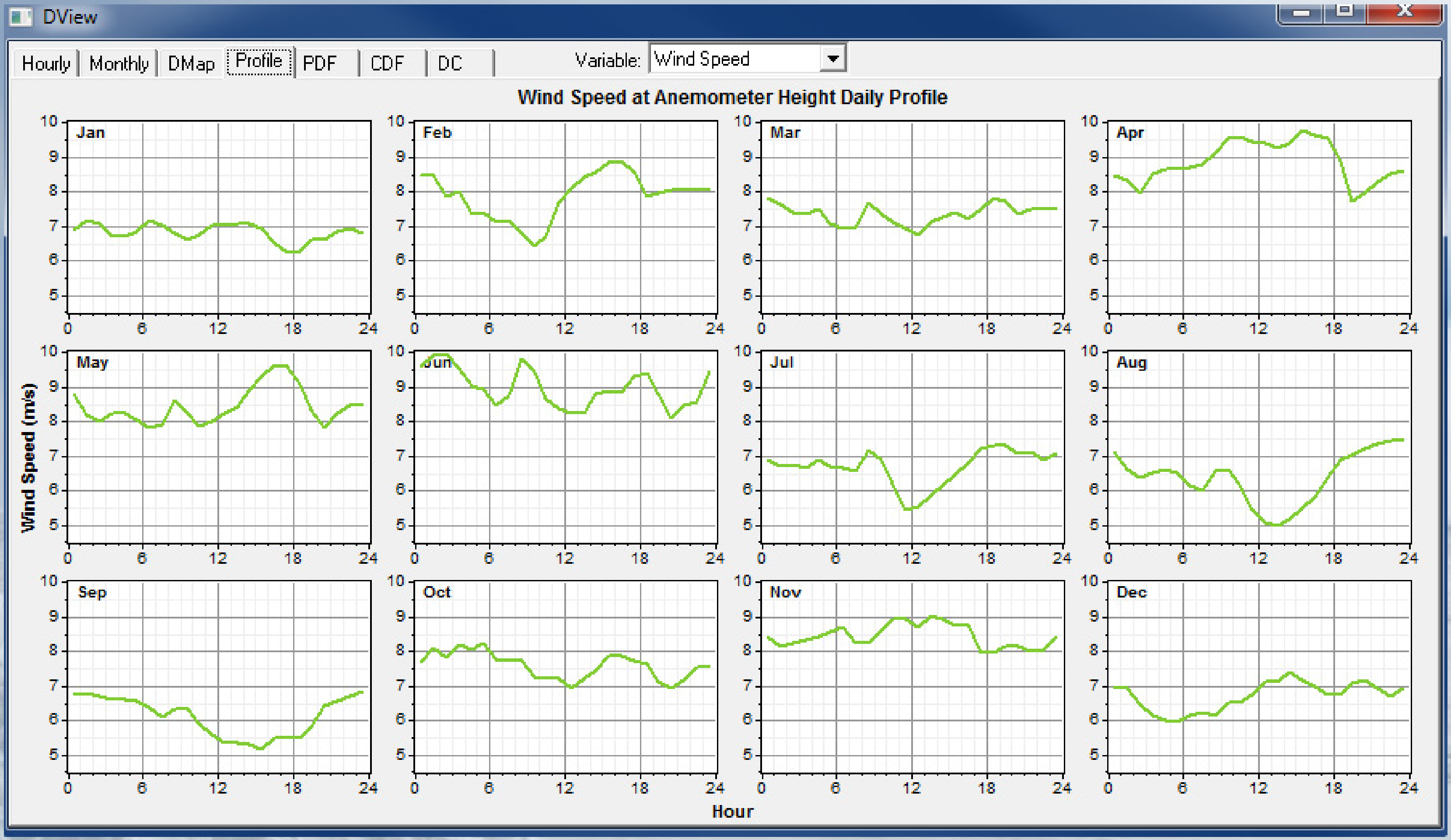
30m data extrapolated to 75m



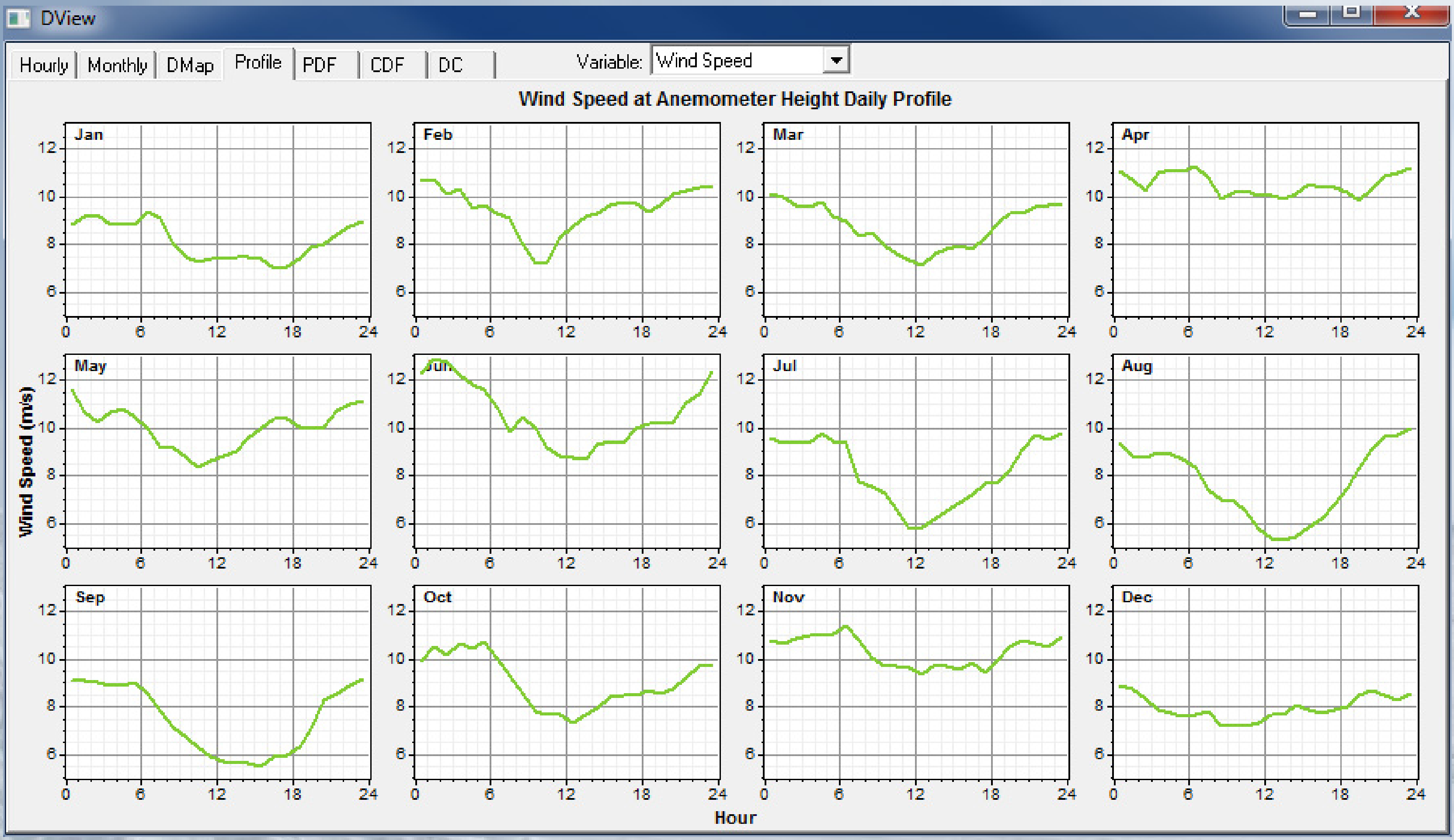
75m data


Simulation Results
System Architecture: 1 EWT 900
710 kW Det Diesel
Total NPC: $ 16,839,062
Levelized COE: $ 0.184/kWh
Operating Cost: $ 1,017,583/yr
Cost Summary
Cash Flow
Electrical
EWT
12V2
Emissions
Time Series
Quantity | Value | Units
Total rated capacity | 900 | kW
Mean output | 470 | kW
Capacity factor | 52.2 | %
Total production | 4,113,295 | kWh/yr
Quantity | Value | Units
Minimum output | 0 | kW
Maximum output | 912 | kW
Wind penetration | 64.8 | %
Hours of operation | 8,723 | hr/yr
Levelized cost | 0.0290 | $/kWh
EWT 900 Output
Hour of Day
24
18
12
6
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
kW
1,000
900
800
700
600
500
400
300
200
100
0
Warning!
XML Report
HTML Report
Help
Close

