ENERCON Rotor Blade Heating System fleet performance assessment

Montreal, April 19th 2021

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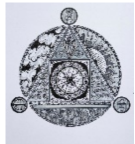
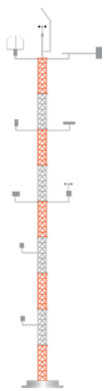
Finding the Philosopher's stone…



?

bitcoin

ice_{mast}

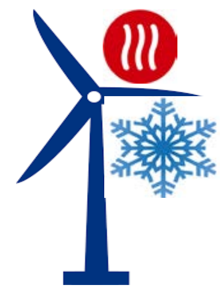


$f(ice_{mast}, x, y, z, t, \alpha, \varphi, etc.)$

Estimated icing loss: $ice_{loss\_estimated}$

?

IPS performance



Estimated icing loss: $ice_{loss\_estimated\_RBHS}$

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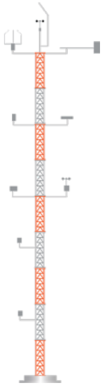
Estimating icing losses during development of a windfarm

ice_{mast}



?

$f(ice_{mast}, x, y, z, t, \alpha, \varphi, etc.)$

Estimated icing loss: $ice_{loss\_estimated}$

IPS performance

?

Estimated icing loss: $ice_{loss\_estimated\_RBHS}$

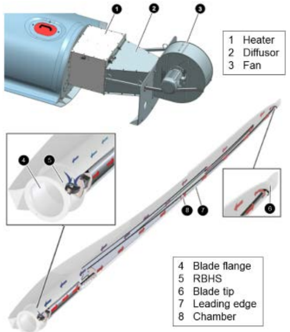
High uncertainties in icing losses estimates

Additional level of conservatism

Underestimates P50 / P90

Increased financing costs

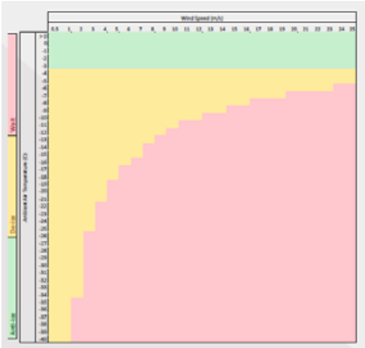
Assessing icing losses



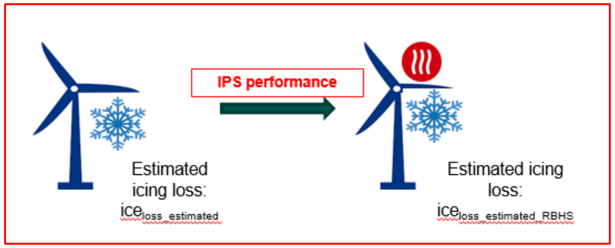
Technology (IPS, WTG, blade shape)

Operation mode

Meteorological variables (V, T, RH etc.)



(1)



Ice severity

Ice type

Windfarm effects

(1) Borealis Wind – Validation of a Hot Air Blade de-icing retrofit (Winterwind 2019)

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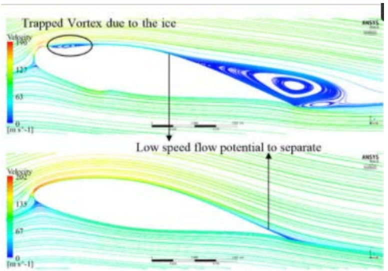
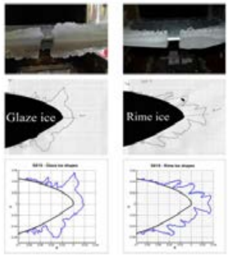
Assessing icing losses

How to assess IPS performance?

Scientific approach	Statistical approach
Scientific approach IPS performance = f(technology, operation mode, wind speed, temperature, ice type, ice severity etc.)	**Statistical approach** Data analysis
Complex relationships High investment in research and validation Site adapted solution	Low investment if data is available Needs robust dataset (geographical location, number of winters…) Not a site specific solution

