DNV·GL

ASSET OPERATION AND MANAGEMENT

Quantification of energy losses cause by blade icing using SCADA data

And the development of an energy loss climatology using data from Scandinavian wind farms

Staffan Lindahl

12 February 2012

Contents

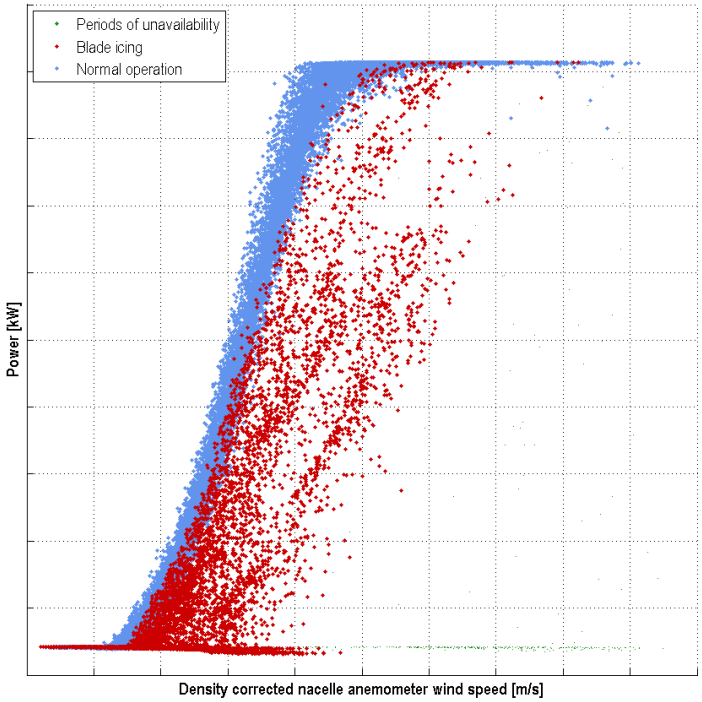
- Ice detection methods using basic SCADA data:
  - How do we identify periods of icing?
  - How do we quantify the energy losses incurred?
  - How accurate are these methods, and what are the limitation?

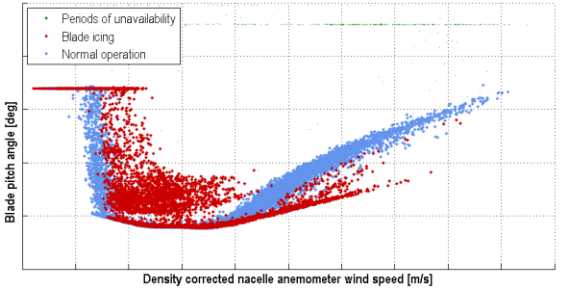
- Review of data analysed.

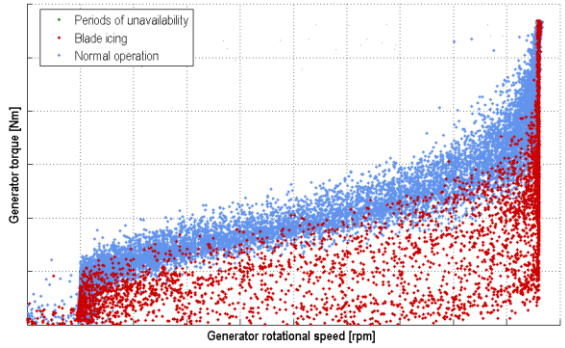
- Key questions and observations:
  - 1) What level of blade icing energy losses do we observe in data from operational wind farms?
  - 2) How much do the icing losses vary with altitude?
  - 3) Can we derive some empirical relationship between blade icing loss, wind farm location and elevation?

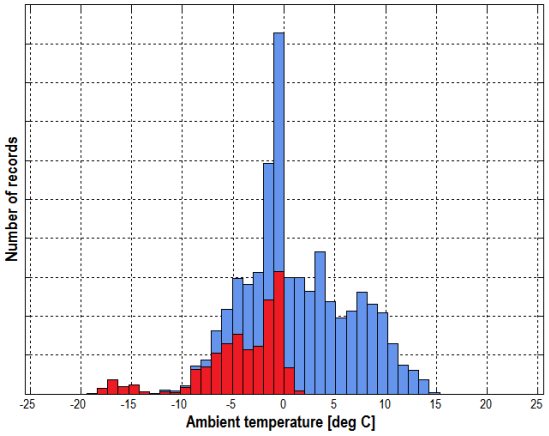
Ice detection using basic SCADA data - Identification

- Detailed review of power, wind speed, pitch, rotational speed, temperature conducted to isolate blade icing periods;
- Typically no reliable ice-sensors installed / maintained.



