Determining Control Deficiencies from Field Data and Applying Corrective Control Actions

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1. Introduction

Field data for wind turbines operating in cold temperatures can show a severe underperformance in power production when the turbine is iced. The effects of ice on the aerodynamics and mass of wind turbine blades can be modelled (e.g. In GH Bladed), resulting in power curves that are similar to the field data. Different control strategies can then be introduced once icing is detected, with corrective control actions implemented to increase rotor speed and hence power production.

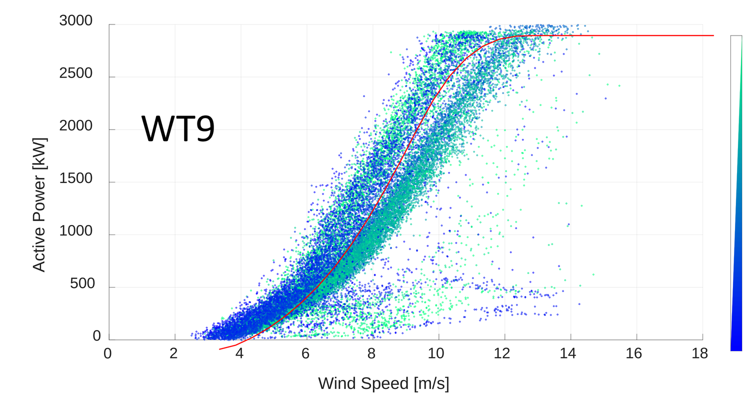
- An 8 week project was undertaken to investigate the application of corrective control action to mitigate deficiencies highlighted by the analysis of field data for wind turbines. Nearly a years worth of SCADA data was provided by SgurrControl.
- A 1.5MW Supergen wind turbine model was used for this project in GH Bladed. Ice was added to each blade and the aerodynamic coefficients modified to model the effects of icing. External controllers with different control strategies were implemented for this model, including the detection of icing and corrective control actions to increase power production.
- Time series simulations were run to check and assess the impact of the corrective control actions.

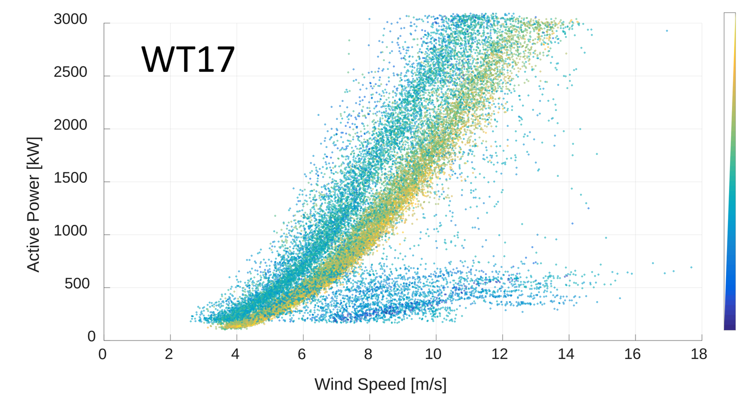
2. Field Data Analysis

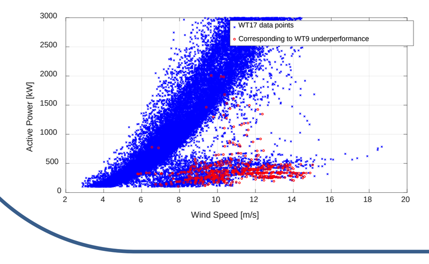
- Field data provided by SgurrControl;
- 24, 3MW wind turbines;
- Nearly a years worth of SCADA data;
- Data cleaned and analysed.

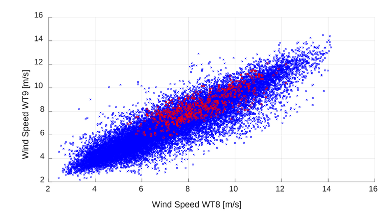
- Two distinct power curves
  → Recalibration
- Severe underperformance in power production at low temperatures
  → Suspected icing

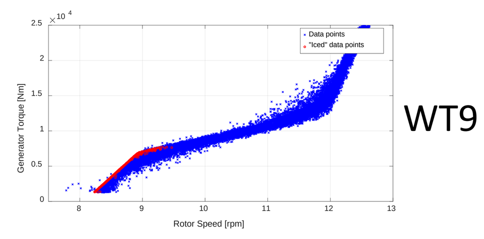
- Check suspected icing data across other turbines (power curves, wind speed and yaw error).