1





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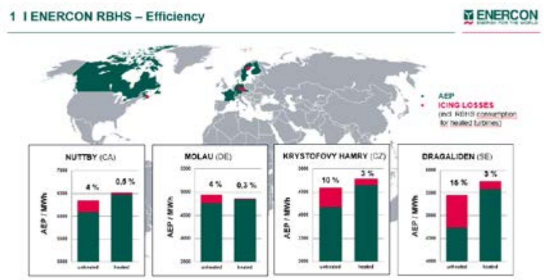
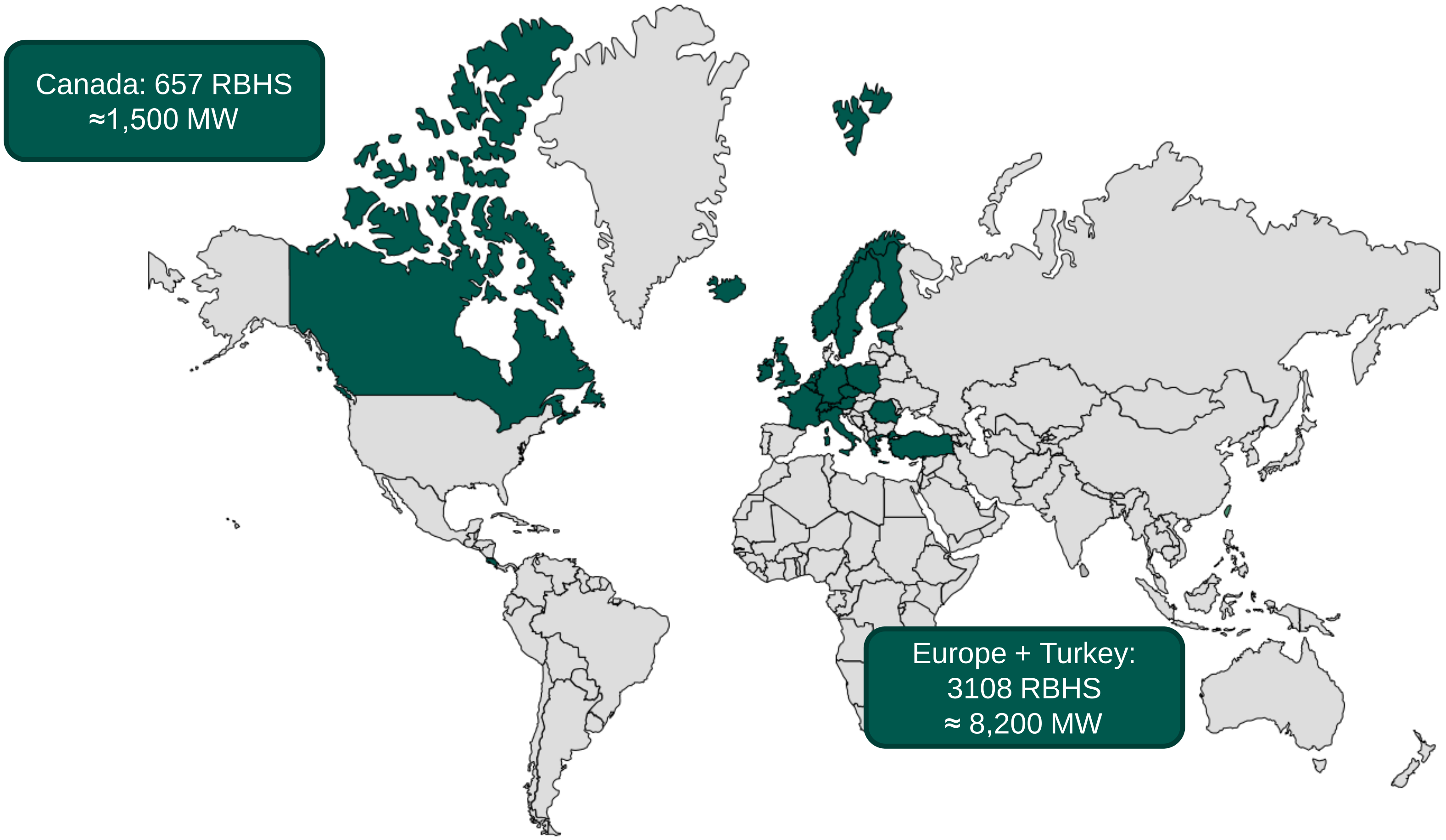


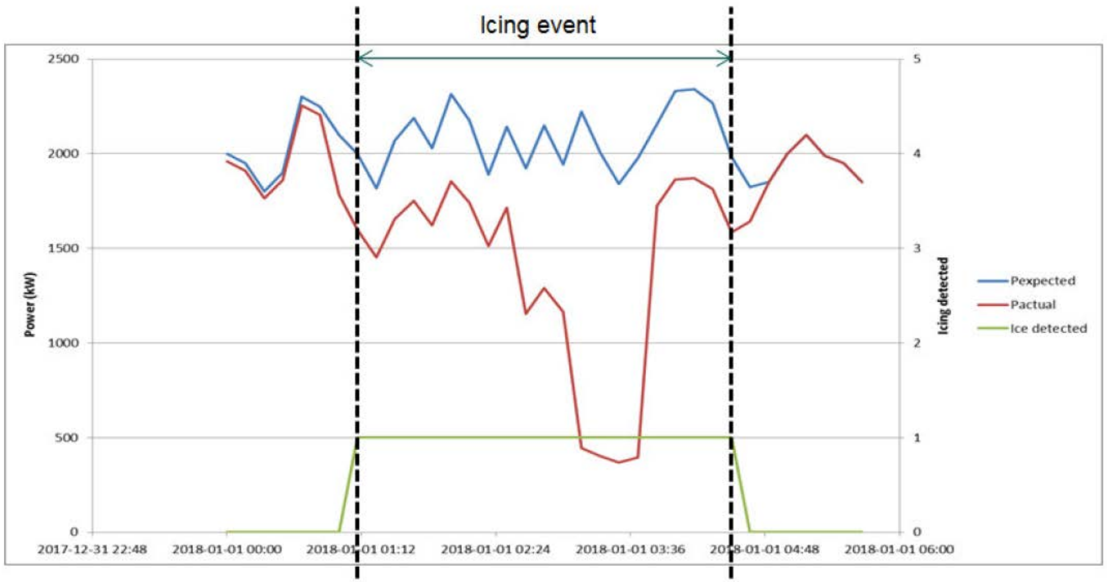
ENERCON RBHS database

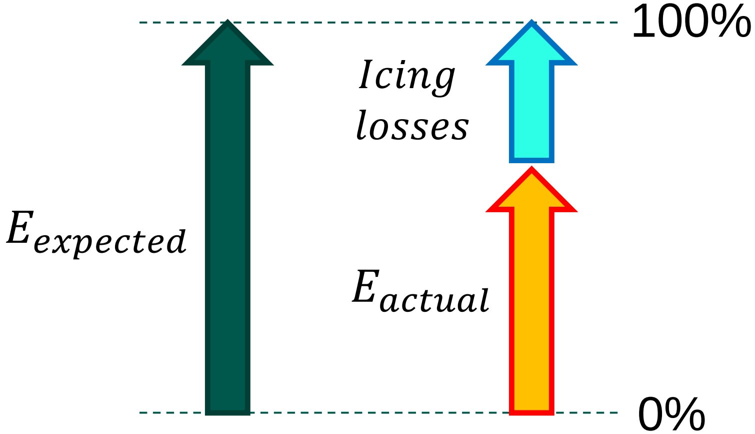
- ENERCON Rotor Blade Heating Systems (RBHS) installed worldwide