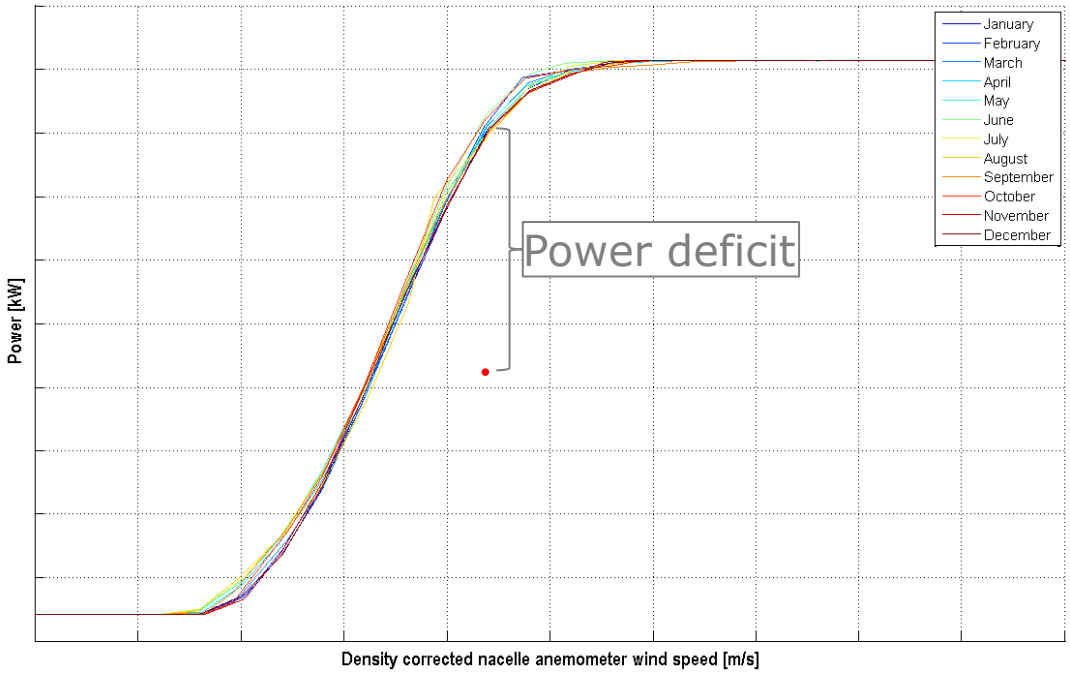


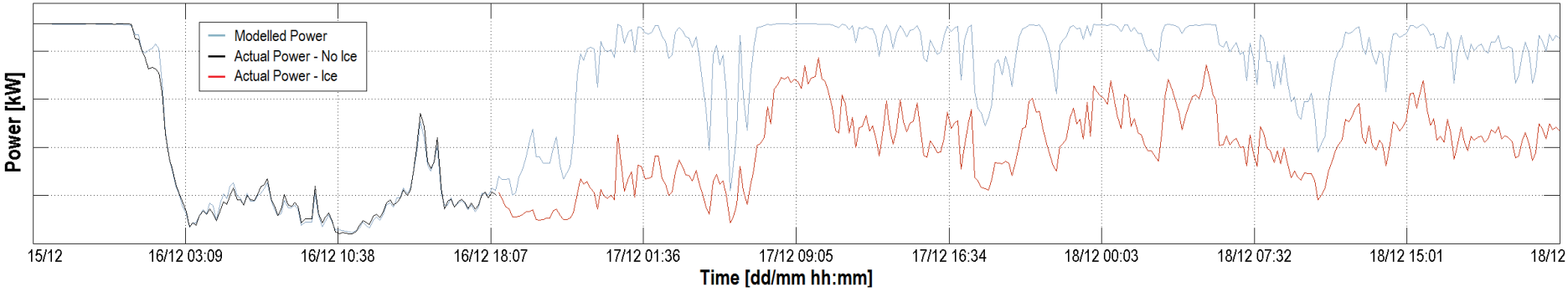




Ice detection using basic SCADA data – Loss quantification

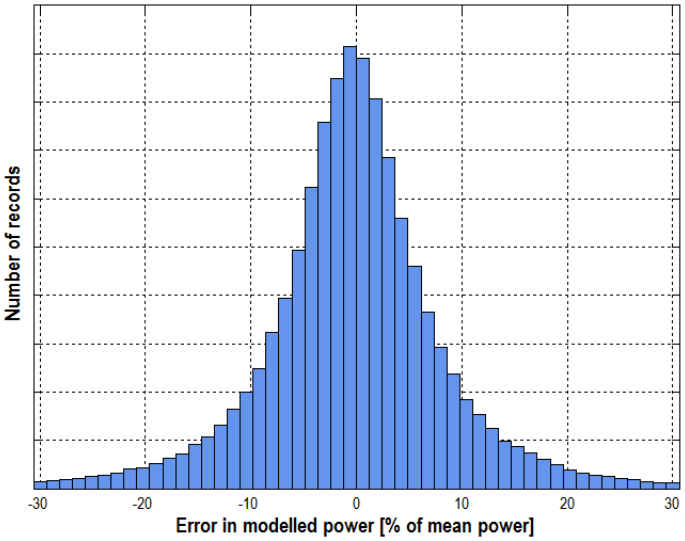
- Define 'Base-line' power curves based on data for Normal operation only;
- The energy loss is defined by the Actual less the Expected production;
- An energy loss value is calculated for each turbine and for each 10-minute record.

