Cold climate, icing and wind turbines

Montevideo 10.10.2019
Timo Karlsson, VTT

Questions to be answered

Who?

Why?

What?

How?

VTT – beyond the obvious

VTT is one of the leading research, development and innovation organizations in Europe. We help our customers and society to grow and renew through applied research. The business sector and the entire society get the best benefit from VTT when we solve challenges that require world-class know-how together and translate them into business opportunities.

Our vision
A brighter future is created through science-based innovations.

Our mission
Customers and society grow and renew through applied research.

Strategy
Impact through scientific and technological excellence.

258 M€
Net turnover and other operating income (VTT Group 2017)

Established in
1942

2,368
Total of personnel (VTT Group 31.12.2017)

Owned by
Ministry of Economic Affairs and Employment

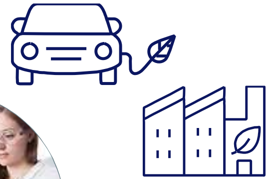
27%
Doctorates and Licentiates (VTT Group 2017)

36%
Net turnover from abroad (VTT Group 2017)

VTT's business areas

KNOWLEDGE INTENSIVE PRODUCTS AND SERVICES

- Sensing and integration
- Connectivity
- Data-driven solutions
- National Metrology Institute VTT MIKES
- Micronova manufacturing services



SMART INDUSTRY AND ENERGY SYSTEMS

- Lifecycle solutions
- Nuclear safety
- Smart energy and transport solutions
- Digital engineering
- Business innovation foresight

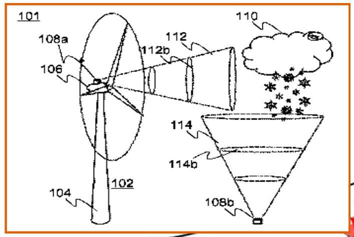
SOLUTIONS FOR NATURAL RESOURCES AND ENVIRONMENT

- Industrial biotechnology and food solutions
- Biomass processing and products
- Sustainable energy and chemical technologies

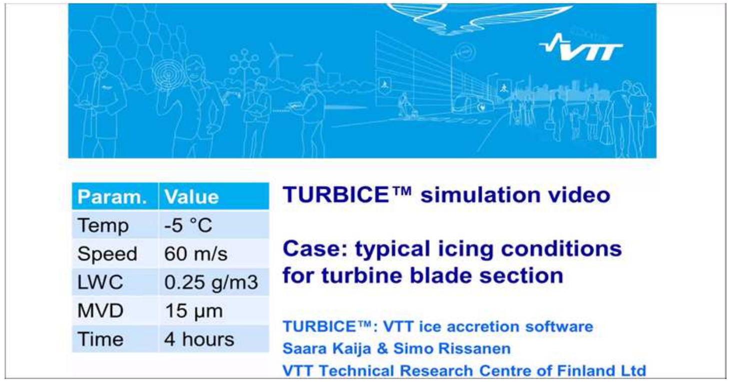
VTT Cold Climate Wind Power

VTT

Patents



[Ice accretion theory 1990s ->](#) (Youtube)

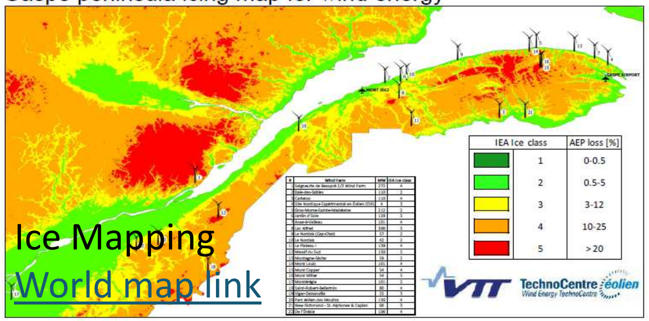


WICETEC
Ice Prevention Systems

Ice Prevention System
Commercial spin-off

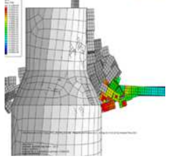
[Icing Wind Tunnel](#)

Gaspé peninsula icing map for wind energy



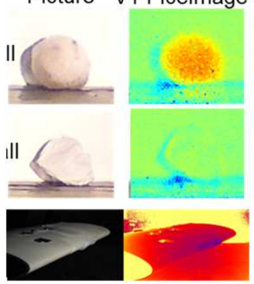
Ice Mapping
[World map link](#)