Metrics to assess IPS performance

- Ice Production Ratio (IPR):
  - Introduced by Nergica*
  - How much energy was produced during an icing event compared to what the turbine should have produced?
  - Simple way to quickly assess IPS performance





$$IPR = \frac{E_{actual}}{E_{expected}}$$

Quantifying advantages of wind turbine blade heating systems in the Canadian icing climate – Introduction of the Ice Production Ratio, N.Swytink-Binnema, Nergica, Canwea 2019

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Metrics to assess IPS performance

- Ice Production Ratio Matrix
  - IPR by wind speed and temperature
  - Based on several studies (Université Laval, Borealis, etc.)
  - IPS performance is affecting by thermal losses (conduction, convection)
  - Integrate site specific aspects

PR100 all years	3	5	7	9	11	13	15	17	19	21	23	25	weighted_average
>= 4													n/a
3													n/a
1	0.57	0.68	0.75	0.77	0.79	0.81	0.90	0.94	0.96	0.96	0.92		0.81
-1	0.56	0.64	0.66	0.66	0.66	0.67	0.75	0.87	0.95	0.96	0.97		0.69
-3	0.42	0.60	0.65	0.66	0.65	0.63	0.75	0.89	0.93	0.94	0.93	0.91	0.69
-5	0.42	0.62	0.64	0.66	0.65	0.66	0.79	0.91	0.94	0.94	0.94	0.91	0.70
-7	0.45	0.61	0.63	0.66	0.68	0.72	0.85	0.93	0.95	0.95	0.93		0.71
-9	0.38	0.61	0.67	0.70	0.71	0.79	0.89	0.94	0.95	0.95			0.76
-11	0.49	0.64	0.70	0.71	0.71	0.77	0.91	0.95	0.96	0.95	0.94	0.90	0.77
-13	0.49	0.65	0.70	0.72	0.70	0.72	0.89	0.94	0.95	0.95	0.94	0.90	0.79
-15	0.40	0.64	0.72	0.77	0.76	0.77	0.89	0.94	0.95	0.95	0.94		0.82
-17	0.39	0.61	0.71	0.77	0.81	0.88	0.92	0.91	0.92	0.90	0.87		0.83
-19	0.19	0.60	0.71	0.77	0.82	0.87	0.93	0.93	0.92	0.91			0.85
-21		0.54	0.68	0.79	0.82	0.87	0.92	0.94	0.94	0.94	0.93		0.87
-23		0.46	0.66	0.77	0.80	0.82	0.90	0.94	0.95	0.94	0.93		0.87
-25		0.67	0.65	0.76	0.78	0.81	0.91	0.94	0.93	0.94	0.94	0.93	0.88
< -26							1.33						1.33
weighted_average	0.47	0.63	0.67	0.69	0.70	0.72	0.85	0.92	0.94	0.94	0.93	0.91	0.75

$$IPR = \left(\frac{E_{actual}}{E_{expected}}\right)_{V,T}$$

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The methodology

ENERCON WEC Database

- At least 3 winters
- Dominant icing markets
- Statistical representation of icing fleet
- Windfarm with more than 1 WEC
- WEC model ≥ E-70