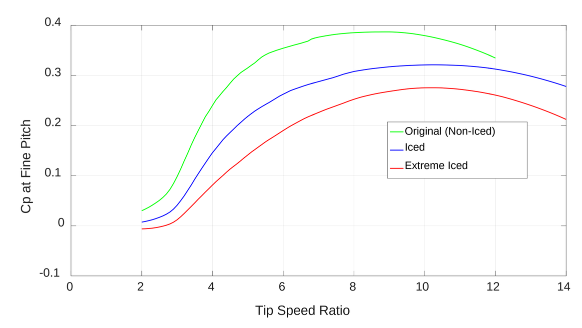


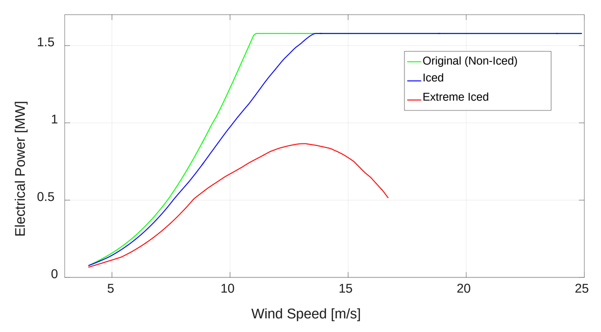




3. Modelling Icing Effects on Wind Turbine Performance

- GH Bladed:
  > Add ice mass to blades by specifying the density of ice and tip chord.
  > Change aerodynamic properties (Cl, Cd, Cm) as per literature.

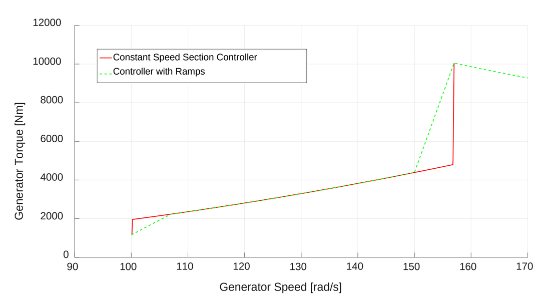




- Under iced conditions the wind turbine will likely be stuck in the first constant speed section of the control strategy, and/or tracking a $C_{p,max}$ value it cannot achieve due to the degradation in aerodynamic performance.
- The torque, and hence power produced is thus degraded for a given wind speed. To increase the power capture an alteration to the control strategy is therefore required to increase the rotational speed of the turbine and hence the power produced.
- "Extreme Ice" Cp and power curve looks more like the underperformance seen in field data

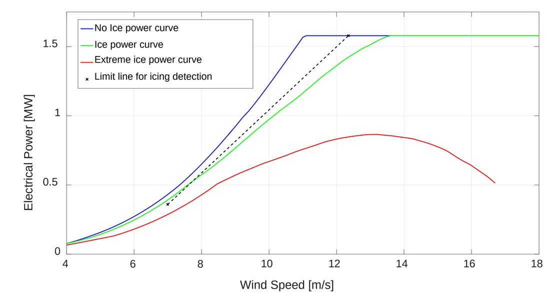
4. Corrective Control Action for Icing

- Bladed external controllers written in C++ .
- PI torque and pitch control implemented with upper and lower constant speed sections.
- Ramped rather than constant speed section controller also created as per field data.