Sea ice



Ice imaging

Picture VTT IceImage®



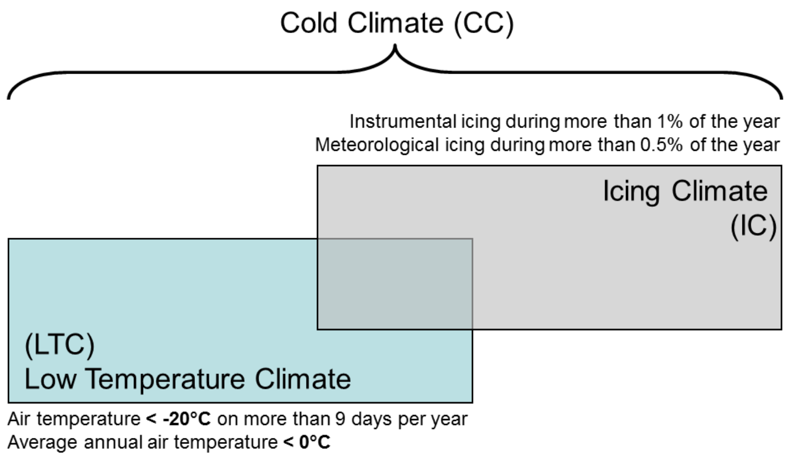
[vttresearch.com\windpower](#)

Timo Karlsson

- Worked with wind power since 2009
- Small and commercial sized wind turbines
- Lately dealing with cold-climate issues

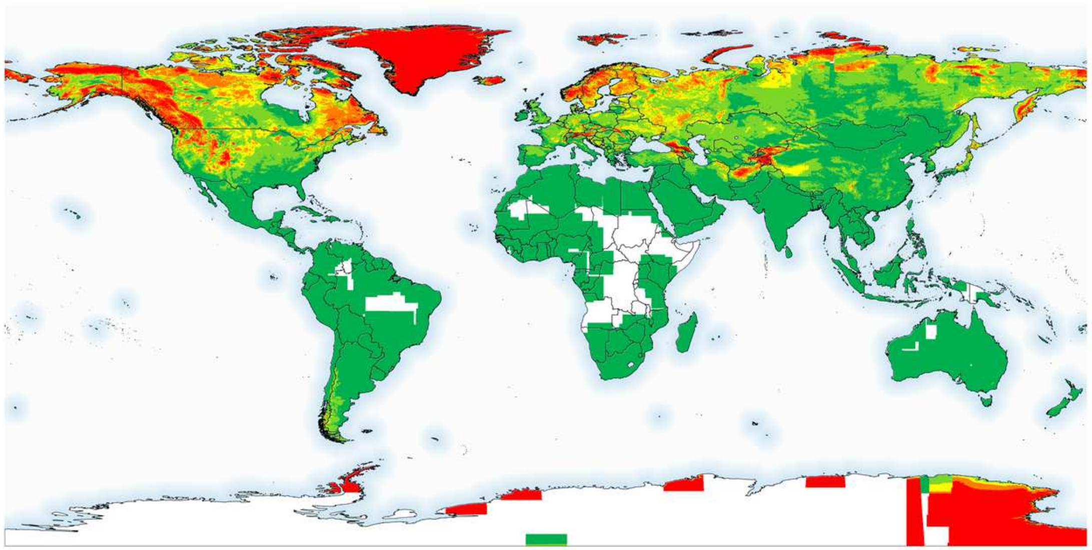
Cold Climate wind

Cold Climate (CC) in wind energy is defined as weather conditions of atmospheric icing and low ambient temperatures which expose wind turbines to conditions outside their normal design limits.



*Source: IEA Wind Task 19 Available Technologies report of Wind Energy in Cold Climates (2016 edition): http://www.ieawind.org/task_19.html

Cold Climate wind



Cumulative installed capacity by end of 2015 [MW]	
Low temperature	Icing*
40 500	86 500

http://www.windpowermonthly.com/article/1403504/emerging-cold

Wind power in cold climate – technical challenges

- External conditions
  - Low temperatures
  - Ice
  - Both
- Access
  - Snow
  - Remoteness
- Infrastructure
  - Transportation and lifting
  - Grid connection

Cold temperature adaptations

Components have an operating temperature range

- Electronics
- Lubricants
- Plastics

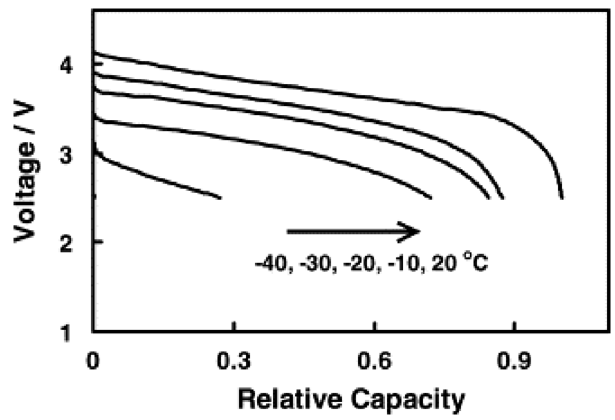
All components installed outside need to be fit for the conditions