↓

Filtered Database → Data QC → Max 10 turbines / WF

The methodology

Canada, Sweden, Austria, Turkey, France, Switzerland

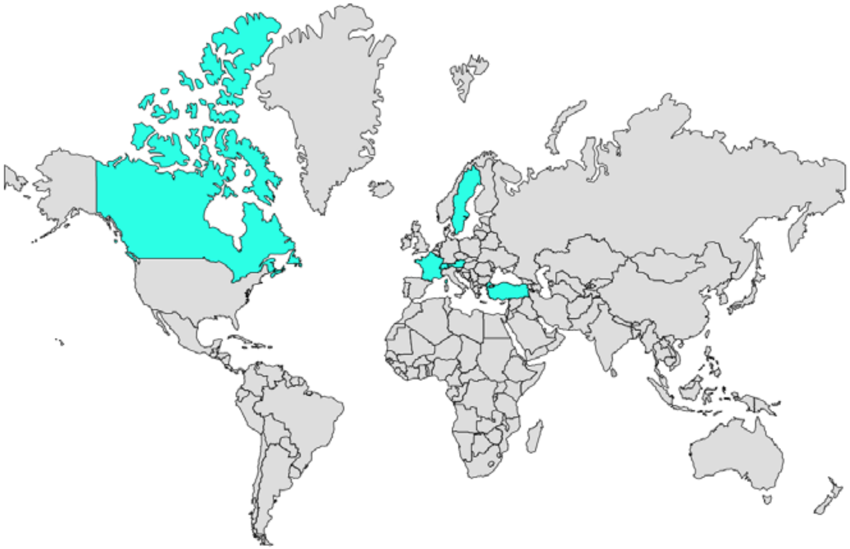
32 Windfarms

E-70, E-82, E-92, E-101

1022 turbine-years

69 years of icing events

Test Database

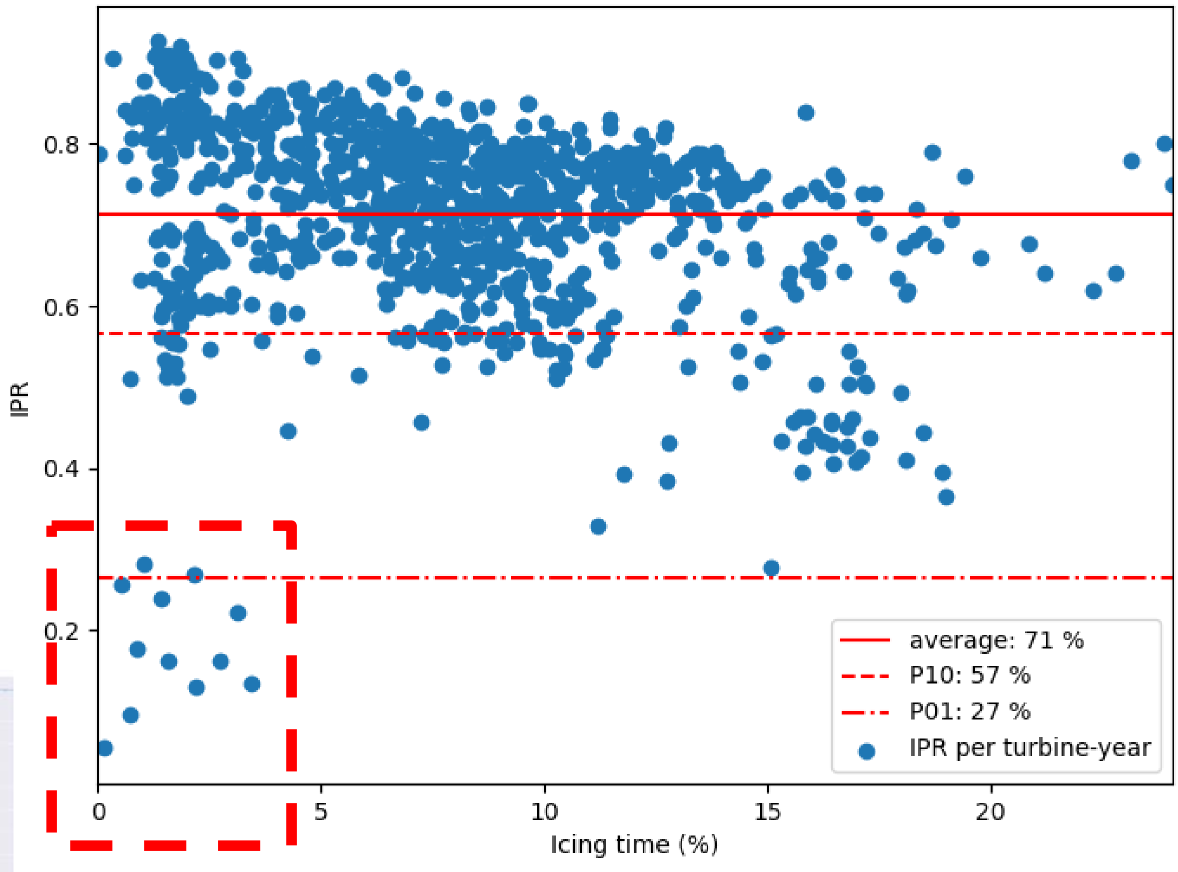


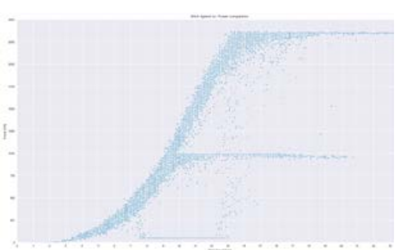