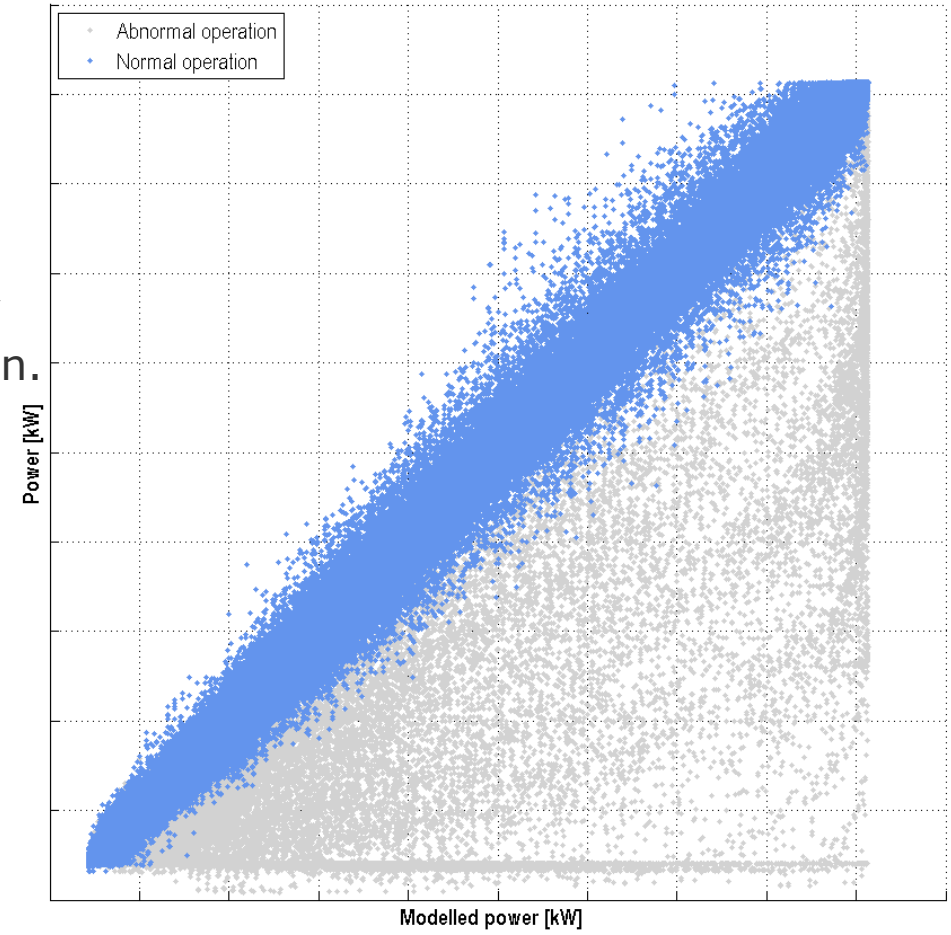




Ice detection using basic SCADA data – Accuracy and limitations

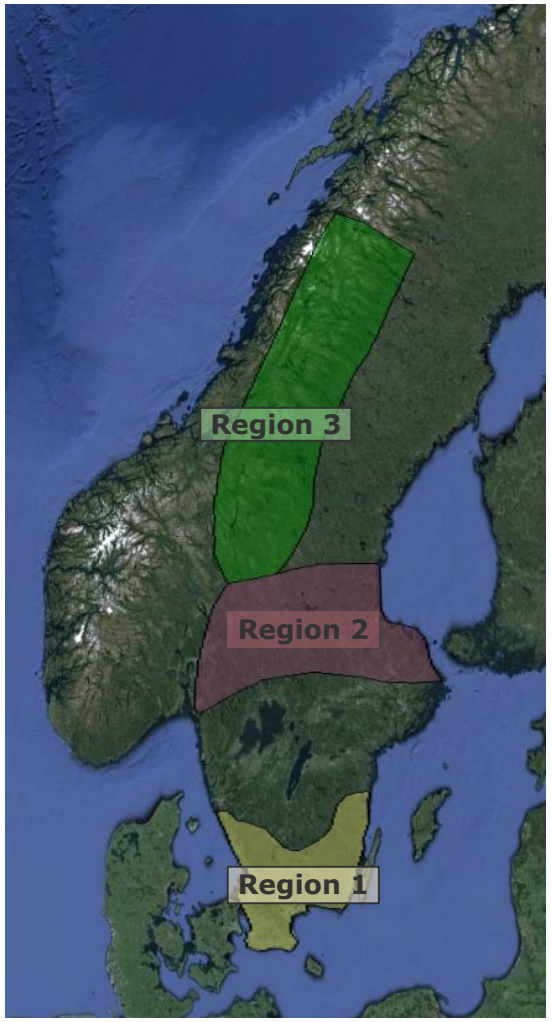
- Accuracy has been defined by the correlation of the Actual and the Predicted power during Normal performance.
- Limitations:
  - SCADA data loss;
  - Nacelle anemometry icing;
  - Un-recorded icing shut-down events;
  - Un-detected performance degradation.





Data analysed

- ~150 wind turbines spread over ~10 wind farms.
- ~20 Wind farm years, with datasets ranging from between 1 and 5 years in length.
- ~300 Turbine-years of operational data.
- Excludes projects were icing shut-down is managed manually, or where blade heating systems are in use.