Water condensation

- Especially in heat-generating components
- Generator, electrical cabinets
    - Heated cabinets

Batteries

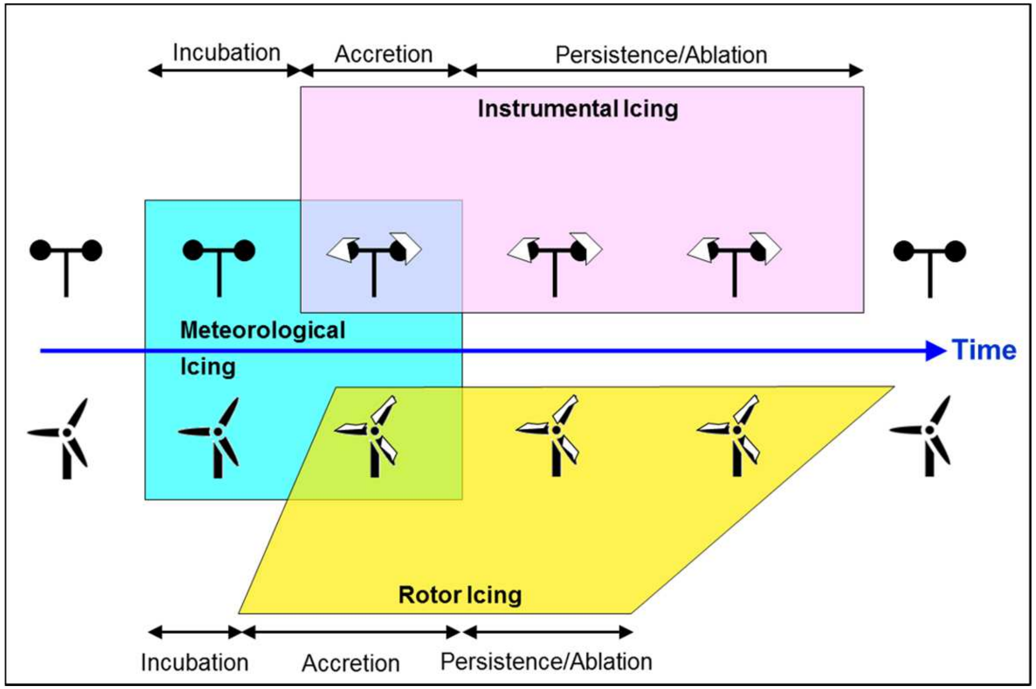
- Batteries have an optimal operating temperature range
- Capacity drops quickly if battery temperature drops below 0 °C
- To be considered:
  - Installation location
  - Weather protection
  - Heating



Discharge curves of a Li-ion cell at various low temperatures.
Source:
[1] S. S. Zhang, K. Xu, and T. R. Jow, “The low temperature performance of Li-ion batteries,” J. Power Sources, vol. 115, no. 1, pp. 137–140, Mar. 2003.

Icing

*Source: IEA Wind Task 19 Available Technologies report of Wind Energy in Cold Climates (2016 edition): http://www.ieawind.org/task_19.html



Icing

- Ice buildup on structures requires two components
  - Temperature < 0° C
  - Liquid water (droplets)
- Freezing rain
- In-cloud icing
  - Cloud droplets become supercooled at cold temperatures but remain liquid

Ice accretion theory

according to ISO 19424

Liquid water droplets & T < 0°C

Ice mass growth:

$$\frac{dM}{dt} = \alpha_1 \alpha_2 \alpha_3 \cdot w \cdot A \cdot V$$

- *A* is the cross-sectional area of the object
- V is wind speed
- w is mass concentration of the particles,
- α_1 is the collision efficiency;
- α_2 is the sticking efficiency;
- α_3 is the accretion efficiency.

Ice accretion theory

according to ISO 19424

Liquid water droplets & T < 0°C

Ice mass growth:

$$\frac{dM}{dt} = \alpha_1 \alpha_2 \alpha_3 \cdot w \cdot A \cdot V$$

- For a wind turbine blade tip
- A is the corss sectional area of the blade
- V is the blade tip speed
  - → Wind turbines quite efficient at collecting ice

Production loss

- Blade icing ruins aerodynamics ➔ Production loss
- Eventually this will stop the turbine
- Ice on the blades makes starting an already stopped turbine especially hard

IEA Ice Class	Duration of Meteorological Icing [% of Year]	Duration of Instrumental Icing [% of Year]	Production Loss [% of AEP]
5	>10	>20	>20
4	5-10	10-30	10-25
3	3-5	6-15	3-12
2	0.5-3	1-9	0.5-5
1	0-0.5	<1.5	0-0.5