Results IPR

Mean

P10

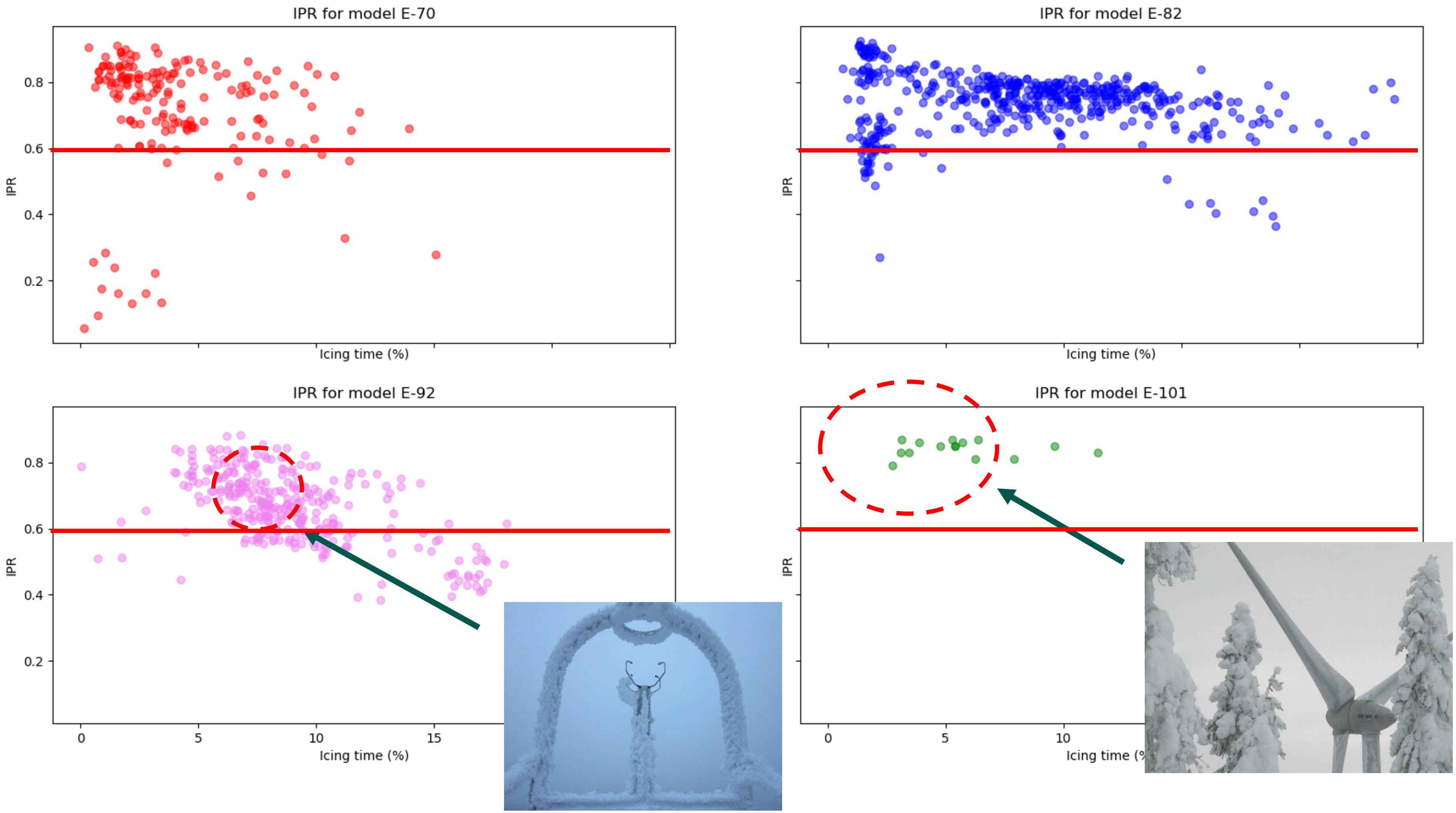
P01



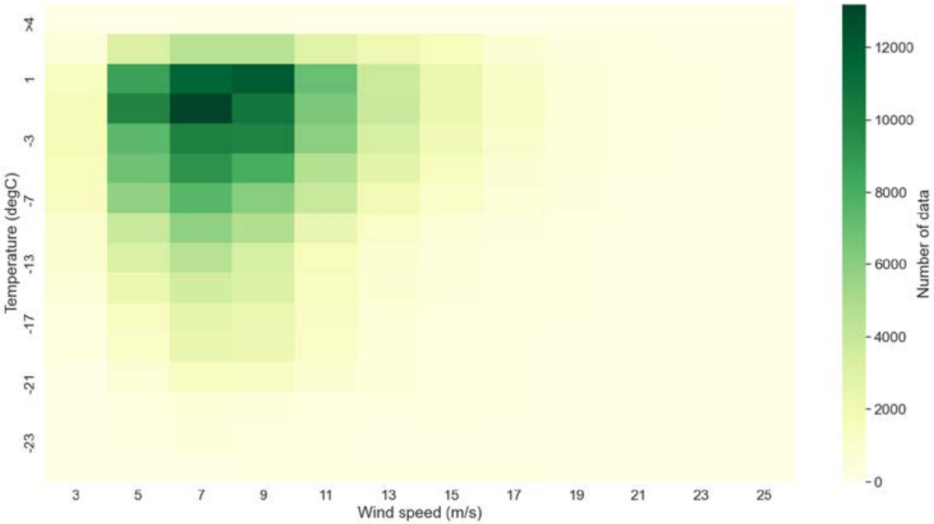


Specific operation mode

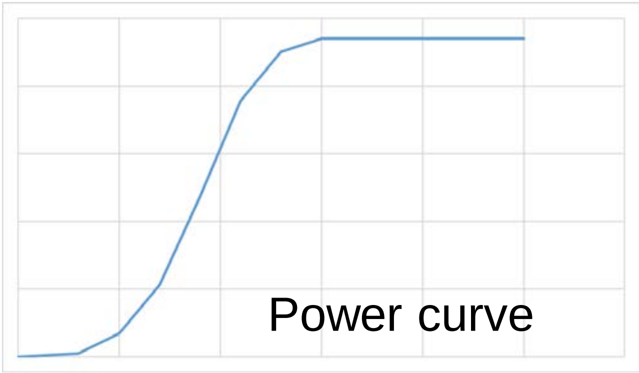
Results IPR


IPR for model E-70
IPR for model E-82
IPR for model E-92
IPR for model E-101
IPR
0.2
0.4
0.6
0.8
Icing time (%)
0
5
10
15