- Includes projects with:
  - turbines that shut down when the controller detects blade icing;
  - projects where the turbines remain operational during blade icing periods.



Key questions

- Question 1 - What blade icing losses do we observe in data from operational wind farms?
- Question 2 - How much do the icing losses vary with altitude?
- Question 3 - Can we derive some empirical relationship between blade icing loss, wind farm location and elevation?

Key questions

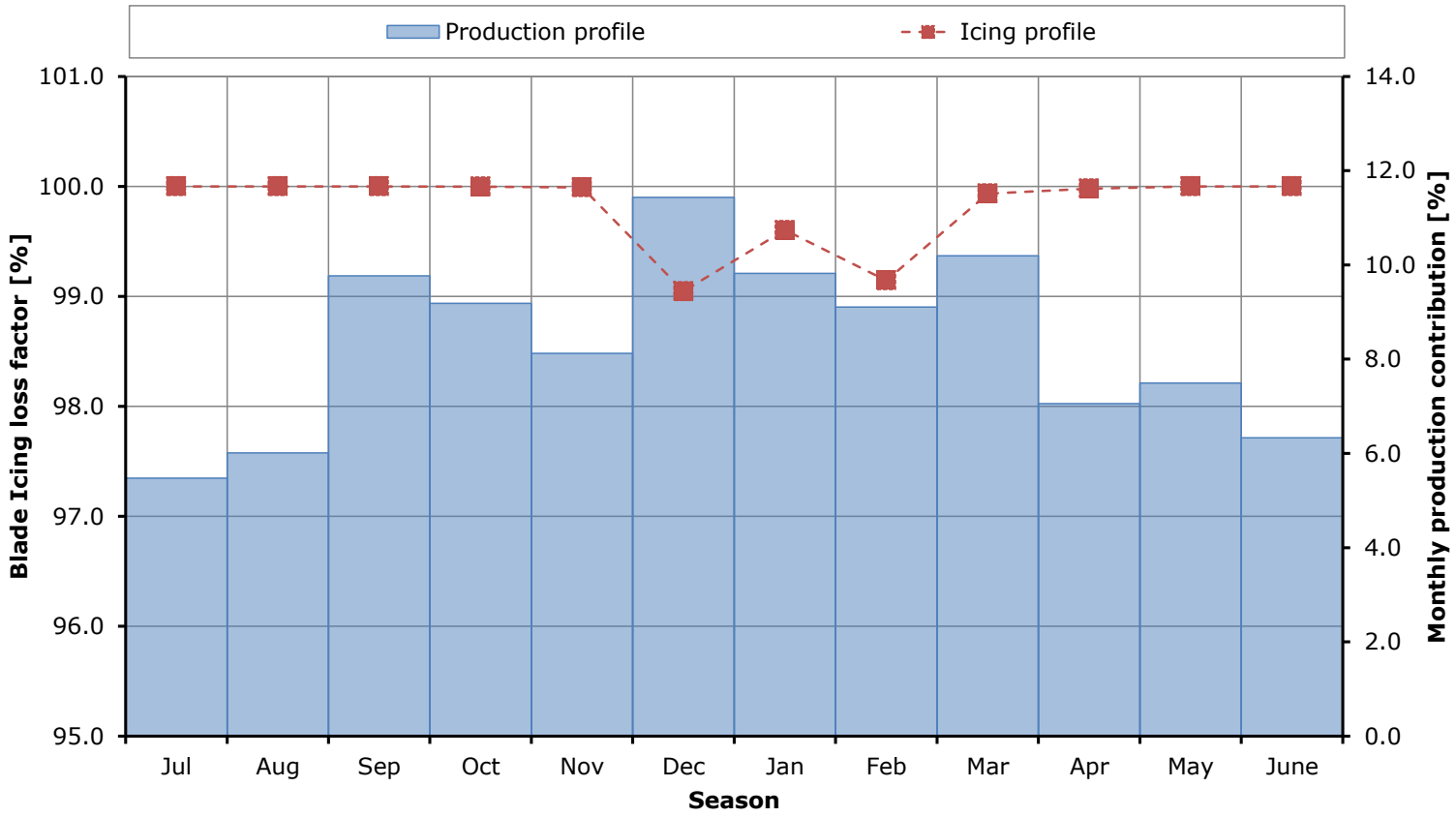
- Question 1 - What blade icing losses do we observe in data from operational wind farms?
- Question 2 -
- Question 3 - wind farm loc