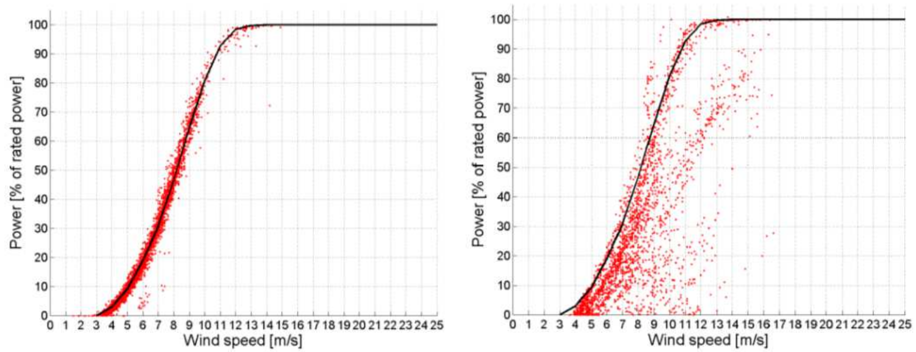


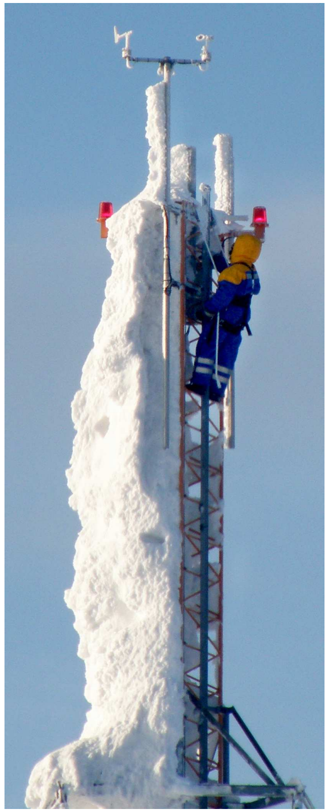
Figure 7-3: Power (% of rated power) as a function of wind speed in two cases. On the left: A power curve registered in May 2010. On the right: An ice-impacted power curve registered in November 2009.

Source: IEA Wind TCP Recommended Practice 13 2nd Edition: Wind Energy in Cold Climates
https://community.ieawind.org/task19/ourlibrary

Smaller scale

- Blades collect ice and stop the turbine
- Smaller blades (shorter chord) relatively more sensitive to icing
- Safety mechanisms like furling systems might also be affected
- Mechanical structure needs to be considered to be appropriate for the conditions

Picture: Test turbine in Pyhätunturi, Finland. Copyright VTT 1991



VTT 2010, Photo by J.Roine

Small scale icing

- One solution, esp if energy requirements low is vertical-axis rotor
- Lower tip speed
- Less sensitive to ice buildup, esp Savonius type rotors

Image sources:
Windside.com,
Hans Bernhoff, https://www.standupforenergy.se/en/research/research-portraits/hans-bernhoff/

Ice throw

- Health and safety risk
- Turbine installation in public places, industrial zones, close to roads, rooftop etc.
- Crew working on site

Ice throw

- Size of blade and installation (release) height affect the ice throw risk
- Risk and safety zones increase when turbine size goes up
- Non-zero risk of ice fall on smaller machines aswell
- Ice has to come down sometime