30m data extrapolated to 75m

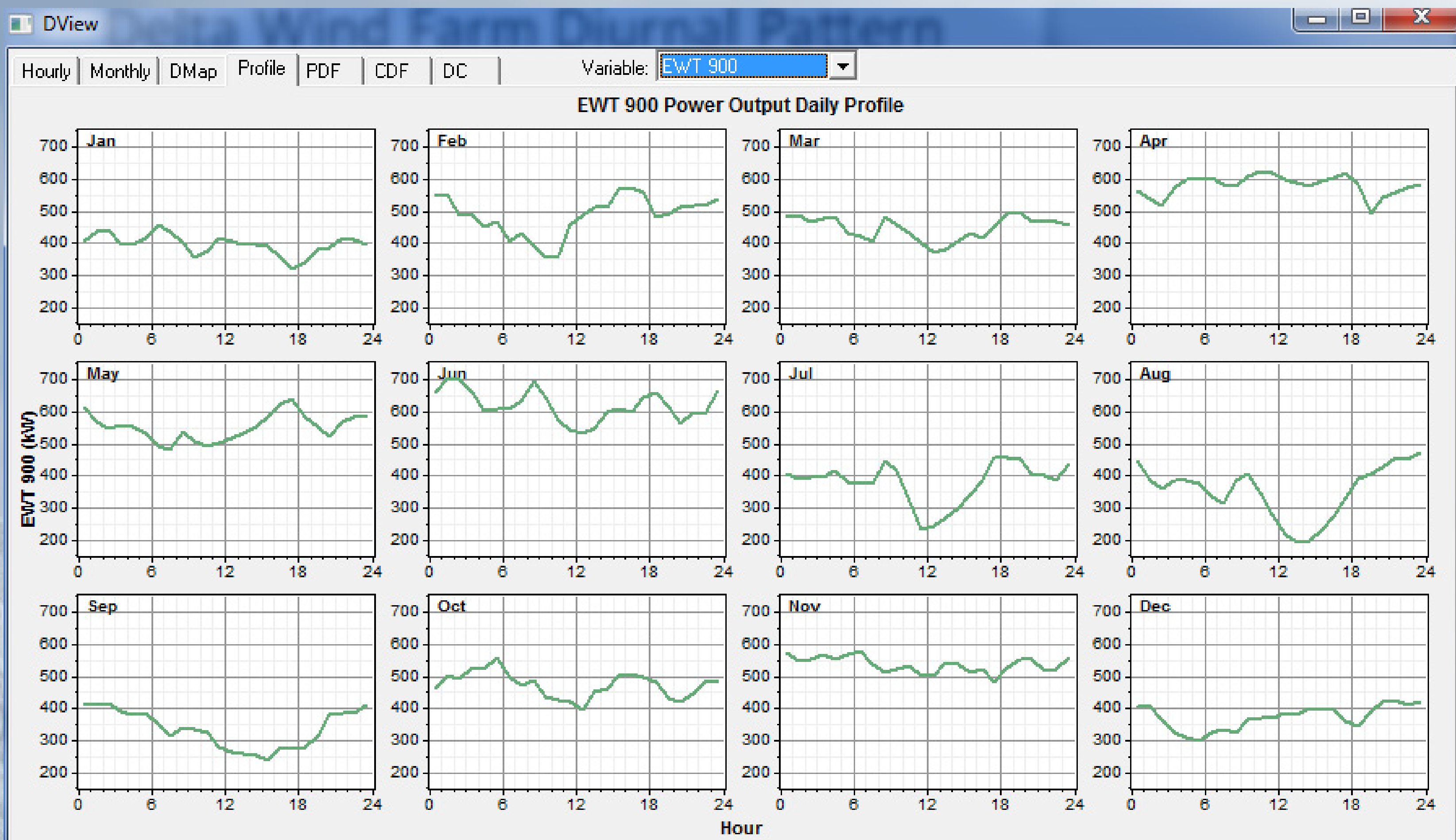


75m data

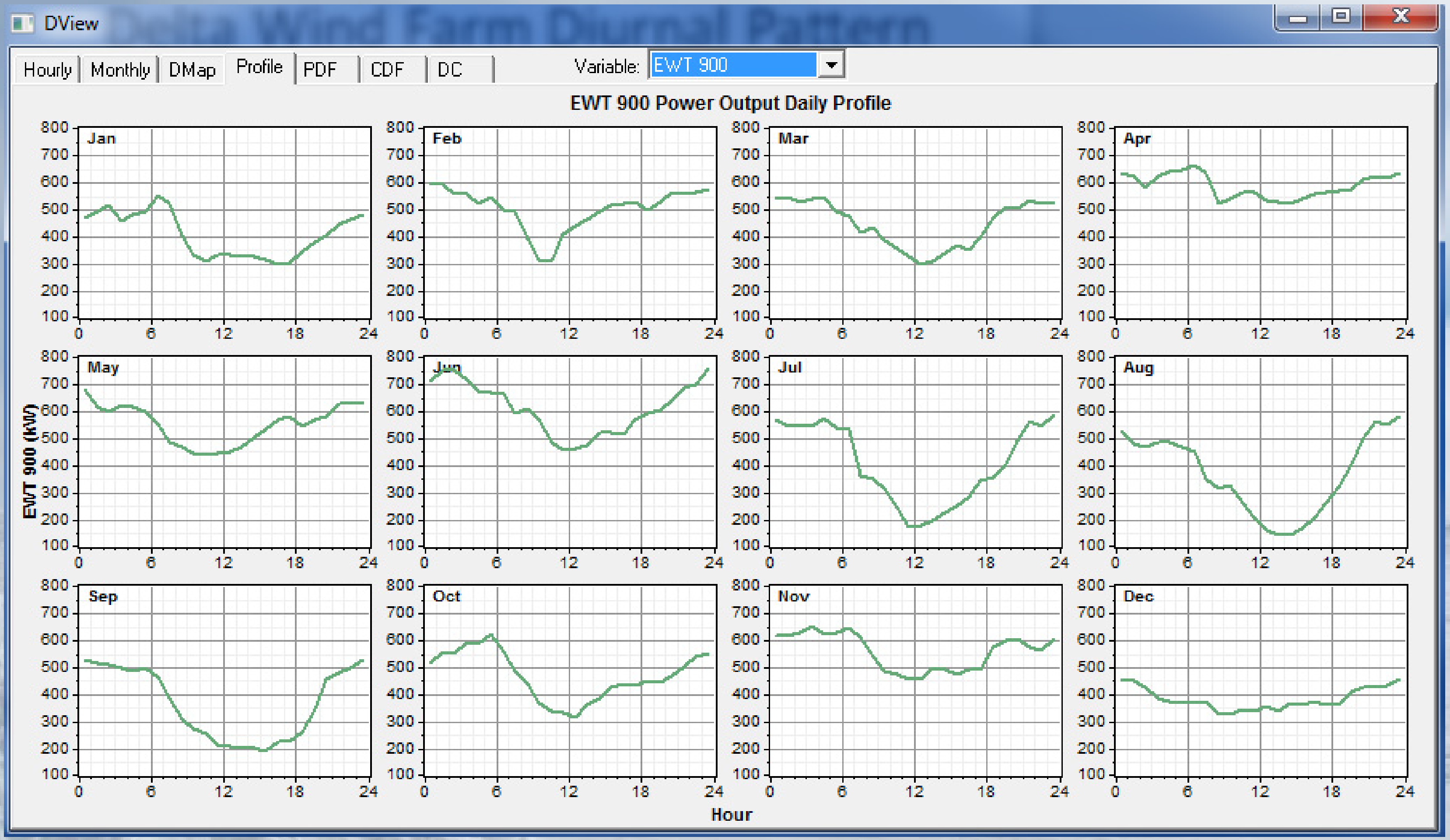


DView
Hourly
Monthly
DMap
Profile
PDF
CDF
DC
Variable:
Wind Speed
Wind Speed at Anemometer Height Daily Profile
Jan
Feb
Mar
Apr
May
Jul
Aug
Sep
Oct
Nov
Dec
Wind Speed (m/s)
Hour

30m data extrapolated to 75m

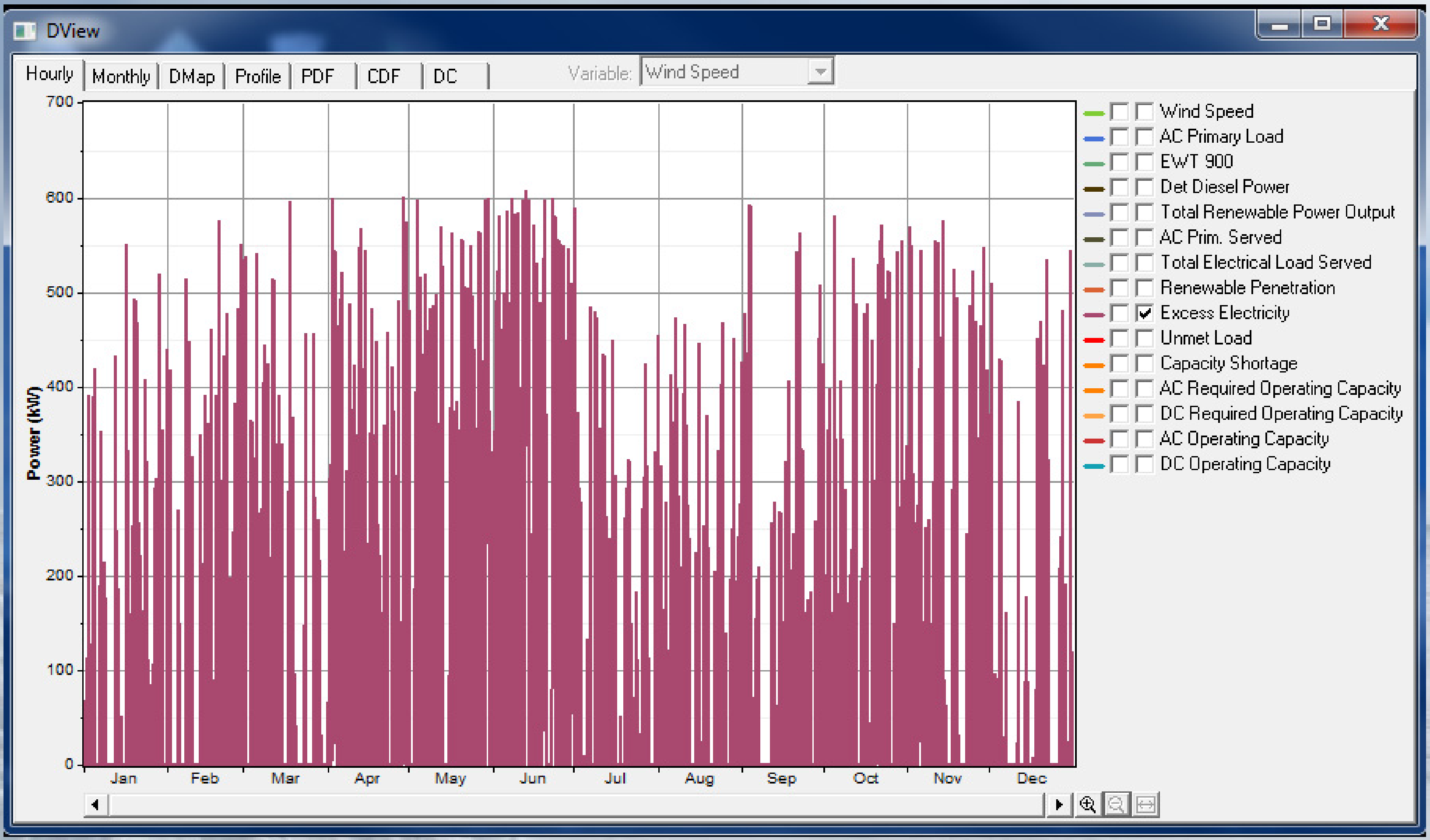


75m data



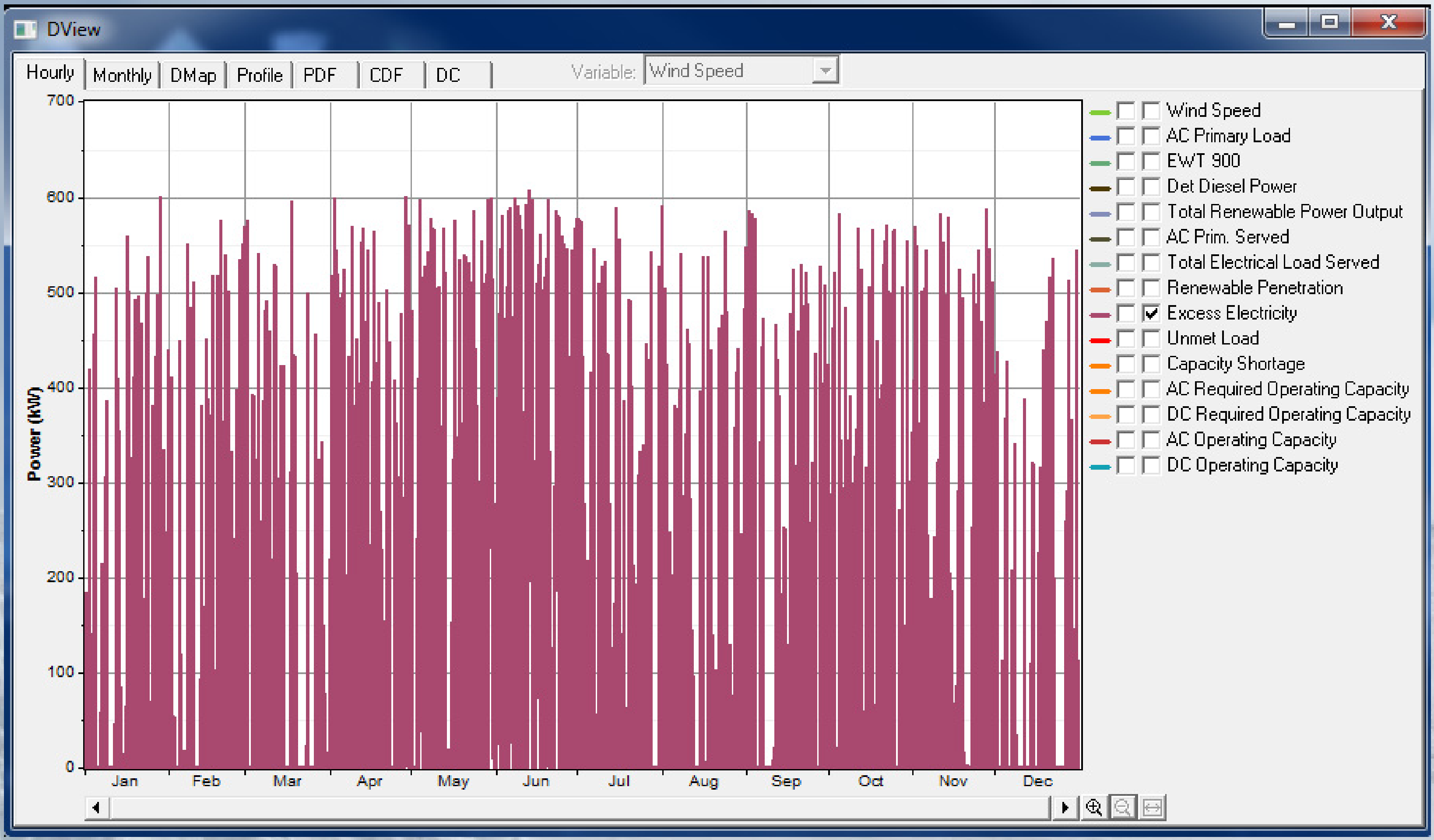
DView
Delta Wind Farm Diurnal Pattern
Hourly
Monthly
DMap
Profile
PDF
CDF
DC
Variable:
EWT 900
EWT 900 Power Output Daily Profile
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
EWT 900 (kW)
Hour