- Derive seasonal ice loss profile for each region:
  - 1) Aggregate icing energy losses on monthly basis for each wind farm;
  - 2) Calculate individual wind farm monthly ice loss factor:

$$[Ice\ Loss\ Factor] = 1 - \frac{[Icing\ loss]}{[Icing\ Loss + other\ losses + Actual\ Production]}$$

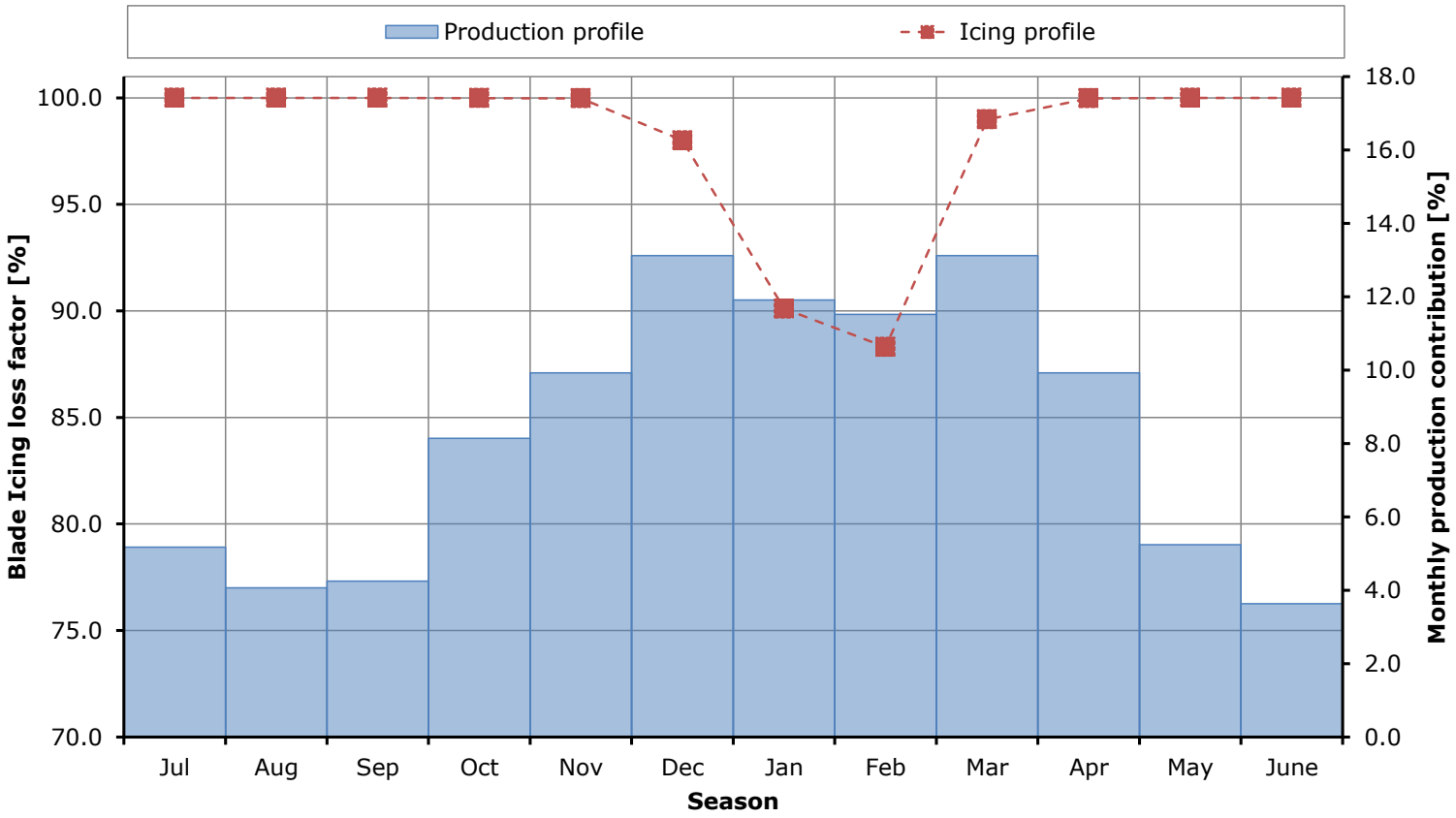
  - 3) Derive monthly icing energy loss index for each Region
    - Monthly icing index value for Region is determined from the average ice loss of the projects in the region;
  - 4) Determine annual mean ice loss for each calendar month from the average ice loss of that month in the monthly time series.