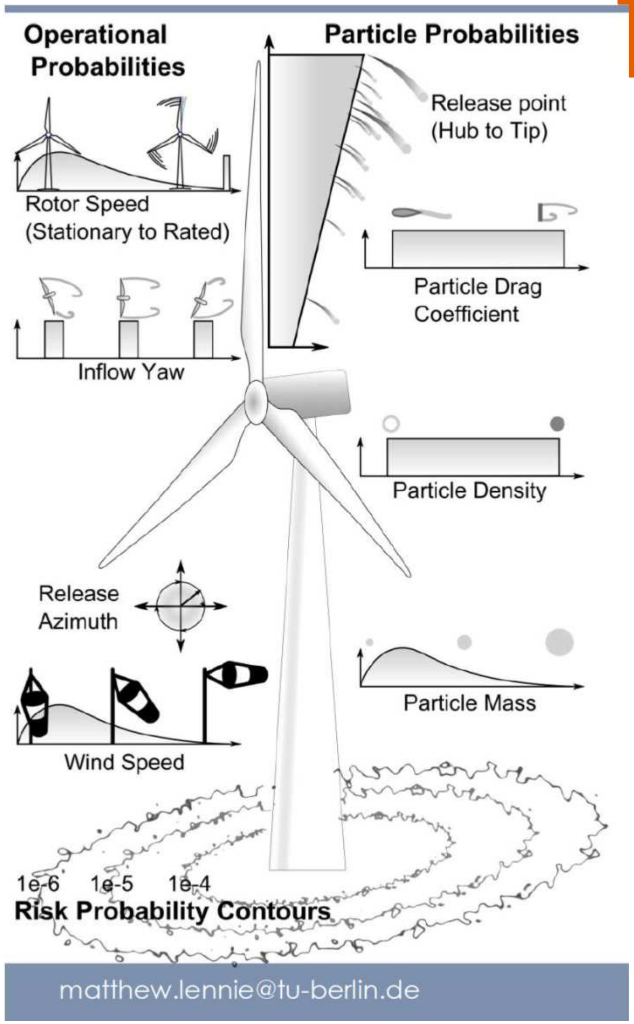


Image source: Matthew Lennie: Importance sampling for ice throw in Qblade, Winterwind conference 2019:

Ice throw

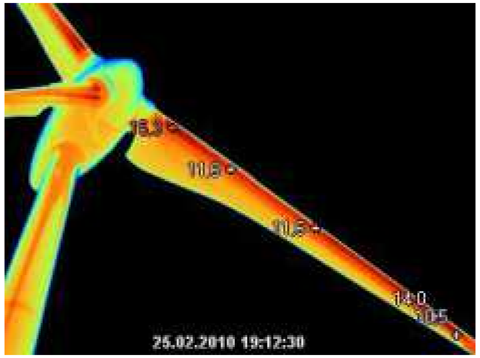
- In many Euorpean contries ice risk assessment mandatory
- Turbine owner responsibility
- Populated areas, buildings
- Risk assessment guidelines, IEA WIND Task 19 2018

Solutions, industrial-grade

1. Control
2. Direct electrothermal heating
3. Hot air
4. Coatings
5. Other

Blade heating

- Melt the ice by embedding heating elements to blade leading edge or by blowing hot air inside the blade
- Loss in efficiency, but keeps turbines rotating
- Scales down poorly
  - Increase in complexity
  - Power requirements



Blade heating

Image source:
Wicetec Oy, www.wicetec.com

Blade heating, Requirements

- Ice detection
  - On blade / off blade
  - Conditions
- Power transmission to the rotating side
  - Slip rings
  - Power supply needed aslo when turbine stopped
- Reliability
  - Maintenance hard in winter
  - Downtime → loss of €

Control of iced turbine

- Stop if ice detected
  - Minimize risk of ice accretion
  - Stopped turbine collects less ice
  - Smaller risk of ice throw
- Limit the amount of ice that will for on the blade
  - Ice accretion rate ⇔ rotor rpm
  - When ice detected move to new power curve
- Adjust controller to be less sensitive to icing caused issues
  - Don’t stop if turbine falls off from power curve

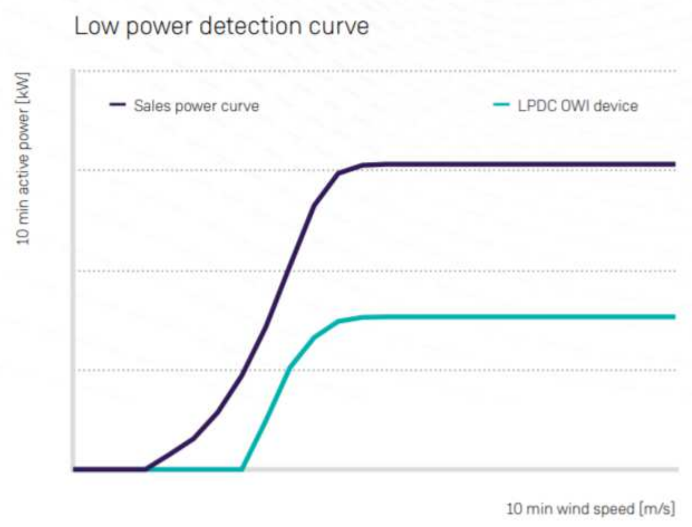


Image source:
http://m.energy.siemens.com/apps/features/service-portfolio/content/3-optimization/2-compatibility/8-operation-with-ice/170830_simwpr1703-05_owi-flyer.pdf