30m data extrapolated to 75m



75m data

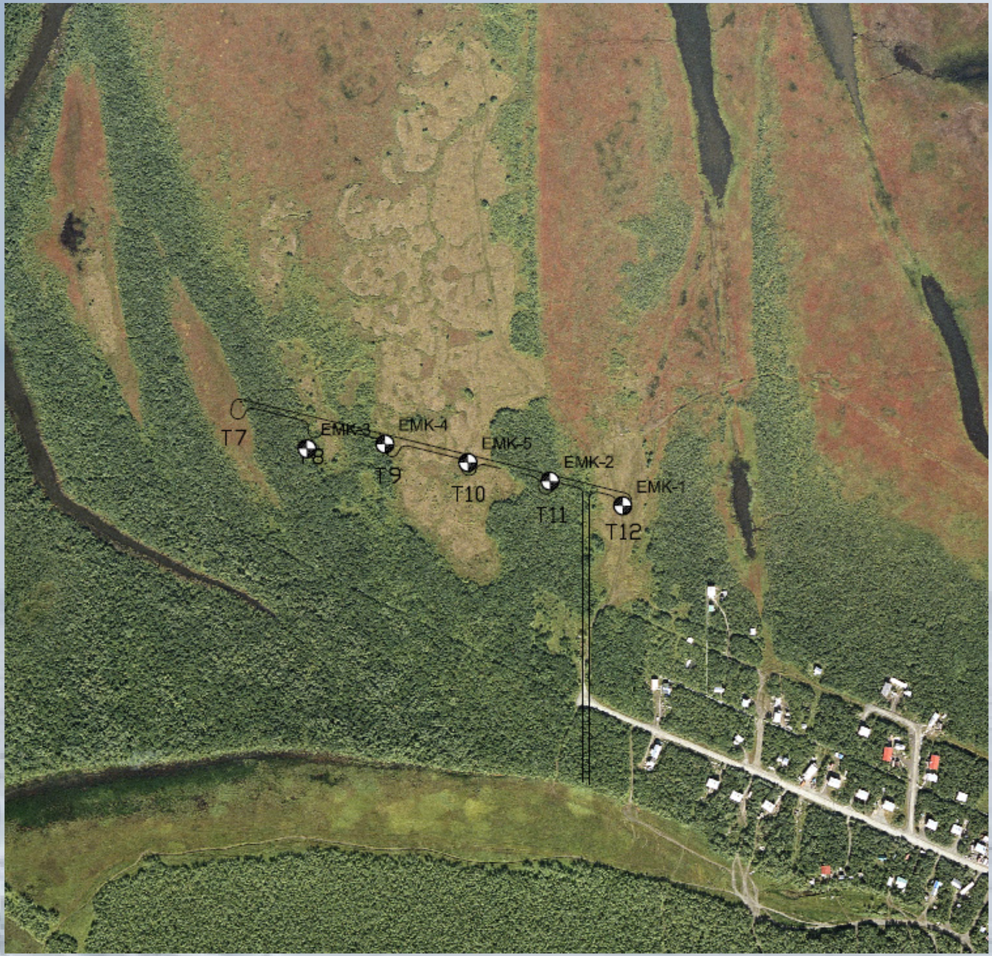
Big change in secondary load considerations



Wind Shade

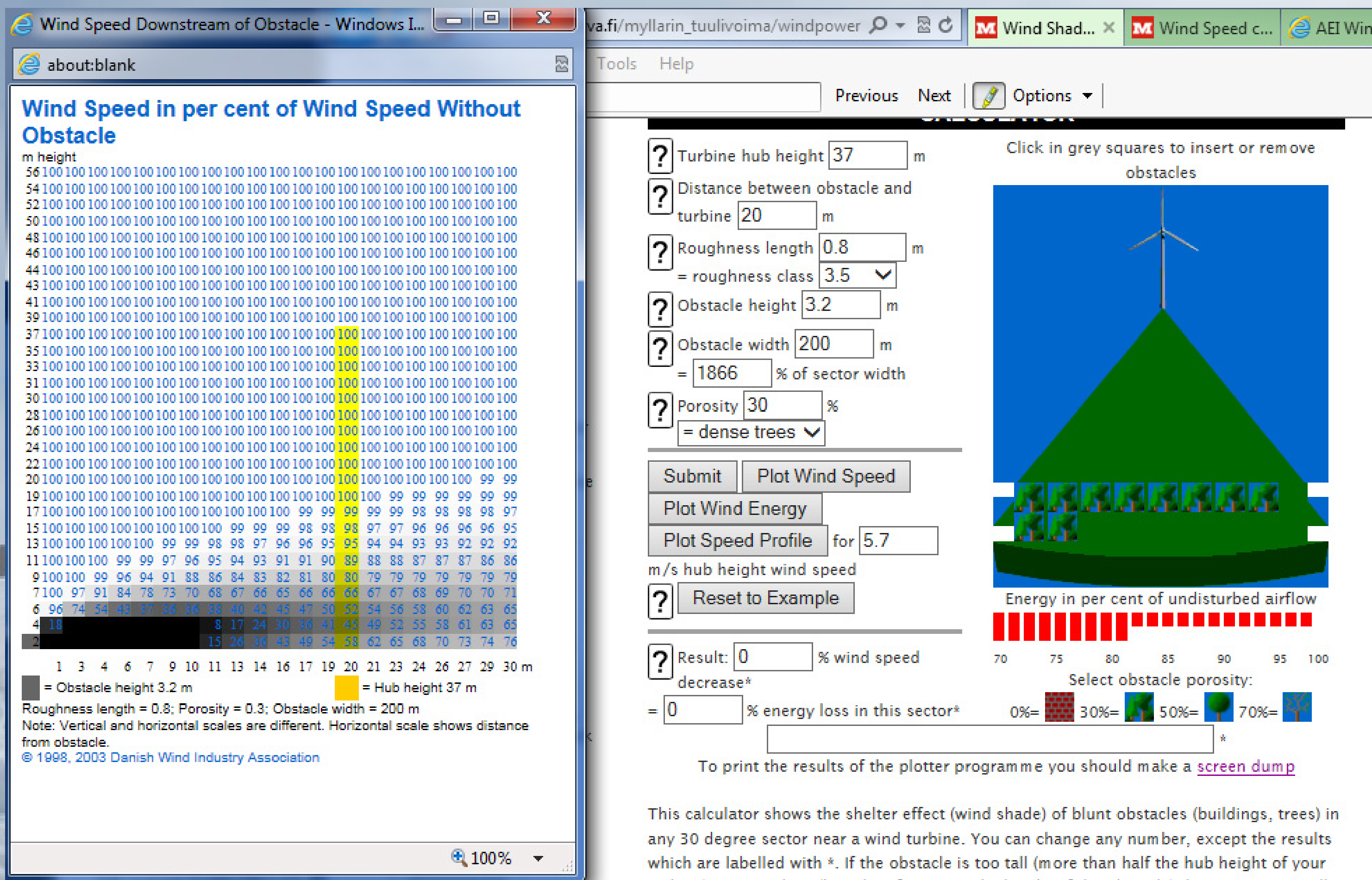
- The higher you are above the top of the upwind obstacle, the less wind shade. The wind shade, however, may extend to up to ~~five~~ 10 times the height of the obstacle at a certain distance.
- If the obstacle is taller than half the hub height, the results are more uncertain, because the detailed geometry of the obstacle, (e.g. differing slopes of the roof on buildings, different species of bushes/trees) will affect the result.

Emmonak Wind Turbine Site



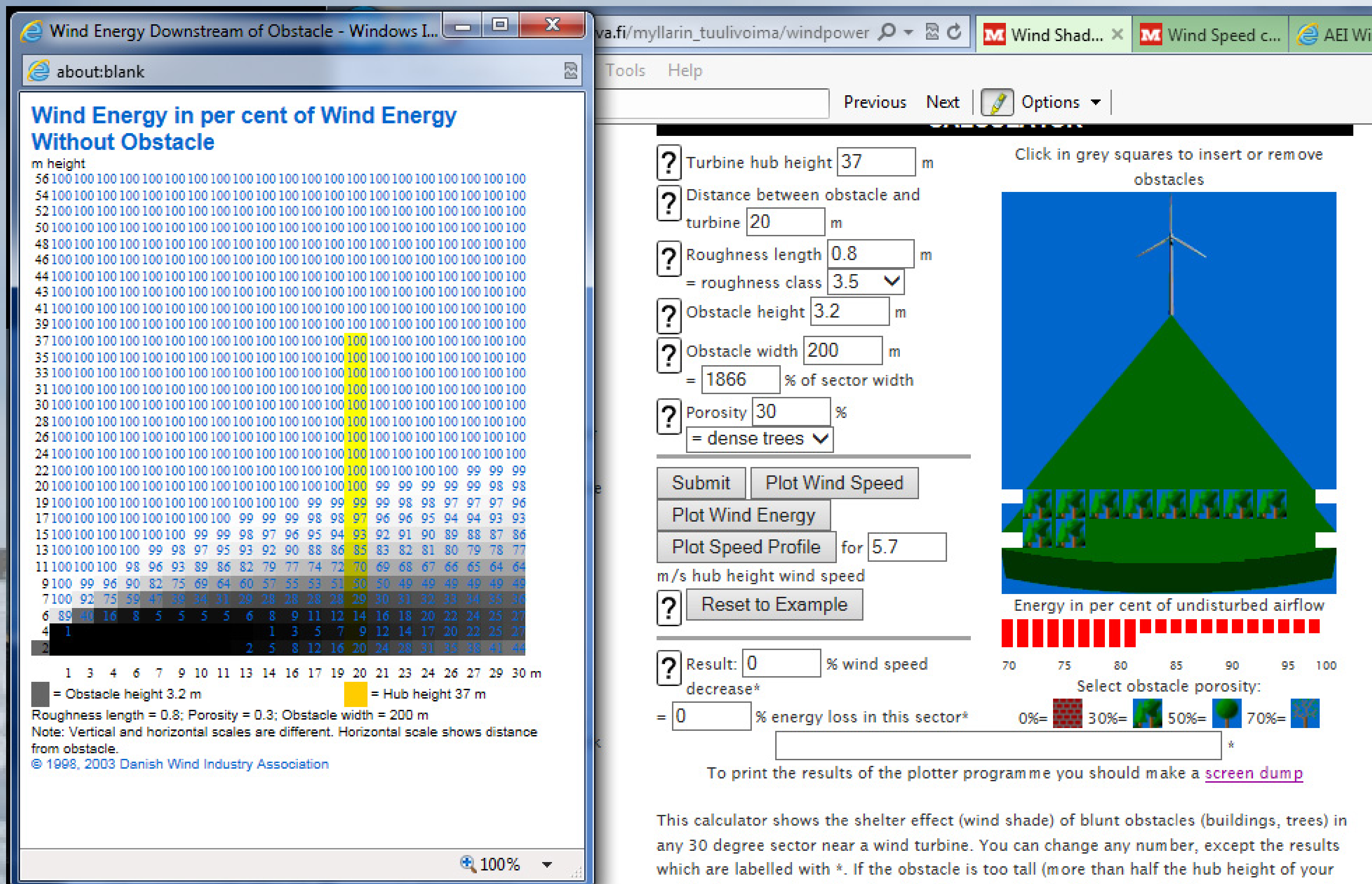
Wind Shade Calculator

http://www.motiva.fi/myllarin_tuulivoima/windpower%20web/en/tour/wres/shelter/index.htm

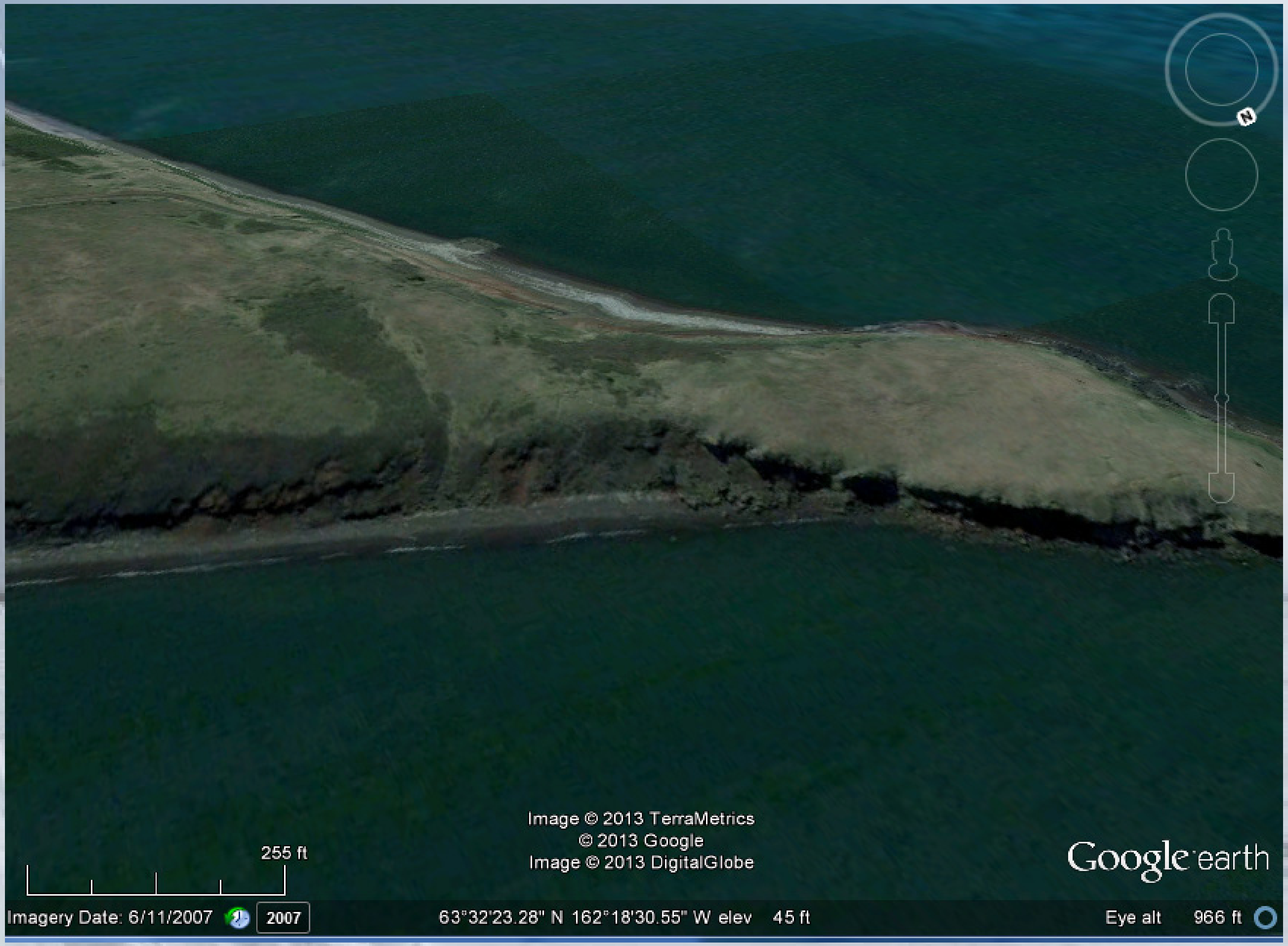


Wind Shade Calculator

http://www.motiva.fi/myllarin_tuulivoima/windpower%20web/en/tour/wres/shelter/index.htm