Observations – regional ice loss profiles – Region 1



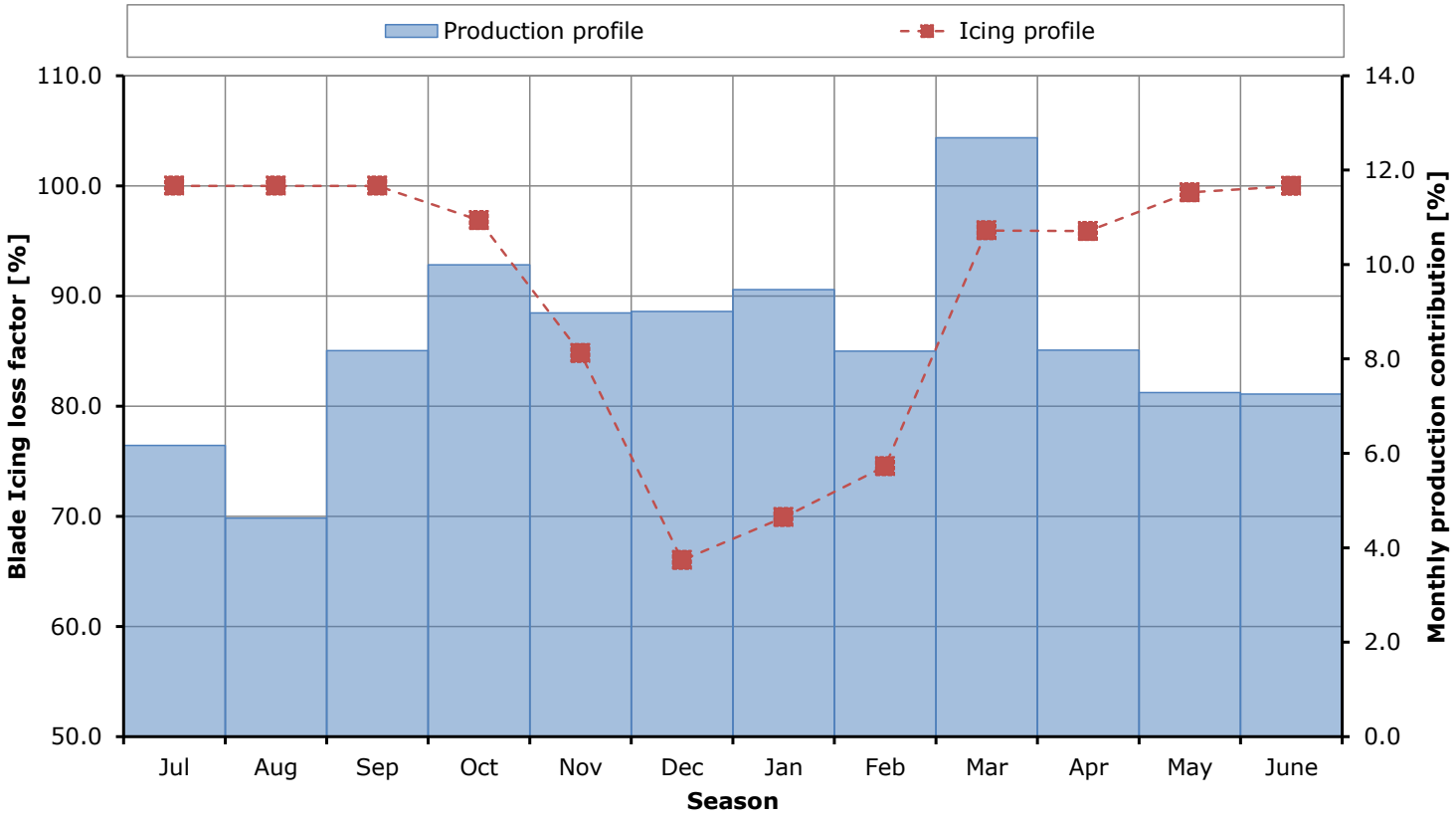
- Mean annual energy loss factor due to blade icing: 99.7%
- Varying from 99.5% to 100% between projects
- The range of turbine base elevations is approximately 100 m