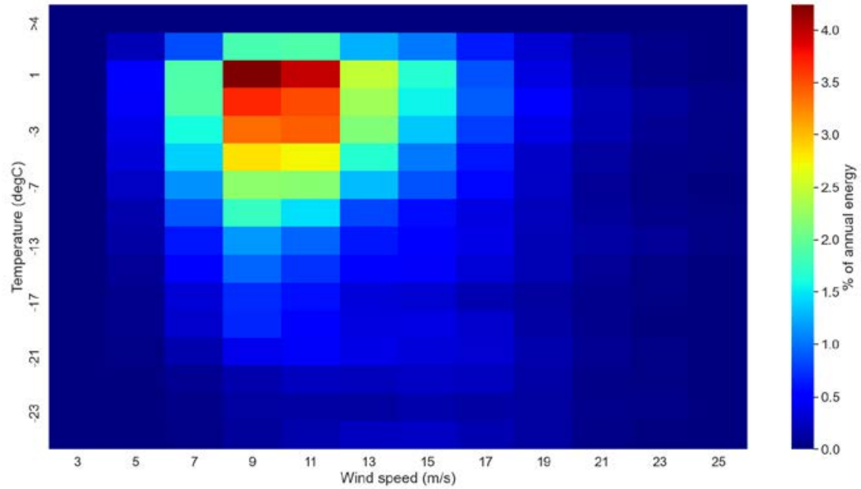
Results IPR matrix



Wind distribution

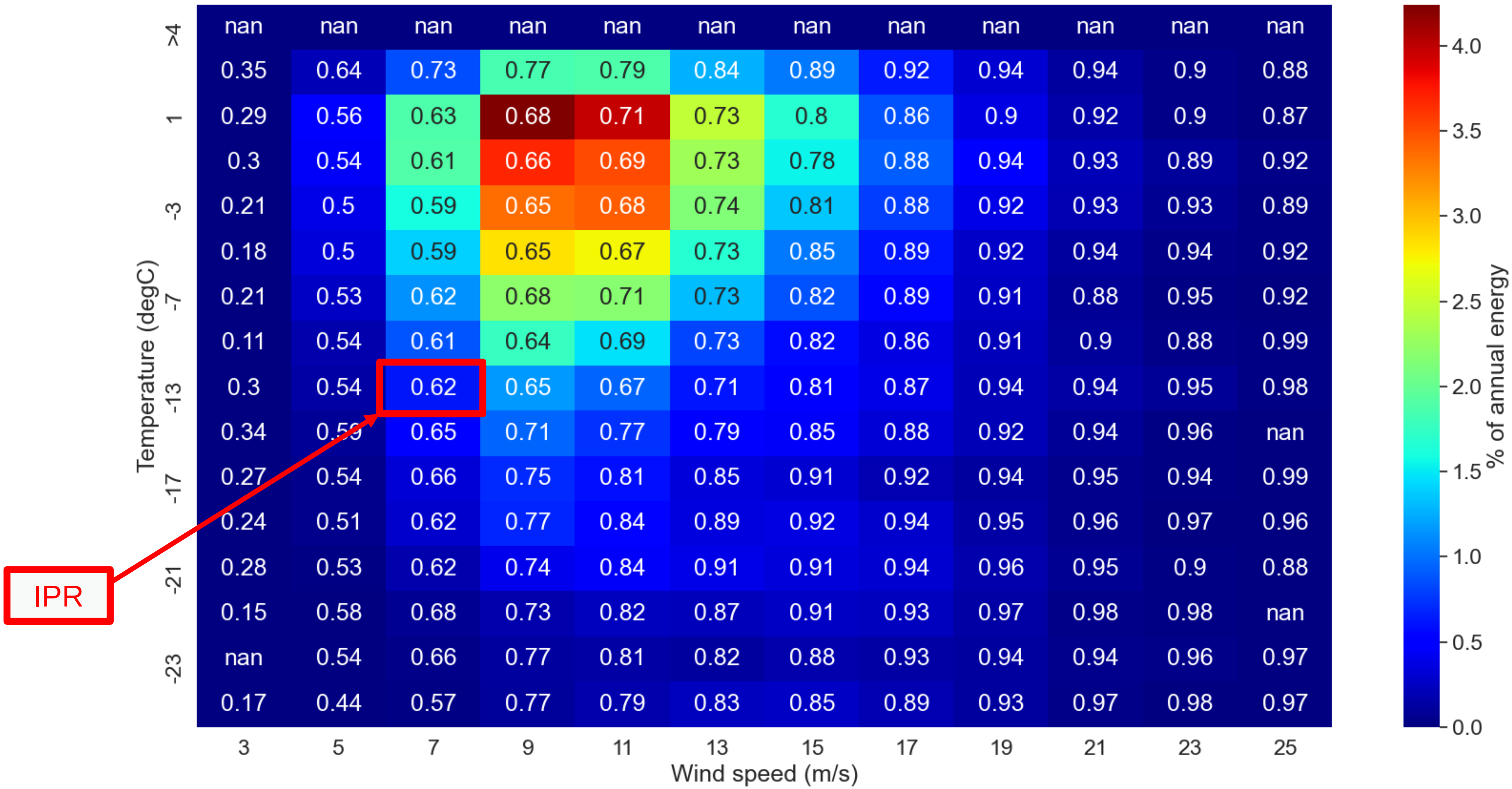


Power curve



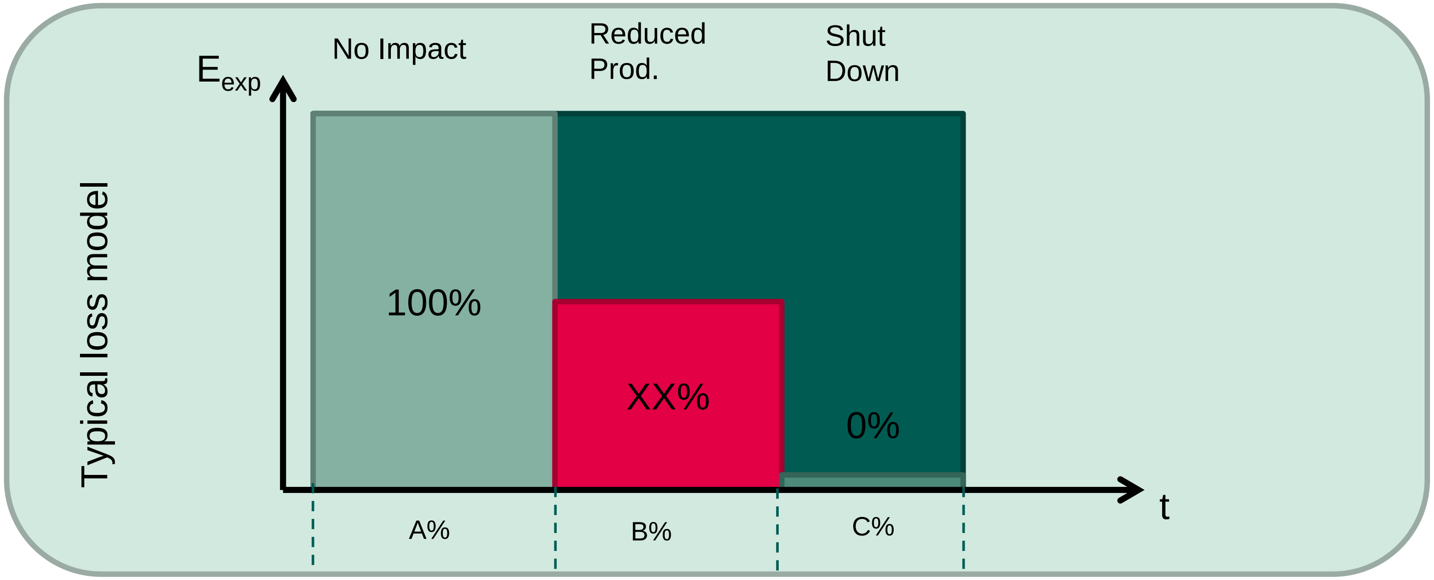
Energy distribution

IPR vs % of annual energy



Case study

$$IPR = \frac{E_{actual}}{E_{expected}}$$



Site 1

Frequent and light icing

Site 2

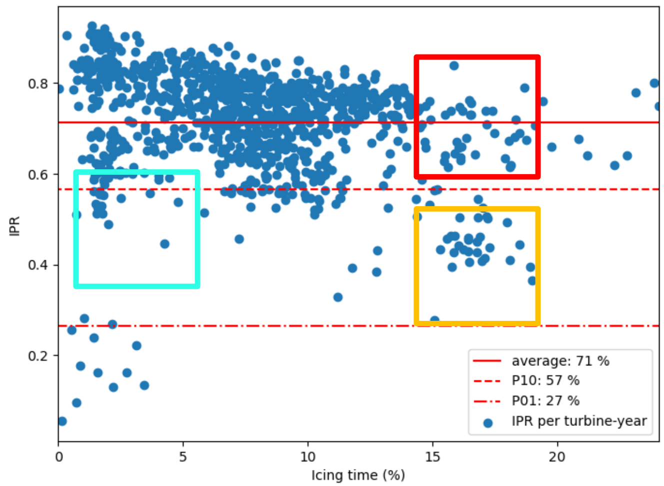
Frequent and severe icing

Site 3

Infrequent and severe icing

Generic estimated (conservative) heating efficiency = 30%

ENERCON Rotor Blade Heating System fleet performance assessment



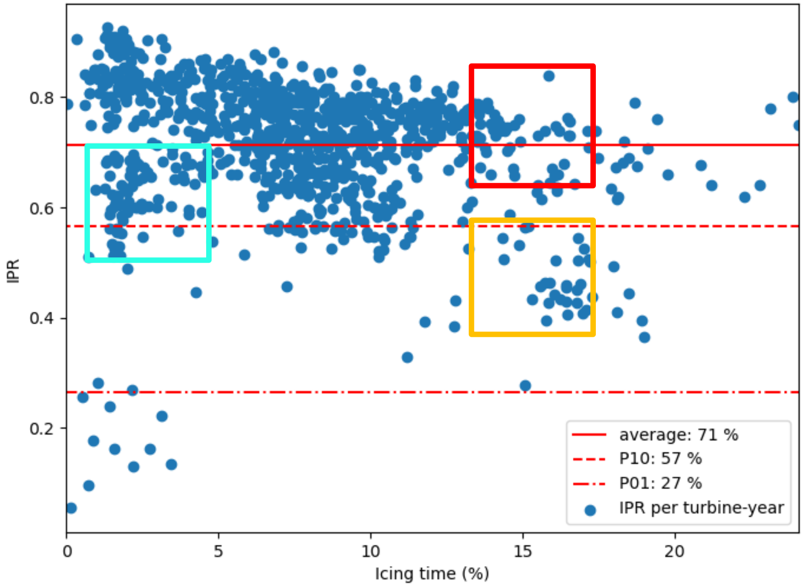
Site 1

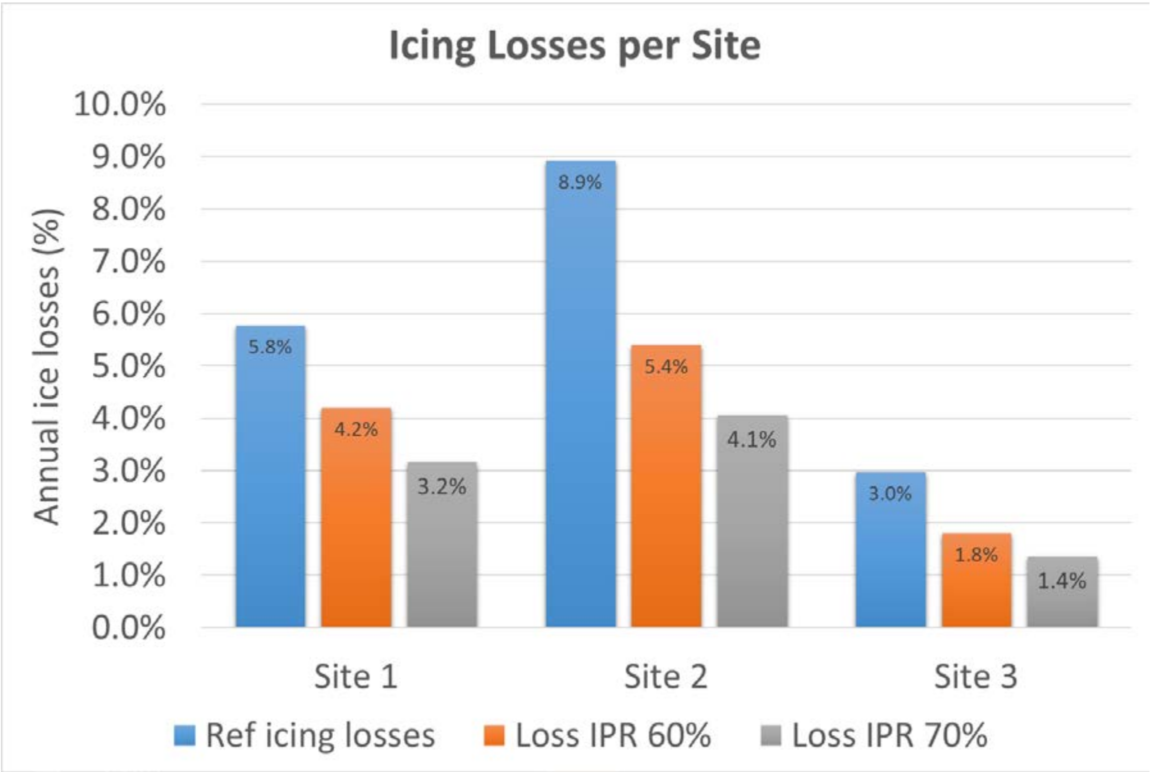
Site 2

Site 3

Icing losses	5.8%	8.9%	3.0%

Case study

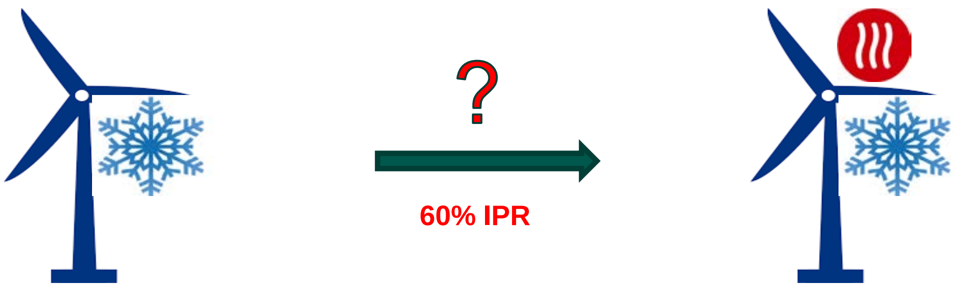




- 60% IPR:
  - Losses can be reduced for each sites from 1.2% to 3.5%
- 70% IPR:
  - Losses can be reduced for each sites from 1.6% to 4.8%

Conclusion

- IPR is a nice tool to characterize IPS performance
- IPR was calculated on about 1000 turbine years in 6 countries on ENERCON WECs
  - ENERCON blade heating system reaches an average IPR of 71%
  - An annual IPR of 60% was reached at more than 90% of the test sites
  - An IPR of 60% was observed in temperatures and wind speed generates most energy
- With an IPR of 60%, losses reduction of 1.2% to 3.5% could be reached
- IPR is site and technology specific



Estimated icing loss: $ice_{loss\_estimated}$

Estimated icing loss: $ice_{loss\_estimated\_RBHS}$

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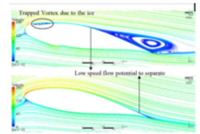
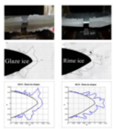
Conclusion

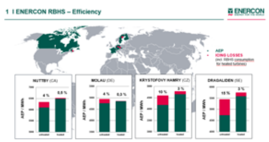
- The problem:
  - Uncertainty and conservatism in ice loss estimates
  - Consequence: Higher financing costs
- The solution:
  - Option 1: Warranty → No standard exists
  - Option 2: Make proper use of available data and link it to scientific models

How to assess IPS performance?

Scientific approach IPS performance = f(technology, operation mode, wind speed, temperature, ice type, ice severity etc.)	Statistical approach Data analysis
Complex relationships High investment in research and validation Site adapted solution	Low investment if data is available Needs robust dataset (geographical location, number of winters…) Not a site specific solution

1 

 2



Realistic IPS performance values:

➡ Increases windfarm financial value

➡ Reduces financial costs

➡ More competitivity towards other technologies

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