Cape Stebbins



Wind Shade Calculator

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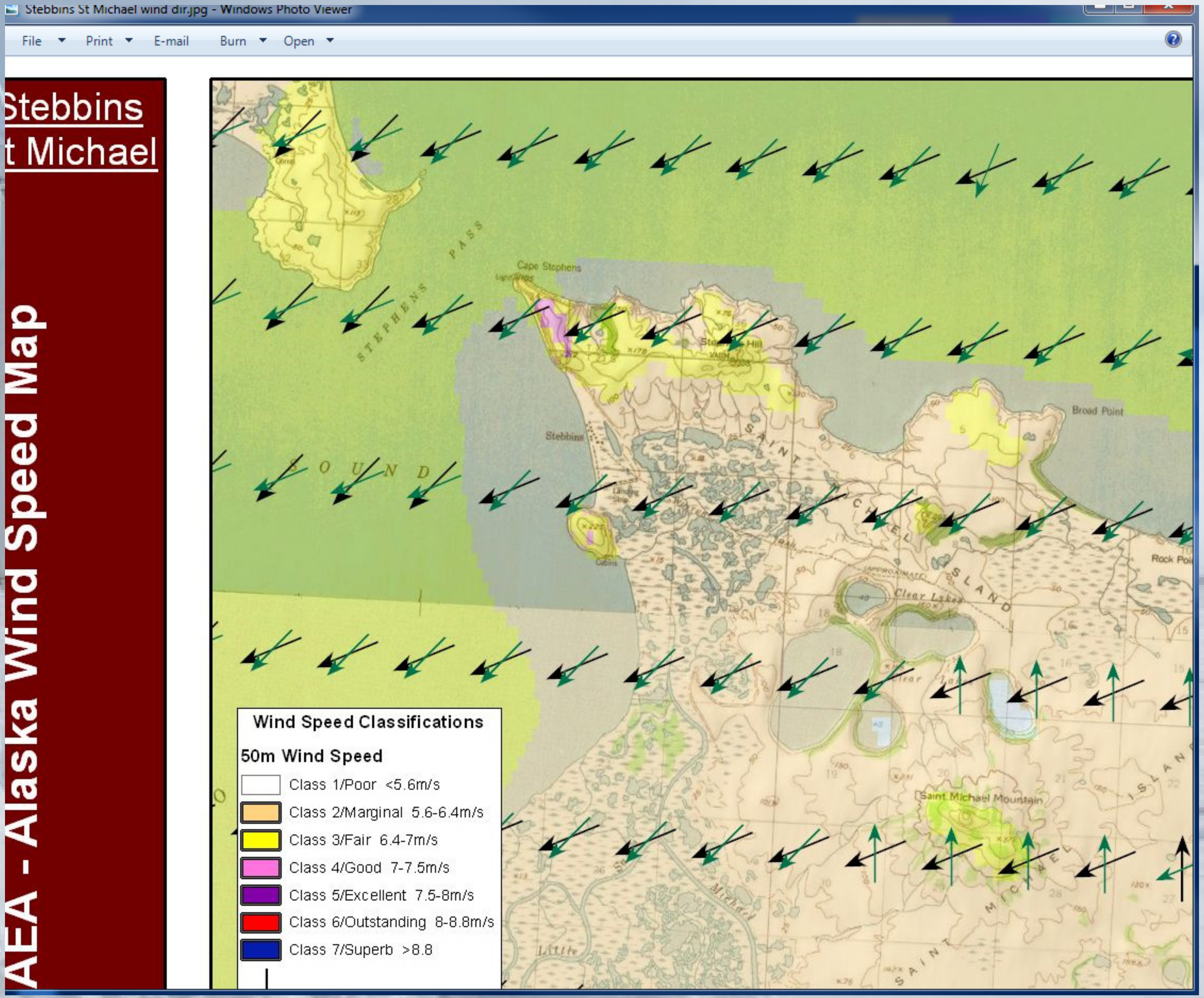

Wind Shade Calculator

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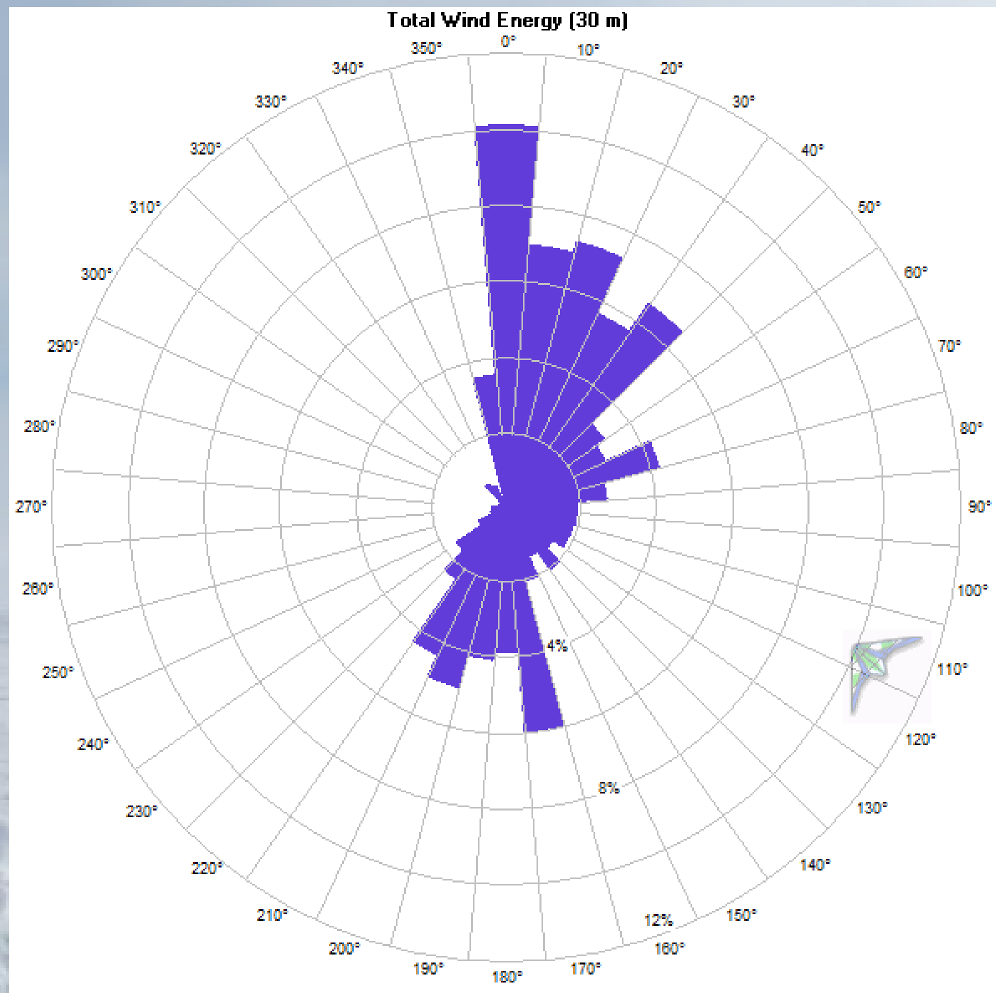
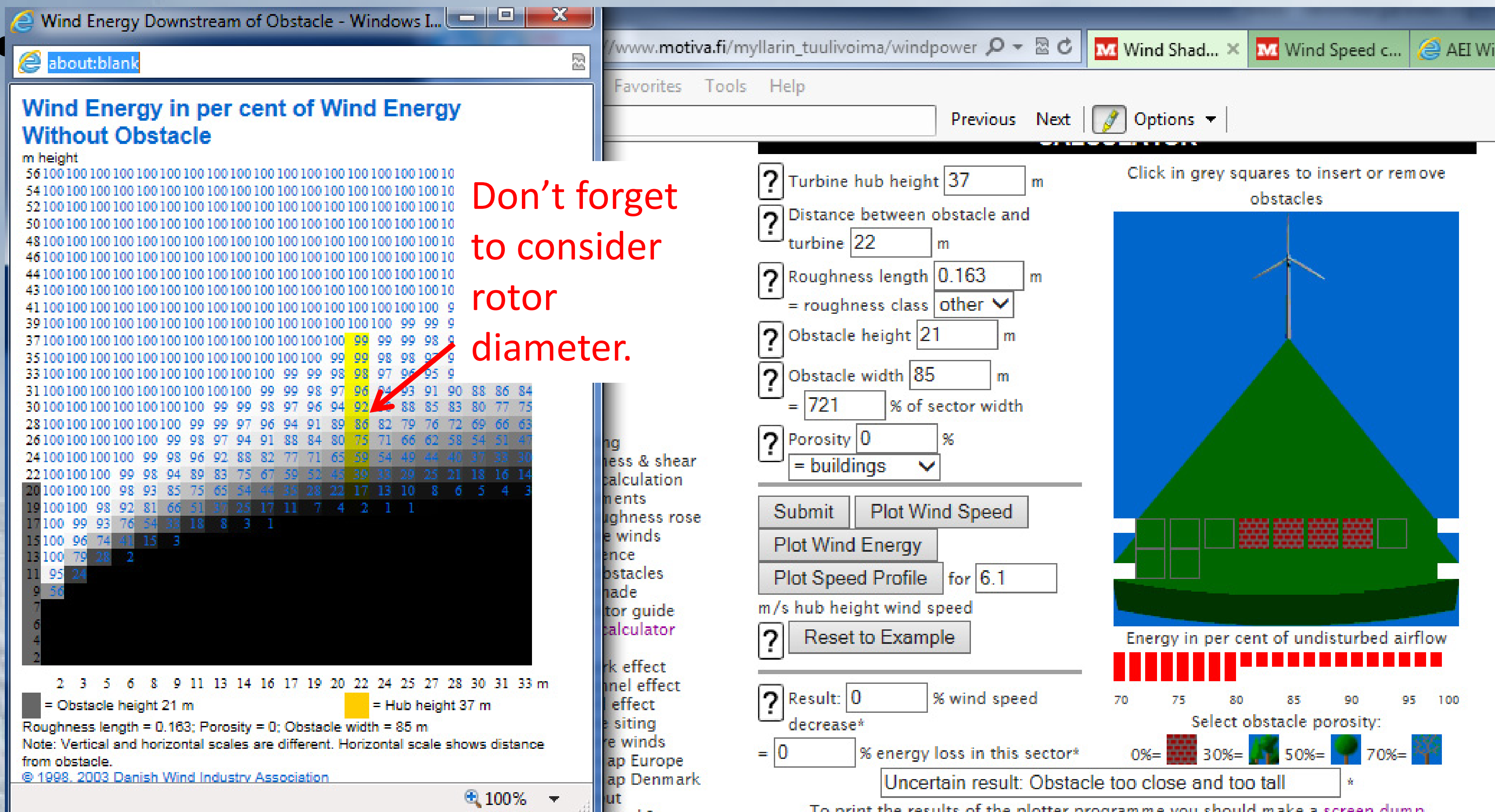
- 