Observations – regional ice loss profiles – Region 2



- Mean annual energy loss factor due to blade icing: 97%
- Varying from 96% to 98% between projects
- The range of turbine base elevations is approximately 100 m

Observations – regional ice loss profiles – Region 3



- Mean annual energy loss factor due to blade icing: 89%
- Varying from 88% to 90% between projects
- The range of turbine base elevations is approximately 100 m

Key questions

- Question 1 - What blade icing losses do we observe in data from operational wind farms?

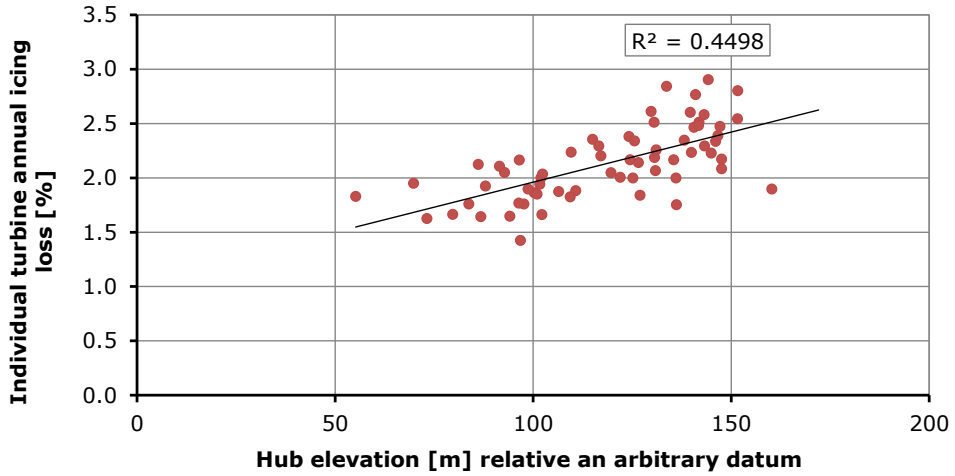
- Question 2 - How much do the icing losses vary with altitude?

- Question 3 – wind farm lo

  - 1) Aggregate blade icing energy losses by turbine for periods where all projects in region have data;

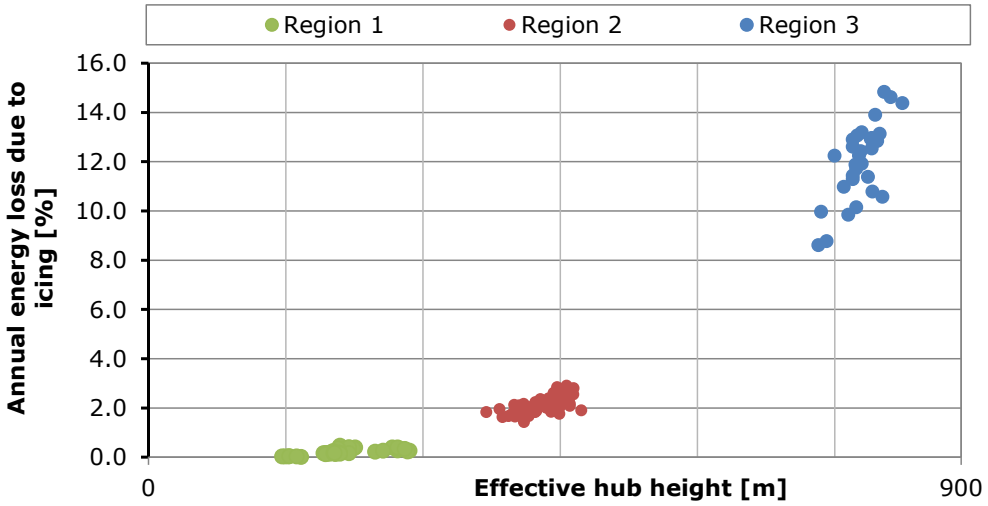
  - 2) Correlate icing losses to effective hub height;
    - Effective hub height is the elevation of the hub above mean sea level

Observations – elevation sensitivity



- Region 2
- Data from ~70 wind turbines
- Some correlation of hub elevation and blade icing losses
- Similar observations in the other regions, but gradients differ

- All regions
- Data from ~150 wind turbines
- Polynomial relationship?
- Gradients:
  - Region 1: 2% km^{-1}
  - Region 2: 9% km^{-1}
  - Region 3: 55% km^{-1}



Key questions

- Question 1 - What blade icing losses do we observe in data from operational wind farms?