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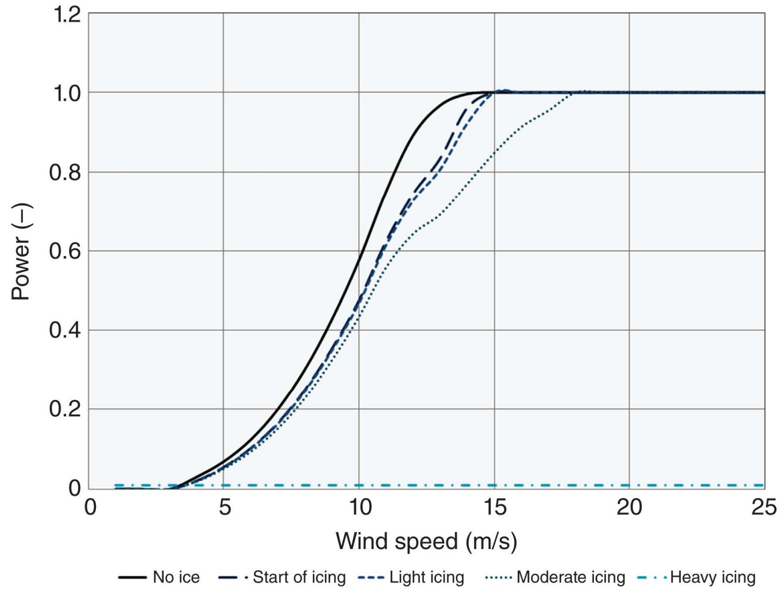
Simple mitigation

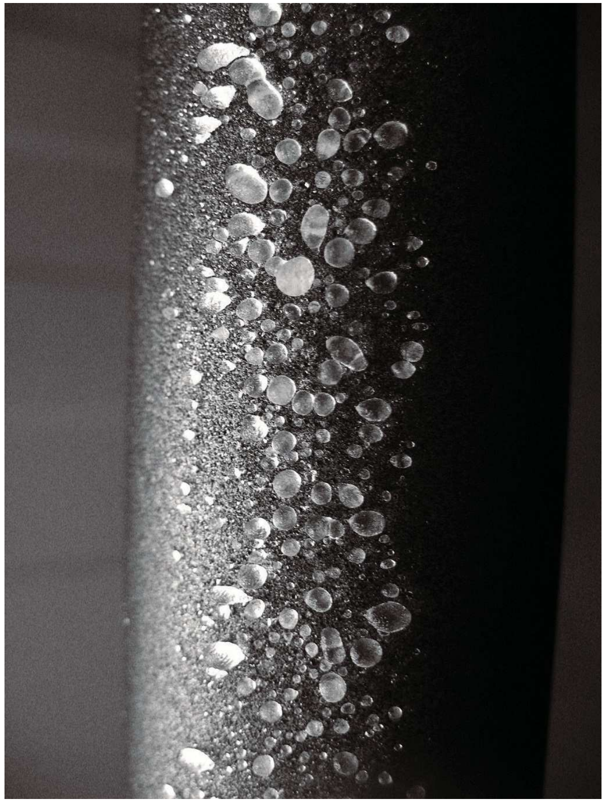
1. Measure wind speed, temperature and generator power
2. Compare generator power to power curve
3. If turbine starts slipping from power curve and temperature low, stop
4. Restart when you can verify no ice on rotor



[1] T. Wallenius and V. Lehtomäki, "Overview of cold climate wind energy: Challenges, solutions, and future needs," Wiley Interdiscip. Rev. Energy Environ., vol. 5, no. 2, 2016.

Coatings

- Icefobic coating
  - prevent ice from forming
  - Reduce friction between ice and blade
- Research still ongoing and active
  - Currently, no coating works alone
  - No ”silver bullet” found yet
- Durability issue
  - Erosion, mechanical stress
  - Re-application



Takeaways

- Cold climate conditions require special adaptations
- Icing can be a safety risk
- Production losses and unwanted stops
- Adaptations possible commercial availability only in utility scale

beyond
the obvious

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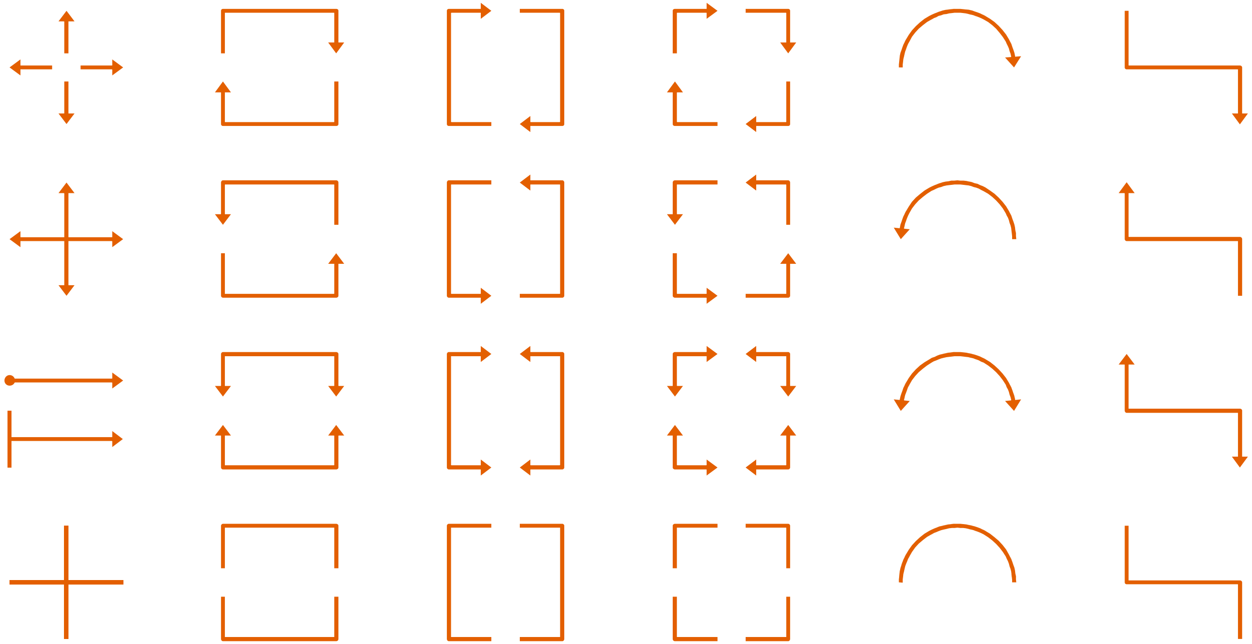
@your_account