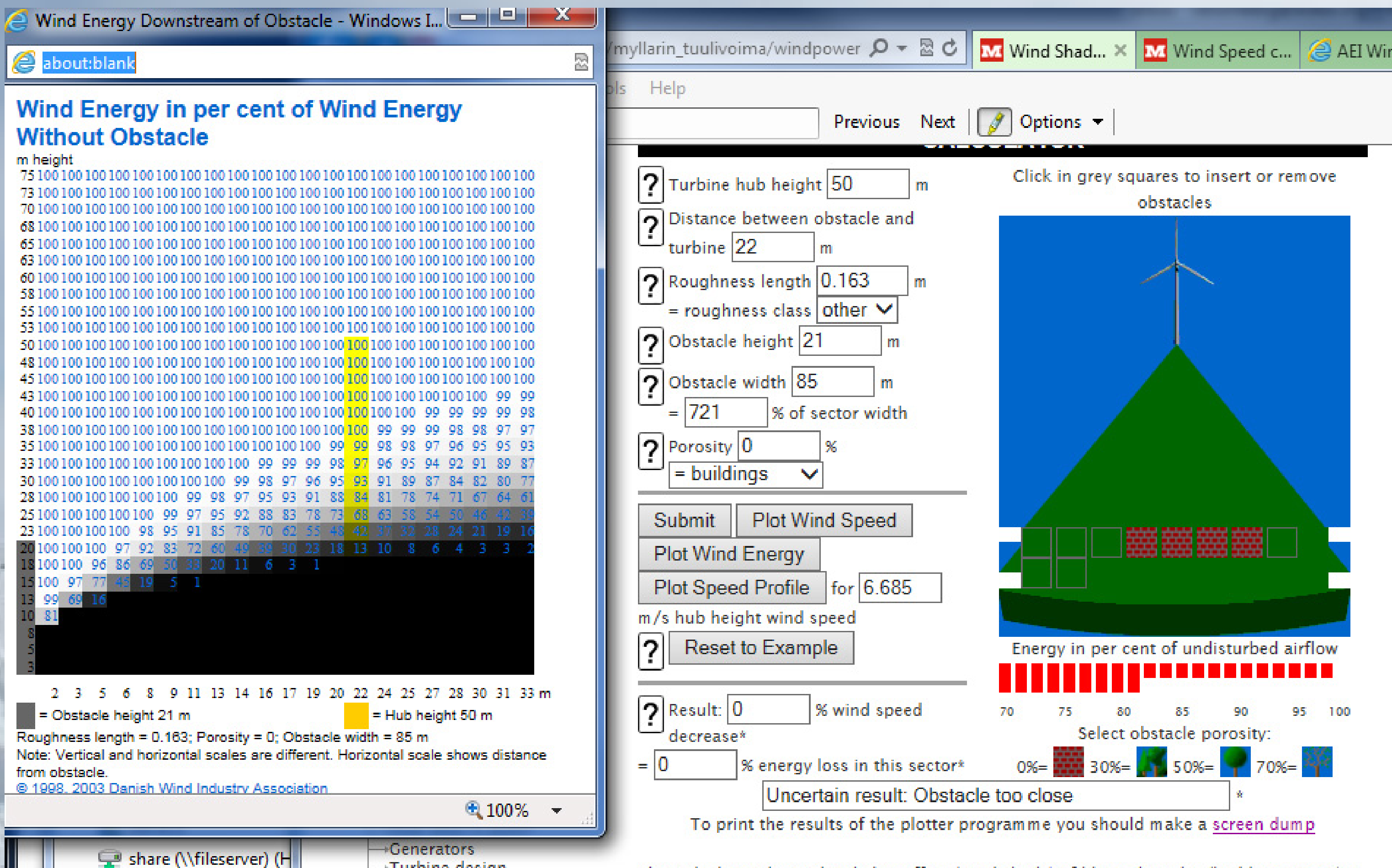
Wind Shade Calculator – 37m Turbine

http://www.motiva.fi/myllarin_tuulivoima/windpower%20web/en/tour/wres/shelter/index.htm



Wind Shade Calculator – 50m Turbine

http://www.motiva.fi/myllarin_tuulivoima/windpower%20web/en/tour/wres/shelter/index.htm



Wind Shade Calculator – 75m Turbine

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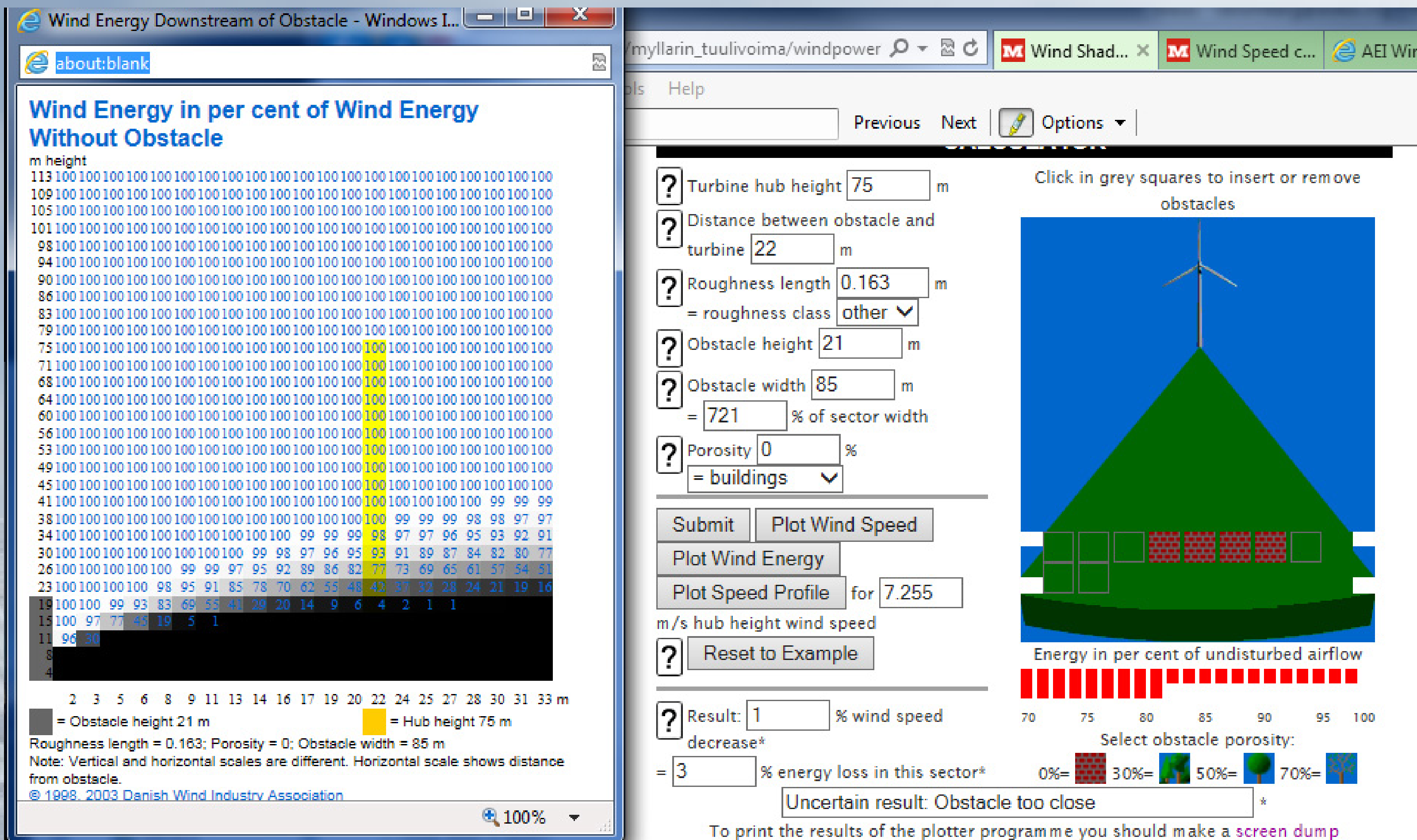
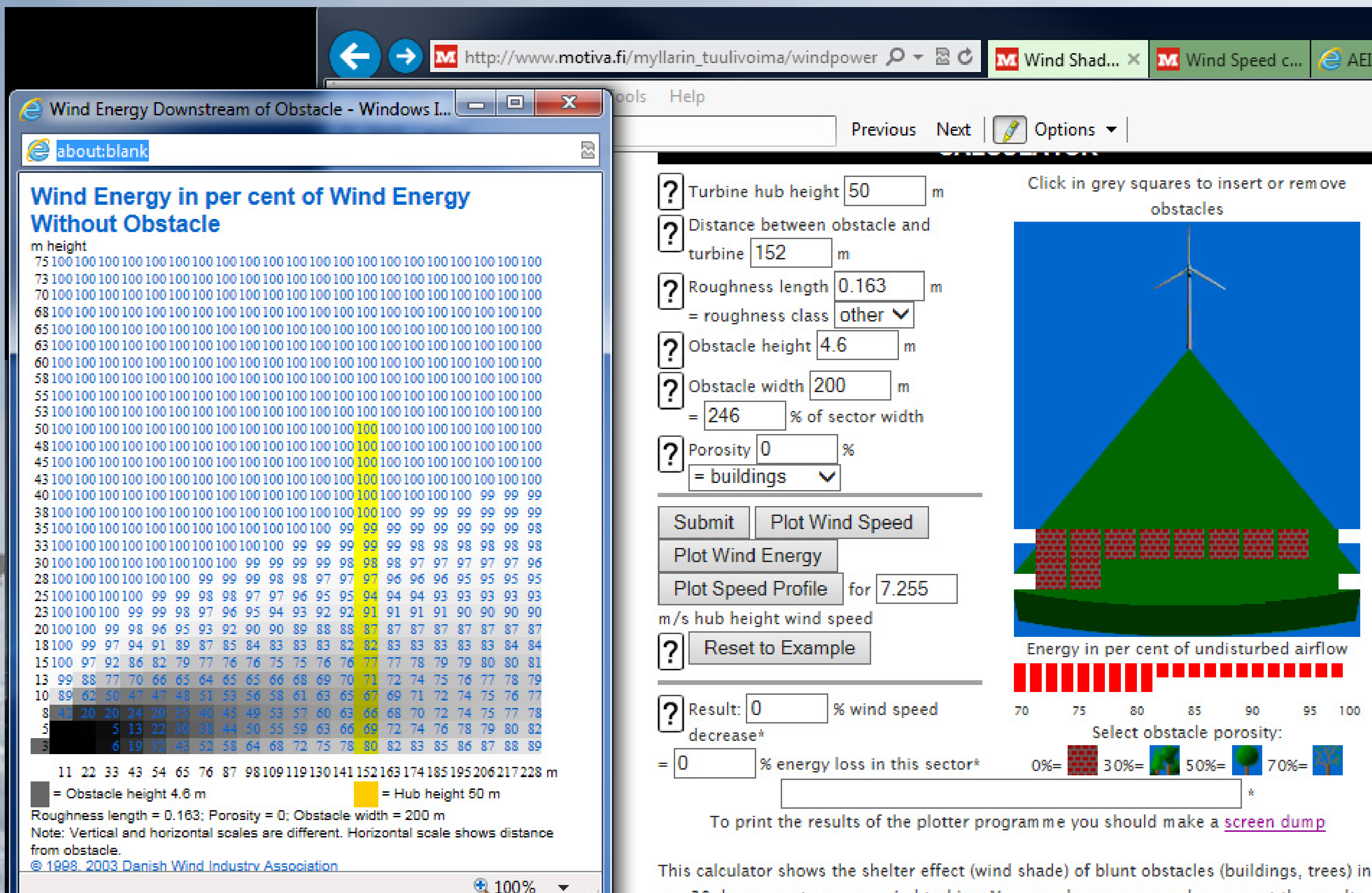


Cape Stebbins Preferred Turbine Site

Wind Shade Calculator – 50m Turbine

http://www.motiva.fi/myllarin_tuulivoima/windpower%20web/en/tour/wres/shelter/index.htm



Voltage Rise in Distributed Generation (DG) Systems

"Connections of distributed generation (DG) in distribution networks are increasing. These connections of distributed generation cause voltage rise in the distribution network." - http://seit.unsw.adfa.edu.au/staff/sites/hrp/papers/mhp11a-c.pdf Analysis of Voltage Rise Effect on Distribution Network with Distributed Generation M. A. Mahmud, M. J. Hossain, H. R. Pota

"Since the modern distribution systems are designed to accept bulk power from the transmission network and to distribute it to customers, the flow of both real and reactive power is always from the higher to lower voltage levels. However, with significant penetration of distributed generation, the power flows may become reversed and the distribution network is no longer a passive circuit supplying loads but an active system with power flows and voltages determined by the generation as well as load."

"Connections of distributed generation in distribution systems are susceptible to voltage rise. Moreover, the impact of losing a single or a few distributed generation following a remote fault may not be significant issue, but the connection or disconnection of a large penetration of distributed generation may become problematic which may lead to sudden appearance of hidden loads and affect the voltage profile of low voltage distribution network."