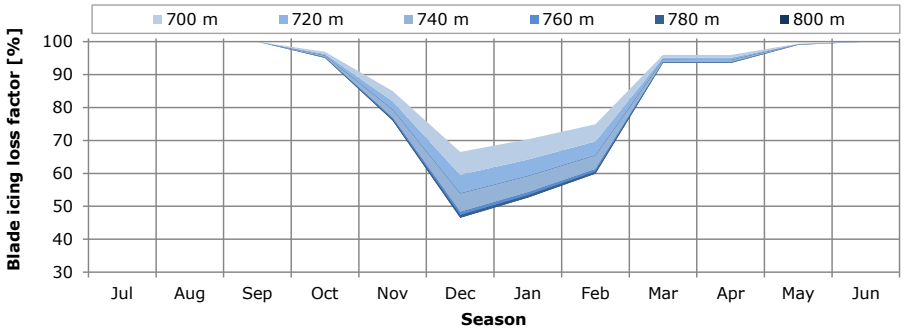
- Question 2 - How much do the icing losses vary with altitude?

- Question 3 - Can we derive some empirical relationship between blade icing loss, wind farm location and elevation?

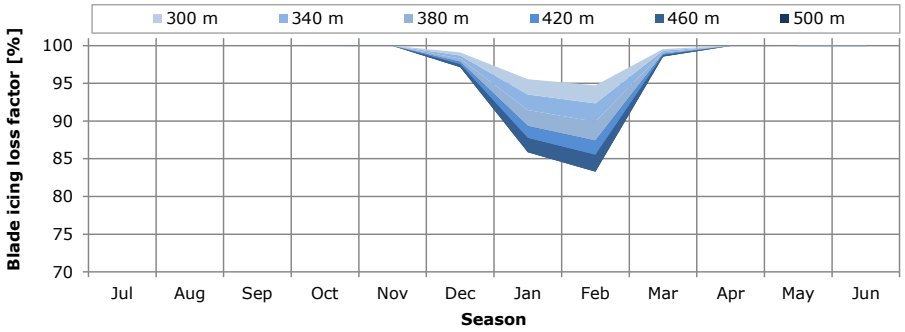
  - We have combined the regional icing loss profiles with the information on the sensitivity of icing losses to changes in effective hub height.

Empirical relation between icing and location?

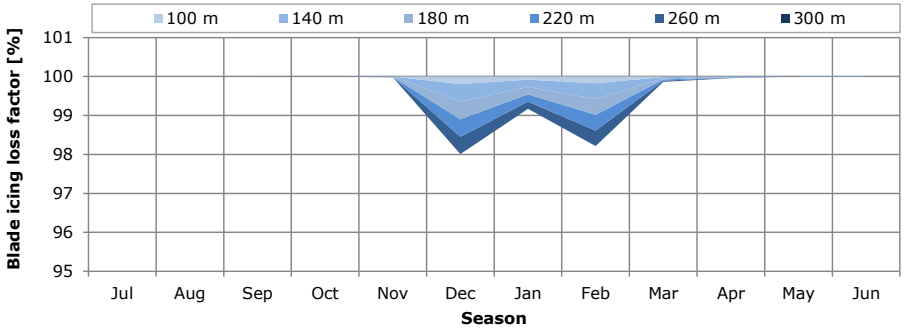
- Seasonal icing profiles by effective hub-height for each Region



- Region 3
- Mean annual losses:
  - 7% @ 700m to
  - 13% @ 800m



- Region 2
- Mean annual losses:
  - 1% @ 300m to
  - 3% @ 500m



- Region 1
- Mean annual losses:
  - 0% @ 100m to
  - 0.5% @ 300m

Conclusions

- There is great scope for accurately determining the actual energy losses caused by blade icing using standard SCADA data – it is a bit laborious.

- There is a great range in the icing losses observed, with close to zero losses at some sites in the south, to losses exceeding 10% in the uplands in the north;

- There is typically a discernable correlation between icing losses and effective hub height. At high elevations the sensitivity to changes in elevation appears to be very high indeed.

- There seems to be good scope for defining empirical relationships of expected blade icing losses based on the specific location of wind farms. However, much more operational data needs to be analysed to develop robust relationships.

Quantification of energy losses cause by blade icing using SCADA data

And the development of an energy loss climatology using data from Scandinavian wind farms

Staffan Lindahl
Staffan.Lindahl@dnvgl.com
+44 (0) 117 972 9900

www.dnvgl.com

SAFER, SMARTER, GREENER