www.vtt.fi

11/10/2019

Element library: lines and arrows.



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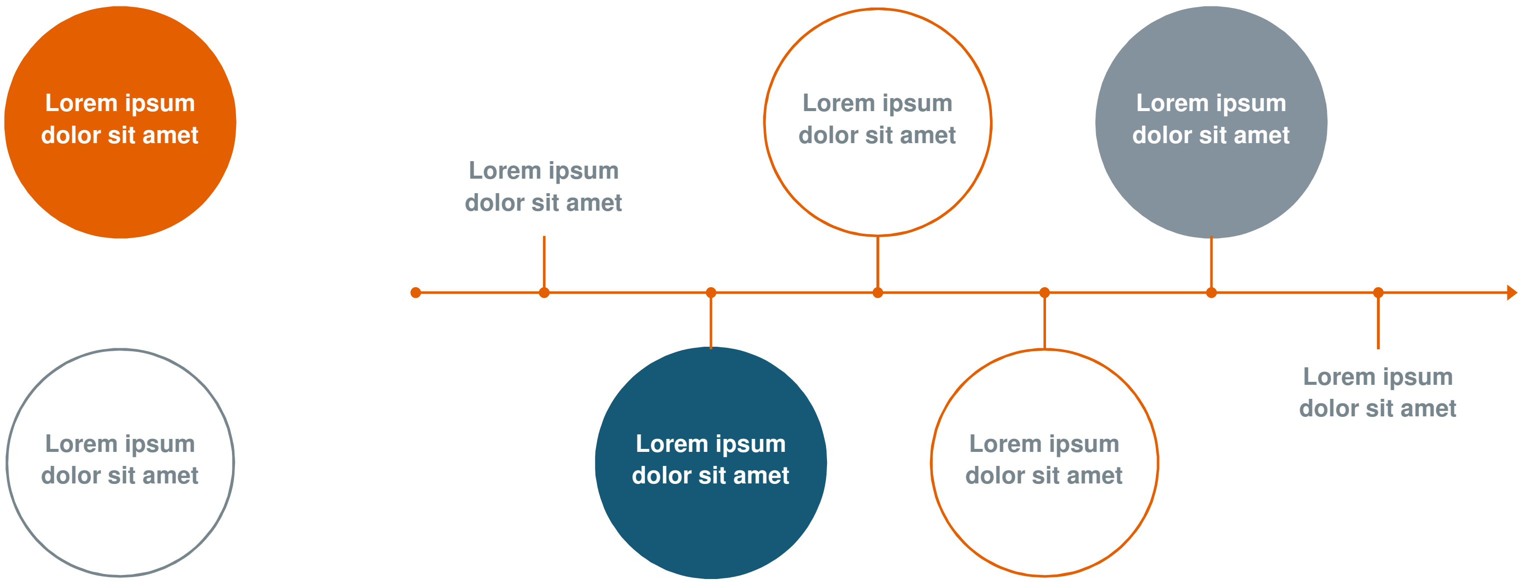
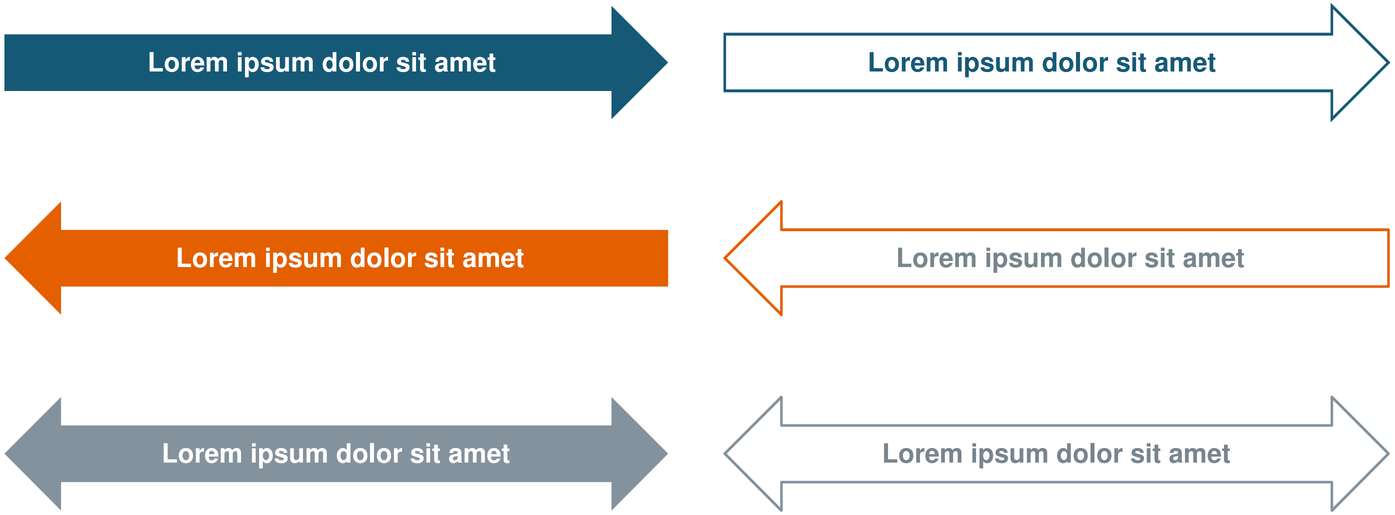