DG Voltage Rise Example

Analysis of Voltage Rise Effect on Distribution Network with Distributed Generation M. A. Mahmud, M. J. Hossain, H. R. Pota

Preprints of the 18th IFAC World Congress
Milano (Italy) August 28 - September 2, 2011

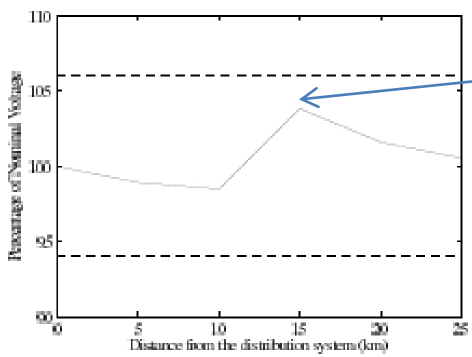


Fig. 6. Voltage Profile of the DS with 240 KW DG (The dashed lines represent the specified ±6% voltage limit and the solid line represents the percentage drop in voltage through the system)

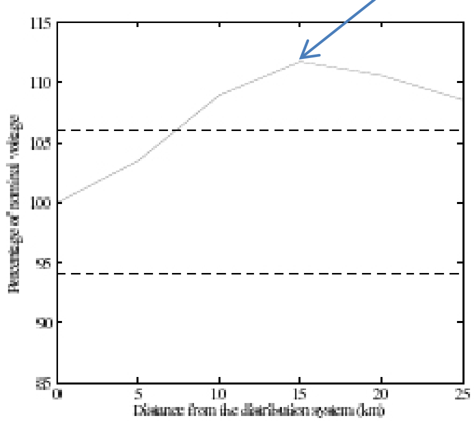


Fig. 7. Voltage Profile of the DS with 1 MW DG (The dashed lines represent the specified ±6% voltage limit and the solid line represents the percentage drop in voltage through the system)

In this case, 240 KW generator 15km away from the primary distribution system is replaced by a 1 MW generator. This increased amount of generation reverses the power flow through the line, from the generator towards the DS.

The voltage profile of DS with 1 MW of distributed generation is shown in Fig. 7. From Fig. 7, it is seen that the voltage in some parts of the system rises above the permitted +6% voltage limit.

DG Voltage Rise Factors

Analysis of Voltage Rise Effect on Distribution Network with Distributed Generation M. A. Mahmud, M. J. Hossain, H. R. Pota

The level of DG generation that can be connected to the distribution system depends on the following factors:

- voltage at the primary DS
- voltage level of the receiving end
- size of the conductors as well distance from the primary DS
- load demand on the system
- other generation on the system

DG Voltage Rise Mitigation

Analysis of Voltage Rise Effect on Distribution Network with Distributed Generation M. A. Mahmud, M. J. Hossain, H. R. Pota

The voltage rise on DS can be mitigated through the following approaches:

- Resistance reduction (increase conductor size or energize to higher voltage)
- Reactive power compensation (switched capacitor or DVAR)
- Coordinated voltage control
- Generation curtailment

DG Voltage Rise – Other Reading

"A Case Study of a Voltage Rise Problem Due to a Large Amount of Distributed Generation on a Weak Distribution Network" – Sami Repo, et al. http://labplan.ufsc.br/congressos/PowerTech/papers/51.pdf

> "The integration of relatively large capacity of wind power into a weak distribution network may cause a voltage rise problem during low demand periods."

"A review on voltage control methods for active distribution networks" – Tengku Hashim, et al http://pe.org.pl/articles/2012/6/71.pdf

> "The conventional distribution networks are designed based on the assumption of unidirectional power flow. With the increasing connection of DG, the network has become more dynamic with bidirectional power flow and it known as active distribution networks (ADN)."
>
> "With the increasing number of DG penetration, the issue of voltage level in distribution systems has become important. Increasing the number of connected generators will result in voltage rise above its permissible level."

DG Voltage Rise – Other Reading

"Integration of Distributed Generation in Low Voltage Networks: Power Quality and Economics" – Konstantinos Angelopoulos
http://www.esru.strath.ac.uk/Documents/MSc_2004/angelopoulos.pdf

"It is possible to estimate the effect of a generator by using the standard voltage drop equations with reverse power flow. The voltage drop along a feeder due to a load is approximately equal to:

$Vdrop = I_R R + I_X X$

Where:

Vdrop= voltage drop along the feeder

R = line resistance, ohms

X = line reactance, ohms

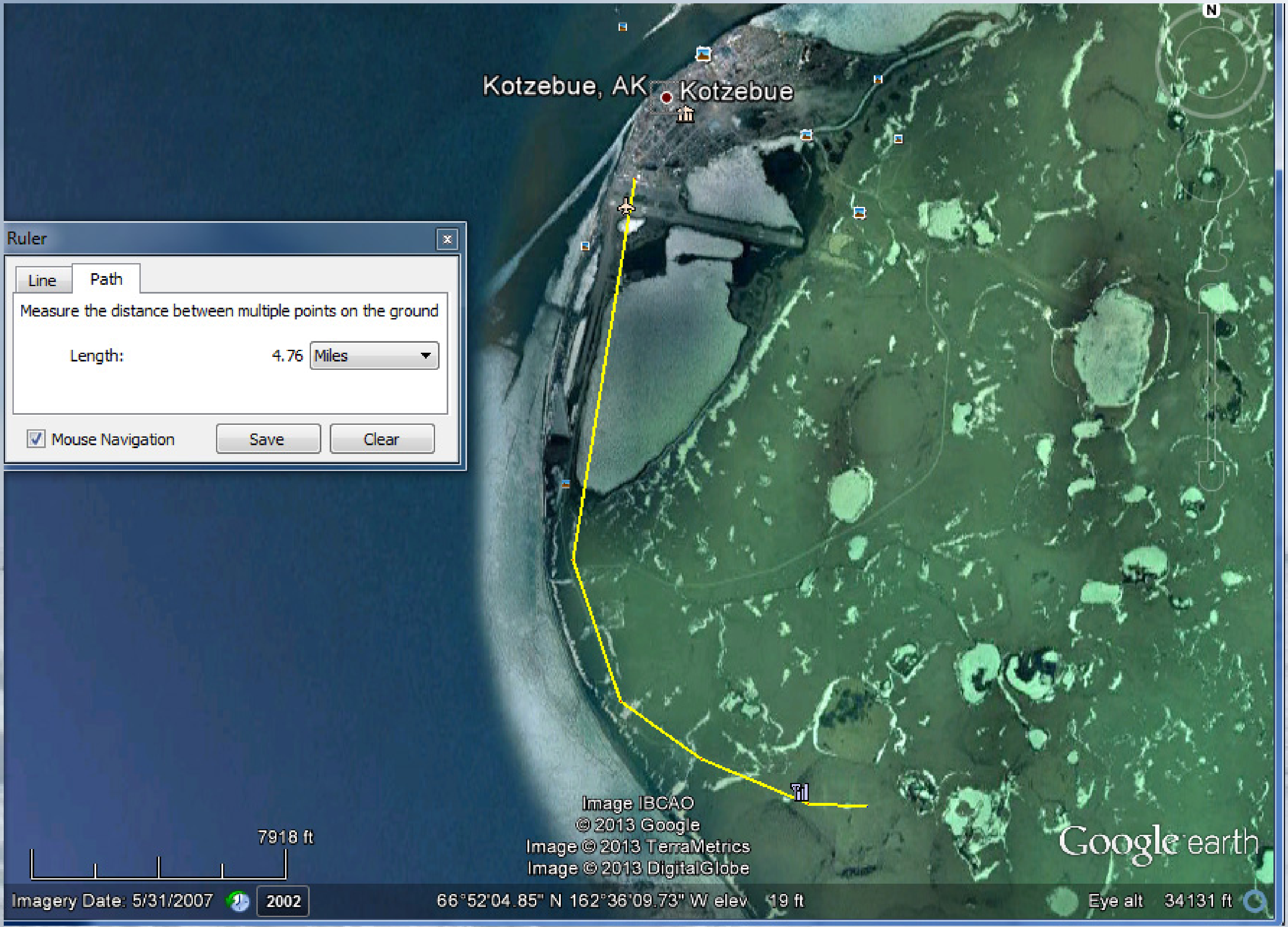
I_R = line current due to real power flow, amps (negative for a generator injecting power)

I_X = line current due to reactive power flow, amps (negative for a capacitor)

DG Voltage Rise Analysis on Alaska WD Systems

- Power flow analysis can be costly and take time, but is needed in come cases.
- UVIG DG toolkit is a quick method to determine if more detailed PF analysis is needed. http://www.uwig.org/distwind/default.htm
- A simple voltage drop/rise calculation can be done in two minutes.

Voltage Rise – Kotzebue Example



Voltage Rise – Kotzebue Example

Single phase VD = (2 * L * R * I) / 1000 ft		
Distance in miles	4	
Equivalent feet	21,120	
Resistance in Ohms/1,000 feet from chart at right	0.1265	2/0 Quail
Load in amps is based on total power and line voltage		
Max power (Watts) from all wind turbines	1,100,000	
Voltage rating of transmission line	12470	
Single phase amps from wind turbine	88.21	
Convert to 3-phase (Div by sqrt of 3) gives load in amps from turbine	50.93	
Using above bold formula, voltage drop/rise is ------>	272.14	
Percentage of voltage drop/rise	2.18%	
3-phase VD = SPVD * (1.732/2) Drop between any 2 phases		
3-phase voltage drop/rise is----------------------------->	235.68	
Percentage of voltage drop/rise	1.89%	

Before adding two EWT 900kW turbines.

<3% is desired

Voltage Rise – Kotzebue Example

Single phase VD = (2 * L * R * I) / 1000 ft		
Distance in miles	4	
Equivalent feet	21,120	
Resistance in Ohms/1,000 feet from chart at right	0.1265	2/0 Quail
Load in amps is based on total power and line voltage		
Max power (Watts) from all wind turbines	2,900,000	
Voltage rating of transmission line	12470	
Single phase amps from wind turbine	232.56	
Convert to 3-phase (Div by sqrt of 3) gives load in amps from turbine	134.27	
Using above bold formula, voltage drop/rise is ------>	717.46	
Percentage of voltage drop/rise	5.75%	
3-phase VD = SPVD * (1.732/2) Drop between any 2 phases		
3-phase voltage drop/rise is---------------------------------->	621.34	
Percentage of voltage drop/rise	4.98%	
	0.622596	

After adding two EWT 900kW turbines.

<3% is desired

Voltage can rise as wind power increases on distributed generation microgrids.

Voltage Rise at KEA After 2013 Energize to 25kV

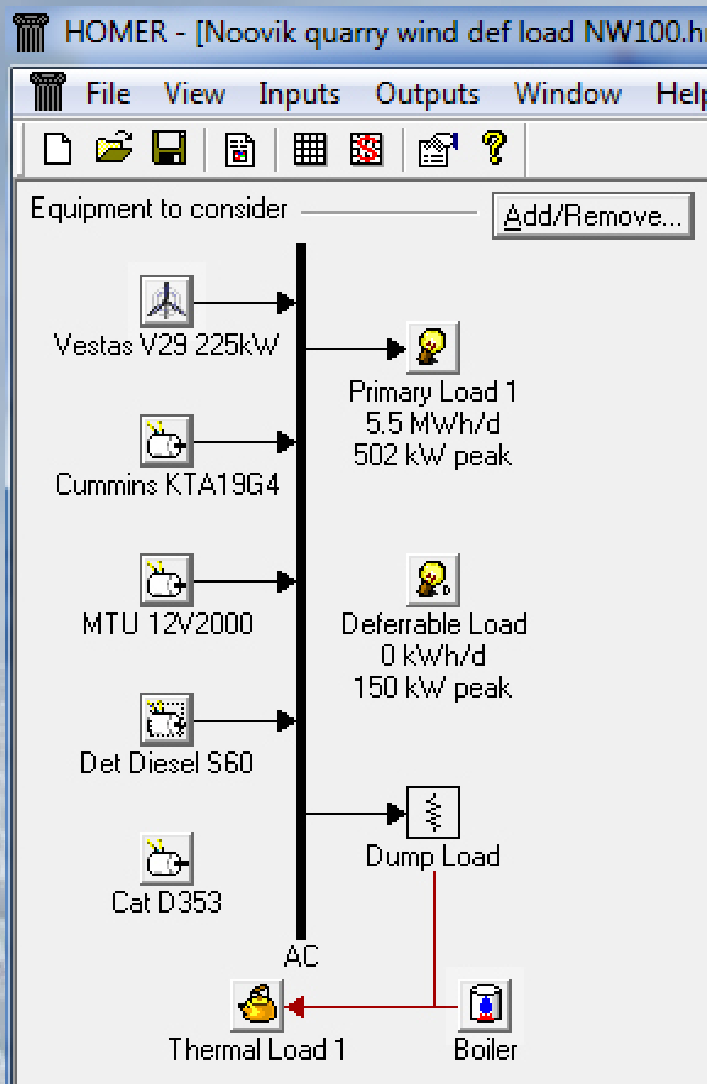
Single phase VD = (2 * L * R * I) / 1000 ft		
Distance in miles	4	
Equivalent feet	21,120	
Resistance in Ohms/1,000 feet from chart at right	0.1265	2/0 Quail
Load in amps is based on total power and line voltage		
Max power (Watts) from all wind turbines	2,900,000	
Voltage rating of transmission line	25000	
Single phase amps from wind turbine	116.00	
Convert to 3-phase (Div by sqrt of 3) gives load in amps from turbine	66.97	
Using above bold formula, voltage drop/rise is ------>	357.87	
Percentage of voltage drop/rise	1.43%	
3-phase VD = SPVD * (1.732 / 2) Drop between any 2 phases		
3-phase voltage drop/rise is---------------------------->	309.92	
Percentage of voltage drop/rise	1.24%	
	0.622596	

Goal achieved

Induction Generators vs. Inverter Systems

- An induction (asynchronous) generator must have its magnetic field maintained through the same mechanism as an induction motor. It must exchange energy with a capacitor or with a synchronous generator that can be adjusted to “act as a capacitor.” In order to function as a generator, an induction generator requires an external source of reactive volt-amperes (VARs). This is typically supplied by the diesel gensets. Power factor drops as the WTG produces more energy.
- Inverter-based WTG controllers create a wall from the microgrid where VARs are produced by the inverter using power from the wind turbine once it has spun-up. The microgrid only sees clean power.