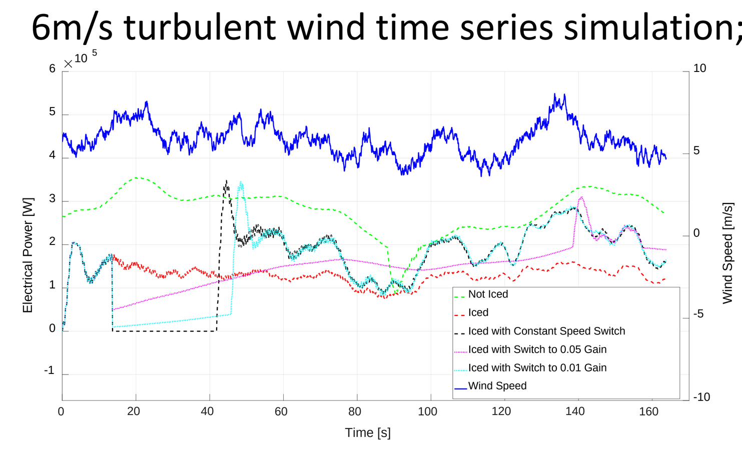
Icing detection & Switch

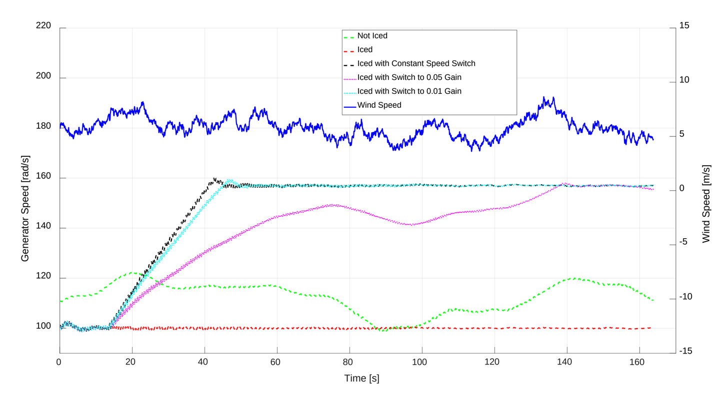
- Icing detection activated based on power curves:
  > Wind speed above 7m/s;
  > Power produced degraded – below limit line
- A good estimate of wind speed is not always available for wind turbines, however for a simple switch it is likely that the wind speed from the turbine should be sufficient.
- Switch – to constant (upper) speed strategy or modify optimal torque gain.
- Modified torque gains of 0 (constant speed), 0.01 and 0.05 (original optimal torque gain of 0.195). Also first attempt made at adaptive torque gain which aimed to drive $\frac{\partial C_p}{\partial \lambda} \rightarrow 0$ (simulation result similar to zero gain so needs refining).



Simulation Result

- Time series simulations run at: 9m/s constant wind speed, 10m/s, 7m/s, 6m/s & 5m/s time varying (turbulent) wind.
- 6m/s turbulent wind time series simulation; Icing detection switch activated at 13.5s:





- The control action initiated by the icing detection drives the generator speed toward rated speed (157 rad/s) and increases the power produced compared to the "Iced" result (with no corrective control action).
- The power production does not reach the levels of the non-iced results, but does show a significant improvement. It is noted that even with the corrective control action the iced turbine cannot reach rated power.
- When switching in to the corrective control strategy, a zero torque gain (or switch to upper constant speed section), produces a period of zero power production while the generator speed is ramping up to rated. This is not particularly desirable. With torque gains of 0.01 and 0.05 the switching causes the power to drop but not to zero, the higher gain producing more power in the switch period although taking longer to reach rated speed.

5. Conclusions

- Field data can be used to highlight control deficiencies such as the effect of icing;
- The icing of blades can be modelled by modifying the mass and aerodynamic coefficients;
- Once icing is detected, corrective control actions (e.g. modifying the optimal torque gain) can increase the power produced by the turbine.
- Estimates of Annual Energy Production using a Rayleigh distribution with mean wind speed of 7.29 m/s (as per field data) and power curves generated from Bladed, showed an increase of ~20% when the corrective control action is applied for the iced turbine model.

6. Future Work

- Development of adaptive torque gain modification;
- Improve icing detection switch (more sophisticated detection logic, including use of temperature measurement). Implement switch turn off logic;
- Improve ice modelling e.g. use XFOIL or TURBICE to generate aerofoils with ice;
- Alternative control strategies e.g. adaptive controllers that do not require $C_{p,max}$ and optimal tip speed ratio to be known;
- Consider other effects of increasing rotor speed when iced (e.g. loads, ice shedding).

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