Element library: large arrows.



Element library: oval/box with arrow.

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Element library: pictograms

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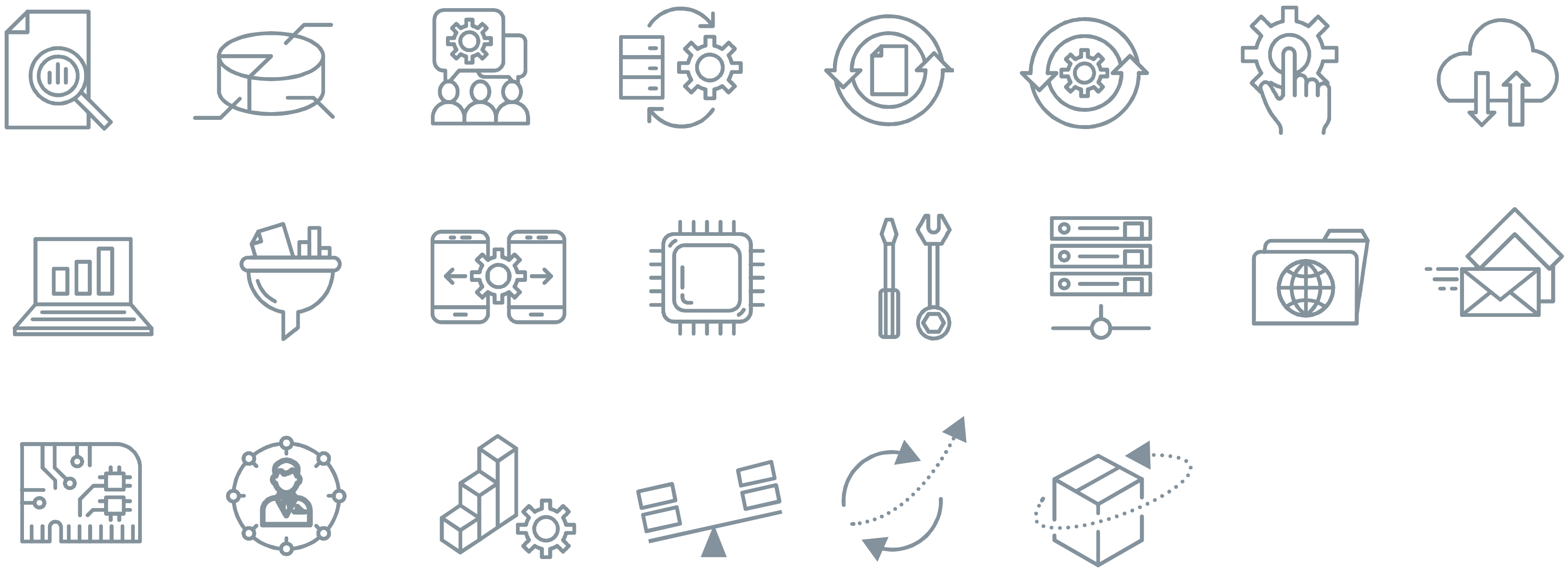

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