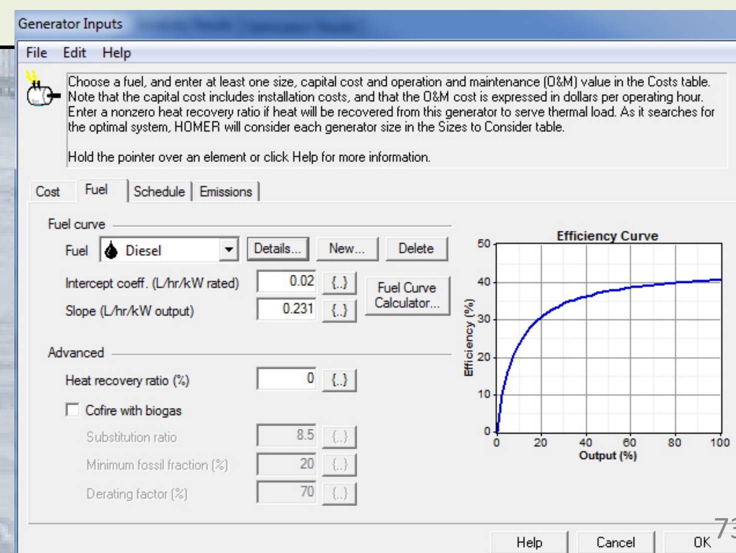
Generator Sizing and Spinning Reserve



Diesel Gensets Noorvik Wind Farm Application/Grant #				
Engine Make/Model Serial #	Min Load %	Rated Capacity (kW) (kVA)	Average Load on Genset	Average Load on Genset w/ Wind
Det diesel 60	30%	363	64%	52%
Cummins KTA 19G4	30%	499	46%	38%
MTU 12V2000	30%	700	33%	27%

Comments: Manual switchgear in Noorvik would need to be upgraded and possibly new feeders.

Heat Recovery Loop: None currently, but possibility for water treatament plant and the school.

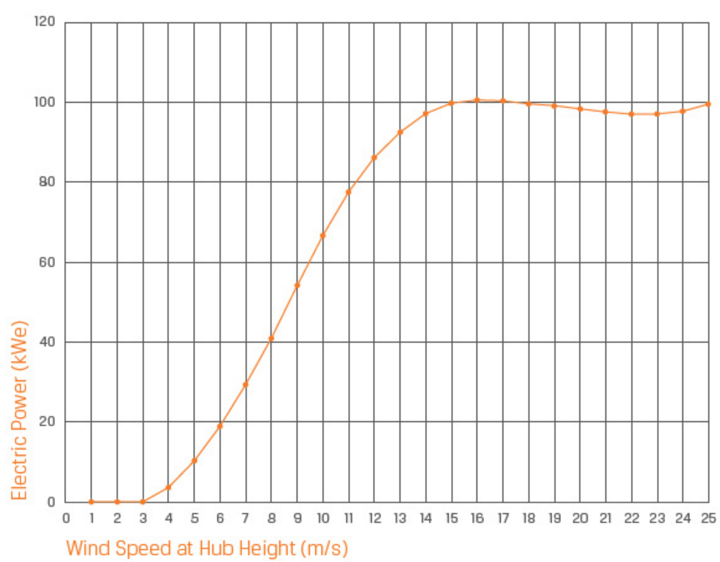


Generator Sizing and Spinning Reserve

- Being able to step up or down to the appropriate size diesel genset as wind production moves up and down can minimize fuel efficiency hit.
- Larger diesel genset may still be needed for VARs support or spinning reserve.
- Sufficient spinning reserve (diesel, battery, etc.) must be maintained to handle sudden drops in wind output. 50% may be needed.
- Diesel generators will see a greater number of starts/stops – some efficiency loss.

What if the wind doesn't drop off suddenly, but keeps getting stronger?

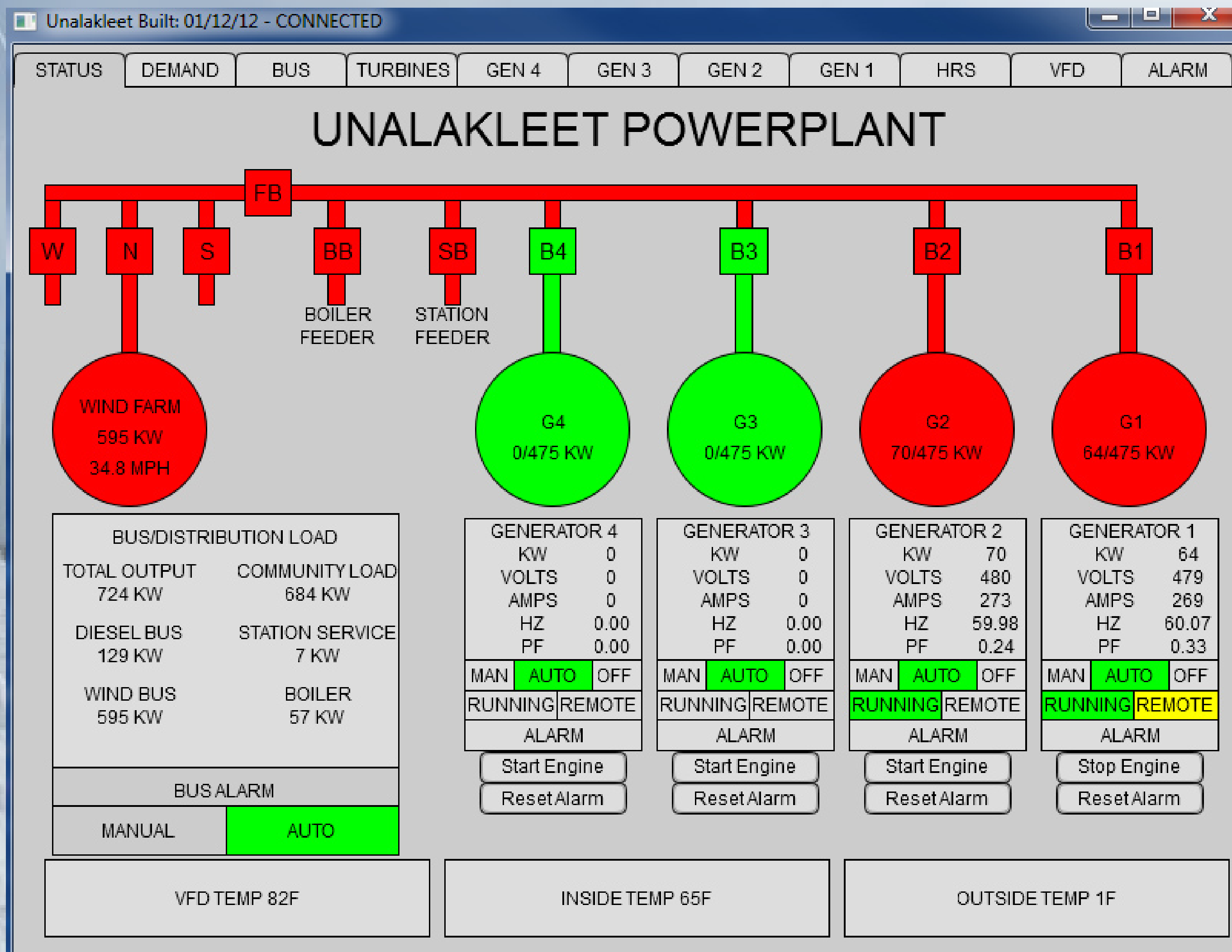
Power Curve: 21-Meter Rotor Standard Air Density (1.225 kg/m³)



Wind Speed (m/s)	Power (kWe)	Wind Speed (m/s)	Power (kWe)
1	0	14	97.3
2	0	15	100.0
3	0	16	100.8
4	3.7	17	100.6
5	10.5	18	99.8
6	19.0	19	99.4
7	29.4	20	98.6
8	41.0	21	97.8
9	54.3	22	97.3
10	66.8	23	97.3
11	77.7	24	98.0
12	86.4	25	99.7
13	92.8		

1 m/s = 2.24 mph

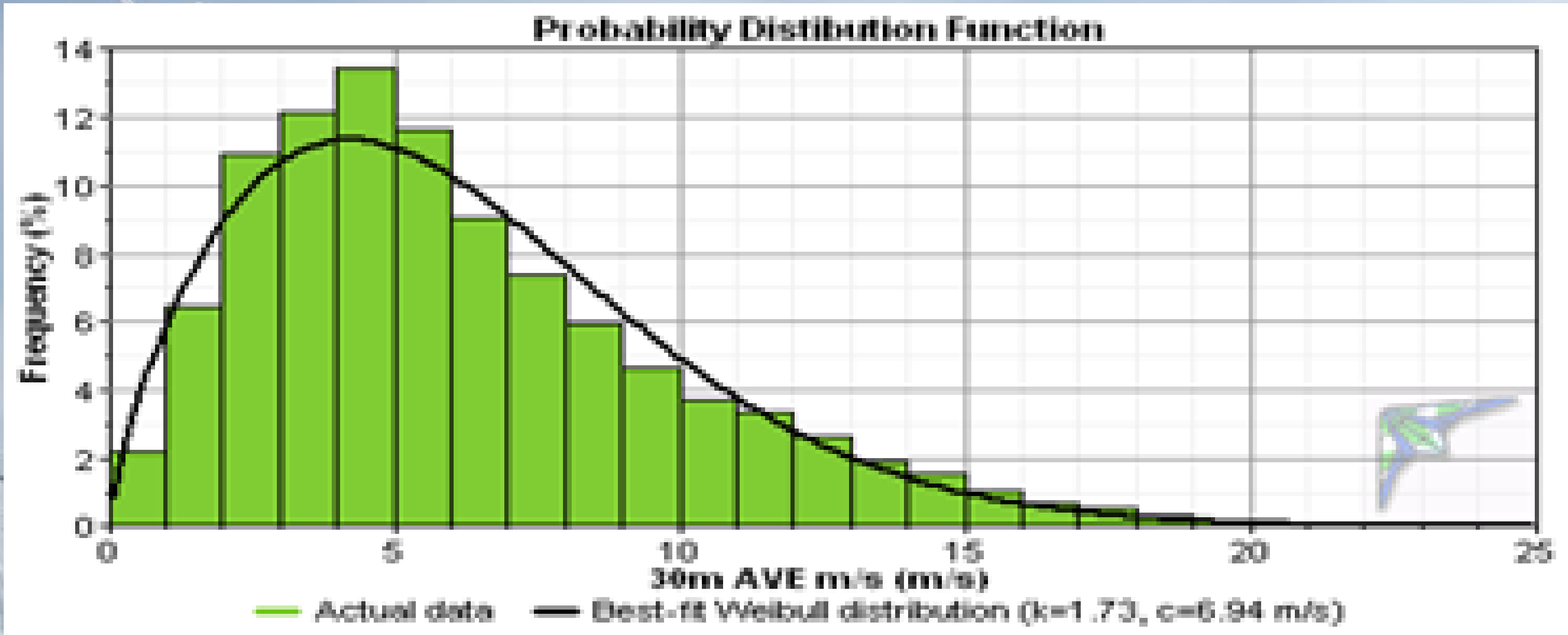
What if the wind doesn't drop off suddenly, but keeps getting stronger?



What if the wind doesn't drop off suddenly, but keeps getting stronger?

- If all turbines are set to trip off at exactly 25 m/s, Unalakleet could lose 600kW of power generation in a few seconds.
- What diesels are online and how quickly can they make up for the 600kW?
- Staggering wind turbine cut-out speeds can minimize the power loss steps to 100 or 200kW.
- Single wind turbines make this harder to accomplish unless they have variable pitch blades plus controls that allow for reducing energy output as the turbine gets close to the cutout speed.
- Smart systems control logic will bring additional spinning reserve online when wind turbines get close to cut-out speed.

12-month Unalakleet met tower study showed no incidents of hitting cut-out speed



However, UVEC has seen instances where wind turbines cut out at 25 m/s and the diesel gensets trip offline.

An opposite problem

- A small community with small load in a class 7 wind regime.
- Average load is 29kW. Average wind penetration is 81%.
- One 65kW wind turbine installed – stall-regulated, basic controller.
- Turning on the wind turbine at 15-25m/s first causes an rush of current into the wind turbine's induction generator. Then, the turbine pushes 65kW of power back onto the local grid.
- If diesel genset and secondary loads can't respond fast enough, high voltage or frequency will trip off the diesel genset and village loses power.

Solutions:

A single smaller turbine.

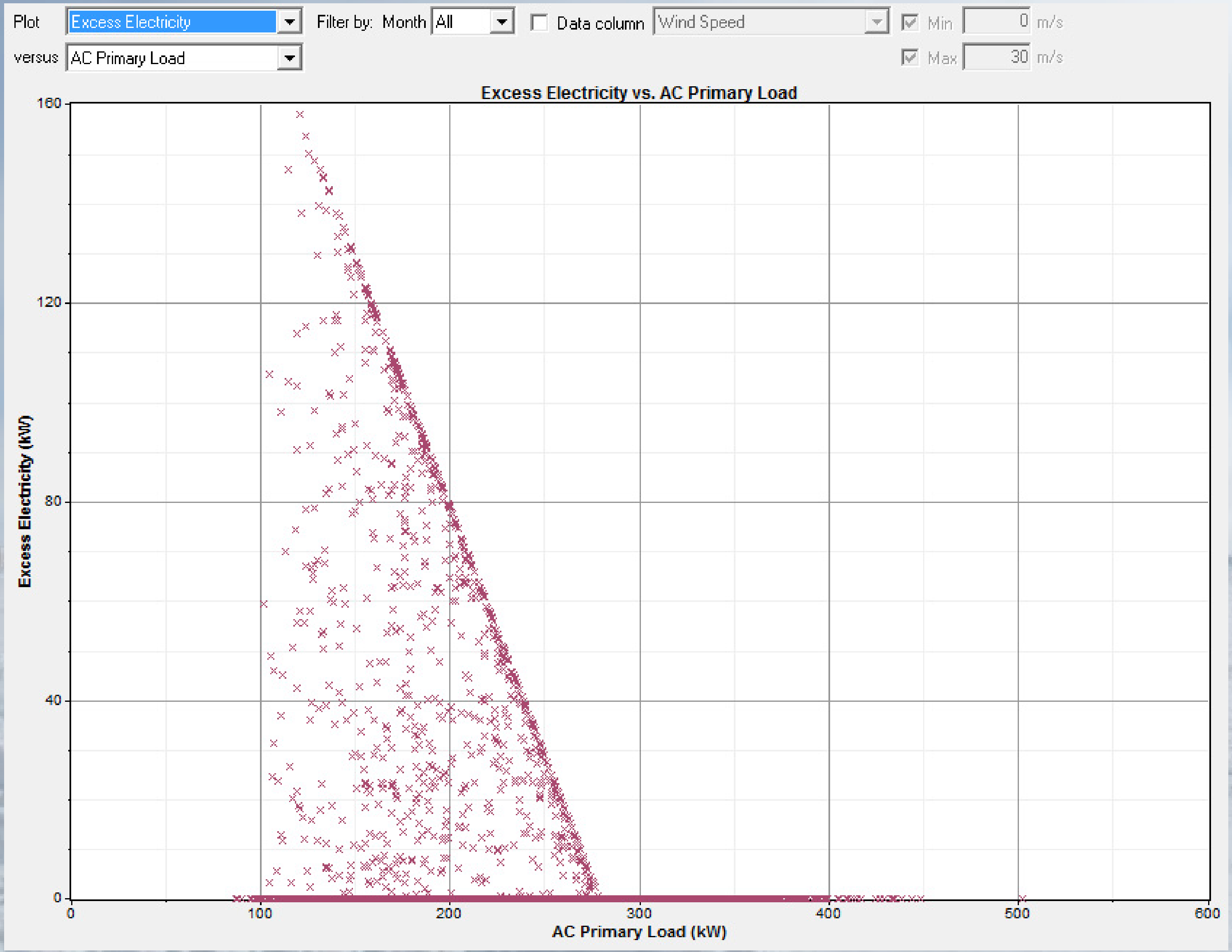
Multiple smaller turbines with automated switchgear that turns on one turbine at a time.

Develop a smart wind turbine controller that starts the turbine with a long ramp rate to max power.

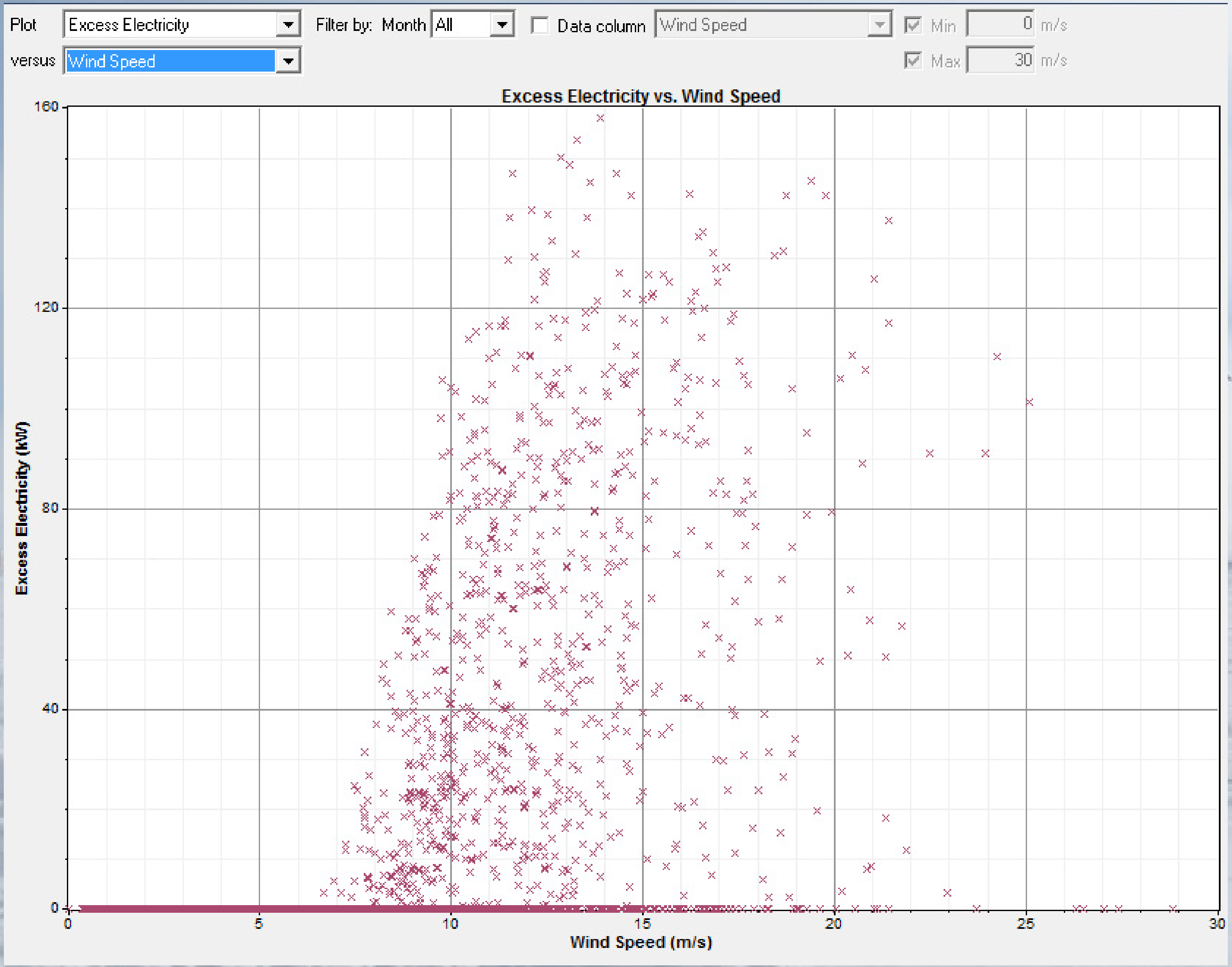
Other wind turbine features to consider

- Soft start
- Dynamic braking
- Variable-pitch blades
- Tilt-up towers vs. monopole towers vs. lattice towers

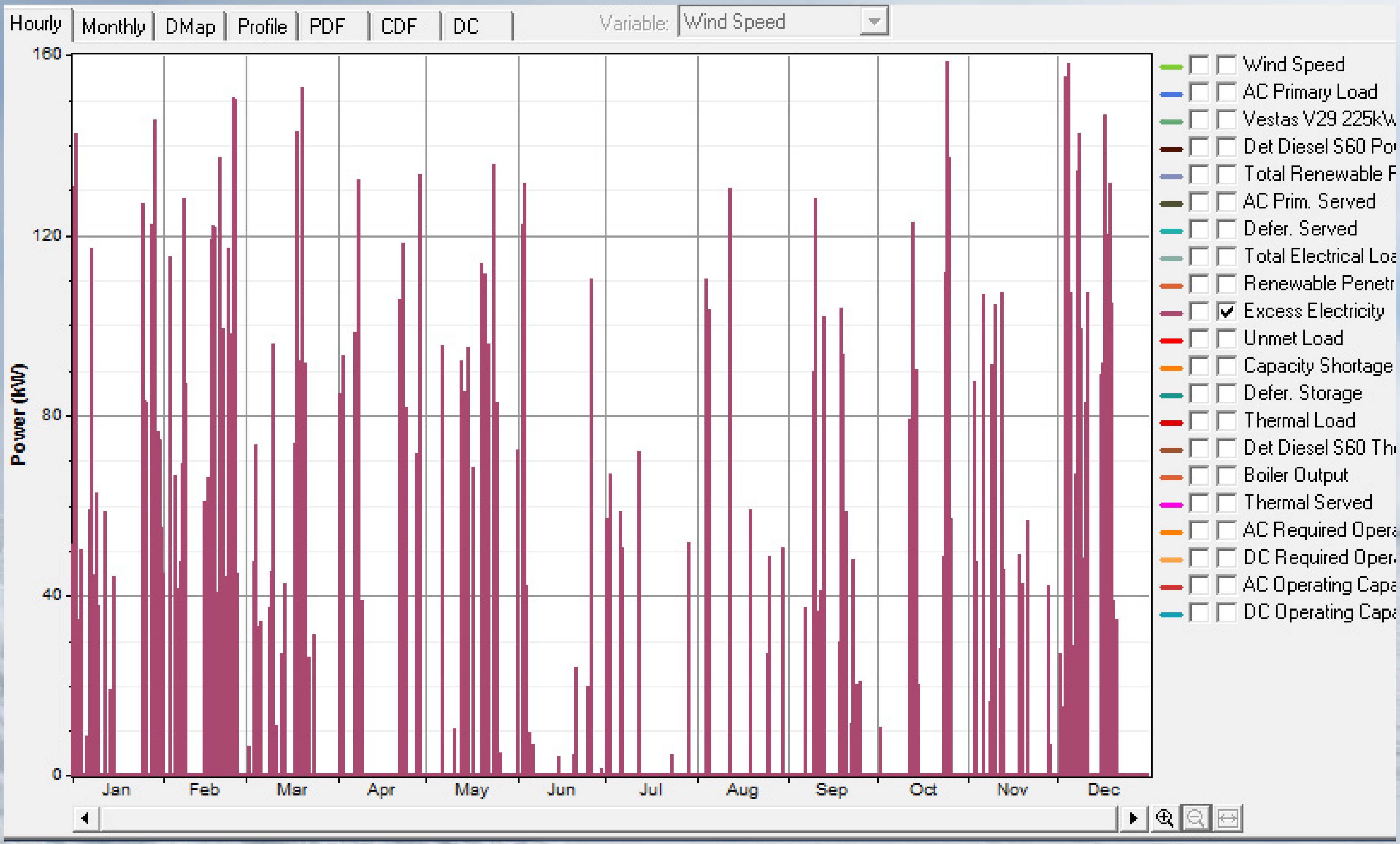
Secondary load considerations



Secondary load considerations



Secondary load considerations



Secondary load considerations

- Is there a heat recovery loop on the existing diesel system?
- How much energy (mmBTUs) currently goes into the HR loop and at what rate throughout the year?
- How much energy is pulled off the HR loop by value loads and non-value loads? At what rate throughout the year?

Secondary load considerations

- Does the "dead zone" where wind picks up and diesels throttle back reduce the energy in the HR loop below the value load demand? If this happens fairly often, consider placing an electric boiler on the HR loop before any other secondary load options.
- If the energy loss in the HR loop rarely or never drops below the value load demand, *an electric boiler on the HR loop buys you no economic benefit for your excess electricity.* You should consider value electric heat loads elsewhere in the community (school, village office, water treatment, washeteria, wastewater system, residential).
- Don't overlook the opportunity for dispatchable electric loads like pumping water.

Secondary load considerations

- At what rate do your thermal loads “consume” heat (mmBTUs)?
- Will your wind turbines produce excess energy at a rate faster than can be absorbed by your secondary thermal loads?
- If so, you will either need to curtail wind turbines and lose economic benefit, send excess power to an open air dump load (no value) or add electric boilers/heaters to value loads elsewhere in your community.

Conclusion

- Much of the needed design activity on Alaska wind-diesel systems deals with integrating wind power with the existing power plant, distribution system and community heat loads.
- Detailed understanding of how your wind turbines will interact with your existing or planned power generation and distribution is key to a successful project that will last decades.